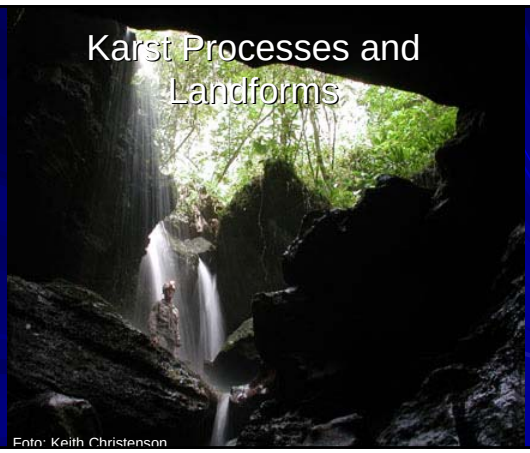
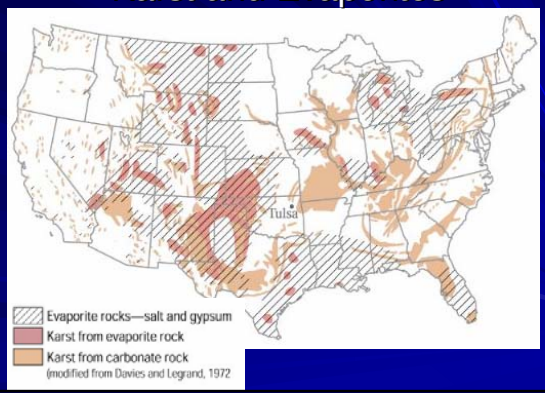
Karst Processes and Landforms



Karst

- Karst is "terrain with distinctive hydrology and landforms arising from a combination of high rock solubility and well-developed secondary porosity". (Bloom, p. 148)
- Most soluble rock is limestone
- Other rocks also contain minor karst

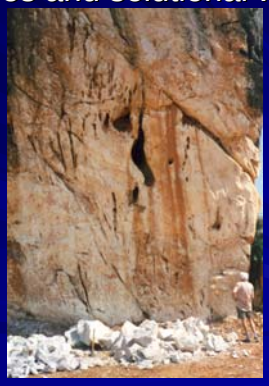
Karst and Evaporites



Lithology and Structure

- Karst dominates in fine-grained, pure (>95% calcite) limestones
- Primary porosity in most limestones is generally low
- Secondary porosity important
  - Joints, bedding planes, fractures, faults
  - Intersection of vertical joint sets promote downward movement of groundwater to form ***shafts***

Fractures and solutional widening



S. Brazil. Foto: Lachniet (1994)

Solution Equations I

- Step 1:
  - $CO_2 + H_2O \rightarrow H_2CO_3$ (carbonic acid)
  - Where does CO_2 come from for rainwater?
- Step 2:
  - $H_2CO_3 \rightarrow H^+ + HCO_3^-$
  - _ carbonic acid dissociates into hydrogen ion and bicarbonate
- pH of rainwater = ???

CO_2 Sources

- "Aggressiveness" of solution is proportional to $[CO_2]$
- Atmospheric CO_2
  - Aerated aqueous solution can dissolve 63 mg/L of calcite
- Biologic CO_2
  - $[CO_2]$ in soil zone many orders of magnitude larger than in the atmosphere
  - Soil water solution can dissolve up to 700 mg/L of calcite
  - Most groundwaters contain 200-400 mg/L of calcite

Solution Equations II

- Step 3:
  - $CaCO_3 \leftrightarrow Ca^{2+} + CO_3^-$
  - Calcite dissociation
- Step 4:
  - $H^+ + CO_3^{2-} \rightarrow HCO_3^-$
- Step 5: Putting it all together
  - $CaCO_3 + H_2O + CO_2 \leftrightarrow Ca^{2+} + 2HCO_3^-$

Solution chemistry

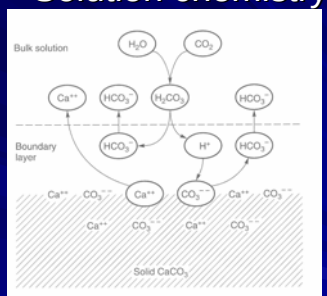
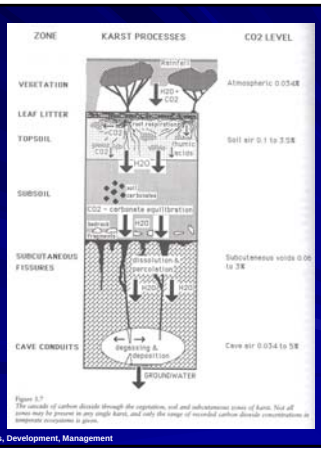


FIGURE 7–13
Steps in the solution of calcite in CO_2-bearing water. (From W. B. White, 1988, Geomorphology and Hydrology of Karst Terrains. Copyright 1988 by Oxford University Press, Inc.)

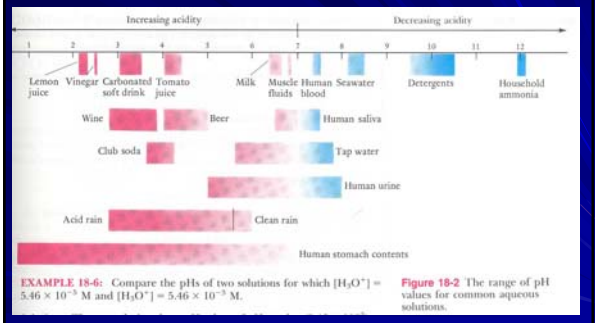
- $CaCO_3 + H_2O + CO_2 \leftrightarrow Ca_2^+ + 2HCO_3^-$



From Gillieson, D. Caves: Processes, Development, Management

Solution continued

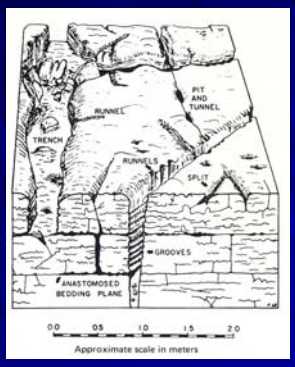
- Cold waters are more soluble to CO_2, thus are potentially more aggressive than warm waters
- But, soil respiration of CO_2 is greatest in hot and humid tropical climates
  - Tropics and mid-latitudes are most prone to karst formation
  - Arctic areas: not enough biologic respiration
  - Deserts: not enough water or biologic respiration



EXAMPLE 18-6: Compare the pHs of two solutions for which $[H_3O^+] = 5.46 \times 10^{-5}$ M and $[H_3O^+] = 5.46 \times 10^{-3}$ M.

Figure 18-2 The range of pH values for common aqueous solutions.

Epikarst landforms



- ***Epikarst*:**
- ***Grikes***: solutionally widened vertical joints
- ***Clints***: remnant pavement surface in between grikes
- Rills and Runnels, a.k.a. "***karren***"
- "***Spongework***" dissolution

From Bloom, 1991, Geomorphology, 2nd Edition, Prentice Hall

Epikarst

Sandia Mountains, New Mexico. Foto: Lachniet (2004)

Epikarst

Sandia Mountains, New Mexico. Foto: Lachniet (2004)

Solution Runnels, trench, pit

Karren on limestone, Syracuse, NY. Foto: Lachniet (1997)

Runnels and joint

Karren on limestone, Syracuse, NY. Foto: Lachniet (1997)

Solution Landforms: Spongework

Guerrero, Mexico. Foto: Lachniet (2002)

Epikarst solution

Sandia Mountains, New Mexico. Foto: Lachniet (2004)

Rillenkarren (or Karren)

Karren, solution features on limestone, Guerrero State, Mexico. Foto: Lachniet (2005)

Karren

Karren, solution features on limestone, Guerrero State, Mexico. Foto: Lachniet (2005)

Major Karst Landforms

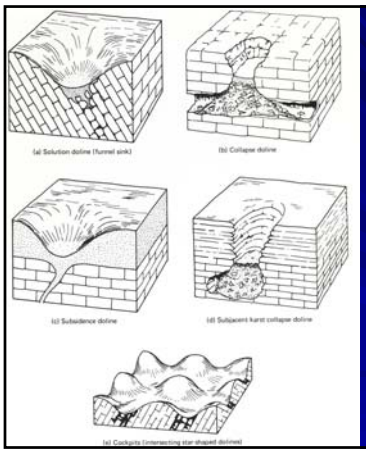
- Fundamental karst landform is the ***sinkhole*** (aka "doline")
  - Solutionally enlarged shaft that serves as a conduit from surface to subsurface
  - Note: most "sinkholes" reported by the media ***are not true karst sinkholes!***

Solution sinkholes

- Formed by dissolution along joints
- Near vertical
- Funnel-shaped
- Most common on
  - flat terrain and elevated plateaus lacking surface drainage

Collapse Sinkholes

- Near-vertical walls
- Roof collapse over solution cavities
- Rapid collapse
  - Often associated with groundwater lowering
  - Filled with blocks of overlying bedrock
  - Common in Florida



Sinkholes

From Bloom, 1991. Geomorphology, 2nd Edition. Prentice Hall.

Winter Park, FL sinkhole

- Collapse sinkhole
- Florida is predominantly limestone
- High rainfall and warm temperatures
- Active karst formation

- Collapse Sinkhole, South Australia

Uvalas and Poljes

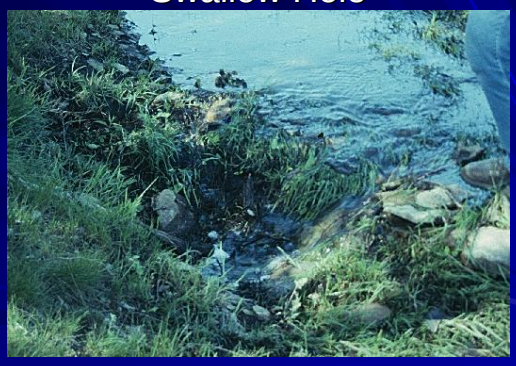
- Uvala is simply a compound sinkhole
  - Enlargement and coalescence of smaller sinkholes
  - Irregular in shape
  - Several square km
  - Up to a few hundred meters deep
- Polje
  - is a large closed depression formed by solutional processes
  - Broad flat alluvial floor that may flood during wet periods
  - Contain blind valleys
  - Often related to geologic structure (folding)
  - Up to 60 km in length and up to 5 km wide

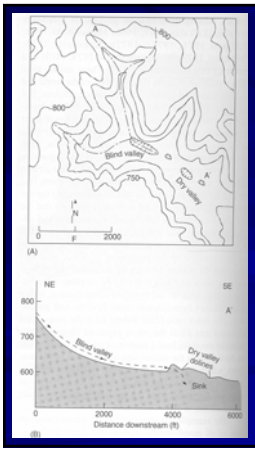
Polje in Sierra Cuchumatanes, Guatemala

Polje solution on limestone, Guatemala. Foto: Lachniet (2006)

Swallow Hole

Swallow Hole





Blind Valley

- A sinking stream flows into groundwater system
- Upstream is called a blind valley
- Downstream is called a dry valley

Epigenic and Hypogenic Caves

- Epigenic:
  - Movement of water from overlying or adjacent recharge surfaces
  - 90% of caves
  - Atmospheric and biologic CO_2 source for aggressive waters
- Hypogenic:
  - Deep-seated water sources
  - 10% of caves
  - Hydrosulfuric acid (H_2S) and igneous carbonic (H_2CO_3) acid
  - Carlsbad Caves, New Mexico

Cave Formation

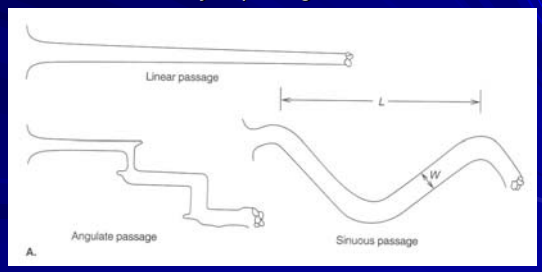
- Form in 10^4 to 10^5 years (typo p. 205)
- A cave is a solutional opening large enough for a person to enter
- Consist of
  - Passages – longer than they are high
  - Rooms – higher than wide

Caves are big enough for a person to fit inside

Death Valley National Park, CA. Photo by Stephen Hlowjski, 2004

Single-conduit Passages

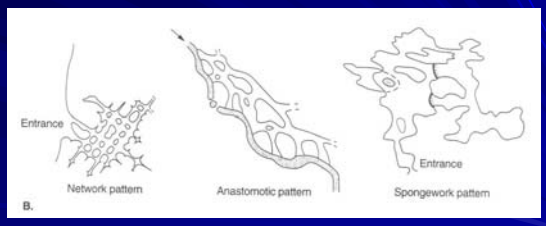
- May have dendritic drainage pattern
- One passage develops more rapidly than others, effectively capturing more water



Sinuous cave stream

Foto: Keith Christenson

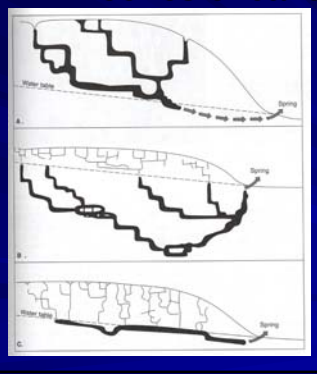
Maze Passages



Three principle theories of Cave origins

- 1) Form above water table by ***vadose water*** (unsaturated zone water)
- 2) Form beneath water table by circulation of ***phreatic water*** (=saturated zone water)
- 3) Form at water table = ***water table caves***

Theories of cave formation



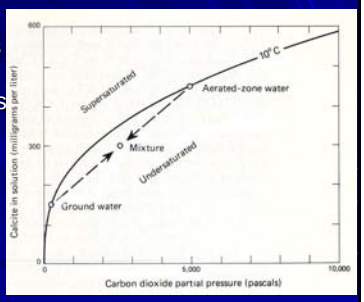
1) Vadose Zone

2) Phreatic Zone

3) Water Table Cave

Mixing Effect

- Mixing two saturated solutions in equilibrium with two [CO_2] produces an undersaturated solution!
- Thus, mixing of different groundwaters will result in additional solution



Water Table Cave, Panama

Foto: Keith Christenson

Domingo's Gullet

Foto: Keith Christenson

Water Table Cave

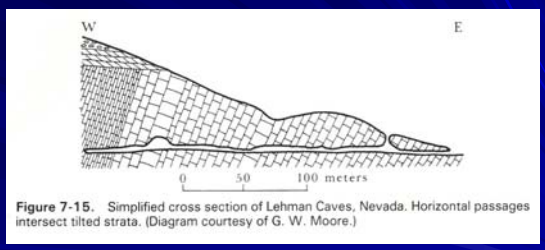


Figure 7-15. Simplified cross section of Lehman Caves, Nevada. Horizontal passages intersect tilted strata. (Diagram courtesy of G. W. Moore.)

From Bloom, 1991. Geomorphology, 2nd Edition. Prentice Hall.

Cave Patterns

Cave equivalent of dendritic drainage

Commonly form along a low angle fracture

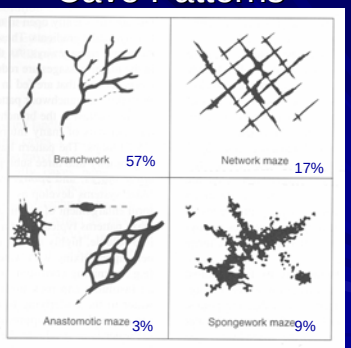


Figure 12.25 Branchwork and maze patterns of cave development. (Palmer 1991)

Single-passage caves 14%

Angular grids of intersecting fissures Diffuse gw flow

May originate from solutional opening of primary porosity; Hypogenic

Residual Karst

- Cockpit karst
  - leaves conical limestone hills separated by star-shaped sinkholes
  - Best developed in humid tropics
  - Sinkhole distribution probably controlled by geologic structure
- Tower Karst
  - Steep to vertical limestone hills
  - Swampy plains

Cockpit Karst in Guatemala

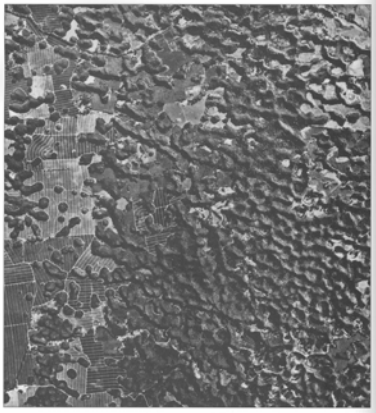
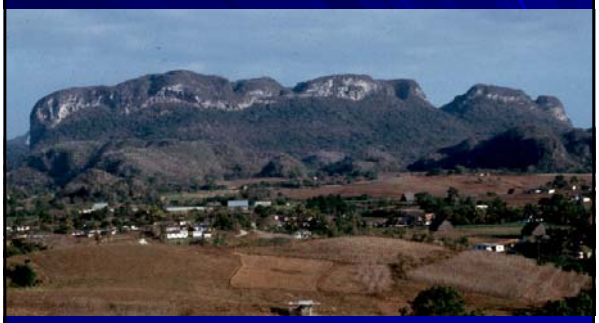


Figure 12.20
Aerial view of cockpit karst.

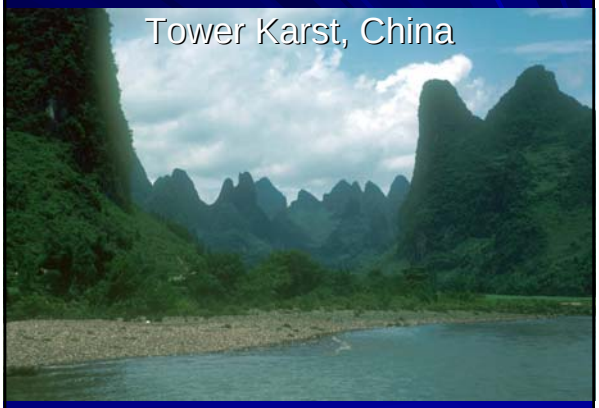
Tower Karst, Cuba



Tower Karst, Costa Rica

Guanacaste Peninsula, NW Costa Rica. Foto: Lachniet (1999)

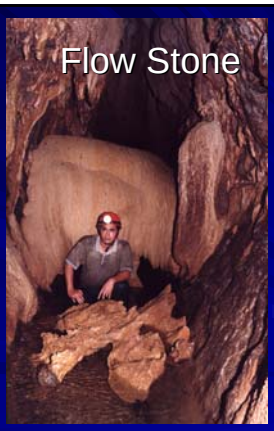
Tower Karst, China



Speleothems

- Cave waters dissolve calcite under high $[CO_2]$ derived from the soil zone
- $CaCO_3 + H_2O + CO_2 \leftrightarrow Ca_2^+ + 2HCO_3^-$
  - $[CO_2]$ in cave passages = atmospheric
  - Saturated drip waters enter cave
  - CO_2 is released
  - Above equation proceeds in reverse
  - calcite is precipitated into amazing cave calcite formations called ***speleothems***

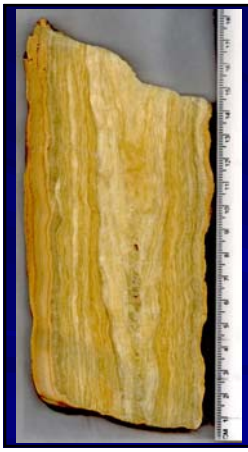
Flow Stone



Cueva Nibida, Panama. Foto: Lachniet (2003)

Stalactites

Foto: Keith Christenson



Stalactite stratigraphy

Stalagmites

Cueva Nibida, Panama. Foto: Lachniet (2002)

Stalagmites, Costa Rica

Stalagmite

Foto: Lachniet (2002)

Column

Chagres area, Panama. Foto: Lachniet (2002)

Rootsicles

Cueva de los raices, Panama. Foto: Lachniet (1994)

Karst Window (skylight)

Form when roof collapses over a cave stream

Foto: Keith Christenson

Natural Bridges

- Form when collapse isolates remnant of limestone

Foto: Lachniet, 2001. Natural Bridge, Panama