

Topic 11: Landslides, Mass Movements and Mass Wasting

test #3 today, due by midnight
 topics 8-10, HW1
 late submission not eligible for extra credit

short videos are
 test material!

HW#3 due tomorrow
 late submissions not eligible for extra/bonus credit

discussion session (TAs): 4 pm York 3030

office hour (Laske): 5 pm Zoom

SIO15 2024: Topic 11 - Landslides, Mass Movements

What is a Mass Movement ?

MASS MOVEMENT

downward movement of mass
 ✦ slope failure
 ✦ collapse of structure beneath

MASS WASTING

more general term including
 ✦ deforestation
 ✦ soil erosion

in U.S.

✦ \$1.5 B in damages/year
 ✦ 25 fatalities/year


compared to earthquakes and volcanoes:

huge anthropogenic component through

- building on unstable ground despite better information
- actually triggering mass movements (at all scales)

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Classical Mass Movements – Hong Kong



Hong Kong

NATURAL:

- ✦ climate (HK: humid/sub-tropical; typhoons)
- ✦ elevation

HUMAN:

- ✦ urban development
- ✦ population pressure
- ✦ building in unstable environment

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This slide features an aerial photograph of a landslide in Hong Kong. The landslide is a large, reddish-brown area of exposed earth and rock, cutting through a densely built-up urban area. The surrounding area is filled with high-rise apartment buildings and green spaces. The text is overlaid on the image, with the title at the top, the location name 'Hong Kong' near the top left, and two boxes containing 'NATURAL' and 'HUMAN' factors on the right side. A footer at the bottom left identifies the source as 'SIO15 2024: Topic 11 - Landslides, Mass Movements'.

Classical Mass Movements – Hong Kong



Hong Kong Stacked Apartments in Quarry Bay source: wikipedia

NATURAL:

- ✦ climate (HK: humid/sub-tropical; typhoons)
- ✦ elevation

HUMAN:

- ✦ urban development
- ✦ population pressure
- ✦ building in unstable environment

This slide features a photograph of a dense, vertical stack of apartment buildings in Quarry Bay, Hong Kong. The buildings are tightly packed, with many balconies and windows visible. The text is overlaid on the image, with the title at the top, the location name 'Hong Kong Stacked Apartments in Quarry Bay source: wikipedia' at the bottom left, and two boxes containing 'NATURAL' and 'HUMAN' factors on the right side.


Understanding Mass Movements- Yungay

31 May 1970 Yungay, Peru

- * Nevado Huascarán > 6,400 m
- * **ice cap**
- * Mw 7.7 EQ triggered debris/mudflow
- * 18,000 fatalities
- * **recurring hazard (1962: 4,000)!!**

NATURAL:

- ✦ climate
- ✦ elevation
- ✦ plate tectonics/EQs



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HUMAN:

- ✦ building in unstable environment

Understanding Mass Movements

22 September 2013

- * Hurricane Ingrid/Gulf of Mexico
- * **Hurricane Manuel/East Pacific**
- * mudslides in Guerrero
- > more than 190 fatalities

NATURAL:

- ✦ climate
- heavy rain from hurricane



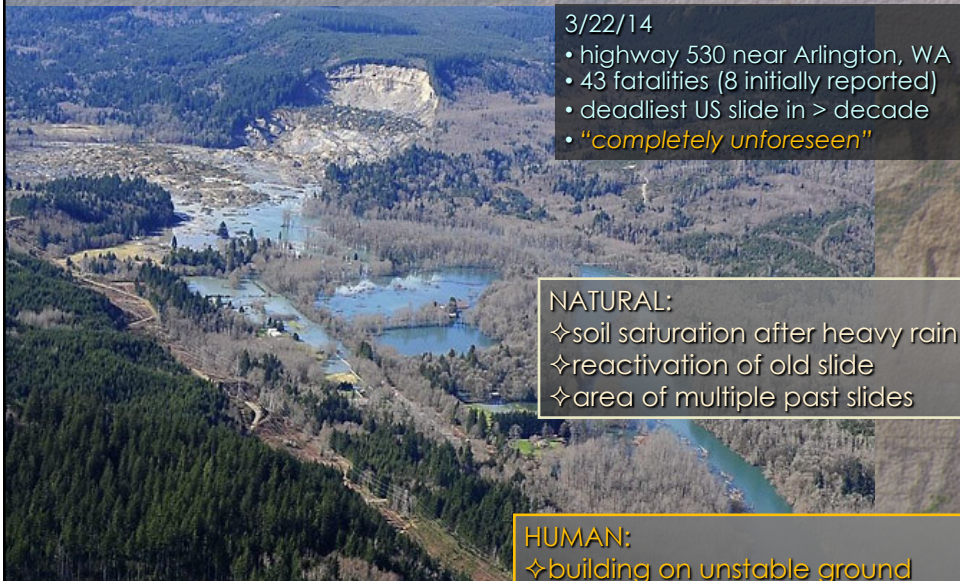
source: CNN

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HUMAN:

- ✦ little warning in remote areas
- ✦ tourism in Acapulco affected (10 years before Hurricane Otis)

Mass Movements 2014: the Oso Mudslide



3/22/14

- highway 530 near Arlington, WA
- 43 fatalities (8 initially reported)
- deadliest US slide in > decade
- "completely unforeseen"

NATURAL:

- ✧ soil saturation after heavy rain
- ✧ reactivation of old slide
- ✧ area of multiple past slides


HUMAN:

- ✧ building on unstable ground
- ✧ careless logging
- ✧ ignorance/disregard of hazards

Hazel Landslide history going back to 1937

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Mass Movements 2014: the Oso Mudslide

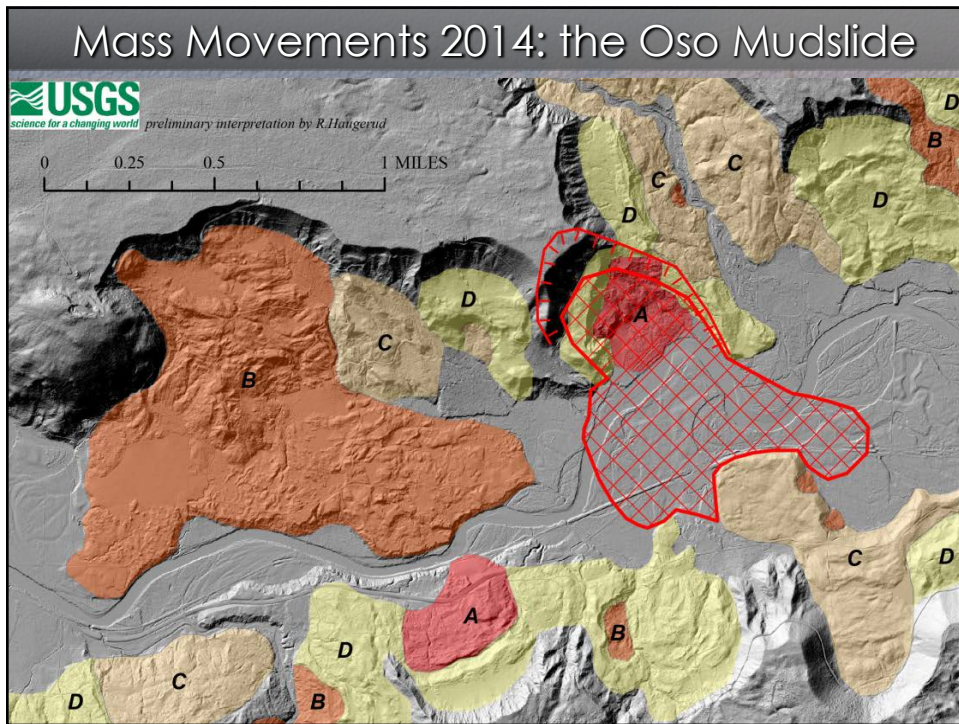
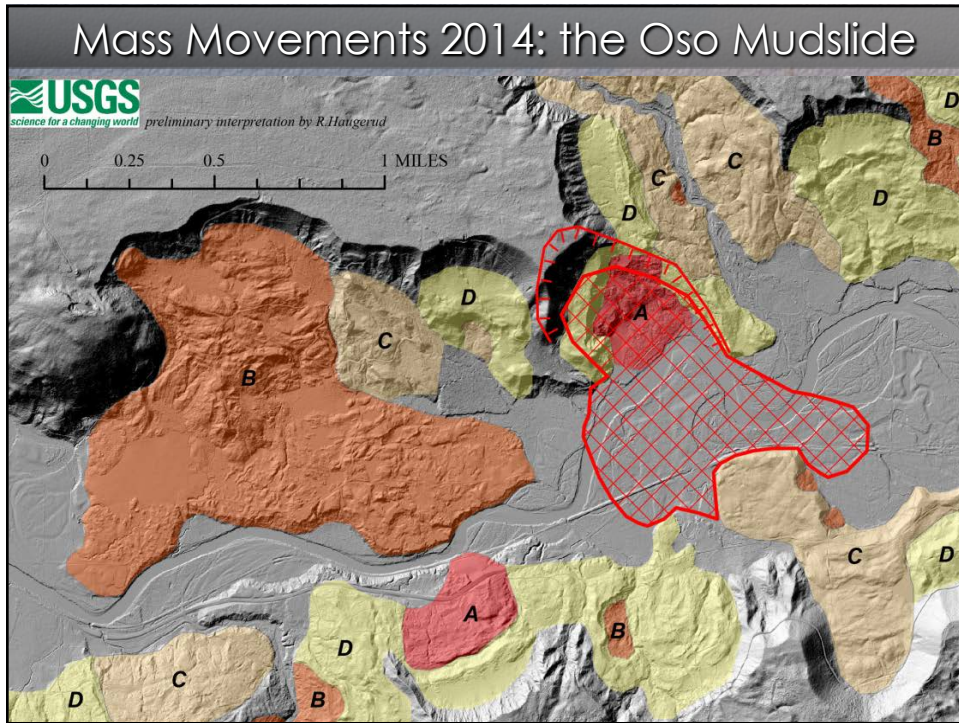


HUMAN:

- ✧ building on unstable ground
- ✧ careless logging
- ✧ ignorance/disregard of hazards

Hazel Landslide history going back to 1937

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9 Jan, 2018 – Montecito/Santa Barbara

second-deadliest US mass movement in modern times



12/4 2017 – 1/12/2018 Thomas fire
282,000 acres burned (largest in modern Cali history, until Aug 2018)
21 fatalities from mudflow Jan 2018

source: Wikipedia

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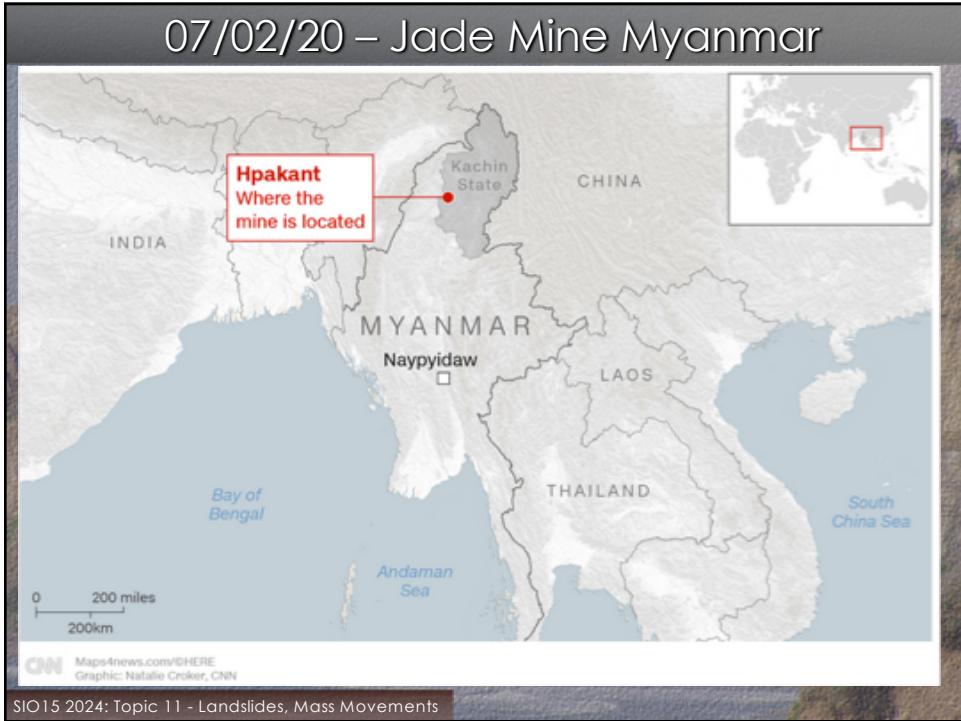
Recent Deadly Mass Movements

Date	Name	# Fatalities	Comment
30 Jul 2024	Wayanad, Kerala, India	443+	multiple slides in Wayanad district
24 May 2024	Enga, Papua N.G.	160-2000	buried 6 villages
6 Feb 2024	Maco, Philippines	92	after heavy rain
22 Jan 2024	Liangshui, China	44	steep cliff top
20 Nov 2023	Wrangell, AK	6	slide buried a family
16 Dec 2022	Batang Kali, Malaysia	31	unlicensed campsites in high-risk area
26 Nov 2022	Ischia, Italy	12	after heavy rain
23 Nov 2022	Palmeira de Faro, Portugal	2	after excavation of unstable rock
29 Oct 2022	Maguindanao, Philippines	63	Tropical Storm Nalgae
30 Jun 2022	Manipur, India	58	
15 Feb 2022	Petropolis, Brazil	231	
3 Jul 2021	Atami, Japan	27	after heavy rain
30 Dec 2020	Gjerdrum, Norway	10	in 'high-risk' zone
7 Aug 2020	Pettimudi, Kerala, India	66+	after heavy rain
2 Jul 2020	Hpakant jade mine, Myanmar	175+	after heavy rain
4-23 Dec 2019	Cibitoke, Burundi	41+	unseasonably heavy rain
9 Aug 2019	Mottama, Myanmar	70	torrential rain
28 Jul 2019	Hpakant jade mine, Myanmar	14	
22 Apr 2019	Hpakant jade mine, Myanmar	57	
22 Dec 2018	Anak Krakatau, Indonesia	426	tsunami from submarine landslide
9 Jan 2018	Montecito, SoCal	20	heavy rain during Thomas fire
14 Aug 2017	Freetown, Sierra Leone	1141+	particularly wet rainy season
24 Jun 2017	Xinmo, Sichuan, SW China	10	after rainy season
17 Jun 2017	Karrat Fjord, Greenland	4	from tsunami, locally 90-100m tall
12 Jun 2017	Bangladesh	152	worst in country's history
2 Apr 2017	Mocoa, Colombia	329+	weather-related
21 Nov 2015	Hpakant jade mine, Myanmar	113	man-made waste pile collapsed
13 Nov 2015	Zhejiang, China	38	

Hpakant 15 Aug
32+ dead
(Aljazeera/CNN/Reuters)

Hpakant:
* 4 out of 28 most deadly recent landslides
* 4 in 5 years

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07/02/20 – Jade Mine Myanmar



Source: BBC, NPR, Aljazeera

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- ✧ > 162 dead (175+ as of 2024)
- ✧ True toll likely unknown
- ✧ Heavy rain
- ✧ Unstable waste pile collapsed

07/02/20 – Jade Mine Myanmar

“one of the worst accidents to hit the treacherous industry”



Source: BBC, NPR, Aljazeera

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- Billion-dollar industry
- reckless, irresponsible mining
- Large-scale, illegal
- poor 'freelance' miners

Deforestation and Mass Wasting



MADAGASCAR

badlands



Before

After

NATURAL:

- ✧ climate
- ✧ tropical rainforest has poor soil

HUMAN:

- ✧ deforestation

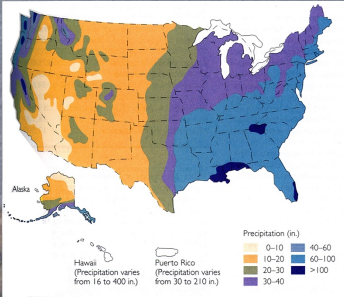
Tropical Rainforest particularly problematic

Tropical Soil:

- thin humus layer
- fast decay
- soil takes long time to form

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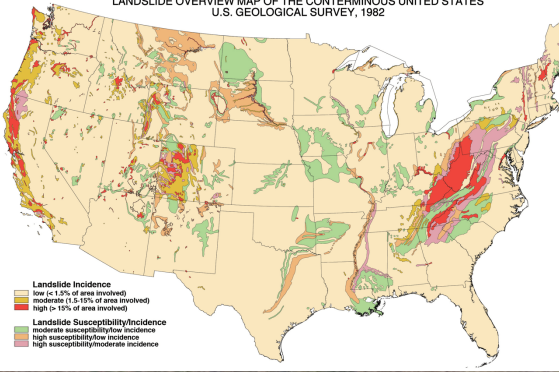
Mass Movements in the U.S.



Precipitation (in.)

Hawaii (Precipitation varies from 16 to 400 in.)

Puerto Rico (Precipitation varies from 30 to 210 in.)



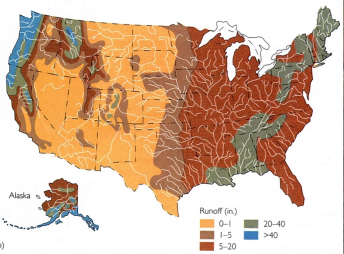
LANDSLIDE OVERVIEW MAP OF THE CONTERMINOUS UNITED STATES
U.S. GEOLOGICAL SURVEY, 1982

Landslide Incidence

- low (< 1.5% of area involved)
- moderate (1.5-15% of area involved)
- high (> 15% of area involved)

Landslide Susceptibility/Incidence

- moderate susceptibility/low incidence
- high susceptibility/low incidence
- high susceptibility/moderate incidence



Runoff (in.)

areas of high precipitation
 areas of steep slopes
 areas of high runoff
 large, meandering rivers

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Types of Mass Movements (e.g. USGS)

USGS
many different categories

Classification may include;

- which material
- how much water is involved
- how a material moves
- speed of movement
- type of environment

Fig. 8.18

The diagram illustrates ten types of mass movements labeled A through J:

- A. Rotational landslide:** Shows a curved failure surface with material rotating as it moves down a slope.
- B. Translational landslide:** Shows a flat failure surface where material slides parallel to the slope.
- C. Block slide:** Shows a large, rigid mass of material sliding along a flat failure surface.
- D. Rockfall:** Shows a rock mass falling from a cliff face.
- E. Topple:** Shows a rock mass rotating and falling from a cliff face.
- F. Debris flow:** Shows a fast-moving flow of a mixture of rock, soil, and water down a slope.
- G. Debris avalanche:** Shows a large volume of debris moving rapidly down a slope.
- H. Earthflow:** Shows a flow of fine-grained soil and clay with a curved failure surface.
- I. Creep:** Shows very slow, continuous movement of soil and rock down a slope.
- J. Lateral spread:** Shows horizontal displacement of soil and rock layers, often due to seismic activity.

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CREEP

too slow to watch but telltale signs

- ❖ tilted poles, fences, gravestones
- ❖ cracked walls
- ❖ bent tree trunks
- ❖ covered roadsides

The diagram illustrates the signs of creep on a slope. A house on the left shows a sagging foundation and cracked walls. A tree trunk in the center is curved. A power pole on the right is tilted. Below the ground surface, a 'Creep zone' is shown with arrows indicating the direction of movement. Below the creep zone is the 'Intact bedrock'. Tilted gravestones are shown at the bottom of the slope.

Gilman Dr., Feb 2005

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Types of Mass Movements

SLIDES

all sizes, speeds at mm/day to m/min
moves down slope as whole
translational

SLUMPS

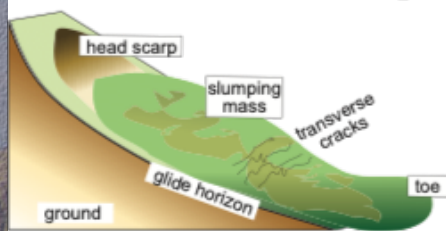
all sizes, speeds at mm/day to m/min
rotates in place as whole
rotational



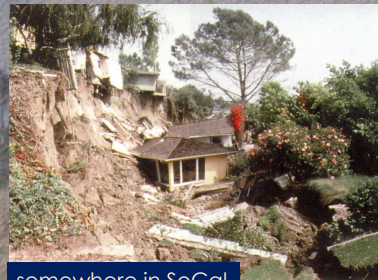
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Basic Features of Slope Failure

The Features of a Slump



top: head scarp/tear-away zone
bottom: toe/pile-up zone
glide horizon/surface of weakness
middle: transverse cracks



somewhere in SoCal



Mt. Soledad, Oct 13, 07

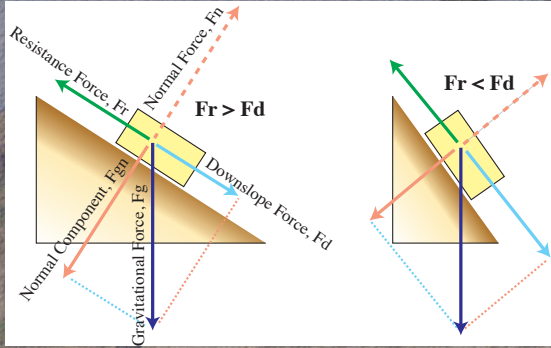
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see Chapter 2 short video 8a

The Role of Gravity

- ◇ pull of gravity downslope -> F_d
- ◇ resistance force due to friction -> F_r

GLIDE HORIZON
surface between
unstable mass and solid ground



NATURAL:
earthquakes lower F_r

HUMAN:
◇ vibrations
◇ heavy traffic

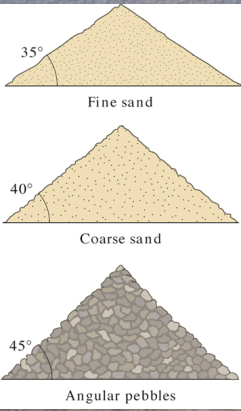
- ◇ $F_r > F_d$ -> mass stays put
- ◇ $F_r < F_d$ -> mass slides down


GRADIENT
vertical/horizontal
(dz/dx)

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The Angle of Repose

- ◇ maximum angle a pile can retain without disintegrating
- ◇ depends on grain properties (size, roundness, cohesion)





Sunset Crater, AZ (cinder cone)
source: volcano.und.edu

WATER

- ◇ a little: adds cohesion, may increase angle of repose (sand castle)
- ◇ a lot: reduces friction, accelerates erosion

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The Role of Water

◇ pull of gravity downslope -> F_d
 ◇ resistance force due to friction -> F_r

ice plants are good and bad!

lubrication of glide horizon
decreases resistance force F_r

NATURAL: rain
 ◇ adds mass
 ◇ reduces frictions

HUMAN:
 ◇ irrigation
 ◇ failing pipes
 ◇ leaky pools

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The Role of Groundwater

OK

BAD

rise of groundwater table above
glide horizon lubricates it;
decreases resistance force F_r

ok:
water table **below**
glide horizon

bad:
water table **above**
glide horizon


NATURAL:
long rain
tectonic changes

HUMAN:
excessive irrigation

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Triggers of Mass Movement

<p>contributing factors</p> <ul style="list-style-type: none"> ✦ preexisting instability ✦ plate tectonics ✦ rain ✦ rising groundwater table ✦ earthquakes ✦ thawing of frozen ground/large change in T 	<ul style="list-style-type: none"> ✦ human construction (roads, houses, grading, dams) ✦ mining ✦ irrigation ✦ excess water withdrawal ✦ traffic ✦ deforestation
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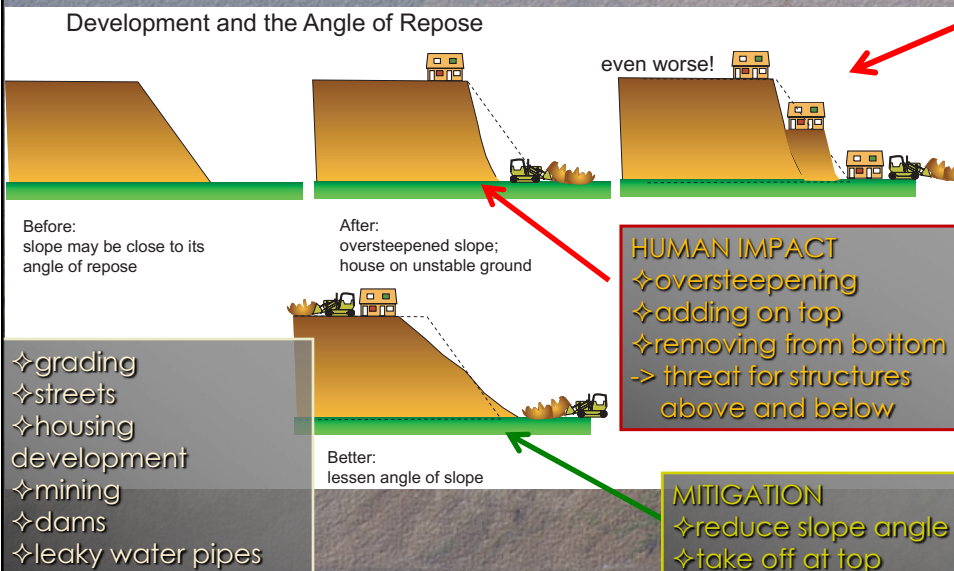


Talus

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... and how humans mess with it

Development and the Angle of Repose



Before: slope may be close to its angle of repose

After: oversteepened slope; house on unstable ground

even worse!

Better: lessen angle of slope

HUMAN IMPACT

- ✦ oversteepening
- ✦ adding on top
- ✦ removing from bottom

-> threat for structures above and below

- ✦ grading
- ✦ streets
- ✦ housing development
- ✦ mining
- ✦ dams
- ✦ leaky water pipes

MITIGATION

- ✦ reduce slope angle
- ✦ take off at top
- ✦ add at bottom
- ✦ protect

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Subsidence – Slow or Sudden Sinking of Surface

Source: Abbott "Natural Disasters"

Winter Park, FL; May 10, 1981



- collapse in karst (limestone) region
- carbonate dissolves on water
 - underground caves
 - sinkholes

NATURAL CAUSES:
subsurface weathering
drought

Karst in Minerve, France



Sinkholes

Source: Abbott "Natural Disasters"

Winter Park, FL; May 10, 1981



HUMAN CAUSES:
excess g.w. withdrawal

- excess irrigation
- failing pipes
- leaking pools
- > subsurface weathering
- > collapse

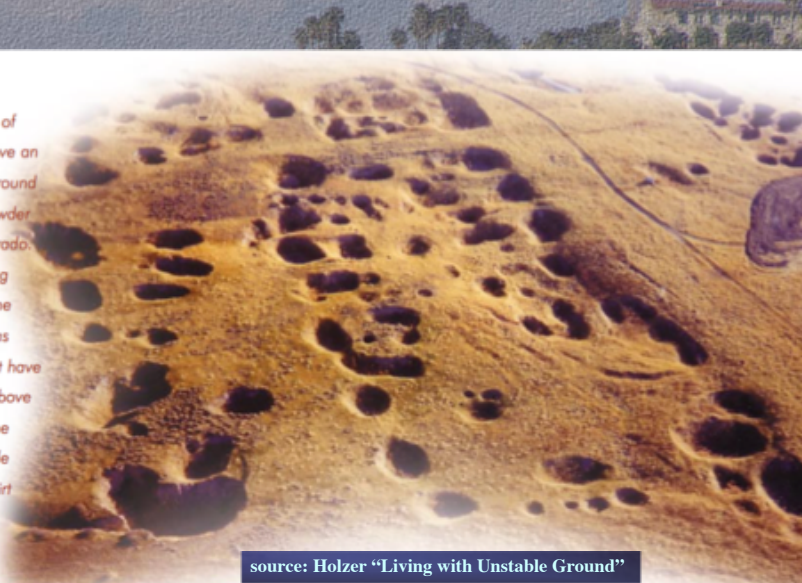
Karst in Minerve, France



Sinkholes - Mining

underground coal mining, CO -> underground cavities -> sinkholes

Fig. 34. Aerial view of subsidence pits above an abandoned underground coal mine in the Powder River Basin of Colorado. Collapse is occurring above "rooms" in the mine where coal was removed. Areas that have not collapsed are above the pillars of coal the miners left to provide support. Note the dirt road for scale.



source: Holzer "Living with Unstable Ground"

Local Sinkholes

Point Loma, San Diego; 19 Oct 2005



Genessee Ave near UCSD; 06 Oct 2011



16 Oct 2014: Sinkhole in Oceanside



- failing underground water infrastructure
- U.S.: 10-30% water unaccounted for (with 30% in cities)
- who pays for repairs?

14 Sep 2017: 20-ft deep; I-8



Subsidence

Central Valley, CA

1925
1955
1977

SAN JOAQUIN VALLEY CALIFORNIA
BH 3461
SUBSIDENCE 9M
1925-1977

San Joaquin Valley

- subsidence of ground: 8.5 m
- drop of groundwater by 1970: 120 m

excess withdrawal for

- farming
- city

Las Vegas

- since 1935, subsidence by several m

About 350 miles (560 km) across

Subsidence

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MISSISSIPPI RIVER
LOUISIANA
New Orleans
DELTA
Margin of 20,000-year-old continental shelf
Gulf of Mexico

0 30 60 km

compaction of sediments

- ◆ New Orleans sunk 3 m in last 50 yrs
- ◆ 45% below sea level

HUMAN CAUSES:

- excess withdrawal (oil, water)
- dredging and canals prevent natural supply of sediments

Delta subsidence in last 20,000 years

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Excess water withdrawal –10/24/16 Newspaper

SAN DIEGO COUNTY

Plan to solve Borrego's water crisis beginning

BORREGO SPRINGS

San Diego County is expected this week to enter into an agreement with the Borrego Water District to begin the preparation of a Groundwater Sustainability Plan aimed at solving the depletion of the underground water table that feeds the Borrego Valley, including Borrego Springs.

The county will commit an initial \$500,000 to the agreement and \$700,000 later as work proceeds on the plan, which is needed to avoid state intervention.

The problem is that Borrego Springs has no feasible way to import water. It relies completely on the underground aquifer that on average is replenished by nature each year to the tune of about 1.8 billion gallons. The amount of water pumped out of the aquifer each year is far greater — most recently, 6.1 billion gallons annually.

Borrego's plan will focus on reducing agriculture in the northern part of the valley where citrus and palm farms consume 70 to 80 percent of underground water. No matter

golf course:
"we have our own aquifer"

replenish: 1.8 B gallons
withdrawal: 6.1 B gallons

north part:
70-80% for citrus and
palm farms