

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

35

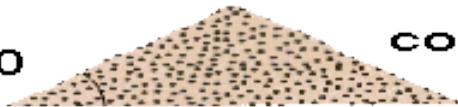


fine sand

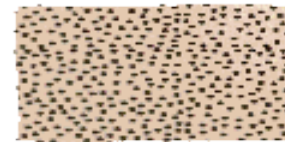
dry sand



40

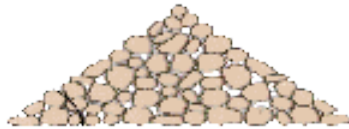


coarse sand



moist sand

45



angular
pebbles



water saturated
sand

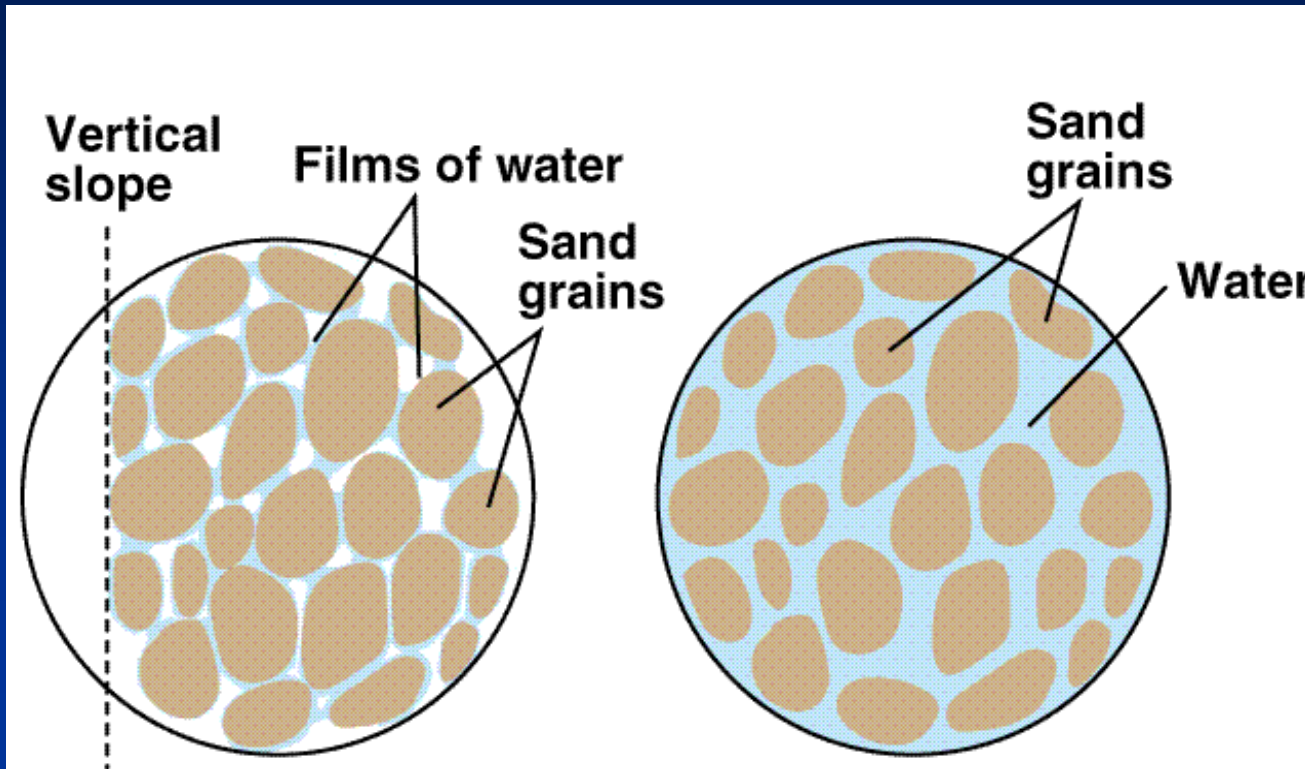
windward

leeward



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 $>35^\circ$ 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).



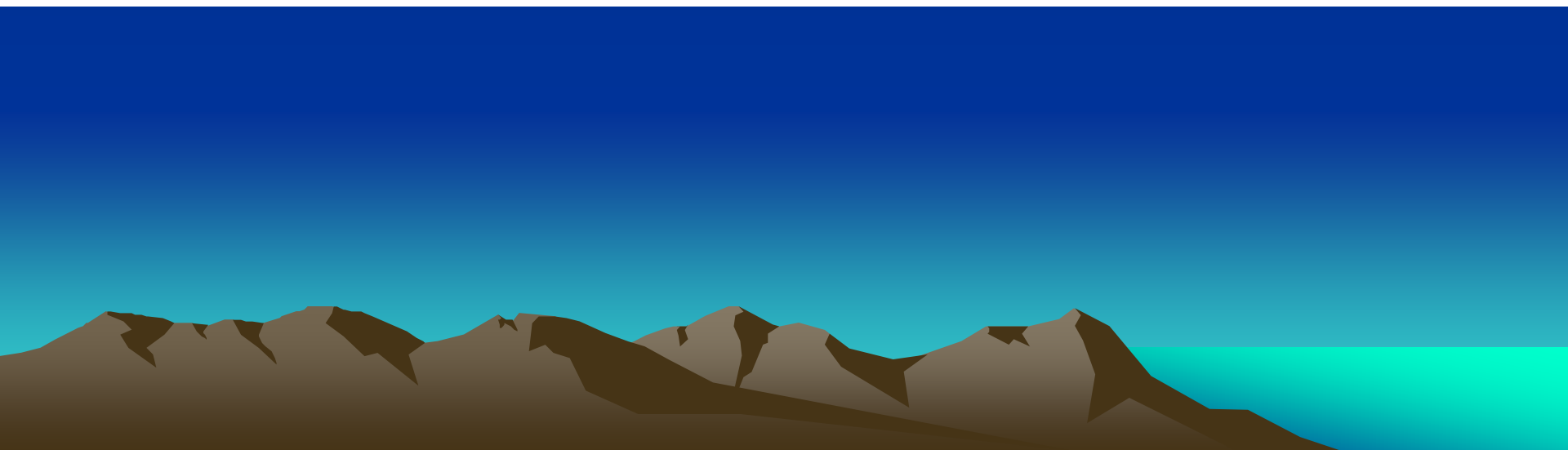
Handout

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 Tumble Clayey gravel Clean sand	
SLIDES	Rotational slump Rupture surface EXTREMELY SLOW TO MODERATE	Slides <i>Rotational Planar</i> Loess Glacial clay Slump Earth flow SLOW	
	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 500m	 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 ↑ Dry Water content ↓ Wet	Loess flow		Slow earthflow
	 Dry sand Firm silt Sand EXTREMELY RAPID	 Loess EXTREMELY RAPID	 Shale Weathered shale
	Rapid earthflow		APPROXIMATE RATE OF MOVEMENT
	 VERY RAPID		
	Sand or silt flow		
 Sand RAPID TO VERY RAPID			
		Debris avalanche	
		 Bedrock Regolith VERY RAPID TO EXTREMELY RAPID	
		Debris flow	
		 VERY RAPID	

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)
<i>Sedimentology</i>			
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
<i>Morphology</i>			
Internal forms	Transverse ridges	Sinuuous 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

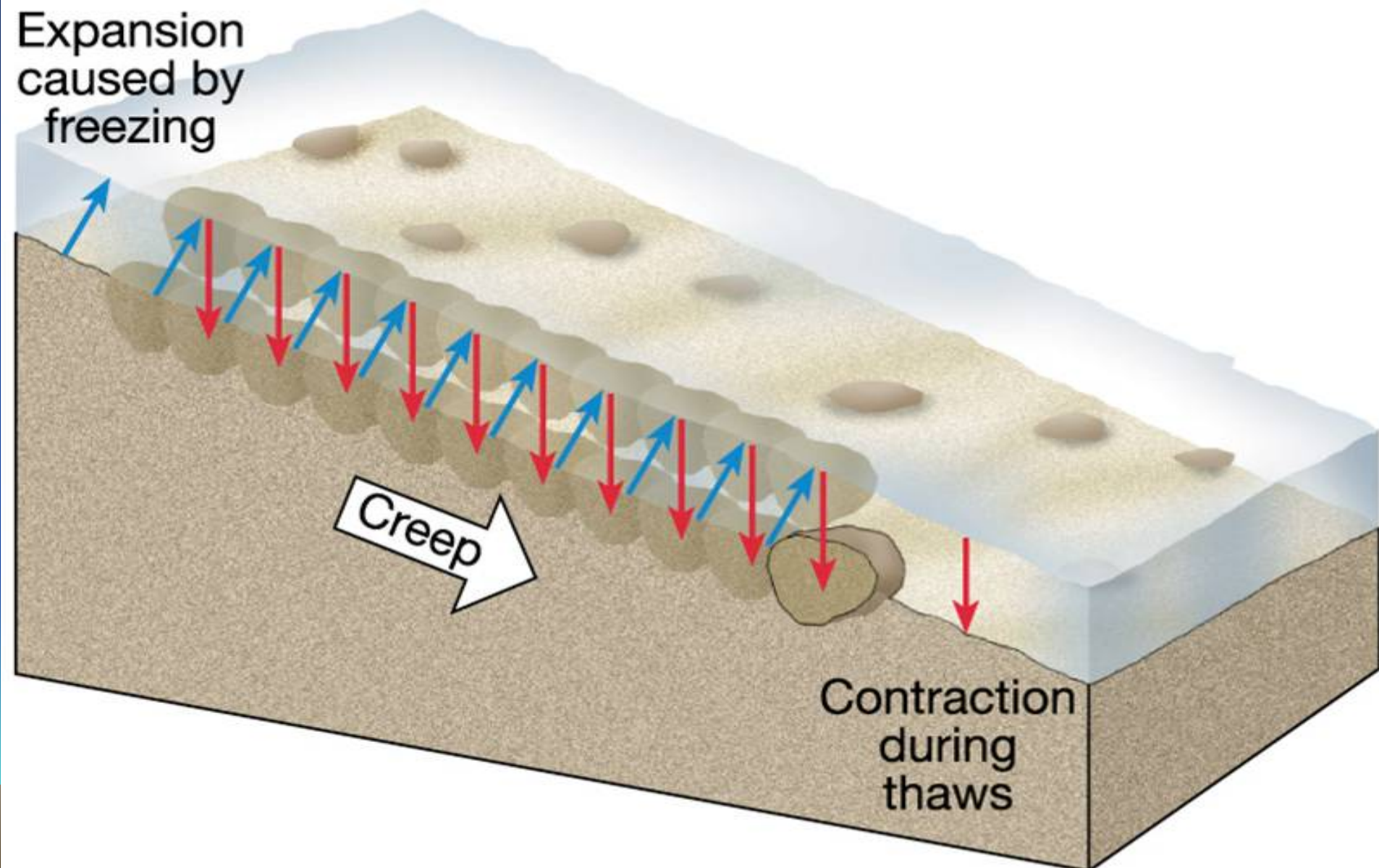


Creep

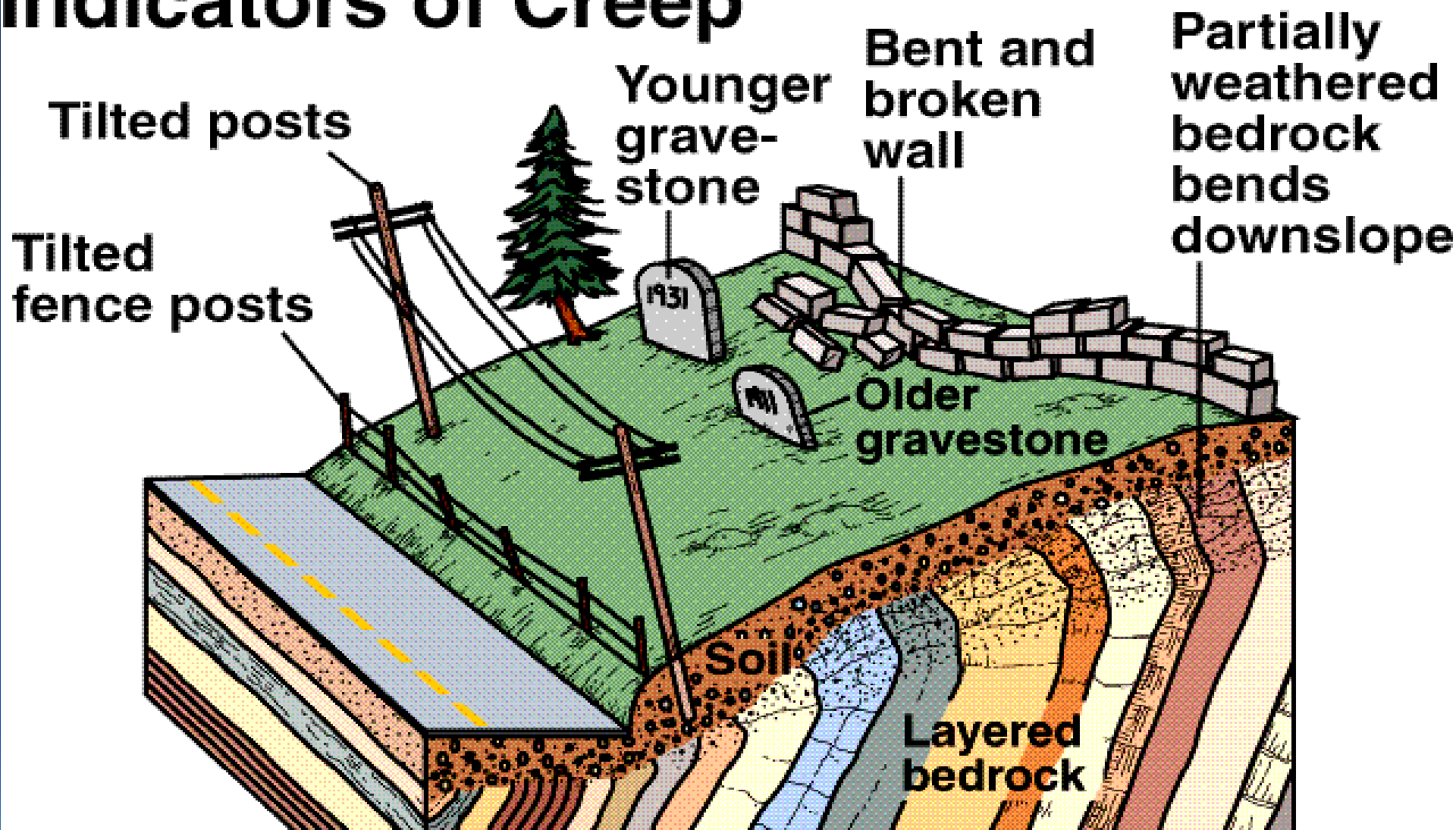
- Barely perceptible down slope movement.
- Particle creep, individual particle movement due to wetting/drying, heating/cooling
- Soil creep, dependent on changing SMR and climates.



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.

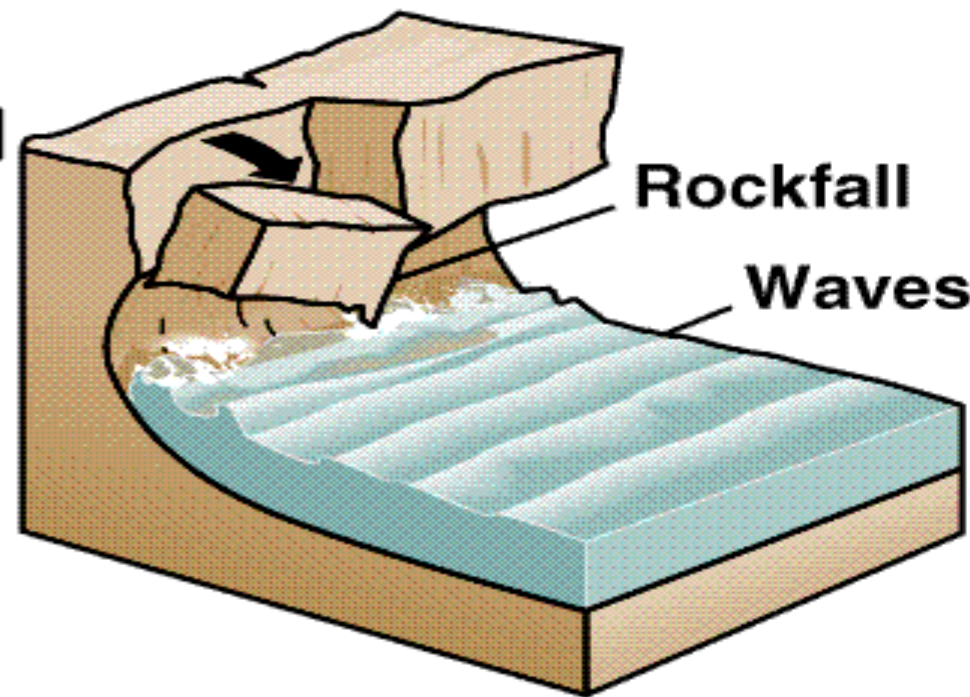
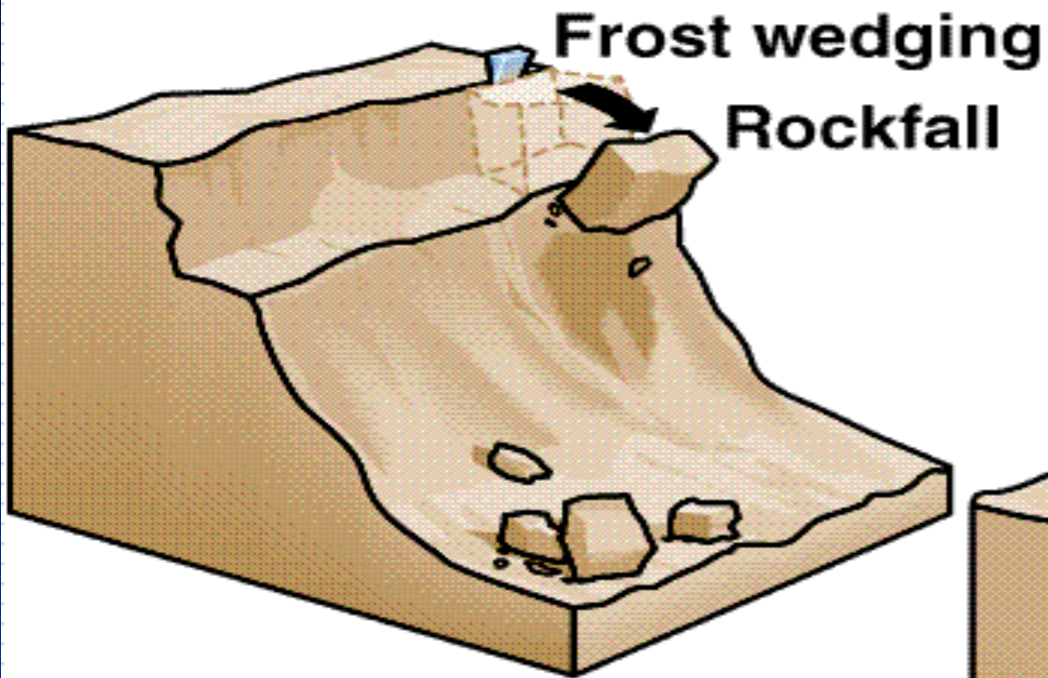


Fall

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

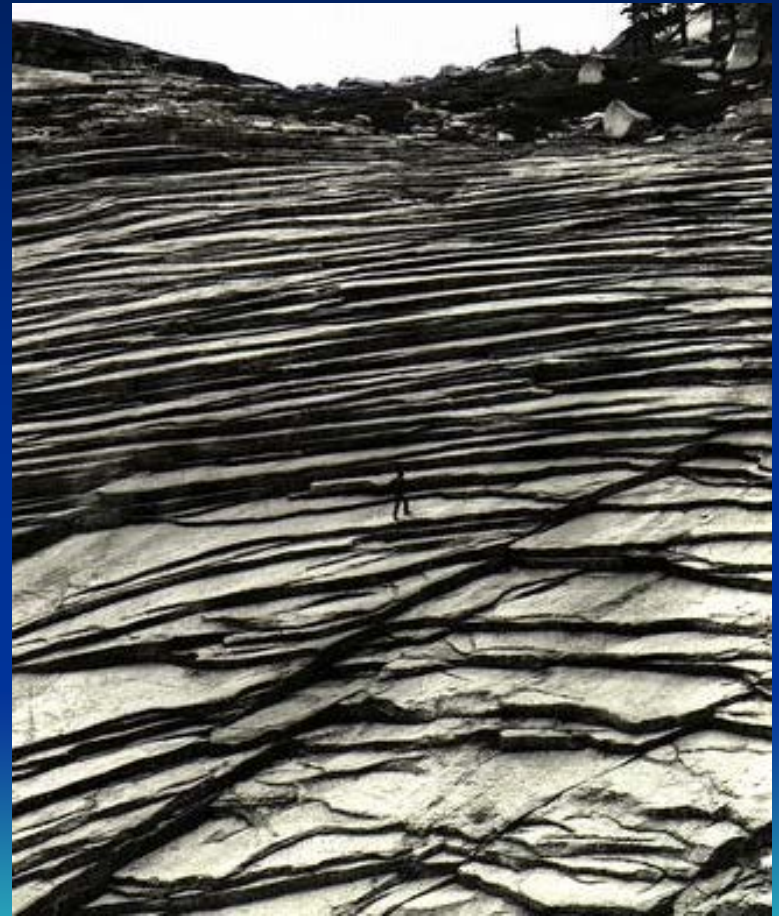


Two Examples of Rockfall



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

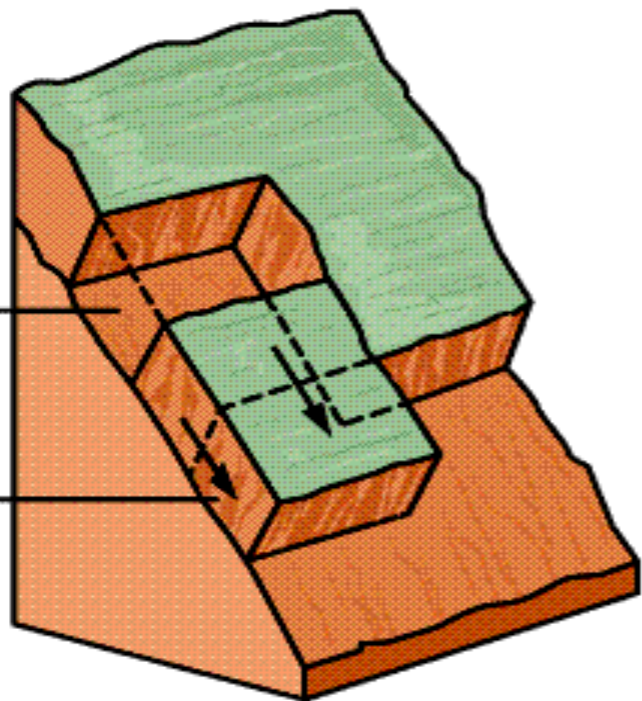
- A *slide* is a mass movement that occurs as one unit.



Slide

Original
position
of mass

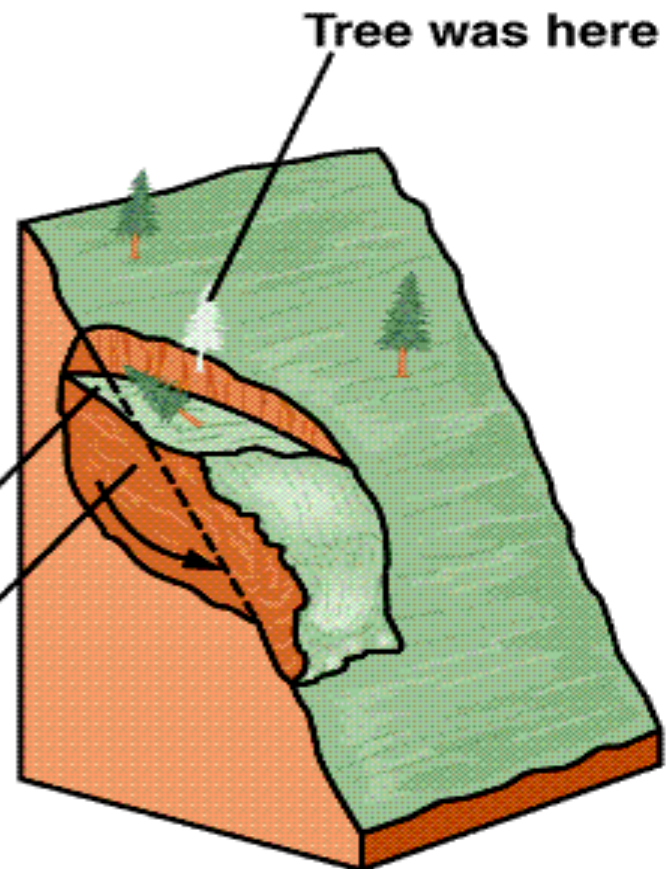
Moving
mass



Translational slide

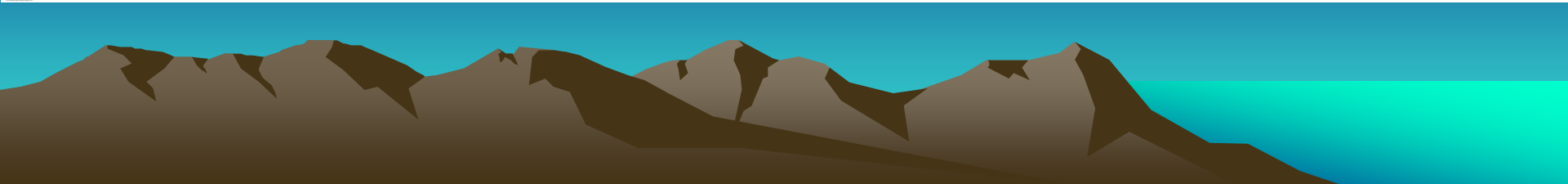
Original position

Moving mass



Rotational slide

B











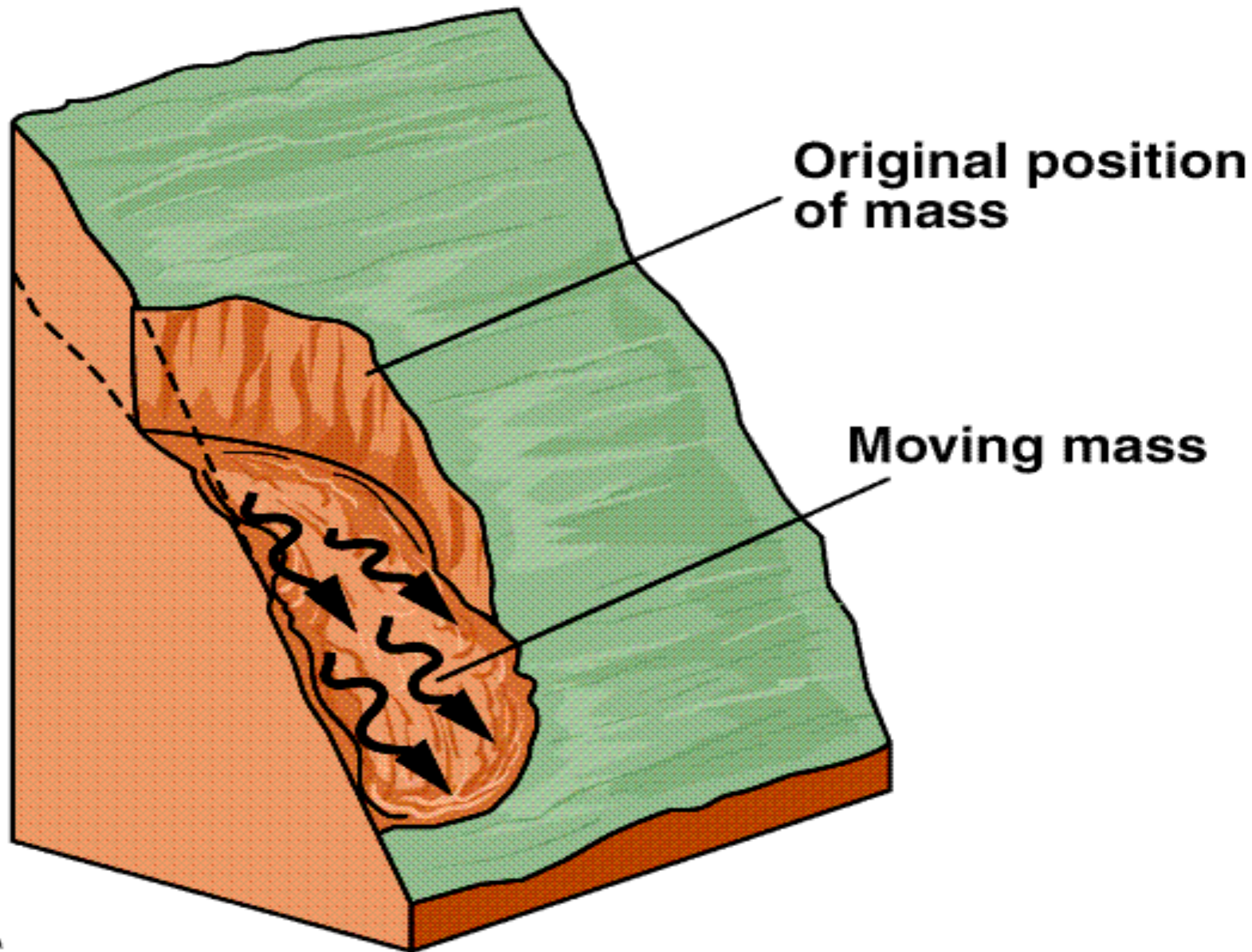


Flow

- 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











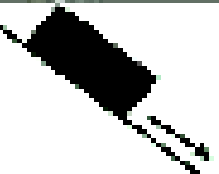








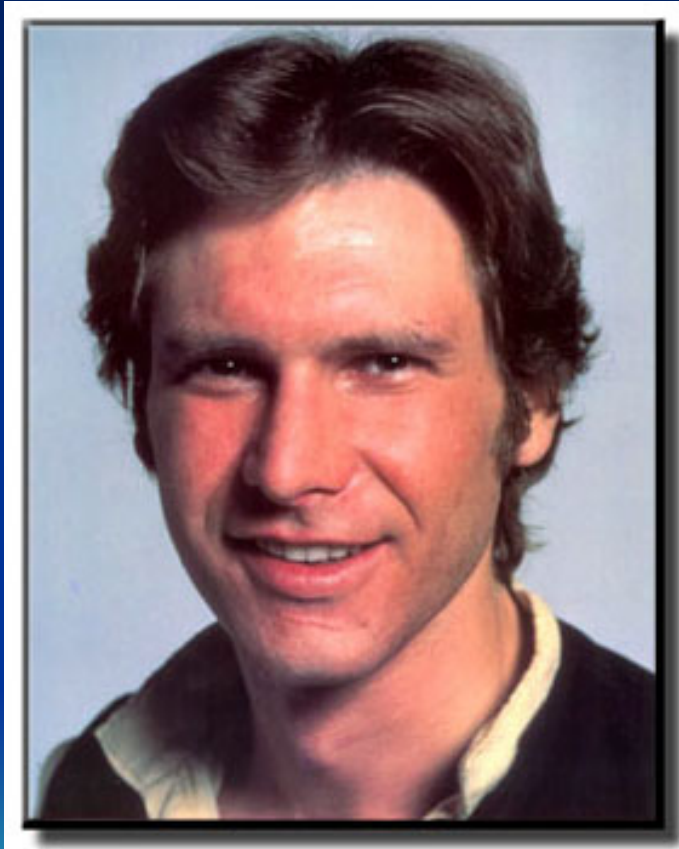


MECHANISM		MATERIAL			Velocity
		Rock	Fine-grained Soil	Coarse-grained Soil	
SLIDE		SLUMP	Earth Slump	Debris Slump	SLOW
		Block glide	Earth slide	Debris slide	RAPID
FLOW		Rock avalanche	Mudflow, avalanche	Debris, flow, avalanche	Very Rapid
		Creep	Creep	Creep	Extremely slow
FALL		Rockfall	Earthfall	Debrisfall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



The physics of mass wasting

Stress Vs. Strain



The physics of mass wasting

Stress Vs. Strain

- Normal stress (σ_n)
($\gamma h \cos^2 \theta$)
- **Shear stress** (σ_s)
($\gamma h \sin \theta \cos \theta$)
- Shear strength (σ_r)
 - Cohesion (c)
 - Mass friction ($\sigma \tan \phi$)Navier-Coulomb criterion

Principle of effective stress

(shear strength, $s = c' + \sigma' \tan \phi'$)

Accounts for dx/dy of pore water pressure



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

- Removal of lateral support
 - Erosion (e.g., rivers, ice, waves)
 - Human activity (e.g., quarries, road cuts)
- Addition of mass
 - Natural (e.g., rain, talus)
 - Human (e.g., fills, ore stockpiles, buildings)
- Earthquakes
- Regional tilting
- Removal of underlying support
 - Natural (e.g., undercutting, solution, weathering)
 - Human activity (e.g., mining)
- Lateral pressure
 - Natural (e.g., swelling, expansion by freezing, water addition)

Factors That Decrease Shear Strength

- Weathering and other physicochemical reactions
 - Disintegration (lowers cohesion)
 - Hydration (lowers cohesion)
- Base exchange
- Solution
- Drying
- Pore water
 - Buoyancy
 - Capillary tension
- Structural changes
 - Remolding
 - Fracturing

(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.



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

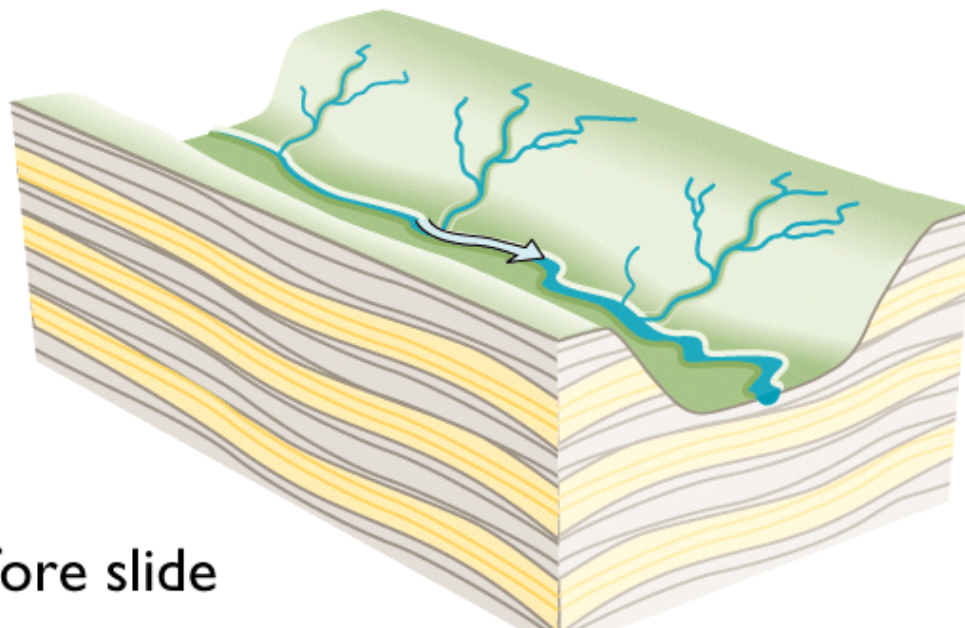
The most
costly single
landslide in
US history:
> \$400 million



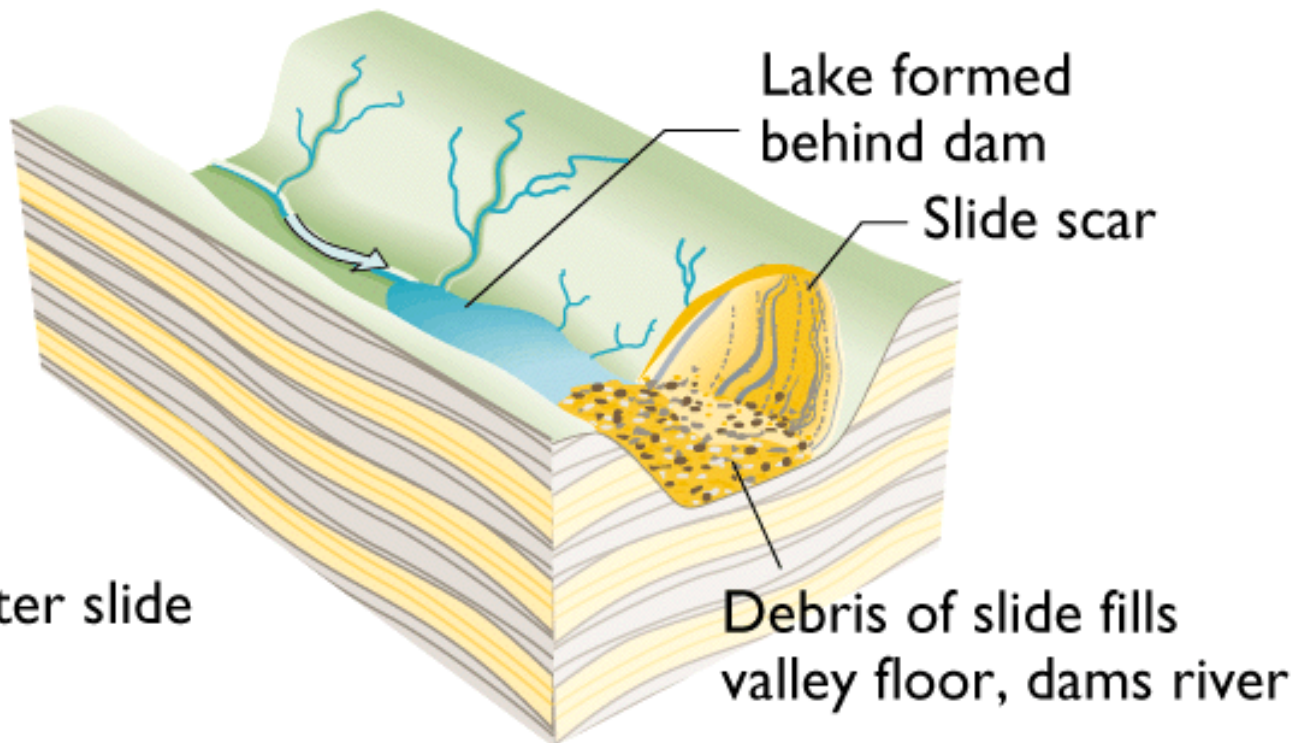
Slide Mountain, NV, 1985



Slide-Induced Flooding

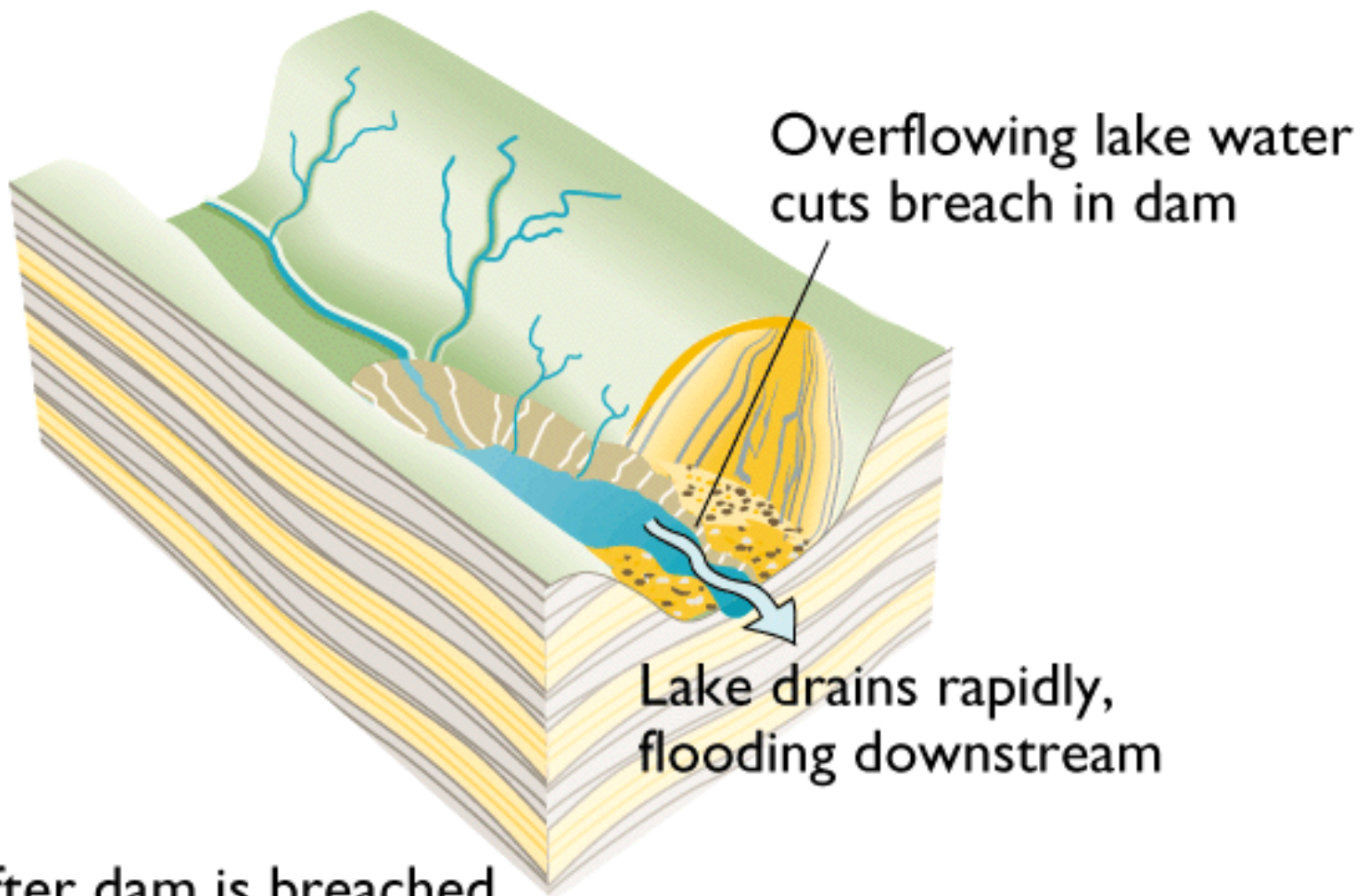


(a) Before slide



(b) After slide

Slide-Induced Flooding



Mamayes, Puerto Rico, 1985

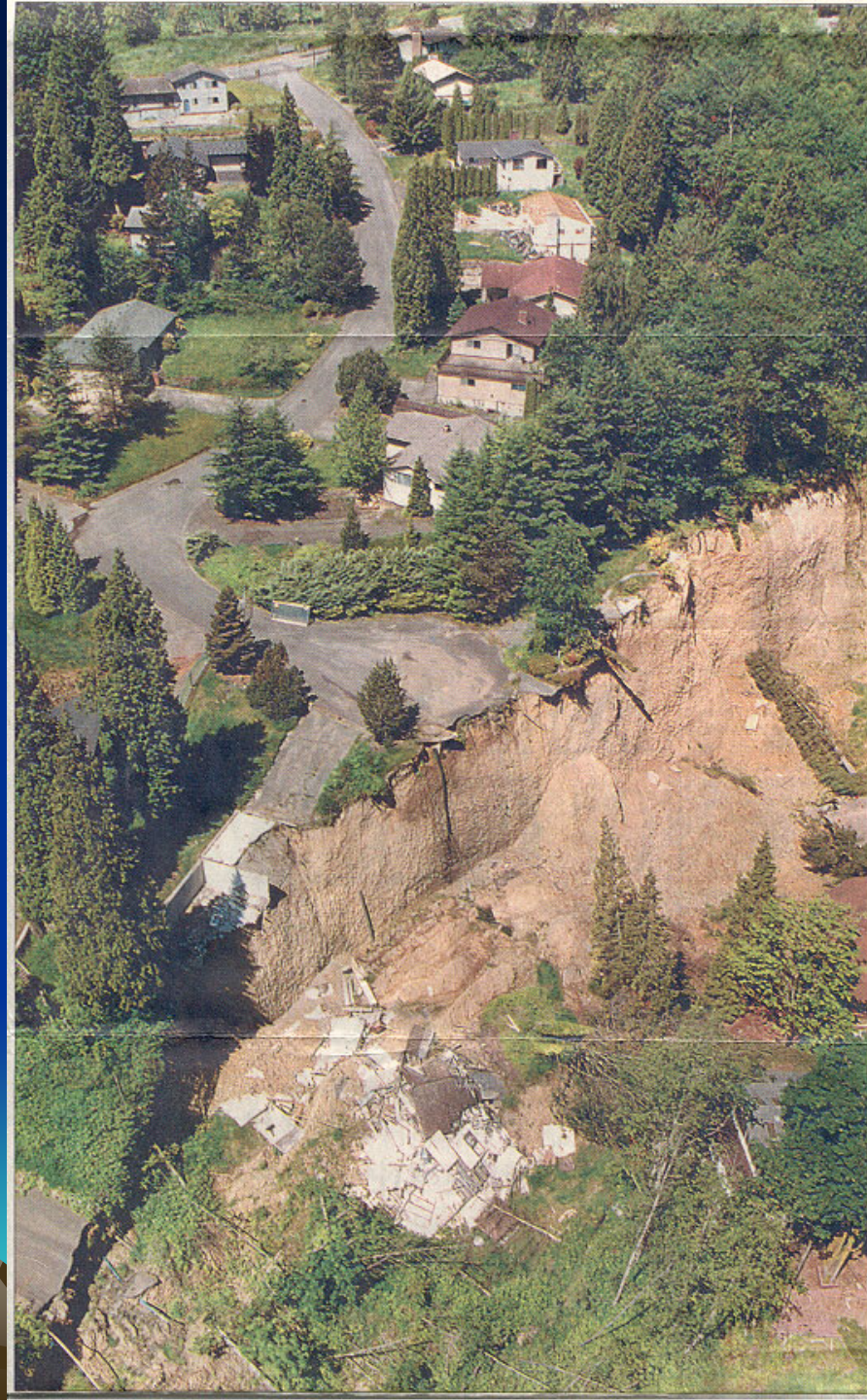
- This landslide was aided by the direct pumping of sewage into the ground.
- * Killed >129, the most ever for a landslide in North America



Kelso, WA

June, 2000

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



Could this have been prevented?



Yes

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



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



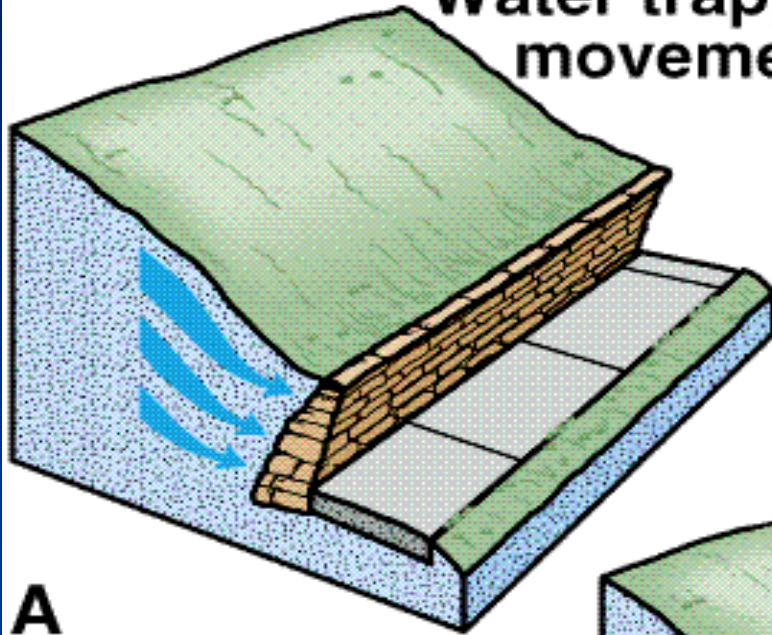
Damn!



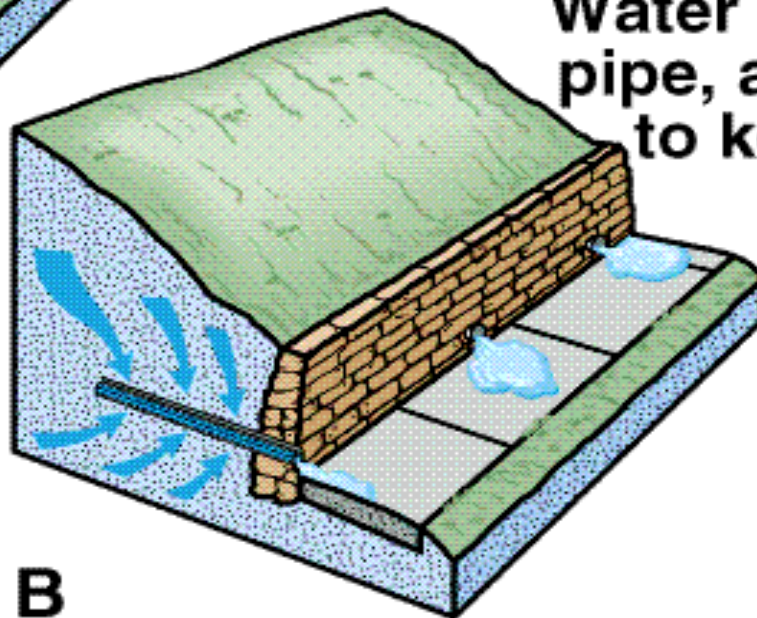
Stabilizing slopes

Mass Wasting Prevention

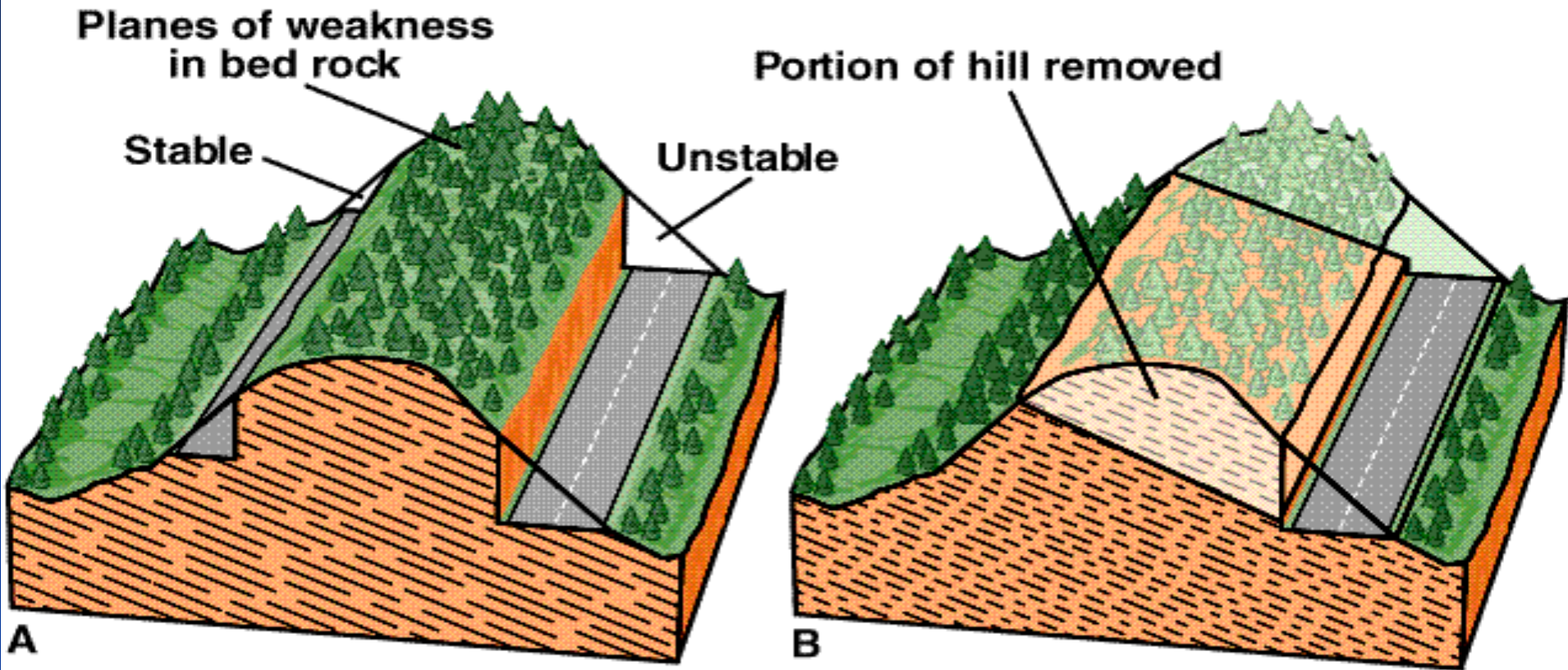
Water trapped in soil causes movement, pushing down retaining wall.



Water drains through pipe, allowing wall to keep slope from moving.



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

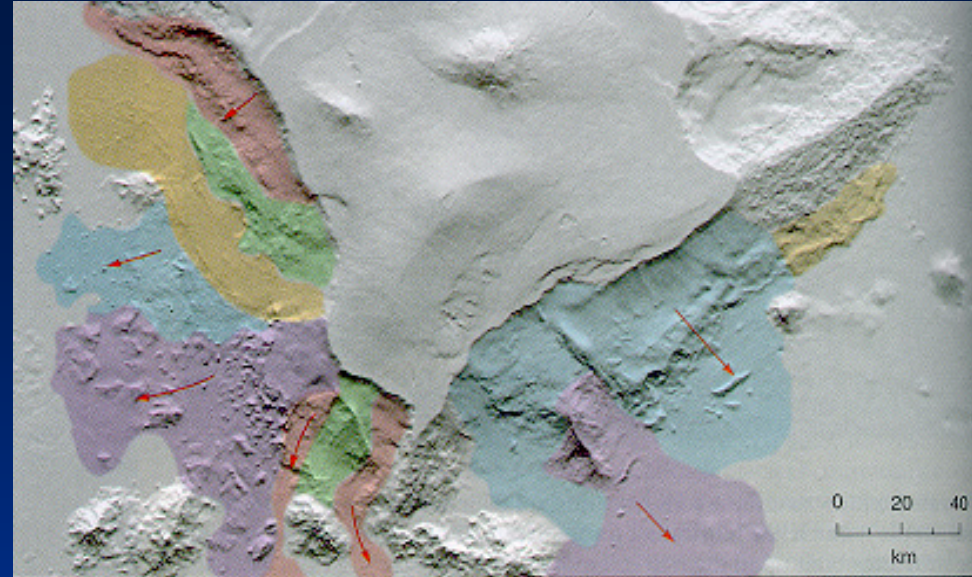
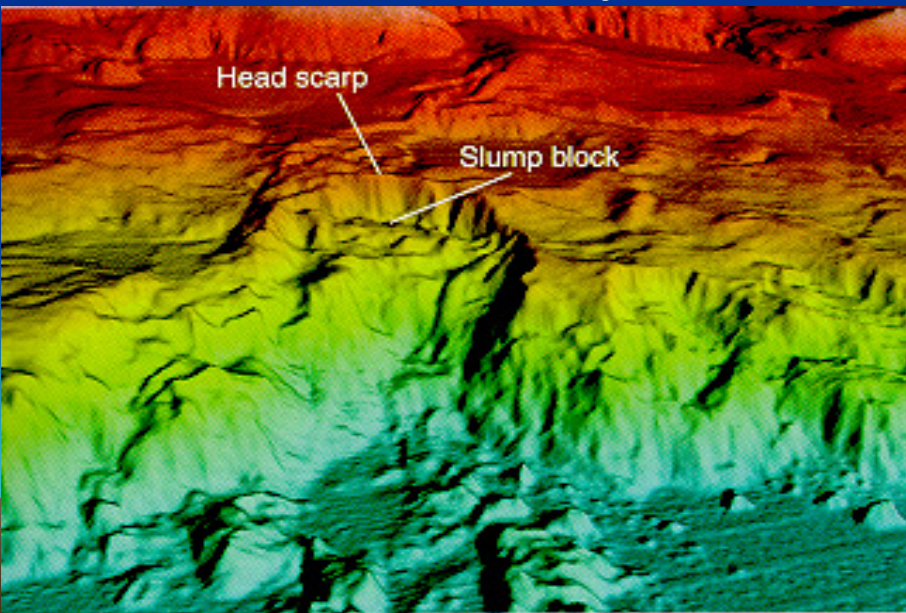


PHOTO: LESLIE HOLTZMAN

Underwater Mass Movements

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

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



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

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

