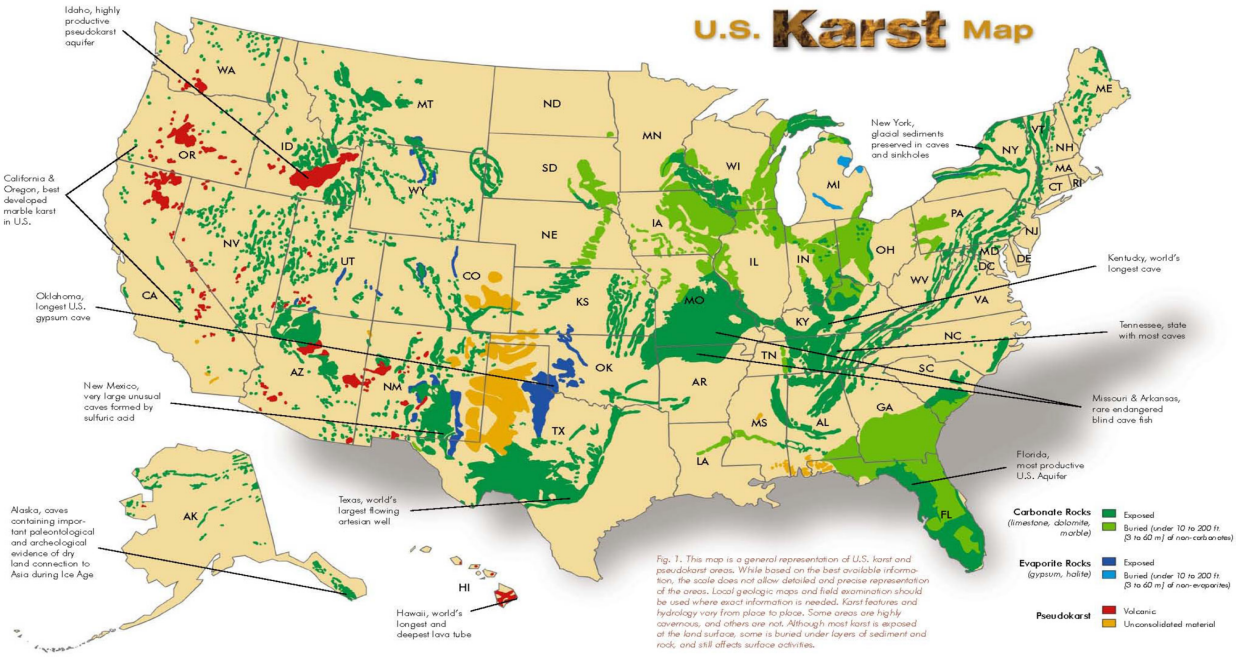
Sinkholes

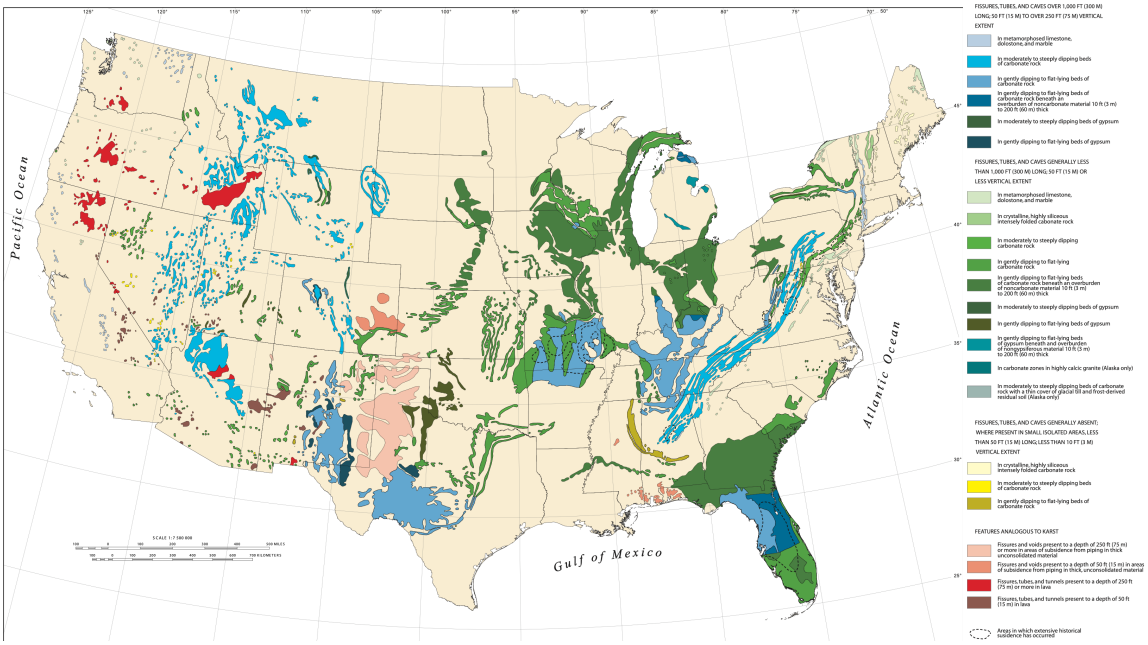
Introduction to Sinkholes

- Geologic Environment
- Karst Development
- Sinkhole Formation Processes
- Types of Sinkholes
- Induced Sinkholes
- Non-Karst Sinkholes
- Detecting Sinkholes

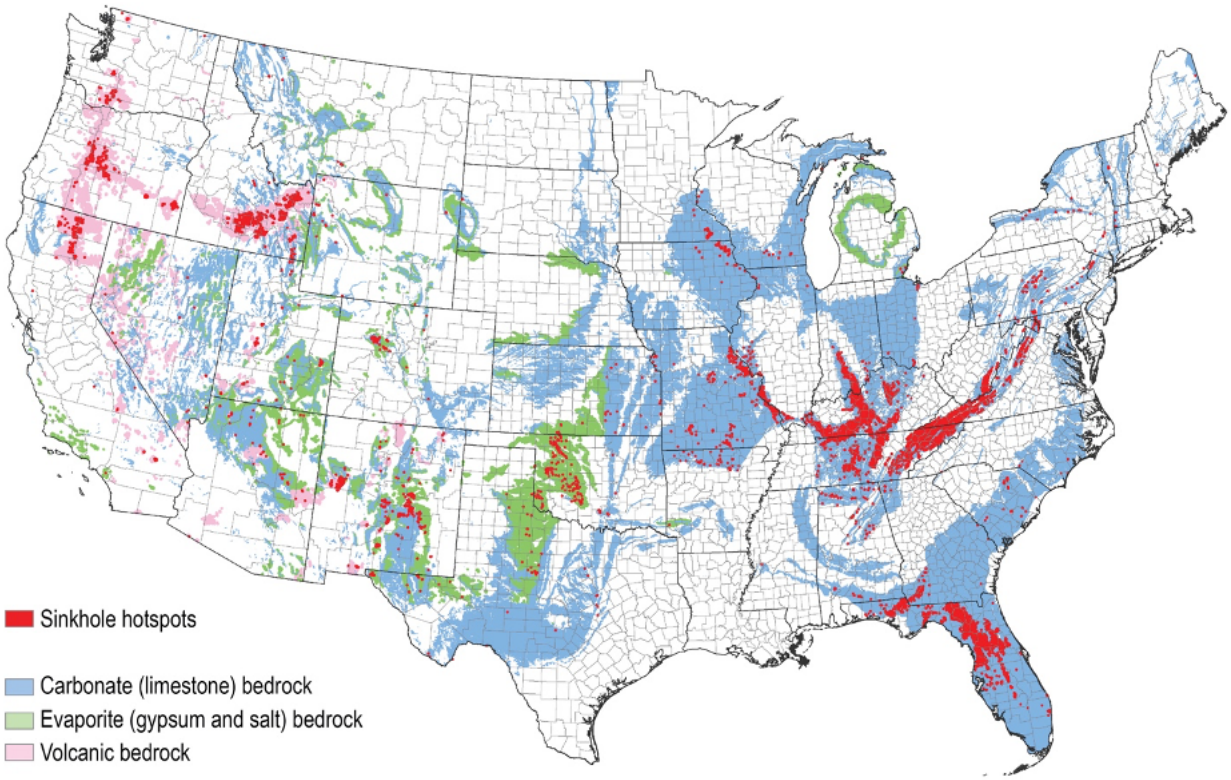
Sinkhole Geologic Environment

1. Karst (carbonate) Geology
   All 50 States
2. Evaporite Deposits (gypsum, halite)
   TX, NM, OK
3. Pseudokarst (volcanic, unconsolidated)
   CO, TX, OK, NM
4. Non-Geology Specific

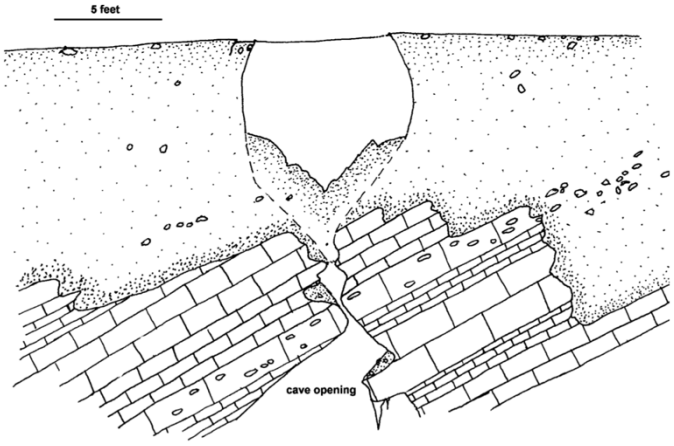




Sinkhole Hotspots



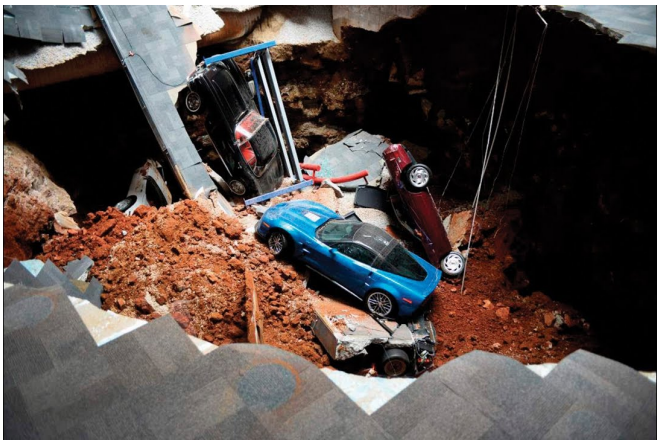
Karst-Related Sinkholes



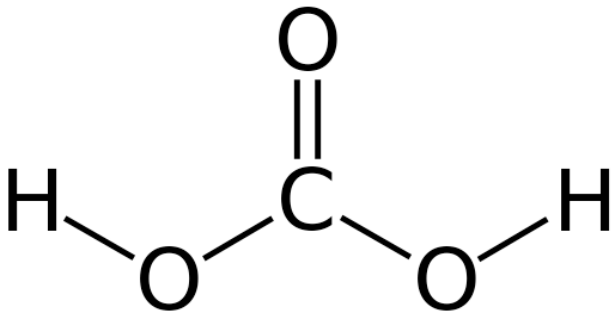
- Sinkholes are surface manifestations of underlying conduits, caves and solution cavities
- Abundance of sinkholes indicate well developed karst
- Alignment of sinkholes can indicate fracture zones

Sinkhole Development in the Orlando, Florida area

National Corvette Museum
Bowling Green, KY (2014)

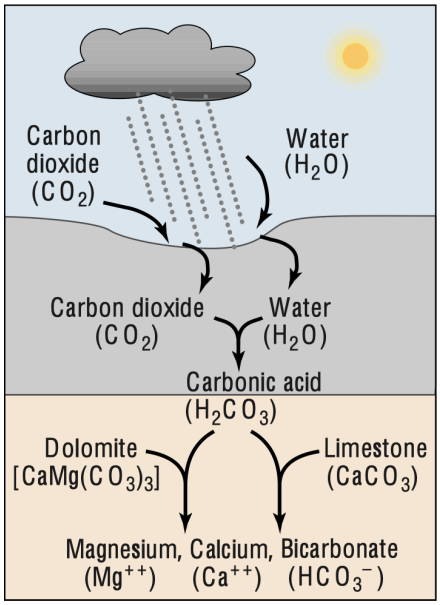


Karst Development
Carbonic Acid Process



Carbonic acid (H_2CO_3), which is a weak acid, forms two kinds of salts: the carbonates and the bicarbonates.
In geology, carbonic acid causes limestone to dissolve, producing calcium bicarbonate, which leads to many limestone features such as stalactites and stalagmites.

Karst Chemistry



Water (H_2O) falling through the atmosphere and percolating the ground dissolves carbon dioxide (CO_2) gas from the air and soil, forming a weak acid—carbonic acid (H_2CO_3).

As the carbonic acid infiltrates the ground and contacts the bedrock surfaces, it reacts readily with limestone ($CaCO_3$) and/or dolomite [$CaMg(CO_3)_3$].

Cavities and voids develop as limestone or dolomite is dissolved into component ions of calcium (Ca^{++}), magnesium (Mg^{++}), and bicarbonate (HCO_3^-).

Dissolution of soluble carbonate rocks by weakly acidic water is ultimately responsible for most sinkholes.

Carbonic Acid Formation

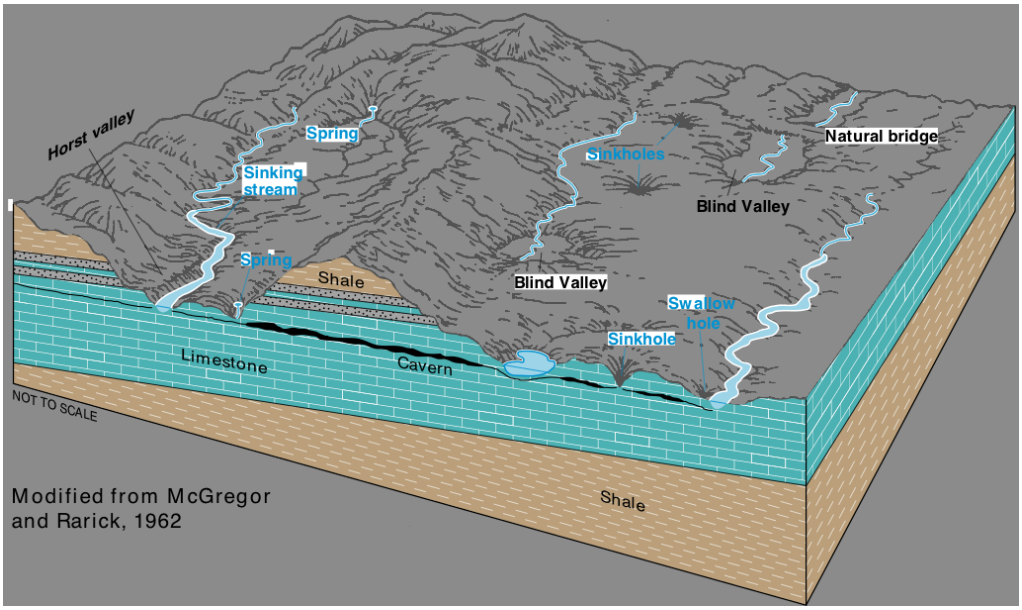
- **Main reaction: $CaCO_3 + H_2O + CO_2 => Ca^{+2} + 2HCO_3^-$**

- **calcite + water + carbon dioxide => calcium ion + carbonic acid**

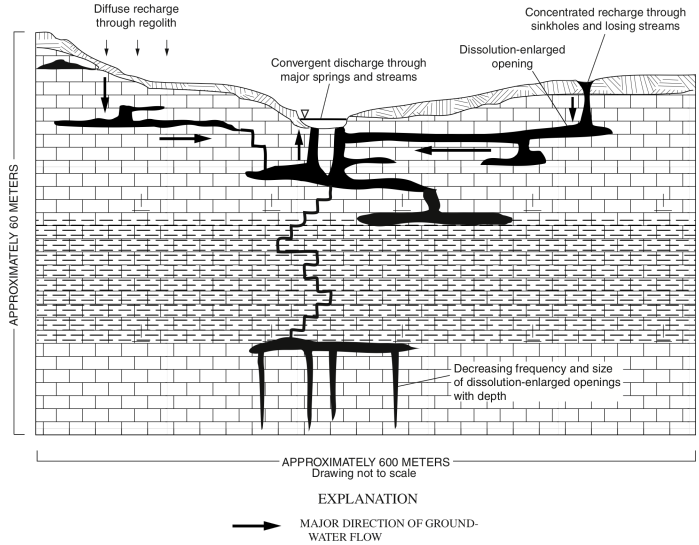
Limestone Dissolution

When the ground water becomes supersaturated with dissolved minerals, further dissolution is not possible, and carbonate salts of calcium and magnesium may precipitate from the water, often forming interesting shapes such as stalactites.

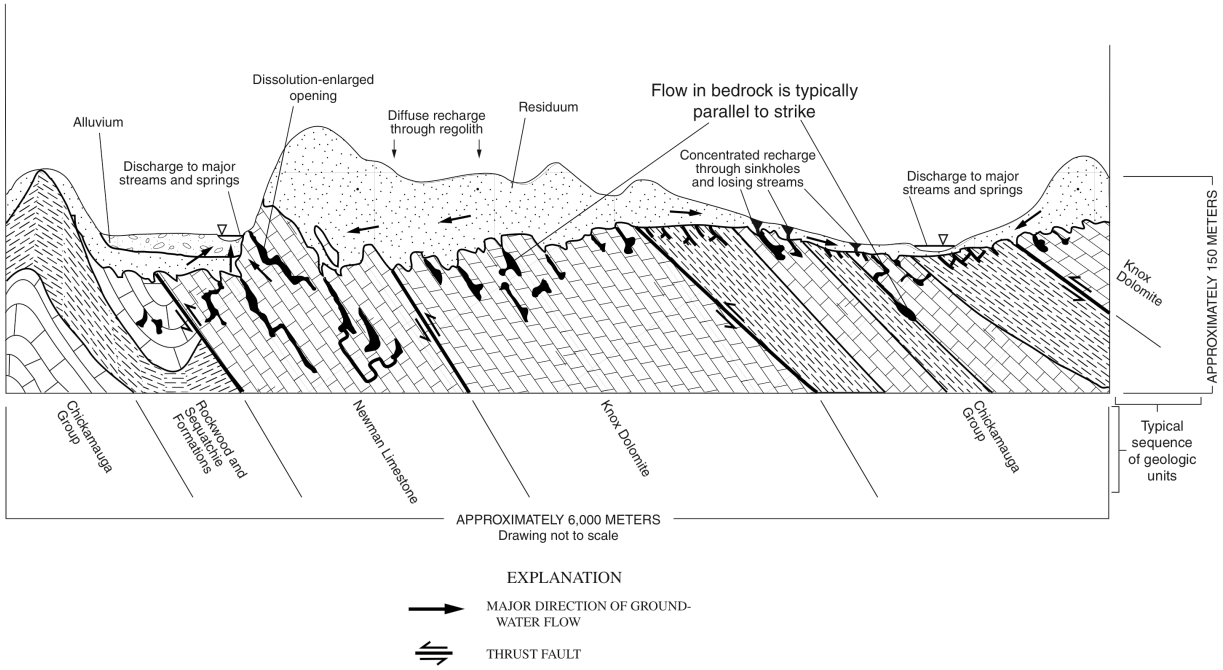
Idealized Diagram of Karst Development



Typical Karst Groundwater Model

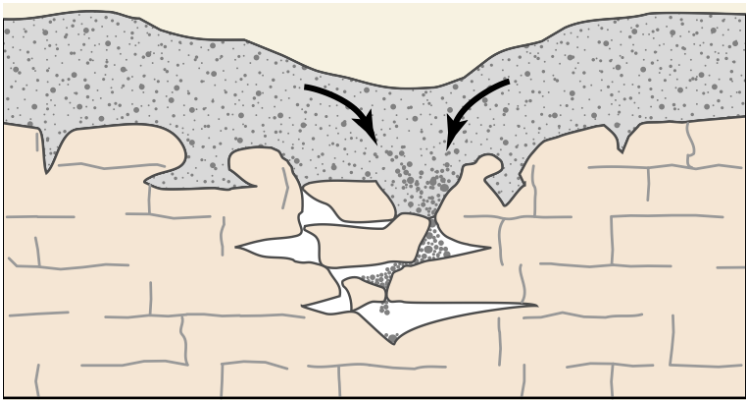


Valley and Ridge Groundwater Model



Sinkhole Formation

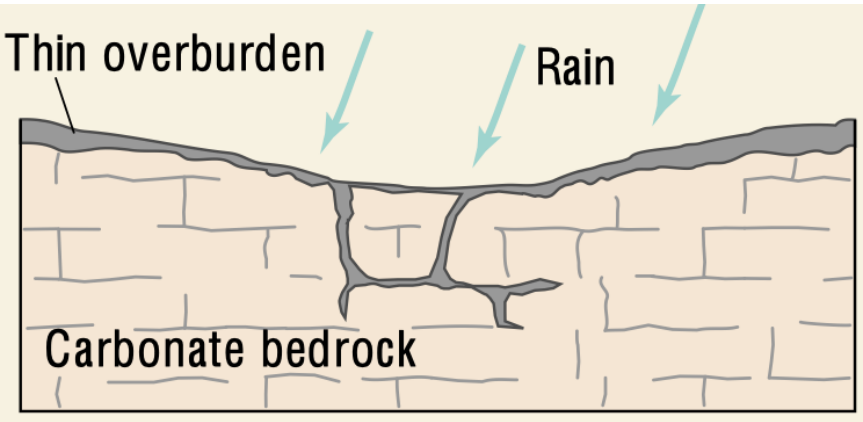
Suffosion



The erosion begins at the top of the carbonate bedrock and develops upward through the overlying sediments toward the land surface.

- Occurs when unconsolidated overburden sediments infill preexisting cavities below them.
- Downward erosion of unconsolidated material into a preexisting cavity is also called raveling.
- Describes both the catastrophic cover-collapse sinkhole and the more gradual cover-subsidence sinkhole.

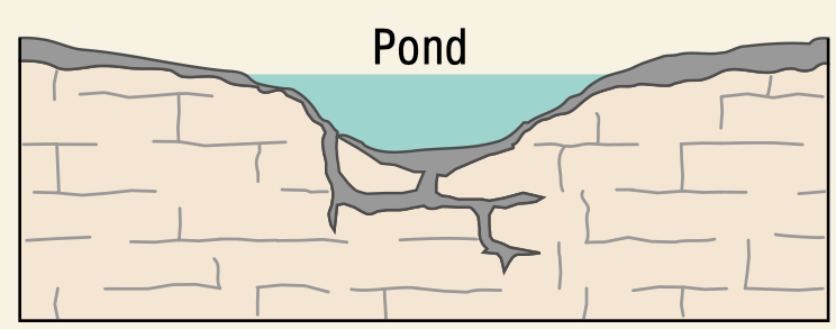
Limestone Dissolution Process



Rainfall and surface water percolate through joints in the limestone. Dissolved carbonate rock is carried away from the surface and a small depression gradually forms.

- Dissolution of the limestone or dolomite is most intensive where the water first contacts the rock surface.
- Aggressive dissolution also occurs where flow is focused in preexisting openings in the rock, such as along joints, fractures, and bedding planes, and in the zone of water-table fluctuation where ground water is in contact with the atmosphere.

Limestone Dissolution Process



On exposed carbonate surfaces, a depression may focus surface drainage, accelerating the dissolution process.
Debris carried into the developing sinkhole may plug the outflow, ponding water and creating wetlands.

- Gently rolling hills and shallow depressions caused by solution sinkholes are common topographic features in karst terrane.

Types of Sinkholes

- Sinkholes typically develop from the bottom up.
- As sinkholes develop, they can become unstable and collapse
- Usually distinguished by some sort of topographic depression.
- Buried sinkholes are the most difficult to identify.

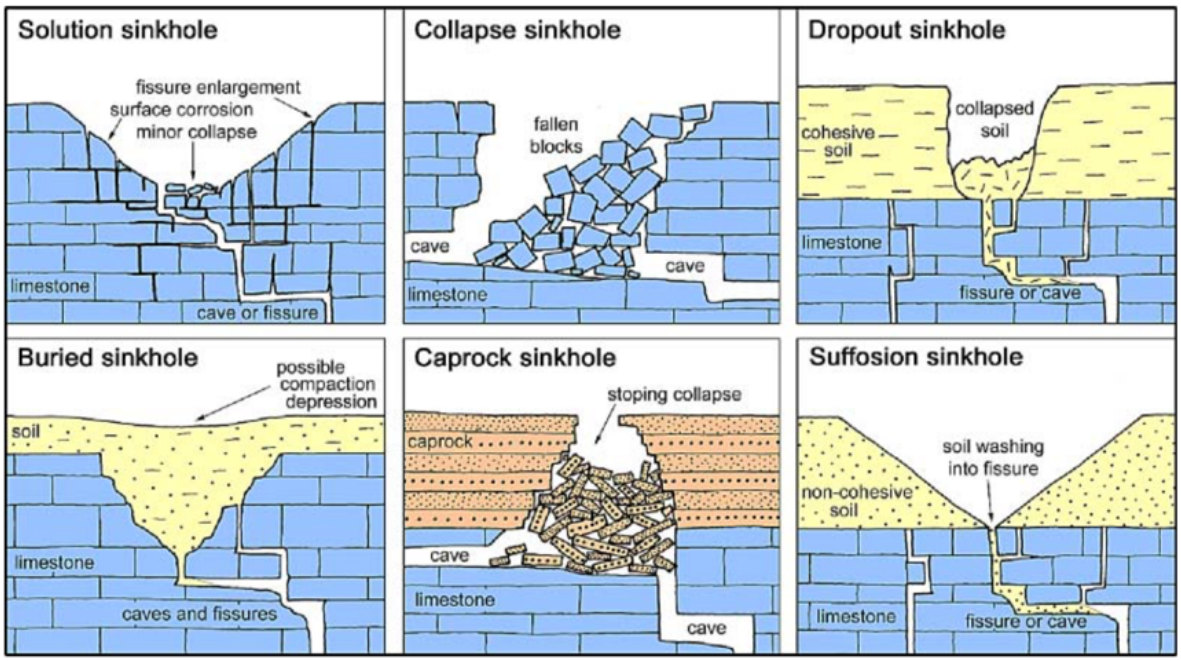
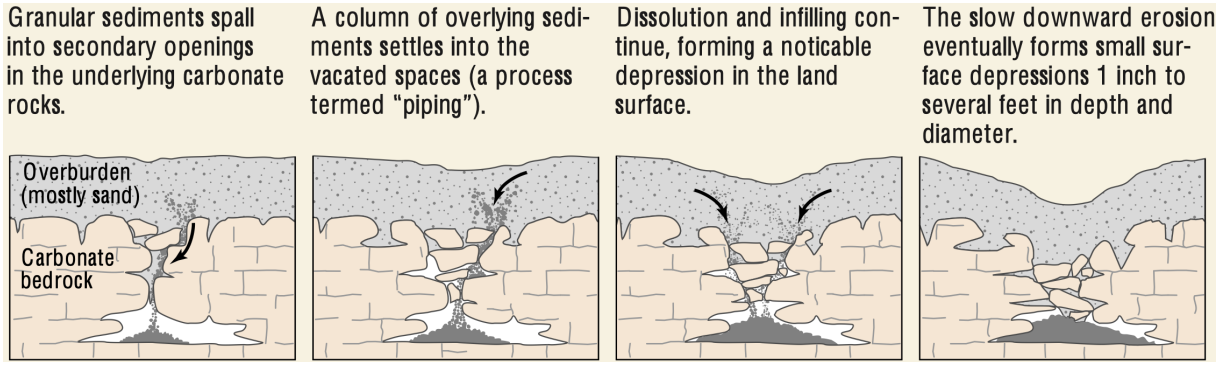
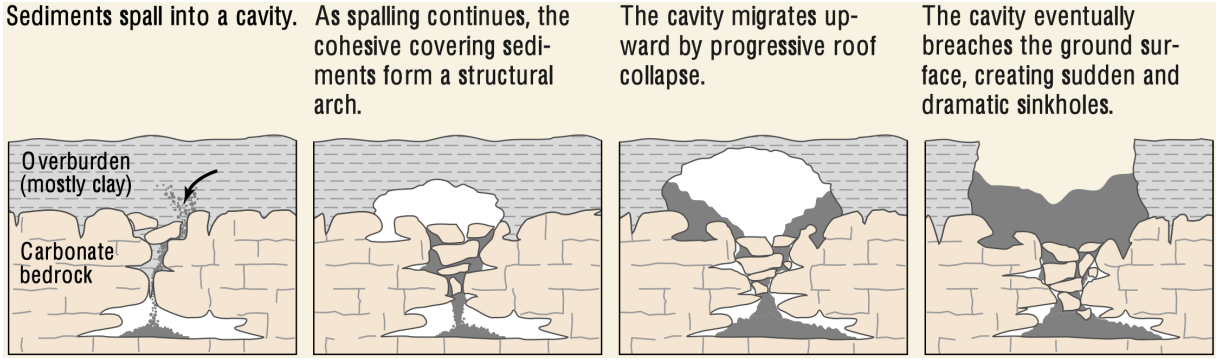


Fig. 5. A classification of sinkholes, with respect to the mechanisms of the ground failure and the nature of the material which fails and subsides; these features are also known as dolines (in the same six classes). The two types on the right may be known collectively as subsidence sinkholes. The structures, cave patterns and sinkhole profiles tend to be more complex in dipping limestone, but the concepts remain the same as those shown by these examples in horizontal limestone; except that the caprock sinkhole cannot exist in conformable vertical beds.

Cover Subsidence Sinkhole



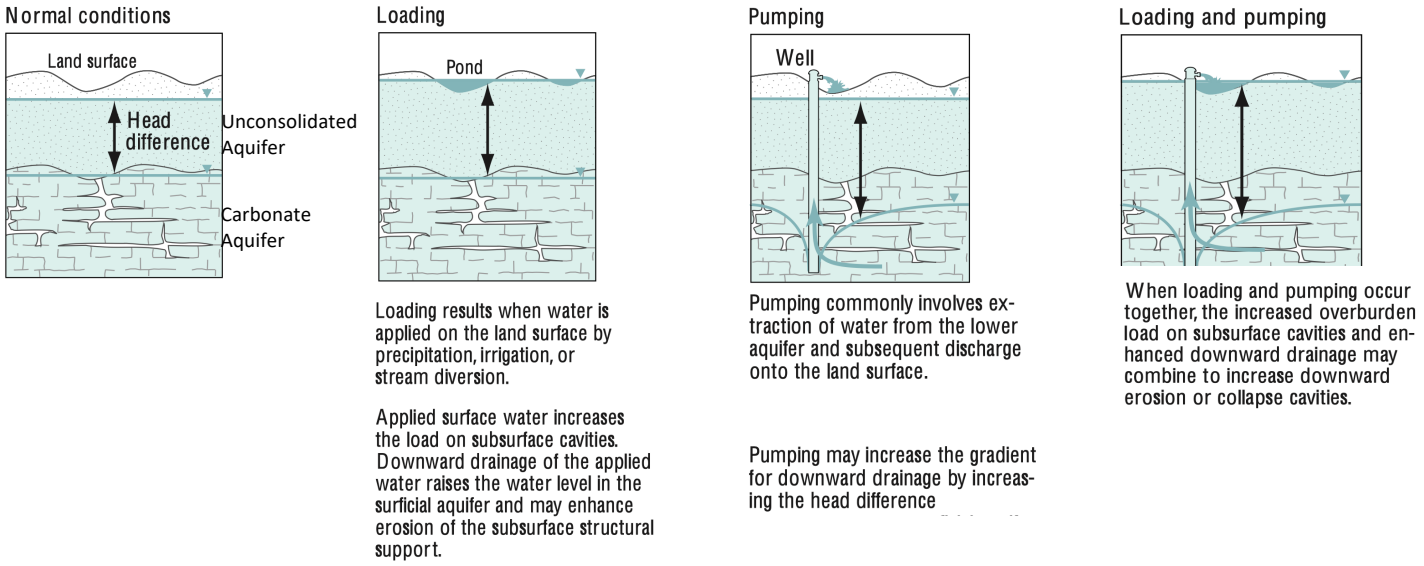
Cover Collapse Sinkhole



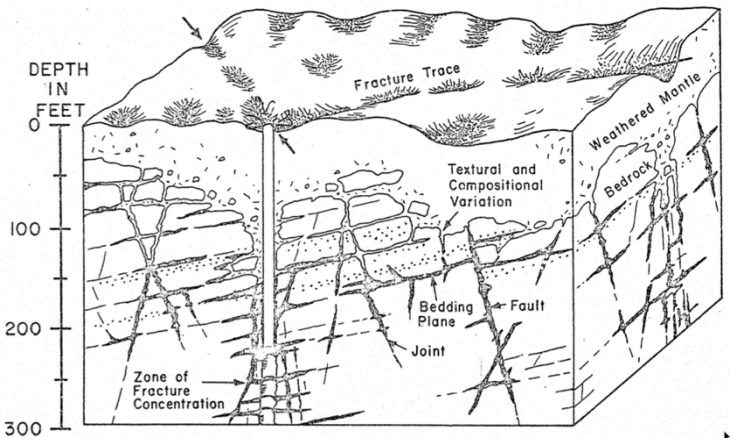
Induced Sinkholes

- New sinkholes have often been correlated to land-use practices
- Induced sinkholes are generally cover-collapse type sinkholes and tend to occur abruptly.
- Induced sinkholes are conceptually divided into two types:
    - Those resulting from ground-water pumping
    - Those related to construction and development practices
- The overburden sediments that cover buried cavities in the aquifer systems are delicately balanced by ground-water fluid pressure.
- In sinkhole-prone areas, the lowering of ground-water levels, increasing the load at land surface, or some combination of the two may contribute to structural failure and cause sinkholes.

Causes



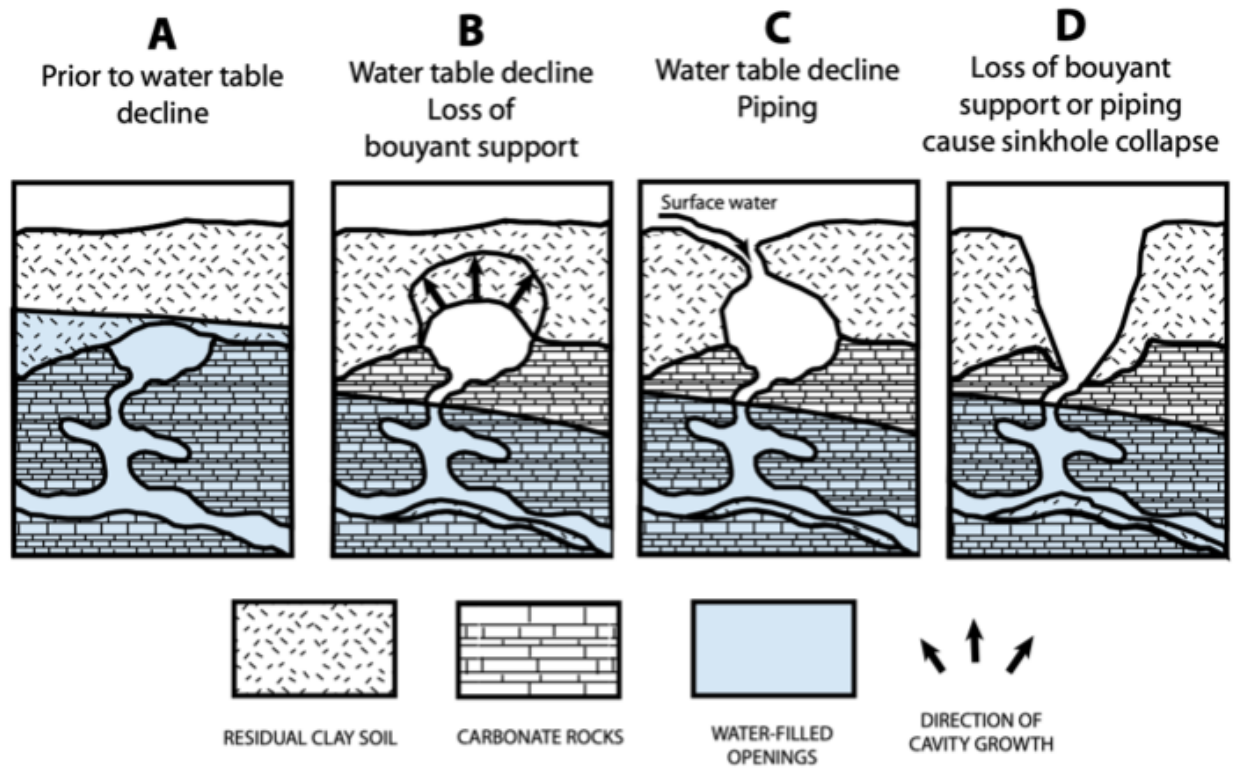
Karst Groundwater Model



The best production zones in karst have the following characteristics

- High concentration of fractures or joints
- Development of interconnected solution channels and cavities along bedding planes

The Role of Hydrostatic Pressure in Induced Sinkholes



Induced Collapse Sinkhole

Non-Karst Sinkholes

Sinkholes Not Related to Karst Geology

- Related to pipe leaks or other man-made conditions (induced).
- Usually a cover collapse type of sinkhole with rapid development.
- Depending on subsurface geology, can be significant size and depth.

Detecting Sinkholes

Methods for Detecting Sinkholes

Simple Methods

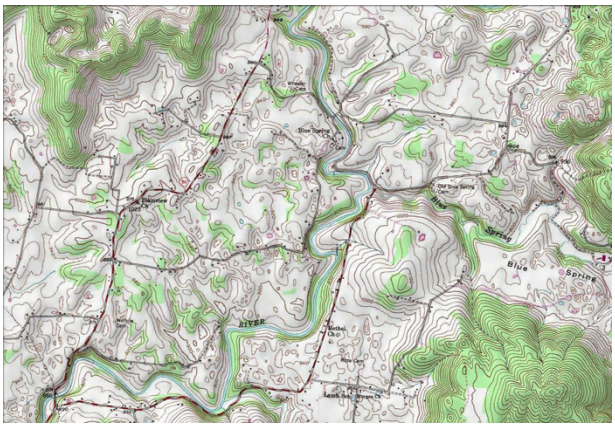
- Topographic Maps
- Aerial Photography
- Geologic Analysis (Karst Geology Conditions)
- Ground Truthing

Complex Methods

- Geophysics (variety of methods)
- LiDAR Analysis
- Dye Tracer Tests

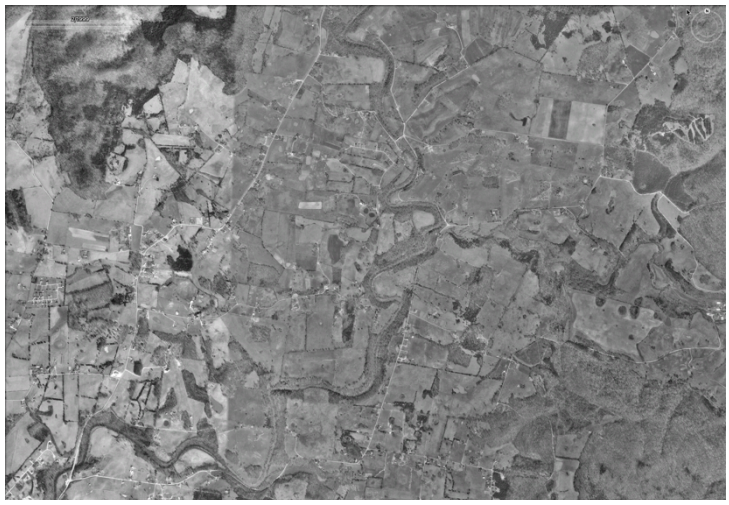
A combination of methods is going to yield the best results

Topographic Maps



- Circular or oblong depressions
- Alignment of depressions
- Round ponds or lakes

Aerial Photography

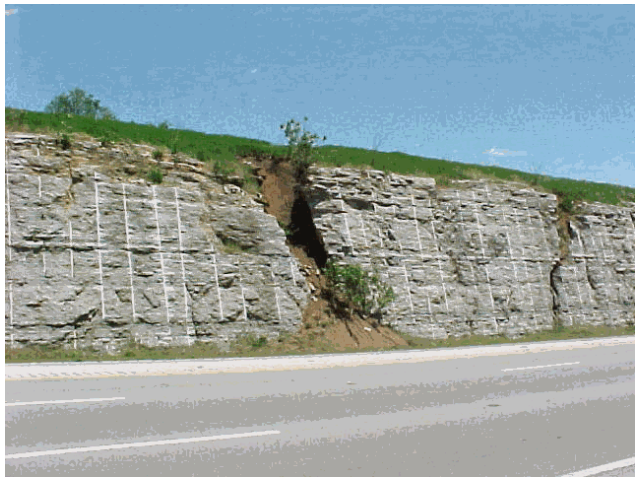


• Black and white aerial photography generally works best
• Vegetation can mask karst features

Geology Counts!

• Limestones that are prone to fractures, solution cavities, caves, conduits (i.e. Karst Geology).
• Aligned springs
• Presence of other sinkholes
• Sinkhole density

Other Karst Features



• Dolines
• Karrens
• Sinking streams
• Pinnacles
• Epikarst

Indicators of karst conduit development

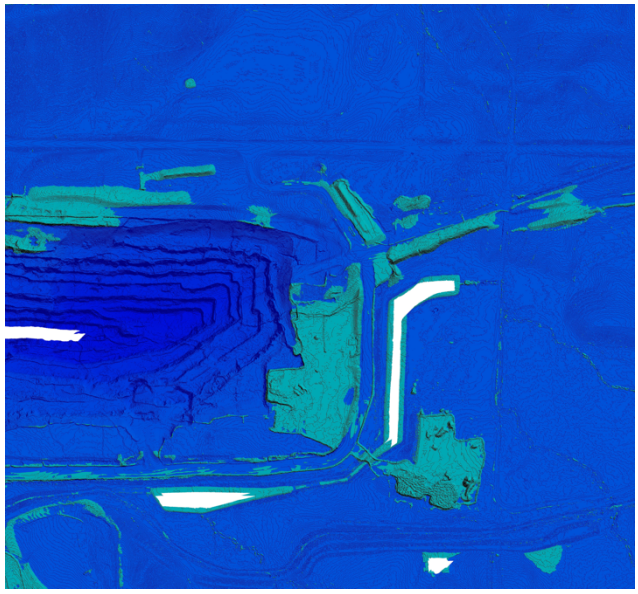
Geophysical Methods

- Can “see” deeper than boreholes and in between
- Can survey large areas relatively quickly
- Can assist in identification of buried sinkholes
- Can be expensive
- Sensitive to “noise”

Most common geophysical methods for karst assessment

- Resistivity
- Ground Penetrating Radar (GPR)
- Electromagnetics (EM)
- Seismic Refraction
- E-Logs

LiDAR-Based Change Analysis



- Use LiDAR imagery from several time intervals (5-10 years apart)
- Prepare Digital Terrane Models
- Subtract older data from younger data
- Analyze differences

Dye Tracer Tests?

- Typically designed for regional studies as opposed to site-specific studies
- Gives a general idea of flow paths and rates
- Can be useful for contamination studies
- Generally can’t be used for to identify sinkholes

Summary

- Sinkholes most often occur in areas of karst geology or karst-like conditions.
- Sinkholes in non-karst environments can occur due to man-made activities.
- Buried sinkholes can be re-activated.
- Cover collapse sinkholes are the most dangerous.