Mass Wasting and Hill-slopes

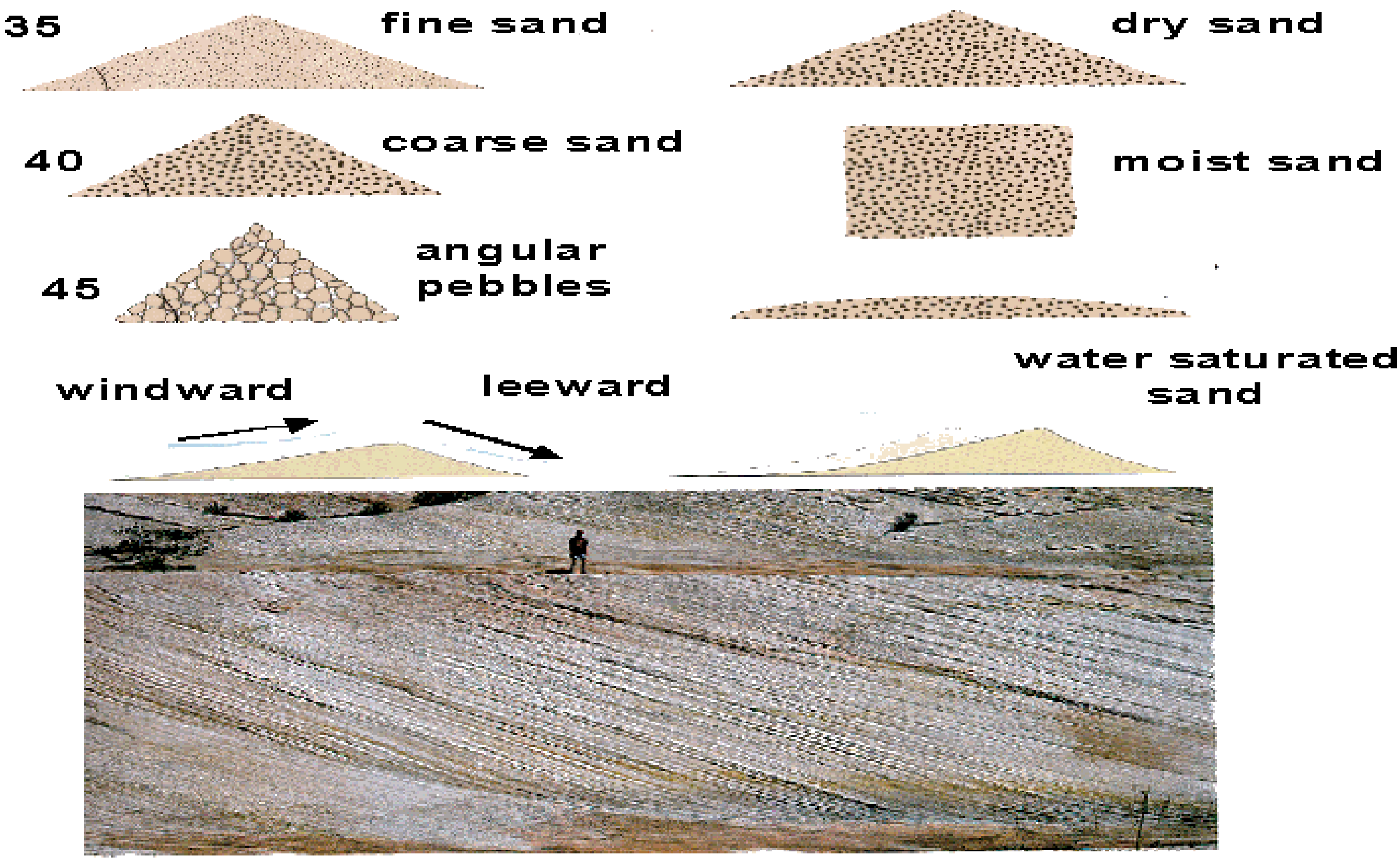
Mass wasting

- Is a collective term addressing all down slope movements of weathered rock (soil) that are created by gravitational forces.
- Gravity is the primary component!
- Vocabulary
  - Colluvium
  - Solifluction (soil flow)

The Angle of Repose

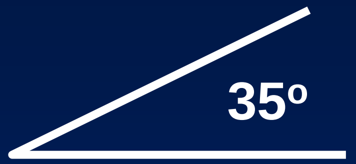
- The maximum slope at which loose, cohesionless material remains stable. It commonly ranges between 33 and 37 on natural slopes.
- Dependent upon size, shape, surface roughness, angularity, of the particles
- Wallace Stegner book as well.

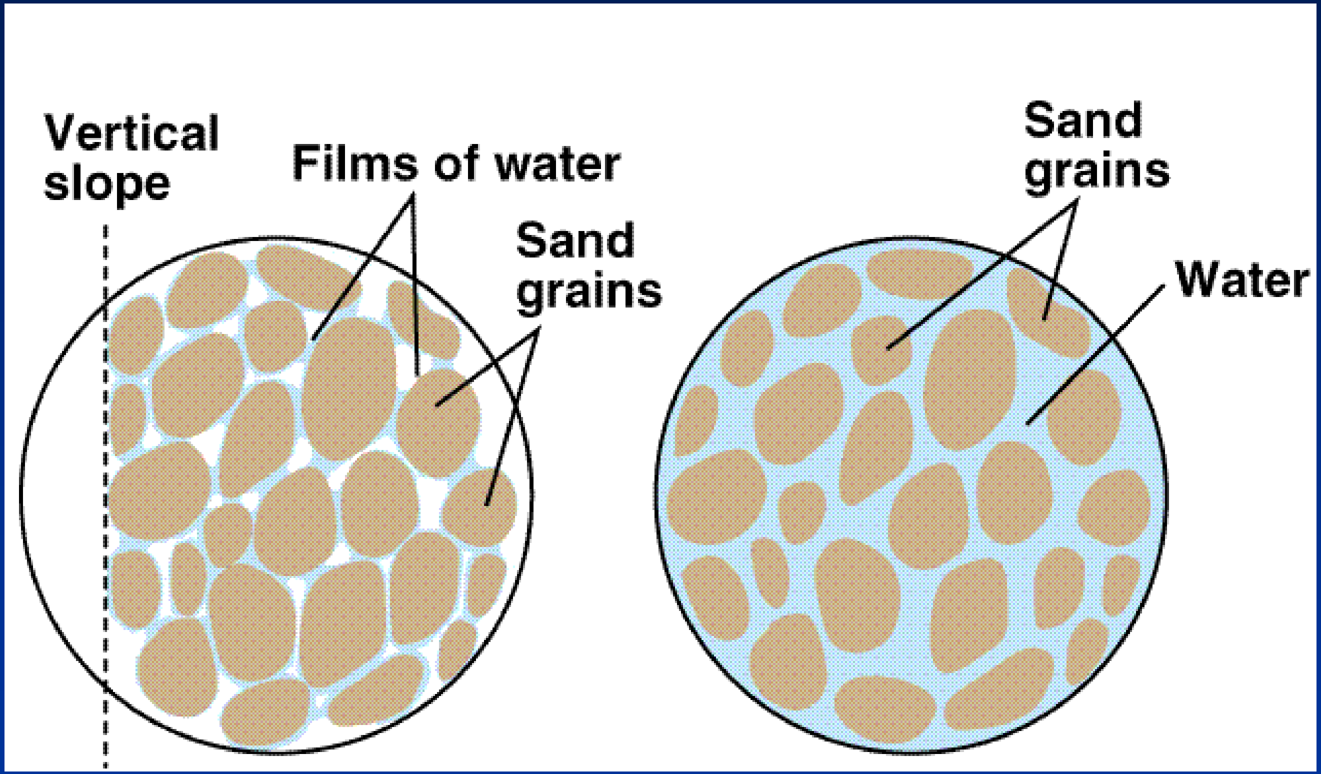
The Angle of Repose



Cross bedding is formed by the migration of sand waves (**ripple marks** or **dunes**) by sand particles travelling up the **windward** face and depositing down the **leeward** face

Dry sand cannot support an angle of >35º from horizontal: this is termed the *angle of repose*.





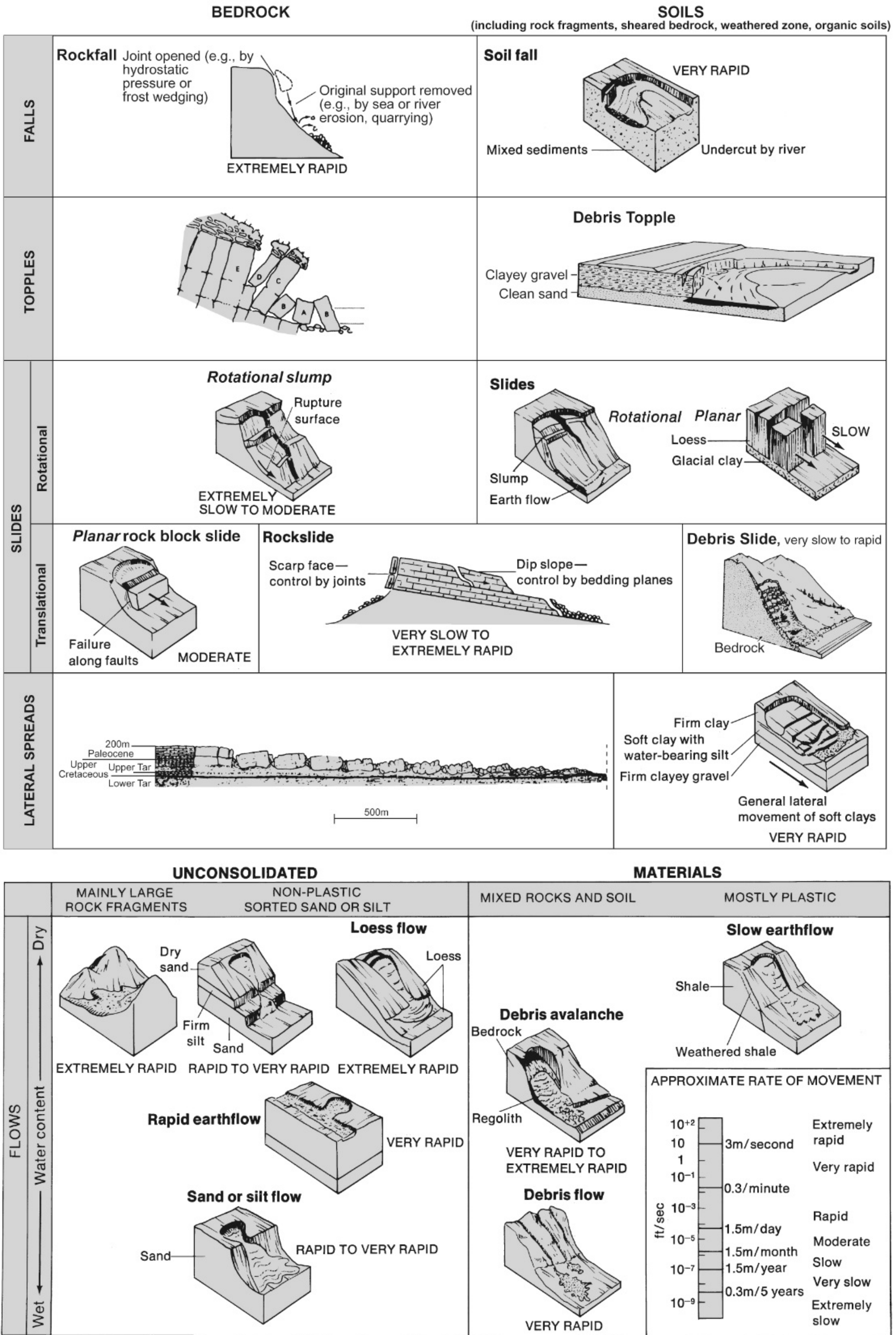
Moderate amounts of water create *increased* structural integrity of sediment due to surface tension between grains. In this way slopes steeper than the angle of repose can be maintained (e.g., sandcastles).

Saturation of sediment by water eliminates any structural competence. This is the condition that often leads to slope instability and mass wasting.

Slope movement types

- When defining mass wasting it is necessary to include
  1) the type of material in motion, including its coherence and dimensions; and
  2) the type and rate of movement including creeping, falling, toppling, sliding, spreading, or flowing (debris flow).

Handout



BEDROCK
SOILS
(including rock fragments, sheared bedrock, weathered zone, organic soils)
FALLS
Rockfall
Joint opened (e.g., by hydrostatic pressure or frost wedging)
Original support removed (e.g., by sea or river erosion, quarrying)
EXTREMELY RAPID
Soil fall
VERY RAPID
Mixed sediments
Undercut by river
TOPPLES
Debris Topple
Clayey gravel
Clean sand
SLIDES
Rotational
Rotational slump
Rupture surface
EXTREMELY SLOW TO MODERATE
Slides
Rotational
Planar
Loess
Glacial clay
SLOW
Slump
Earth flow
Translational
Planar 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, very slow to rapid
Bedrock
LATERAL SPREADS
200m
Paleocene
Upper Cretaceous
Upper Tar
Lower Tar
500m
Firm clay
Soft clay with water-bearing silt
Firm clayey gravel
General lateral movement of soft clays
VERY RAPID
UNCONSOLIDATED
MATERIALS
MAINLY LARGE ROCK FRAGMENTS
NON-PLASTIC SORTED SAND OR SILT
MIXED ROCKS AND SOIL
MOSTLY PLASTIC
FLOWS
Water content
Dry
Wet
Dry sand
Firm silt
Sand
Loess flow
Loess
EXTREMELY RAPID
RAPID TO VERY RAPID
EXTREMELY RAPID
Rapid earthflow
VERY RAPID
Sand or silt flow
Sand
RAPID TO VERY RAPID
Debris avalanche
Bedrock
Regolith
VERY RAPID TO EXTREMELY RAPID
Debris flow
VERY RAPID
Slow earthflow
Shale
Weathered shale
APPROXIMATE RATE OF MOVEMENT
ft/sec
10⁺²
10
1
10⁻¹
10⁻³
10⁻⁵
10⁻⁷
10⁻⁹
3m/second
0.3/minute
1.5m/day
1.5m/month
1.5m/year
0.3m/5 years
Extremely rapid
Very rapid
Rapid
Moderate
Slow
Very slow
Extremely slow

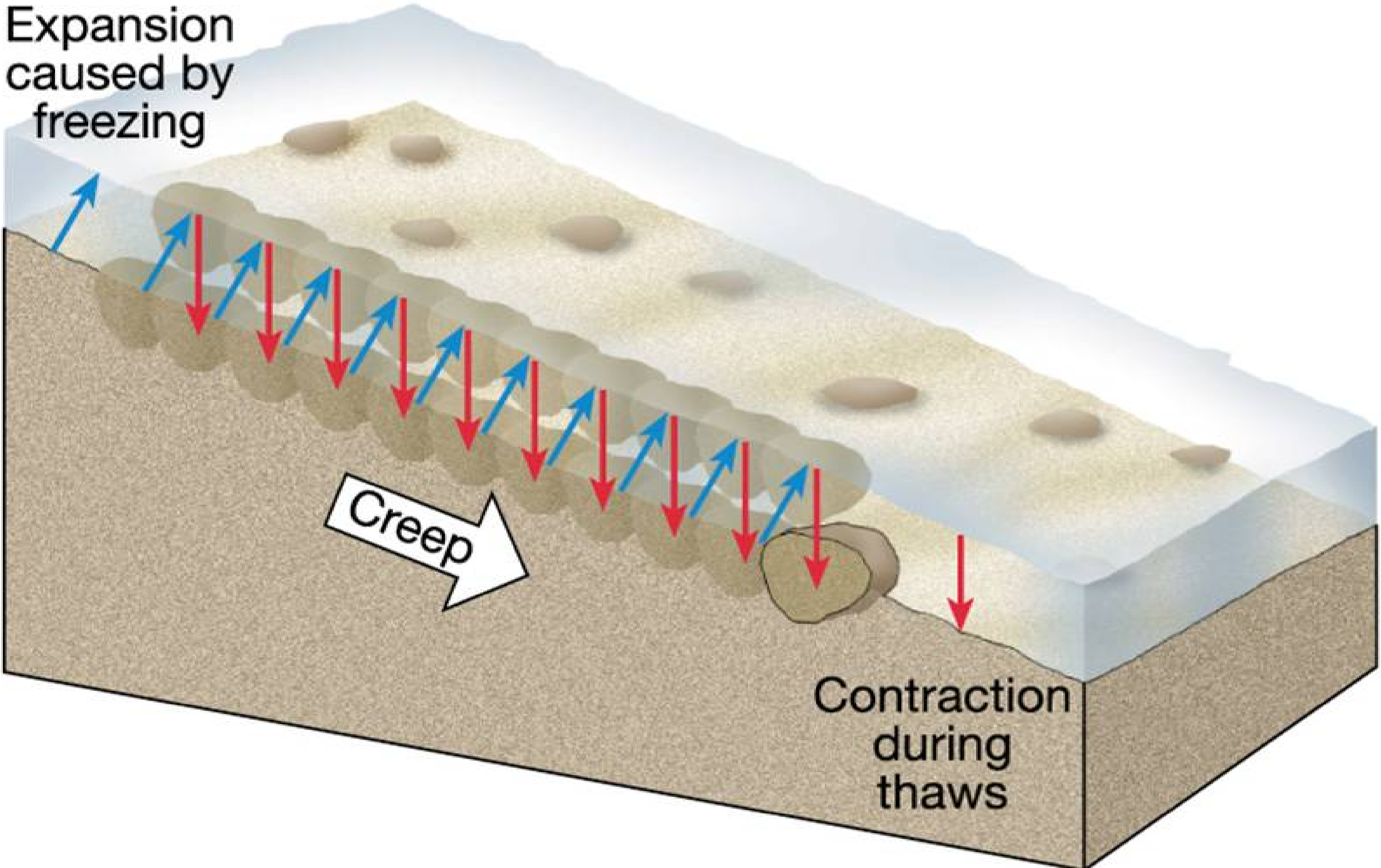
Table 4.11 Distinguishing Landslide Deposits from Coarse-Grained Sediments Deposited by Glacial and Fluvial Processes

Characteristic	Landslide Deposits	Glacial Deposits (till)	Fluvial Deposits (coarse)
Sedimentology			
Sorting	Very poor	Very poor	Variable, generally good
Roundness	Angular	Moderately rounded	Rounded
Grain size	Variable, may be large	Variable, may be large	Generally finer-grained
Fabric	Generally lacking	Generally lacking	Imbricated
Composition	Local, monolithologic	Variable, extrabasinal	Variable, within basin
Stratification	None	None to poor	Well-layered
Transport process	Creep, sliding	Ice	Tractive-bedload
Morphology			
Internal forms	Transverse ridges	Sinuous moraines	Lacking ridges
Surface relief	Hummocky	Hummocky	Organized bedforms
Drainage	Poor, undrained sags	Poor, undrained sags	Well-drained
Head region	Scarp, local	None or cirque	None
Profile	Convex-up surface	Irregular	Concave-up longitudinal
Valley form	None specific	U-shaped	None specific
Lateral associations	Source region upslope	Downstream outwash and loess	Downstream-fining fluvial deposits

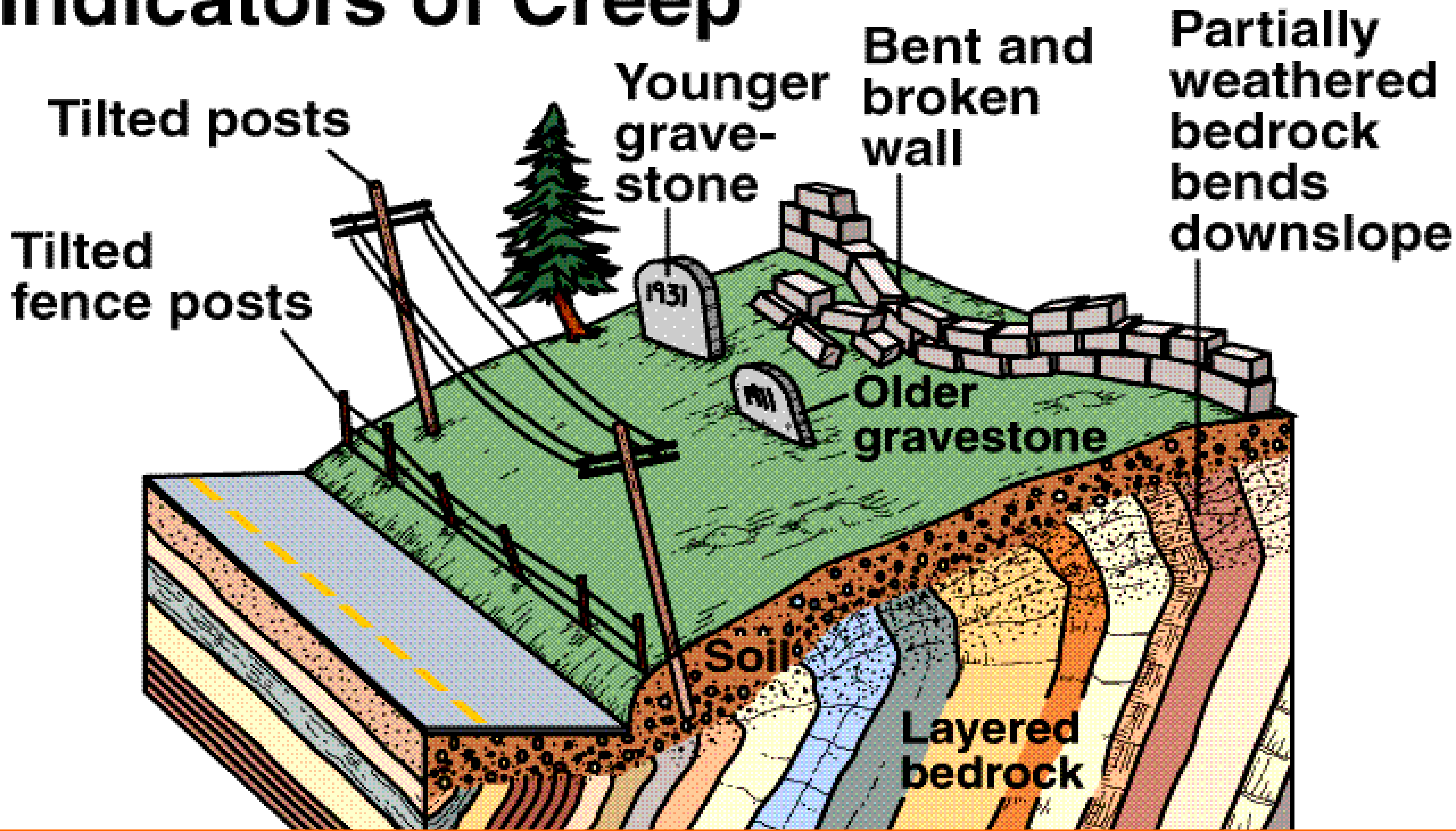
Creep

- Barely perceptible down slope movement.
- Particle creep, individual particle movement due to wetting/drying, heating/cooling
- Soil creep, dependent on changing SMR and climates.

Creepy drawing



Indicators of Creep

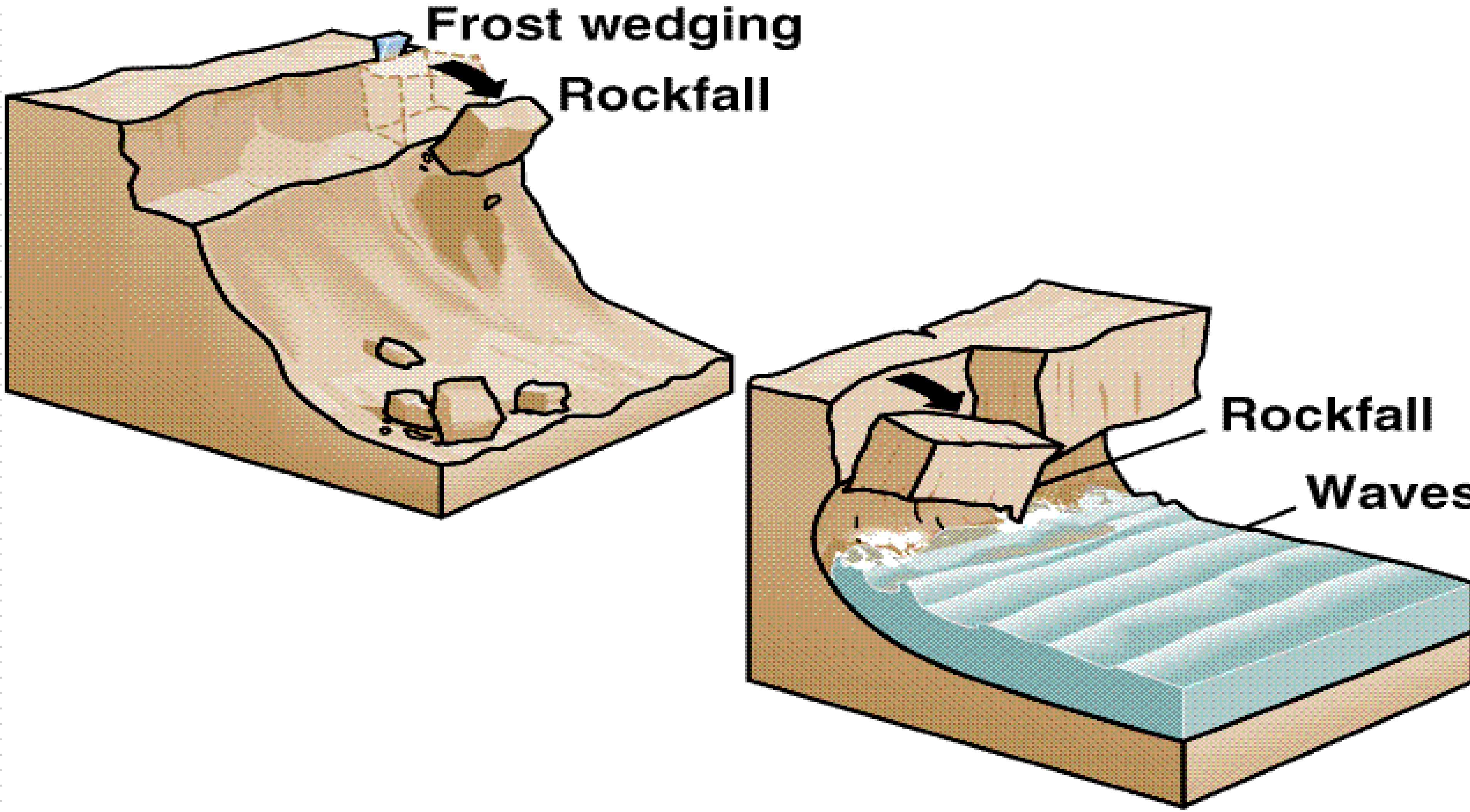


Creep (or soil creep) works at a pace of mm/yr. It is generally related to (seasonal) wet-dry or freeze thaw changes.

Fall

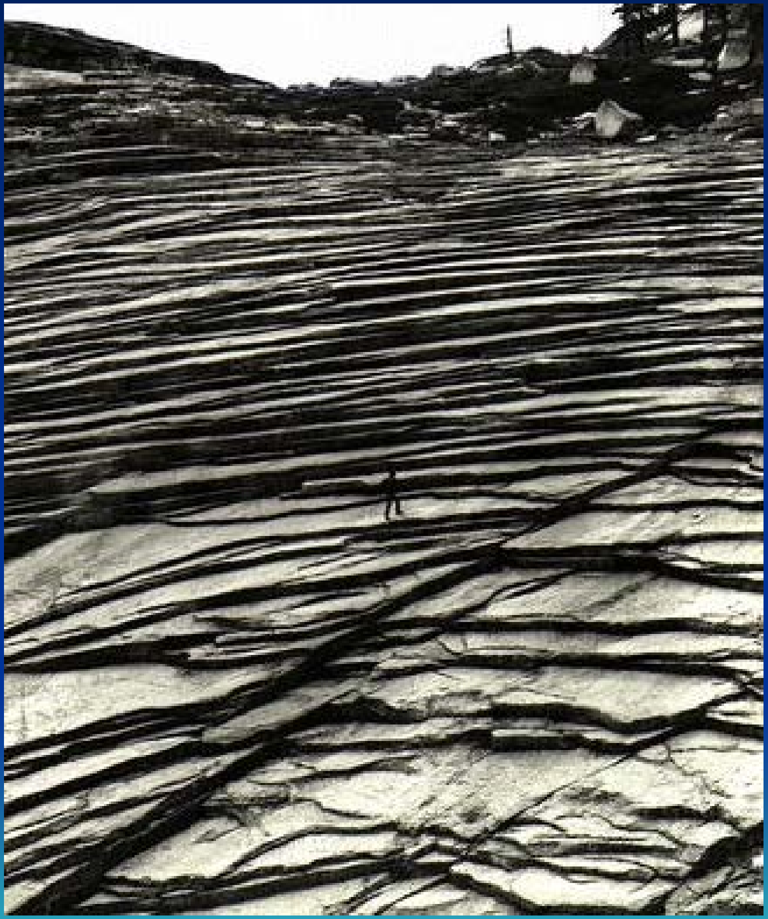
- A *fall* is a mass movement where singular or multiple blocks of rock plunge from a height.

Two Examples of Rockfall



Yosemite, CA

Looks like an ideal place for a rock fall or a rock slide, thanks to exfoliation of granite batholiths.



Yosemite

- A rock fall in this area in July, 1996, had rather amazing consequences.
- A single granite block weighing ~200 tons broke free and disintegrated upon impact.
- The burst of air from the impact flattened some 2000 trees and the area was showered with dust from the obliterated boulder.
- Only one person was killed

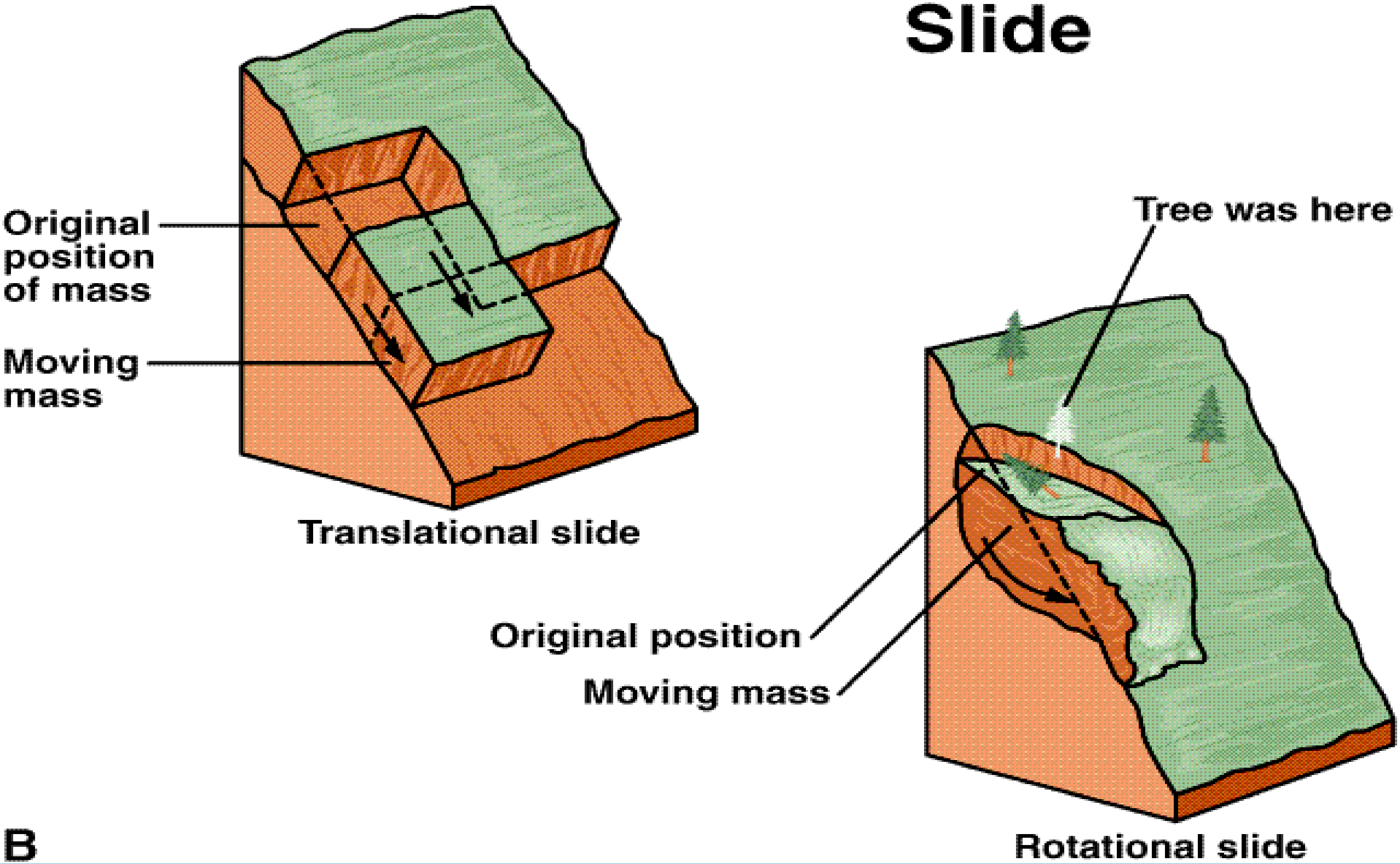
Topple

- Large joint bounded sheets or blocks, slowly creep or lean outward until they become unstable and topple over or slide down hill.

Slide

- A *slide* is a mass movement that occurs as one unit.

Slide


Original position of mass
Moving mass
Translational slide
Tree was here
Original position
Moving mass
Rotational slide
B



40
10

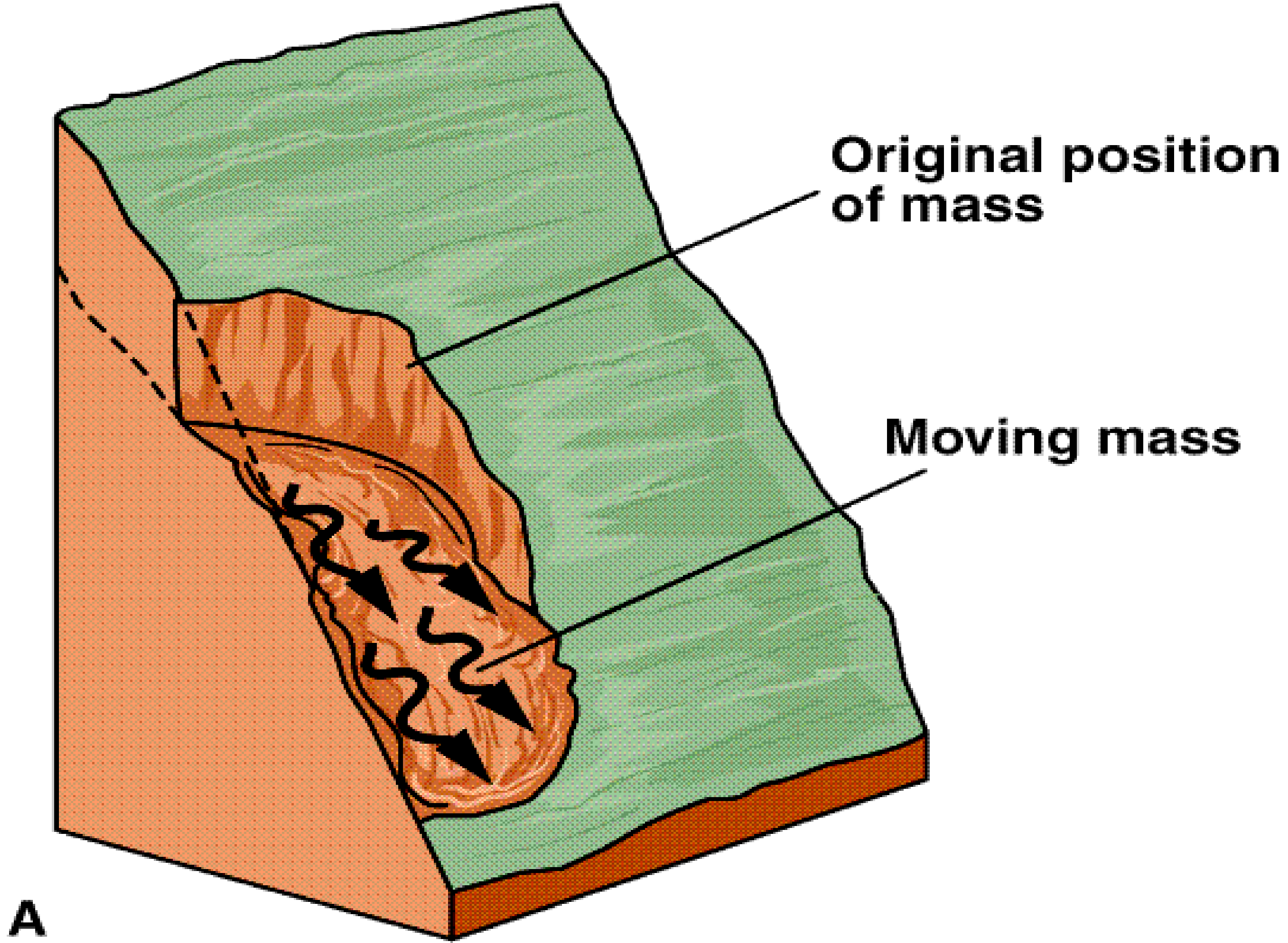

40

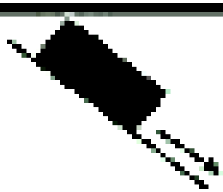
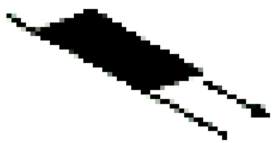
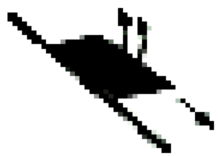
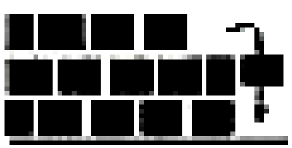
UNI

Flow

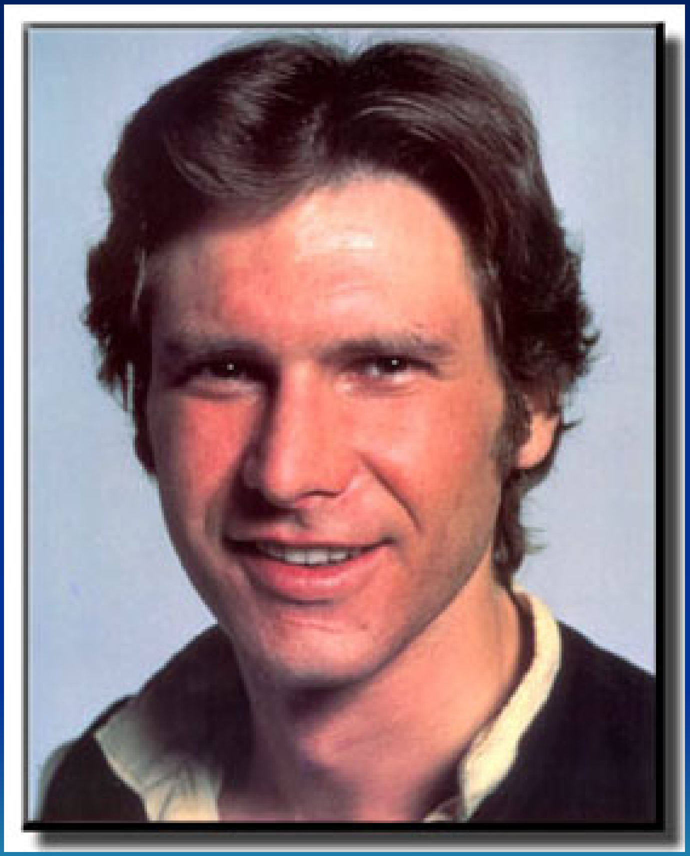
- A *flow* is a mass movement that is internally chaotic and turbulent. What begins as a slide may become flow as it moves down slope and disaggregates.

Flow



		MATERIAL			
MECHANISM		Rock	Fine-grained Soil	Coarse-grained Soil	Velocity
SLIDE		SLUMP	Earth Slump	Debris Slump	SLOW
		Block glide	Earth slide	Debris slide	RAPID
FLOW		Rock avalanche	Mudflow, avalanche	Debris,flow, avalanche	Very Rapid
		Creep	Creep	Creep	Extremely slow
FALL		Rockfall	Earthfall	Debrisfall	Extremely rapid

The physics of mass wasting
Stress Vs. Strain



The physics of mass wasting
Stress Vs. Strain

- Normal stress (σ_n)
  (γh cos^2 θ)

- Shear strength (σ_r)
  - Cohesion (c)
  - Mass friction (σ tan φ)
  Navier-Coulomb criterion

Principle of effective stress

(shear strength, s = c’ + σ’ tan φ’)

Accounts for dx/dy of pore water pressure

- Shear stress (σ_s)
  (γh sin θ cos θ)

Resisting Forces (Shear Strength)

- Forces that act to maintain slope stability
  1. Cohesion
  2. Effective normal stress
  3. Friction

Factors that tend to decrease shear strength

- Weathering, reduces cohesion
- Pore water, an increase in the amount of pore water present will increase the internal pressure within a mass of sediment, leading to instability.
- Structural or human induced changes.

Table 4.5 Factors That Influence Stress and Resistance in Slope Materials

Factors That Increase Shear Stress	Factors That Decrease Shear Strength
Removal of lateral support	Weathering and other physicochemical reactions
Erosion (e.g., rivers, ice, waves)	Disintegration (lowers cohesion)
Human activity (e.g., quarries, road cuts)	Hydration (lowers cohesion)
Addition of mass	Base exchange
Natural (e.g., rain, talus)	Solution
Human (e.g., fills, ore stockpiles, buildings)	Drying
Earthquakes	Pore water
Regional tilting	Buoyancy
Removal of underlying support	Capillary tension
Natural (e.g., undercutting, solution, weathering)	Structural changes
Human activity (e.g., mining)	Remolding
Lateral pressure	Fracturing
Natural (e.g., swelling, expansion by freezing, water addition)	

(After Varnes 1958)

Examples of Catastrophic Mass Wasting

- Economic impact
  - Agriculture
  - Roadways
  - Mining
- Deaths

Nevado Huascaran, Peru, 1970

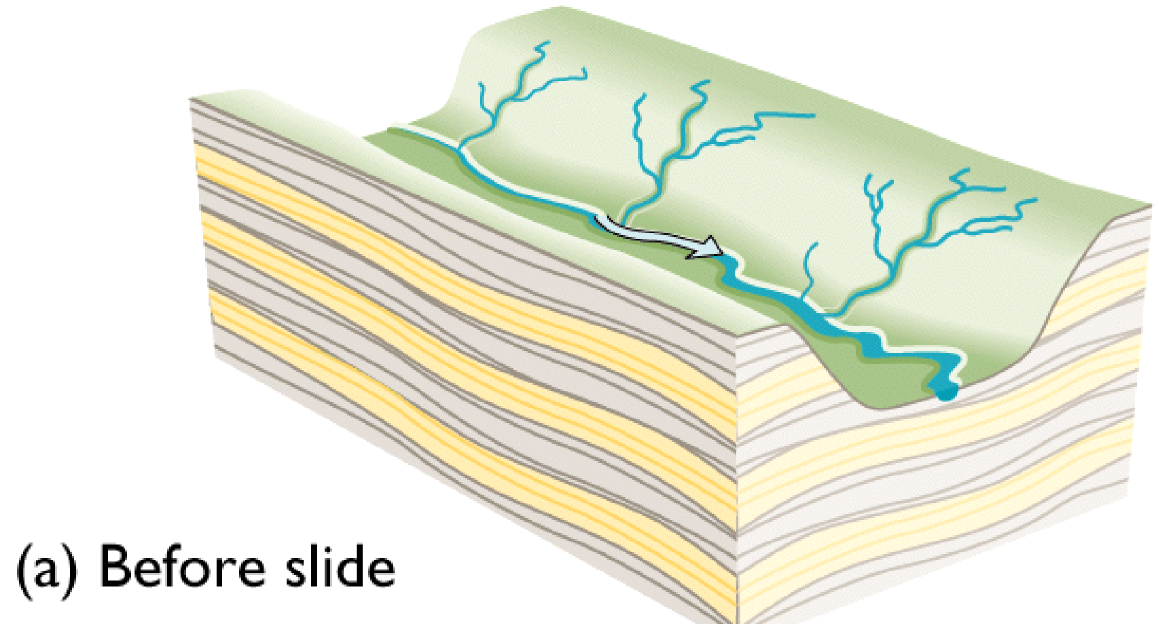
- It began high in the mountains as an earthquake-induced avalanche of snow and ice, but picked up glacial sediment on its way.
- It hit the towns of Yungay and Ranrahirca, 18 km away, at around 150 km/hr. The former town was completely buried.
- An astounding 66,000 people were estimated dead as a result of this massive debris avalanche.

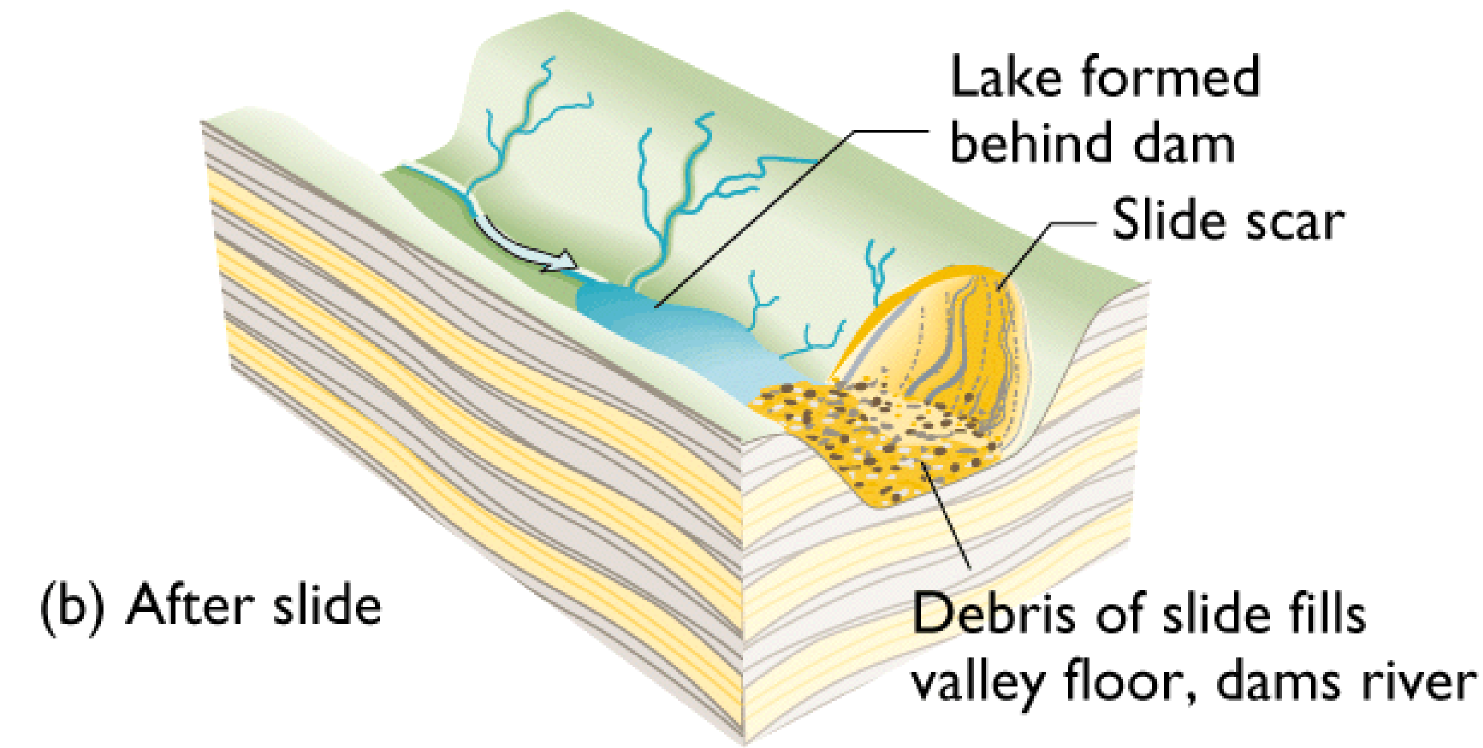
The landslide destroyed major highway and rail line, and also dammed the Spanish Fork River, flooding out the town of Thistle.

The most costly single landslide in US history:
> $400 million

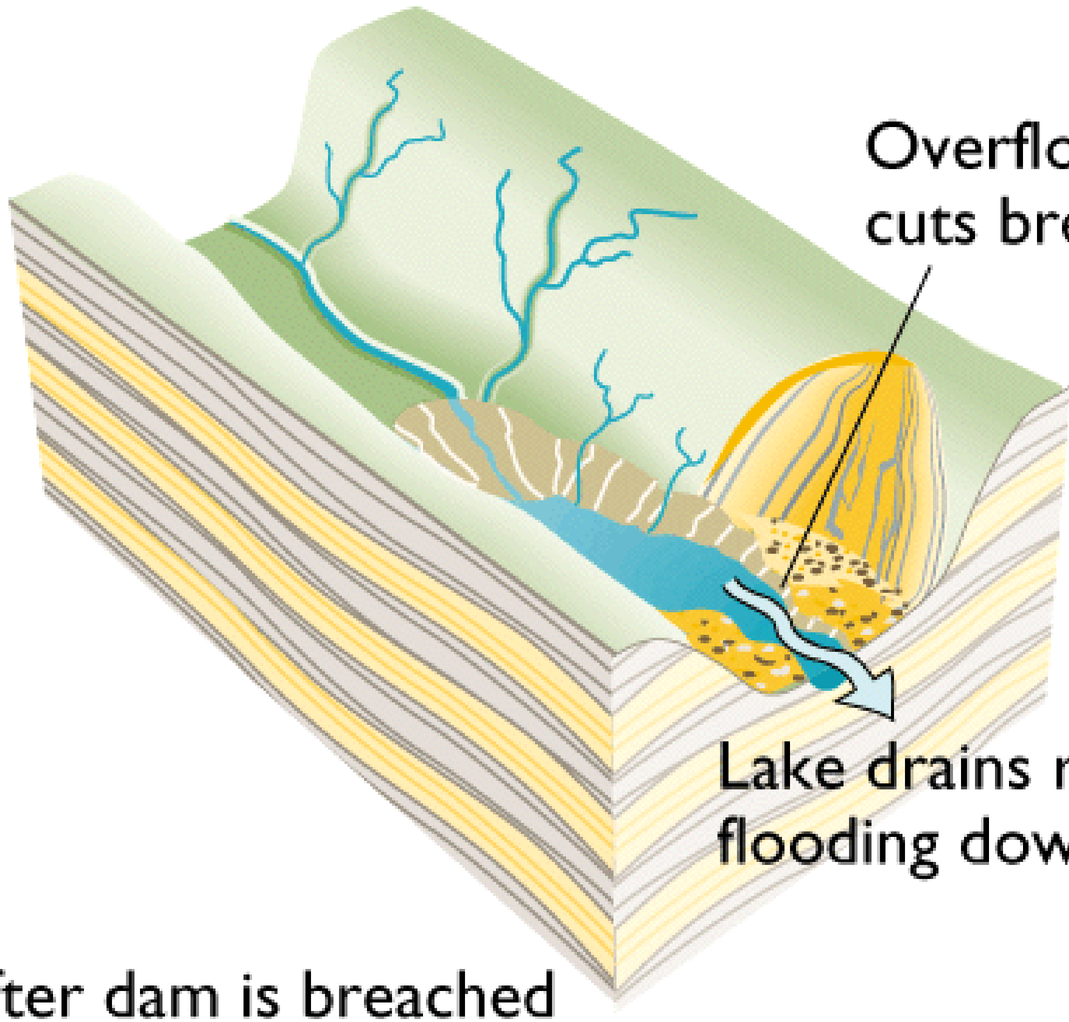
Slide Mountain, NV, 1985

Slide-Induced Flooding





Slide-Induced Flooding



(c) After dam is breached

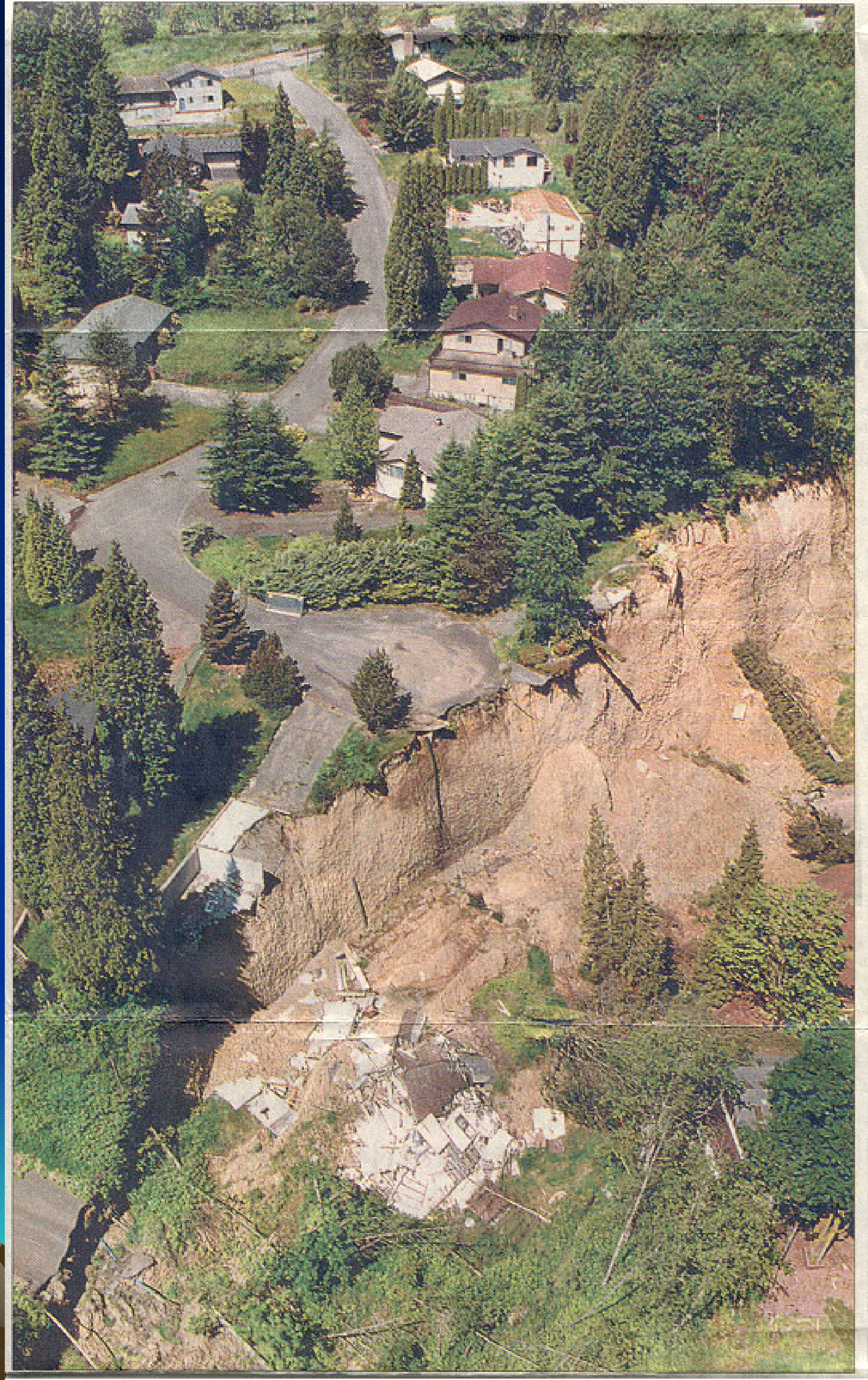
Mamayes, Puerto Rico, 1985

- This landslide was aided by the direct pumping of sewage into the ground.

* Killed >129, the most ever for a landslide in North America

Kelso, WA
June, 2000

- Landslides cost over $2 billion annually in the US, and take 25-50 lives.



Could this have been prevented?

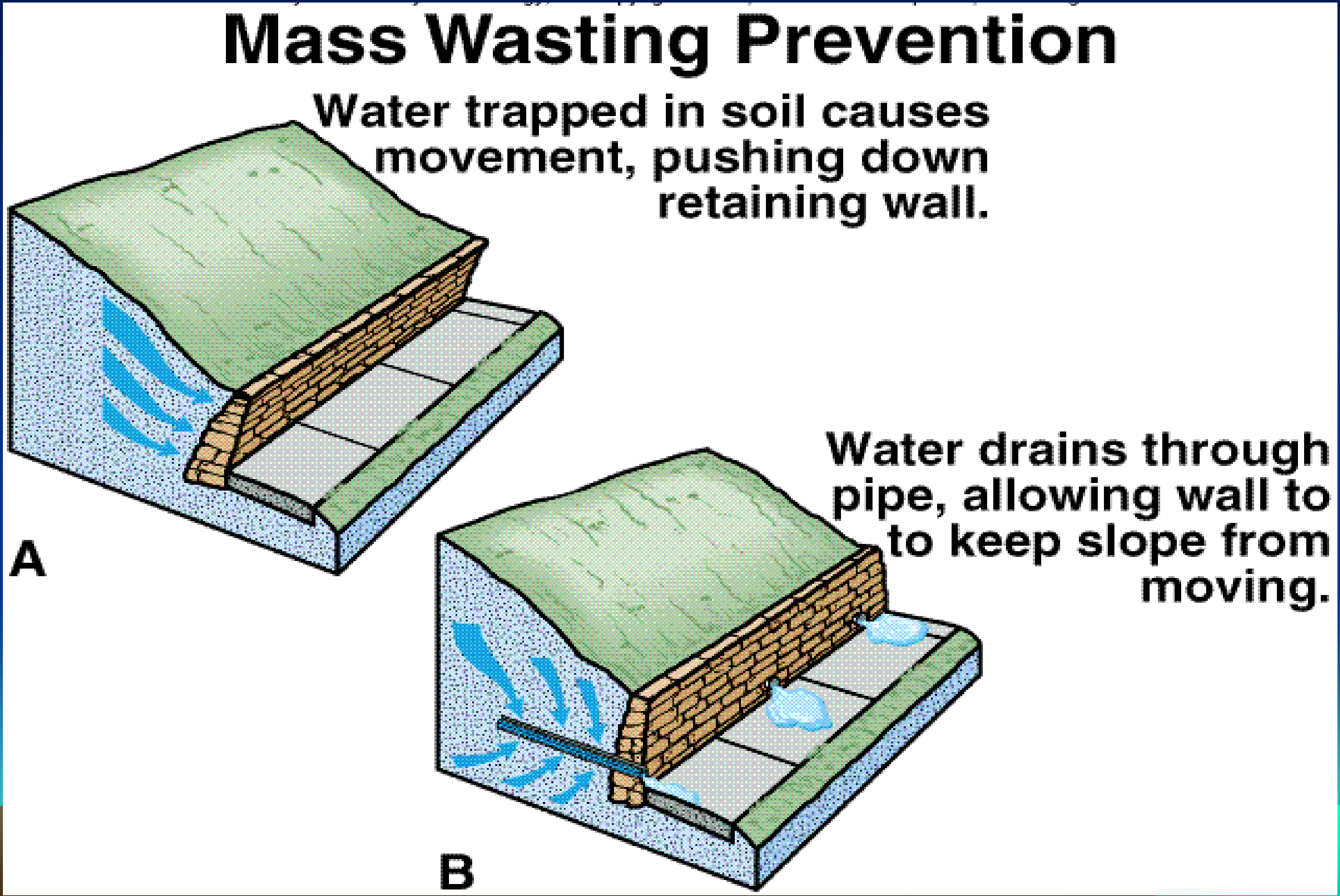
Yes

- <u>Early warning signs</u>
- *Indoors*: popping nails, cracking plaster, water seepage, sticking doors and windows

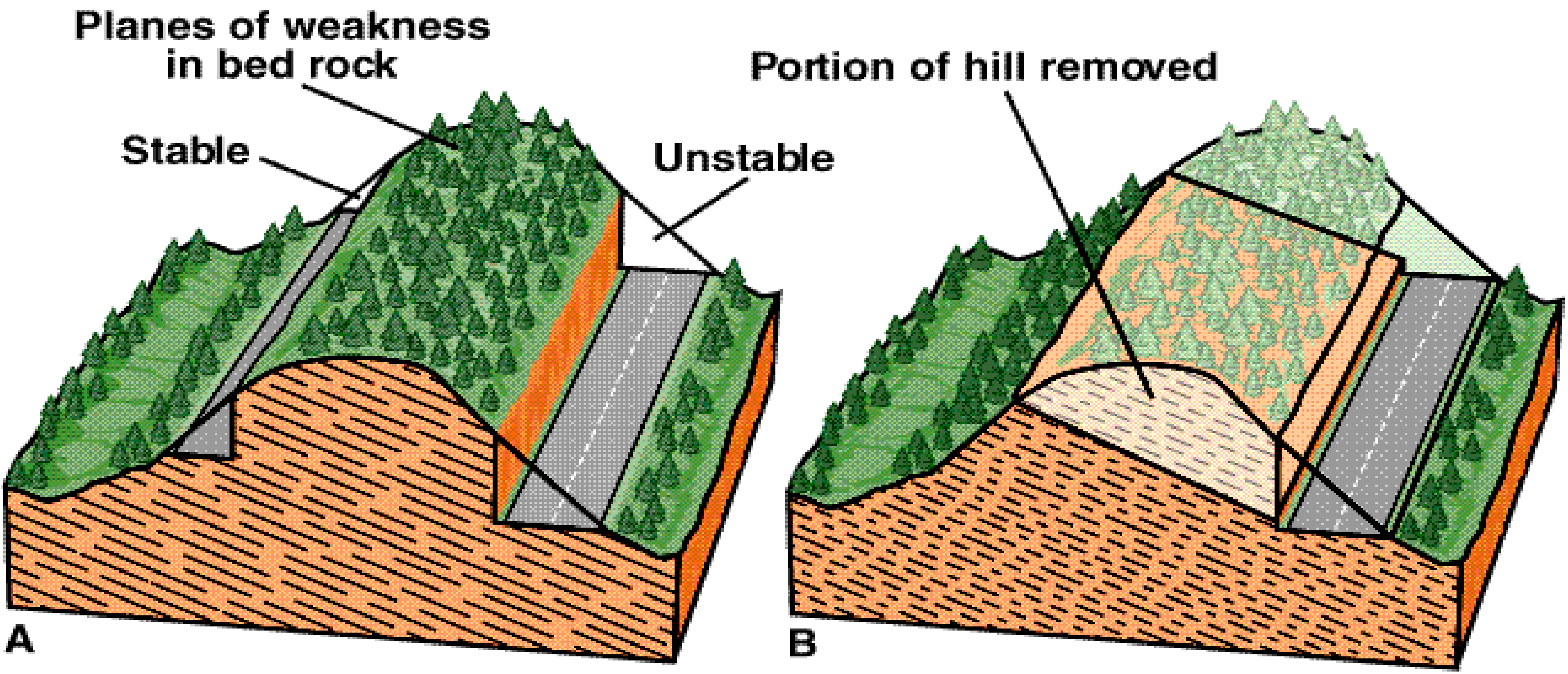
- *Outdoors*: cracking pavement and foundations, slump formation, broken pipes, leaning trees

Damn!

Stabilizing slopes



Safe and Hazardous Road Cuts



Points to Remember

- Eliminate oversteepened surfaces (use terraces)
- Pay attention to structure in rock/soil
- Avoid the avoidable: don’t build in areas where slopes have long history of failure

Rock fall protection

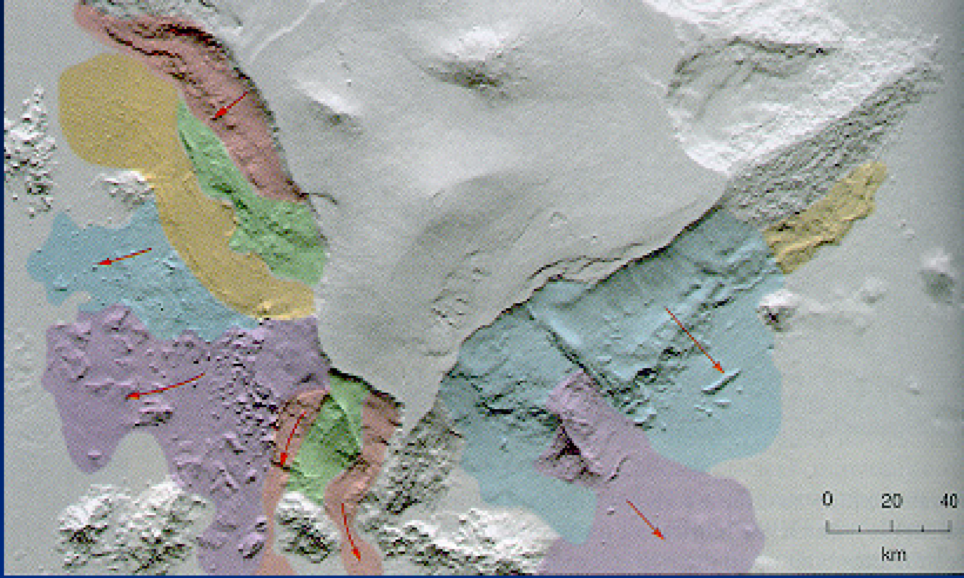
Fences

- Highway protection

PHOTO: LESLIE HOLTZMAN

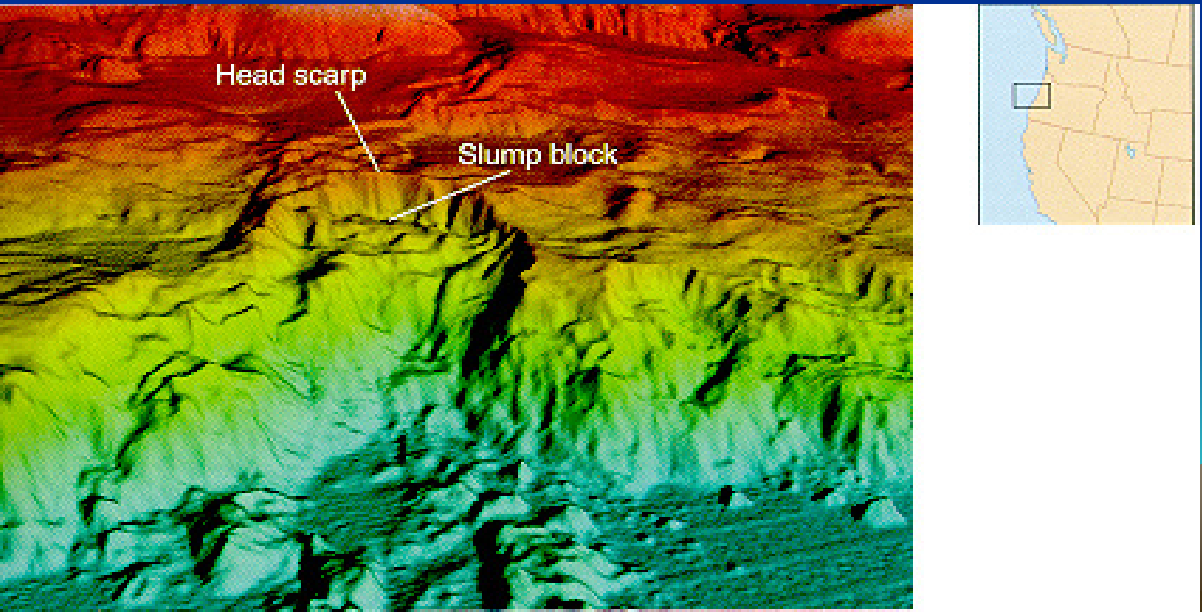
Underwater Mass Movements

•Various subaqueous mass movements affect large areas of the seafloor and are probably as common as those on land.



Vast subaqueous slumps and flows flank the island of Hawaii. Arrows show direction of flows.

A subaqueous landslide off of the coast of Oregon formed when tectonic activity made the slope too steep.



Active near deltas and convergent plate margins where sediment accumulates rapidly and slopes are steep.