- What is land subsidence and why does it occur?
- How does land subsidence effect us?
- What mitigation strategies are available to avoid or minimize land subsidence?

Land Subsidence

- Deformation of land surface due to compaction, consolidation, or collapse of the subsurface

- The **sudden sinking or gradual downward settling** of land with little or no horizontal motion, **caused by a loss of subsurface support** which may result from a number of natural and human caused occurrences including **subsurface mining or the pumping of oil or ground water**. Land Subsidence events, depending on their location, can pose **significant risks to health and safety or interruption to transportation and other services.**

Land Subsidence?

- Pumping reduces fluid pressure in pore spaces between sediment grains in unconsolidated materials
- Results in reduction in support for “skeleton” of aquifer system
- Weight of over-burden causes collapse, particularly in fine-grained layers

Human-induced subsidence is caused by:

- Withdrawal of fluids from subsurface reservoirs (**water, oil**)
- Collapse of soil and rock over subsurface holes (**underground mines**)
- Draining of wetlands causing the oxidation of organic soils

Sinkholes and Subsidence

Sinkholes

- Solutional
- Collapse

Subsidence

- Sediment and Soil Compaction
  - Collapse soils
  - Fine Sediment
  - Expansive Soils
- Tectonism
- Permafrost
- Lava Tubes

Karst

- Certain rocks are water-soluble, particularly those with gypsum and salt.
- Limestone and other carbonate rocks need acidic water for sinkholes to develop (*karst* terrain)

Sinkhole, Jan 2005, Colorado. On the northern limit of a swarm of sinkholes that extends to Carbondale. The underlying bedrock is evaporite (e.g., gypsum, anhydrite, siltstone and halite). Two electric golfcarts, stored under the structure, disappeared into the sinkhole.

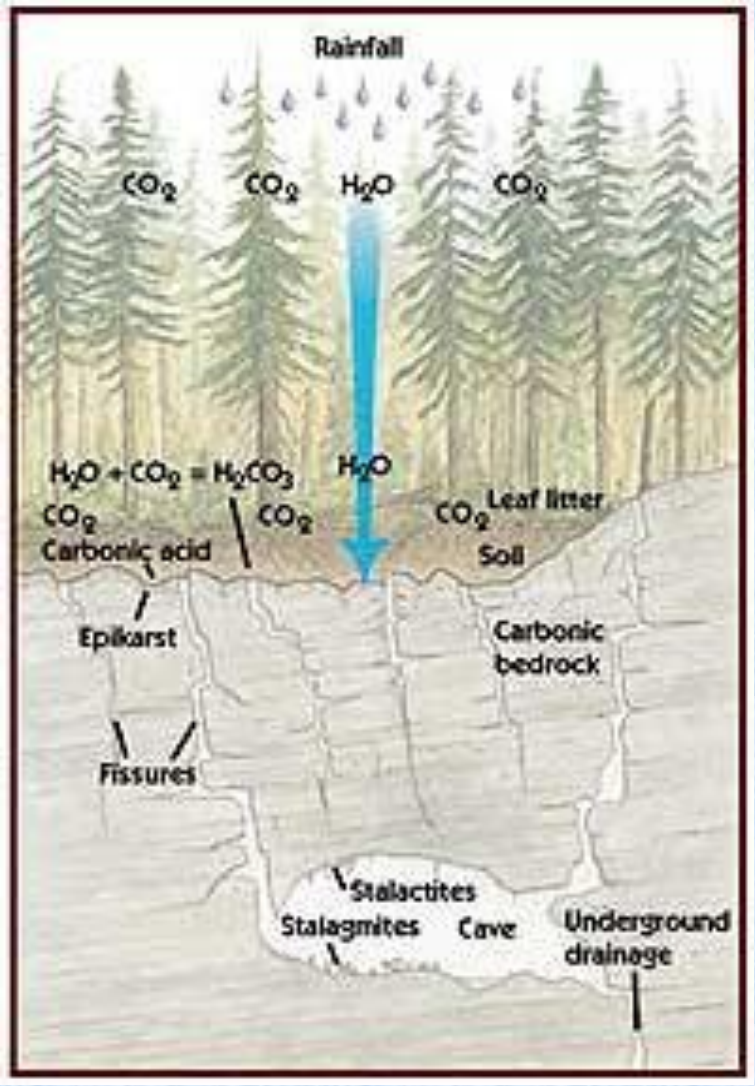
Karst terrain

Areas underlain by limestone or dolostone.

Susceptible to dissolution by acidic rainwater (carbonic acid)

$H_2O + CO_2 = H_2CO_3$
(carbonic acid in water)

Areas underlain by jointed rock are especially vulnerable.



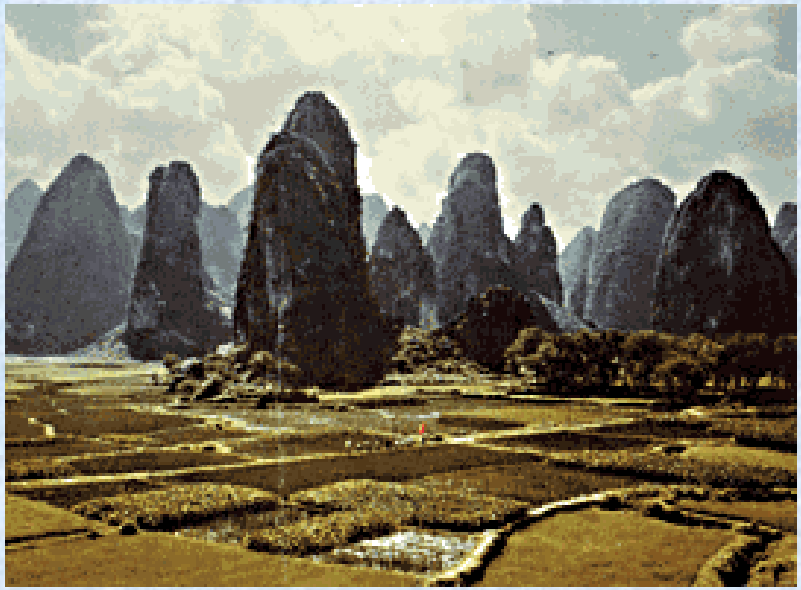
Sinkholes

Come in a variety of scales.

Some may be individuals.

Others occur in large numbers forming a pockmarked plain known as a karst plain.

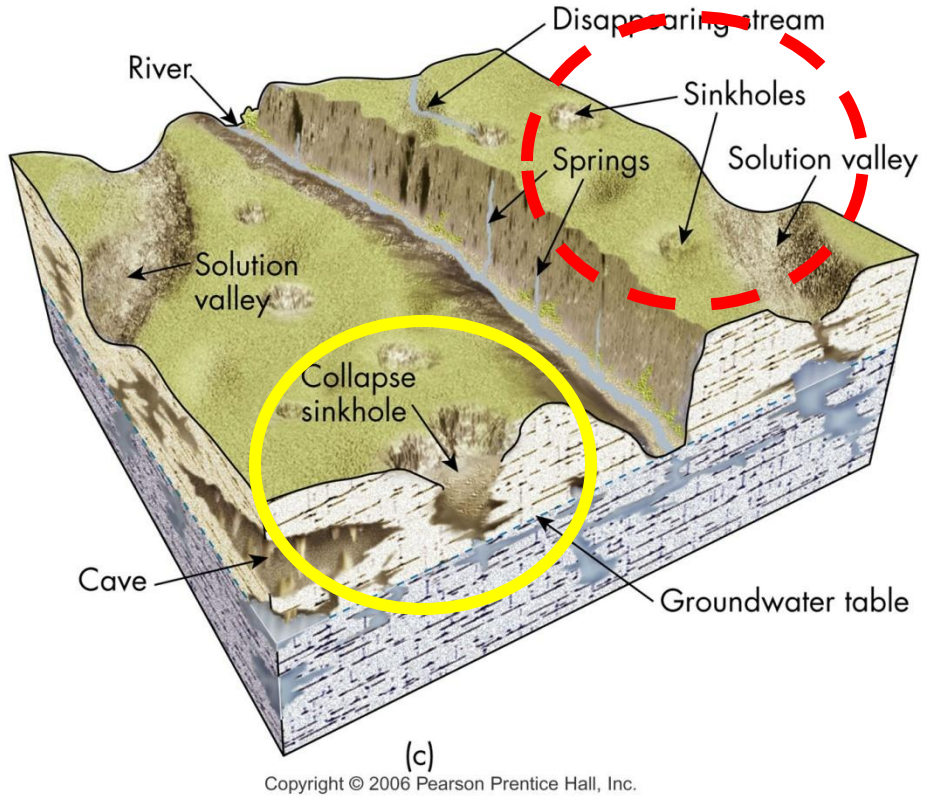
Karst plain, Arizona



Many karst areas underlain by extensive cave systems.

In humid regions, less soluble material is left behind, creating *tower karst*.

Solutional and collapse sinkholes

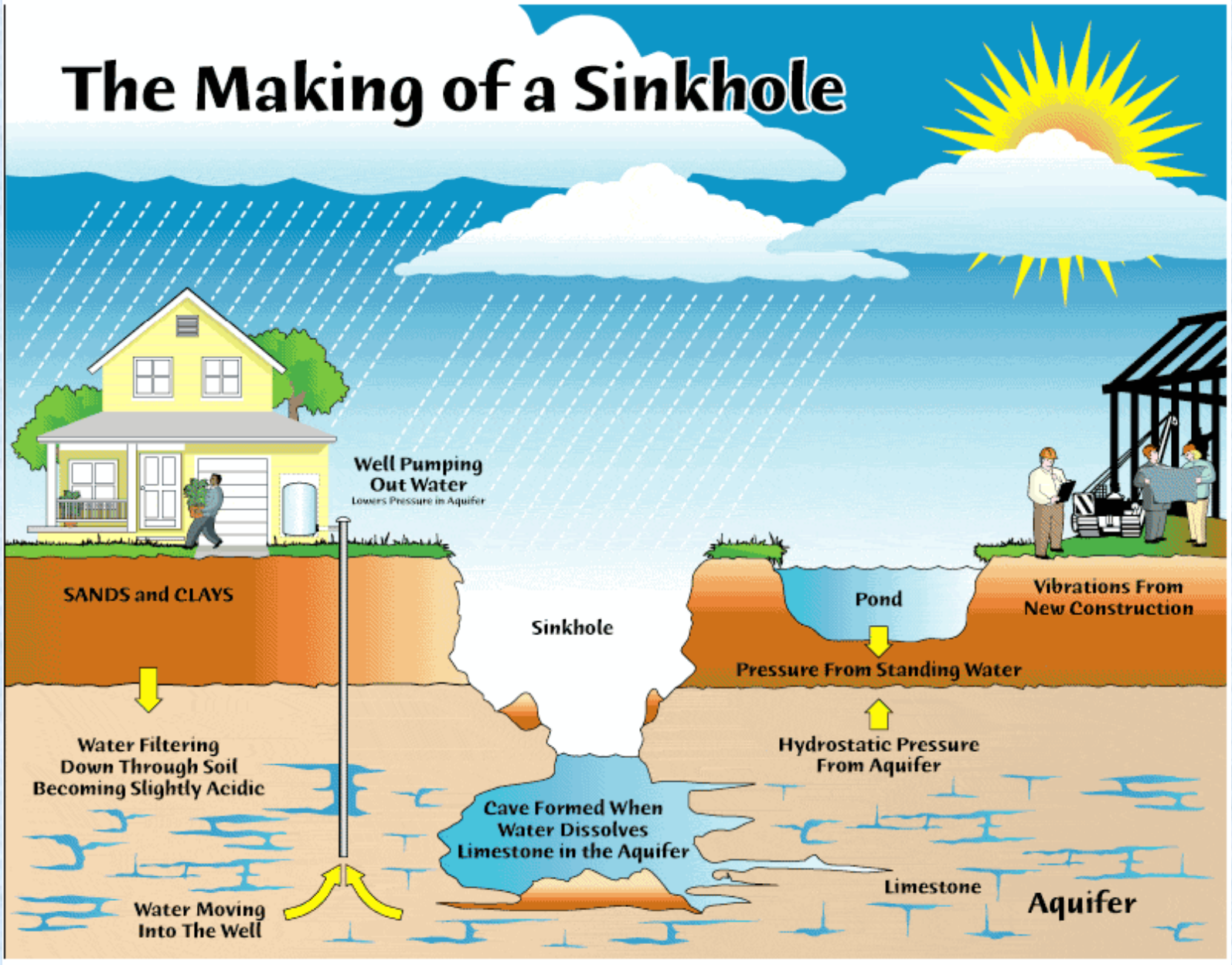


Solutional sinkholes:

- Form by dissolution as acidic groundwater is concentrated in holes associated with joints.

Collapse sinkholes

- Most common type: develop by collapse of near surface material into part of an underground cavern systems. Can be spectacular


The Making of a Sinkhole
Well Pumping Out Water
Lowers Pressure in Aquifer
SANDS and CLAYS
Sinkhole
Pond
Vibrations From New Construction
Pressure From Standing Water
Water Filtering Down Through Soil Becoming Slightly Acidic
Hydrostatic Pressure From Aquifer
Cave Formed When Water Dissolves Limestone in the Aquifer
Limestone
Aquifer
Water Moving Into The Well

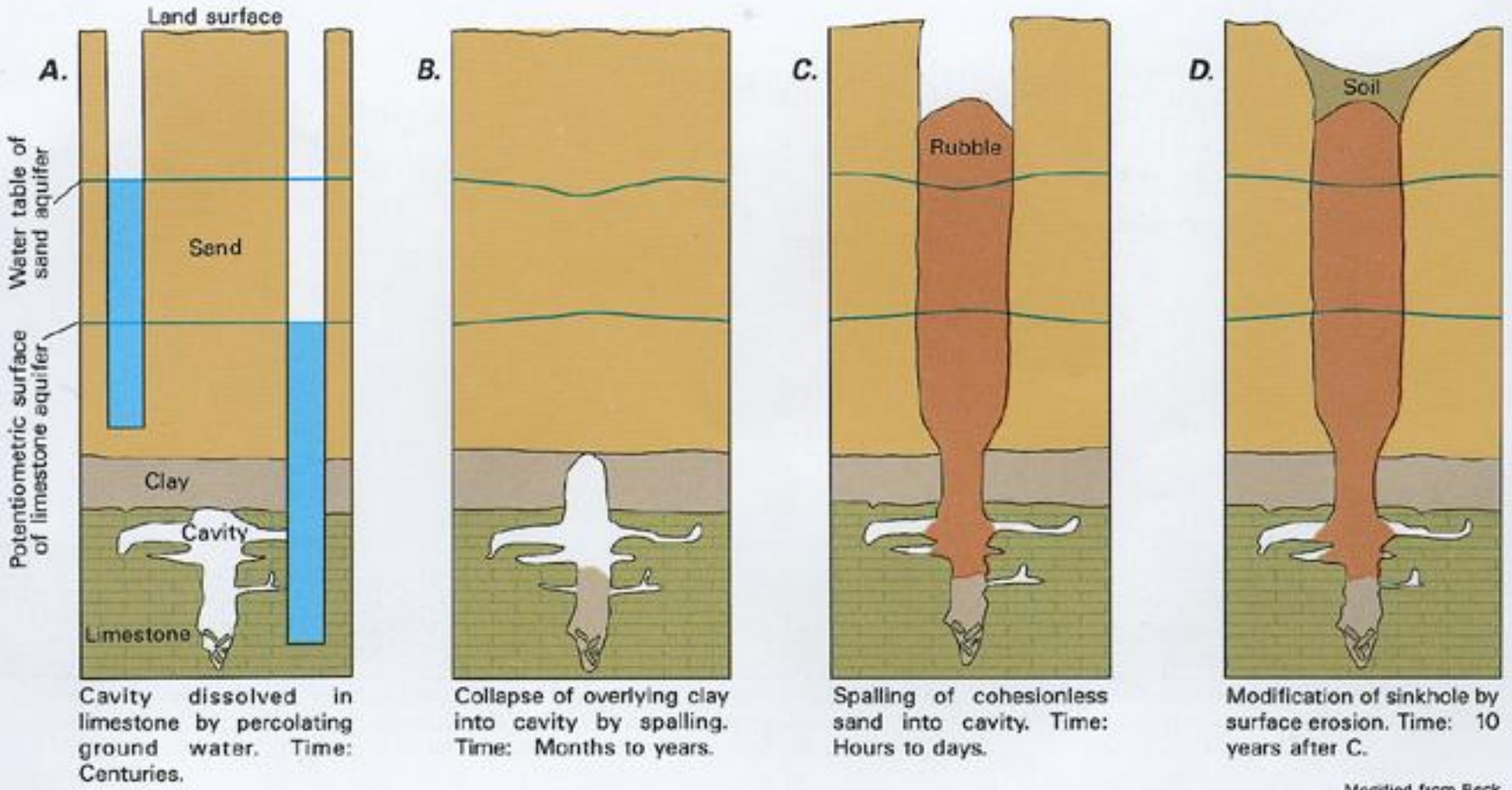


Figure 64. *Collapse sinkholes form suddenly as a cavity roof collapses after dissolution of the limestone beneath the roof. The roof may consist either of clay, as shown here, or of limestone.*

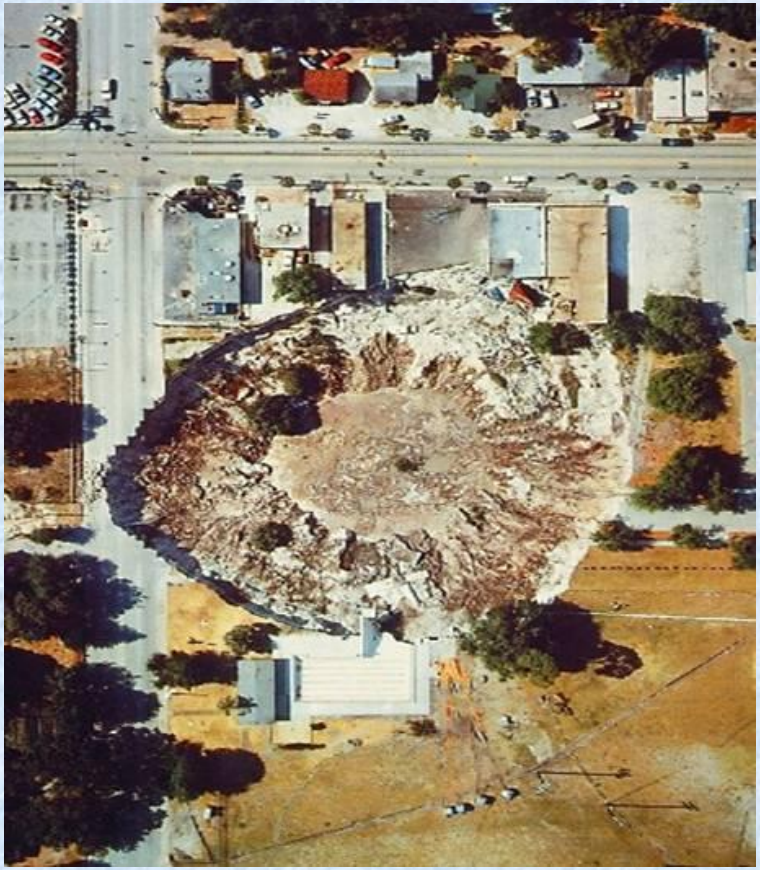
Hazards?

Easily polluted water supplies

- Rapid water flow and little filtration. Point source pollution drains rapidly to drinking water source.
- The municipal sewage lagoons have collapsed in southeastern Minnesota, sending millions of gallons of sewage to the aquifer!

Loss of buildings and infrastructure

Collapse of dissolving bedrock



Florida

Sinkholes

The sudden and sometimes catastrophic collapse may be triggered by groundwater declines caused by pumping

The high solubility of salt and gypsum permit cavities to form in days to years

Carbonate bedrock: slow process- centuries to millennia

Human activities *expedite* cavity formation

Sinkhole at Winter park, Florida, 1981. Occurred in a single day. It was sealed and converted to an urban lake.

Other Karst

Disappearing Streams

Karst Springs

Tower Karst

Disappearing Streams

Karst Springs

Tower Karst

Subsidence

Less obvious than catastrophic sinkhole formation

Develops gradually and is typically widespread

Mapping is critical: InSAR (inteferometric synthetic aperture radar) uses repeat-pass radar images from Earth-orbiting satellites to measure subsidence at sub-centimeter resolution

Ground subsidence

Can occur owing to the compaction of material as

- Water is drained from the soil, often caused by a reliance on groundwater supplies.
- Organic material decays
- Oil is removed

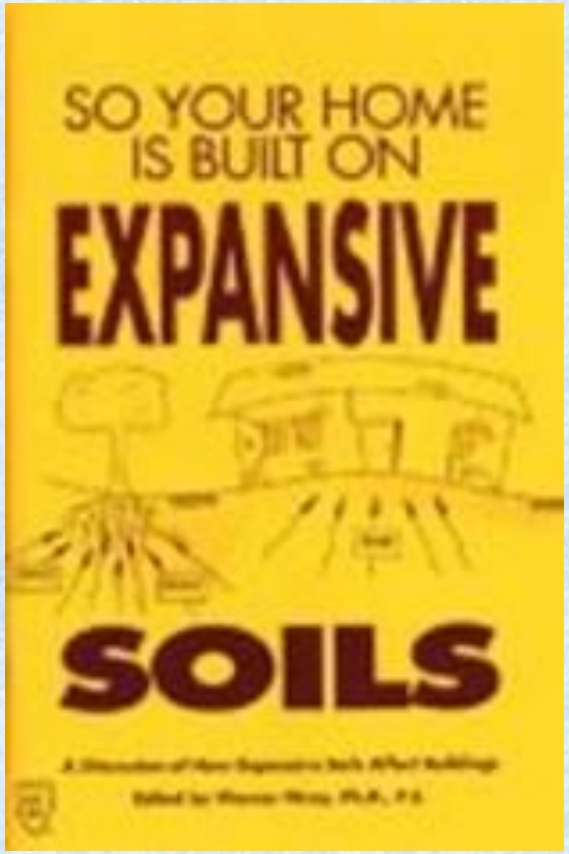
Figure 4. Earth fissure near Picacho, Arizona.

In the arid southwest USA, a visible sign may be fissuring of the earth.

Subsidence…free home remodeling.

Las Vegas

Expansive soils

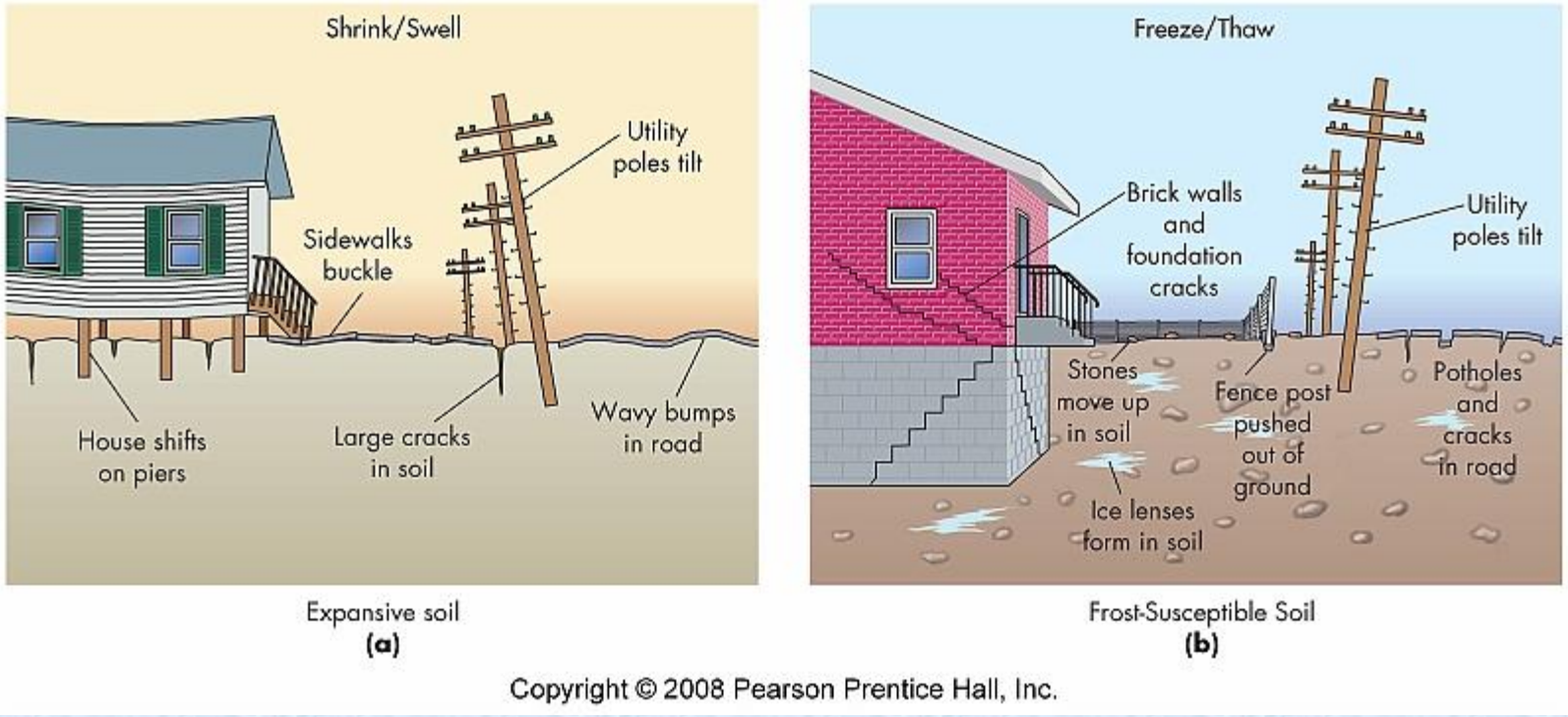


Soils which shrink in dry periods and swell during wet periods.

Causes differential movement which damages foundations.

Clay-rich

Expansive Soils



Expansive soil
(a)

Frost-Susceptible Soil
(b)

Expansive Soils

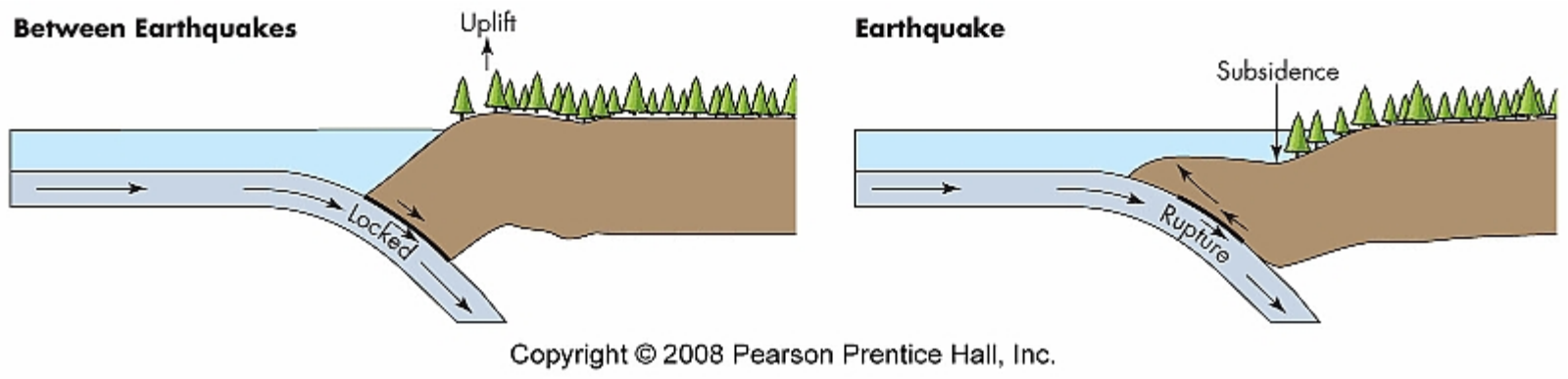
Check the soils report for your area.

Tectonic Subsidence

Land subsidence due to earthquakes

- Fault movement
- Crustal deformation

Tectonic Subsidence



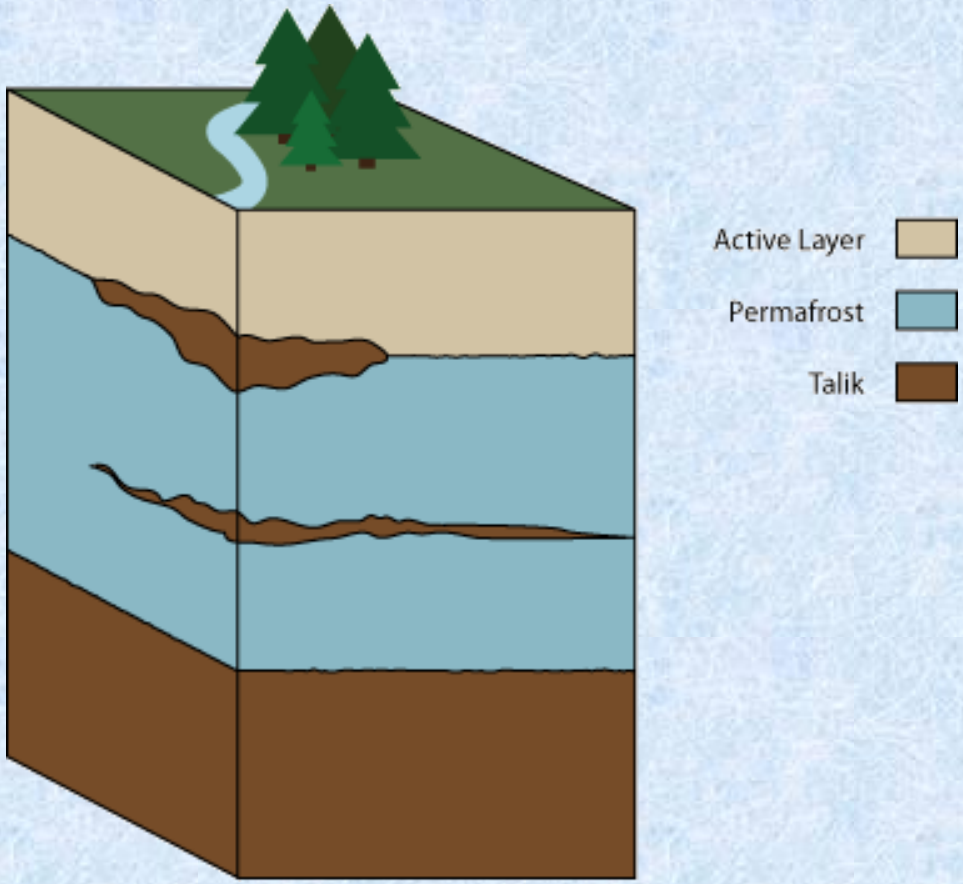
Permafrost

Melting of frozen soils

Common at higher latitudes

Frost Heaving (opposite of subsidence) also a hazard

Permafrost



Permafrost

Permafrost

Permafrost

Deflation of Magma Chambers

Lava tubes may collapse much like caves

Lava Tube Collapse

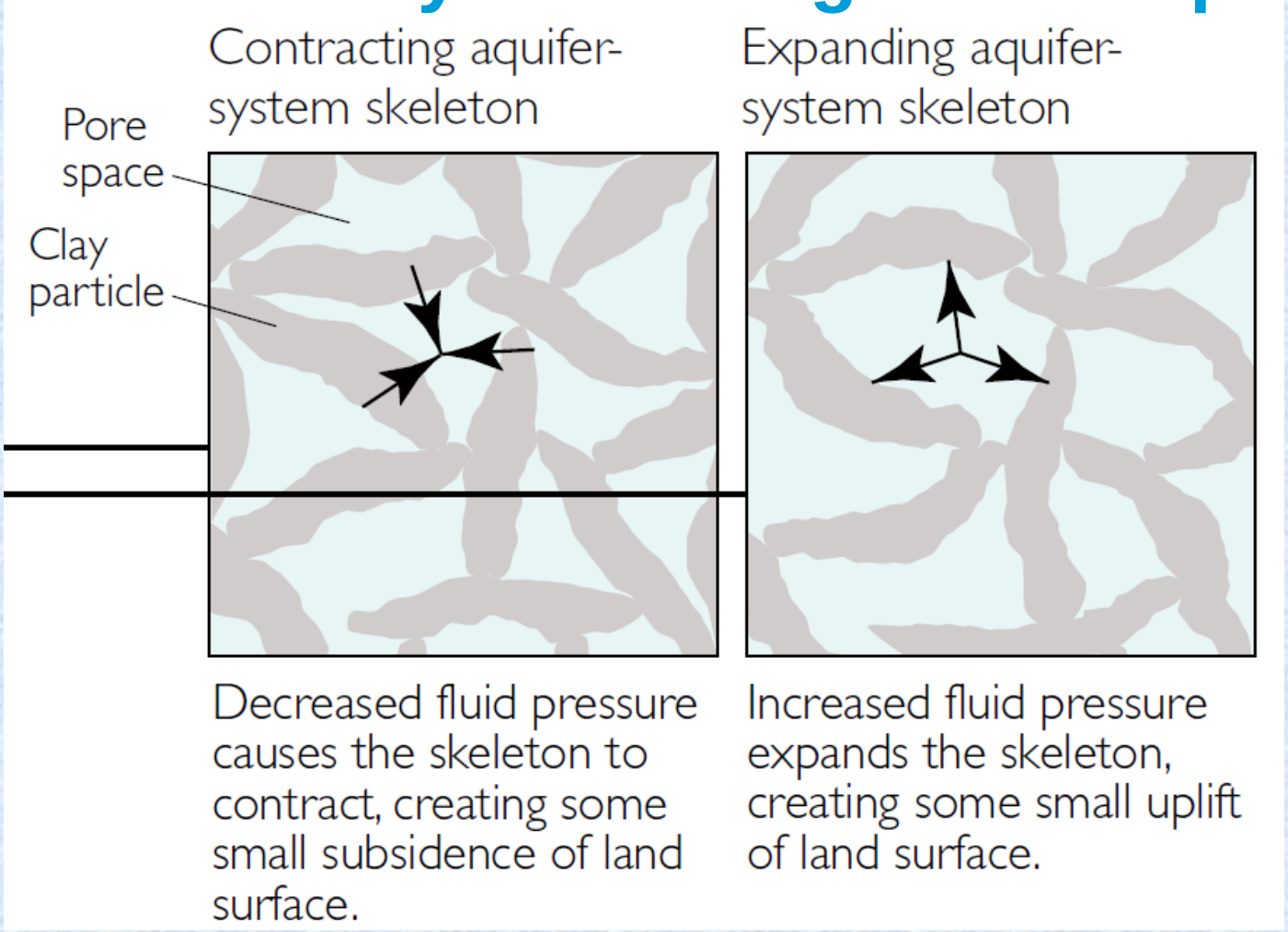
Lava Tube Collapse

Mineral King

Best alpine karst in nation

- Hundreds of sinkholes
- ~130 cave entrances
- Numerous springs and disappearing streams
- Not fully mapped until……

What is Actually Occurring in the Aquifer?



What Do We Need to Know?

- Results in largely permanent loss in aquifer storage
- Can continue after pumping stops due to delayed drainage from fine-grained layers
- Is exacerbated by increasing over-burden

What Do We Need to Know?

- Recharge basins
- Wastewater discharge ponds

Not all basins are created equal

- Same water level decline does not result in same subsidence
- Thickness of fine-grained units is critical!

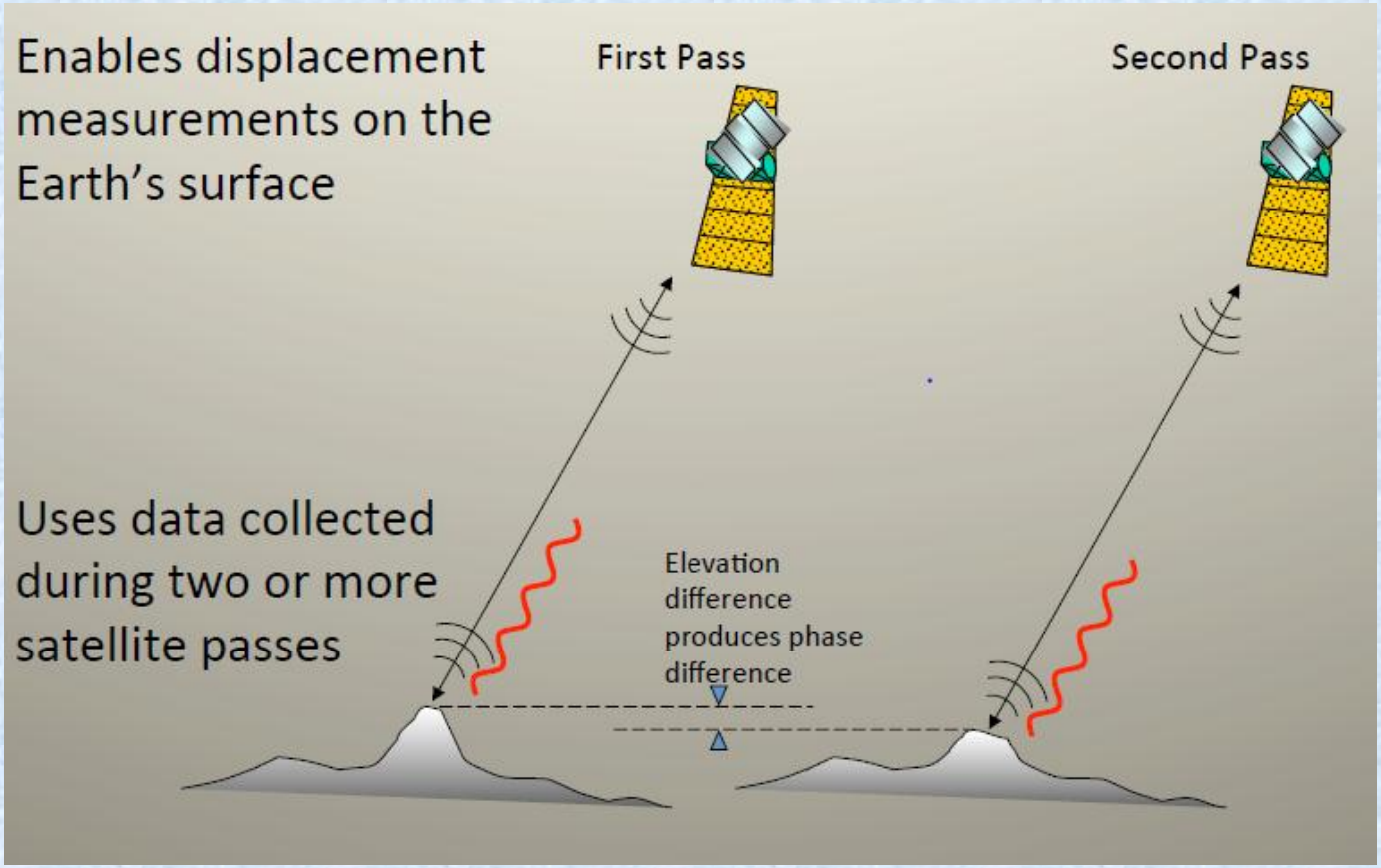
Measuring Land Subsidence
Different techniques used

Traditionally land subsidence was measured using spirit leveling, Vertical Extensionometers and more recently Global Positioning System. Even more recently a new tool is used called InSAR.

Different methods of measuring land subsidence

METHOD	Component displacement	Resolution[1] (millimeters)	Spatial density[2] (samples/survey)	Spatial scale (elements)
Spirit level	vertical	0.1–1	10–100	line-network
Geodimeter	horizontal	1	10–100	line-network
Borehole extensometer	vertical	0.01–0.1	1–3	point
Horizontal extensometer:				
Tape	horizontal	0.3	1–10	line-array
Invar wire	horizontal	0.0001	1	line
Quartz tube	horizontal	0.00001	1	line
GPS	vertical horizontal	20 5	10–100	network
InSAR	range	5–10	100,000–10,000,000	map pixel[3]

How is Subsidence Monitored?



InSAR = Interferometric Synthetic Aperture Radar

Used by ADWR since 2002

What about Earth Fissures?

- Caused by differential settling
- Can show up suddenly and be widened/deepen during rain storms
- Can be miles long, >10 feet wide, and 100s of feet deep

What about Earth Fissures?

What are the Impacts of Subsidence and Earth Fissures?

Largely permanent loss in aquifer storage

Damage to surface and subsurface infrastructure

- Surface – buildings, roads, bridges, pipelines, canals, recharge & wastewater basins
- Subsurface – pipelines, foundations, underground tanks

What are the Impacts of Subsidence and Earth Fissures?

Problems with gravity conveyance systems

- Sewer systems, CAP canal, irrigation ditches

Fissures can provide avenues for contaminants to enter aquifers

What Can be Done?

- Characterize aquifer, focusing on identifying fine-grained layers
- Analyze and project maximum anticipated drawdown
- Design well fields and pumping strategies to minimize well interference and drawdown
- Identify signs of existing subsidence and/or fissures

What Can be Done?

Monitor changes over time

- Track pumping and water level data
- Geologic reconnaissance
- InSAR, if available
- Fissure mapping, if available
- Aerial photography
- Geophysics


SUBSIDENCE
AREA


EARTH
FISSURES
POSSIBLE
25
MPH


DANGER
KEEP OUT
SUBSIDENCE
AREA

Problems caused by subsidence

1.Damage to bridges, canals, roads, storm drains, sewers, canals and levees

2.Damage to buildings

3.Failure in well casings

- In low lying areas subsidence can result in tides moving into areas that were once above sea level
- Large economic costs