Environmental Geology Lab 5 - Mass Wasting Hazards

Many landslides, slope failures or sinkholes (collapse structures formed in terrain underlain by limestone rocks) occur during or immediately after periods of heavy rain. It is commonly thought that the infiltration "lubricates" the soil or rock and hence weakens it. This is actually very rare because, with the exception of some swelling clays, the shear strength of most geologic materials does not change appreciably with moisture content. Some of the ways in which groundwater can contribute to these types of hazards are described below:

1. Water pressure.

Water pressure reduces the effective stress (and hence the frictional resistance to movement) between particles in the soil, or along fracture or fault surfaces due to the buoyant effect of the water. During or after a heavy rain the water table rises which further increases the buoyant effects, while adding to the total weight of material above the failure surface. If this change exceeds the shear strength of the soil or rock movement along the failure surface will occur (Figures 1a and 1b). Groundwater pressure has a similar effect along major faults and is a contributing factor in the occurrence of earthquakes. Another example of its influence on slope stability is illustrated in Figure 1c, where infiltration fills up a tension crack at the top of the slope. The water pressure in the slope tends to push the block of soil or rock outwards. This type of movement can be repeated over and over with the block moving a little further during each rainstorm until, finally, it topples over. One of the most effective ways to increase the strength of a soil or rock slope is to install drainage wells or conduits to lower the water table and prevent a build-up of pressure in tension cracks.

2. Erosion.

Groundwater discharging from springs along a slope can cause erosion of soils at the base of a steep slope, undermining the overlying soil or rock. Another important effect of erosion is the role it plays in the development of *sinkholes* which are collapse structures that can develop, sometimes in a matter of a few hours, in carbonate rocks. A typical sinkhole forms due to groundwater erosion of the residual soils overlying a karstic limestone. As shown in Figure 2, the soil is eroded from the bottom by groundwater flowing into a karst conduit. A cavity in the soil can form over a period of years and then gradually or suddenly the ground surface may collapse. This is a common phenomenon in the eastern United States (including central Texas) and numerous sinkholes can be observed as circular depressions in aerial photographs or topographic maps.

In the Laredo area the surface geology consists of the Laredo Formation (see lab #3, Figure 1), which consists of sandstone and shale. In the San Antonio area the bedrock consists of the limestone (Edwards Formation).

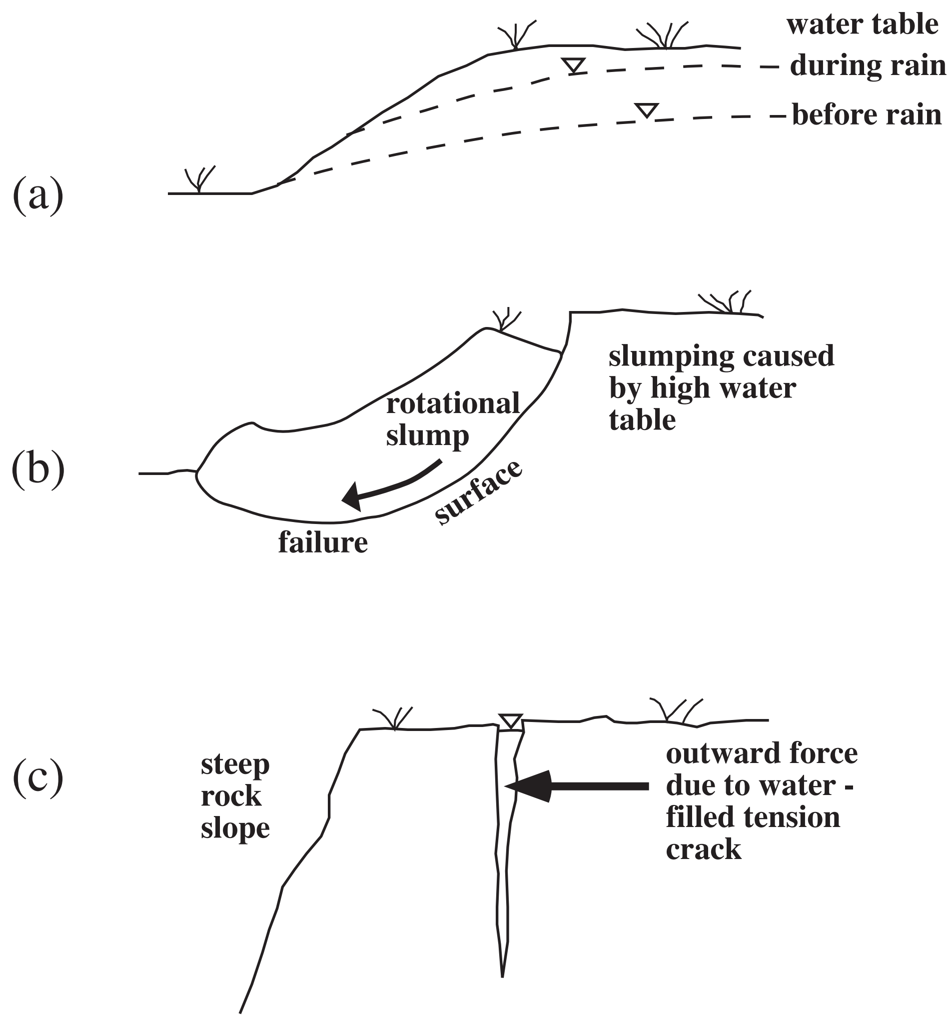

Figure 1. Sketches illustrating slope failure due to increased water pressure: **(a)** rising water table before slope failure; **(b)** slope failure in soils; **(c)** rock slope instability due to water pressure in tension crack.

3. Freezing.

In areas experiencing seasonal freeze-thaw cycles, groundwater discharging from a steep slope can freeze in the fractures in the rock. During freezing the water expands and can pry open the fractures. Also, freezing at the surface of the slope can block the outlets for natural drainage and cause the water table to rise, which can then reduce the slope stability as described above. Freezing is a common cause of small-scale slope failures along railway or highway cuts. Look for ice build-ups on rock slopes the next time you drive through the mountains during the winter!

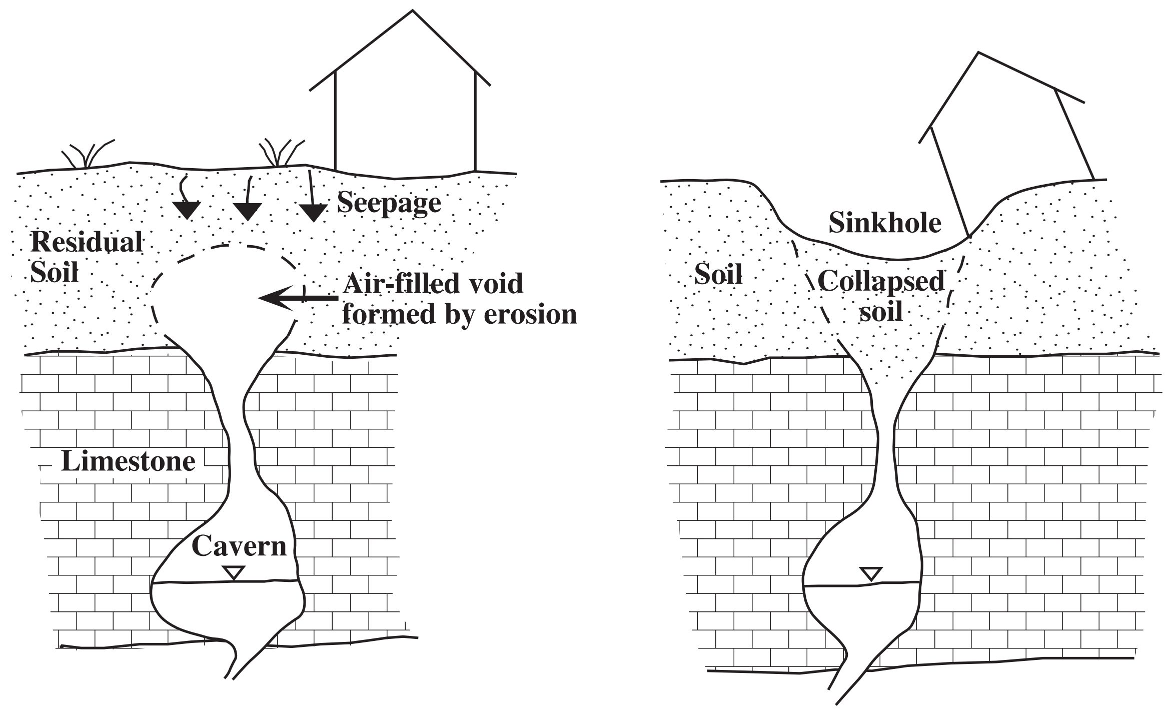

Figure 2 a. Formation of a typical sinkhole which **b.** broaches the surface.

4. Liquefaction.

Loose, fine-grained, saturated sands and silts can be subject to a phenomenon referred to as *liquefaction*. If these materials are subjected to sudden vibrations, usually caused by seismic activities, the structure of the soil collapses and, if saturated, it essentially becomes a fluid. This is a major factor in the settlement, and sometimes toppling, of buildings or other structures in soft deltaic or fill deposits (example: extensive damage in the San Francisco Bay area during the October 1989 earthquake). Poorly constructed earth-fill dams or piles of fine-grained wastes from mining activities are especially sensitive to liquefaction. One classic example is the failure of the Barahona dam in Chile in the early 1900's. The dam was built of loose, silt-sized material, enclosed an impoundment of tailings from a copper mine, and it failed during an earthquake, with the fluidized sand and silt flowing for tens of miles down the steep valley and destroying everything in its path.

QUESTIONS

1. What measures involving groundwater might you recommend to stabilize a mountain slope that is adjacent to a busy major highway.

2. Describe how a sinkhole forms and in describe how a landscape consisting of sinkholes appears on a map? In google search for satellite images of sinkholes.

3. Would you expect sinkholes in the Laredo area? What about around San Antonio? Explain your answer. Hint: think about the differences in the geology that underlie both of these cities. Hint: What type of bedrock is present in Laredo versus San Antonio?

4. Examine Mamamoth Cave map in the front of the class. What type of contour lines indicate the depressions formed by the sinkholes on this map. Draw it. Hint: look at the numbers of the index contour lines that indicate elevation. Do they increase or decrease toward the center of this feature.

5. What specific type of weather conditions will maximize mass wasting associated with freezing?

6. Discuss the connection between liquefaction and seismic activity. Is the danger from liquefaction greater on solid bedrock or soft muddy sediments. Explain.

The factors that influence slope stability and the susceptibility to mass wasting are numerous.

1. Angle of Slope Material
2. Seismic Activity
3. Mass Present on Slope
4. Type of Slope Material
5. Moisture Content within Slope
6. Presence of Vegetation

Factors 1 to 3 have a straightforward relationship with slope stability. Steeper slopes, slopes with seismic activity, and slope with great masses sitting on them tend to be less stable. Factors 4 and 5 have a more complex relationship with slope stability as shown in Figure 3.

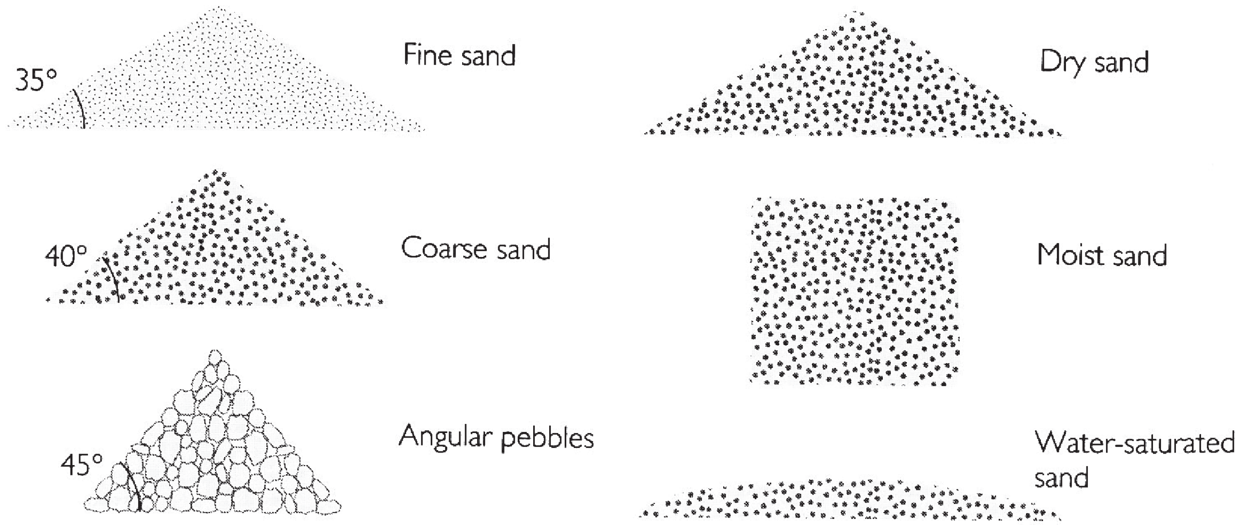

Figure 3. Relationship between material type and moisture content on angle of repose. Materials on the left side of the figure represent dry conditions.

The angle of repose is the highest angle that a stable slope can exist at. Typically, gravel has a steep angle of repose than sand. Clay/silt generally has a low angle of repose indicating that slopes consisting of this material tend to be unstable. Bedrock generally forms the most stable slopes with in some cases an angle of repose of 90° (*i.e.* a cliff). Moisture content affect the stability of sandy slopes in a complex manner. Dry sand has an angle of repose of (30 to 40°) depending on exact size. However, slightly moist sands form exceptional stable slopes as testified by the ability to use slightly moisture sand to build sand castles, which have an angle of repose of 90°. Completely saturated sands have little stability and can undergo the process of *liquefaction* becoming quicksand.

The presence of vegetation also has a complex influence on slope stability. The roots of vegetation tend to hold the soil together promoting soil stability. Conversely, vegetation adds mass to the slope decreasing slope stability. However, in most places the overall affect of vegetation is to in general enhance slope stability.

Answer the following true/false questions that test your knowledge about how the above factors can influence slope stability.

7. Stepper slopes are more stable? True False

8. Seismic activity increases slope stability? True False

9. The less the mass sitting on the slope the greater the slope stability? True False

10. Fine sand can forms a stepper slopes than coarse sand? True False

11. Slightly moist sand has the lowest angle of repose? True False

QUESTIONS

12. Describe three ways in which building a subdivision on a hillside can decrease slope stability. Hint: Think about the factors that control slope stability as listed on the bottom of pg. 4.

13. A hilly region experiences a prolonged drought and all the vegetation dies. Is this region now more susceptible to mass wasting especially if there is then a heavy rainfall event that follows the drought?

14. Based on a review of the slope stability factor discussed above, which combination of factor will results in greatest slope stability if the hillside consists of sand? Circle the correct answer

Angle of Slope Material	Greater	or	Less
Mass Present on Slope	Greater	or	Less
Moisture Content within Slope	Low	Moderate	Saturated

15. Which combination of factor will results in least slope stability? Circle the correct answer.

Angle of Slope Material	Greater	or	Less
Mass Present on Slope	Greater	or	Less
Moisture Content within Slope	Low	Moderate	Saturated

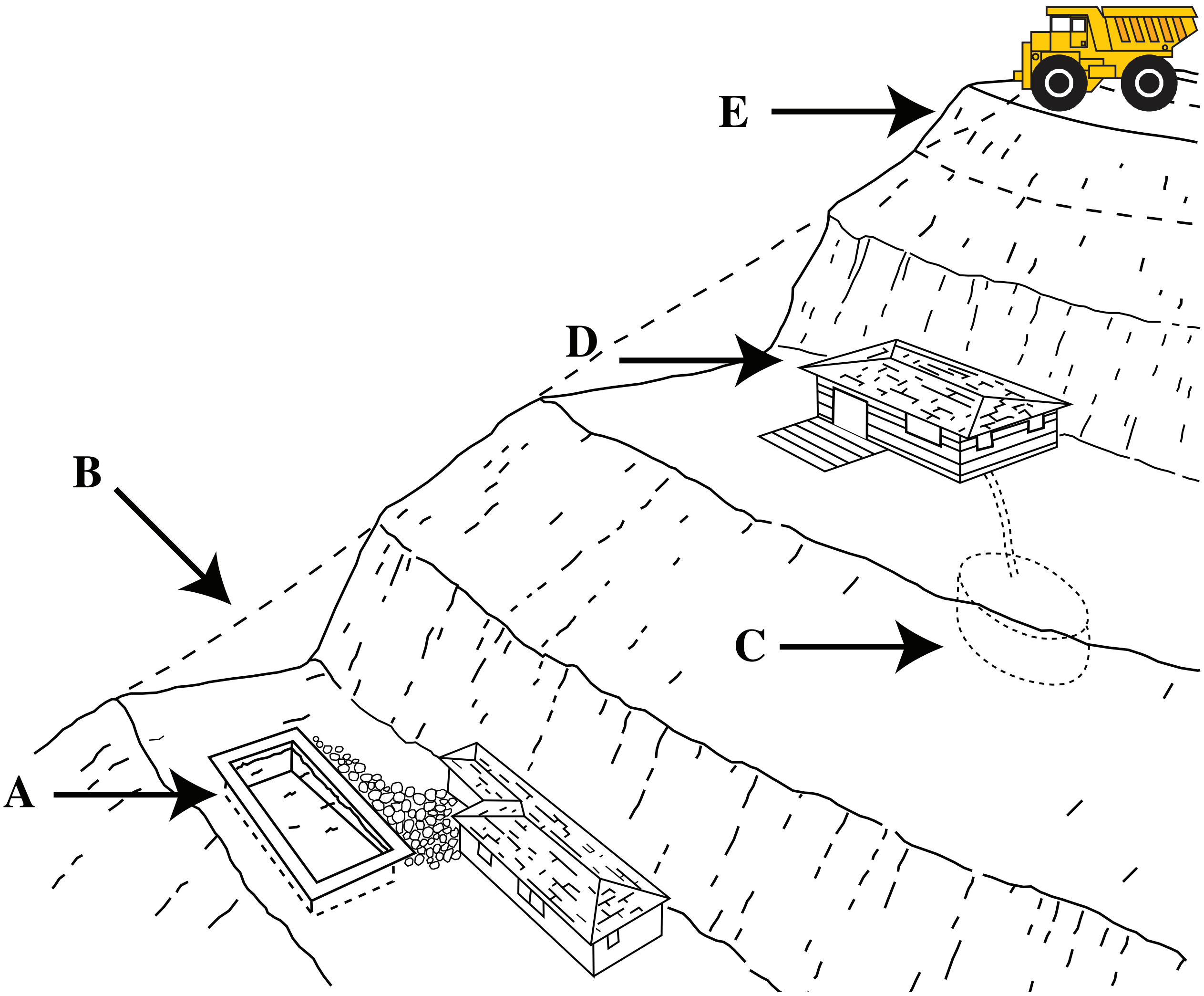

Figure 4. What is wrong with this picture?

16. Examine Figure 4 and how human modifications have decreased the stability of this slope. Your answers should focus on **slope angle**, **mass present on slope**, and/or **moisture content**. There can be more then one answer for a letter.

A. ____

B. ____

C. ____

D. ____

E. ____

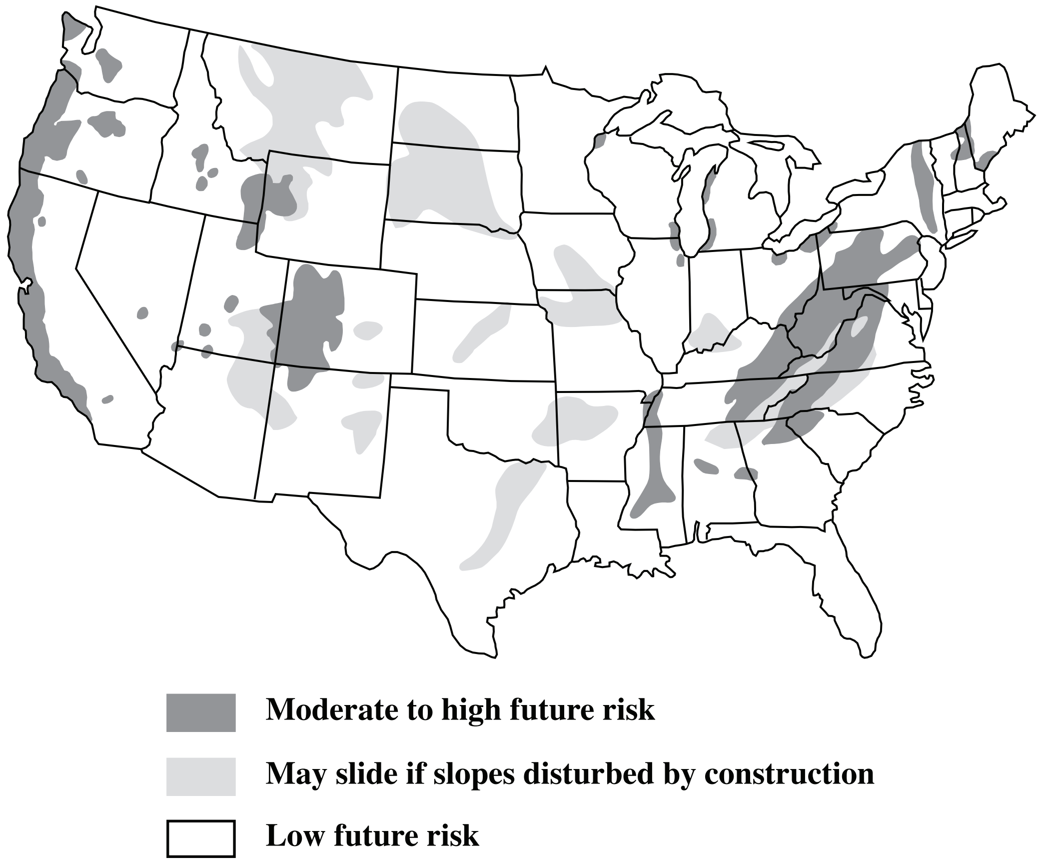

Figure 5. US Mass Wasting Risk.

Answer the following questions based on an examination Figure 5.

QUESTIONS

17. Name three states west of Texas have a moderate-to-high risk of future mass wasting?

18. Which slope stability factor (from the bottom of page 4) that is unique to the coastal Pacific region contributes to the moderate-to-high risk in this region? Hint: is this a seismical active region?

19. Why is there a higher susceptibility to mass wasting in central Texas compared to the rest of the state? Hint: Examine the limestone sample in front of the classroom.

20. Explain why Texas does not have a moderate to high future risk of mass wasting unlike other regions in the country.

SPECIFIC MASS WASTING RISKS

Mass wasting processes operate at a wide range of rates, from imperceptibly slow to hazardously fast. The different types discussed below are listed in approximate order of speed, starting with the slowest one.

Types of Mass Wasting

Soil Creep

This is grain-by-grain movement of loose material on a slope. As soil expands due to freezing or getting wet, it expands outward from the slope surface. As it shrinks due to thawing or drying out, it settles directly downward due to the pull of gravity. Each outward-downward cycle produces very small movement of the particles downhill, but with this cycle repeated up to hundreds of times each year, this slowly works soil downslope, and is significant over time. It often moves at rates of millimeters per year.

Slump

This slope movement is characterized by downward and outward movement of a portion of a hillside. The part that moves usually slips on a curved surface within the soil. It often resembles a shovel-shaped scoop of material. It generally moves at rates of centimeters per hour.

Mud or Debris Flow

It is a mass of unconsolidated soil and clay (mud flow) or with coarser particles mixed in (debris flow), saturated with water, and moving as a slurry. Many of these resemble a milkshake or pouring wet cement as they move. They typically move a few kilometers per hour.

Rockslide
A large mass of bedrock detaches from the rock below, often along joints or bedding planes, and slides downhill. These bodies often move more or less as a unit, can be extremely large (whole mountainsides) and often move at rates of many kilometers per hour.

Rock or Debris Fall
This type of slope movement consists mainly of blocks of bedrock (rock fall) or of unconsolidated rock and sediment (debris fall). It will freefall from a cliff or steep slope. As with any falling object, it moves under the acceleration of gravity (9.8 meters per second per second), so watch out below!

Debris or Rock Avalanche
This type of movement is similar to snow avalanches, where large masses of material break loose and travel swiftly downhill mixed with and cushioned by air. This air cushion allows them to travel quite fast, up to hundreds of kilometers per hour. Such mass movements can be triggered by earthquakes.

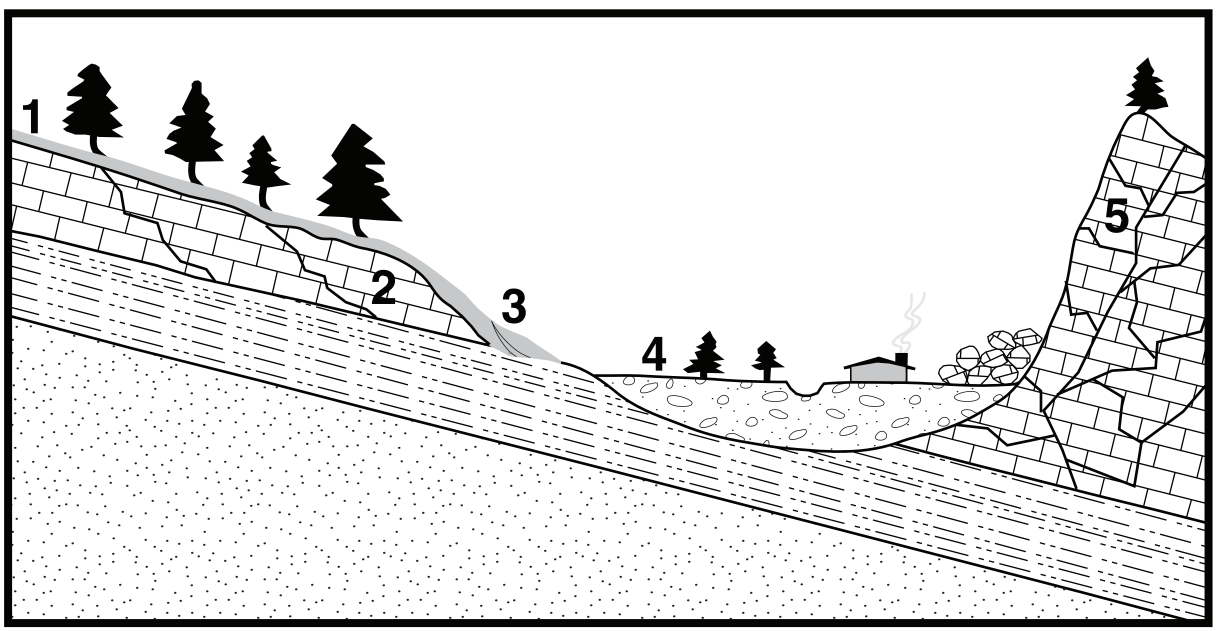

Figure 6. Find the different types of mass wasting. Dot pattern indicates sandstone bedrock. Line pattern indicates shale bedrock. Block pattern indicates limestone bedrock. Gray overburden is soil. Fill with round blocks under the cabin was producted by a debris flow.

Examine the sandstone and shale samples provided at the front of the classroom. Some sample identification will be included on the next lab quiz.

QUESTIONS

21. Figure 6 includes five of the six potential types of mass wasting described above. Identify them.

1 ______________________ 2 _________________________

3 ______________________ 4 _________________________

5 _________________________

22. Besides the danger of mass wasting, what other major of geohazards may affect the cabin in Figure 6. Hint: the cabin was surveyed to be within the 100-year flood zone.

23. Rank the mass wasting types in order from slowest to fastest.

24. Examine the cabin in Figure 6. Your good friend has the opportunity to purchase this riverside land in a beautiful canyon at a real good price with a log cabin on the site. Knowing some geology, would you advise her to buy this cabin or not? Explain if this deal would be a good investiment for your friend.