Introduction to landslides
Part 1: Types and causes

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Landslides

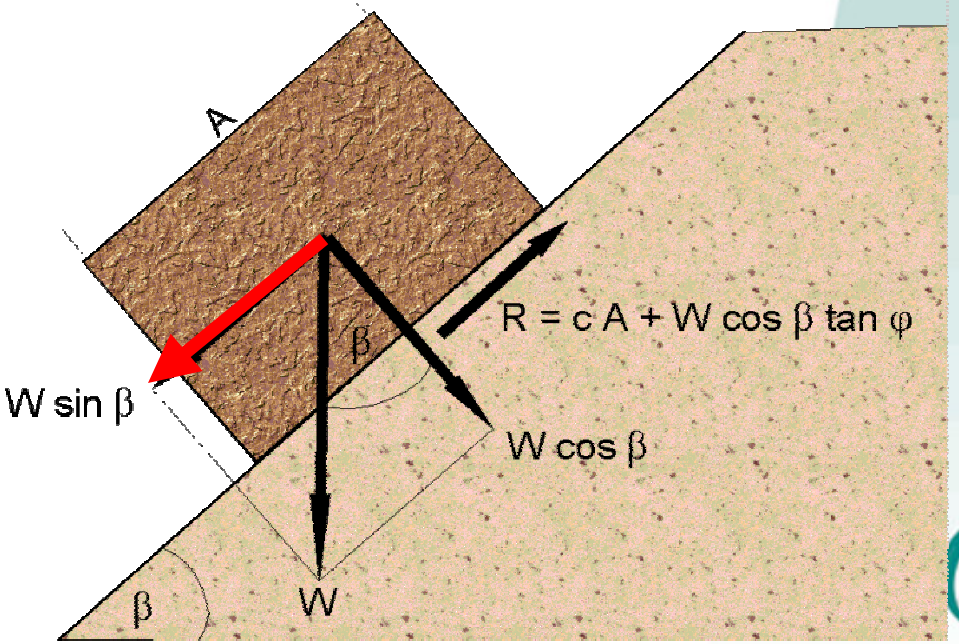
- There is a wide variety of names for the denudational process whereby soil or rock is displaced along the slope by mainly gravitational forces.
  - "mass movement"
  - "slope movement",
  - "landslide"
- Landslide = "the movement of a mass of rock, debris or earth down the slope" (Cruden, 1991).

Landslides

The occurrence of slope movements is the consequence of a complex field of forces (stress is a force per unit area) which is active on a mass of rock or soil on the slope.

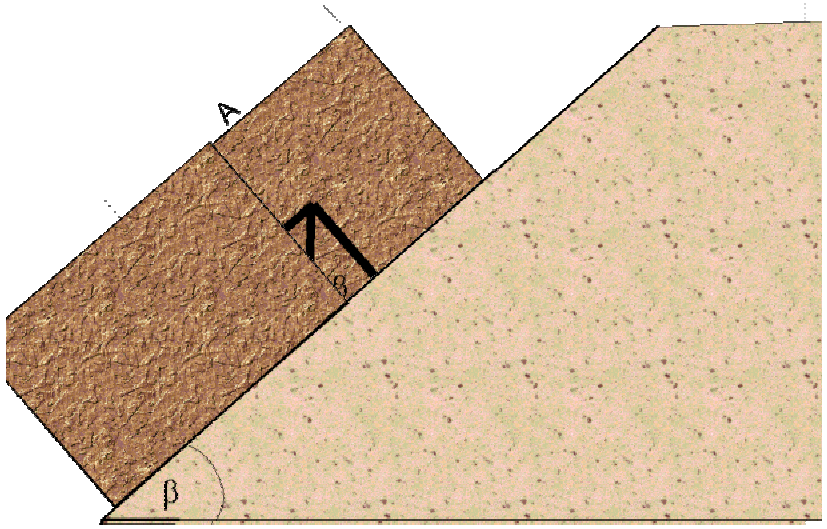
Movement occurs when the shear stress exceeds the shear strength of the material. Difference with soil erosion.

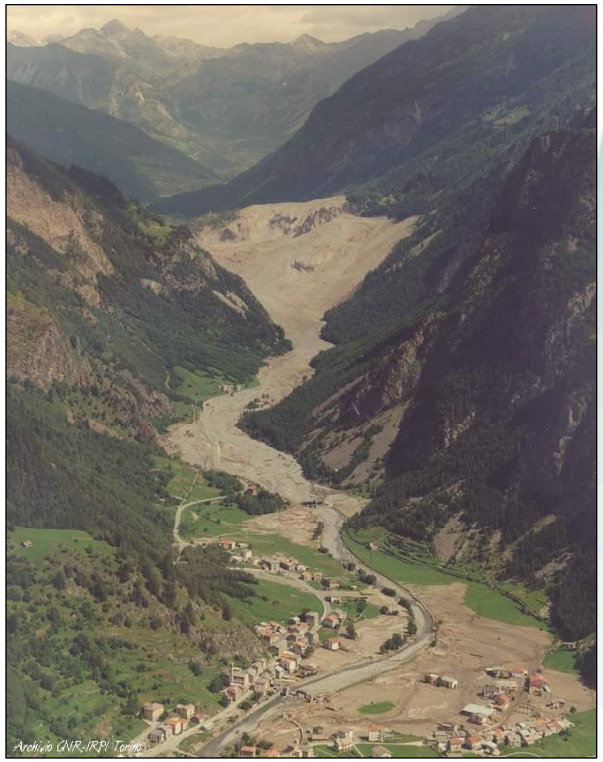
The consequence of these forces in conjunction to the slope morphology and the geotechnical parameters of the material define together the specific type of landslide which might occur.



Landslide definition

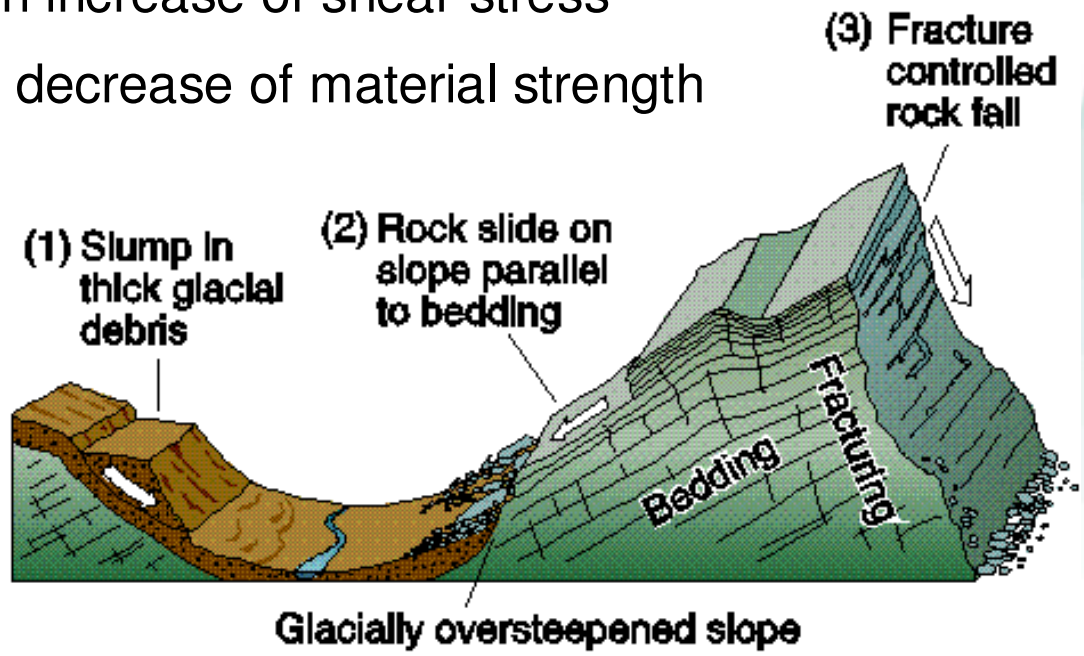
- Landslide is defined as the movement of a mass of rock, debris or earth down the slope, when the shear stress exceeds the shear strength of the material.





Landslide causes

- The occurrence of landslides is the consequence of a complex field of forces (stress is a force per unit area) which is active on a mass of rock or soil on the slope. Basically, the two main determinative parameters are:
  - An increase of shear stress
  - A decrease of material strength



Increase in shear strength

- Removal of lateral and underlying support (erosion, previous slides, road cuts and quarries)
- Increase of load (weight of rain/snow, fills, vegetation)
- Increase of lateral pressures (hydraulic pressures, roots, crystallisation, swelling of clay)
- Transitory stresses (earthquakes, vibrations of trucks, machinery, blasting)
- Regional tilting (geological movements).

Reduction of material strength

- Decrease of material strength (weathering,
- Change in state of consistency)
- Changes in intergranular forces (pore water pressure, solution)
- Changes in structure (decrease strength in failure plane, fracturing due to unloading)

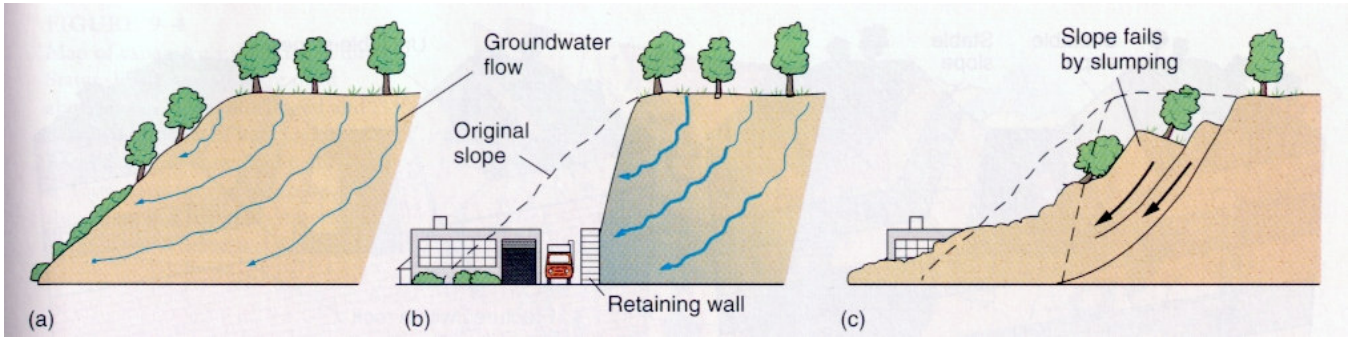
Checklist of causes

- Geological causes
- Morphological causes
- Physical causes
- Human causes

- Weak material
- Sensitive material
- Weathered material
- Sheared material
- Jointed or fissured material
- Adversely oriented mass discontinuity (bedding, schistocity, etc)
- Adversely oriented structural discontinuity (fault, unconformity etc)
- Contrast in permeability
- Contrast in stiffness (stiff, dense material over plastic material)

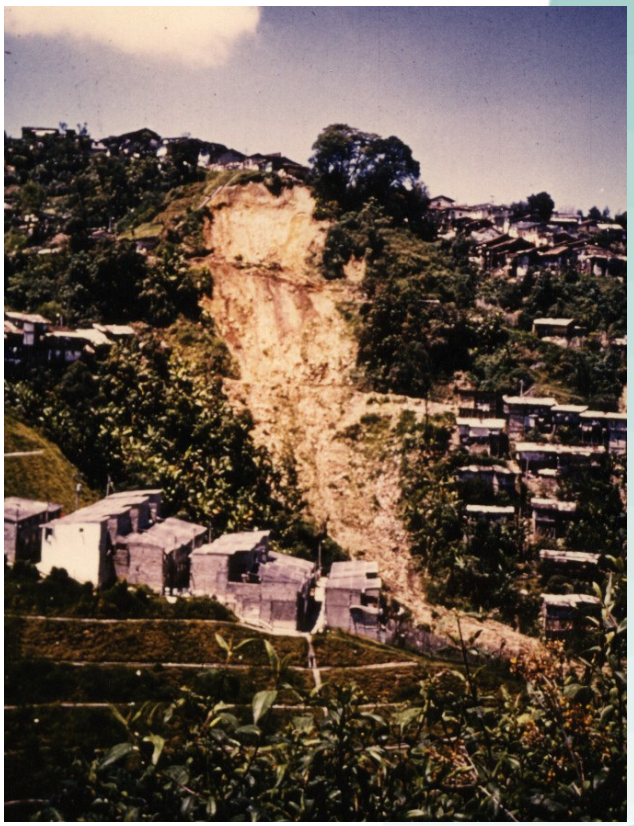
- Removal of lateral support
- Removal of underlying support
- Removal of support
- Loading of the slope or its crest
- Loading of the slope or its crest
- Loading of the slope or its crest
- Drawdown (of reservoirs)

- Intense rainfall
- Rapid snowmelt
- Prolonged exceptional precipitation
- Rapid snowmelt / Thawing / Freeze-and-thaw weathering
- Earthquake / Volcanic eruption
- Undercutting
- Erosion of lateral margins
- Subterranean erosion (solution, piping)
- Deposition of load on the slope or its crest
- Vegetation removal
- Vegetation growth



Impact of landslides

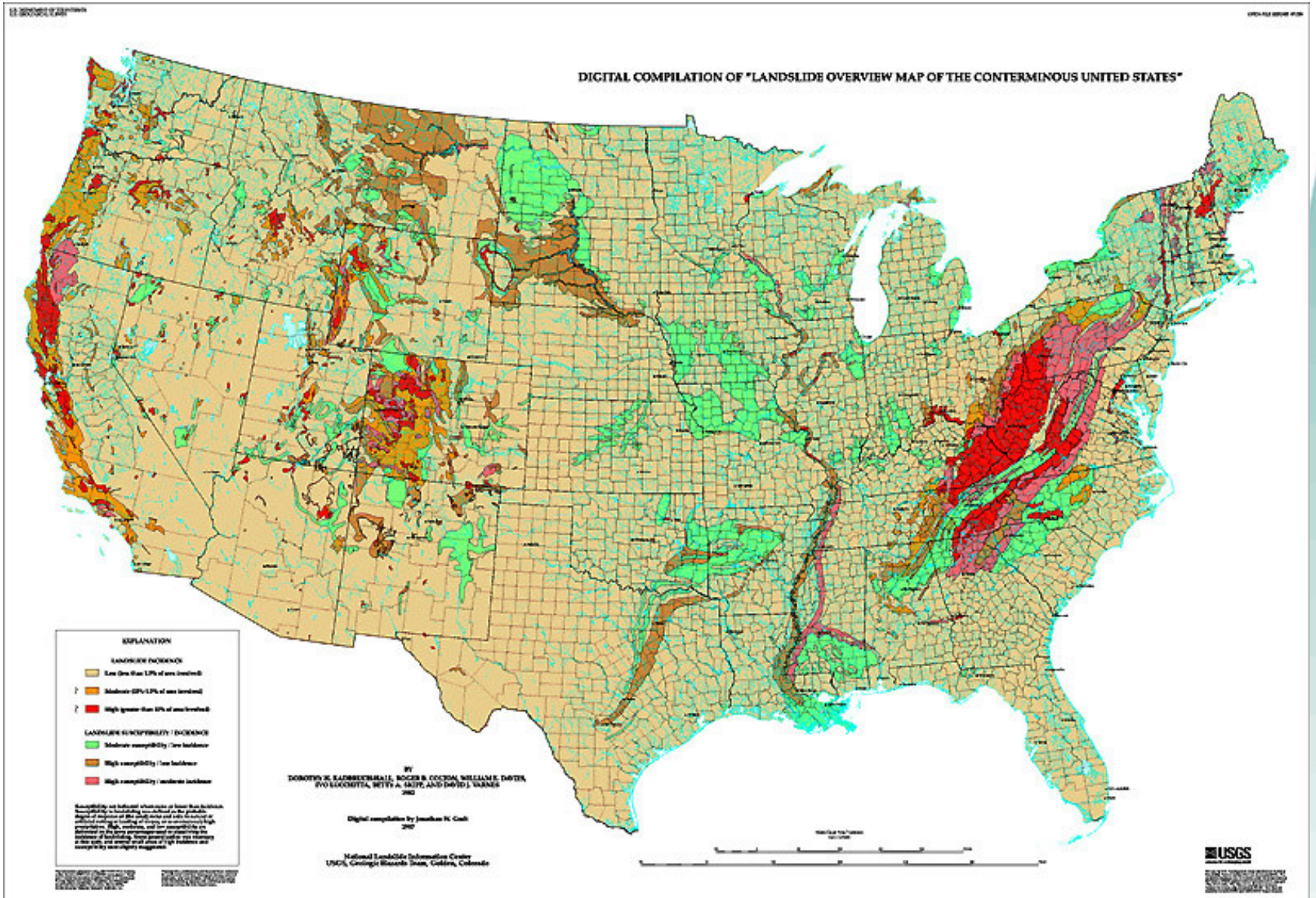
- **Worldwide landslide activity is increasing, due to:**
  - Increased urbanization and development in landslide-prone areas.
  - Continued deforestation of landslide-prone areas
  - Increased regional precipitation caused by changing climate patterns



Economic losses due to landslides

- **Direct costs:**
  - Repair, replacement, or maintenance resulting from damage to property or infrastructure due to landslides
- **Indirect costs:**
  - Loss of productivity and revenues
  - Reduced land value
  - Loss of tax revenues
  - Landslide mitigation measures
  - Adverse effect on water quality/ sedimentation/ siltation of reservoirs
  - Loss of human or animal productivity because of injury/ trauma
  - Secondary effects, such as landslide-caused flooding

Example: La Siria, Manizales, Colombia



- **Schuster (1978) : US $ 1.000 million per year (direct and indirect costs)**
- **Brabb (1984): US $ 250 million per year (direct only)**
- **Schuster & Fleming: $ 1.800 million per year**

Landslide losses

Country	Yearly losses Million US $
Japan	4.700
Italy	2.600
United States	1.800
India	1.350
China	500
Spain	220
Canada	50
Hong Kong	25
New Zealand	12
Norway	6

Landslide casualties

Year	Location	Type	No. Of deaths
1786	Sichuan (China)	Earthquake, landslide dam	100.000
1786	Calabria (S. Italy)	Earthquake, malaria	50.000
1920	Gansu (China)	Earthquake, severe winter	100.000
1933	Sichuan (China)	Earthquake, landslide dam	6.800
1949	Tadzhikistan	Earthquake	20.000
1963	Vaiont (Italy)	Landslide in dammed lake	2.000
1970	Huascaran (Peru)	Earthquake, debris avalanche	18.000
1985	Armero (Colombia)	Volcanic lahar	20.000

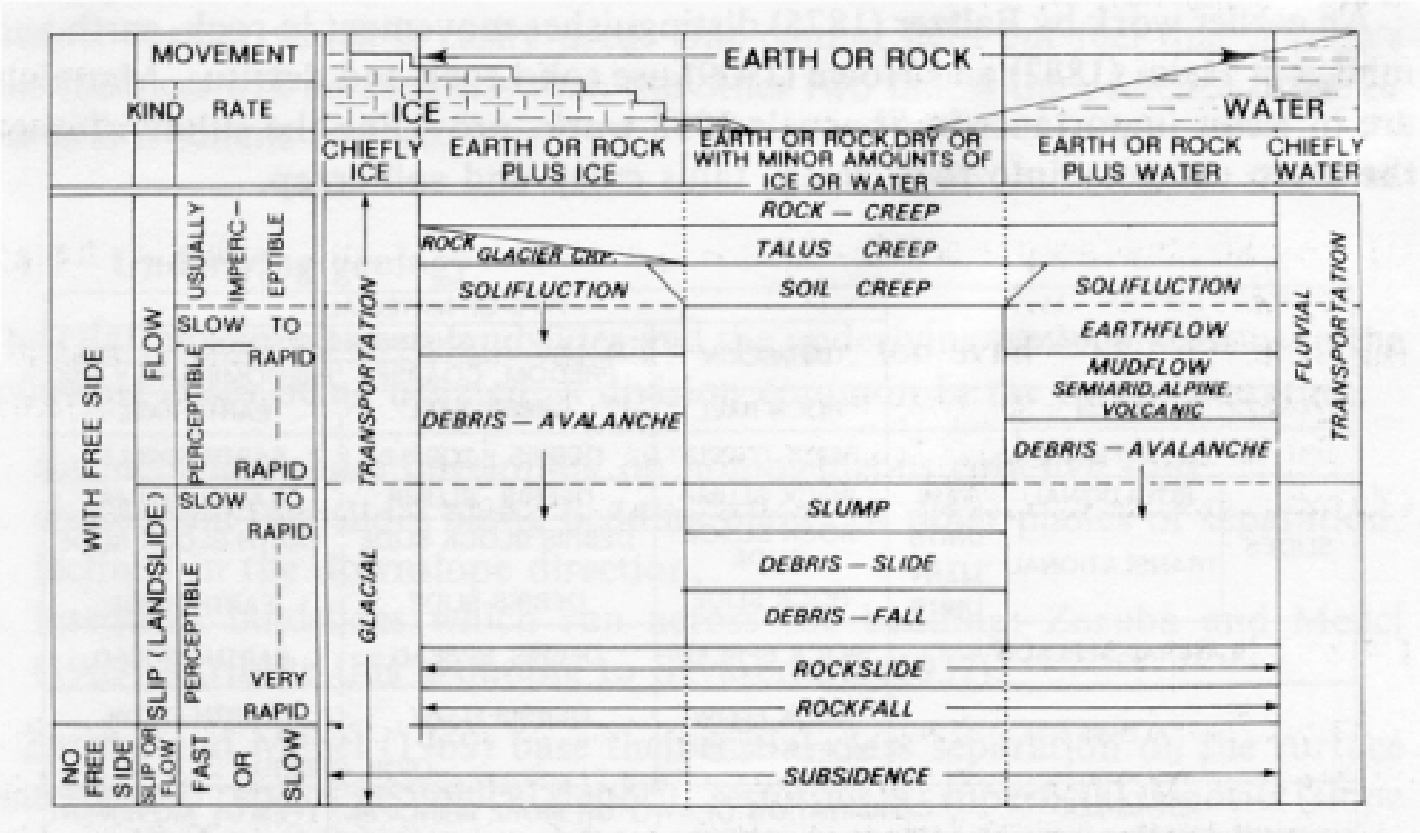
- Estimated casualties per year, world-wide: 600 - 1000 persons
- In US: 25 - 50 per year.

Landslide classification

The following factors can be used and have been used to classify landslides:

- Material: **Rock, Soil Lithology, structure, Geotechnical properties**
- Geomorphic attributes: **Weathering, Slope form**
- Landslide geometry: **Depth, Length, Height etc.**
- Type of movement: **Fall, Slide, Flow etc**
- Climate: **Tropical, Periglacial etc.**
- Water: **Dry, wet, saturated**
- Speed of movement: **Very slow, slow etc.**
- Triggering mechanism: **Earthquake, rainfall etc.**

Classification by Sharpe (1938)



- Material — earth, rock
- Movement — flow, slip
- Velocity — slow to very rapid
- Water/ice content

Varnes (1978)

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				PREDOM. COARSE	PREDOMINANTLY FINE
FALLS			ROCK FALL	DEBRIS FALL	EARTH FALL
TOPPLES			ROCK TOPPLE	DEBRIS TOPPLE	EARTH TOPPLE
SLIDES	ROTATIONAL	FEW UNITS	ROCK SLUMP	DEBRIS SLUMP	EARTH SLUMP
	TRANSLATIONAL	FEW UNITS	ROCK BLOCK SLIDE	DEBRIS BLOCK SLIDE	EARTH BLOCK SLIDE
		MANY UNITS	ROCK SLIDE	DEBRIS SLIDE	EARTH SLIDE
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		

- Material — bedrock, debris, earth
- Movement — fall, topple, slide, flow, complex
- Secondary — water content (dry to wet)
  velocity (slow to rapid)

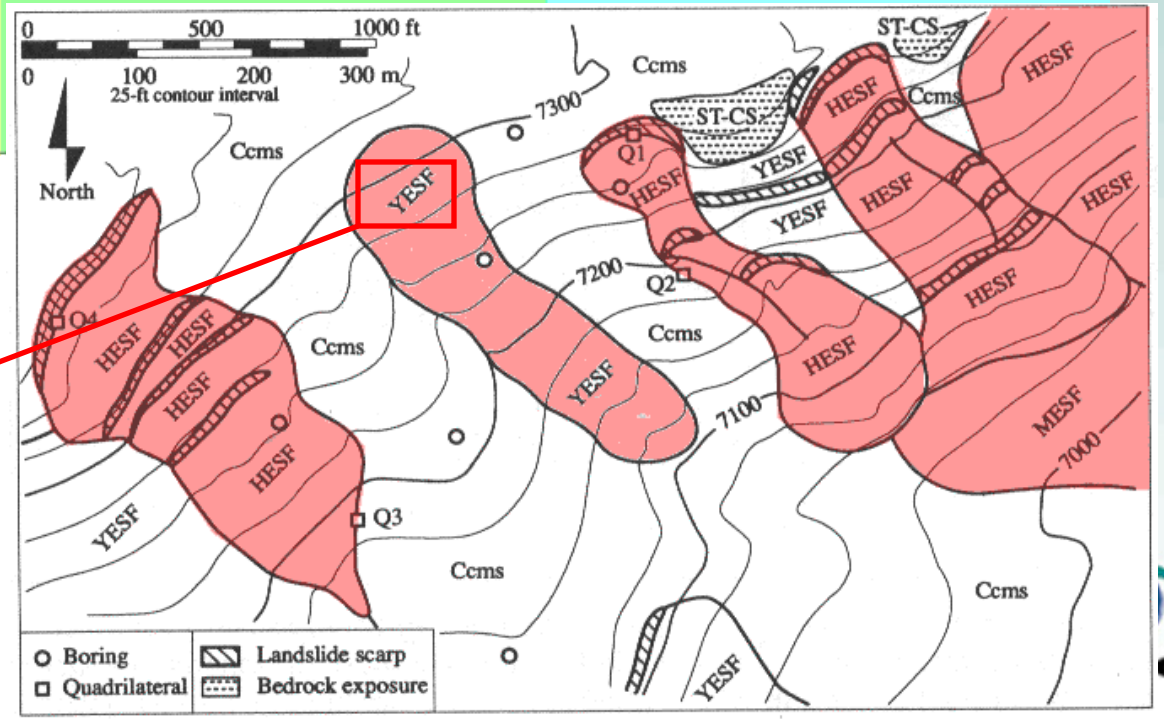
Hutchinson (1988)

- **Rebound**. When ground is unloaded, either artificially by encavation or naturelly by erosion, the unloaded area responds, initially elastically and subsequently by slow swelling (Peterson, 1958)
- **Creep**. Any extremely slow movements which are imperceptible except through long-period measurement
- **Sagging of mountain slopes**. A general term for these deep-seated deformations of mountain slopes, which, in their present state of development, do not justify classification as landslides.
- **Landslide**. Relatively rapid downslope movements of soil and rock, which take place chararcteristically on one or more discrete bounding slip surfaces which divine the moving mass.
- **Debris movement of flow like form**. Term covering five types of movement of flow-like form, which differ markedly in mechanism: non-periglacial mudslides, periglacial mudslides, flow slides, debris flows and sturzstroms.
- **Topple**. A movement that occurs when the vector of resultant applied forces falls through, or outside a pivot point in the base of the affected block.

Wieczorek:
Unified Landslide Classification System

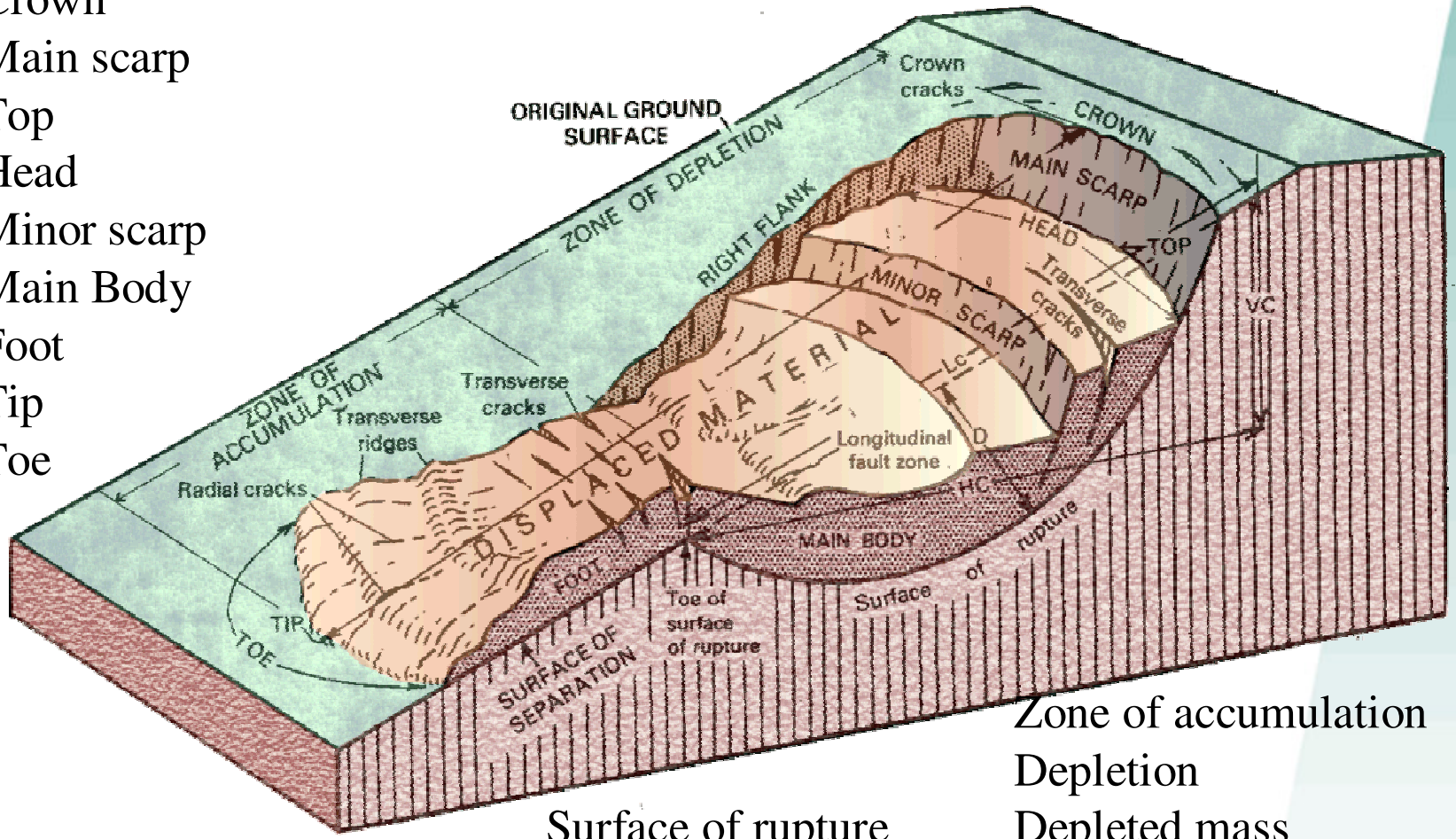
Age of Most Recent Activity[a]		Dominant Material[b]		Dominant Type of Slope Movement[b]	
Symbol	Definition	Symbol	Definition	Symbol	Definition
A	Active	R	Rock	L	Fall
R	Reactivated	S	Soil	T	Topple
S	Suspended	E	Earth	S	Slide
H	Dormant-historic	D	Debris	P	Spread
Y	Dormant-young			F	Flow
M	Dormant-mature				
O	Dormant-old				
T	Stabilized				
B	Abandoned				
L	Relict				

YESF:
Y = Dormant-Young
E = Earth
S = Slide
F = Flow



Landslide features

Crown
Main scarp
Top
Head
Minor scarp
Main Body
Foot
Tip
Toe



Surface of rupture
Surface of separation
Zone of depletion

Zone of accumulation
Depletion
Depleted mass
Accumulation
Flank

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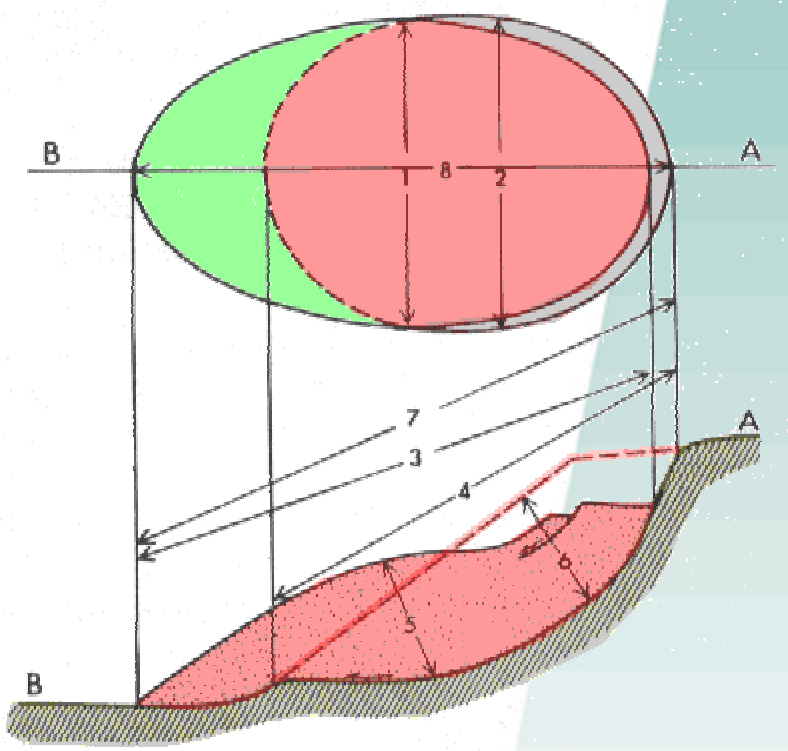
Landslide dimensions

1. Width of displaced mass (W_d)
2. Width of surface of rupture (W_r)
3. Length of displaced mass (L_d)
4. Length of surface of rupture (L_r)
5. Depth of displaced mass (D_d)
6. Depth of surface of rupture (D_r)
7. Total Length (L)
8. Length of center line (L_{cl})



Type of Movement	Type of Material		
	Bedrock	Engineering Soils	
		Predominantly Coarse	Predominantly Fine
Fall	Rock fall	Debris fall	Earth fall
Topple	Rock topple	Debris topple	Earth topple
Slide	Rock slide	Debris slide	Earth slide
Spread	Rock spread	Debris spread	Earth spread
Flow	Rock flow	Debris flow	Earth flow

Activity		
State	Distribution	Style
Active	Advancing	Complex
Reactivated	Retrogressive	Composite
Suspended	Widening	Multiple
Inactive	Enlarging	Successive
Dormant	Confined	Single
Abandoned	Diminishing	
Stabilized	Moving	
Relict		

Description of First Movement			
Rate	Water Content	Material	Type
Extremely rapid	Dry	Rock	Fall
Very rapid	Moist	Soil	Topple
Rapid	Wet	Earth	Slide
Moderate	Very wet	Debris	Spread
Slow			Flow
Very slow			
Extremely slow			

Description of Second Movement			
Rate	Water Content	Material	Type
Extremely rapid	Dry	Rock	Fall
Very rapid	Moist	Soil	Topple
Rapid	Wet	Earth	Slide
Moderate	Very wet	Debris	Spread
Slow			Flow
Very slow			
Extremely slow			

Cruden and Varnes (1996)
IAEG Commission UNESCO Working Party on World Landslide Inventory (WP/WLI).

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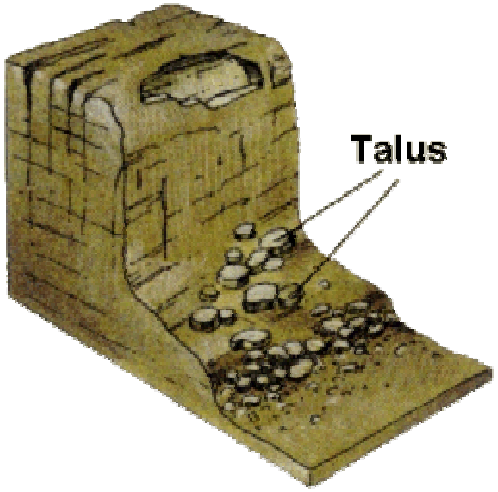
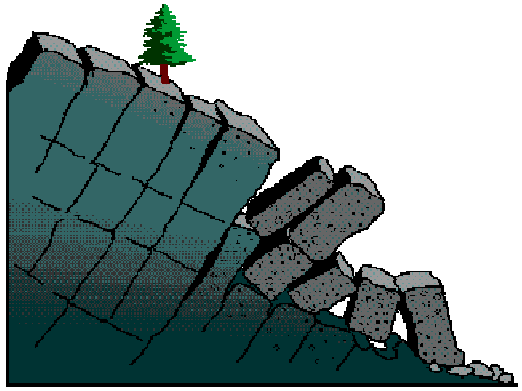
Types of landslides

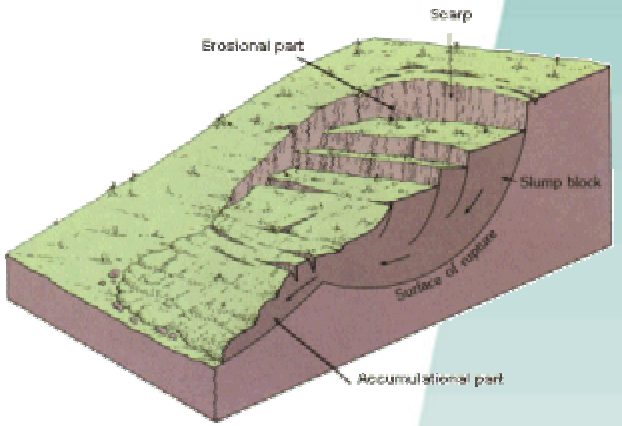
Fall



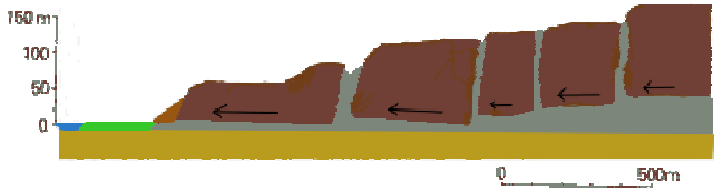
Topple



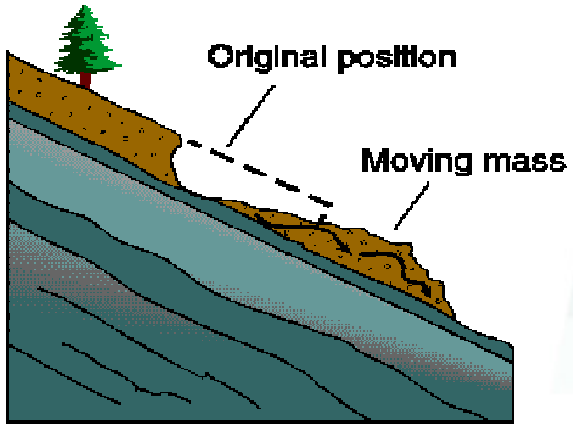
Slide



Spread

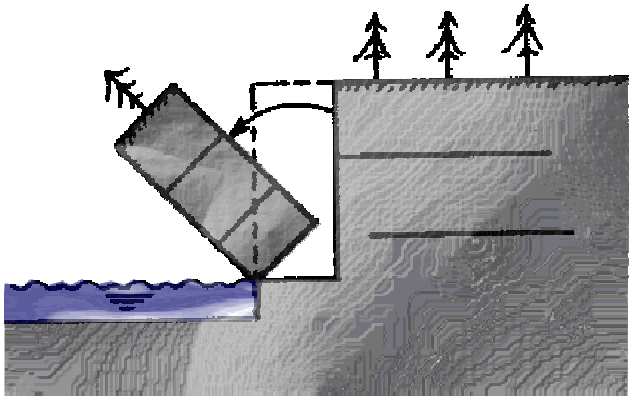


Flow

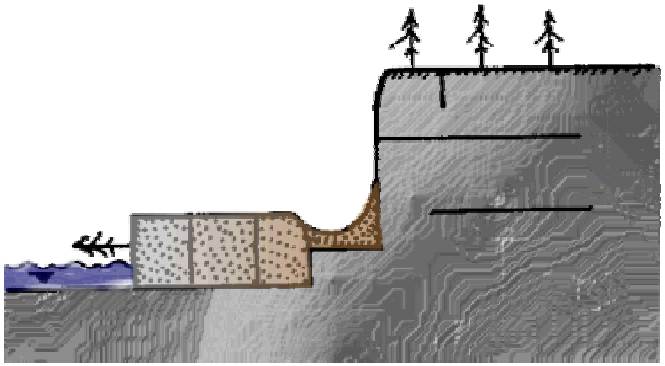


State of activity (1)

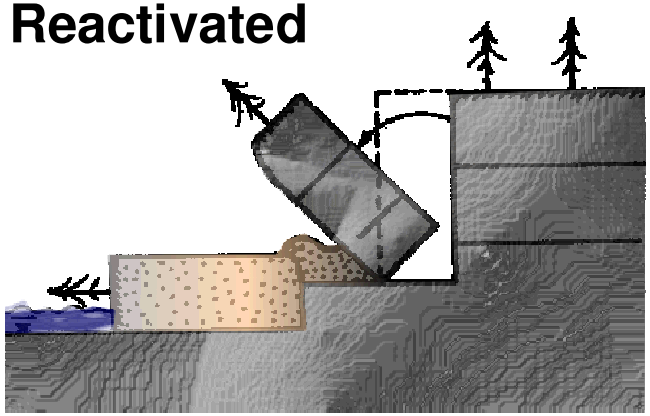
Active



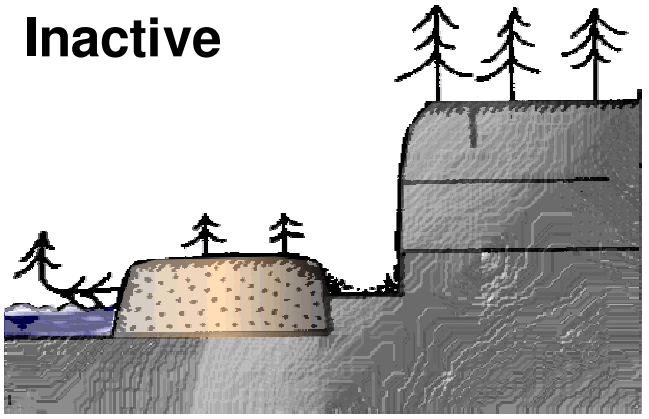
Suspended



Reactivated



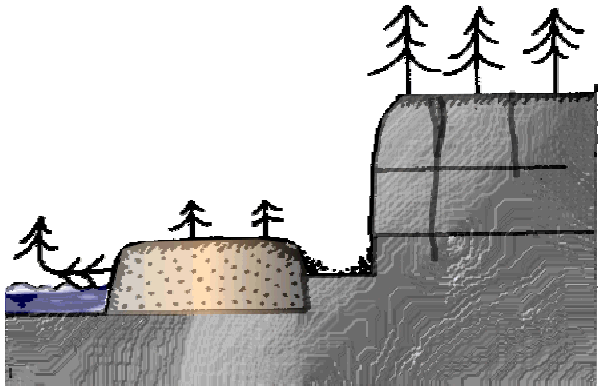
Inactive



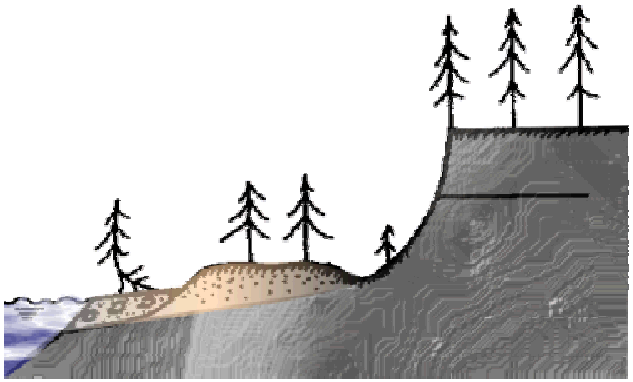
- Active
- Suspended
- Reactivated
- Inactive
- Dormant
- Abandoned
- Stabilized
- Relict

State of activity (2)

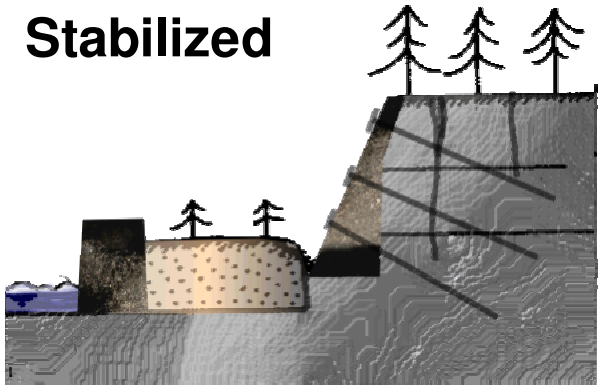
Dormant



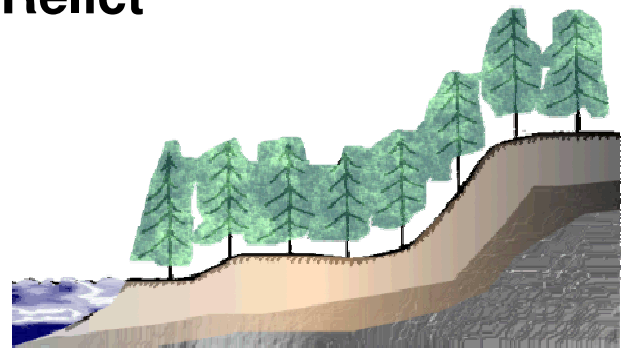
Abandoned



Stabilized



Relict

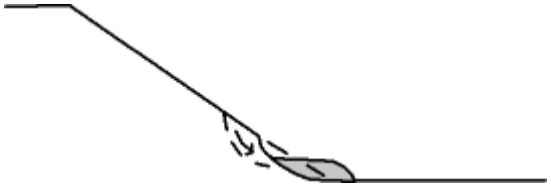


- Active
- Suspended
- Reactivated
- Inactive
- Dormant
- Abandoned
- Stabilized
- Relict

Distribution of activity

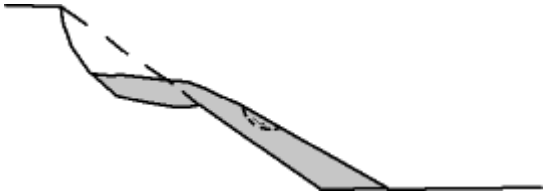
Advancing

Retrogressive



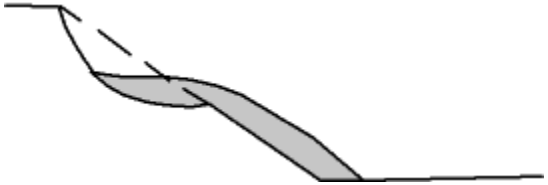
Enlarging

Diminishing

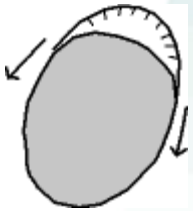


Confined

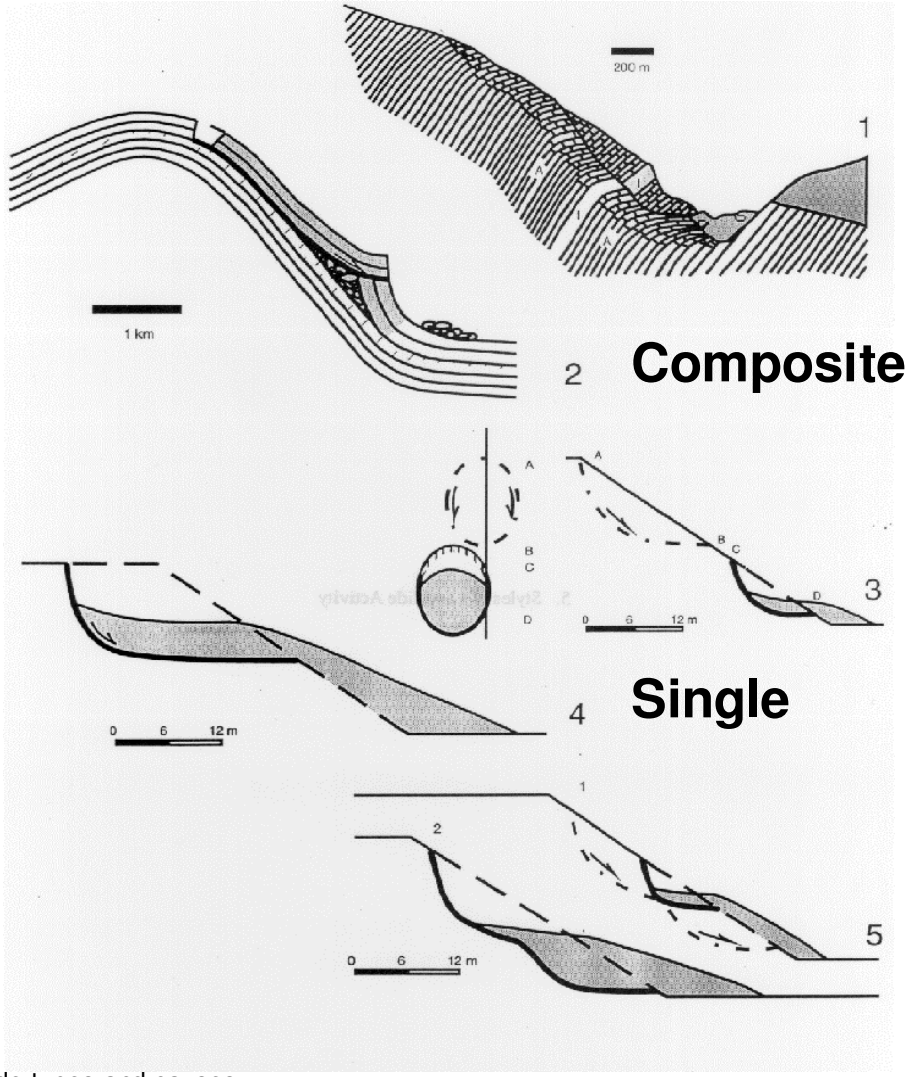
Moving



Widening



Styles of activity



Complex

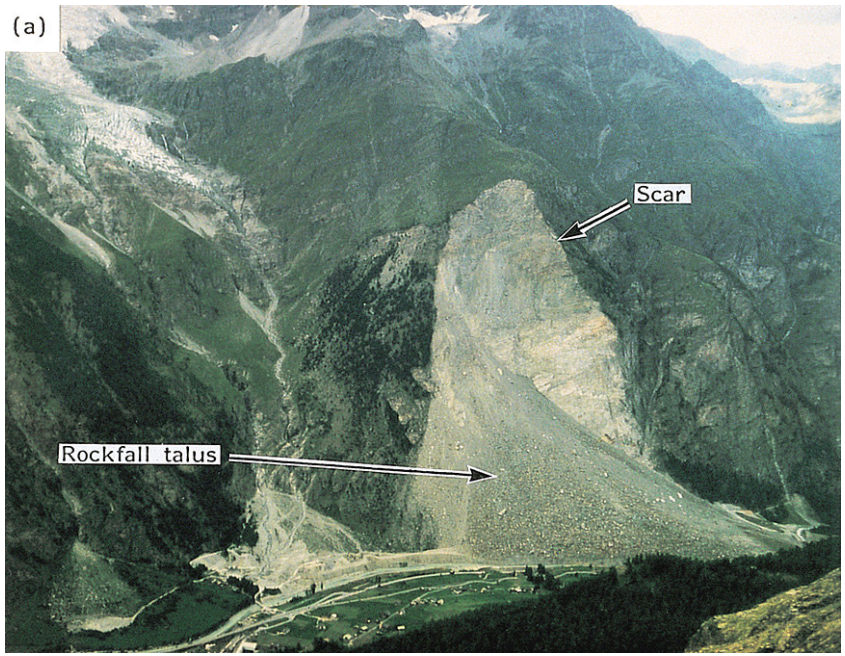
Composite

Successive

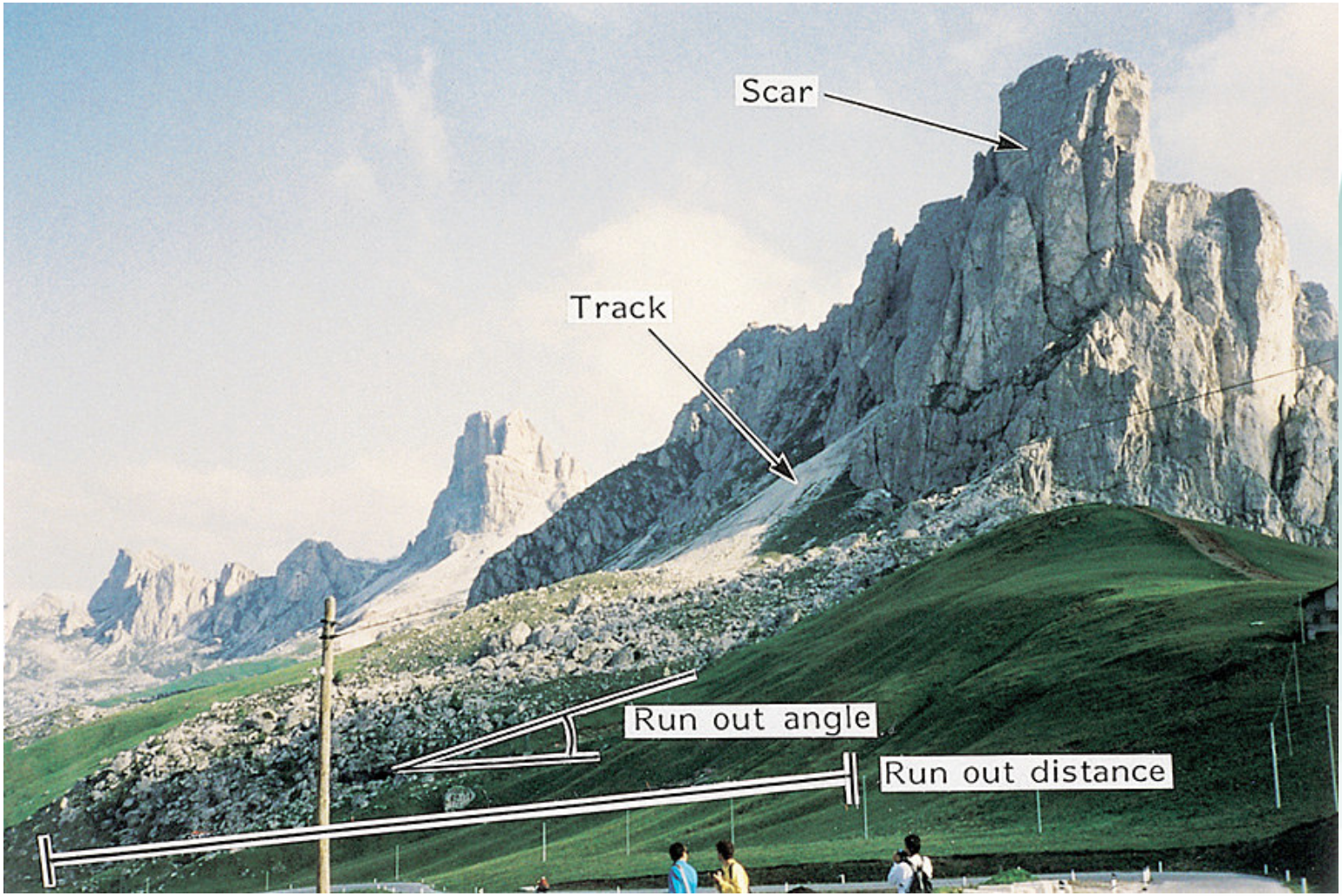
Single

Multiple

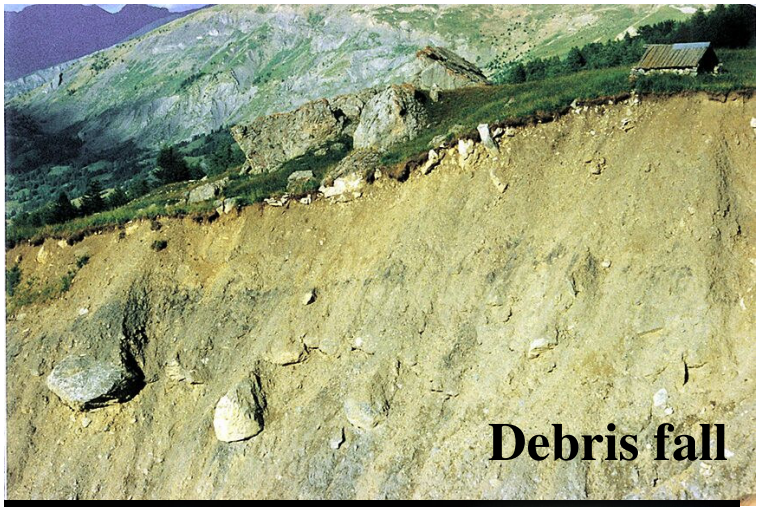
Fall examples



Rockfall

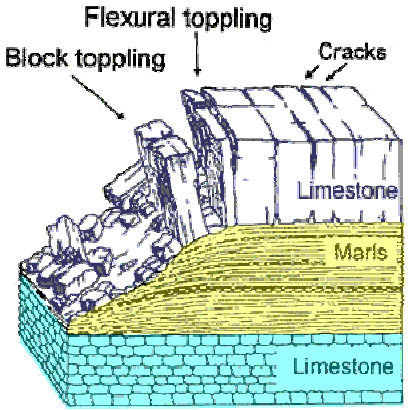


Examples: fall

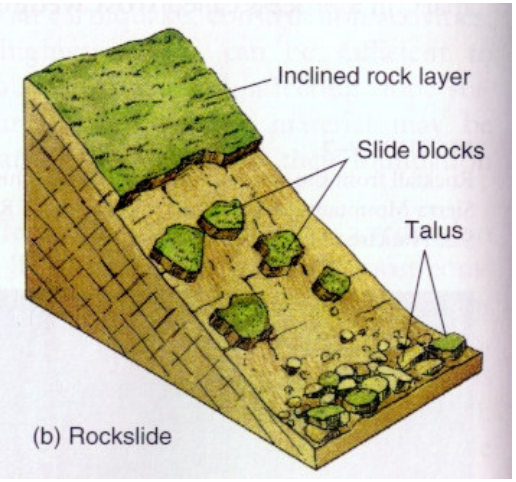


Typical rockfall deposits: talus slopes

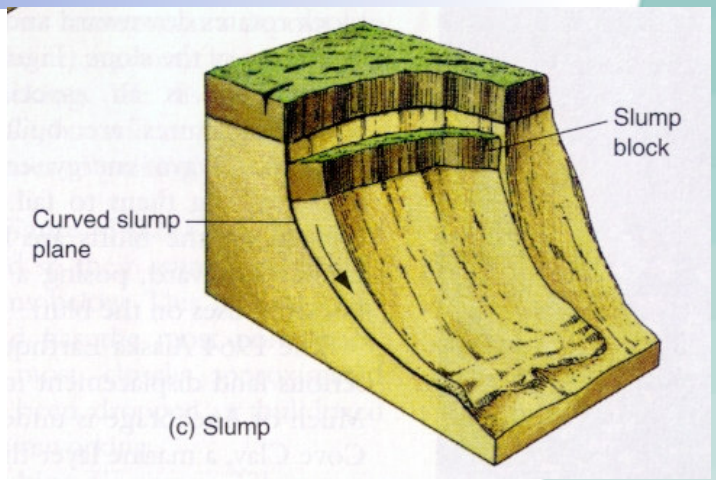
Examples toppling

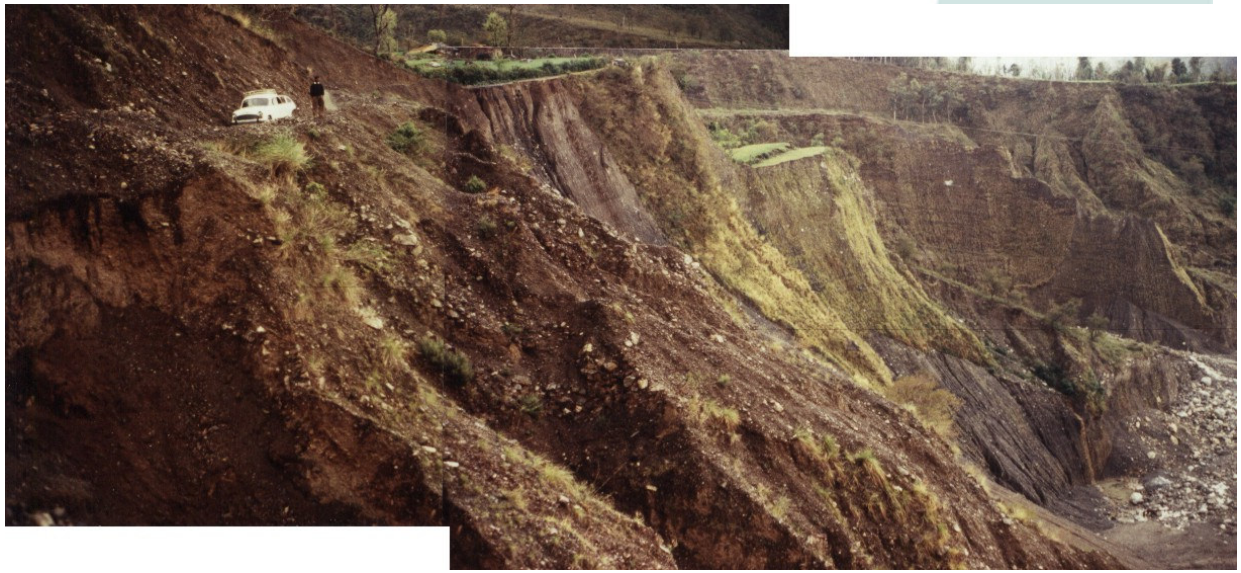


Translational slide



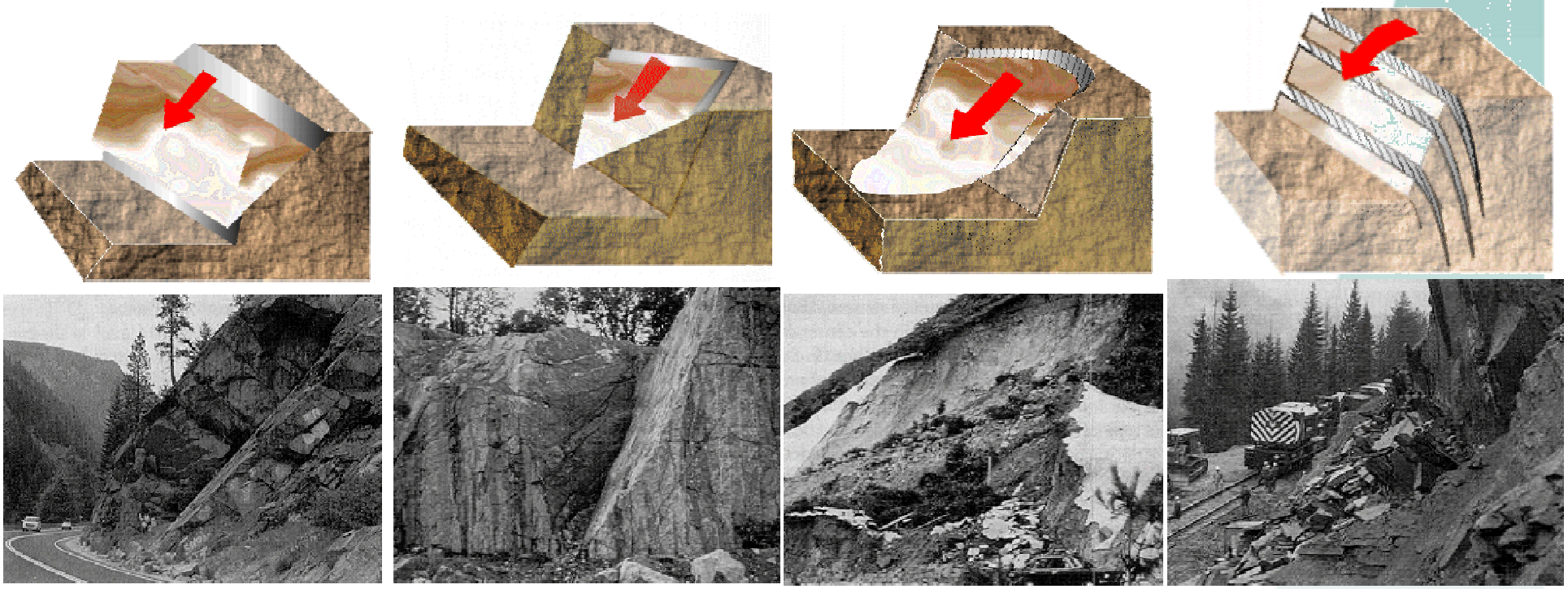
Rotational slide (Slump)





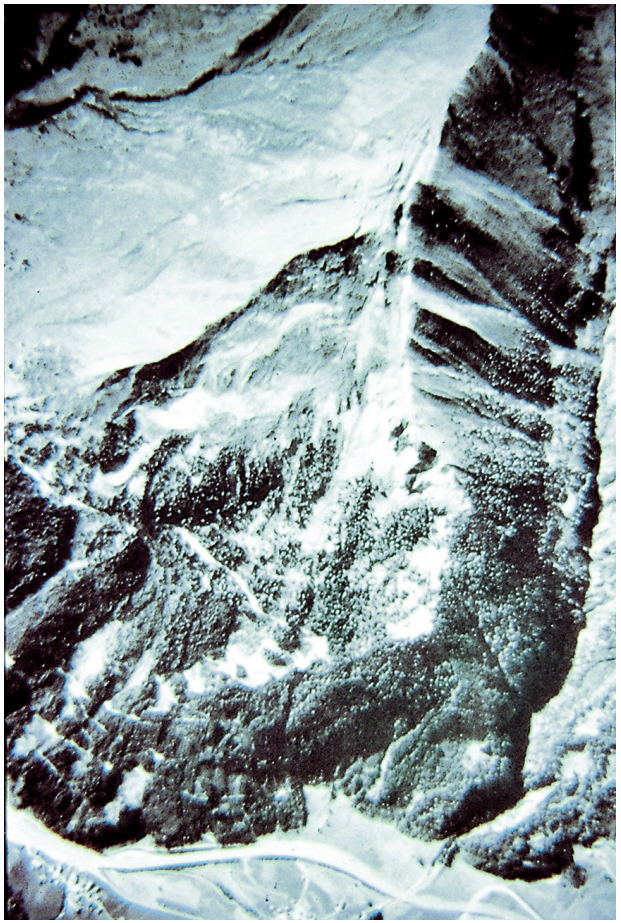
Rock slides

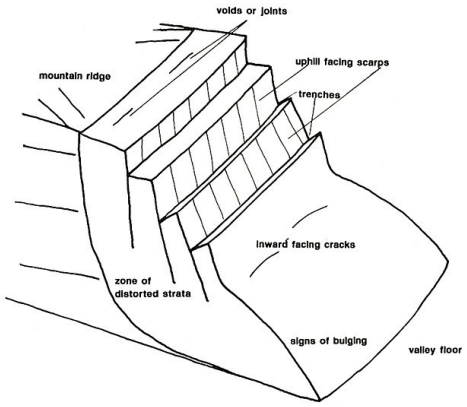
Planar failure **Wedge failure** **Rotational** **Toppling**



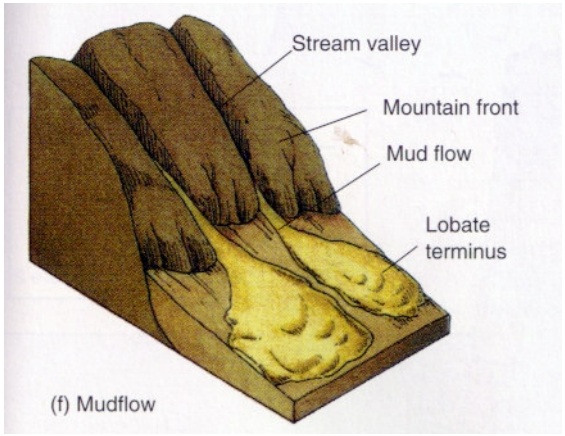
Type of rockslide depends on discontinuities in the rock mass

Sagging / Sackungen



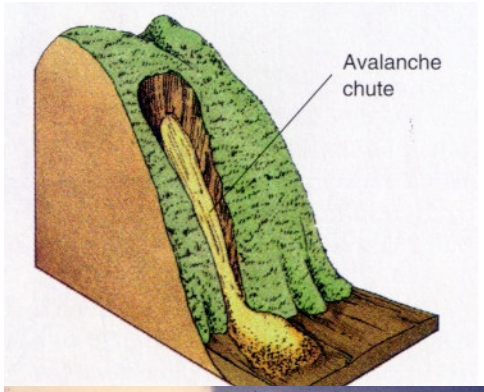


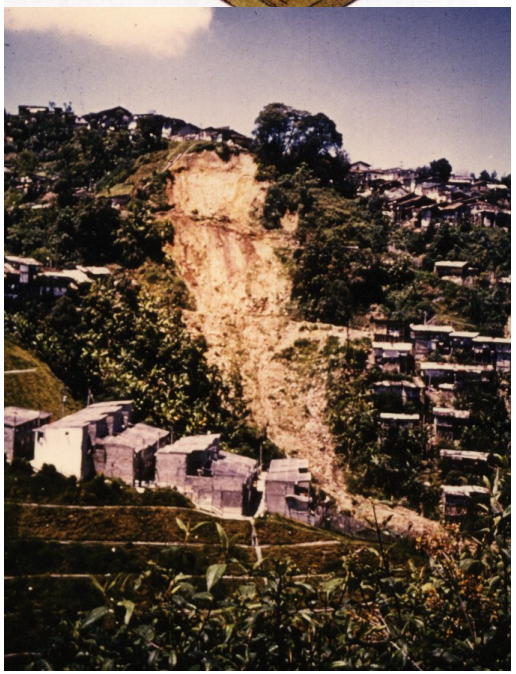
Flow type movements: debris flow



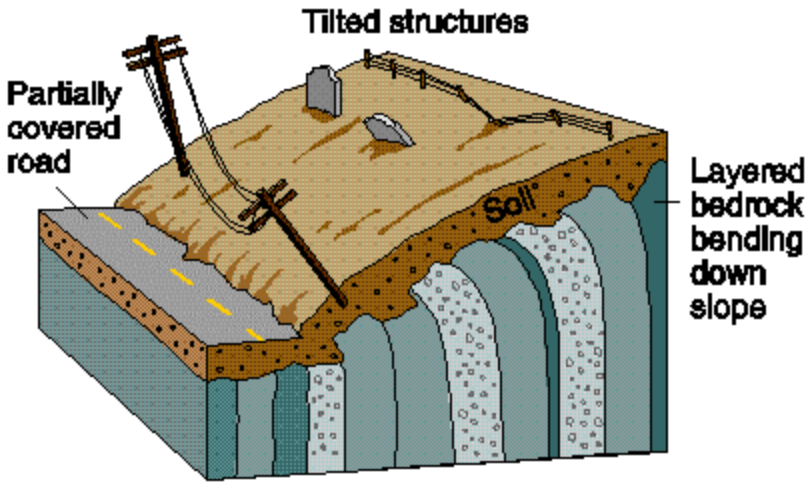
Flow type movements: earthflow

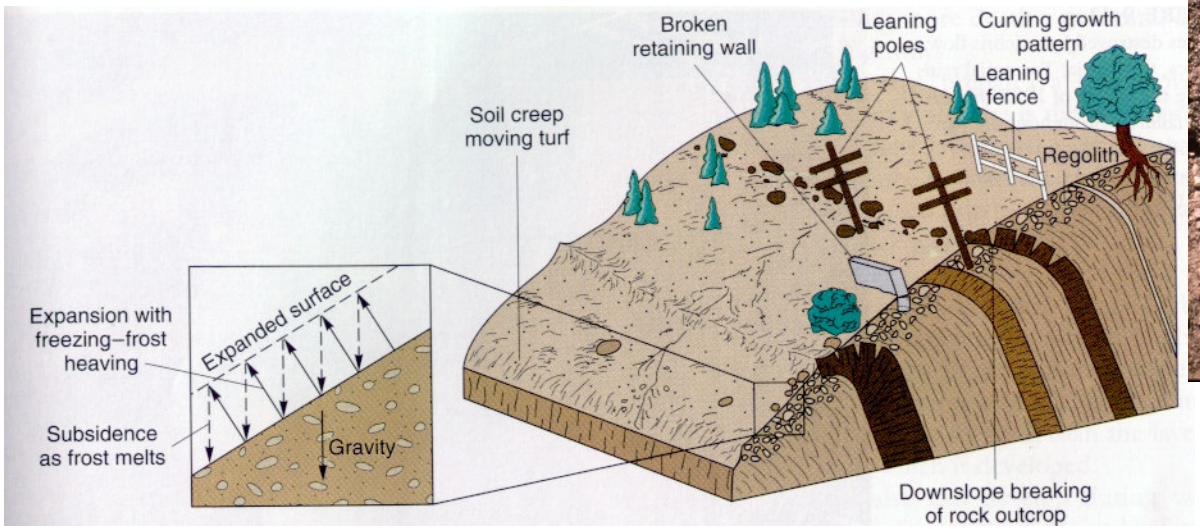
Flow type movements: Debris avalanche



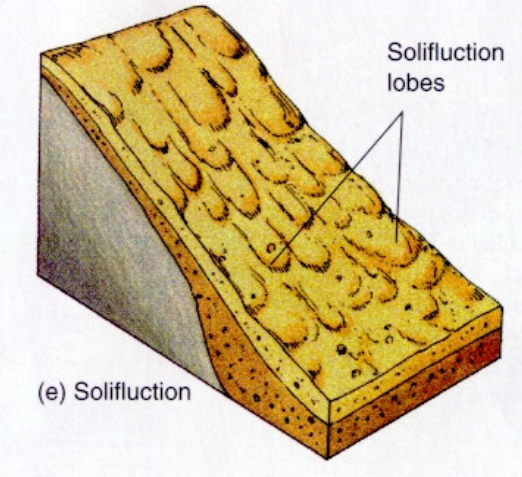


Creep


Tilted structures
Partially covered road
Soil
Layered bedrock bending down slope


Broken retaining wall
Leaning poles
Curving growth pattern
Leaning fence
Soil creep moving turf
Regolith
Expansion with freezing–frost heaving
Expanded surface
Subsidence as frost melts
Gravity
Downslope breaking of rock outcrop

Solifluction & Rock glaciers



Solifluction

Rock glacier