The community of La Conchita, California—soft marine terrace above it gave way when soaked with too much water.

irrigated avocado field is visible at the top of the terrace in this photograph, which was taken the day after the landslide in 1995.

talus slope of basalt blocks formed as rocks fell from the cliff and rolled down the slope to rest at their angle of repose (Columbia River Plateau near Palouse Falls, WA).

The main features of a rotational landslide:

- steeper slope has a larger force parallel to the slope (red arrow)
- for the gentler slope, the friction force (f) is larger than the force pulling parallel to the slope (F).

forces on a mass resting on a slope:

- \( \theta \) is slope angle
- \( W \) is load or weight
- \( F_p \) is force perpendicular to the slope
- \( F_{\parallel} \) is force parallel to the slope
- \( F_f \) is friction holding the mass from sliding
Capillary cohesion in the narrow necks between grains pulls the grains together.

Water pressure at depth is equal to the load or weight of the overlying water.

Water (dark) seeps out of the soil below the sharply defined saturation level exposed in a road cut in Glacier National Park, Montana.

1999 Dana Point landslide north of San Diego, California.

Filling a reservoir behind a dam raises groundwater in the adjacent slopes, often leading to sliding into the reservoir.

Installation of a perforated drainpipe can lower the water table and reduce the chance of sliding.
Low permeability of this shale necessitates many drainpipes.

Water drains from perforated groundwater-drainage pipes in shale road cut on U.S. Highway 101 north of Garberville, California.

Loosely packed grains provide large pore spaces for water. If the grains collapse to a tighter arrangement, much of the water must be squeezed out.

Three typical types of ground failure during liquefaction.

Clay grains deposited in random orientation have especially large pore spaces—a "house of cards" arrangement. After collapse, compacted clays take up much less space so water in pore spaces must escape.

Lemieux flow in a horizontal terrace of the Leda Clay of the St. Lawrence River Valley near Ottawa, Ontario, settled and flowed into the adjacent river on 6/20/93.
**Rissa Landslide, 1978 near Rissa Norway**

http://geotechnical.ce.washington.edu/courses/cee522/RissaLandslide/rissa.html

*The Northridge earthquake caused a swarm of landslides*

**Mitigation:** Installing heavy wire mesh over a dangerous rockfall area above the Trans Canada Highway.

**Magn. 7.9 earthquake on the Denali Fault 2003 caused landslide onto Black Rapids Glacier, Alaska Range**

**Workers drill and bolt a rock cliff above Highway 1 at mouth of Topanga Canyon, CA, west of Los Angeles**

**Rockbolts and shotcrete stabilize a heavily fractured road cut below houses in Acapulco, Mexico**
Subsidence and seaward spreading of the marine terrace in Anchorage

This dropped trough formed at the head of the L Street landslide.

Steeply dipping limestone beds slope toward and daylight over a coastal highway near Sorento, Italy.

Subtle evidence!

Hummocky landslide terrain is near Gardena, north of Boise, Idaho.

Marble Canyon, Arizona, recent rockfall debris forms talus fallen from the visible scar on the cliff above.

Table 8-1. Classification of Mass Movements

<table>
<thead>
<tr>
<th>Type</th>
<th>Rock (Other Broken)</th>
<th>Debris (Mostly &lt;1 mm)</th>
<th>Soil (Mostly &lt;2 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td>Rockfall</td>
<td>Debris fall</td>
<td>Earth fall</td>
</tr>
<tr>
<td>Slump</td>
<td>Rock slumping</td>
<td>Debris slump</td>
<td>Earth slumping</td>
</tr>
<tr>
<td>Block rotational</td>
<td>Rock block</td>
<td>Debris block</td>
<td>Earth block</td>
</tr>
<tr>
<td>Lateral spreading</td>
<td>Rock spread</td>
<td>Debris spread</td>
<td>Earth spread</td>
</tr>
<tr>
<td>Flow</td>
<td>Rock flow</td>
<td>Debris flow</td>
<td>Earth flow</td>
</tr>
</tbody>
</table>
Some rockfall problems arise where a strong layer such as sandstone overlies a weak layer such as shale or clay in Pennsylvania.

“runout” distance traveled by a debris avalanche depends principally on the height of the mass before it falls and therefore its potential energy. The values are variable, but an approximation is provided by the formula above:

\[
\text{Length} = \frac{\text{Height}}{\tan(\alpha)}
\]

A 4.5-meter boulder crushed the living room, bathroom, and part of the bedroom of this house at Rockville, Utah, near Zion National Park at 5:38 A.M. on October 18, 2001.

The source of the boulders was a massive sandstone and conglomerate cliff above the location shown in Figure 8-26. The boulder is partly visible middle right. The man at left provides scale.

a) The Madison slide collapsed into the Madison River canyon and continued upslope to the north. It dammed the river to form Earthquake Lake.

layers and parallel orientation of micas in the schist almost parallel to the slope at Madison slide headscarp.
Frank slide peeled off the whole east face of Turtle Mountain and spread a bouldery limestone deposit across the valley and up the slope to the west.

Mount Nevados Huascarán debris avalanche in 1970 buried the town of Yungay

McClure slide south of Aspen, Colorado, is notorious for continuing to slide. The car plunged off the severed road in 1994.

Blackfoot landslide in Montana

Rotation of a slump block
A house begins to break up in a series of rotational slumps in Colorado River bluffs, Grand Junction, Colorado.

Crushed rock is scattered along the failure surface of a landslide at Newport, Oregon (see arrow).

Heavy boulders are often piled on the lower part of a slide to resist movement. This road, cut through a landslide on U.S. Highway 101 near Garberville, in northern California.

A section of coastal cliff at the edge of Puget Sound, near Seattle, collapsed, crushing and burying a home on the narrow strip of beach.

Sackung features in the high mountains of British Columbia.
The 1983 Thistle landslide southeast of Salt Lake City, Utah, began in response to rising groundwater levels from heavy spring rains. Within a few weeks, the slide dammed the Spanish Fork River and took out U.S. Highway 6 and a major railroad line. Water behind the slide dam submerged the town of Thistle.

October 1985, a landslide destroyed 120 houses in Mamayes, Puerto Rico, and killed at least 129 people. The catastrophic block slide was triggered by a tropical storm with extremely heavy rainfall.

Slumgullion earthflow of southwestern Colorado--volcanic rock peaks in the background are heavily altered to slippery clays, spreading out into Cristobal Lake in the lower right.

Aldercrest landslide in southwestern Washington at Kelso; > 60 homes destroyed.

Disastrous 1963 Vaiont slide in northeastern Italy moved cataclysmically on weak layers of shale within limestone beds parallel to the mountain face.

North-south cross section shows the Vaiont Reservoir area, preslide mass, and landslide.
A stronger layer over weak clays may fail by lateral spreading. Parts of the spreading mass may drop as it spreads.

Debris flows from the huge fault scarp of the Wasatch Front behind Salt Lake City, Utah, in 1983

1996 debris-flow channel, a tributary to the Columbia River, near Dodson

Debris flow in the Andes of northwestern Argentina

Slide Mountain, Nevada, southwest of Reno in May of 1983
This diagram shows the distribution of grain sizes and water in a debris flow.

May 1998, a muddy debris flow from the steep hillside to the right of this house in Siano, Italy, east of Mount Vesuvius

The small community of Orting, Washington, is built on huge mudflows that poured down a valley from Mount Rainier 500 years ago. Earlier mudflows filled the same valley; undoubtedly, mudflows will do so again.

May 1998, a muddy debris flow from the steep hillside to the right of this house in Siano, Italy, east of Mount Vesuvius

The end of this apartment building on the Caraballeda fan collapsed when debris-flow boulders crushed key support columns. The largest boulder is more than 2 meters high.
Venezuela were crushed as the slopes gave way in the saturating rain.

A modern debris-flow collection basin was built in Rubio Canyon, north of Pasadena, California.

1978 storm filled the basin behind this debris-flow dam and overtopped the dam at La Crescenta, California.

Debris basin north of Pasadena

Sleeping Child Creek, south of Hamilton, Montana, in July 2001; Note scarring and abrasion of bark.

Note abrasion line on trees.
fast-moving mudflows racing right to left down the valley from Mount Pinatubo in the Philippines

A large earthquake on January 13, 2001, triggered this devastating mudslide in a middle-class subdivision in Colonia Las Colinas, El Salvador. It killed ~585.

Soil creep produces a slow downslope movement of the upper layers of soil or soft rocks.

Pistol-butt trees are often a signal of soil creep.
hummocks deposited as a massive landslide from Mount Shasta, visible in the upper left. This slide occurred between 300,000 and 380,000 yr ago and was 25 km$^3$
Sidebar 8-4

The distance traveled by a debris avalanche depends principally on the height of the mass before it falls and therefore its potential energy. The values are variable, but an approximation is provided by the formula below:

- Original position of rock
- Height
- Length
- Tangent (slope angle, \( \alpha \)) = Height / Length

\[
\text{Length} = \frac{\text{Height}}{\text{tangent } \alpha}
\]

Sidebar 8-5

Specifically, estimates for the peak discharge for a landslide dam failure are (Costa and Schuster, 1988):

- \( Q_{\text{max}} = 6.3H^{1.39} \)
- \( Q_{\text{max}} = 672V^{0.56} \)
- \( Q_{\text{max}} = 181(HV)^{0.43} \)

where

- \( Q \) = peak discharge in m³/sec.
- \( V \) = reservoir volume in millions of m³
- \( H \) = height in meters