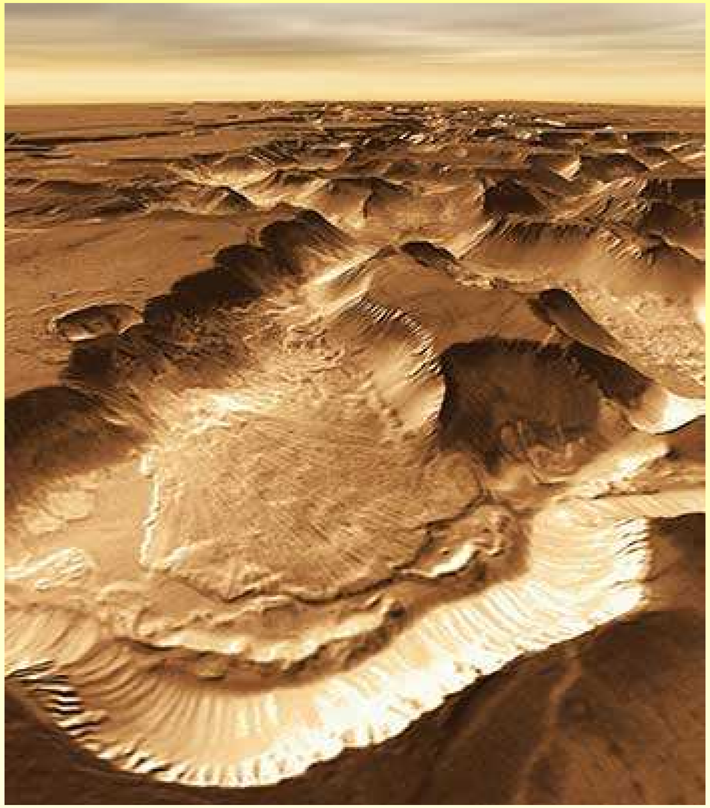

Valles Marineris, Mars, NASA

Landslide Analysis
part 2

Based on a lecture of Thomas Lebourg

Presented by Thomas Lebourg

Landslide Analysis

- ✓ Part 1 - What are landslides ? Definitions and Morphologies
- ✓ **Part 2 - Factors that Influence Slope Stability**
- ✓ Part 3 – Investigation method, scientific approaches : case studies
- ✓ Part 4 - Natural Hazard and Risk Mapping
- ✓ Part 5 - Underwater landslides and tsunami risk associated

Landslide Analysis

✓ **Part 2 - Factors that Influence Slope Stability**

I- Introduction
II- Gravity
III- The role of Water
IV- Troublesome Earth Materials
V- Weak Materials and Structures
VI- Triggering events
    1- Shocks
    2- Slope Modification and Undercutting
    3- Changes in Hydrologic Characteristics
    4- Volcanic Eruptions
VII- Assessing and Mitigating Mass-Wasting Hazards
    1- Prediction and Hazard Assessment
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I. Introduction

Several causes (to add to **GRAVITY**) like:

- **Petrographic or structural causes**: rock with a weak cohesion, rock easily erodible, presence of fracturation inducing some discontinuities, alternation of rocks with a different permeability in a stratigraphic unit

- **Gemorphologic and geological causes**: volcanic or tectonic uplift, earthquake, post-glacial bounce, slope modification by a river or a glacier, vegetation destruction by fire

- **Human causes**: slope modification by excavation or by overloading, deforestation (like a fire!)

⇓

TIME aspect to take into account

Among these factors some of them are:

- Preliminary factors which are a slow action in the time but they reduce the resistance of soil or rock shear, thus these factors favoring the move down-slope but don't trigger them.

- Triggering factors which have a slow or a quick action and directly leading to the break off : example, the water

See the following details

Landslide Analysis

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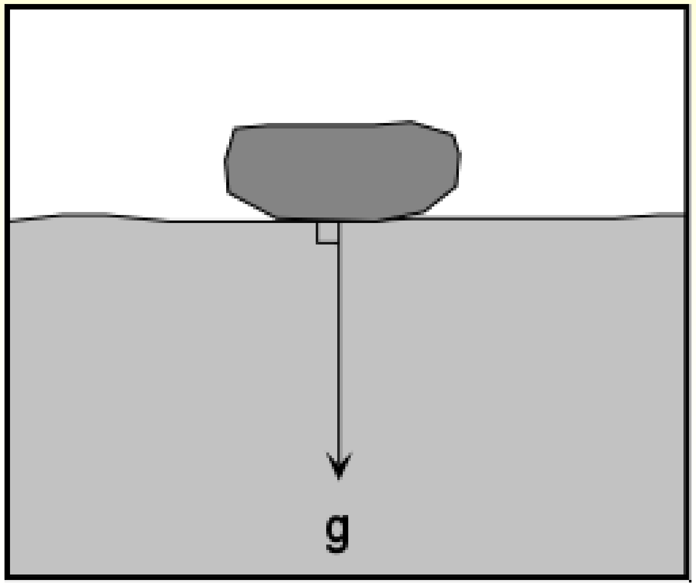
II- Gravity

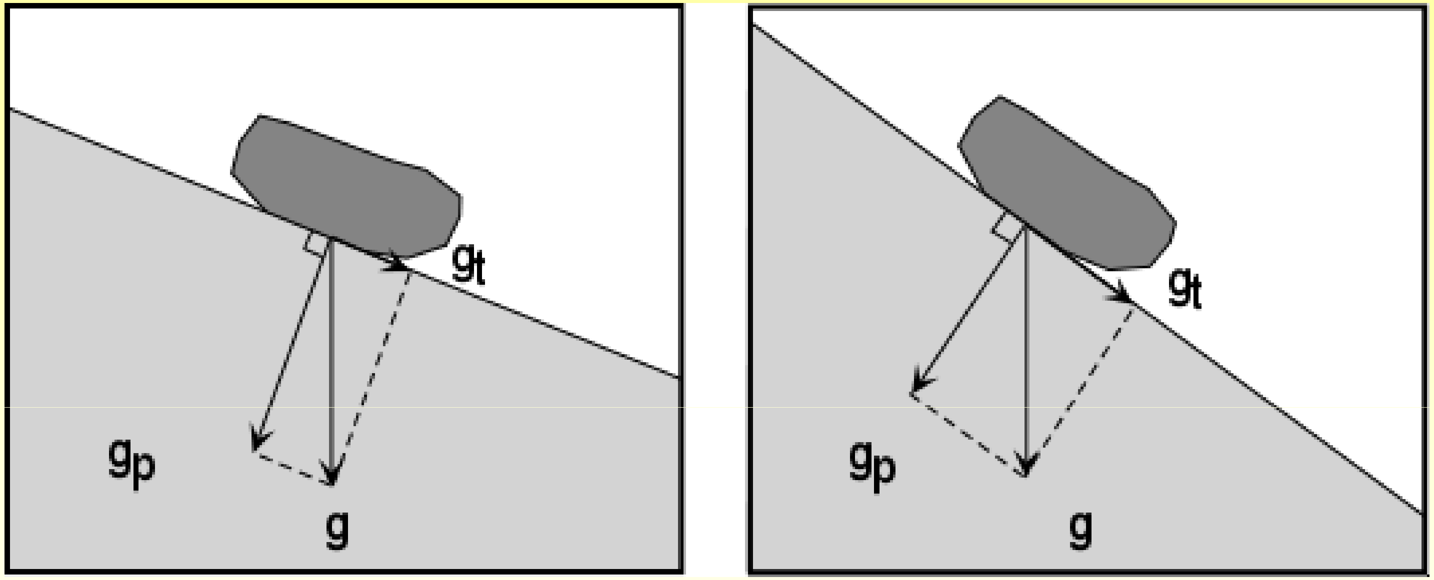
✓ The main force responsible for mass wasting is gravity.

✓Gravity is the force that acts everywhere on the Earth's surface, pulling everything in a direction toward the center of the Earth.

✓ On a flat surface the force of gravity acts downward. So long as the material remains on the flat surface it will not move under the force of gravity.

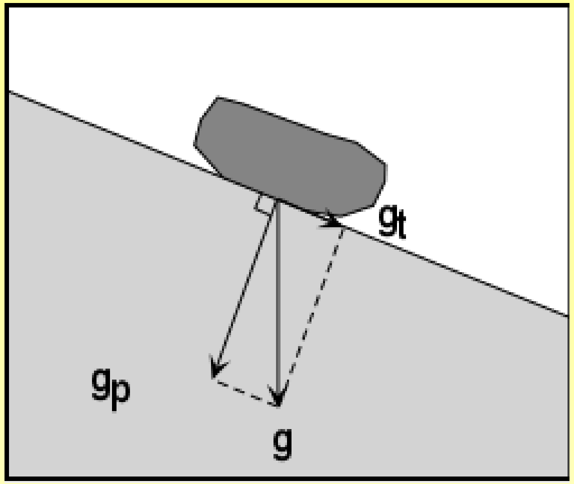


✓ On a slope, the force of gravity can be resolved into two components: a component acting perpendicular to the slope and a component acting tangential to the slope.



✓ The **perpendicular component** of gravity, g_p, helps to **hold** the object in place on the slope. The **tangential component** of gravity, g_t, causes a **shear stress (driving force)** parallel to the slope that pulls the object in the down-slope direction parallel to the slope.

✓ On a steeper slope, the shear stress or tangential component of gravity, g_t, increases, and the perpendicular component of gravity, g_p, decreases.



✓ The forces resisting movement down the slope are grouped under the term **shear strength (resistance)** which includes **frictional resistance and cohesion** among the particles that make up the object.

✓ When the **shear stress** becomes **greater than** the combination of **forces holding the object** on the slope, the object will **move down-slope**.

✓Alternatively, if the object consists of a collection of materials like **soil, clay, sand, etc.,** if the **shear stress** becomes **greater than** the **cohesional forces holding the particles together**, the particles will separate and **move or flow down-slope**.

✓ Thus, down-slope movement is **favored** by **steeper slope angles** which increase the shear stress, and anything that **reduces the shear strength**, such as lowering the cohesion among the particles or lowering the frictional resistance.

✓ This is often expressed as the **safety factor**, F_s, the ratio of shear strength to shear stress.

F_s = Shear Strength/Shear Stress

↓

If the safety factor becomes less than 1.0, slope failure is expected.

Landslide Analysis

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III- The Role of Water

Although water is not always directly involved as the transporting medium in mass-wasting processes, it does play an important role.

Water becomes important for several reasons

↓

1- Water adds weight to the slope:

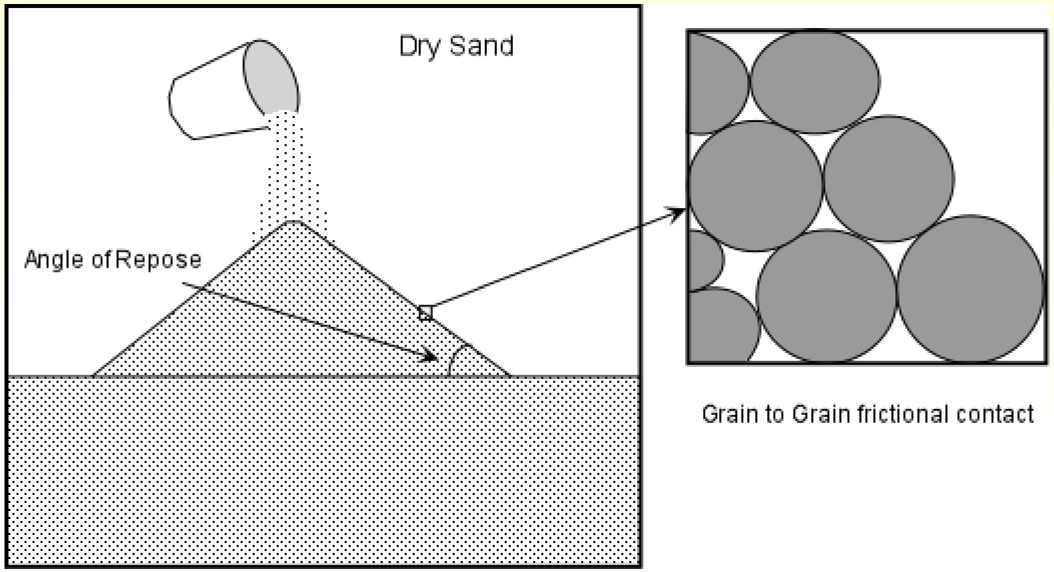
Addition of water from rainfall or snow melt adds weight to the slope. Water can seep into the soil or rock and replace the air in the pore space or fractures. Since water is heavier than air, this increases the weight of the soil. Weight is force, and force is stress divided by area, so the stress increases and this can lead to slope instability.

2- Water has the ability to change the angle of repose (the slope angle which is the stable angle for the slope).

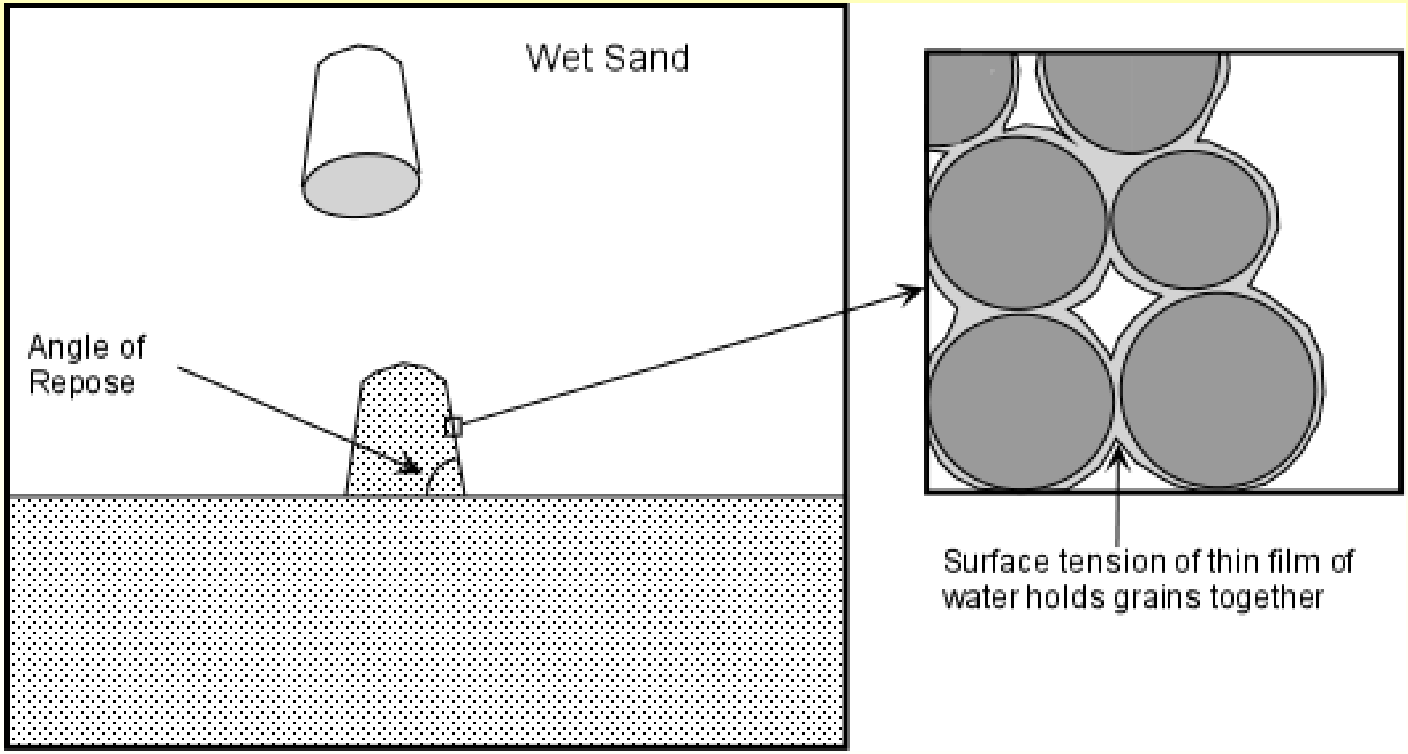
✓ Think about building a sand castle on the beach. If the sand is totally dry, it is impossible to build a pile of sand with a steep face like a castle wall. If the sand is somewhat wet, however, one can build a vertical wall. If the sand is too wet, then it flows like a fluid and cannot remain in position as a wall.

✓Dry unconsolidated grains will form a pile with a slope angle determined by the **angle of repose**. The angle of repose is the steepest angle at which a pile of unconsolidated grains remains stable, and is controlled by the frictional contact between the grains.

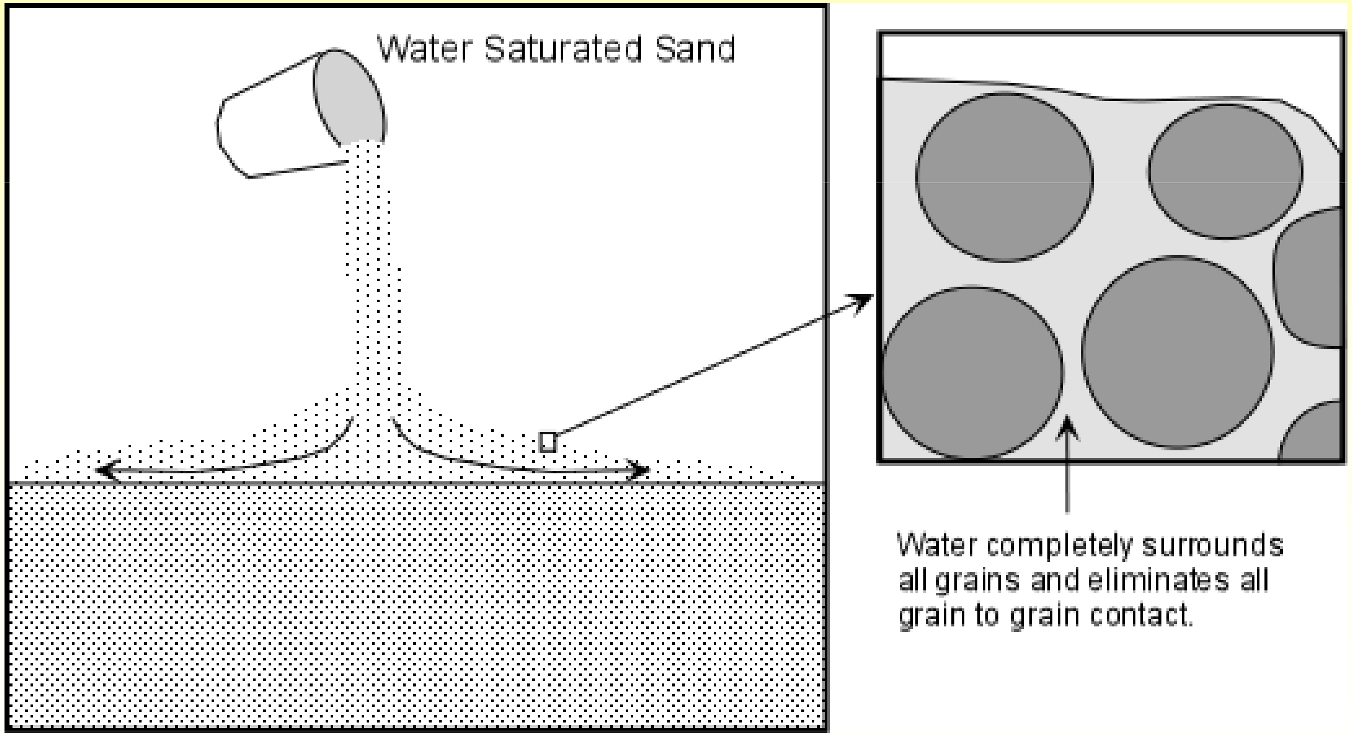
✓In general, for dry materials the angle of repose increases with increasing grain size, but usually lies between about 30 and 37º.



✓ Slightly wet unconsolidated materials exhibit a very high angle of repose because surface tension between the water and the solid grains tends to hold the grains in place.



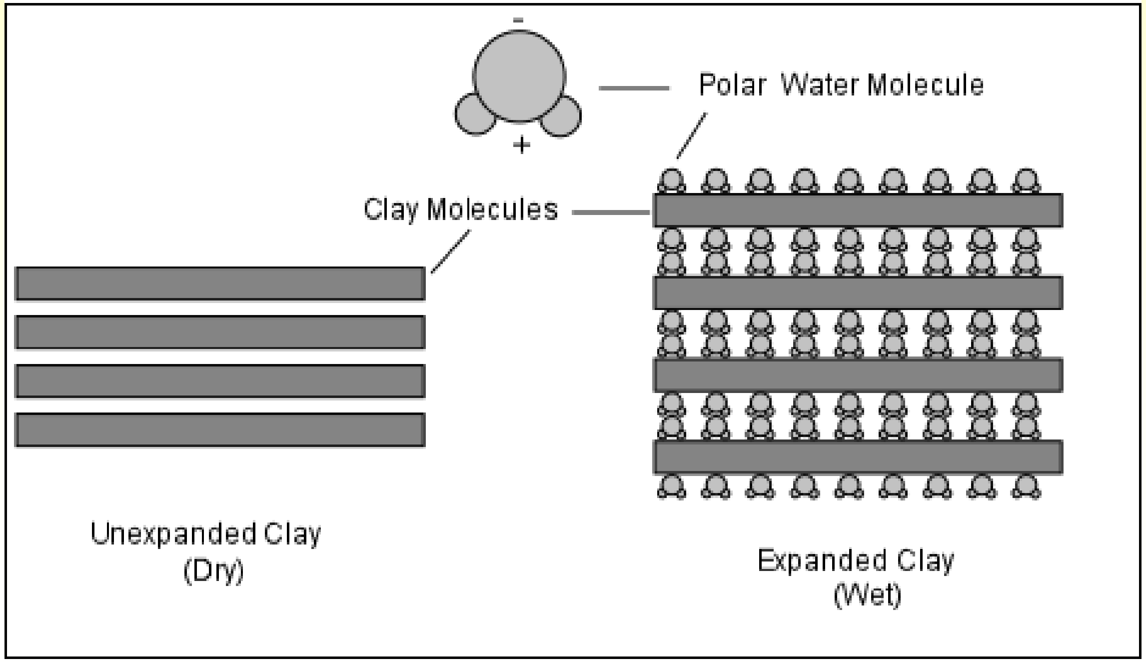
✓ When the material becomes saturated with water, the angle of repose is reduced to very small values and the material tends to flow like a fluid. This is because the water gets between the grains and eliminates grain to grain frictional contact.



3- Water can be adsorbed or aborted by minerals in the soil.

✓ Adsorption, causes the electronically polar water molecule to attach itself to the surface of the minerals. Absorption causes the minerals to take the water molecules into their structure. By adding water in this fashion, the weight of the soil or rock is increased.

✓ Furthermore, if adsorption occurs then the surface frictional contact between mineral grains could be lost resulting in a loss of cohesion, thus reducing the strength of the soil.



In general, wet clays have lower strength than dry clays, and thus adsorption of water leads to reduced strength of clay-rich soils.

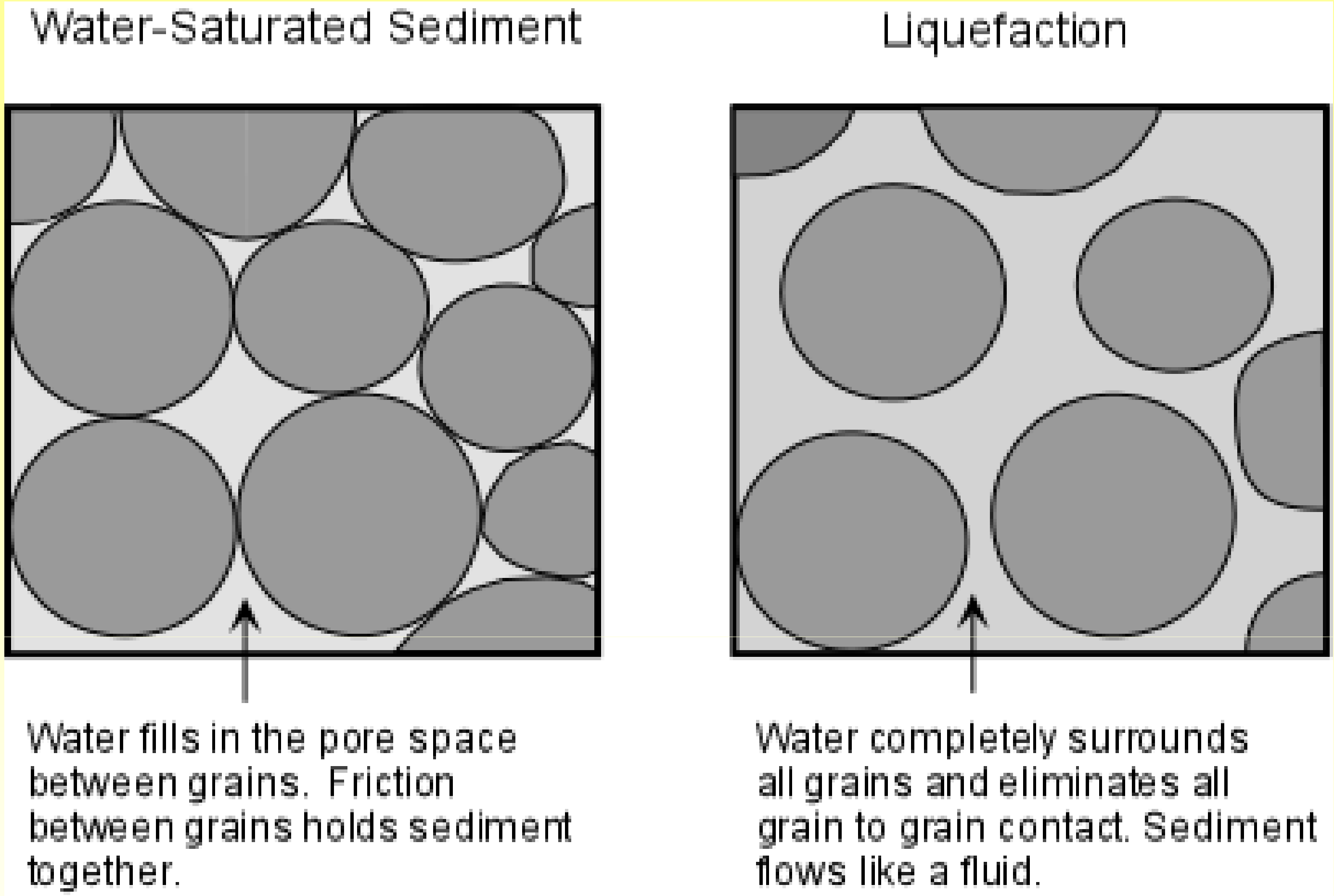
4- Water can dissolve the mineral cements that hold grains together.

✓ If the cement is made of calcite, gypsum, or halite, all of which are very soluble in water, water entering the soil can dissolve this cement and thus reduce the cohesion between the mineral grains.

5- Liquefaction

✓ Liquefaction occurs when loose sediment becomes oversaturated with water and individual grains loose grain to grain contact with one another as water gets between them.

✓This can occur as a result of ground shaking or can occur as water is added as a result of heavy rainfall or melting of ice or snow. It can also occur gradually by slow infiltration of water into loose sediments and soils.

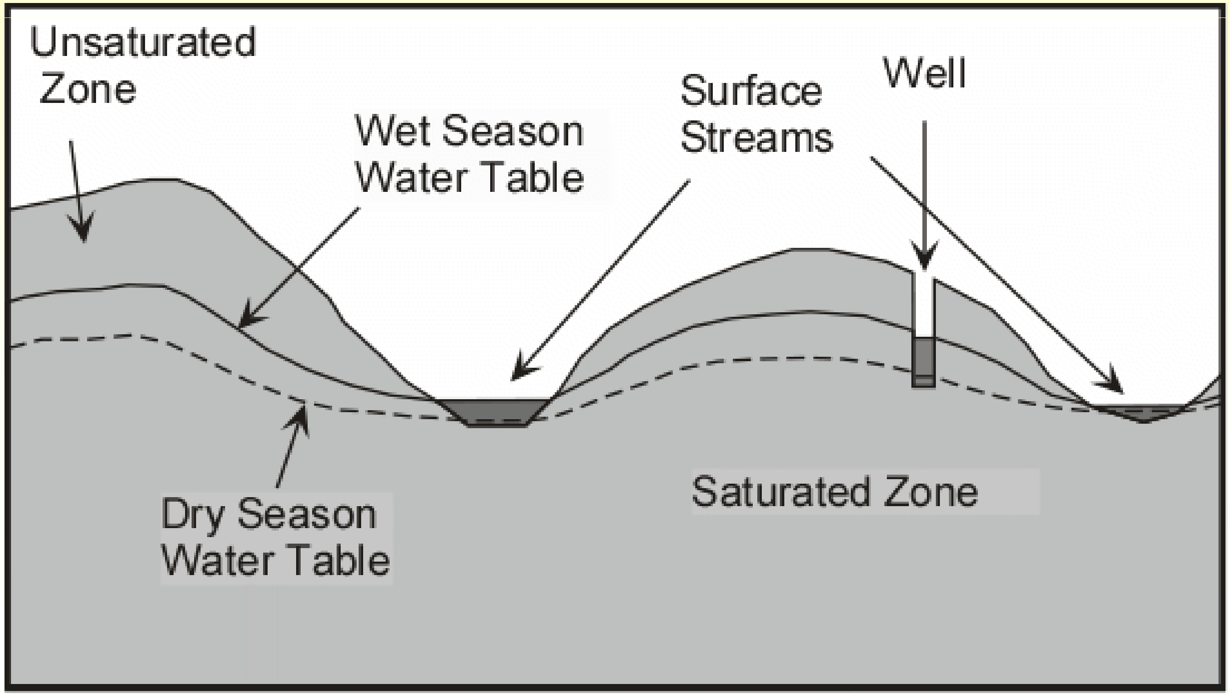


✓ The amount of water necessary to transform the sediment or soil from a solid mass into a liquid mass varies with the type of material.

✓ Clay bearing sediments in general require more water because water is first absorbed onto the clay minerals, making them even more solid-like, then further water is needed to lift the individual grains away from each other.

6- Groundwater

✓ Groundwater exists nearly everywhere beneath the surface of the earth.
✓It is water that fills the pore spaces between grains in rock or soil or fills fractures in the rock.
✓The water table is the surface that separates the saturated zone below, wherein all pore space is filled with water from the unsaturated zone above.
✓Changes in the level of the water table occur due changes in rainfall.
✓ The water table tends to rise during wet seasons when more water infiltrates into the system, and falls during dry seasons when less water infiltrates.

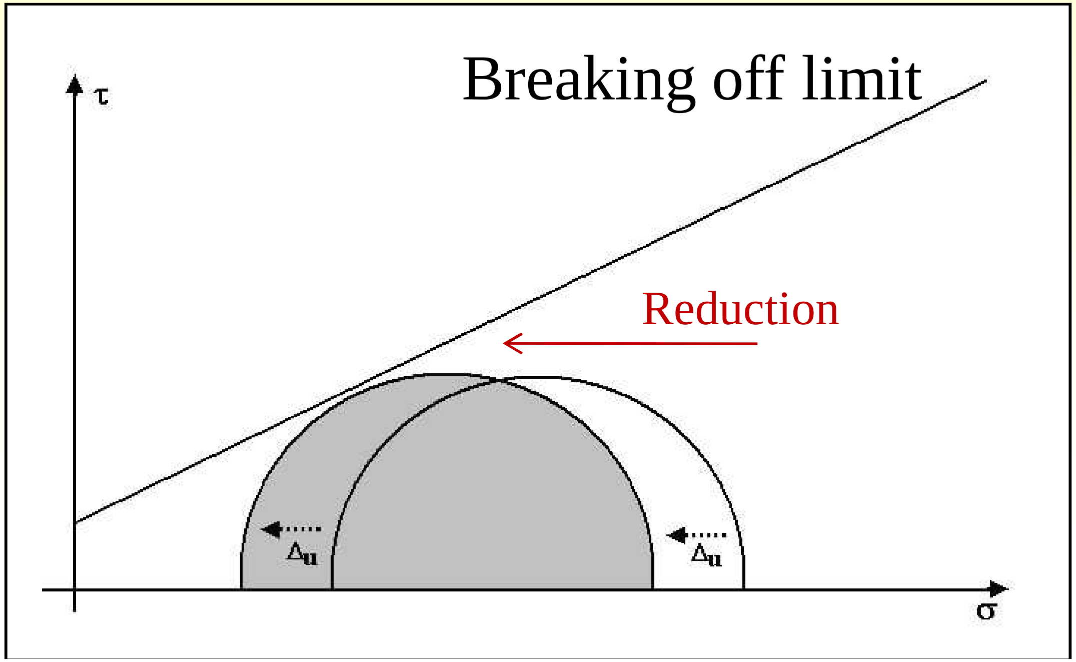


✓Such changes in the level of the water table can have effects on the factors (1 through 5) discussed above.

7- Fluid Pressure

✓ Fluid Pressure is another aspect of water that affects slope stability.
✓ As soil and rock get buried deeper in the earth, the grains can rearrange themselves to form a more compact structure, but the pore water is constrained to occupy the same space.
✓This can increase the fluid pressure to a point where the water ends up supporting the weight of the overlying rock mass.
✓When this occurs, friction is reduced, and thus the shear strength holding the material on the slope is also reduced, resulting in slope failure.

Mohr Cercle



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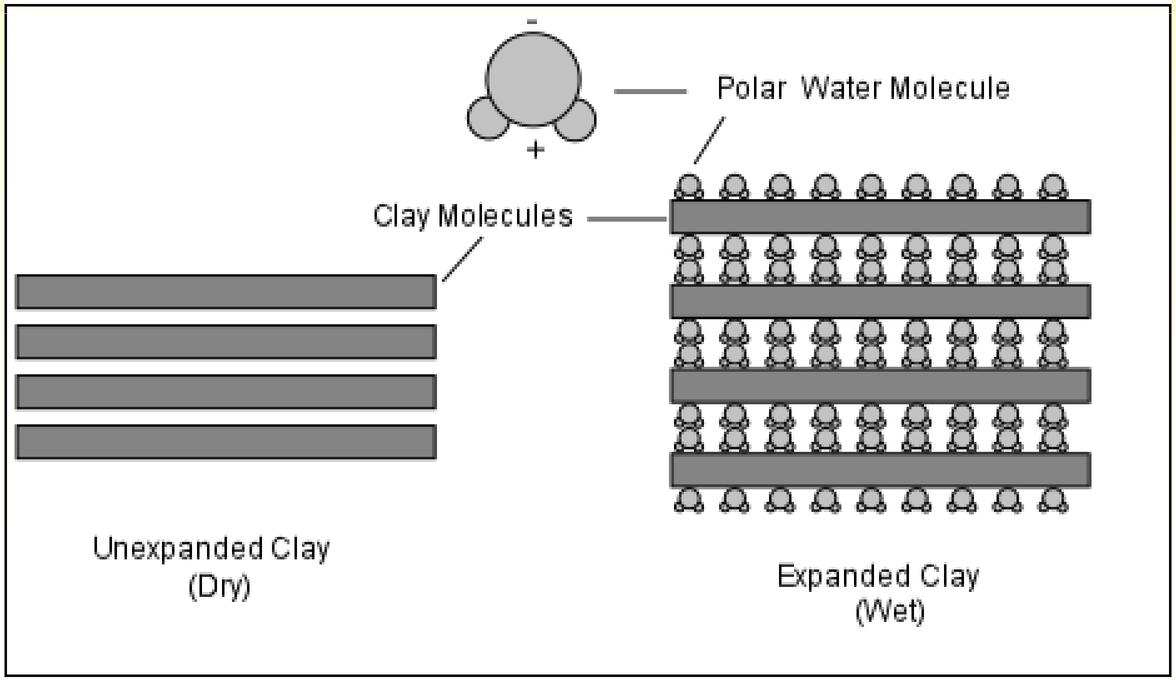
IV-Troublesome Earth Materials

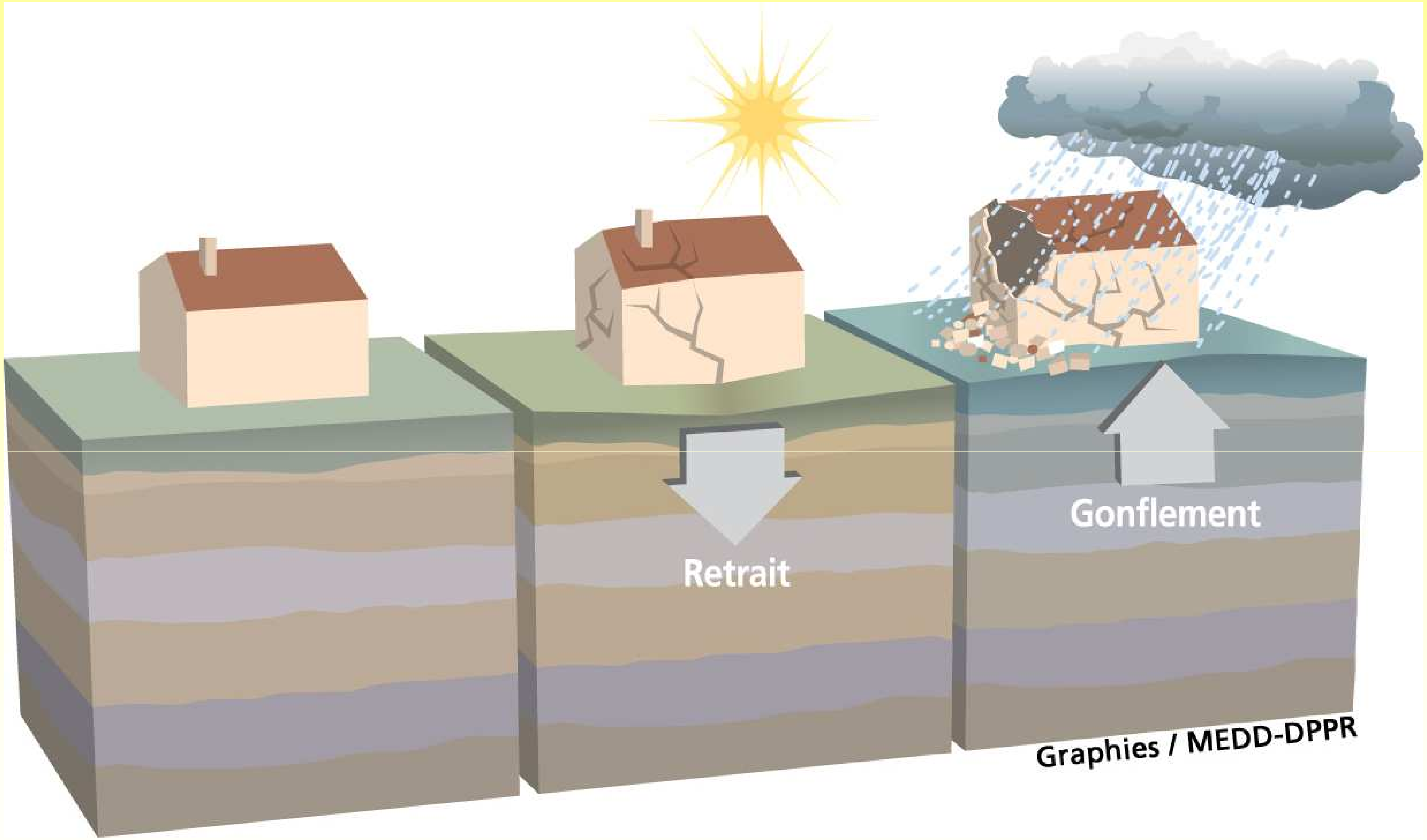
1- Expansive and Hydrocompacting Soils

✓ These are soils that contain a high proportion of a type of clay mineral called smectites or montmorillinites.

✓Such clay minerals expand when they become wet as water enters the crystal structure and increases the volume of the mineral.

✓When such clays dry out, the loss of water causes the volume to decrease and the clays to shrink or compact (This process is referred to as hydrocompaction).



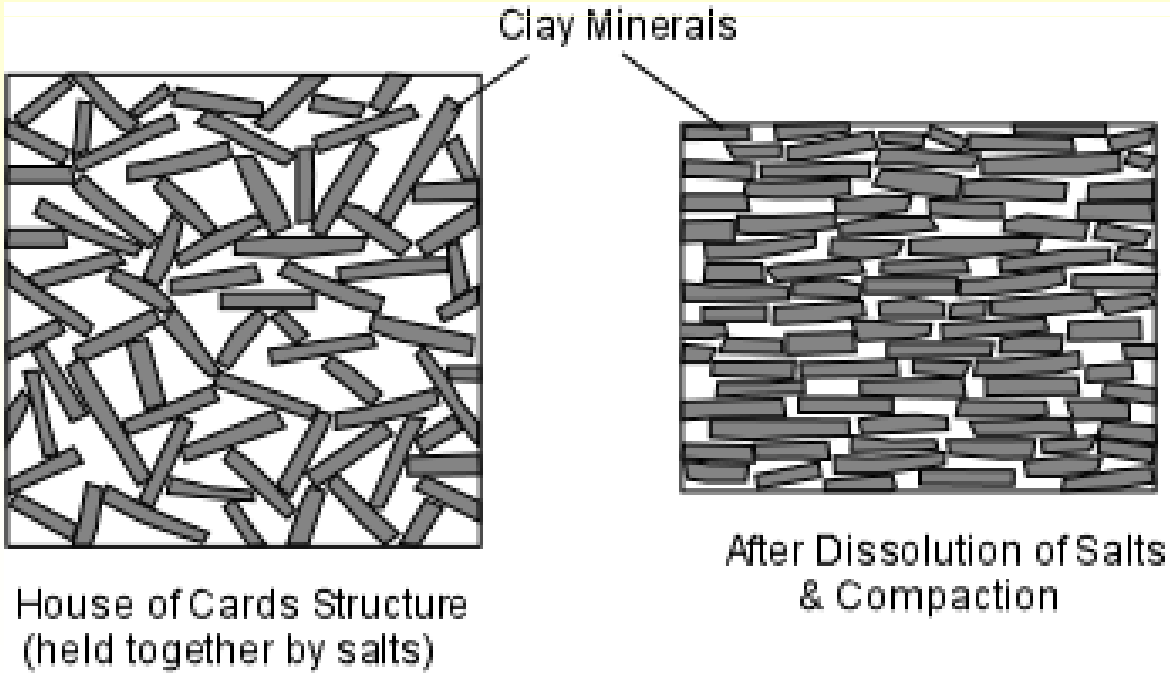

Retrait
Gonflement
Graphies / MEDD-DPPR

Here is a result of expansive and hydrocompacting soils

Pisa, Italy

2- Sensitive Soils

✓ In some soils the clay minerals are arranged in random fashion, with much pore space between the individual grains.
✓This is often referred to as a "house of cards" structure.
✓Often the grains are held in this position by salts (such as gypsum, calcite, or halite) precipitated in the pore space that "glue" the particles together.
✓As water infiltrates into the pore spaces, as discussed above, it can both be absorbed onto the clay minerals, and can dissolve away the salts holding the "house of cards" together.



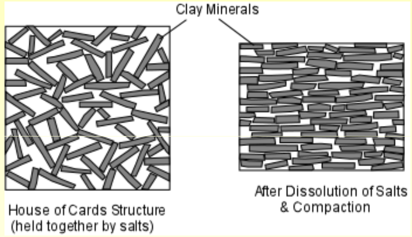
✓ Compaction of the soil or shaking of the soil can thus cause a rapid change in the structure of the material.

✓ The clay minerals will then line up with one another and the open space will be reduced.

✓But this may cause a loss in shear strength of the soil and result in slippage down slope or liquefaction.

✓This is referred to as **remolding**.

✓Clays that are subject to remolding are called **quick clays**.



3- Other case: the thixotropic effect

✓ Some clays, called **thixotropic clays**, when left **undisturbed** can **strengthen**, but when **disturbed** they **loose their shear strength**.

✓Thus, small earthquakes or vibrations caused by humans or the wind can suddenly cause a loss of strength in such materials (!!).

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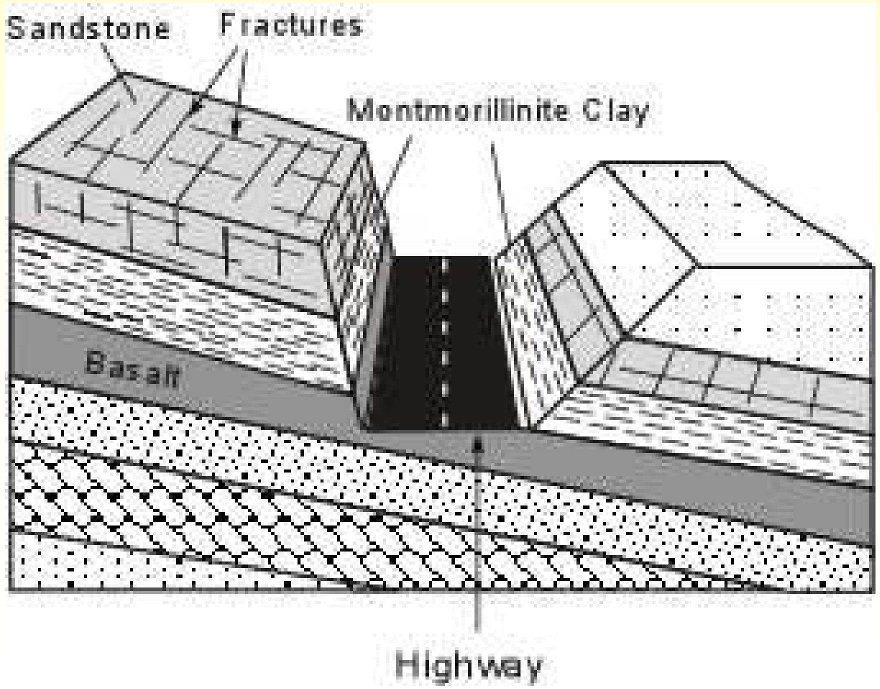
V- Weak Materials and Structures

1- Bedding Planes

✓ These are basically planar layers of rocks upon which original deposition occurred.

✓Since they are planar and since they may have a dip down-slope, they can form surfaces upon which sliding occurs, particularly if water can enter along the bedding plane to reduce cohesion.

✓In the diagram below, note how the slope above the road on the left is inherently less stable than the slope above the road on the right.



2- Weak Layers

✓ Some rocks are stronger than others. In particular, clay minerals generally tend to have a low shear strength.

✓ If a weak rock or soil occurs between stronger rocks or soils, the weak layer will be the most likely place for failure to occur, especially if the layer dips in a down-slope direction as in the previous illustration.

✓Similarly, loose unconsolidated sand has no cohesive strength. A layer of such sand then becomes a weak layer in the slope.

Geological discontinuity

3- Joints & Fractures

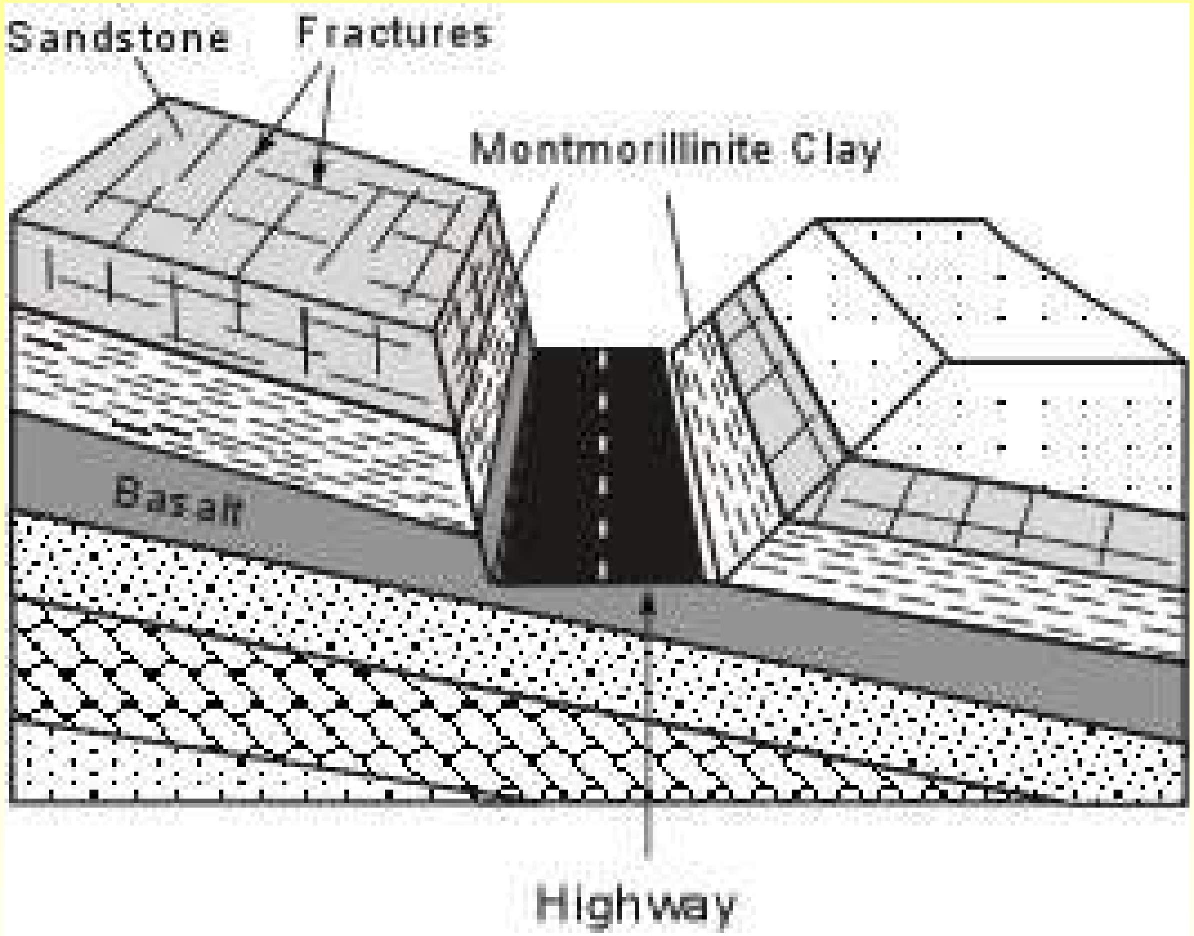
✓ Joints are regularly spaced fractures or cracks in rocks that show no offset across the fracture (reminder: fractures that show an offset are called faults).

- Joints form as a result of expansion due to cooling, or relief of pressure as overlying rocks are removed by erosion.

- Joints form free space in rock by which water, animals, or plants can enter to reduce the cohesion of the rock.

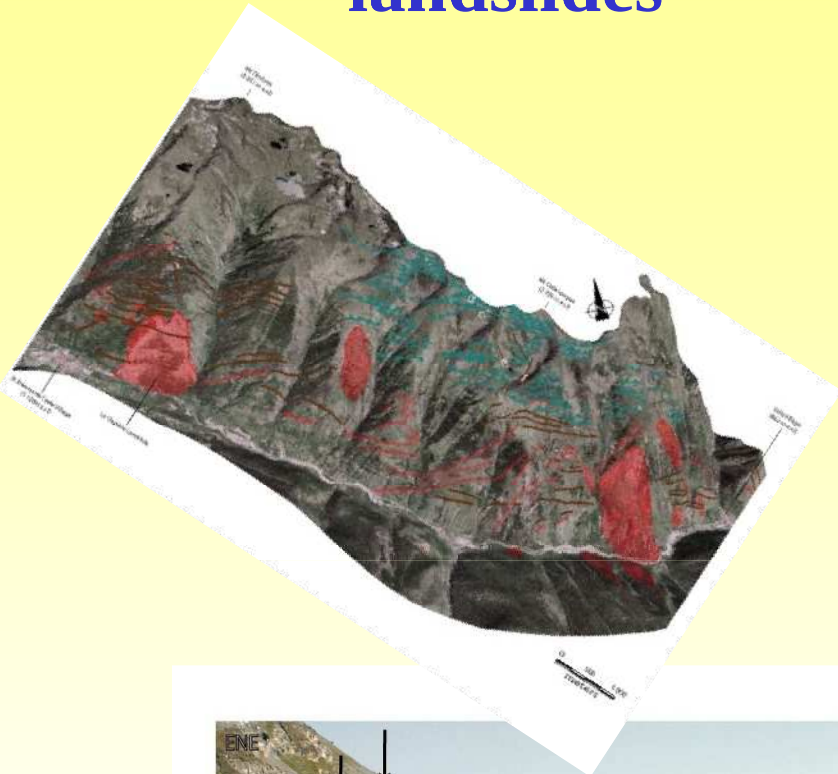
✓ If the joints are parallel to the slope they may become a sliding surface.

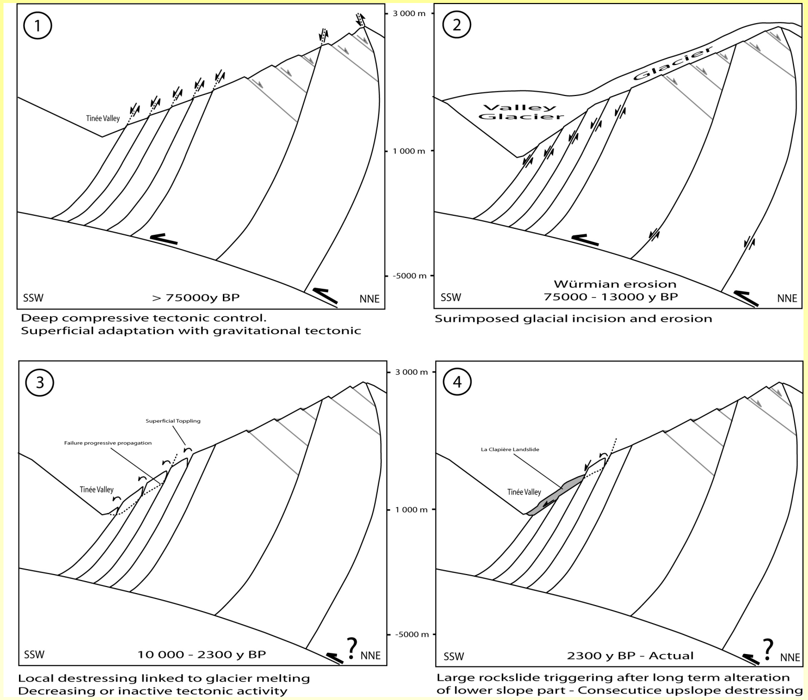
✓Combined with joints running perpendicular to the slope (as seen in the sandstone body in the illustration), the joint pattern results in fractures along which blocks can become loosened to slide down-slope.



✓Combined with joints running perpendicular to the slope (as seen in the sandstone body in the illustration), the joint pattern results in fractures along which blocks can become loosened to slide down-slope.

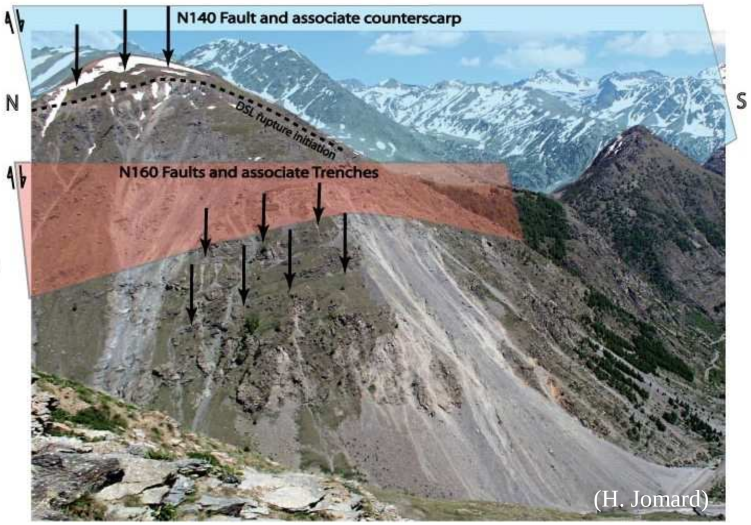
Tectonic inheritance and landslides



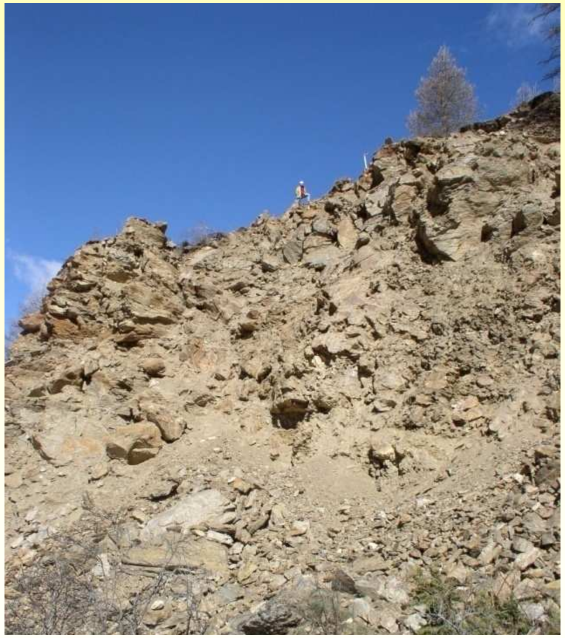


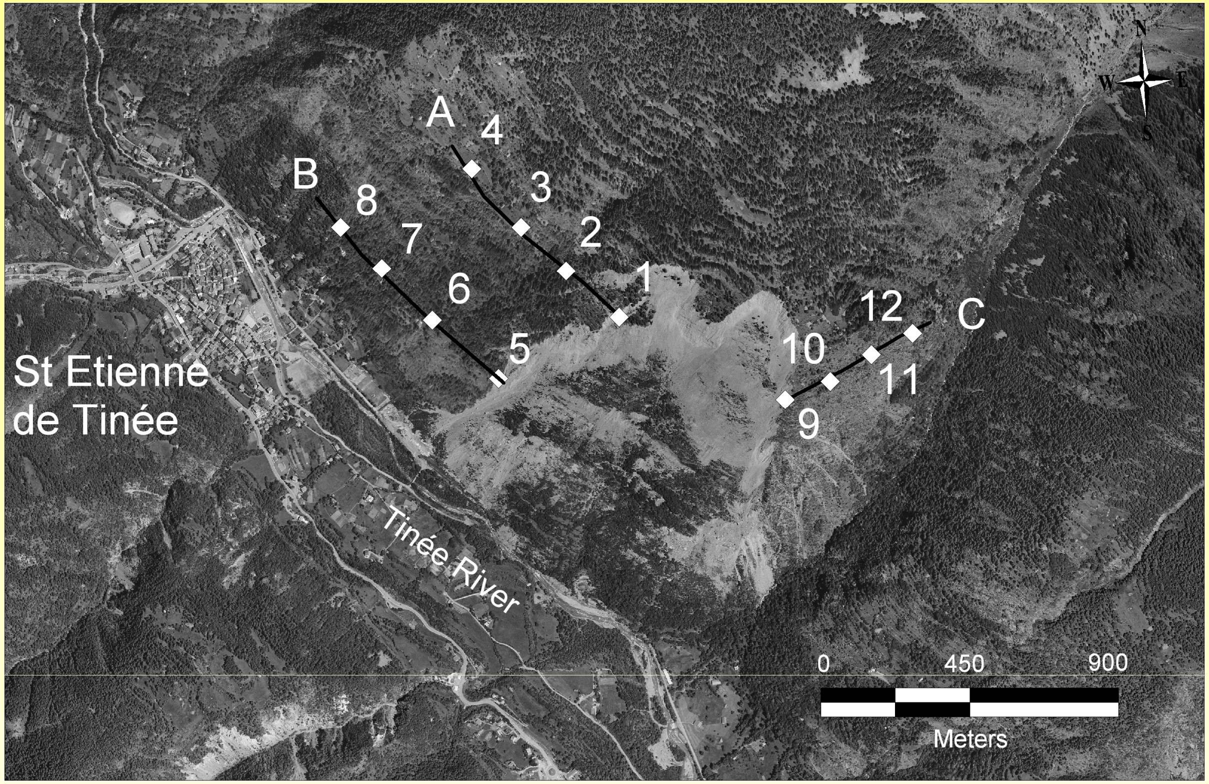
b)

c)



Cartography of the shearing zones A, B, C and the samples zones 1 to 12, around the La Clapière Landslide on air photography





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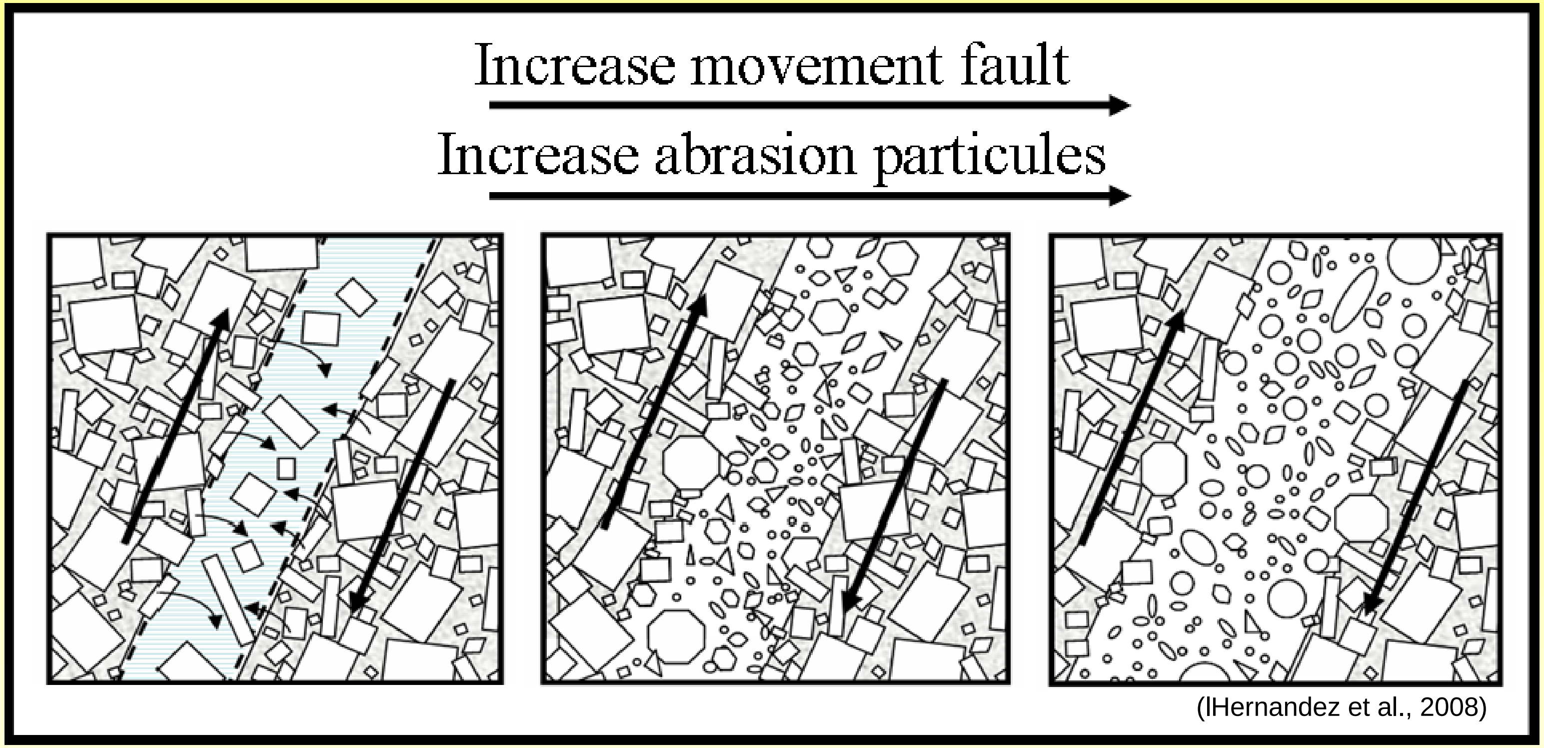
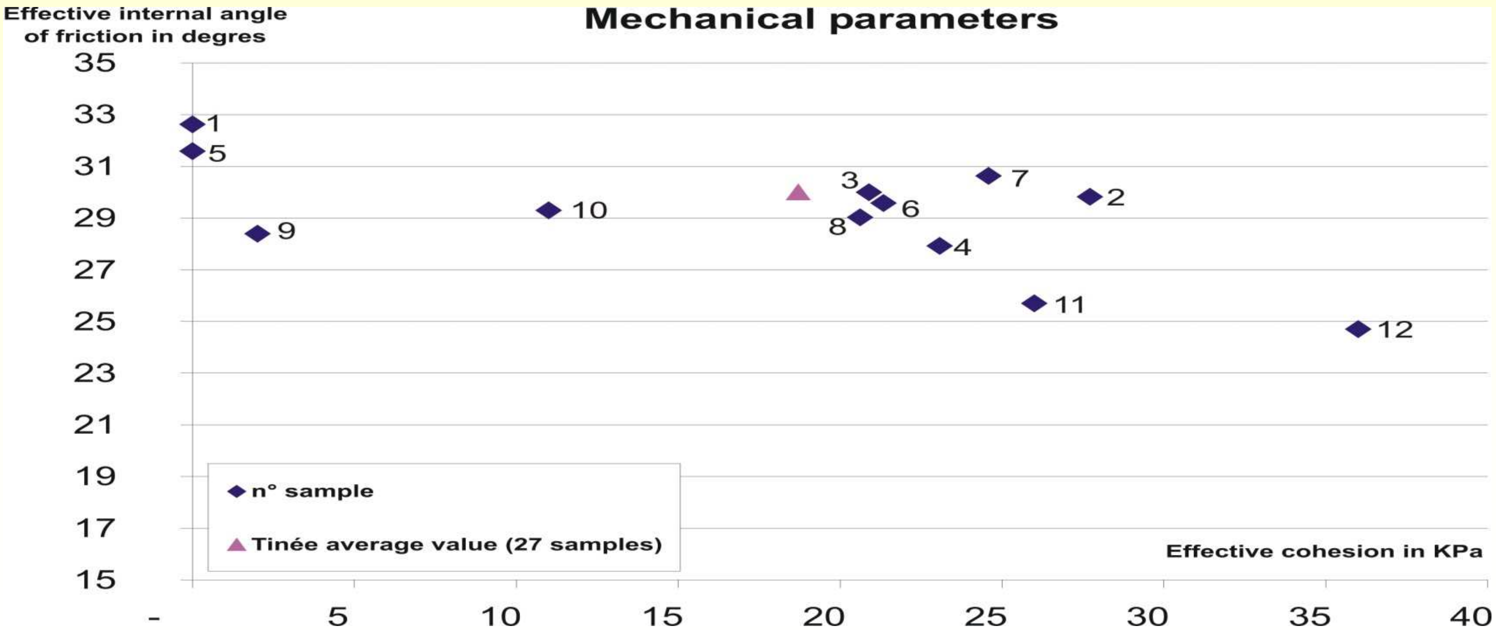

Increase movement fault
Increase abrasion particules
(lHernandez et al., 2008)


Mechanical parameters
Effective internal angle of friction in degres
Effective cohesion in KPa
n° sample
Tinée average value (27 samples)
35
33
31
29
27
25
23
21
19
17
15
-
5
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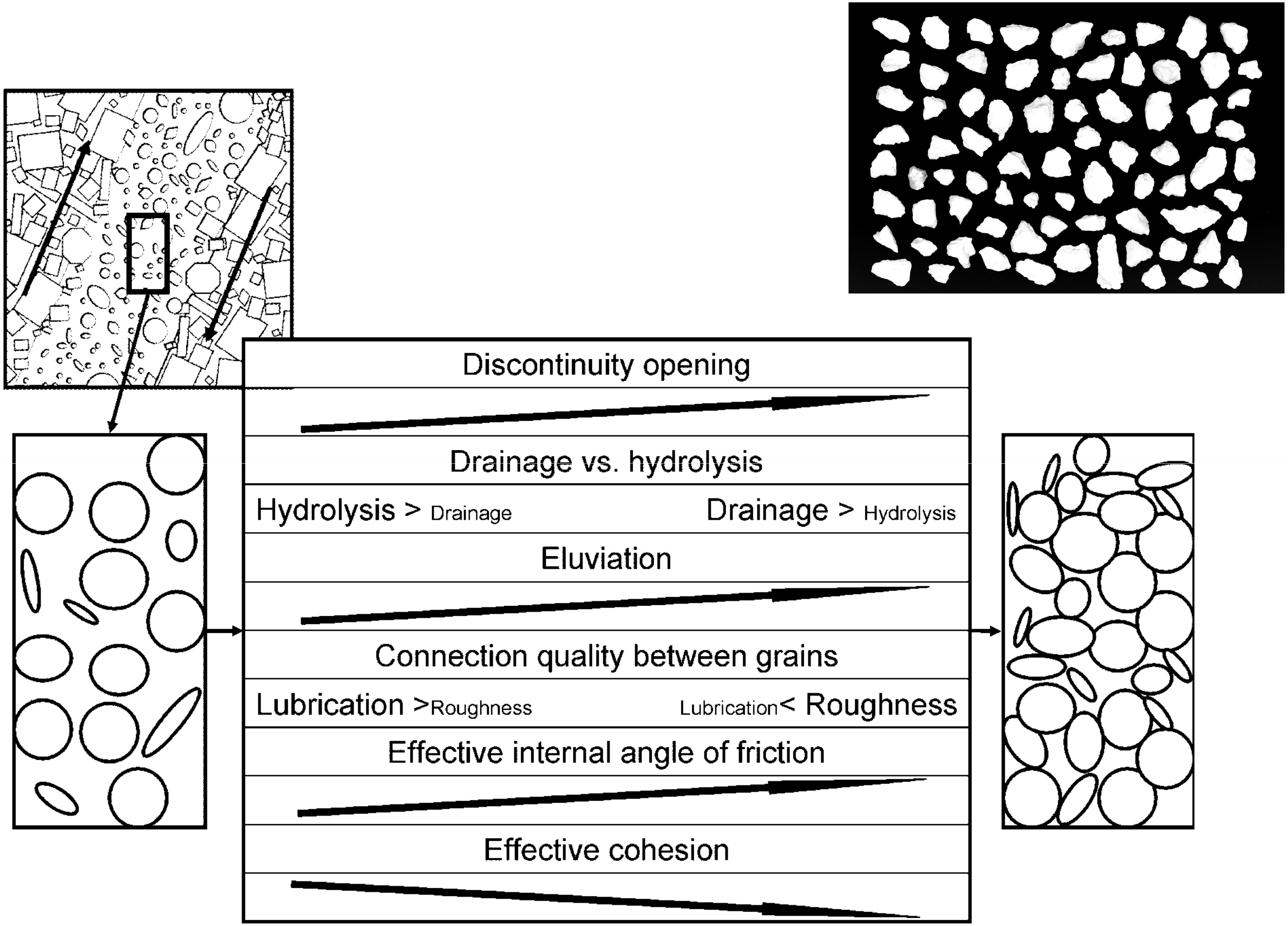


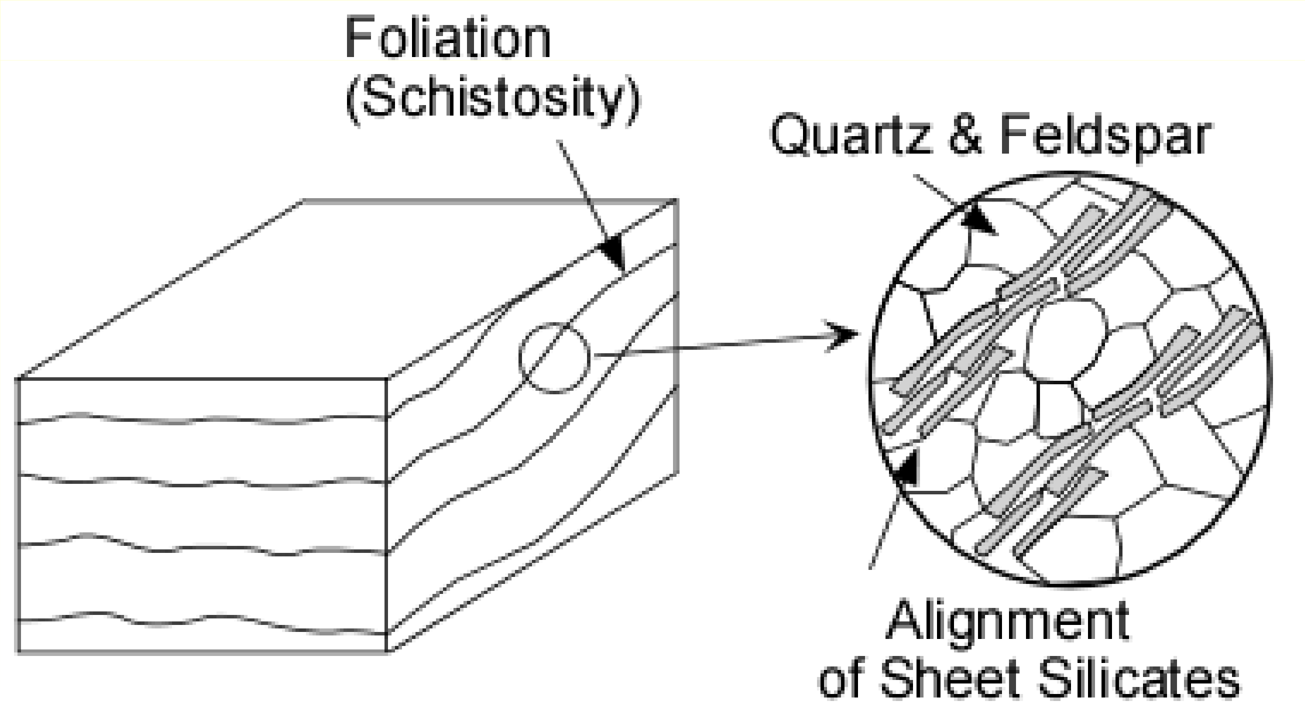
(Lebourg et al., 2003, Hernandez et al., 2008)

4- Foliation Planes

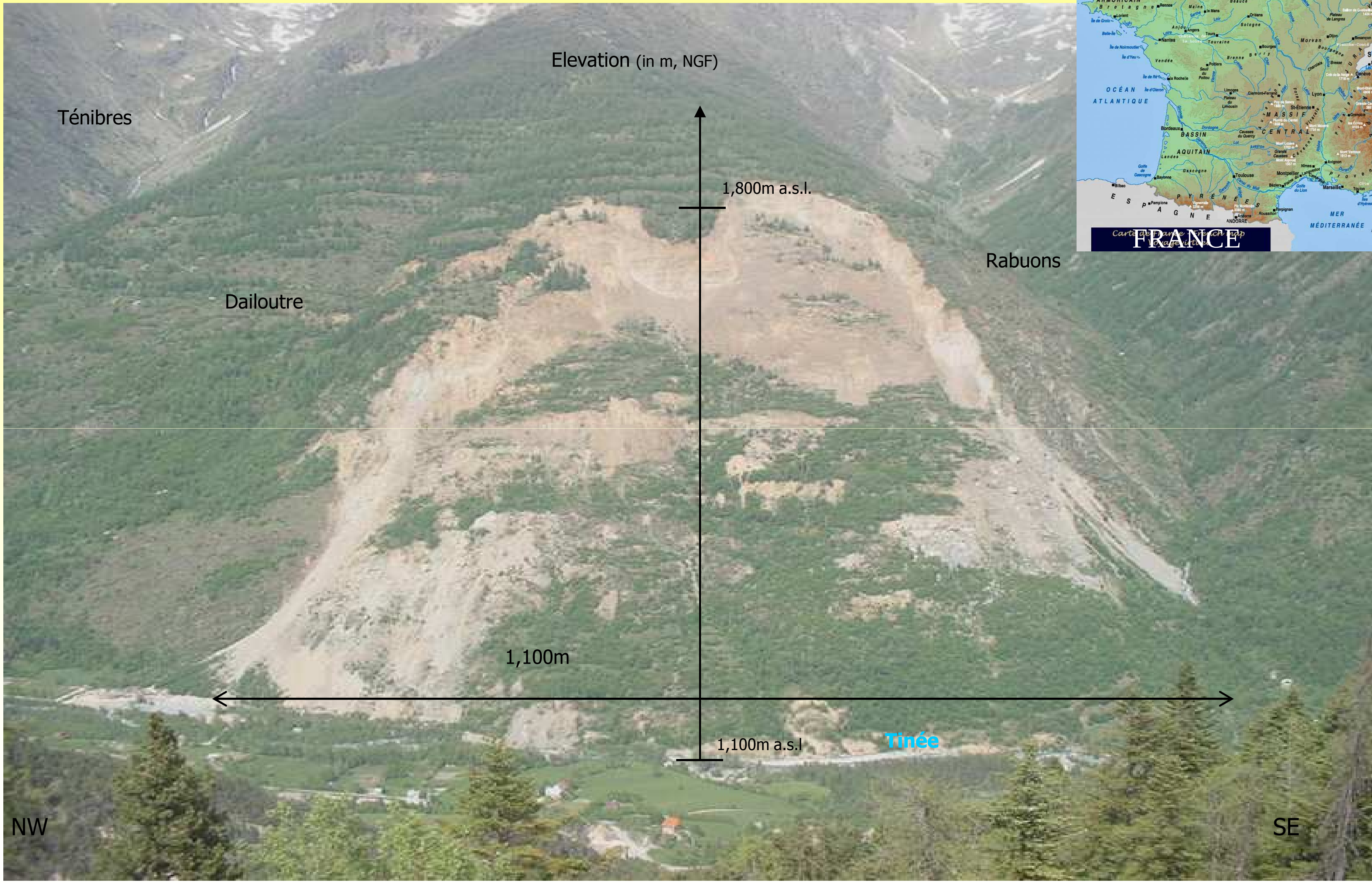
✓ During metamorphism of rock, differential stress causes sheet silicate minerals, like clay minerals, biotite, and muscovite, to grow with their sheets parallel to one another.

✓ This results in the rock = a foliation or schistosity

✓Because the sheet silicates can break easily parallel to their sheet structure, the foliation or schistosity may become a slip surface, particularly if it dips in the down-slope direction.



La Clapière, Alps, France



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VI- Triggering Events

A mass-wasting event can occur any time a slope becomes unstable. Sometimes, as in the case of creep or solifluction, the slope is unstable all of the time and the process is continuous.

But other times, triggering events can occur that cause a sudden instability to occur.

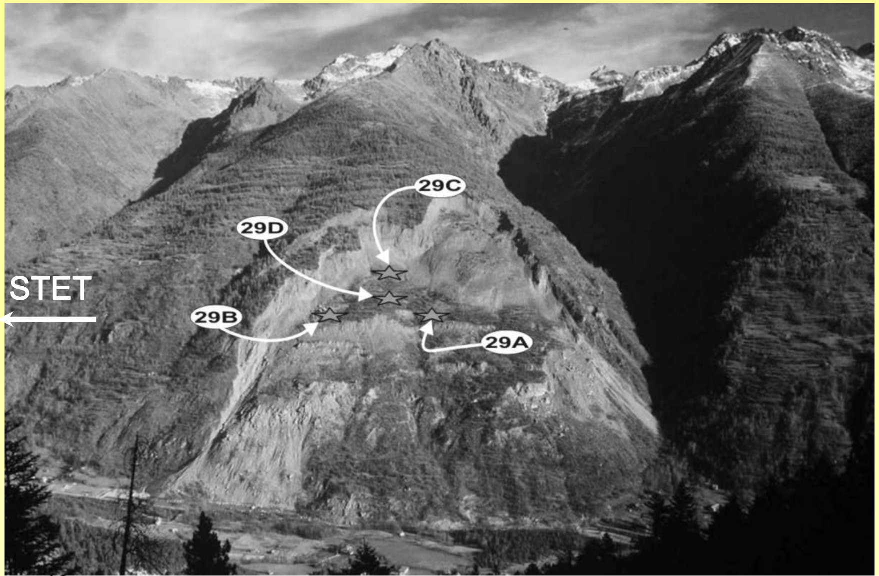
Here we’ll discuss major triggering events, but it should be noted that it if a slope is very close to instability, only a minor event may be necessary to cause a failure and disaster.

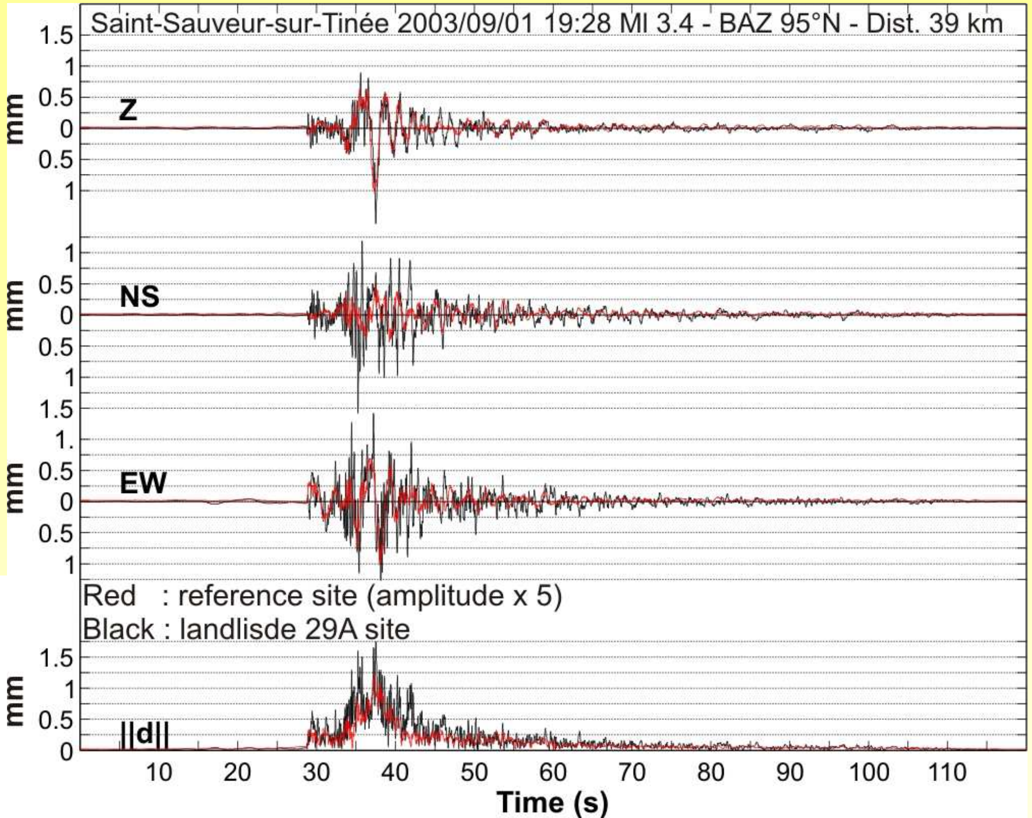
1- Shocks

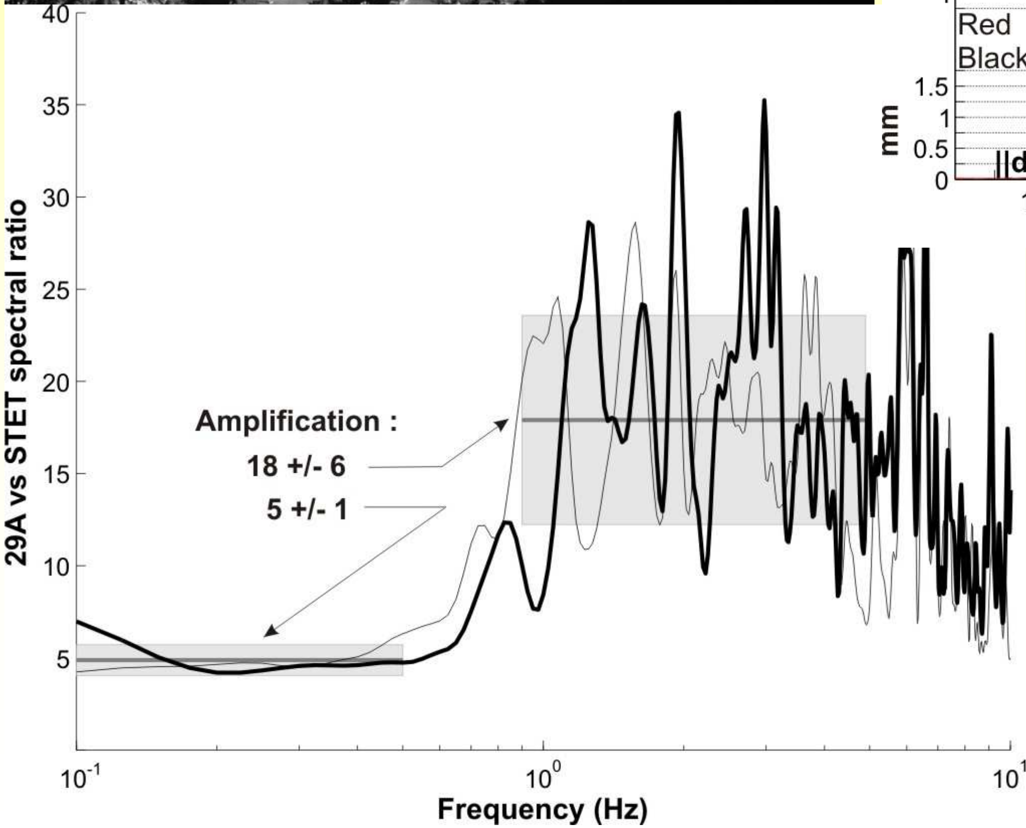
✓ A sudden shock, such as an earthquake may trigger slope instability.

✓ Minor shocks like heavy trucks rambling down the road, trees blowing in the wind, or human made explosions can also trigger mass-wasting events.

- ✓ Quantification of the spoiling of a rock massif due to earthquakes
- ✓Example 1: Turnagain Heights Alaska, 1964, Earthquake on March 27
- ✓ Example 2: Nevados de Huascarán, Peru, 1962 and 1970







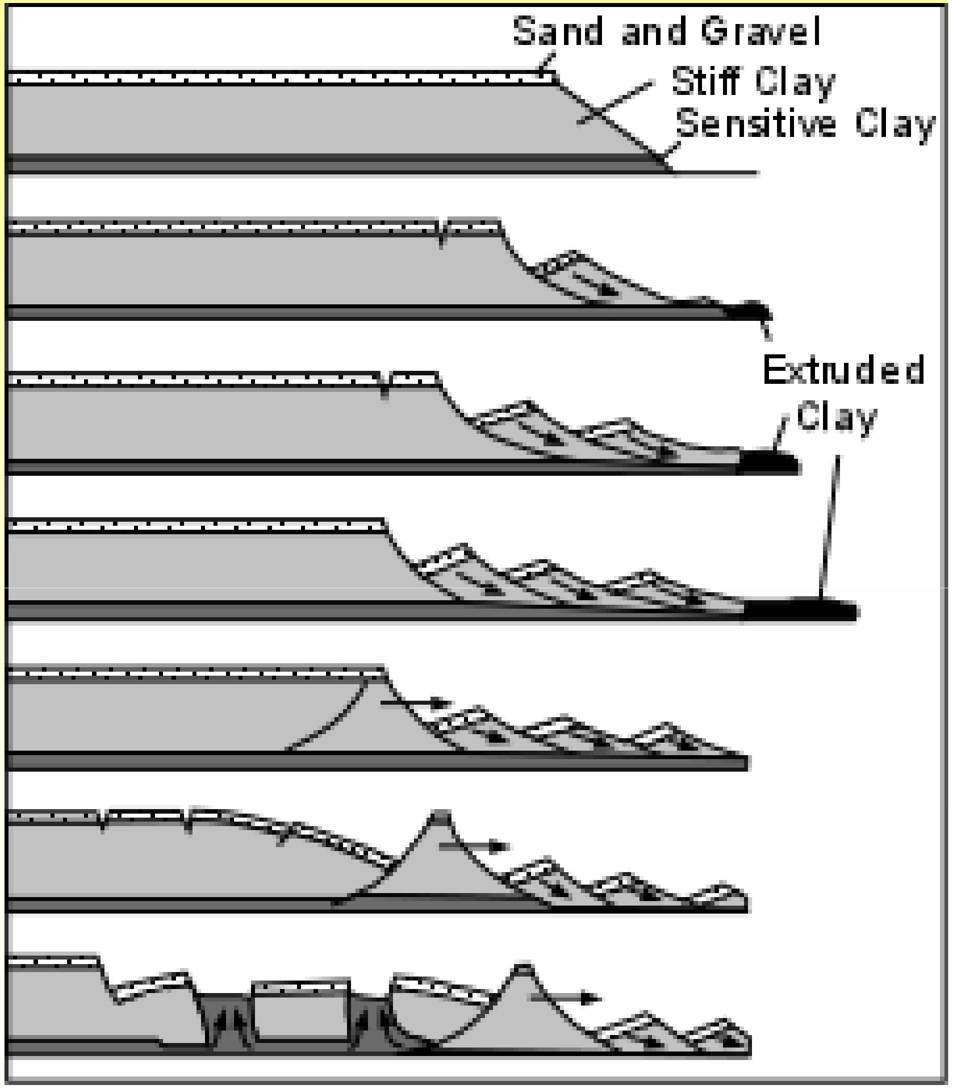
Massif spoiling (endommagement)

Amplification of the soil movements at the surface of the landslide comparated at those in the stable site STET, 1 km away northwards

Time 5 pour f < 1 Hz

Time18 pour f > 1 Hz

✓**Example 1 : Turnagain Heights Alaska, 1964, Earthquake on March 27**, near Anchorage, Alaska, an area known as Turnagain Heights broke into a series of slump blocks that slid toward the ocean.



After Abbott, 1996

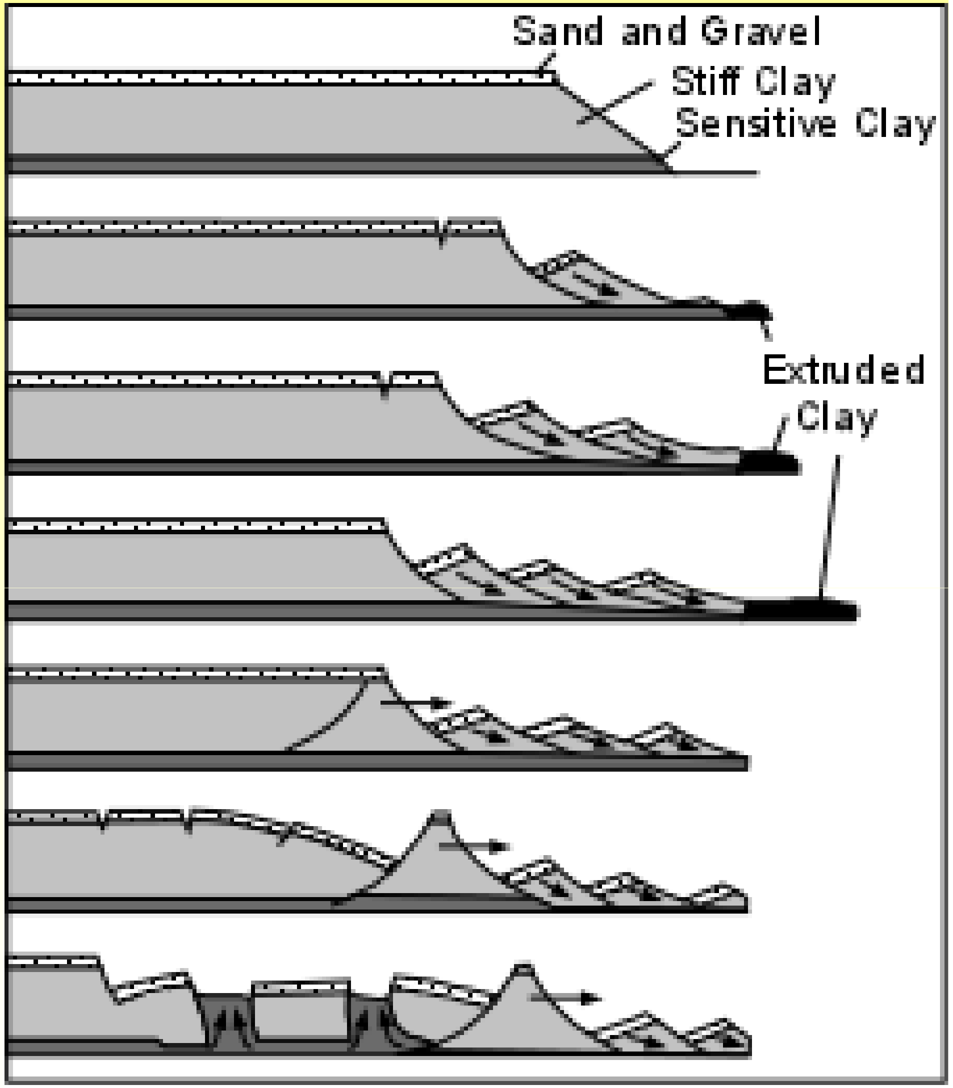
✓This area was built on sands and gravels overlying marine clay.

✓ The upper clay layers were relatively stiff, but the lower layers consisted of a sensitive clay, as discussed above.

✓Example 1 : Turnagain Heights Alaska, 1964, Earthquake on March 27, near Anchorage, Alaska, an area known as Turnagain Heights broke into a series of slump blocks that slid toward the ocean.

✓ The slide moved about 610 m toward the ocean, breaking up into a series of blocks.

✓ It began at the sea cliffs on the ocean after about 1.5 minutes of shaking caused by the earthquake, when the lower clay layer became liquefied.

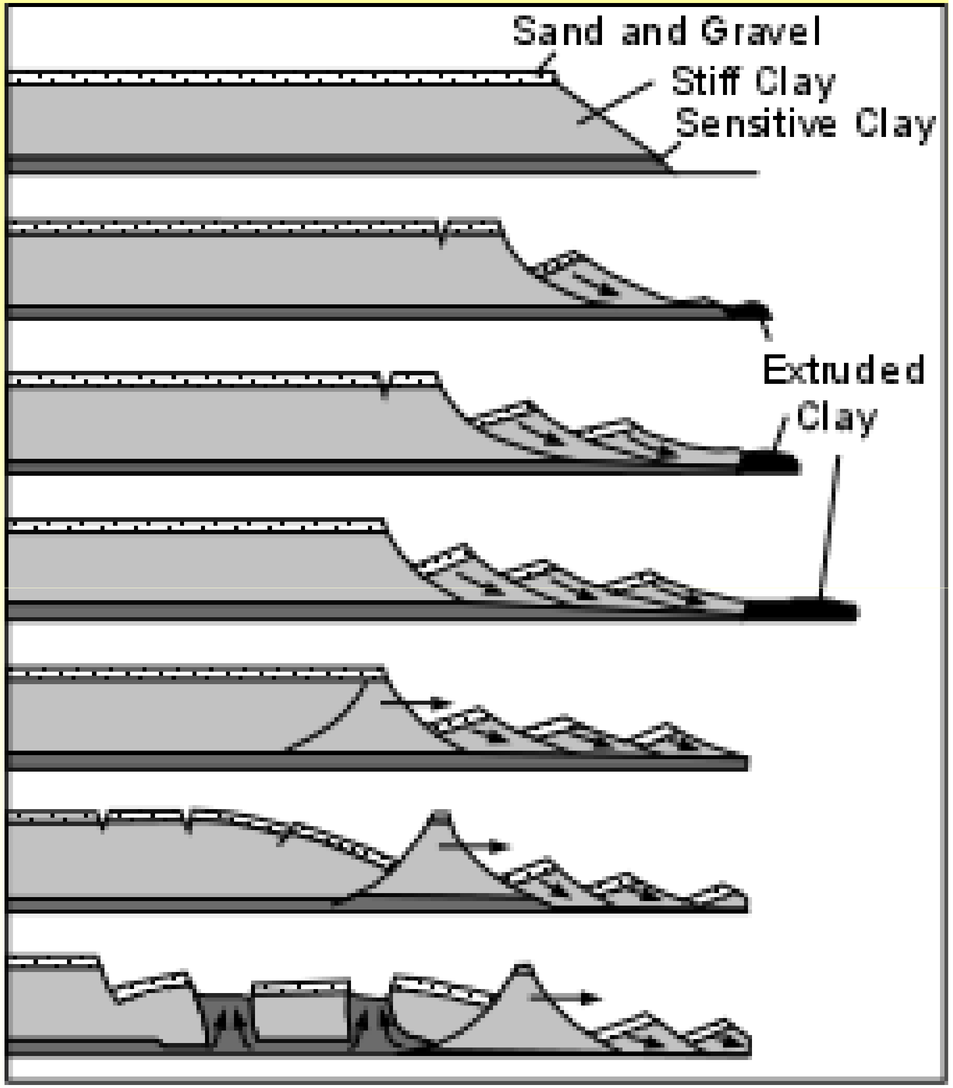


After Abbott, 1996

✓Example 1 : Turnagain Heights Alaska, 1964, Earthquake on March 27, near Anchorage, Alaska, an area known as Turnagain Heights broke into a series of slump blocks that slid toward the ocean.

✓ As the slide moved into the ocean, clays were extruded from the toe of the slide.

✓The blocks rotating near the front of the slide, eventually sealed off the sensitive clay layer preventing further extrusion.

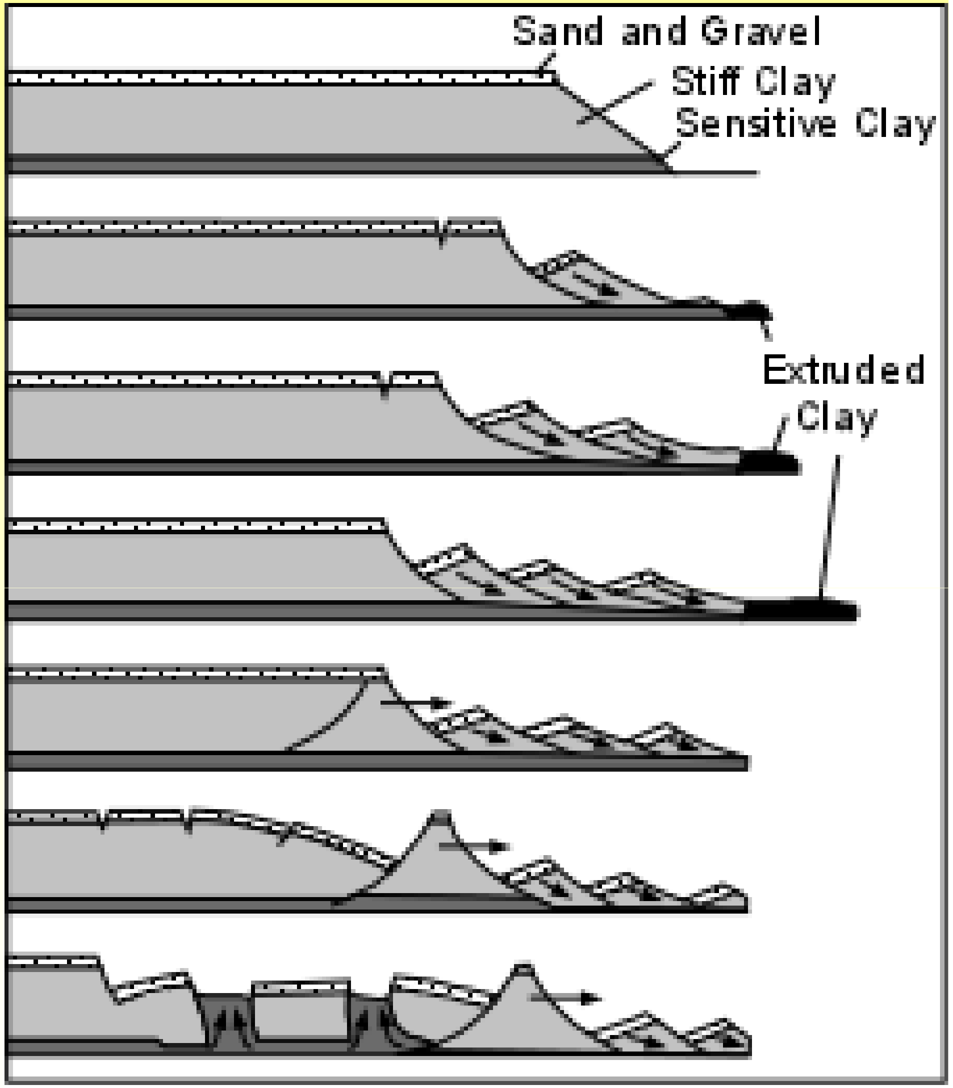


After Abbott, 1996

✓**Example 1 : Turnagain Heights Alaska, 1964, Earthquake on March 27**, near Anchorage, Alaska, an area known as Turnagain Heights broke into a series of slump blocks that slid toward the ocean.

✓ This led to pull-apart basins being formed near the rear of the slide and the oozing upward of the sensitive clays into the space created by the extension.

✓75 homes on the top of the slide were destroyed by the movement of the mass of material toward the ocean.



After Abbott, 1996

✓ **Example 2: Nevados de Huascarán, Peru, 1962 and 1970**

✓ Nevados de Huascarán is a high peak in the Peruvian Andes Mountains.

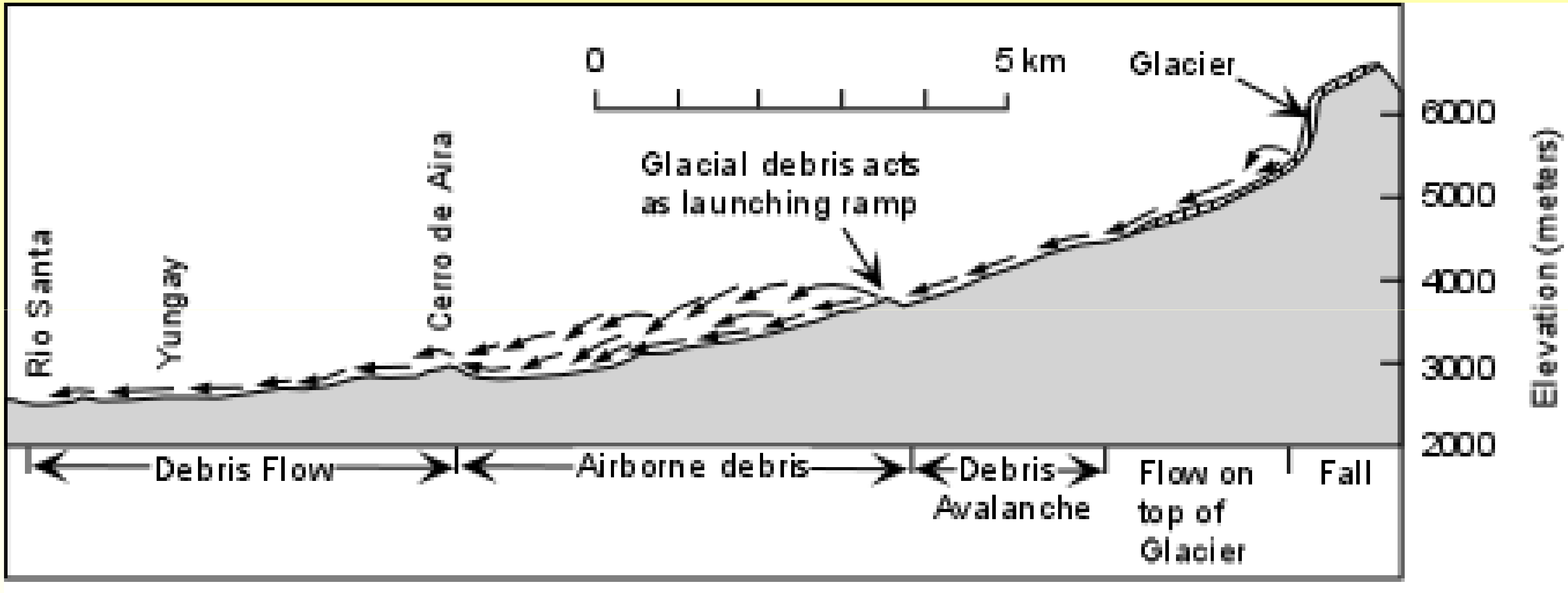
✓The peak consists of granite with nearly **vertical joints** (fractures) covered by **glacial ice**.

✓On January 10, 1962 a huge slab of rock and glacial ice suddenly fell, with **no apparent triggering mechanism**.

✓This initiated a debris flow that moved rapidly into the valley below and killed 4,000 people in the town of Ranrahirca, but stopped when it reached the hill called Cerro de Aira, and did not reach the larger population center of Yungay.

✓ **Example 2: Nevados de Huascarán, Peru, 1962 and 1970**

✓ On May 31, 1970 a magnitude 7.7 earthquake occurred on the subduction zone 135 km away from the Nevados de Huascarán.



After Abbott, 1996

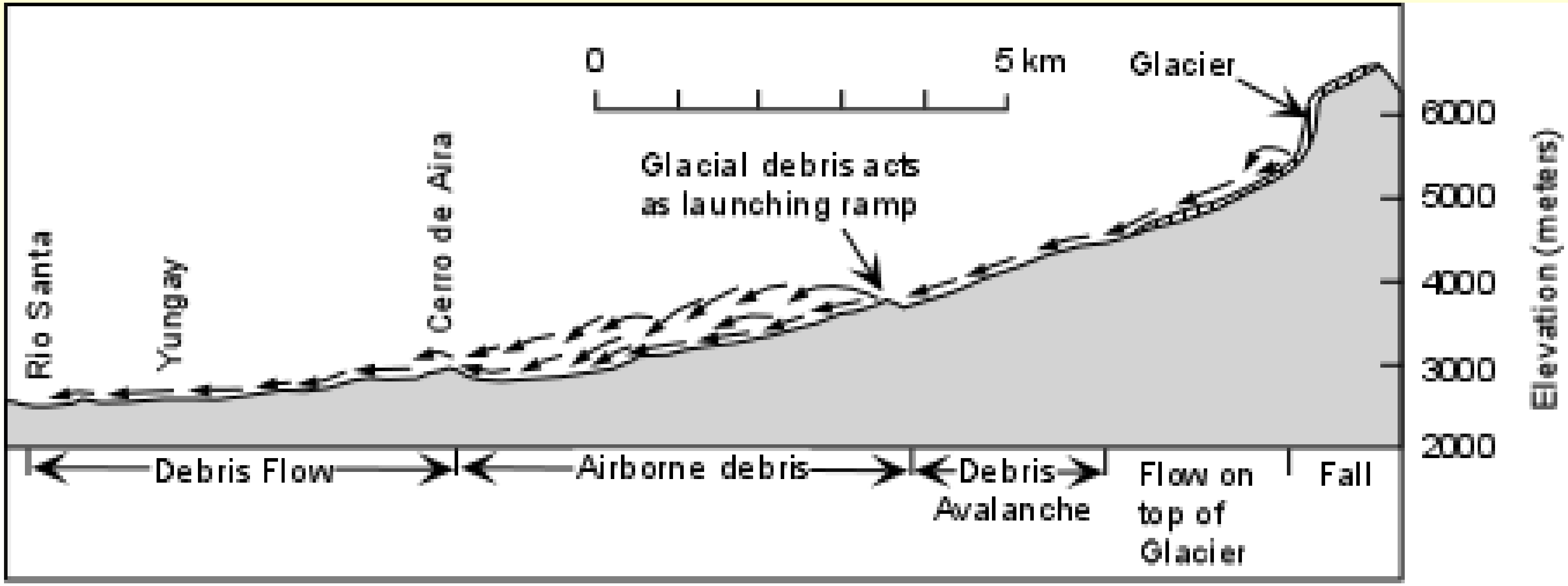
✓ Shaking in the area lasted for 45 seconds, and during this shaking another large block of the Nevados de Huascarán between 5,500 and 6,400 meters elevation fell from the peak.

✓ Example 2: Nevados de Huascarán, Peru, 1962 and 1970

✓ This time it became a debris avalanche sliding across the snow covered glacier and moving down slope at velocities up to 335 km/hr.

✓The avalanche then hit a small hill composed of glacially deposited sediment and was launched into the air as an airborne debris avalanche.

✓From this airborne debris, blocks the size of large houses fell on real houses for another 4 km. The mass then recombined in the vicinity of Cerro de Aira and continued flowing as a debris flow, burying the town of Yungay and its 18,000 residents.

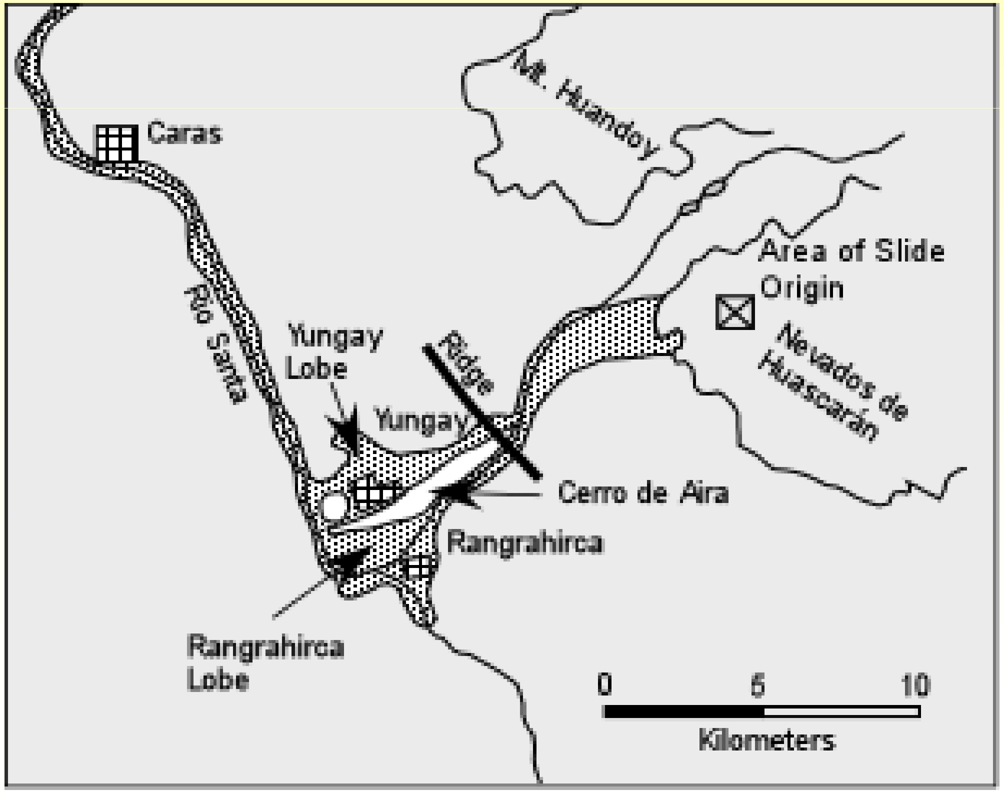


After Abbott, 1996

✓ **Example 2: Nevados de Huascarán, Peru, 1962 and 1970**

✓ The debris flow reached the valley of the Rio Santa and climbed up the valley walls killing another 600 people on the opposite side of the river.

✓Since then, the valley has been repopulated, and currently large cracks are seen on the remains of the glacier that still covers the upper slopes of Nevados de Huascarán.

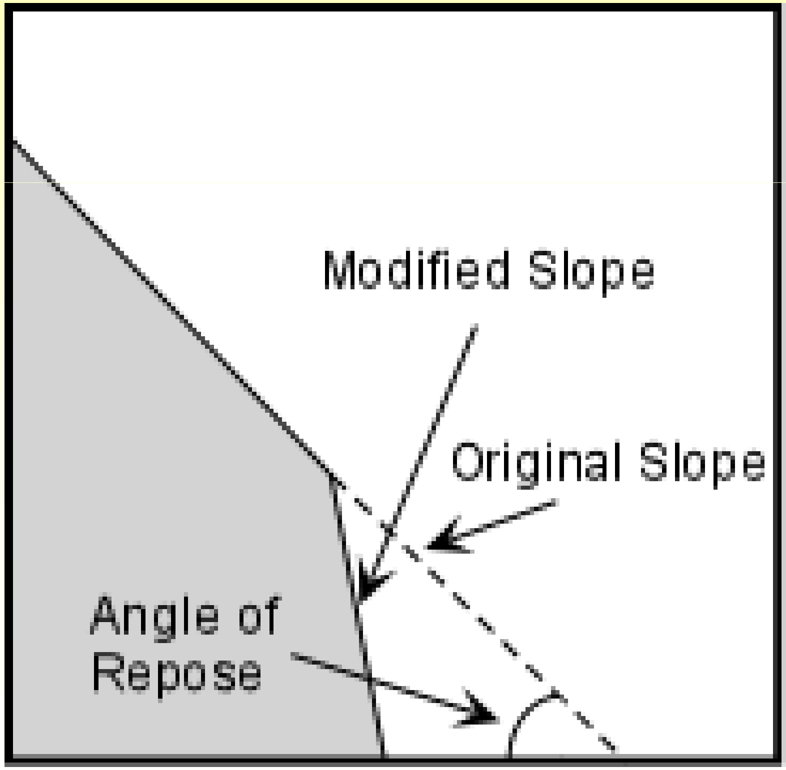


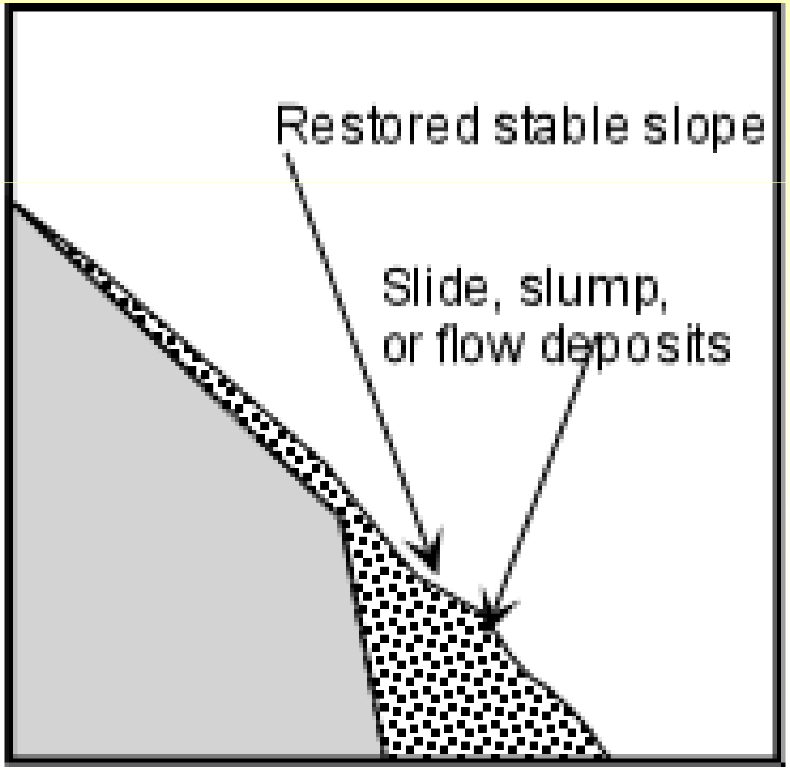
After Browning, 1973

2- Slope Modification and undercutting

✓ Modification of a slope either by humans or by natural causes can result in changing the slope angle so that it is no longer at the angle of repose.

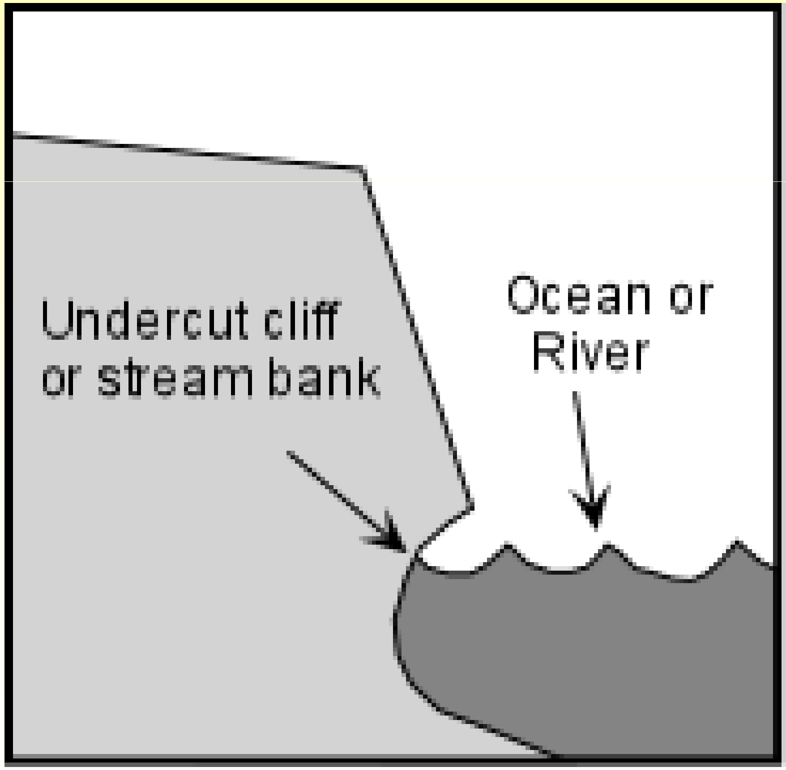
✓A mass-wasting event can then restore the slope to its angle of repose.

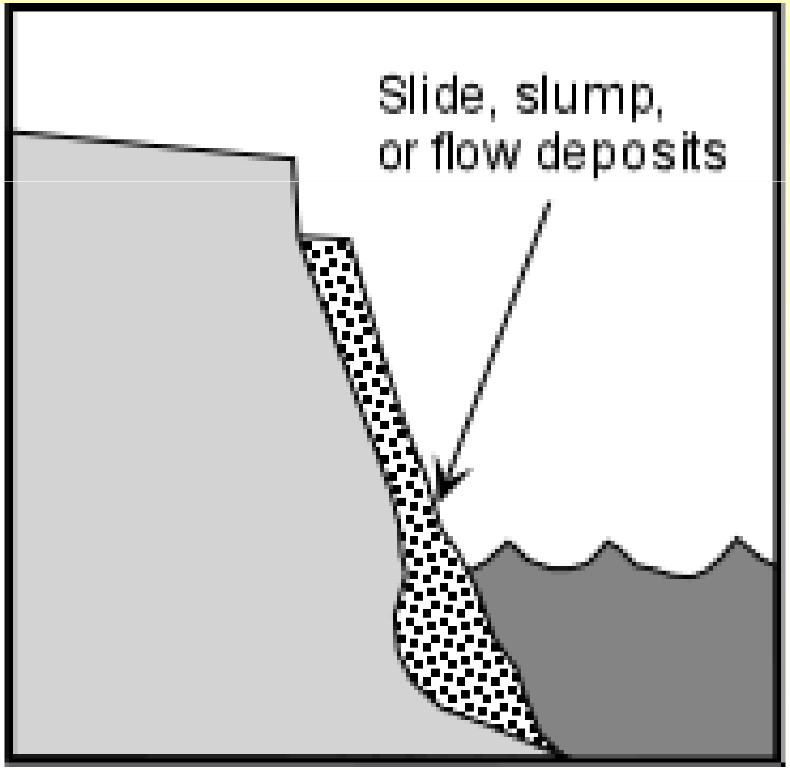




Undercutting

✓Streams eroding their banks or surf action along a coast can undercut a slope making it unstable.





✓**Example: Elm Switzerland, 1881**

✓In 1870s there was a large demand for slate to make blackboards throughout Europe.

✓To meet this demand, miners near Elm, Switzerland began digging a slate quarry at the base of a steep cliff.

✓Slate is a metamorphic rock with an excellent planar foliation that breaks smoothly along the foliation planes.

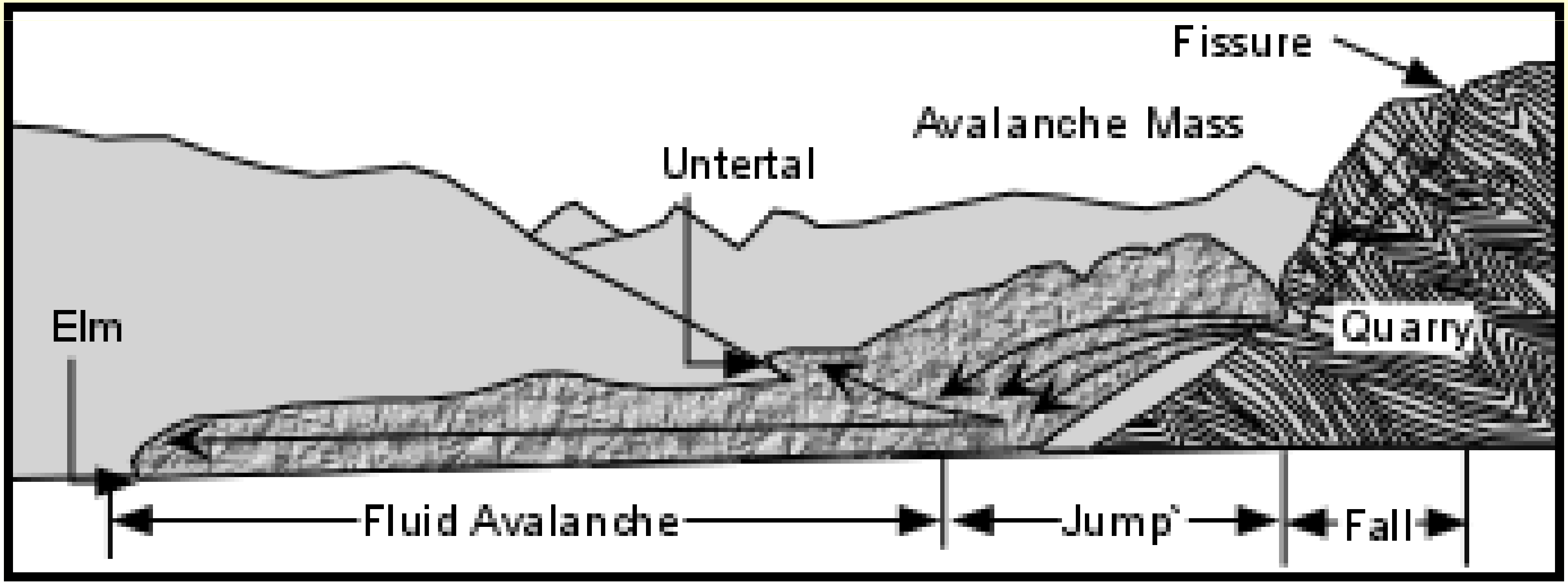
✓By 1876 a "v" shaped fissure formed above the cliff, about 360 meters above the quarry.

✓By September 1881, the quarry had been excavated to where it was 180 m long and 60 m into the hill below the cliff, and the "v" shaped fissure had opened to 30 m wide.

✓**Example: Elm Switzerland, 1881**

✓Falling rocks were frequent in the quarry and their were almost continuous loud noises heard coming from the overhang above the quarry.

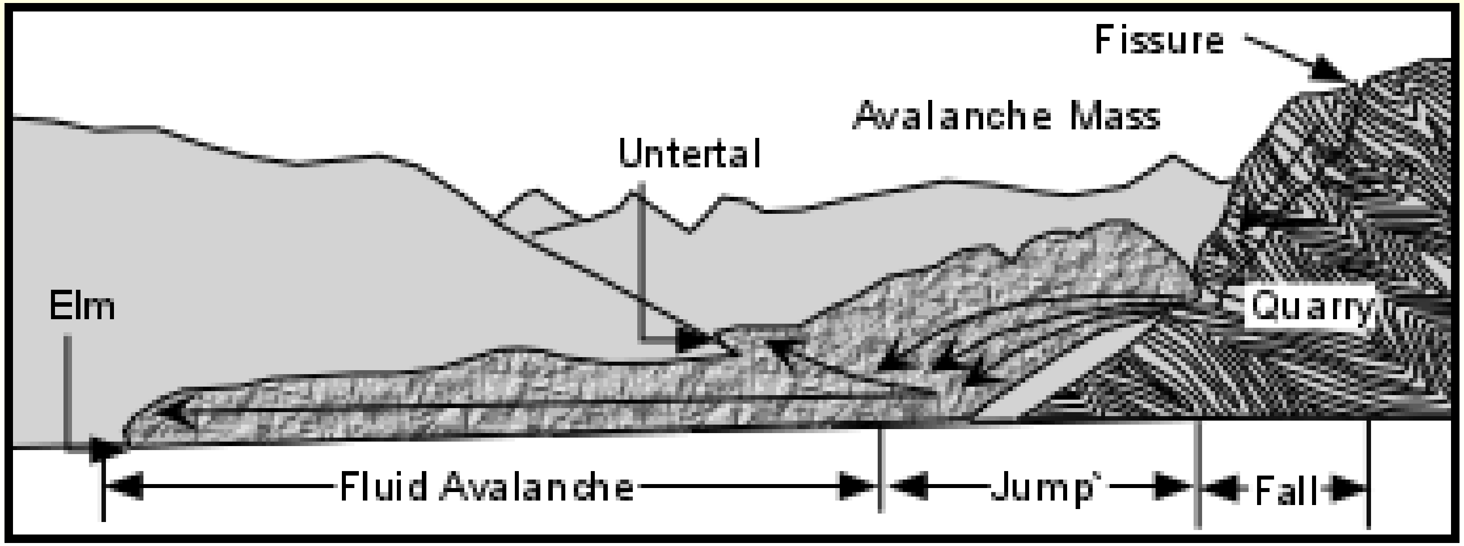
✓Realizing that the slope had become unstable, the miners stopped working, thinking that the rock mass above the quarry would probably fall down.



After Abbott, 1996

✓Example: Elm Switzerland, 1881

✓ On September 11, 1881 the 10 million m^3 mass of rock above the quarry suddenly fell.
✓But, it did not stop when it hit the quarry floor.
✓Instead, it broke into pieces and rebounded into the air. Residents in Untertal, on the opposite side of the valley from the slide, saw the mass of rebounded rock coming at the them and ran uphill.
✓But the mass of rock continued up the walls of the valley and buried them.
✓The avalanche then turned and ran an additional 2,230 m as a dry avalanche traveling at 180 km/hr burying the village of Elm.
✓The avalanche killed 115 people.



After Abbott, 1996

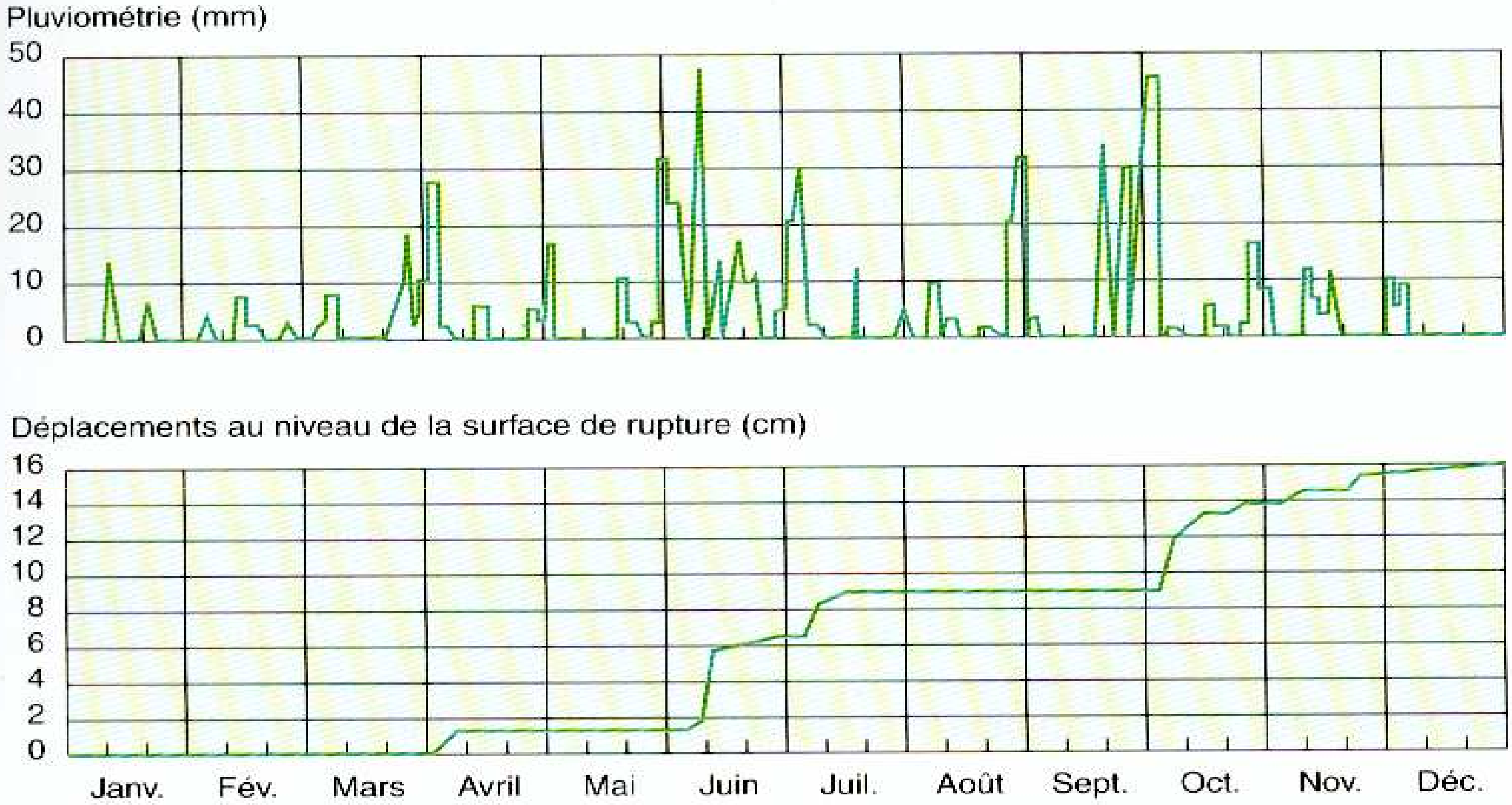
3- Changes in Hydrologic Characteristics

✓ Heavy rains can saturate regolith (sediment weathered on place) reducing grain to grain contact and reducing the angle of repose, thus triggering a mass-wasting event.

✓Heavy rains can also saturate rock and increase its weight.

✓Changes in the groundwater system can increase or decrease fluid pressure in rock and also trigger mass-wasting events.

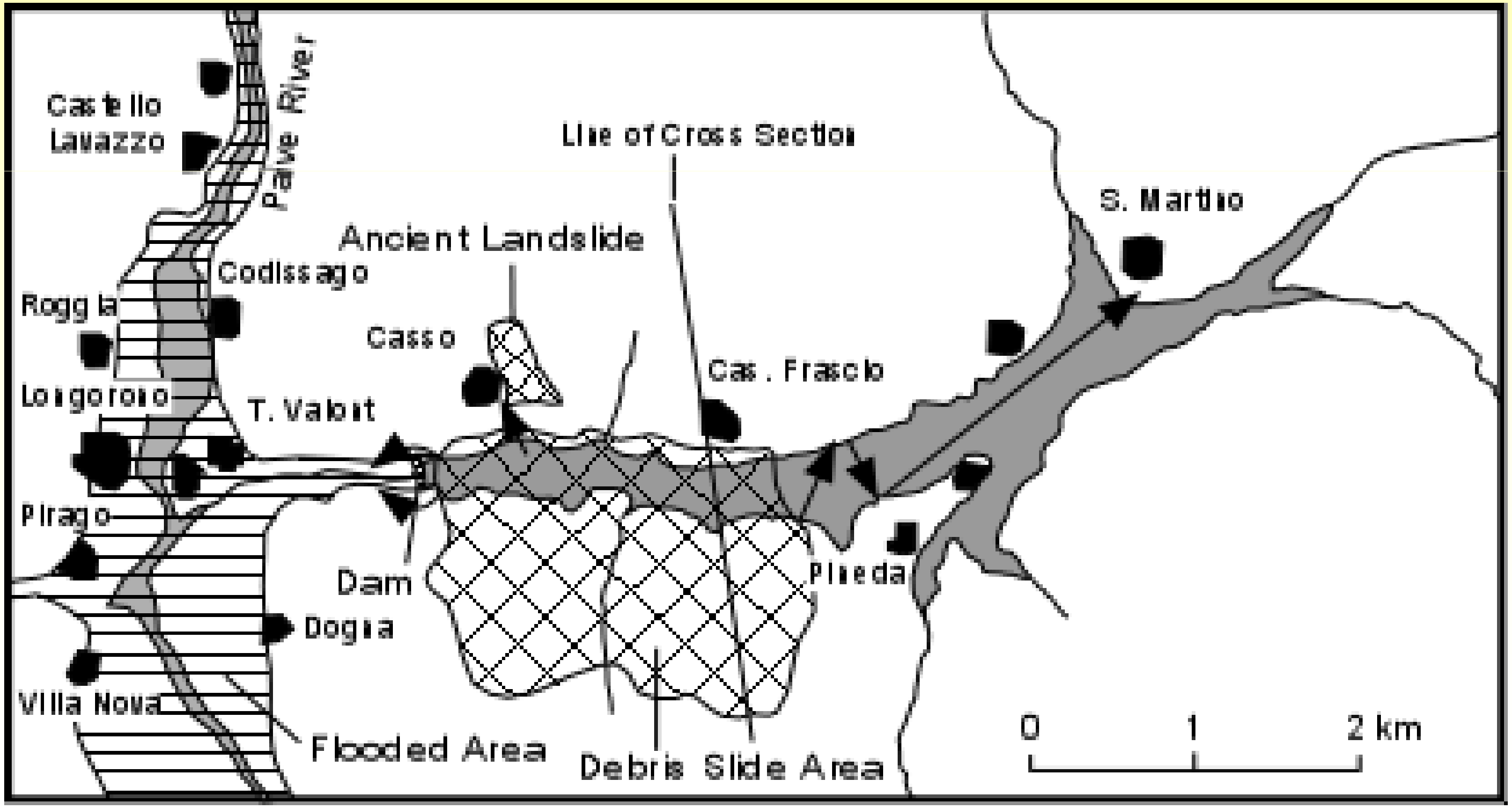
✓Example: Vaiont Reservoir, Italy, 1963


Pluviométrie (mm)
50
40
30
20
10
0
Déplacements au niveau de la surface de rupture (cm)
16
14
12
10
8
6
4
2
0
Janv.
Fév.
Mars
Avril
Mai
Juin
Juil.
Août
Sept.
Oct.
Nov.
Déc.

✓ Example: Vaiont Reservoir, Italy, 1963

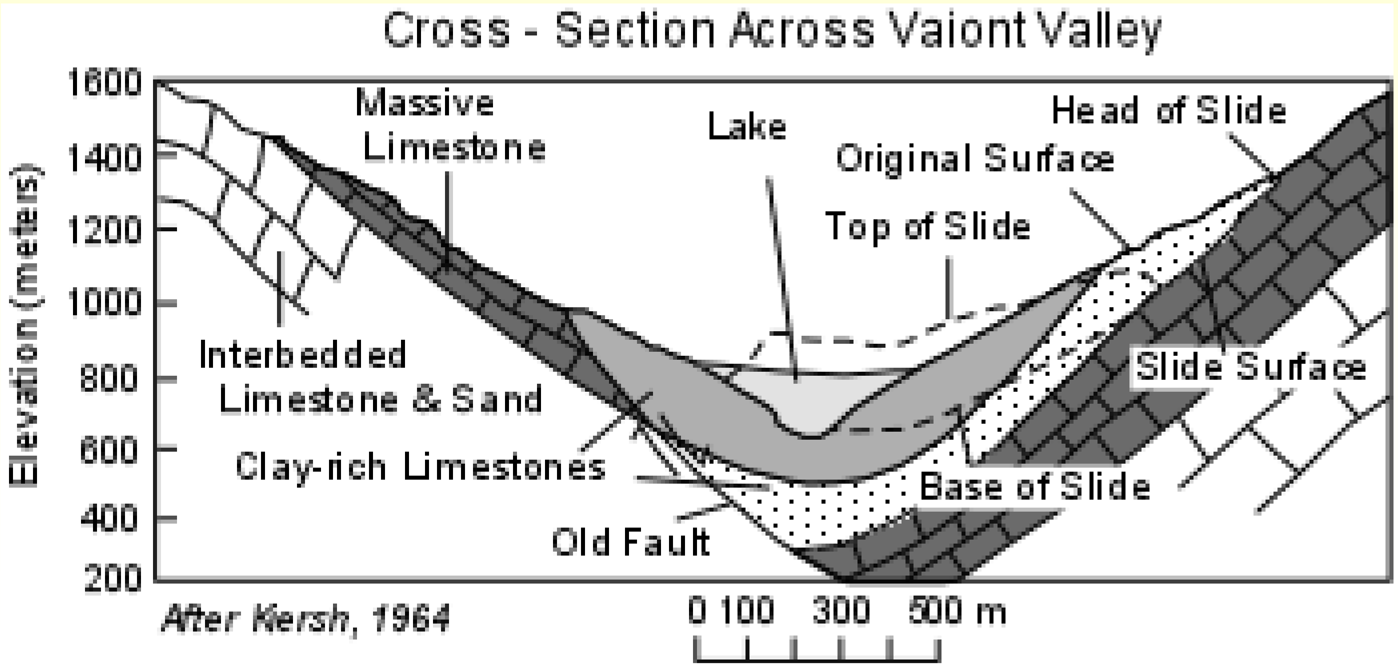
✓In 1960 a dam was built across the Vaiont Valley in northeastern Italy near the border with Austria and Slovenia.

✓ The valley runs along the bottom of a geologic structure called a syncline, wherein rocks have been folded downward and dip into the valley from both sides (see cross section).



✓ Example: Vaiont Reservoir, Italy, 1963

✓The rocks are mostly limestones, but some are interbedded with sands and clays.
✓These sand and clay layers form bedding planes that parallel the syncline structure, dipping steeply into the valley from both sides.
✓Fracture systems in the rocks run parallel to the bedding planes and perpendicular to bedding planes.
✓The latter fractures had formed as a result of glacial erosion which had relieved pressure on the rocks that had formed deeper in the Earth.



✓ **Example: Vaiont Reservoir, Italy, 1963**

✓ Some of the limestone units have caverns that have been dissolved in the rock due to chemical weathering by groundwater.

✓Furthermore, the dam site was built near an old fault system. During August and September, 1963, heavy rains drenched the area adding weight to the rocks above the dam.

✓On October 9, 1963 at 10:41 P.M. the south wall of the valley failed and slid into the reservoir behind the dam.

✓The slide mass was 1.8 km long and 1.6 km wide with a volume of 240 million m^3.

✓As the slide moved into the reservoir it displaced the water, forcing it 240 meters above the dam and into the village of Casso on the northern side of the valley.

✓Subsequent waves swept up to 100 meters above the dam. Although the dam did not fail, the water rushing over the dam swept into the villages of Longorone and T. Vaiont, killing 2,000 people.

✓ **Example: Vaiont Reservoir, Italy, 1963**

✓ Waves also swept up the reservoir where they first bounced off the northern shore, then back toward the Pineda Peninsula, and then back up the valley slamming into San Martino and killing another 1000 people.

✓The debris slide had moved along the clay layers that parallel the bedding planes in the northern wall of the valley.

✓A combination of factors was responsible for the slide.

✓First filling of the reservoir had increased fluid pressure in the pore spaces and fractures of the rock.

✓Second, the heavy rains had also increased fluid pressure and also increased the weight of the rock above the slide surface.

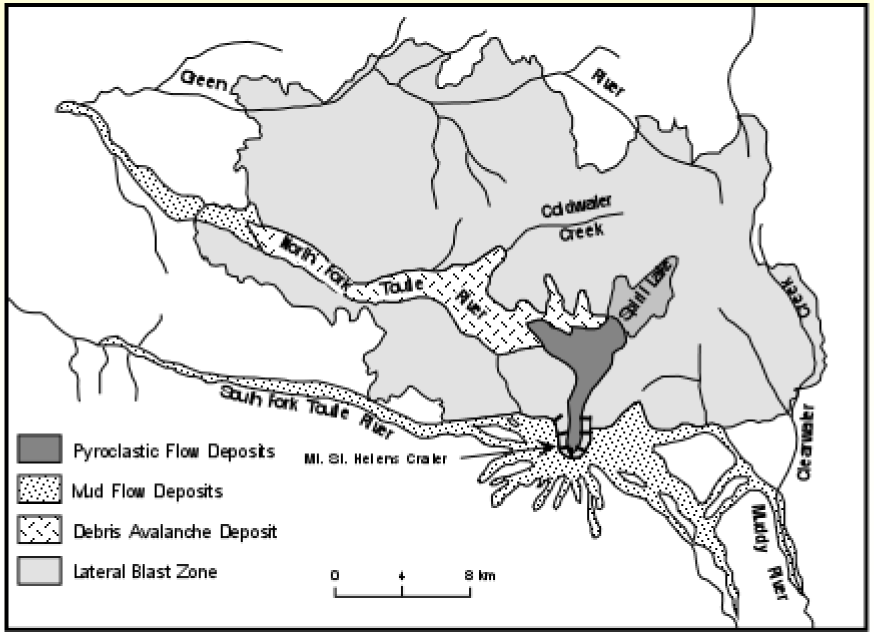
✓ After the slide event, parts of the reservoir were filled up to 250 m above the former water level, and even though the dam did not fail, it became totally useless. **This event is often referred to as the world's worst dam disaster.**

4- Volcanic Eruptions

✓ Volcanic Eruptions produce shocks like explosions and earthquakes.

✓ They can also cause snow to melt or empty crater lakes, rapidly releasing large amounts of water that can be mixed with regolith to reduce grain to grain contact and result in debris flows, mudflows, and landslides.

✓The mudflows and debris avalanche produced by the 1980 eruption of Mount St. Helens is an example



After Tilling, 1984

Landslide Analysis

✓ **Part 2 - Factors that Influence Slope Stability**

I- Introduction
II- Gravity
III- The role of Water
IV- Troublesome Earth Materials
V- Weak Materials and Structures
VI- Triggering events
- 1- Shocks
- 2- Slope Modification and Undercutting
- 3- Changes in Hydrologic Characteristics
- 4- Volcanic Eruptions

➡ VII- Assessing and Mitigating Mass-Wasting Hazards
- 1- Prediction and Hazard Assessment
- 2- Prevention and Mitigation

VII- Assessing and Mitigating Mass-Wasting Hazards

➢ As we have seen mass-wasting events can be extremely hazardous and result in extensive loss of life and property.

➢ But, in most cases, areas that are prone to such hazards can be recognized with some geologic knowledge, slopes can be stabilized or avoided, and warning systems can be put in place that can minimize such hazards.

1- Prediction and Hazard Assessment

✓ Because there is usually evidence in the form of distinctive deposits and geologic structures left by recent mass wasting events, it is possible, if resources are available, to construct maps of all areas prone to possible mass-wasting hazards.

✓Planners can use such hazards maps to make decisions about land use policies in such areas or, as will be discussed below, steps can be taken to stabilize slopes to attempt to prevent a disaster.

…BUT…

…BUT…

✓Short-term prediction of mass-wasting events is somewhat more problematical.

✓For earthquake triggered events, the same problems that are inherent in earthquake prediction are present.

✓Slope destabilization and undercutting triggered events require the constant attention of those undertaking or observing the slopes, many of whom are not educated in the problems inherent in such processes.

✓Mass-wasting hazards from volcanic eruptions can be predicted with the same degree of certainty that volcanic eruptions can be predicted, but again, the threat has to be realized and warnings need to be heeded.

✓Hydrologic conditions such as heavy precipitation can be forecast with some certainty, and warnings can be issued to areas that might be susceptible to mass-wasting processes caused by such conditions.

✓Still, it is difficult to know exactly which hill slope of the millions that exist will be vulnerable to an event triggered by heavy rainfall.

2- Prevention and Mitigation

✓ **All slopes** are susceptible to mass-wasting hazards if a triggering event occurs.

✓Thus, all slopes should be assessed for potential mass-wasting hazards.

✓Mass-wasting events can sometimes be avoided by employing engineering techniques to make the slope more stable.

- Steep slopes can be covered or sprayed with concrete covered with a wire mesh to prevent rock falls.

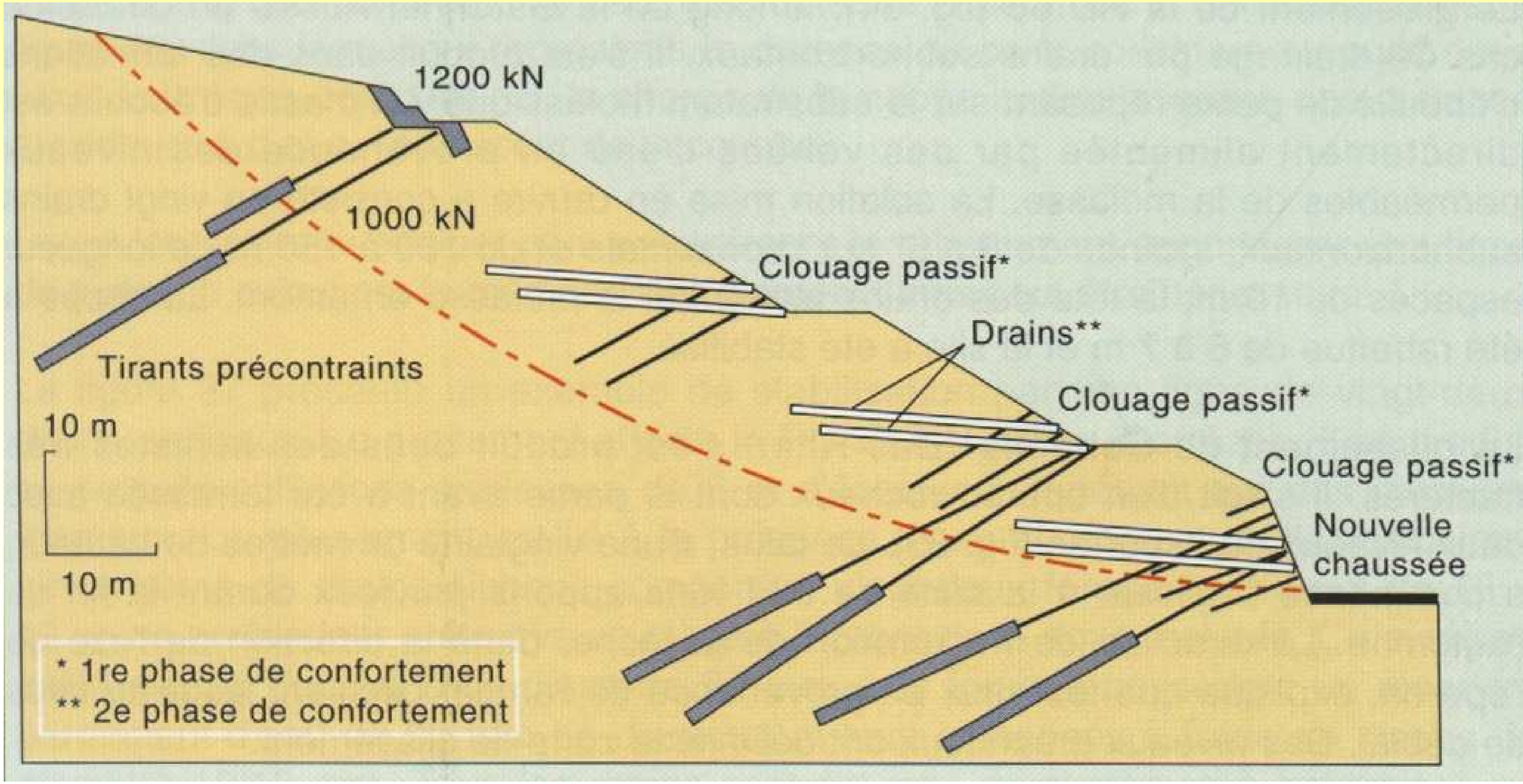
- Retaining walls could be built to stabilize a slope.

▪ If the slope is made of highly fractured rock, rock bolts may be emplaced to hold the slope together and prevent failure.

▪ Some slopes, however, cannot be stabilized. In these cases we can use wire nettings

…or block traps

▪ Drainage pipes could be inserted into the slope to more easily allow water to get out and avoid increases in fluid pressure, the possibility of liquefaction, or increased weight due to the addition of water.



▪ Other possibilities:

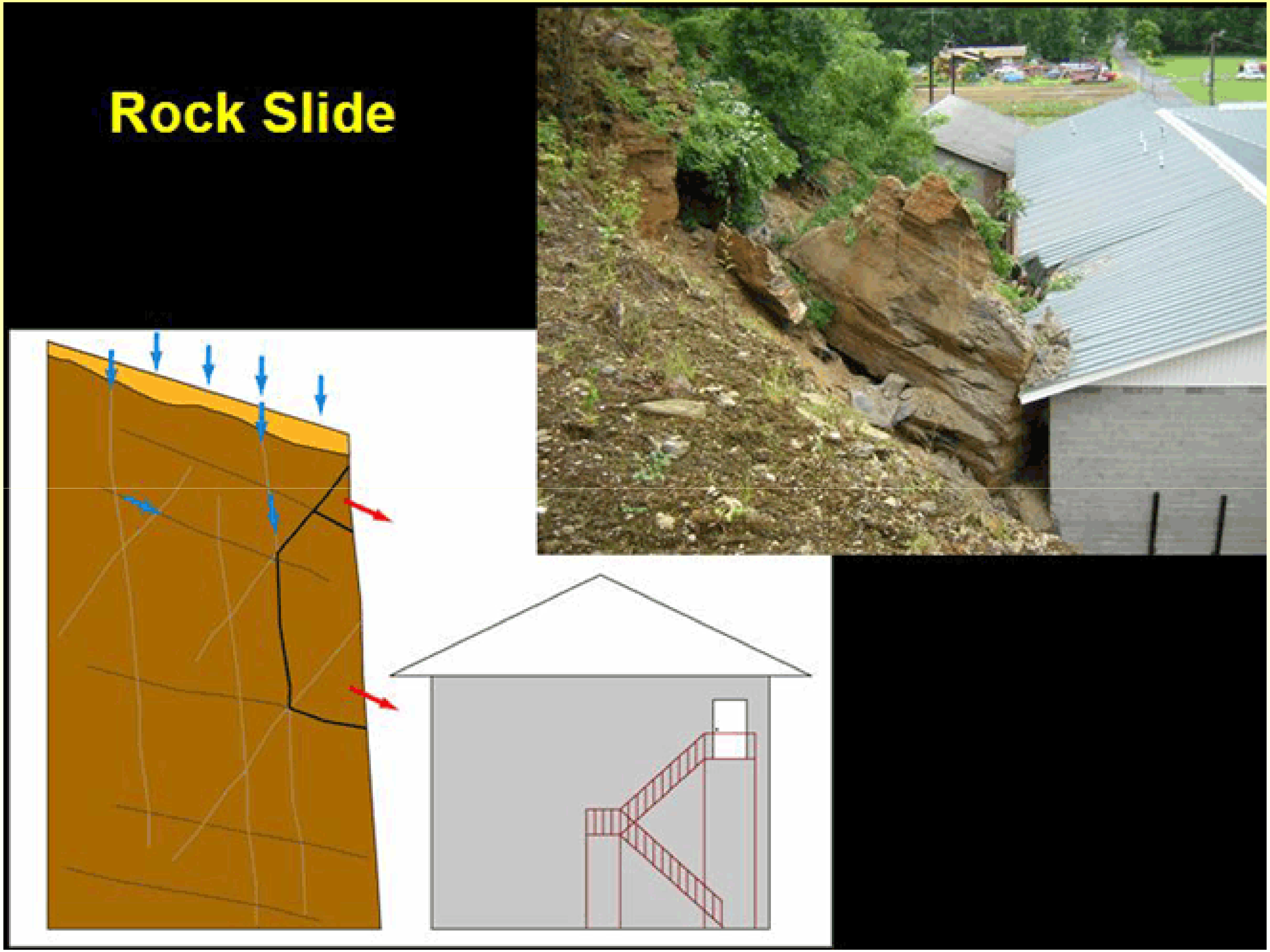
▪Oversteepened slopes could be graded to reduce the slope to the natural angle of repose.

▪ In mountain valleys subject to mudflows, plans could be made to rapidly lower levels of water in human-made reservoirs to catch and trap the mudflows.

▪ **Where nothing can be done, humans should avoid these areas or use them for purposes that will not increase susceptibility of lives or property to mass-wasting hazards.**

A lot of works is still to be done…

Rock Slide



Fire Station

Broad River FD - Buncombe County

Tropical Storm Cindy - July 6-7,2005