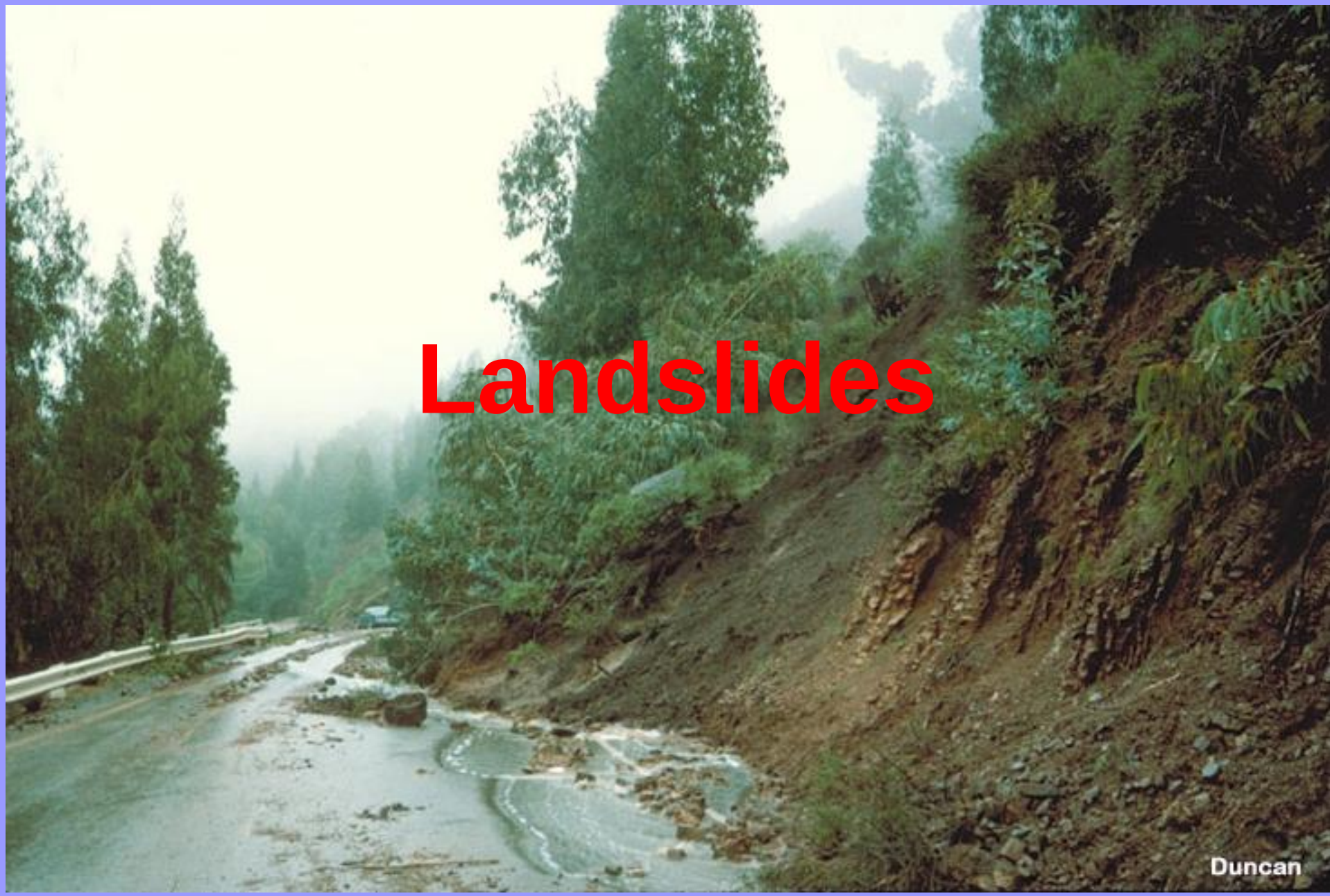

Landslides
Duncan

What is Landslide ?

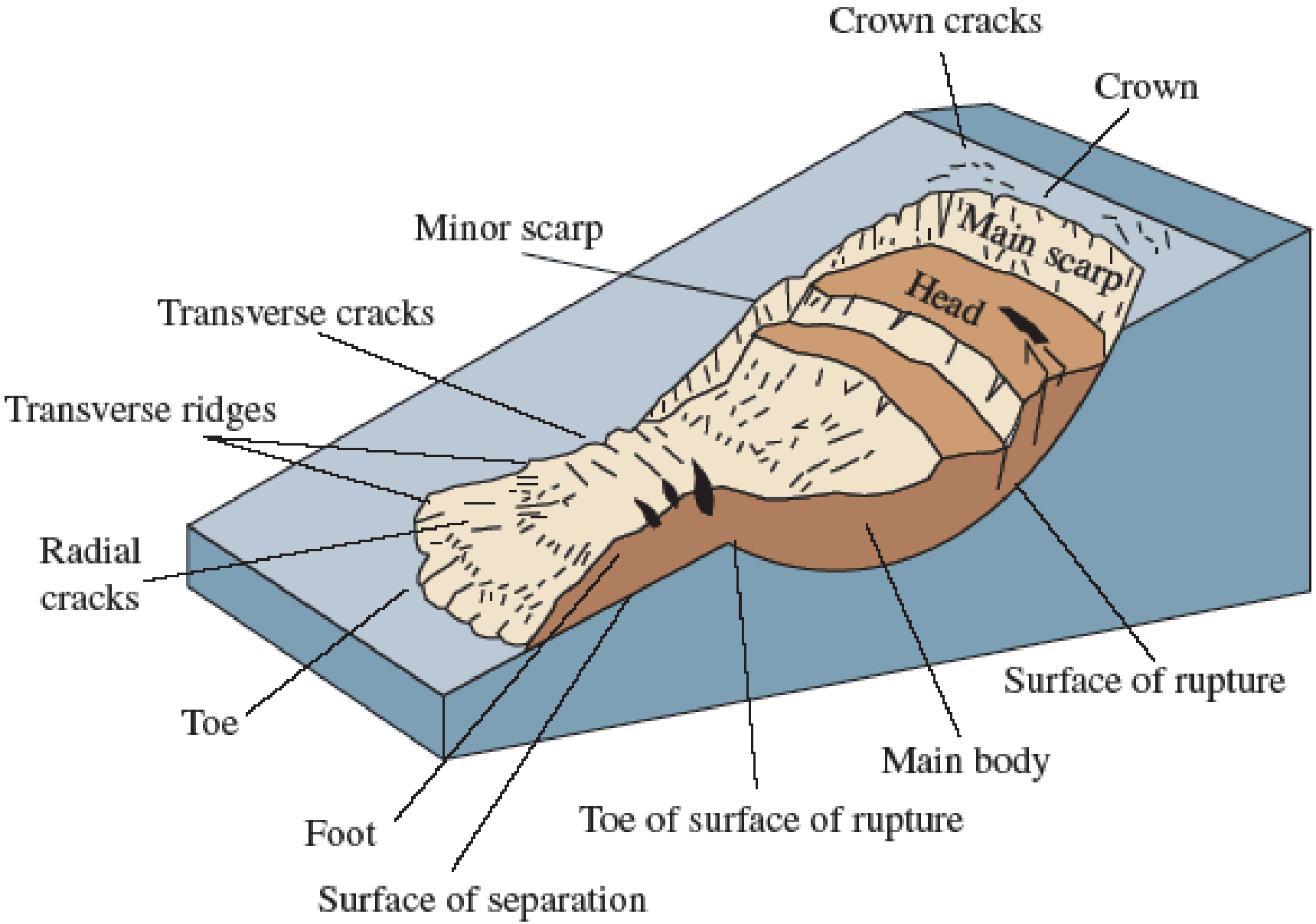
Downward and outward movement of slope forming materials composed of **rocks, soils, artificial fills or combination of all these** materials along surfaces of separation by falling, sliding and flowing, either slowly or quickly from one place to another.

Problems of Land Slide

- **Landslides constitute a major geologic hazard because they are widespread, occurring damages with losses of live.**
- **Landslides pose serious threats to highways, lifelines, and structures that support fisheries, tourism, timber harvesting, mining, and energy production as well as general transportation.**
- **Landslides commonly occur with other major natural disasters such as *earthquakes and floods* that exacerbate relief and reconstruction efforts and expanded development and other land use has increased the incidence of landslide disasters.**

- Source: The National Landslide Hazards Program (2002)

An idealized slump-earth flow showing commonly used nomenclature for labeling the parts of a landslide.

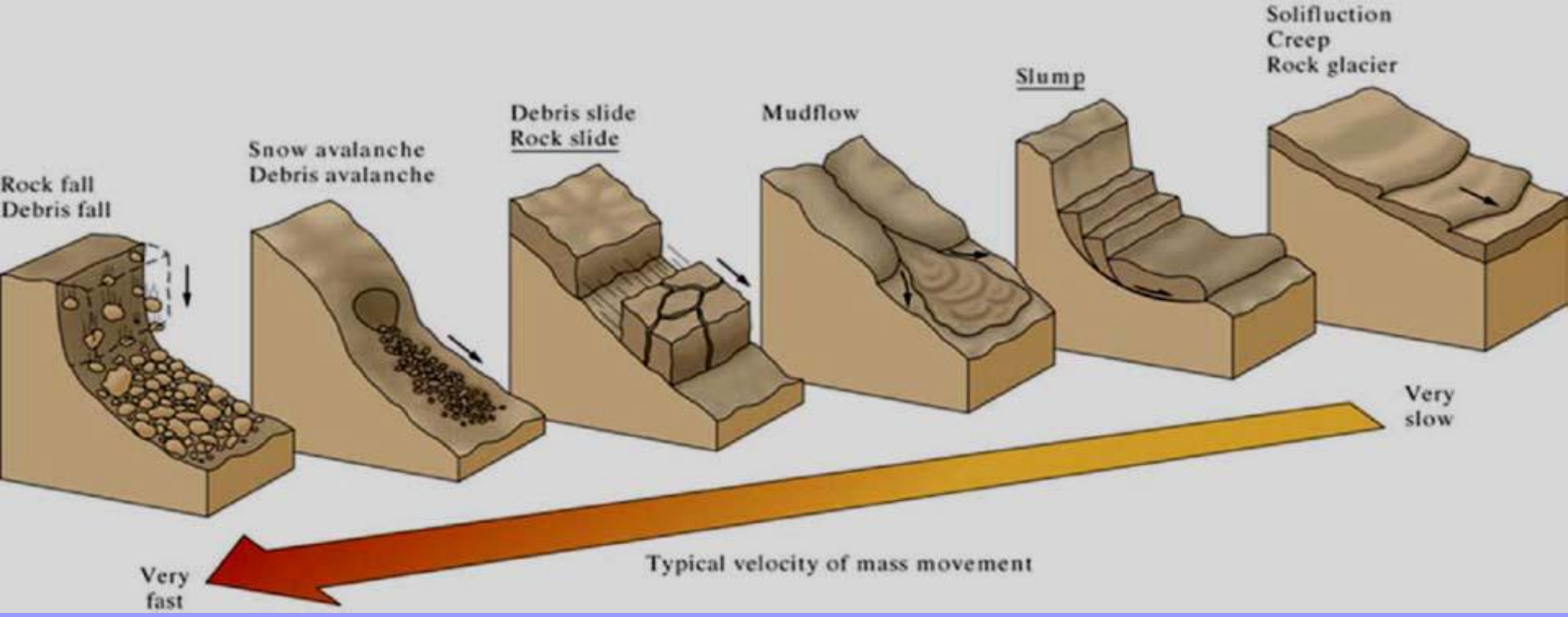


Classification with respect to depth of slide

Type	Maximum depth (m)
Surface slide	< 1.5
Shallow slide	1.5 – 5
Deep slide	5 – 20
Very deep slide	> 20

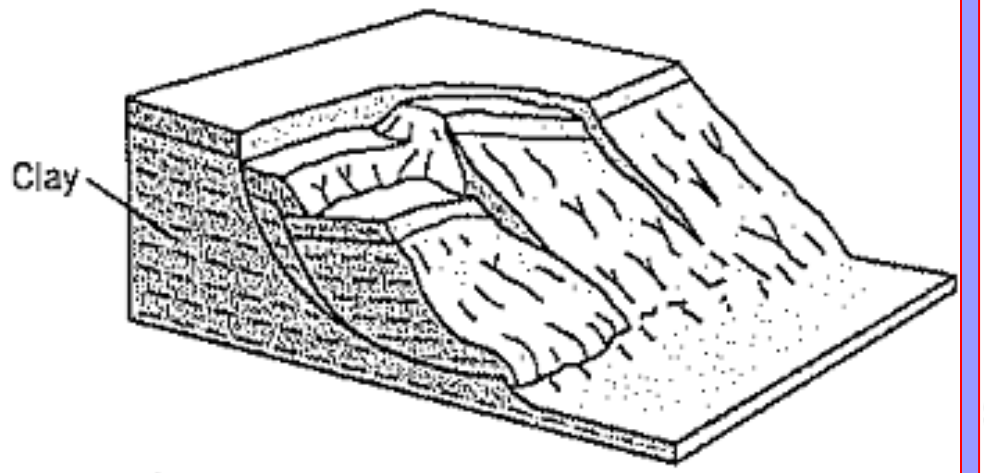
Types of landslides

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		



- The speed of the movement may range from very slow to rapid.
- The speed of the landslide will make an even more or less avoidable and therefore, more or less risky.
- It is important to distinguish the different types of landslides to be able to understand how to deal with each of them.

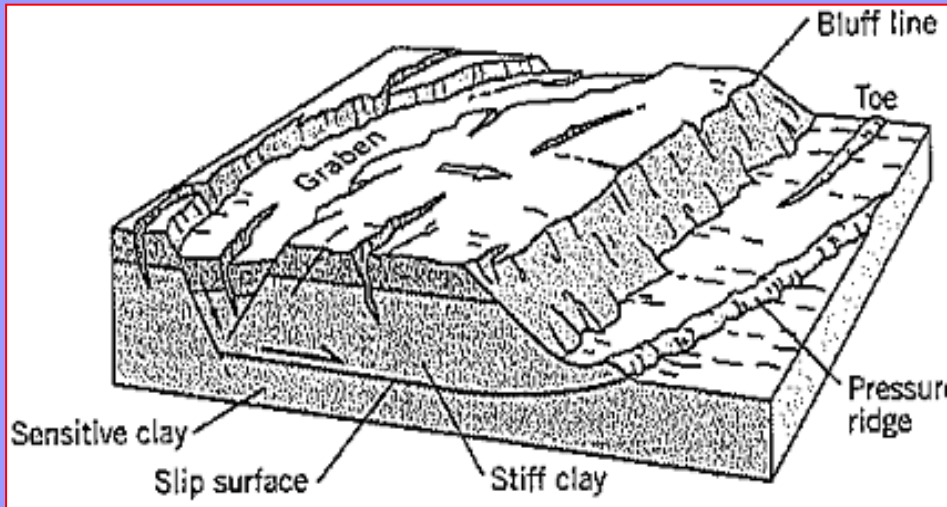
Rotational



C. Slide
Shear failure causing slump to more stable configuration.

move along a surface of rupture that is curved and concave.

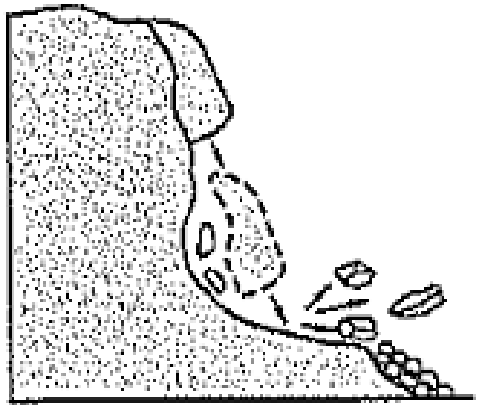
Translational landslide



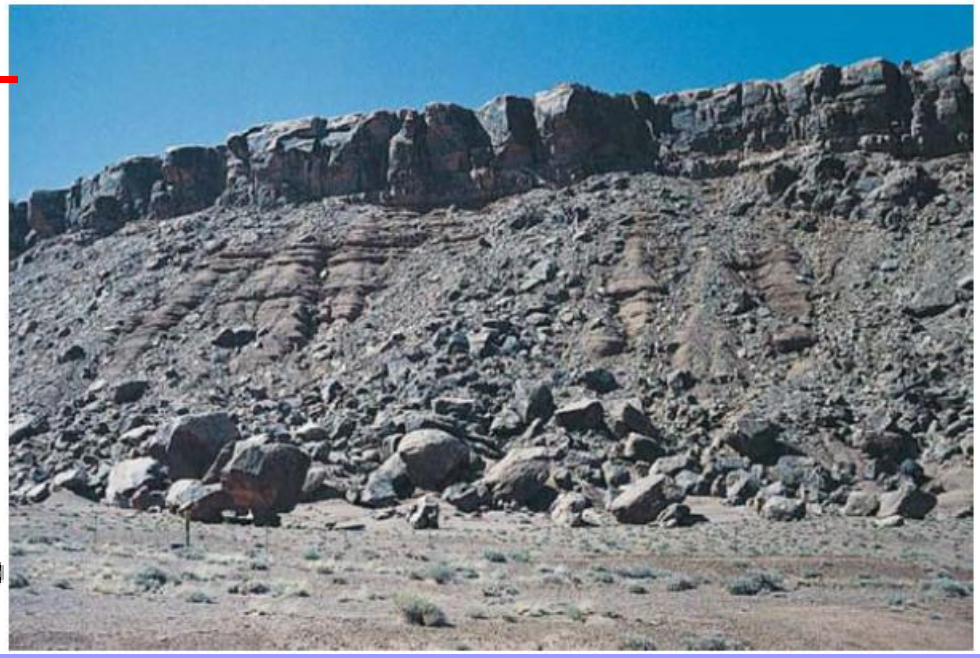
E. Slide
Translational movement of major part of slip surface; common on larger slides

occurs when the failure surface is approximately flat or slightly undulated

Rockfall

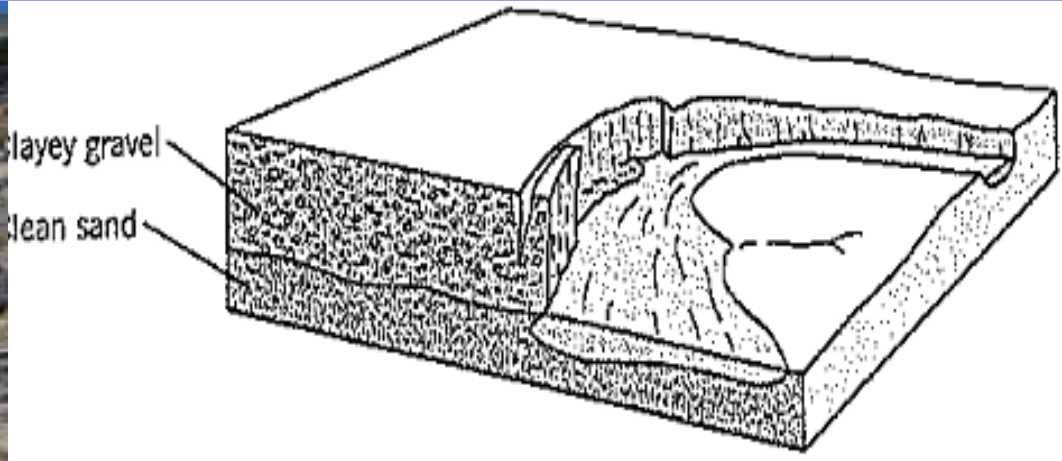


A. Falls
Detached from a steep slope; descends mostly through air by free fall, leaping, rolling. Very rapid to extremely rapid movements



Free falling of detached bodies of bedrock (boulders) from a cliff or steep slope

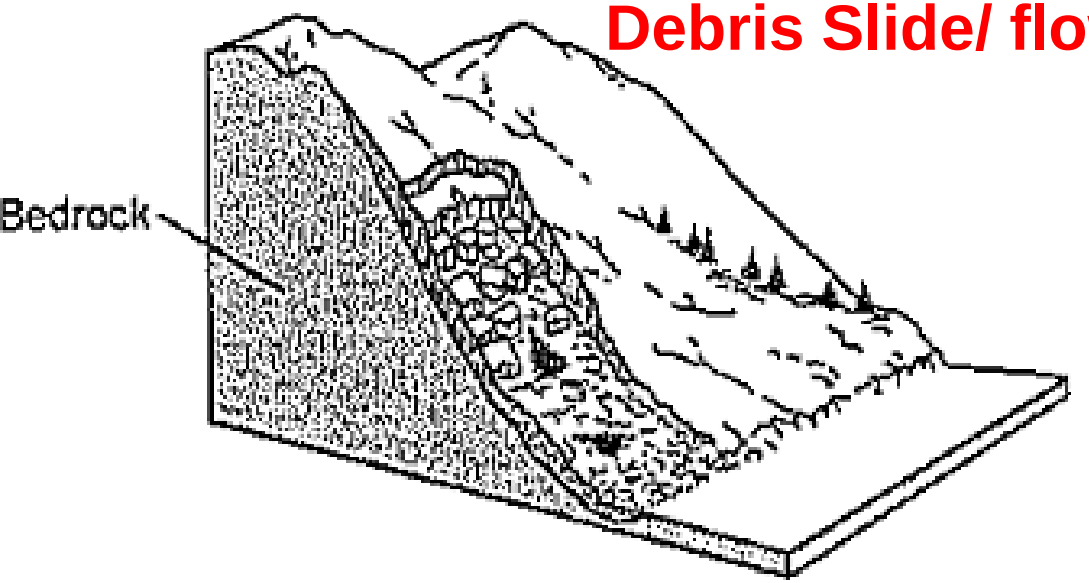
Topples



B. Topples
Forward rotation about some pivot point under the action of gravity and forces exerted by adjacent units or fluids in cracks.

occurs when one or more rock units rotate about their base and Collapse.

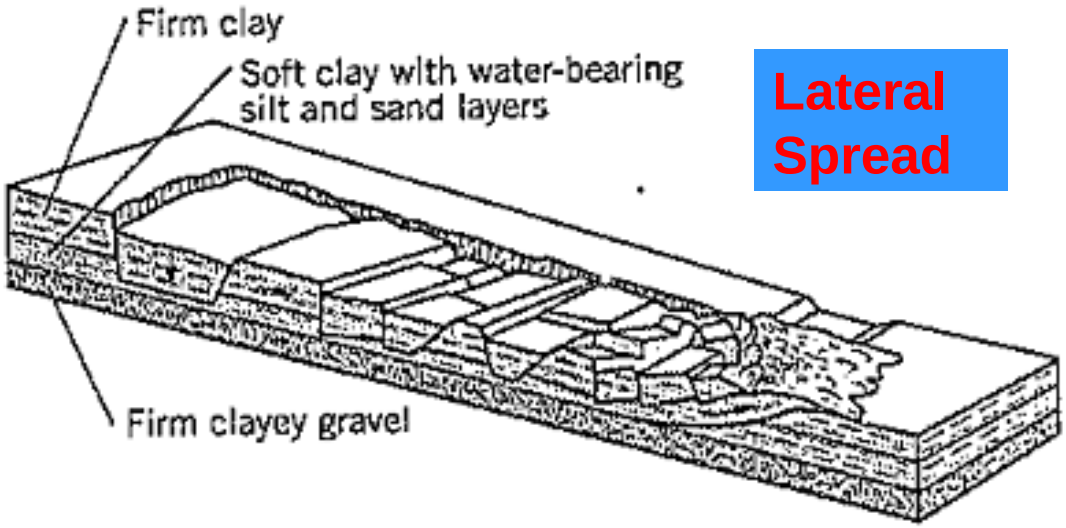
Debris Slide/ flow



D. Slide
Debris can slide in shear or become flow slide.

Down slope movement of collapsed, unconsolidated material typically along a stream channel

Fire-related debris flows from Storm King Mountain, Colorado. Debris flows blocked Interstate-70 during Labor Day weekend, 1994.

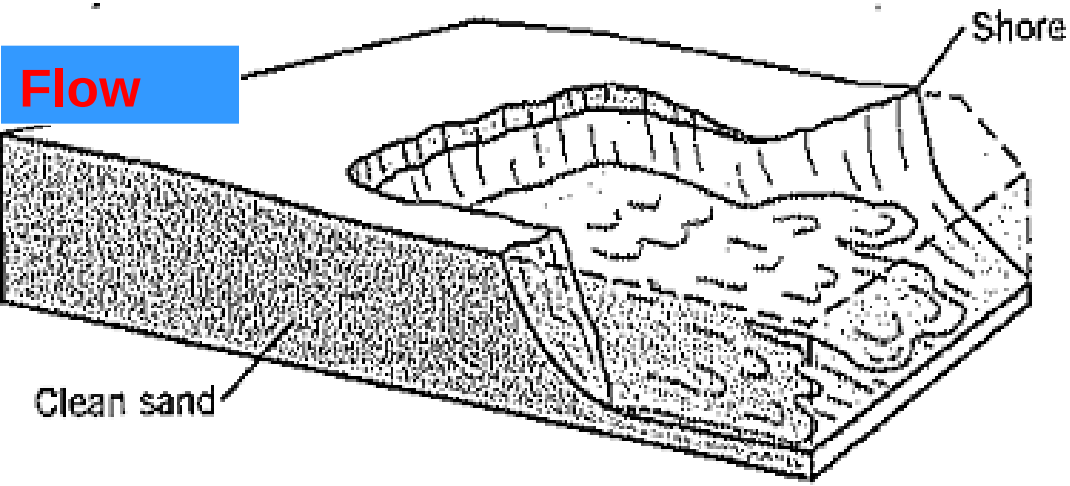


Lateral Spread

F. Lateral spread
Shear failure or liquefaction along nearly horizontal soil layers

occurs when the soil mass spreads laterally and this spreading comes with tensional cracks in the soil mass.

Flow



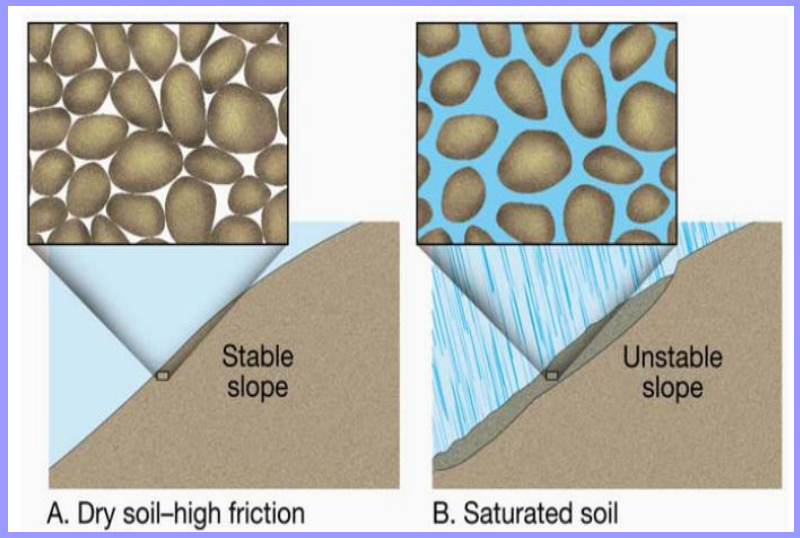
G. Flow
Flow slide in sand.

Causes of landslides

A) Natural Factors:

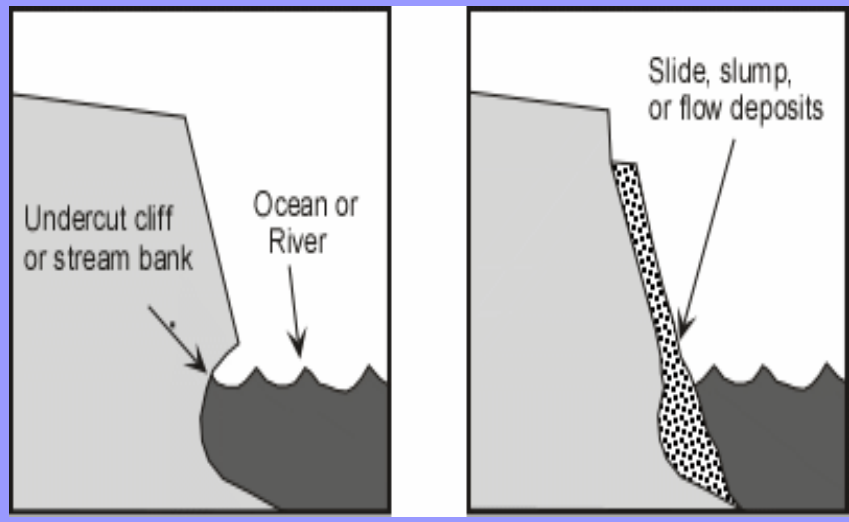
- **Gravity:** Gravity works more effectively on steeper slopes.

Geological factors: Geology setting that places permeable sands and gravels above impermeable layers of silt and clay or bedrock.

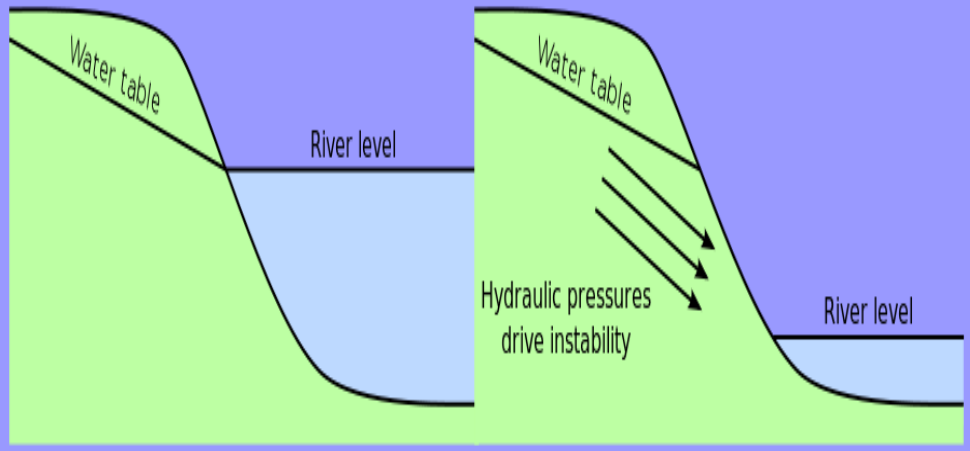


- **Heavy and prolonged rainfall:** slides occur often with intense rain by creating zone of weakness, also water tables rise with heavy rain makes some slopes unstable.
- **Earthquakes:** Ground vibrations created during Earthquakes.

- **Waves:** Wave action can erode the beach or the toe of a bluff, cutting into the slope, and setting the stage for future slides.



- **Volcanoes:** volcanic ash deposits (sometimes called as lahars deposits) are prone to erosion and subjected to mud flows due to intense rainfall.
- Fluctuation of water levels due to the tidal action.
- Deposition of loose sediments in delta areas.



B) **Anthropogenic Factors:**

Inappropriate drainage system: Surface runoff of irrigated water on slopes exposes soil under cultivation to erosion. Part of this water is absorbed by soil increasing its weight, which can put an additional load on the slope.

Cutting & deep excavations on slopes for buildings, roads, canals & mining: causes modification of natural slopes, blocking of surface drainage, loading of critical slopes and withdrawal to toe support promoting vulnerability of critical slopes.

Change in slope/land use pattern, deforestation, agricultural practices on steep slopes: contributed to creep and withdrawal of toe support in many cases.

C) **Combination of factors:**

For example, an earthquake may trigger a landslide, which in turn may dam a valley causing upstream flooding and subsequent dam burst. This will lead to flooding in lower catchments areas.

Effects and losses due to landslides

A) **Direct Effects:**

- -Physical Damage-Debris may block roads, supply lines (telecommunication, electricity, water, etc.) and waterways.
- Causalities- deaths and injuries to people and animals.

B) **Indirect Effects:**

- **Influence of landslides in dam safety-** failure of the slopes bordering the reservoir, Flooding caused by movements of large masses of soil into the reservoir.

- **Landslides and flooding-** Debris flow can cause flooding by blocking valleys and stream channels, forcing large amounts of water to backup causing backup/ flash flood.

C) **Direct losses:**

- Loss of life, property, infrastructure and lifeline facilities, Resources, farmland and places of cultural importance.

D) **Indirect losses:**

- Loss in productivity of agricultural or forest lands, Reduced property values, Loss of revenue, Increased cost, Adverse effect on water quality and Loss of human productivity,

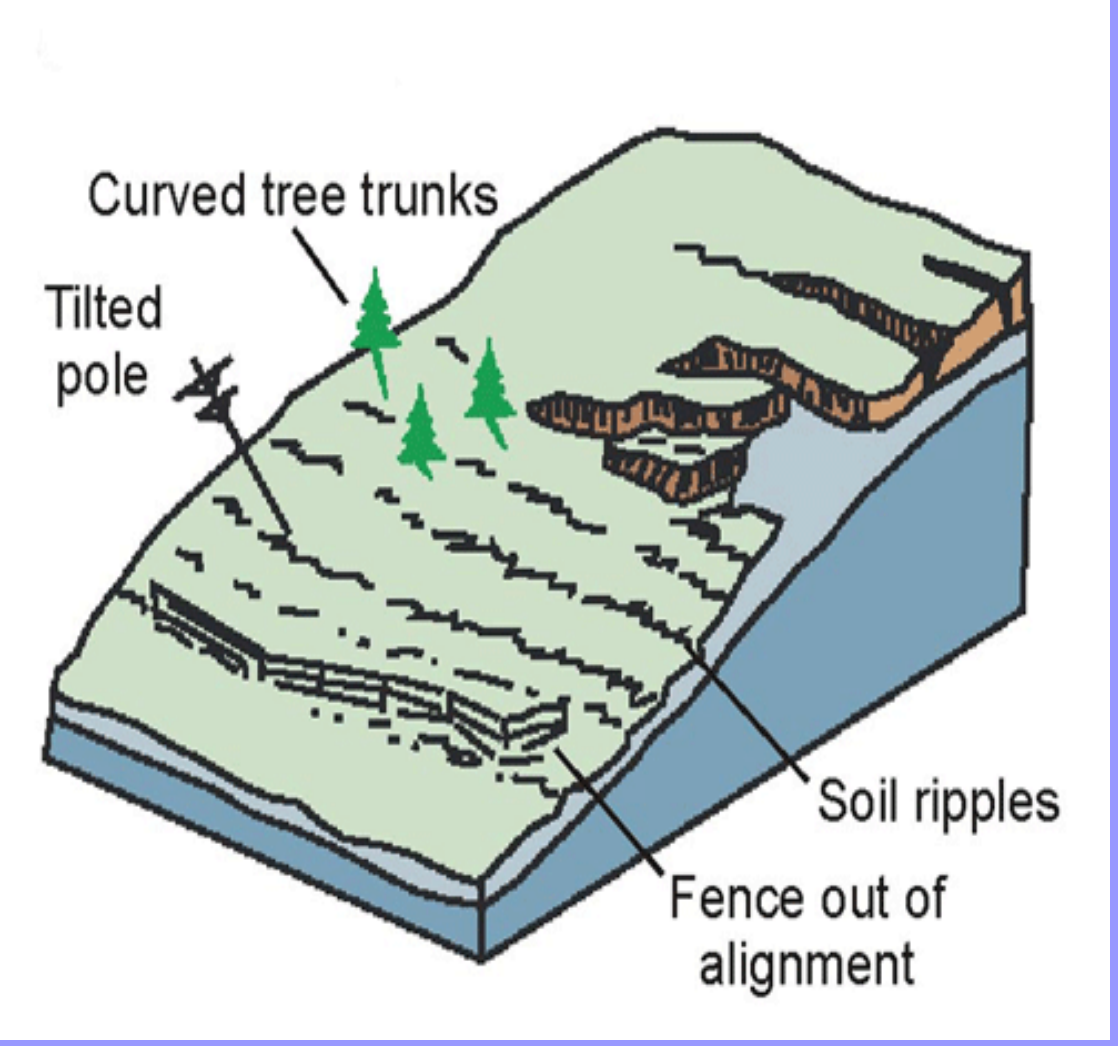
Indicators of landslides phenomenon

A) Terrain/Morphologic Features Indicating Risk of a Landslide-

- **Steep slopes:** slope with angles over 30 degrees should be avoided if possible.
- **Old landslides sites:** the old landslide can be reactivated, for example, by heavy rainfall or an earthquake.
- **New cracks** or unusual bulges in the ground or street pavements.

B) **Landslide Risk Indicators:**

- Tilting or cracking of concrete floors and foundations.
- Soil moving away from foundations.
- Broken water lines and other underground utilities.
- Leaning telephone poles, trees, retaining walls, or fences.
- Rapid increase in ground water levels, possibly accompanied by increased turbidity (soil content).
- Sticking doors and windows, and visible open spaces indicating jambs.
- Sudden decrease in ground water levels though rain is still falling or just recently stopped.



- **In most cases in the field there will be a combination of morphological and landslide risk indicators to be considered.**

How to Minimize Landslide Hazards

A) Passive Intervention

- Choose a safe location to build your home, away from steep slopes and places where landslides have occurred in the past.
- Prevent deforestation and vegetation removal.
- Avoid weakening the slope.

B) Active Preventive Intervention

- **Reforestation:** Root systems bind materials together and plants do both prevent water percolation and take water up out of the slope.
- **Proper water** runoff must be ensured by providing a proper canalization network.
- **Drainage:** good ground drainage is essential to prevent saturation and consequent weakening. Drainage is also needed in civil work, like retaining walls.

- **Proper land use measures**: Adopt effective land-use regulations and building codes based on scientific research.
- **Structural measures:** Nets, Retaining walls and major civil works to mitigate landslides. (**Bioengineering)**.

C) Non- Structural measures:

- **Awareness generation:** Educate the public about signs that a landslide is imminent so that personal safety measures may be taken.
- **Financial Mechanisms:** Support the establishment of landslide insurance.
- **Legal and Policy:** legislation to direct a governmental or private program to reduce landslide losses should be strengthened.

D) Landslide Hazard Mapping and Use of GIS:

- Landslide Hazard Zonation of the Vulnerable Areas.
- Use of remote sensing and ground truth data for making landslide hazard zone map.
- Here, such maps are used to develop mitigation plans in consultation with experts.

LANDSLIDE PREPAREDNESS AND SAFETY MEASURES

A) Before a landslide:

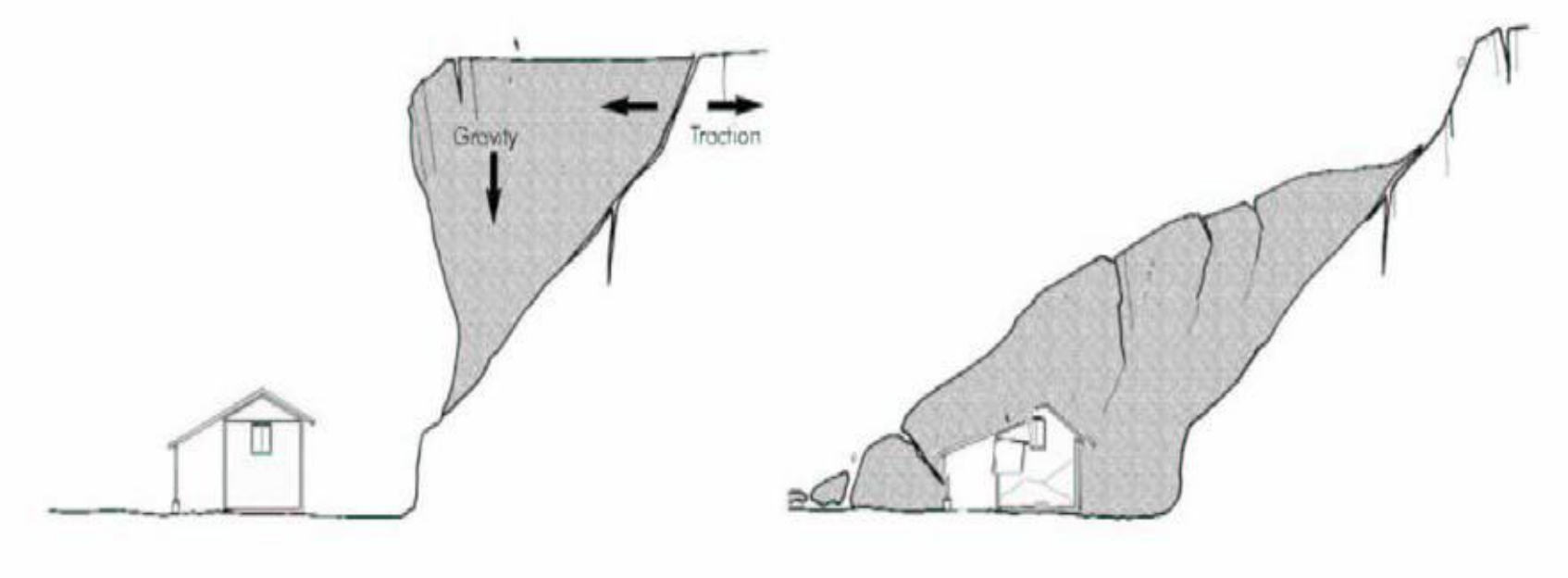
- Find out if landslides have happened in your area in the past.
- Look out for landslide warning signs like doors or windows jammed for the first time, new cracks appear in walls, bricks, foundations, retaining walls, tilt of utility poles or trees.
- Consider relocation in case your house is located in an area particularly vulnerable to landslides. While doing so, **remember**:

i) Do not build on or at the base of unstable slopes, on or at the base of minor drainage hollows, at the base or on top of an old fill slope, at the base or top of a steep cut slope.

ii) Do not cut down trees or remove vegetation or avoid slope weakening.

iii) If the house cannot be relocated, then ensure proper drainage and proper retaining walls.

- **Always stay alert and awake!!!** Listen to radio/television for warnings of intense rainfall, storm and damp weather. These usually trigger landslides/debris or mudflow.
- Make an evacuation plan in case of a landslide with all the emergency items.



B) **During a landslide:**

- Listen to any unusual sounds that might indicate moving debris, such as trees cracking or boulders knocking together. A trickle of flowing or falling mud or debris may precede larger flows.

❖ While you are outdoors during a landslide

- Try to get out of the path of the landslide or mudflow by running to the nearest high ground or away from the path.
- If you are near a river, be alert for any sudden increase or decrease in water flow or for a change from clear to muddy water. Such changes may indicate landslide upstream. So move quickly to safer areas.

- If the rocks and other debris are approaching, run to the nearest shelter such as group of trees or a building.

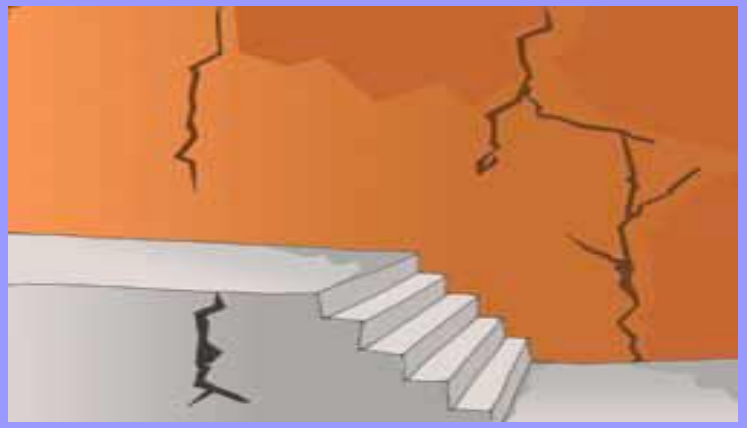
❖ While you are indoors during a landslide

- Stay inside and remain alert. Listen to radio/ television for any update. i.e. if landslide occurs outside.
- If your house falls apart due to landslide and if there is no escape, hold on to something strong and protect your head.

C) After a landslide:

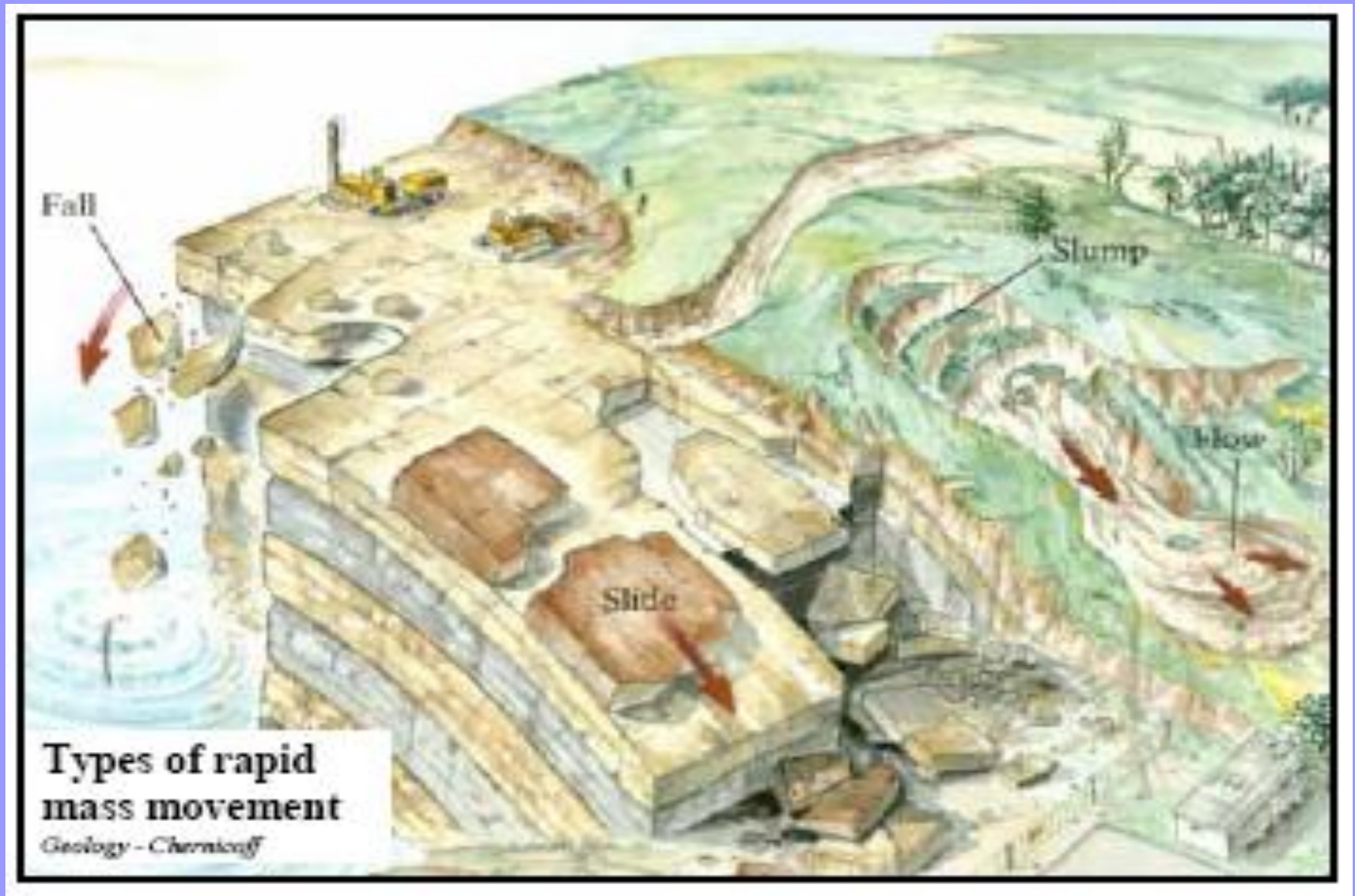
- Stay away from the landslide area as there may be danger of additional slides. Do not drive through.
- Watch for flooding which may occur after a landslide.
- Check for injured or trapped persons near the slide, without entering the slide area. Direct rescuers to their locations.

- Help neighbours who may require special assistance– infants, elderly people and disabled people.

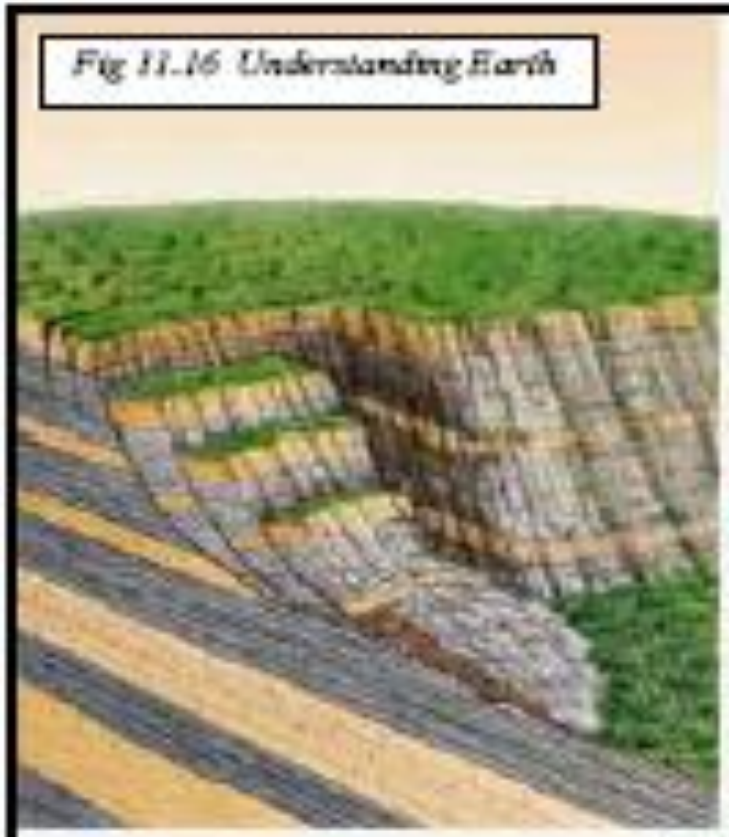


- Listen to local radio/television stations for the latest emergency information.
- Look for and report broken utility lines to appropriate authorities.
- Check the building foundation, walls and surrounding land for damage. The safety of the areas needs to be assured before reoccupation.

Types of rapid mass movement



Slump



Slump - a type of slide that separates along a concave surface. Slumps generally do not travel far, and the material within the slump tends to move as a unit and not become mixed. *Fig 11.16 Understanding Earth*

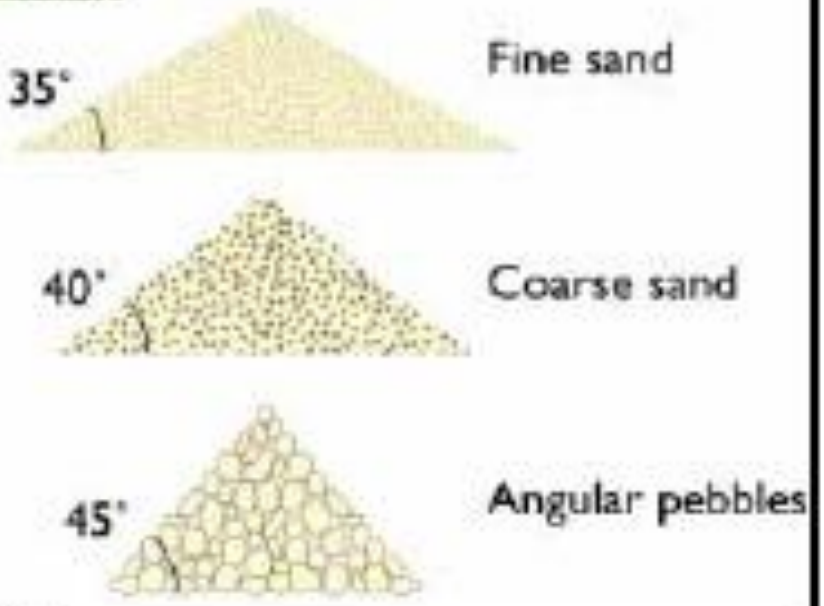
Slump near Naches, Washington - 8 Feb

Factors that control slope stability

Factors That Control Slope Stability

1. Slope angle and material properties

Steep slopes with loose sediment are at a high risk of mass movement. The steepest stable slope for loose (unconsolidated) sediment varies with particle size and shape. This maximum stable slope angle is called the angle of repose.



Figs 11.1 and 11.6 Understanding Earth

Factors that control slope stability

2. Cutting into slopes to build roads and buildings increases the risk of mass movement by making slopes steeper.

Small landslide (slump and earthflow) in a roadcut along Hwy 70 in CA

Small rockfall in a road cut in the Blue Mountains of Oregon

1994 landslide near McClures Pass, Colorado
USGS

Factors that control slope stability

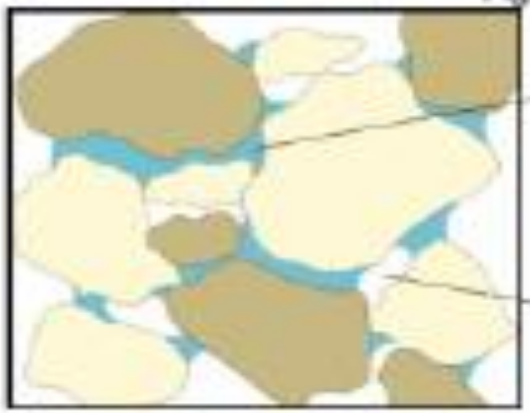
3. Fire can remove vegetation and decrease slope stability thereby increasing the potential for erosion and mass movement

Fig 11.5 Understanding Earth

Factors that control slope stability

4. The amount of water has a major effect on slope stability, especially for loose sediments

Figs 11.1, 11.3, 11.4 Understanding Earth



Water in some pore spaces binds particles

Pore space filled with air

Dry sand

Moist sand

Water between all particles keeps them apart and allows them to flow

Water-saturated sand

CAUSES OF LANDSLIDES

- *Geological Weak material*
- *Erosion*
- *Intense rainfall*
- *Human Excavation*
- *Earthquake shaking*
- *Volcanic eruption*

Causes of Landsliding

Geologists use a variety of classification schemes to describe causes of landslides. Because of wide variety of causes, no single scheme has yet been developed that address or describe all types of landslides.

External

Geometrical change

1. Gradient
2. Height
3. Slope length

Unloading

1. Natural
2. Human-induced

Loading

1. Natural
2. Human-induced

Shocks and Vibrations

1. Single
2. Multiple/continuous

Internal

Progressive failure (internal response to unloading, etc.)

1. Expansion, swelling
2. Fissuring
3. Strain softening
4. Stress concentration

Weathering

1. Physical property changes, swelling
2. Chemical changes

Seepage Erosion

1. Removal of cements
2. Removal of fines

Water Regime Change

1. Saturation
2. Rise in water table
3. Excess pressures
4. Drawdawn

Source: The Royal Academy of Engineering. 1995. *Landslides Hazard Mitigation*. Westminster, London: The Royal Academy of Engineering.

Human causes

a. Excavation of slope or its toe
b. Loading of slope or its crest
c. Drawdown (of reservoirs)
d. Deforestation
e. Irrigation
f. Mining
g. Artificial vibration
h. Water leakage from utilities

Zone Significance of Landslides

The four point hazard scale of the Landslide Zones are – (1) Severe to Very High, (2) High, (3) Moderate to low, (4) Unlikely, was considered adequate. The zonal significance is given below:

Zone	Significance
Severe to Very High	The area is well known for the danger of landslides, and for the perennial threat to life and property. Restrictions on all new constructions and adoption of improved land use and management practices deserve to be encouraged. Investments on landslide remediation measures, on public education and on early warning systems are strongly indicated.
High	This is a zone in which landslides have occurred in the past and are already to be expected in the future. New constructions in this zone should be strictly regulated and construction should be done only after proper site investigation and implementation of appropriate remedial package. Before the new construction projects are cleared in this zone, environment impact assessment should be made mandatory.
Moderate to Low	Engineered and well-regulated new construction activities and well-planned agricultural practices could be permitted. All construction activities should however be based on technically evaluated and certified plans by established institutions and authorized consultants.
Unlikely	No visible sign of slope instability are seen in this zone in the present stage of knowledge. No blanket restriction needs to be imposed on various land use practices provided they confirm to the prevailing building regulations and bye-laws. Location specific limitations may become necessary for high-density urban areas.
	Snow covered areas

MAIN MITIGATION STRATEGIES

Hazard mapping

Land use

Retaining Walls

Surface Drainage Control Works

Engineered structures

Increasing vegetation cover

Insurance

MAIN MITIGATION STRATEGIES

Hazard mapping will locate areas prone to slope failures. This will permit to identify avoidance of areas for building settlements.

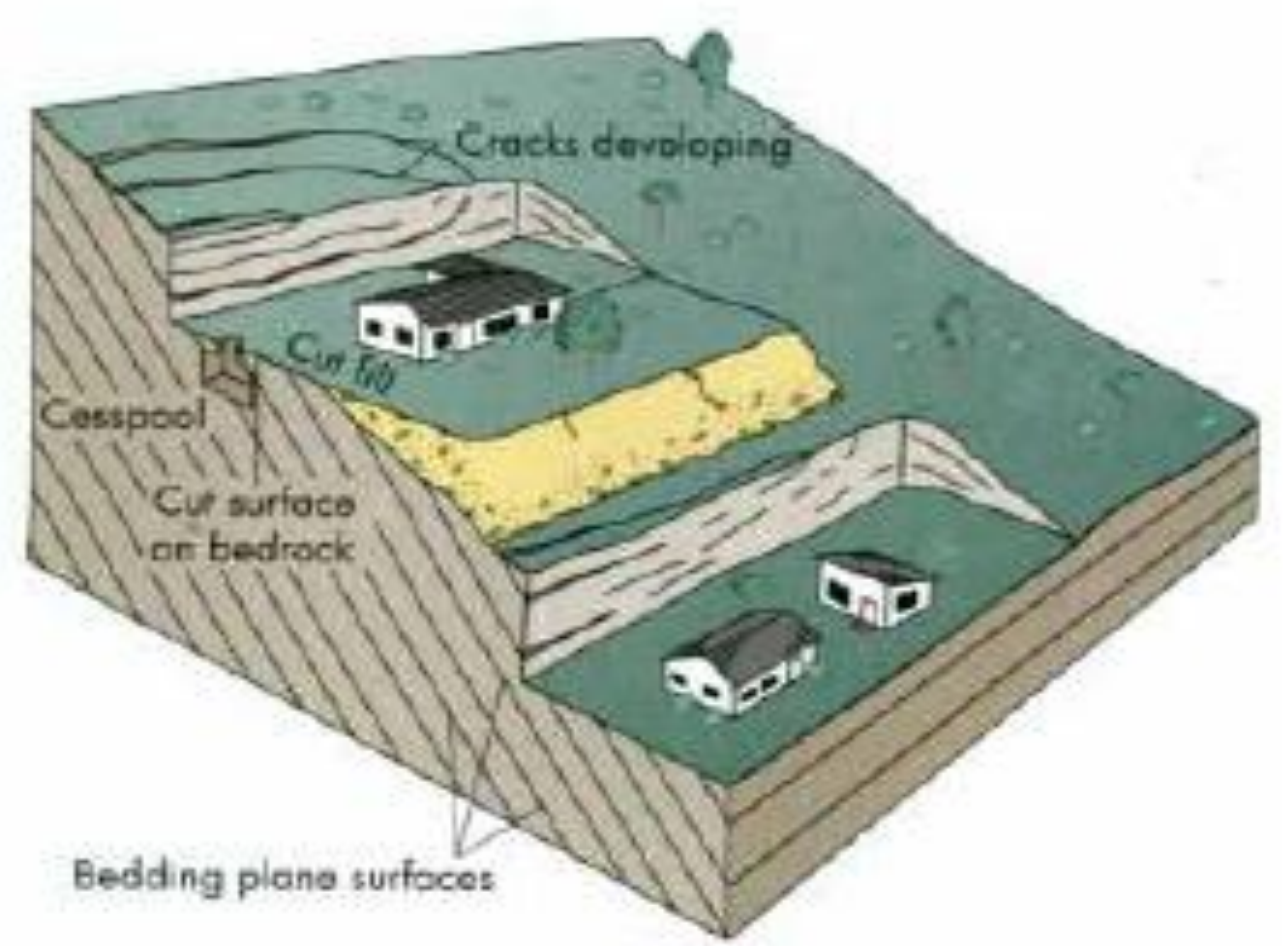
These maps will serve as a tool for mitigation planning.

MAIN MITIGATION STRATEGIES

Land use practices such as:

- Areas covered by degraded natural vegetation in upper slopes are to be afforested with suitable species. Existing patches of natural vegetation (forest and natural grass land) in good condition, should be preserved
- Any developmental activity initiated in the area should be taken up only after a detailed study of the region and slope protection should be carried out if necessary.
- In construction of roads, irrigation canals etc. proper care is to be taken to avoid blockage of natural drainage
- Total avoidance of settlement in the risk zone should be made mandatory.
- Relocate settlements and infrastructure that fall in the possible path of the landslide
- No construction of buildings in areas beyond a certain degree of slope.

Avoid building on or near steep, high-risk slopes and avoid modifications that increase the risk of landslides



MAIN MITIGATION STRATEGIES

Retaining Walls can be built to stop land from slipping (these walls are commonly seen along roads in hill stations). It's constructed to prevent smaller sized and secondary landslides that often occur along the toe portion of the larger landslides.

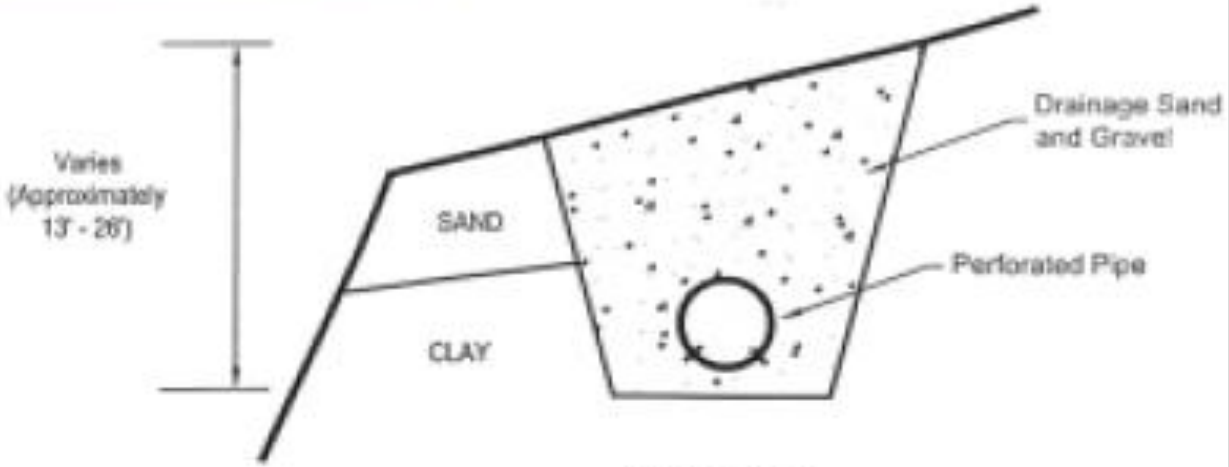
MAIN MITIGATION STRATEGIES

Surface Drainage Control Works. The surface drainage control works are implemented to control the movement of landslides accompanied by infiltration of rain water and spring flows.

Keller – Environmental Geology

Control water and improve drainage

Installing drain systems to reduce the amount of water in a slope can reduce the risk of landslides.



Shannon & Wilson, Inc.

MAIN MITIGATION STRATEGIES

- ***Engineered structures*** with strong foundations can withstand or take the ground movement forces.
- Underground installations (pipes, cables, etc.) should be made flexible to move in order to withstand forces caused by the landslide

MAIN MITIGATION STRATEGIES

Increasing vegetation cover is the cheapest and most effective way of arresting landslides. This helps to bind the top layer of the soil with layers below, while preventing excessive run-off and soil erosion.

MAIN MITIGATION STRATEGIES

Insurance will assist individuals whose homes are likely to be damaged by landslides or by any other natural hazards. For new constructions it should include standards for selection of the site as well as construction technique.

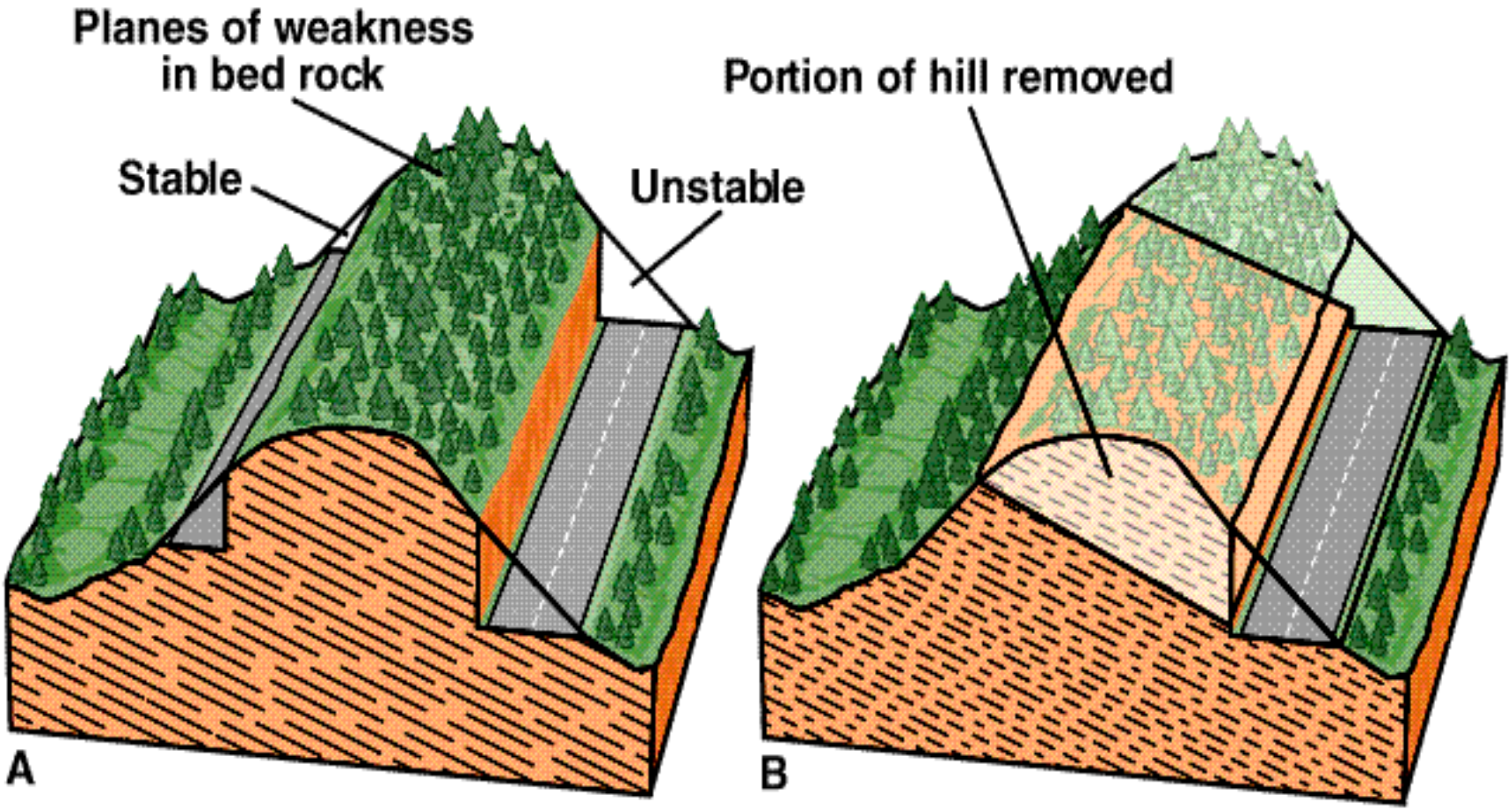
Flattening of the slope

Slope at the point of failure may be stabilised by grading the slope to a flatter angle on the basis of proper geotechnical investigation

Done either by regarding the slope from bottom to the top with benching, wherever necessary or cut in upper hills.

Plummer/McGeary/Carlson *Physical Geology*, 8e. Copyright © 1999, McGraw-Hill Companies, Inc. All Rights Reserved.

Safe and Hazardous Road Cuts



Stitching of the debris cover to the rock

Movement of surface soil can be controlled by stitching the debris to the base rock with help of micro-piles (e.g. timber piles)

Retaining walls

Built at the bottom of the slope but the base of the wall should be properly anchored into the rock.

Big landslides cannot be controlled by retaining walls

Grouting

Effective method of improving the shear strength and decreasing the permeability of coarse-grained soil. Suitable for filling voids in the rock mass.

Cement grouts are injected under pressure to close the voids in the rock

Geotextiles

Geotextiles wrapped filler drains are inserted into the slope extending beyond the estimated slip surface.

They are connected to a crib wall at the base which is made of crushed rock to provide drainage of water from the transverse drain.

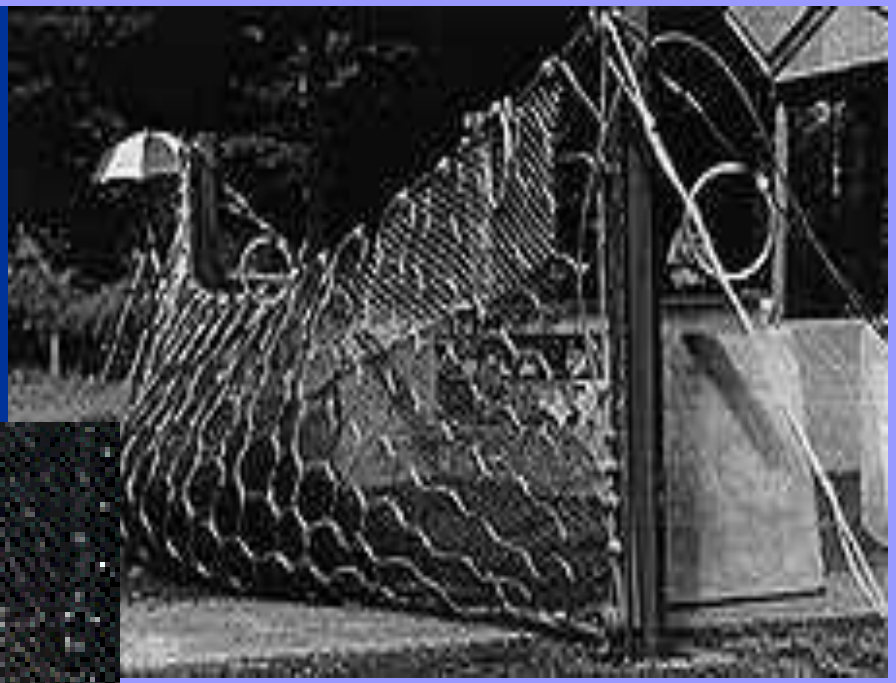
Rockfall Protection

In many areas rock faces are ‘stitched’ with massive steel bolts to try to keep material from being lost to active weathering.

Alternately, surfaces can be covered with strong mesh or boulder catching nets can be used.

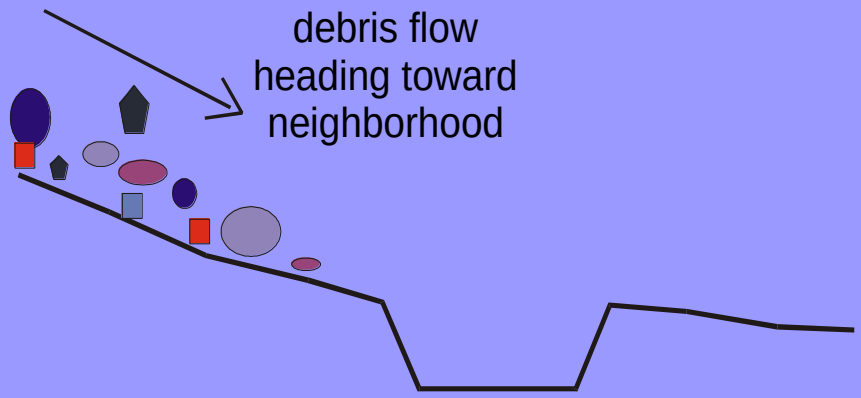
Mudflow Barriers

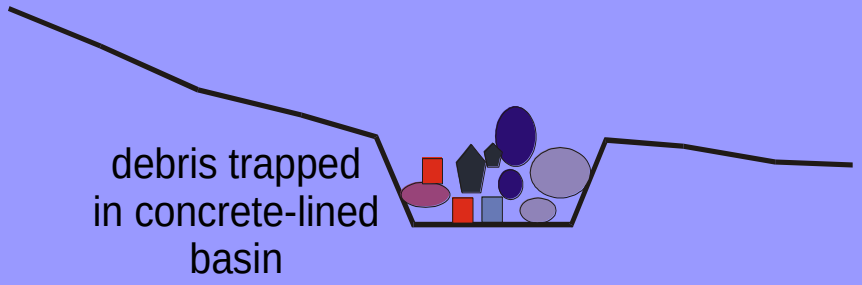
These kinds of barriers are designed to catch most sediment, but are not capable of stopping very large and very fast moving debris.



Debris Basins

These require periodic (regular) removal of trapped material.





The hazard from landslides can be reduced by avoiding construction on steep slopes and existing landslides, or by stabilizing the slopes.

Stability increases when ground water is prevented from rising in the landslide mass by

(1) covering the landslide with an impermeable Membrane
(2) directing surface water away from the landslide
(3) draining ground water away from the landslide
(4) Minimizing surface irrigation.

Slope stability is also increased when a retaining structure and/or the weight of a soil/rock berm are placed at the toe of the landslide or when mass is removed from the top of the slope.