Some folks learn about geologic hazards the hard way! Bluff failure caused extensive damage to these coastal properties in Leucadia, CA. This is an example of **mass wasting** -- a hazard that costs more in property damage each year than most other geologic hazards combined.
Summary of Important Concepts

**Mass wasting** is the term geologists use to describe **downslope movement of rock, soil or debris directly due to gravity**. Specific types of mass wasting are **Falls, Flows, and Slides**.

1. **Falls** - Near-vertical fall of material from a cliff or steep slope. Primary causes are undercutting and oversteepening of cliff areas, either by natural processes or human activities.

2. **Flows** - Downslope movement of loose material in a plastic or semi-fluid state. 2 main types:
   - **Creep**: slow downslope movement of loose particles, caused by the soil zone expanding and contracting.
   - **Debris flow**: fast-moving fluid mixture of particles, mud and water (like a mass of wet concrete flowing downhill). The term **debris avalanche** is used for a particularly fast-moving debris flow.

Debris flows are generally caused by the combination of **heavy rainfall**, **sparse vegetation**, and **accumulated loose rock and soil**. They occur mostly in arid regions subject to occasional heavy rainfall.
Summary of Important Concepts, continued

3. Slides - Downslope movement of a large unit of rock or soil down a distinct surface of failure or slide plane. 2 main types:
   - Rotational slide (slump) occurs on a curving, concave-up surface.
   - Translational slide (block glide) occurs on a flat inclined surface.

Slides are generally caused by one or more of the following:
   - water saturation +/- or weathering which weakens a slope
   - increased steepness of a slope caused by undercutting at the base
   - increased weight added at the top of a slope
   - shaking (by earthquakes, explosions) that triggers movement on a vulnerable slope

In addition to the above, there are two other important types of mass wasting.
• Lateral spreading occurs where water saturated ground spreads outward horizontally, rather than down a slope.
• Snow avalanches are essentially “landslides” of snow.
Mitigation of mass wasting problems is accomplished by:

- **Sinking foundations down into solid rock** below weaker surface zones.
- **Hazard zone mapping** to identify areas where movements have occurred in the past. Such areas may be likely to move again.
- **Building codes** that limit the steepness of slopes and the types of fill used in construction.
- **Drainage systems** that drain water from the surface and/or the subsurface.
- **Buttress fills** and **retaining devices** to hold slopes in place. Examples include retaining walls, “shotcrete”, and rock bolts.
- For debris flows, one can build **deflection walls** to send the flows around structures.
Summary of Important Concepts, continued

**Subsidence** is the **sinking downward of the earth’s surface**. It can be caused by natural processes, but most problems involving subsidence are caused by human activities. Common causes of subsidence include:
- pumping of water, crude oil, or natural gas from deep underground
- collapse of underground mines or natural caves

Subsidence causes problems in the form of cracked ground, and damage or destruction of structures, pipelines, drainage systems, and sewer systems.

**Mitigation** of subsidence is accomplished by:
- replacing underground fluids as they are pumped out
- support pillars and infilling of underground mines to prevent collapse
- building structures on deep foundation pillars to hold them in place if the ground subsides
Mass wasting is the term geologists use to describe downslope movement of rock, soil or debris directly due to gravity. Most non-geologists call such features “landslides”, although the term is not specific enough to be much use to geologists. As we will see, there are several different types of “landslides” that are distinguished by differences in how they form, the nature of the material that forms them, and how fast they move.

This map makes a simple and clear point: mass wasting is most severe in states with hilly or mountainous terrain: the eastern states of the Appalachian Mountains, and the mountainous states of the western U.S.
The three major categories of mass wasting are **Falls**, **Flows**, and **Slides**. We will look at the specific features of each in this order. You may find it useful to refer back to the figure below as we review the different types.

<table>
<thead>
<tr>
<th>MECHANISM</th>
<th>MATERIAL</th>
<th>VELOCITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLIDE</td>
<td>Slump</td>
<td>Slow</td>
</tr>
<tr>
<td></td>
<td>Earth slump</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Debris slump</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Block glide</td>
<td>Rapid</td>
</tr>
<tr>
<td></td>
<td>Earth slide</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Debris slide</td>
<td></td>
</tr>
<tr>
<td>FLOW</td>
<td>Rock avalanche</td>
<td>Very Rapid</td>
</tr>
<tr>
<td></td>
<td>Mudflow, avalanche</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Debris flow, avalanche</td>
<td></td>
</tr>
<tr>
<td>FALL</td>
<td>Creep</td>
<td>Extremely slow</td>
</tr>
<tr>
<td></td>
<td>Creep</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Creep</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rockfall</td>
<td>Extremely rapid</td>
</tr>
<tr>
<td></td>
<td>Earthfall</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Debrisfall</td>
<td></td>
</tr>
</tbody>
</table>

© 2001 Brooks/Cole - Thomson Learning
Falls are the simplest and most common form of mass wasting. Falls are vertical or near-vertical fall of rock material from a cliff or steep slope. Primary causes of falls are weakening of the rock in a steep area, and/or undercutting and oversteepening of the area.

In the photograph, rock broken apart by repeated freezing and thawing in the high cliffs has fallen vertically and piled up at the base of the mountain, forming a steep pile of rock debris called a talus slope.
Flows are defined as downslope movement of loose material in a fluid-like state. The idea here is that the material moves something like a thick fluid rather than as a single solid mass of rock. In most cases water is involved. Water lubricates particles and combines with rock particles and mud to form a fluid-like flowing mass.

The two main types of FLOWS are Creep and Debris Flows.

Creep is very slow downslope movement of loose particles. Loose material on a slope “creeps” downhill almost imperceptibly at rates of a few inches to a few feet per year. The downslope movement is generally related to processes that cause soil and loose rock to expand and contract, such as periodic wetting and drying or freezing and thawing.
This figure shows how periodic freezing and thawing will cause slope material to expand (when freezing) and shrink (when thawing), causing the surface layer to gradually creep downhill. (See the bent tree trucks in this figure? Compare to next slide...)
If you have spent any time hiking in forests in hilly areas, you may have noticed the uphill bending of tree trunks like those pictured here. As the slope creeps downhill (to the right in this picture), the trees begin falling over. Since the trees want to grow straight up, they curve as they grow to make up for downhill creep!
Debris flows are dense, fast-moving fluid mixtures of rock particles, mud and water. The best way to imagine a debris flow is to think about material with the consistency of wet concrete flowing down a slope.

Debris flows are called debris avalanches if they are particularly fast moving. Debris flows and debris avalanches are two terms of the same process; the distinction between them is speed.

Debris flows and avalanches are generally caused by the combination of heavy rainfall, sparse vegetation, and accumulated loose rock and soil. They occur mostly in arid regions subject to occasional periods of heavy rainfall. Loose rock and soil can build up on slopes and in canyons between times of heavy rain. When heavy rains come they can mobilize this material into a moving fluid mass.
A **debris flow** typically starts high up in a slope area, generally initiated by heavy rainfall which weakens and lubricates a mass of loose rock debris. It moves downslope as a dense, fluid mass, burying and/or smashing most things in its path. Because of the **high density** of the mass of moving material, debris flows can carry large objects for great distances!
These debris flows in Puerto Rico wiped out paths of standing trees and hit a residential area. They were caused by heavy rainfall.
This home in Oregon was buried nearly to the roofline by a debris flow that occurred during heavy rains. The flow carried bus-sized rocks down and out of the canyon where it formed, burying and destroying a number of homes near the mouth of the canyon.
Debris flows in California were particularly common in the wet rainy years associated with the El Nino conditions in 1982-83 and 1997-98. Compare the rainfall in those years to the normal rainfall (shown by the red line).
Slides are defined as downslope movement of a large unit of rock or soil along a distinct surface of failure (= slide plane).

The 2 main types of slides are Rotational Slides (also called Slumps), and Translational Slides (also called Block Glides).

The difference between these two types of slides relates to the shape of the surface of failure along which the mass of rock moves. A rotational slide (slump) occurs along a curving, concave-up surface. A translational slide (block glide) occurs on a relatively flat sloping surface.
A Rotational Slide occurs along a curving, concave-up surface of failure, often spoon-like in shape (see “a” below). Because the failure surface curves upward, the mass rotates as it moves downhill (note backward tilting of the trees in “b” below). The mass pushes out at the bottom of the slide to form a bulge of material called the toe (shown in “c” below).
A rotational slide that has been moving gradually for decades in San Pedro, CA. The rock is broken up into multiple backward-rotating blocks. Slumps like this one continue to cause extensive damage to houses and roads in this area.
A **Translational Slide** (block glide) occurs on a relatively flat sloping surface of failure.

One very common cause of translational slides is **dipping planes of weakness in the rock**. These planes might be sedimentary bedding planes, metamorphic foliation planes, faults, or fractures in the rock. A translational slide is likely to occur if the slope dips at an angle that is greater than the dip of the planes of weakness in the rock.

For example, in this figure the slope has been cut at an angle that is greater than the dip angle of the planes of weakness in the sedimentary layers. With nothing to hold the layers back, they may slide onto the house.
A translational slide waiting to happen!! Notice on the point of land with the house that the sedimentary layers dip toward to ocean. A layer of weaker rock could form a failure surface that would cause the overlying layers to slide into the sea (along with the house). The most likely time for a slide to occur would be after heavy rains had saturated the rock layers. An earthquake could also trigger the slide.
Causes of Mass Wasting

Mass wasting processes generally result from a combination of factors that all work together to cause a slope to fail. The most important factors are:

1. **Water saturation.** The single most important factor in most mass wasting. Water saturation can result from heavy rain, rapid snowmelt, leaking water or sewage lines, or poor drainage. Water saturation weakens rock by building up pore pressure and by lubricating contacts between particles.

2. **Reduction of slope strength** by weathering, by burrowing animals, or by infiltration of water.

3. **Increase in slope steepness.**

4. **Increase in weight at top of a slope.**

5. **Removal of support at the base of a slope.**

6. **Shaking** by either natural processes (earthquakes) or human activities (explosions, heavy traffic).
Many landslides are triggered by earthquakes. The land under these houses in Anchorage slid during the great 1964 Alaska quake.
Mitigation of mass wasting problems is accomplished by:

- **Sinking foundations down into solid rock** below weaker surface zones.

- **Hazard zone mapping** to identify areas where movements have occurred in the past. Such areas may be likely to move again.

- **Building codes** that limit the steepness of slopes and the types of fill used in construction.

- **Drainage systems** that drain water from the surface and/or the subsurface.

- **Buttress fills** and **retaining devices** to hold slopes in place. Examples include retaining walls, “shotcrete”, and rock bolts.

- For debris flows one can build **deflection walls** to send the flows around structures.
A simple mitigation method for creep. Structures will shift and slide if they are built on the creeping surface layer. By sinking foundations down through the creeping surface zone and anchoring the footings of the structure in solid bedrock, the structure will remain in place even if the surface creeps.
Building codes are an effective way to reduce sliding problems. Many state and local governments throughout the country have adopted codes for the maximum steepness of slopes when building in hilly areas. Common guidelines require:
- a slope steepness of no more than 2:1 (equals a 27 degree slope angle)
- drainage benches placed at regular intervals to catch water runoff
Since *WATER* is a major factor in most mass wasting problems, control of water on the surface and below ground figures prominently in most mitigation methods.

Water within the ground can be controlled by **hydrauger holes**: horizontal holes drilled into the ground and lined with perforated pipe. Excess water leaks into the pipes and flows into other pipes that take it away from the slide-prone area. An example is shown in this photograph.
Control of surface water flow on vulnerable slopes can be done by **planting vegetation**, and/or by **drainage ditches** set at regular intervals on the slope. Both methods have been used on the slope shown here. Notice how much better the area with plant cover and drainage ditches is holding up compared to the area to the left.
** Buttress fills -- compacted earth that is laid onto a slope to hold it in place -- are a commonly used to stabilize slopes. A buttress fill used together with internal and external drainage systems, such as shown in the diagram below, makes for a very stable slope. 

![Diagram showing Buttress fill and drainage systems](image)
Retaining devices are also commonly used to stabilize slopes, typically in places where the base of the slope has been cut away to create more flat building area.

Retaining walls must be strong enough to replace the resisting force supplied by the original slope. It must also be equipped with a water drainage system, as shown here. The layer of gravel in back of the wall allows water behind the wall to drain into perforated pipes, called weep holes.
“Shotcrete” is another type of retaining device. A layer of concrete is sprayed out of a pressurized gun to cover a slope. It is important to install drain systems to remove water from within the slope, so water does not build up behind the shotcrete layer.
Rock bolts are a type of retaining device used to reinforce slopes consisting of cracked and fractured rock. They can be used to reinforce cliffs, overhangs, and tunnels. Bolts that are anchored in concrete are particularly strong. (See above left.)
Mitigation of debris flows presents its own special problems. Since debris flows can begin in high mountain canyons and travel great distances, the issue is not how to prevent them so much as how to reduce damage from them.

One method, shown at the house here, is to build a deflecting wall, which will (hopefully) divert the flow around the house into the drainage ditch. The wall shown here would stop only small debris flows.
Up to this point, we have discussed MASS WASTING -- the downward movement of material due directly to gravity. Another type of “downward movement” that causes problems is SUBSIDENCE-- the sinking downward of the earth’s surface.

Subsidence is not dangerous, but it does cause major economic problems in the form of earth fissures (large cracks in the ground), and damage to structures, pipelines, drainage systems, and sewer systems.

Subsidence can be caused by natural processes. For example, large earthquakes commonly cause vast areas of land to sink downward in some places, and rise upward in other places. But most problems involving subsidence are caused by human activities. Some of the most severe subsidence problems in the U.S.A. occur in agricultural areas with intensive groundwater pumping. The San Joaquin Valley of California is one such place.
One major cause of subsidence is pumping of water, crude oil, or natural gas from deep underground. This is called deep subsidence because it is caused by removal of material from great depths. In contrast shallow subsidence is the term used to describe subsidence from the removal of material at shallow depths, such as when underground mines or natural caves collapse.

This figure shows why subsidence occurs when fluid (water, oil, natural gas) is pumped out of the ground. When the fluid pressure on the surrounding rock particles is reduced, the particles settle closer together, and the ground sinks.
Long Beach, CA, has experienced as much as 30 vertical feet of subsidence as oil has been pumped from deep underground. The building and parking lot at the left are several feet below sea level. Walls hold back the ocean, and boat owners walk *uphill* from the parking lot to get onto their boats!
This dog is thinking “How can I use that hydrant way up there?!”

The hydrant was at ground level when it was installed. The hydrant was held in place by the piping system as the ground subsided around it. (This is in Long Beach, CA; same as previous slide).
Areas of Mexico City have subsided as ground water has been pumped out from the sedimentary layers beneath the city. This church’s foundation was built half on firm bedrock and half on sedimentary layers that subsided as water was withdrawn. It’s pretty easy to tell here which side is which!

Because Mexico City now imports most of its water through an aqueduct system, and has stopped most pumping of groundwater below the city, subsidence problems have decreased a great deal.
Mitigation of subsidence can be accomplished by:

1. Replacing underground fluids as they are pumped out. This can stop further subsidence from occurring, but it cannot reverse subsidence. Once the ground has subsided, there is no effective way to make it “bounce back”.

2. In cases of subsidence caused by collapse of underground mines, one can install support pillars and/or fill in the mines to prevent collapse.

3. Building structures on deep foundation pillars to hold them in place if the ground subsides.