Landslide Evidence of Weathering and Erosion

An Educational Activity to Support Next Generation Science Standard 4-ESS2-1

4-ESS2-1 – Make observations and/or measurements to provide evidence of the effects of weathering or the rate of erosion by water, ice, wind, or vegetation.

Angela Chandler
Arkansas Geological Survey

2017

Bekki White
Director and State Geologist

STATE OF ARKANSAS
Asa Hutchinson, Governor

Arkansas Geological Survey
Bekki White, State Geologist and Director

COMMISSIONERS

Little Rock, Arkansas
2017

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Introduction

Landslides create problems for those traveling roadways in the state. They also disrupt multi-use trail systems throughout the state. In 2016 and 2017, landslides caused 8 and 16 million dollars, respectively, in damage to our roads (AHTD personal communication). That is not taking into consideration the manpower and tools used to reconstruct trails in State and Federal Parks and National Forests. Landslides shape the landscape around us, therefore, students need to be aware of the effects of weathering and erosion.

Use the following information to determine which types of landslides are present in Arkansas: Background Information, Landslide Factsheet from the U.S. Geological Survey, charts, and data in each Landslide Exercise. All of these landslides are on public land, either a State Park or road side, providing easy access for fieldtrips. If you would like to set up a fieldtrip please contact Angela Chandler using the information provided below.

It would be helpful for the students to have samples of sandstone and shale to compare. It might be possible to collect samples near your location. If that is not an option, contact the Arkansas Geological Survey to have samples sent to your school. You can also go to your nearest Science Specialist or Education Cooperative and ask them to loan their Teacher Rock and Mineral Kit from the Arkansas Geological Survey.

Contact Angela Chandler at angela.chandler@arkansas.gov or 501-683-0111 for more information regarding rock samples or fieldtrips. Comments and suggestions are also welcome!

The two main rock types in Arkansas that are most likely to cause landslides and rock falls are shale and sandstone, respectively. Definitions of these rocks are provided below:

Sandstone – a clastic or detrital sedimentary rock composed of rounded to angular fragments of sand size material cemented by iron-oxide, silica (quartz), or calcium carbonate (calcite). The sand particles commonly consist of quartz.

> Quartz has a hardness of 7 on Moh's hardness scale and is non-reactive to chemicals. Therefore, sandstone is generally a harder rock that is relatively resistant to weathering and erosion compared to shale.

Shale – a clastic or detrital sedimentary rock formed by the consolidation of clay or mud size material. It is characterized by thin layers and is generally less durable than sandstone.

> Shale is susceptible to sliding due to its lack of durability and ability to retain water. Once it becomes saturated with water it will slide along its bedding planes or allow heavier rocks above it to slide.

Background Information

Physical and Geological Causes for Landslides in Arkansas

For a complete list of landslide causes, refer to the Landslide Causes and Triggering Mechanisms charts on page 17.

The main Physical Causes and Triggers in Arkansas are:

- intense or prolonged rainfall and flooding
- freeze-and-thaw weathering
- shrink-and-swell weathering

Freeze-and-thaw weathering develops after water continually seeps into cracks in the rock, freezes, expands, and eventually breaks the rock apart.

Shrink-and-swell weathering results after water binds with the molecular structure of a clay causing it to expand. When the water is released and the clay dries, it shrinks. This happens most in climates that have a distinct wet and dry season. Shale is composed of clay particles, therefore, when shale is at or near the ground surface and becomes saturated with water, it can slide.

The main Geological Causes are:

- susceptible and weathered material
- jointed/fractured material
- adversely oriented structural discontinuity
- contrast in stiffness – stiff dense material over plastic material

Susceptible and weathered material – those materials that are prone to landslides due to shrink-and-swell or freeze-and-thaw weathering. Clay and shale are more prone to shrink-and-swell weathering while sandstone is prone to freeze-and-thaw weathering.

Jointed/fractured materials – Joint is a geological term for a set of fractures having certain orientation and spacing. They are common features in most rocks. Rocks that contain a well-developed joint system are considered highly weathered. The joints and fractures create pathways for water to percolate down and into the rock. In sandstone, the cement that holds the grains of quartz together can be dissolved, causing the grains to fall apart and weather away. This process can enlarge the fractures, and eventually cause large blocks to break away or topple off a bluff.

Adversely oriented discontinuity - This relates to the bedding within the rock and/or if the landslide is located on a fault. In certain areas of the state, rock layers are not flat lying. Instead, they are inclined or dipping. This causes steep sided outcrops where the rock becomes more susceptible to sliding.

A fault is a zone of weakness within a rock where the rock is broken. There can be a highly weathered zone around the fault that contains clay or other weak materials. This zone is usually more susceptible to slides.

Contrast in stiffness – stiff dense materials over plastic materials.

Stiffness refers to the consistency a material, usually soil, which is made up of silt and clay. It measures how easily the material can be molded, indented, and excavated. A very stiff soil can only be indented by a thumbnail. If a material cannot be indented and is difficult to excavate, it is referred to as hard. Plastic materials are materials that change their shape or deform due to applied weight or other forces. Therefore, when a load, or weight overlying the material, causes the material to behave in an elastic manner, the material can fail. The material may fail by sliding, falling, or breaking apart.

Often bluffs are held up by hard dense material like sandstone that is relatively resistant to weathering and erosion. These bluffs are commonly underlain by plastic material such as shale, a material susceptible to deforming under the heavier weight of the sandstone. This may lead to undercutting or sliding of the stronger material on the underlying weaker material.

Directions for the Activities

Read each landslide case study and look at the photos paying attention to the type and size of the material. Relative terms may be used to describe the size, such as large or small pieces, or terms such as boulder, pebble, sand, silt and clay. A grain size chart using these terms is provided. Objects in the photographs, such as people and trees, can also be used for comparison. You can even use adjectives such as car- or house-sized blocks. If you are able to visit the sites in the field, then rulers or measuring tape can be used to measure the material.

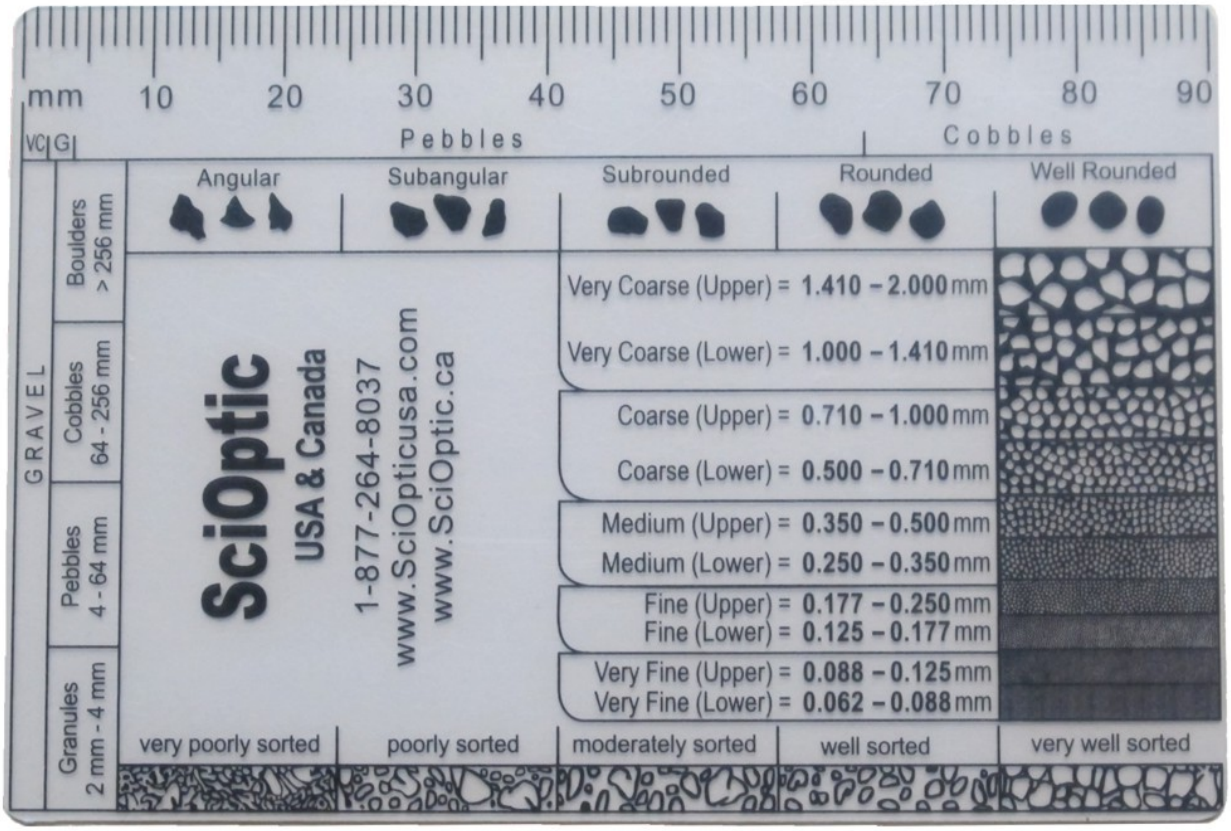
This is a good opportunity to add in a small amount of topographic map reading skills by looking at the steepness of the slope on a topographic map. A map was not provided for each of the activities, however, if you wish to use one, use the contact information at the beginning of the activity to request one. Again, use a relative term for steepness, such as gentle slope, fairly steep, or steep. Other terms can be used to describe the slope such as steep river bank or vertical bluff. The landform can also be described as a mountain or hillside. Try to engage the students by creating a mental image of the environment.

This is a good time to look at two abundant rock types in the State of Arkansas: sandstone and shale. Provide samples of the rock types and discuss their properties.

Discuss physical and geological causes and triggers of landslides with the students. Use the charts in this booklet to determine what they might be and determine the type of landslide.

Answers are provided at the end of this booklet.

A grain size chart is provided on the next page. This can be cut out and used in the field.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VC G
Pebbles
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GRAVEL
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Cobbles 64 - 256 mm
Pebbles 4 - 64 mm
Granules 2 mm - 4 mm
Angular
Subangular
Subrounded
Rounded
Well Rounded
SciOptic
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Very Coarse (Upper) = 1.410 – 2.000 mm
Very Coarse (Lower) = 1.000 – 1.410 mm
Coarse (Upper) = 0.710 – 1.000 mm
Coarse (Lower) = 0.500 – 0.710 mm
Medium (Upper) = 0.350 – 0.500 mm
Medium (Lower) = 0.250 – 0.350 mm
Fine (Upper) = 0.177 – 0.250 mm
Fine (Lower) = 0.125 – 0.177 mm
Very Fine (Upper) = 0.088 – 0.125 mm
Very Fine (Lower) = 0.062 – 0.088 mm
very poorly sorted
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moderately sorted
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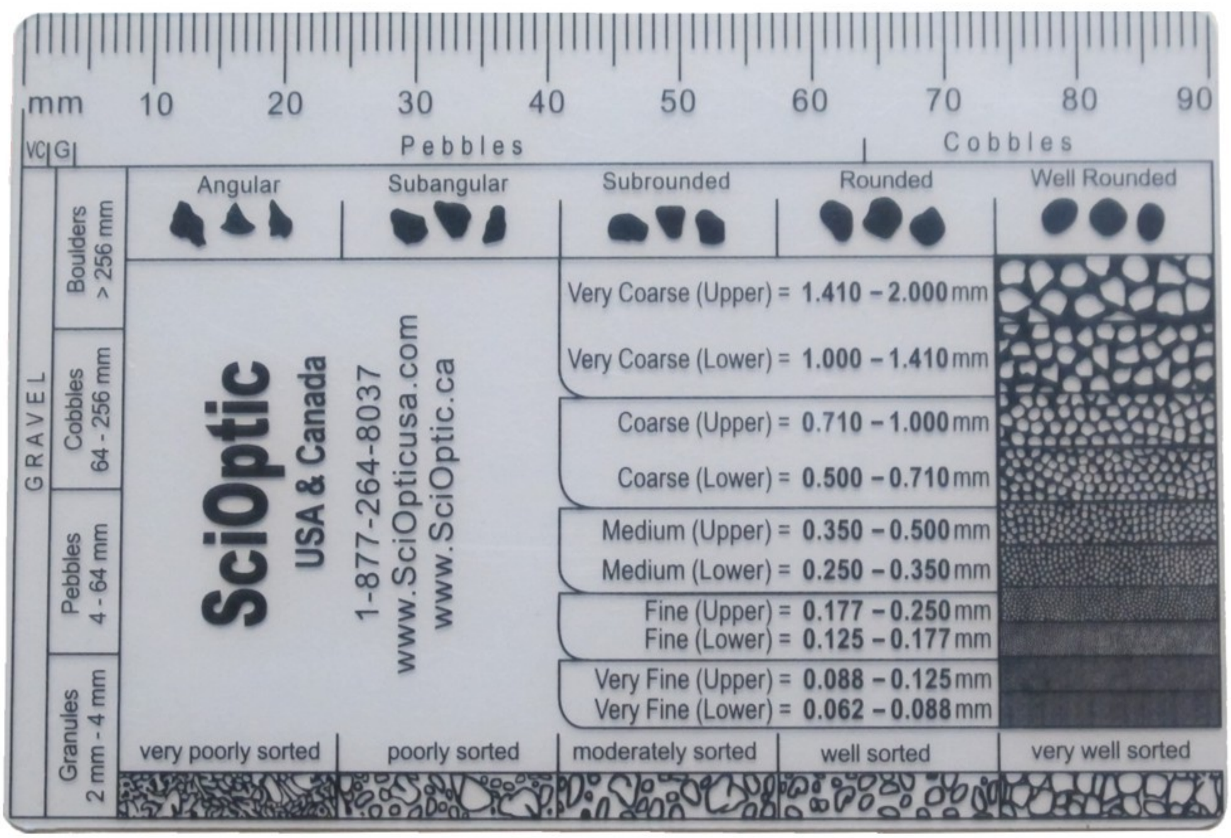
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Landslide Types and Processes

Landslides in the United States occur in all 50 States. The primary regions of landslide occurrence and potential are the coastal and mountainous areas of California, Oregon, and Washington, the States comprising the intermountain west, and the mountainous and hilly regions of the Eastern United States. Alaska and Hawaii also experience all types of landslides.

Landslides in the United States cause approximately $3.5 billion (year 2001 dollars) in damage, and kill between 25 and 50 people annually. Casualties in the United States are primarily caused by rockfalls, rock slides, and debris flows. Worldwide, landslides occur and cause thousands of casualties and billions in monetary losses annually.

The information in this publication provides an introductory primer on understanding basic scientific facts about landslides—the different types of landslides, how they are initiated, and some basic information about how they can begin to be managed as a hazard.

La Conchita, coastal area of southern California. This landslide and earthflow occurred in the spring of 1995. People were evacuated and the houses nearest the slide were completely destroyed. This is a typical type of landslide. *Photo by R.L. Schuster, U.S. Geological Survey.*

TYPES OF LANDSLIDES

The term "landslide" describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing. Figure 1 shows a graphic illustration of a landslide, with the commonly accepted terminology describing its features.

The various types of landslides can be differentiated by the kinds of material involved and the mode of movement. A classification system based on these parameters is shown in figure 2. Other classification systems incorporate additional variables, such as the rate of movement and the water, air, or ice content of the landslide material.

Although landslides are primarily associated with mountainous regions, they can also occur in areas of generally low relief. In low-relief areas, landslides occur as cut-and-fill failures (roadway and building excavations), river bluff failures, lateral spreading landslides, collapse of mine-waste piles (especially coal), and a wide variety of slope failures associated with quarries and open-pit mines. The most common types of landslides are described as follows and are illustrated in figure 3.

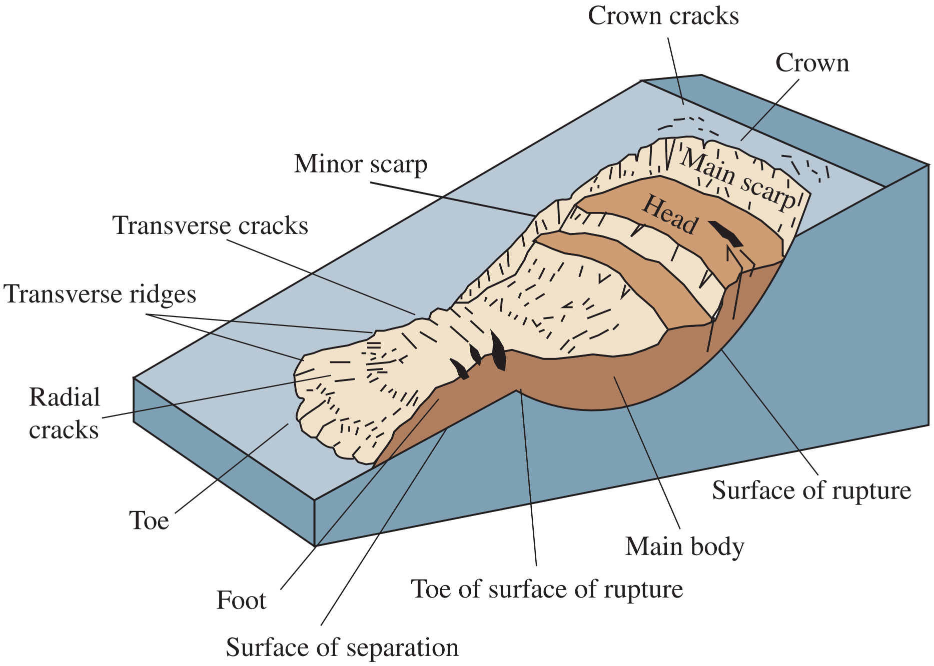

Figure 1. An idealized slump-earth flow showing commonly used nomenclature for labeling the parts of a landslide.

SLIDES: Although many types of mass movements are included in the general term "landslide," the more restrictive use of the term refers only to mass movements, where there is a distinct zone of weakness that separates the slide material from more stable underlying material. The two major types of slides are rotational slides and translational slides.

Rotational slide: This is a slide in which the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface and transverse across the slide (fig. 3A).

Translational slide: In this type of slide, the landslide mass moves along a roughly planar surface with little rotation or backward tilting (fig. 3B). A *block slide* is a translational slide in which the moving mass consists of a single unit or a few closely related units that move downslope as a relatively coherent mass (fig. 3C).

FALLS: Falls are abrupt movements of masses of geologic materials, such as rocks and boulders, that become detached from steep slopes or cliffs (fig. 3D).

TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOILS	
			Predominantly coarse	Predominantly fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Rock flow (deep creep)	Debris flow	Earth flow
			(soil creep)	
COMPLEX		Combination of two or more principal types of movement		

Figure 2. Types of landslides. Abbreviated version of Varnes' classification of slope movements (Varnes, 1978).

Separation occurs along discontinuities such as fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water.

TOPPLES: Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks (fig. 3E).

FLOWS: There are five basic categories of flows that differ from one another in fundamental ways.
a. Debris flow: A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope (fig. 3F). Debris flows include <50% fines. Debris flows are commonly caused by intense surface-water flow, due to heavy precipitation or rapid snowmelt, that erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt- and sand-sized material. Debris-flow source areas are often associated with steep gullies, and debris-flow deposits are usually indicated by the presence of debris fans at the mouths of gullies. Fires that denude slopes of vegetation intensify the susceptibility of slopes to debris flows.
b. Debris avalanche: This is a variety of very rapid to extremely rapid debris flow (fig. 3G).
c. Earthflow: Earthflows have a characteristic "hourglass" shape (fig. 3H). The slope material liquefies and runs out, forming a bowl or depression at the head. The flow itself is elongate and usually occurs in fine-grained materials or clay-bearing rocks on moderate slopes and under saturated conditions. However, dry flows of granular material are also possible.
d. Mudflow: A mudflow is an earthflow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand-, silt-, and clay-sized particles. In some instances, for example in many newspaper reports, mudflows and debris flows are commonly referred to as "mudslides."
e. Creep: Creep is the imperceptibly slow, steady, downward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation, but too small to produce shear failure. There are generally three types of creep: (1) seasonal, where movement is within the depth of soil affected by seasonal changes in soil moisture and soil temperature; (2) continuous, where shear stress continuously exceeds the strength of the material; and (3) progressive, where slopes are reaching the point of failure as other types of mass movements. Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small soil ripples or ridges (fig. 3I).

LATERAL SPREADS: Lateral spreads are distinctive because they usually occur on very gentle slopes or flat terrain (fig. 3J). The dominant mode of movement is lateral extension accompanied by shear or tensile fractures. The failure is caused by liquefaction, the process whereby saturated, loose, cohesionless sediments (usually sands and silts) are transformed from a solid into a liquefied state. Failure is usually triggered by rapid ground motion, such as that experienced during an earthquake, but can also be artificially induced. When coherent material, either bedrock or soil, rests on materials that liquefy, the upper units may undergo fracturing and extension and may then subside, translate, rotate, disintegrate, or liquefy and flow. Lateral spreading in fine-grained materials on shallow slopes is usually progressive. The failure starts suddenly in a small area and spreads rapidly. Often the initial failure is a slump, but in some materials movement occurs for no apparent reason. Combination of two or more of the above types is known as a complex landslide.

LANDSLIDE CAUSES

1. Geological causes
   - a. Weak or sensitive materials
   - b. Weathered materials
   - c. Sheared, jointed, or fissured materials
   - d. Adversely oriented discontinuity (bedding, schistosity, fault, unconformity, contact, and so forth)
   - e. Contrast in permeability and/or stiffness of materials

2. Morphological causes
   - a. Tectonic or volcanic uplift
   - b. Glacial rebound
   - c. Fluvial, wave, or glacial erosion of slope toe or lateral margins
   - d. Subterranean erosion (solution, piping)
   - e. Deposition loading slope or its crest
   - f. Vegetation removal (by fire, drought)
   - g. Thawing
   - h. Freeze-and-thaw weathering
   - i. Shrink-and-swell weathering

3. Human causes
   - a. Excavation of slope or its toe
   - b. Loading of slope or its crest
   - c. Drawdown (of reservoirs)
   - d. Deforestation
   - e. Irrigation
   - f. Mining
   - g. Artificial vibration
   - h. Water leakage from utilities

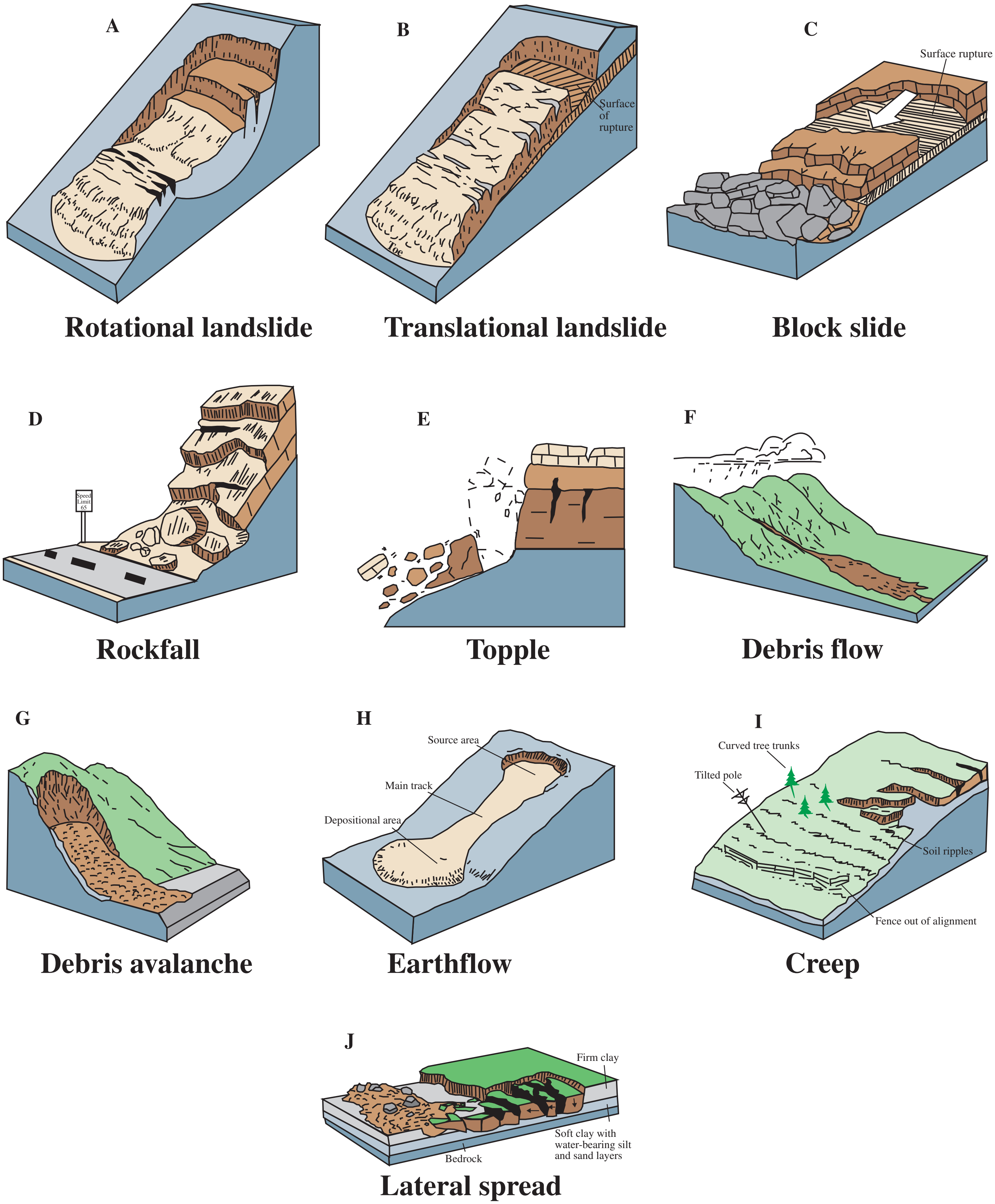

Figure 3. These schematics illustrate the major types of landslide movement that are described in the previous pages. For additional information on these processes and where to find photos, please see "Where to Go For More Information" at the end of this fact sheet.

Although there are multiple types of causes of landslides, the three that cause most of the damaging landslides around the world are these:

Landslides and Water

Slope saturation by water is a primary cause of landslides. This effect can occur in the form of intense rainfall, snowmelt, changes in ground-water levels, and water-level changes along coastlines, earth dams, and the banks of lakes, reservoirs, canals, and rivers.

Landsliding and flooding are closely allied because both are related to precipitation, runoff, and the saturation of ground by water. In addition, debris flows and mudflows usually occur in small, steep stream channels and often are mistaken for floods; in fact, these two events often occur simultaneously in the same area.

Landslides can cause flooding by forming landslide dams that block valleys and stream channels, allowing large amounts of water to back up. This causes backwater flooding and, if the dam fails, subsequent downstream flooding. Also, solid landslide debris can "bulk" or add volume and density to otherwise normal streamflow or cause channel blockages and diversions creating flood conditions or localized erosion. Landslides can also cause overtopping of reservoirs and/or reduced capacity of reservoirs to store water.

Landslides and Seismic Activity

Many mountainous areas that are vulnerable to landslides have also experienced at least moderate rates of earthquake occurrence in recorded times. The occurrence of earthquakes in steep landslide-prone areas greatly increases the likelihood that landslides will occur, due to ground shaking alone or shaking-caused dilation of soil materials, which allows rapid infiltration of water. The 1964 Great Alaska Earthquake caused widespread landsliding and other ground failure, which caused most of the monetary loss due to the earthquake. Other areas of the United States, such as California and the Puget Sound region in Washington, have experienced slides, lateral spreading, and other types of ground failure due to moderate to large earthquakes. Widespread rockfalls also are caused by loosening of rocks as a result of ground shaking. Worldwide, landslides caused by earthquakes kill people and damage structures at higher rates than in the United States.

Landslides and Volcanic Activity

Landslides due to volcanic activity are some of the most devastating types. Volcanic lava may melt snow at a rapid rate, causing a deluge of rock, soil, ash, and water that accelerates rapidly on the steep slopes of volcanoes, devastating anything in its path. These volcanic debris flows (also known as lahars) reach great distances, once they leave the flanks of the volcano, and can damage structures in flat areas surrounding the volcanoes. The 1980 eruption of Mount St. Helens, in Washington triggered a massive landslide on the north flank of the volcano, the largest landslide in recorded times.

Landslide Mitigation—How to Reduce the Effects of Landslides

Vulnerability to landslide hazards is a function of location, type of human activity, use, and frequency of landslide events. The effects of landslides on people and structures can be lessened by total avoidance of landslide hazard areas or by restricting, prohibiting, or imposing conditions on hazard-zone activity. Local governments can reduce landslide effects through land-use policies and regulations. Individuals can reduce their exposure to hazards by educating themselves on the past hazard history of a site and by making inquiries to planning and engineering departments of local governments. They can also obtain the professional services of an engineering geologist, a geotechnical engineer, or a civil engineer, who can properly evaluate the hazard potential of a site, built or unbuilt.

The hazard from landslides can be reduced by avoiding construction on steep slopes and existing landslides, or by stabilizing the slopes. Stability increases when ground water is prevented from rising in the landslide mass by (1) covering the landslide with an impermeable membrane, (2) directing surface water away from the landslide, (3) draining ground water away from the landslide, and (4) minimizing surface irrigation. Slope stability is also increased when a retaining structure and/or the weight of a soil/rock berm are placed at the toe of the landslide or when mass is removed from the top of the slope.

Compiled by Lynn Highland
Graphics and layout design by Margo Johnson

This fact sheet is available online at
http://pubs.usgs.gov/fs/2004/3072/

Where to go for more information

1. The U.S. Geological Survey Landslide Program has information, publications, and educational information on its Web site. Please see:
http://landslides.usgs.gov
or phone toll-free:
1-800-654-4966

2. For general information about slides, debris flows, rock falls, or other types of landslides in your area, contact your city or county geology or planning office. In addition, all 50 States have State Geological Surveys that can be accessed through a link at the USGS Web site,
http://landslides.usgs.gov

3. For an assessment of the landslide risk to an individual property or homesite, obtain the services of a State-licensed geotechnical engineer or engineering geologist. These professionals can be found through the membership listings of two professional societies, the American Society of Civil Engineers (ASCE), *http://www.asce.org* and the Association of Engineering Geologists *http://www.aegweb.org*. Often, personnel in State or county planning or engineering departments can refer competent geotechnical engineers or engineering geologists.

4. For more information about the design and construction of debris-flow mitigation measures which may include debris basins, debris fences, deflection walls, or other protective works, consult your city or county engineer, local flood-control agency, or the U.S. Department of Agriculture, Natural Resources Conservation Service:
http://www.ncgc.nrcs.usda.gov/

5. For photos of landslide types please see:
http://landslides.usgs.gov/html_files/nlic/nlicmisc.html

6. For more detailed information: two excellent publications that very clearly describe the processes of landslides were consulted for this fact sheet:

Varnes, D.J., 1978, Slope movement types and processes, *in* Schuster, R.L., and Krizek, R.J., eds., Landslides—Analysis and control: National Research Council, Washington, D.C., Transportation Research Board, Special Report 176, p. 11–33.

Turner, Keith A., and Schuster, Robert L., 1996, Landslides—Investigation and mitigation: Transportation Research Board, National Research Council, National Academy Press.

Landslide Classification Chart

TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOILS	
			Predominantly coarse	Predominantly fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
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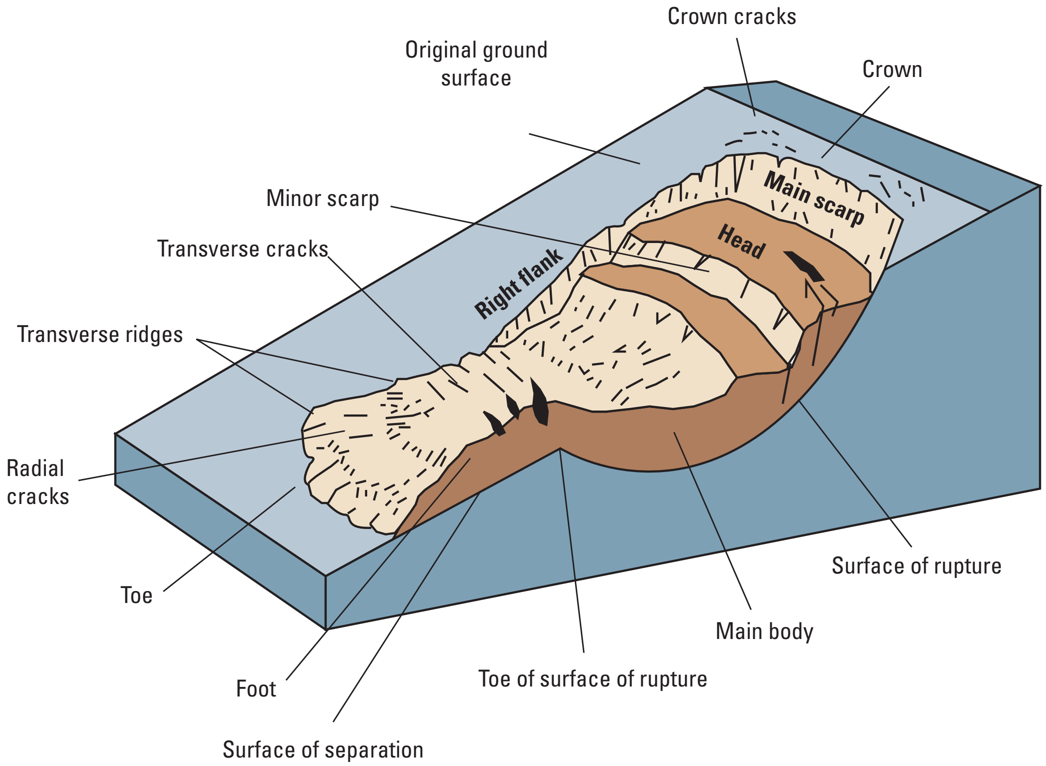
Parts of a Landslide—Description of Features/Glossary



Parts of a landslide. (Modified from Varnes, 1978, reference 43).

accumulation The volume of the displaced material, which lies above the original ground surface.

crown The practically undisplaced material still in place and adjacent to the highest parts of the main scarp.

depletion The volume bounded by the main scarp, the depleted mass and the original ground surface.

depleted mass The volume of the displaced material, which overlies the rupture surface but underlies the original ground surface.

displaced material Material displaced from its original position on the slope by movement in the landslide. It forms both the depleted mass and the accumulation.

flank The undisplaced material adjacent to the sides of the rupture surface. Compass directions are preferable in describing the flanks, but if left and right are used, they refer to the flanks as viewed from the crown.

foot The portion of the landslide that has moved beyond the toe of the surface of rupture and overlies the original ground surface.

head The upper parts of the landslide along the contact between the displaced material and the main scarp.

main body The part of the displaced material of the landslide that overlies the surface of rupture between the main scarp and the toe of the surface of rupture.

main scarp A steep surface on the undisturbed ground at the upper edge of the landslide, caused by movement of the displaced material away from the undisturbed ground. It is the visible part of the surface of rupture.

minor scarp A steep surface on the displaced material of the landslide produced by differential movements within the displaced material.

original ground surface The surface of the slope that existed before the landslide took place.

surface of separation The part of the original ground surface overlain by the foot of the landslide.

surface of rupture The surface that forms (or which has formed) the lower boundary of the displaced material below the original ground surface.

tip The point of the toe farthest from the top of the landslide.

toe The lower, usually curved margin of the displaced material of a landslide, it is the most distant from the main scarp.

top The highest point of contact between the displaced material and the main scarp.

toe of surface of rupture The intersection (usually buried) between the lower part of the surface of rupture of a landslide and the original ground surface.

zone of accumulation The area of the landslide within which the displaced material lies above the original ground surface.

zone of depletion The area of the landslide within which the displaced material lies below the original ground surface.

Sources of information on nomenclature:

1. Cruden, D.M., 1993, The multilingual landslide glossary: Richmond, British Columbia, Bitech Publishers, for the IUGS Working Party on World Landslide Inventory in 1993.

2. Varnes, D.J., 1978, Slope movement types and processes, *in* Schuster, R.L., and Krizek, R. J., eds., Landslides—Analysis and control: Transportation Research Board Special Report 176, National Research Council, Washington, D.C., p. 11–23.

Landslide Causes and Triggering Mechanisms

Physical Causes—Triggers

- Intense rainfall
- Rapid snowmelt
- Prolonged intense precipitation
- Rapid drawdown (of floods and tides) or filling
- Earthquake
- Volcanic eruption
- Thawing
- Freeze-and-thaw weathering
- Shrink-and-swell weathering
- Flooding

Natural Causes

Geological causes

- Weak materials, such as some volcanic slopes or unconsolidated marine sediments, for example
- Susceptible materials
- Weathered materials
- Sheared materials
- Jointed or fissured materials
- Adversely oriented mass discontinuity (bedding, schistosity, and so forth)
- Adversely oriented structural discontinuity (fault, unconformity, contact, and so forth)
- Contrast in permeability
- Contrast in stiffness (stiff, dense material over plastic materials)

Morphological causes

- Tectonic or volcanic uplift
- Glacial rebound
- Glacial meltwater outburst
- Fluvial erosion of slope toe
- Wave erosion of slope toe
- Glacial erosion of slope toe
- Erosion of lateral margins
- Subterranean erosion (solution, piping)
- Deposition loading slope or its crest
- Vegetation removal (by forest fire, drought)

Human Causes

- Excavation of slope or its toe
- Use of unstable earth fills, for construction
- Loading of slope or its crest, such as placing earth fill at the top of a slope
- Drawdown and filling (of reservoirs)
- Deforestation—cutting down trees/logging and (or) clearing land for crops; unstable logging roads
- Irrigation and (or) lawn watering
- Mining/mine waste containment
- Artificial vibration such as pile driving, explosions, or other strong ground vibrations
- Water leakage from utilities, such as water or sewer lines
- Diversion (planned or unplanned) of a river current or longshore current by construction of piers, dikes, weirs, and so forth

Exercise 1

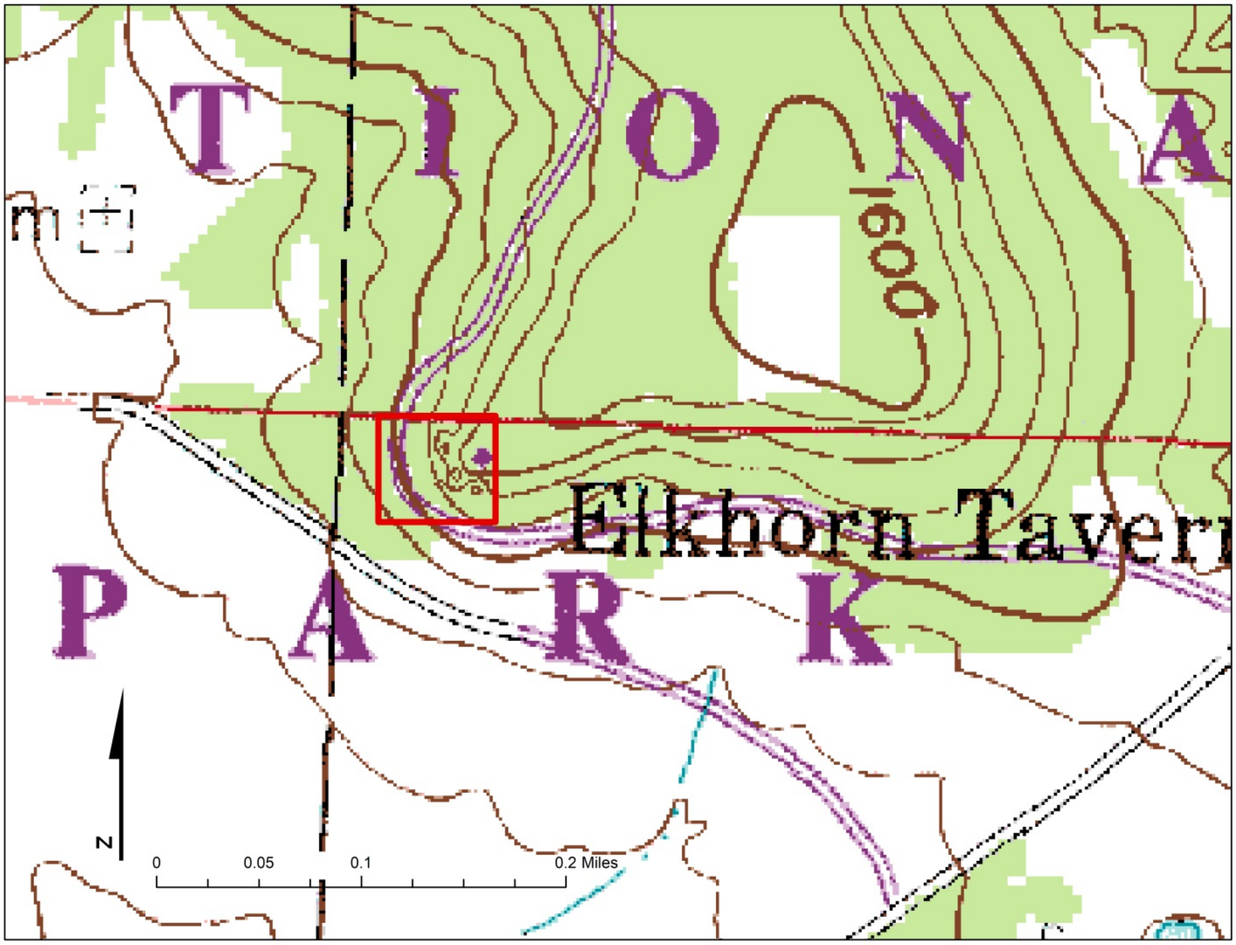
Pea Ridge National Military Park

Location: This National Park is a drive-through park. Drive to the East Overlook located at the eastern end of Elkhorn Mountain. Large boulders can be viewed from the Overlook, however, it is easier to park on the road below the overlook and walk up to the landslide area. Lat: 36°27'14.08" Long: 94°1'24.142". Pea Ridge 7.5-minute quadrangle, Benton County, Arkansas.

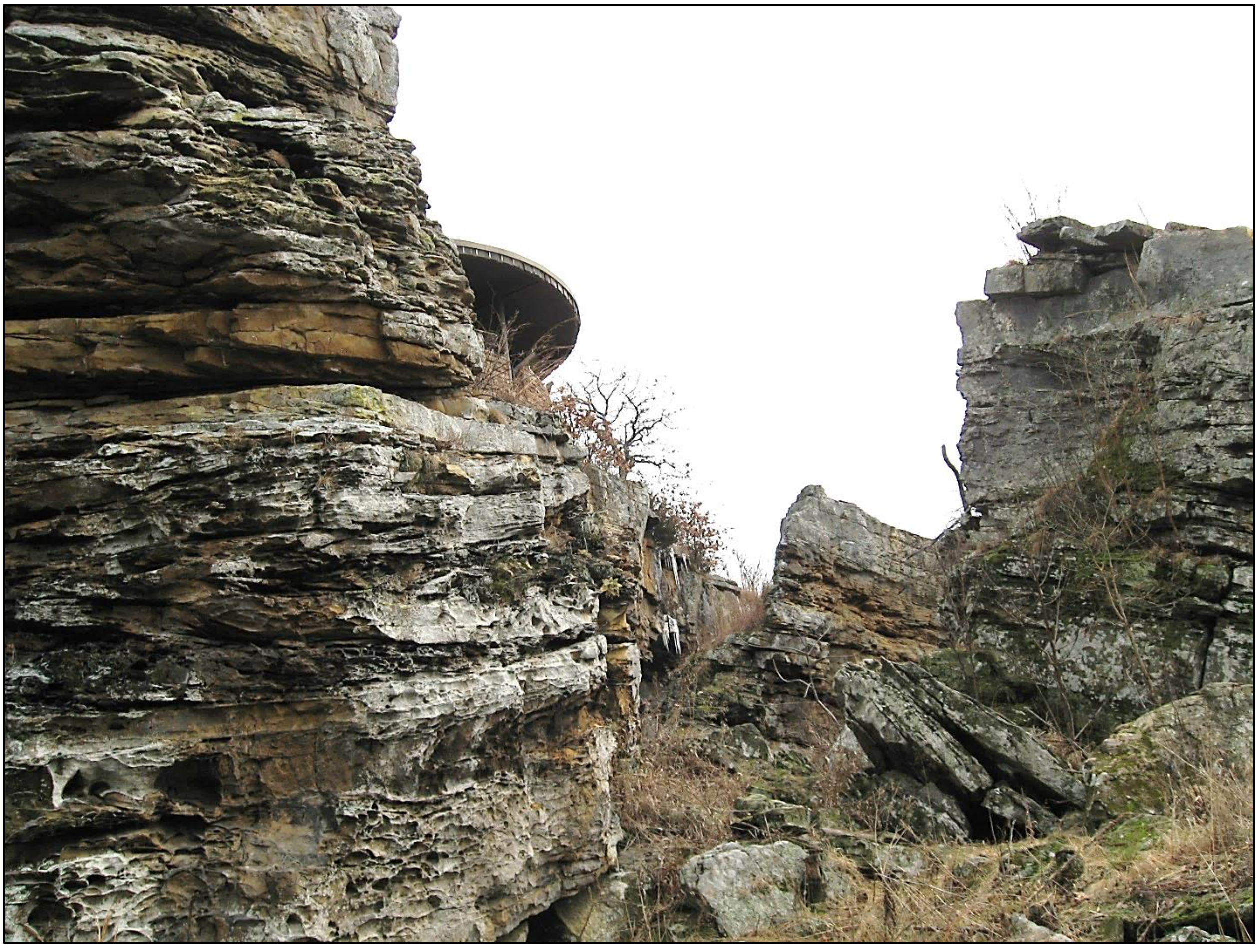
Landslide Case Study Activity Data - Pea Ridge National Military Park

Use the USGS Landslide Factsheet along with the following photographs and data to answer the activity questions.

The photo above was taken from the road below the East Overlook that is built on top of a sandstone bluff. Notice the fresh rock exposed near the top of the photograph. Also, notice large boulders of sandstone on the slope above the road. The covered slope above the road consists of a thin soil over shale up to the bluff.



The map above is taken from the Pea Ridge 7.5-minute topographic quadrangle. The contour interval is 20 feet. The landslide area is outlined in the red box. Notice the small enclosed contours below the lookout tower (purple). These represent large rock boulders that are detached from the bluff. The next photo shows the bluff and one of the boulders.



The disc-shaped object in the center left of the photo is the top of the East Overlook tower on top of the sandstone bluff. Note the rock boulders in the right half of the photo that have broken off and slid away from the bluff.

This photo shows the main boulder from which the slide material originated. Note the geologist for scale. You can see the fresh surfaces of rock but also the older boulders which would suggest this is not the first time there has been a landslide in this area.

Trees were knocked down as a result of this landslide.

Landslide Case Study Activity Questions – Pea Ridge National Military Park

1) Determine the relative size (look for objects in the photographs for comparison) and type of the material that has slid or fallen.
2) Determine the steepness of the slope relative to the surrounding area or the landform, such as a hill or mountain.
3) Look at the large slide blocks to determine geological causes for the landslide.
4) What physical causes were involved?
5) Use the Landslide Classification Chart to determine the type of landslide.
6) What concerns should the park have regarding this landslide?

Exercise 2

Devils Den State Park

Location: This landslide is located near the beginning of the Fossil Flats Trail that starts at the end of Campground Loop A. Coordinates start at the trailhead. Lat: 35°47'3.178" Long: 94°14'41.967". Winslow 7.5-minute quadrangle, Washington County, Arkansas.

Landslide Case Study Activity Data – Devils Den State Park

Use the USGS Landslide Factsheet along with the following photos and data to answer the activity questions.

The photo above shows the head scarp of a landslide along a trail at Devils Den State Park. The edge of the scarp has dropped about 3 feet. Notice the absence of large blocks of sandstone. In the upper right corner of the photo you can see Lee Creek. The trail is located on top of a high bank above the creek.

Continuing along the trail, past the first photo, you can turn and look back upon the landslide. This location allows a good view of Lee Creek. Notice the steepness of the bank and the size of the slide material. The bank of the creek is made up of black shale. There are several sandstone blocks that have fallen from farther up the hillside. Think about the erodibility of certain rock types. Research the difference between shale and sandstone.

This photo was taken in the creek below the landslide. It shows the black shale in the creek. Note the steep bank along the creek. The lower half of the creek bank is made up of gravel deposited by the stream. The upper half of the bank consists of black shale. This shale was deposited onto the river gravel by a previous landslide. Notice black shale that has recently slid to the bottom half of the bank.

This photo shows the landslide above the creek bank in the previous photos. The surface of rupture is curved concavely upward (like a smiley face) which would make it a rotational slide.

Landslide Case Study Activity Questions – Devils Den State Park

1) Determine the size and type of the material that has slid or fallen.
2) Determine the steepness of the slope relative to the surrounding area.
3) Look at the rock type to determine a geological cause.
4) What physical causes are involved?
5) Use the Landslide Classification Chart to determine the type of landslide.
6) Should the State Park have any concerns regarding this landslide? If so, what are they?

Exercise 3
Mt. Nebo State Park

Location: This landslide is located on top of Mt. Nebo at the Gum Springs Trail where the Hartshorne Sandstone forms a bluff along the top rim. We will walk down the trail a short distance to the landslide. Lat: 35^{o}13'1.012" Long: 93^{o}15'31.674". Chickalah Mountain East 7.5-minute quadrangle, Yell County, Arkansas

Landslide Activity – Mt. Nebo State Park

Use the USGS Landslide Factsheet, along with the following photographs and data, to answer the activity questions.

This photo was taken below, or at the toe of the slide looking upward toward the top of the bluff. Notice the portions of rock cropping out along the bluff beside the cedar trees at the top of the photo. Also, notice the size of the material. The majority of material is at least 1 foot in length and many are larger. Are they rounded or angular? What does this mean?

Outcrop (in place) above rocky boulders. The boulders eroded from this outcrop. Look at characteristics of outcrop to determine why the boulders fell from the outcrop. Notice the natural fractures in the rock and think of some of the physical causes for landslides.

This photo shows the steepness of the slope. Keep in mind this location is on top of Mt. Nebo, a mesa-like mountain in the Arkansas River Valley.

Landslide Case Study Activity Questions – Mt. Nebo State Park

1) Determine the size and type of the material that has slid or fallen.
2) Determine the relative steepness of the slope.
3) Look at the rock that is still in place to determine a geological cause.
4) What physical cause is involved?
5) Use the Landslide Classification Chart to determine the type of landslide

Exercise 4

Near Mockingbird Hill

Location: Travel southeast on Highway 374 from Mockingbird Hill just south of Jasper, Arkansas. Landslide is located above the highway (east side) and possibly overgrown at this time. Lat: 35°57'42.14" Long: 93°8'28.883". Parthenon 7.5-minute quadrangle, Newton County, Arkansas.

Landslide Case Study Activity Data – Highway 374 near Mockingbird Hill, Arkansas

Use the USGS Landslide Factsheet, along with the following photographs and data, to answer the activity questions.

This landslide came close to reaching the highway. Notice the size of the material and compare it to other geological materials in the previous activities. Notice the relatively gentle slope along the road here. What do you see in the photo that gives you a hint of what triggered the landslide?

This landslide started approximately 300 feet above the highway and carried the material you see over a 30 foot thick sandstone bluff. Notice the size of the material in relation to the previous photo. This is hilly terrain in the Ozarks of northern Arkansas with a bench-bluff type of topography, meaning there will be vertical bluffs separated by fairly steep slopes and benches. The bluffs consist of sandstone while the less steep slopes consist mainly of shale.

This landslide carried different sizes of material and knocked down trees in its path. This photo shows the area below the bluff in the previous photo. Note the geologist for scale. This illustrates the power of geological processes.

Landslide Case Study Activity Questions – Hwy 374 Mockingbird Hill, Arkansas

1) Determine the size of the material that has slid closest to the road.
2) Determine the relative steepness of the slope. Note the absence or presence of a steep bluff.
3) Look at the rock type to determine a geological cause.
4) What triggered this event?
5) Use the Landslide Classification Chart to determine the type of landslide.
6) What concerns should the Arkansas Department of Transportation have regarding this landslide?

DEBRIS FLOW FOLLOW UP

Debris flows of this type are not uncommon events in the Ozarks. They usually happen during or after extended periods of rain. However, most of these landslides are out of sight of the highways and are quickly grown over and obscured.

This debris flow was the product of a heavy rainfall event that occurred in Boone and Newton Counties during the 21st and the 24th of April 2004. The National Weather Service at Little Rock noted 9.32 inches of precipitation at Deer, Arkansas, Newton County (approx. 10 miles from this debris flow), within a seventy-two hour period (through 7 am on 4/24/2004), with isolated 10+inch amounts noted.

Answers to Activities

Pea Ridge National Military Park

1. Large blocks
2. Fairly steep
3. Large, heavy, highly fractured sandstone blocks sitting on a clay shale
4. Rainfall, freeze-and-thaw weathering of sandstone; shrink-and-swell weathering of underlying clay causing blocks of sandstone to slide
5. Rock fall
6. The park needs to watch for large block falling or rolling onto the road.

Devils Den State Park

1. Mostly small material
2. Steep bank along creek
3. Clay shale – susceptible material
4. Flooding, rainfall, creek cutting into bank
5. Rotational slide – just get the point across that the rock is moving downslope and rotating.
6. The landslide is cutting out the trail above, so the park had to re-route the trail.

Mt. Nebo State Park

1. Large blocks
2. Very steep
3. Jointed/fractured material – sandstone
4. Freeze-and-thaw
5. Rock fall

Mockingbird Hill

1. Small, mud
2. Fairly steep
3. Shale – susceptible material
4. Intense rainfall, or prolonged intense rainfall, flooding
5. Debris flow
6. Keep watch during heavy or prolonged rain events so that material does not cover the road.