THE EDWARDS AQUIFER:
A GLOBAL PERSPECTIVE

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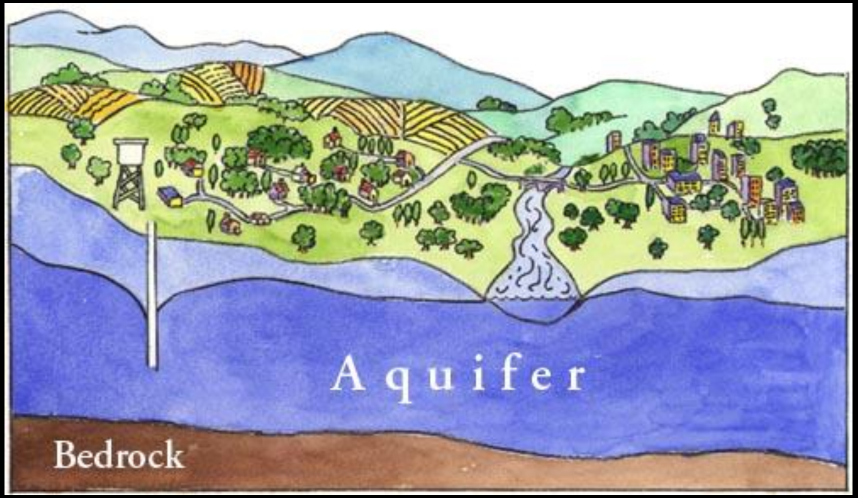
GOALS

- Differentiate karst aquifers from ‘sand and gravel’ aquifers
- Explain the components of a ‘classic’ karst aquifer
- Show how unique and sensitive the Edwards Aquifer is– from a caver’s view
- Dispel myths associated with the Edwards

WHAT IS AN AQUIFER?

- Aquifer is any unit capable of storing and transmitting water in usable quantities
- Rock
  - Igneous
  - Metamorphic
  - Sedimentary
- Unconsolidated sediment
  - Sands and gravels



IGNEOUS AND METAMORPHIC AQUIFERS

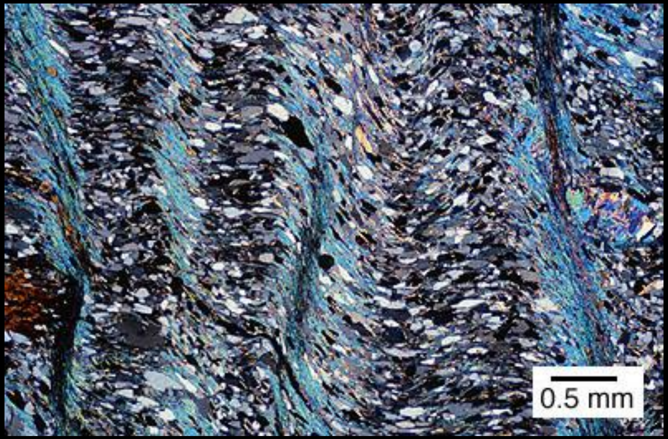
- Low porosity because interlocking crystals

- Range of porosities; permeability low
  - granite vs. pumice

- Larger bodies can have decent amounts of water

IGNEOUS AND METAMORPHIC AQUIFERS

Thin section of granite

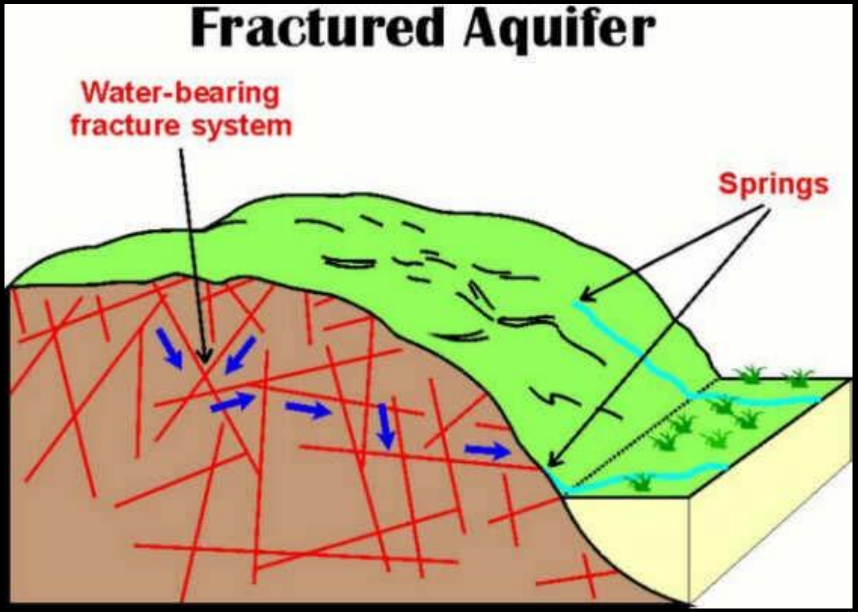


Thin section of schist

- Virtually no porosity

- Fractures can increase flow greatly in aquifers

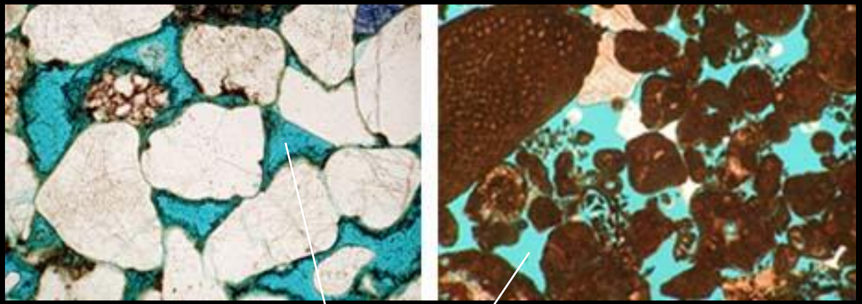
- Larger bodies can be productive aquifers if fractured enough



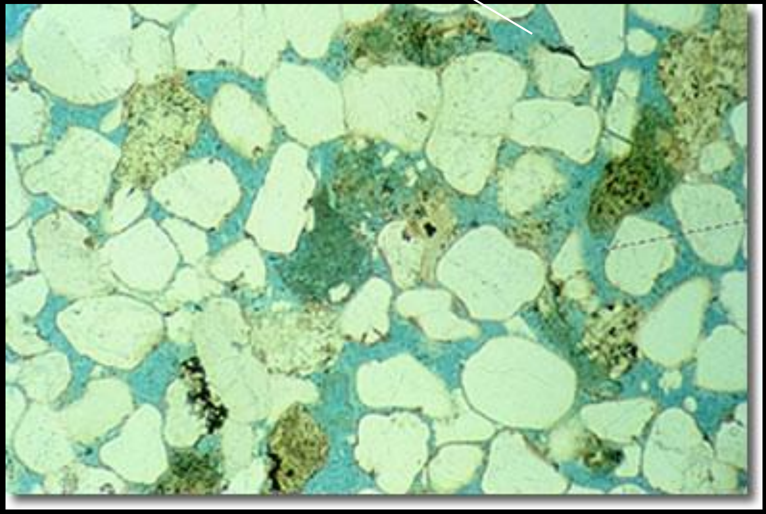
→Can be productive aquifers, but highly productive sedimentary aquifers are more common than productive crystalline aquifers

SEDIMENTARY AQUIFERS

- Made of grains of other rocks
- Grains do not fit tightly together
- Space is left between the grains
- Mechanical filtration occurs

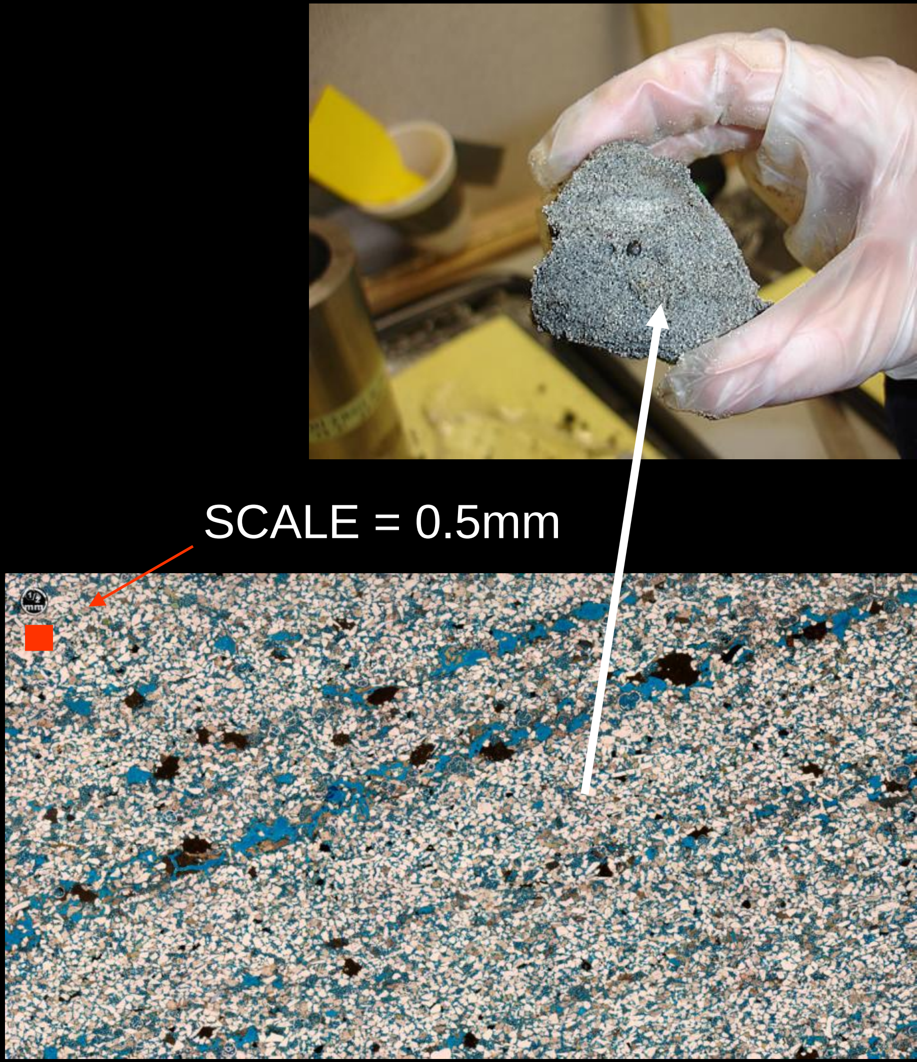


Pore space



SEDIMENT POROSITY

Well sorted sand	25 - 50%
Mixed sand & gravel	20 - 35%
Glacial till	10 – 20%
Clay	33 – 60%



Sandstone

Fetter, C.W. Applied Hydrogeology

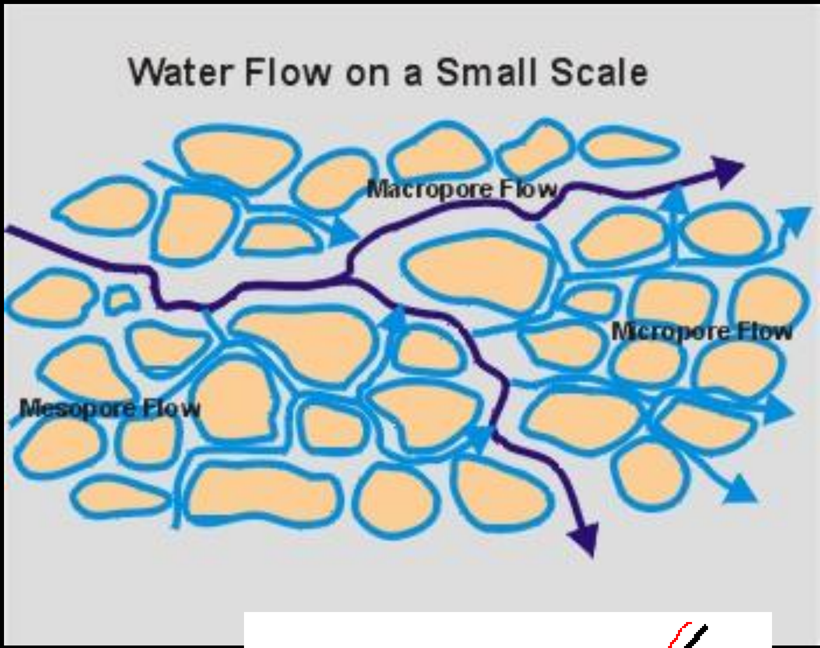
SEDIMENTARY ROCK POROSITY AND PERMEABILITY

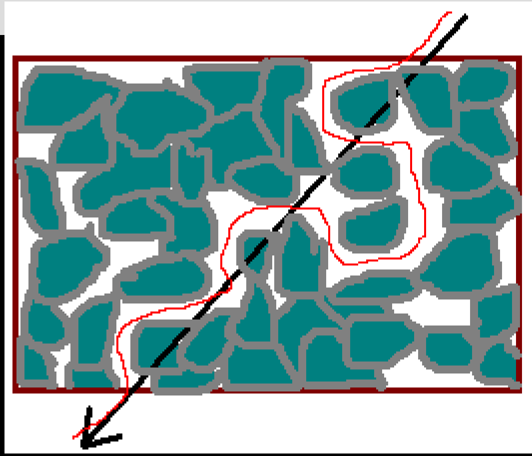
ROCK	POROSITY	PERMEABILITY
Sandstone	43%	20 – 90 cm/d
Mixed sand & gravel	33%	30 – 150 cm/d
Shale	43%	8 cm/d

Karanth, K.R. Hydrogeology

SEDIMENTARY AQUIFER

Glacial Till

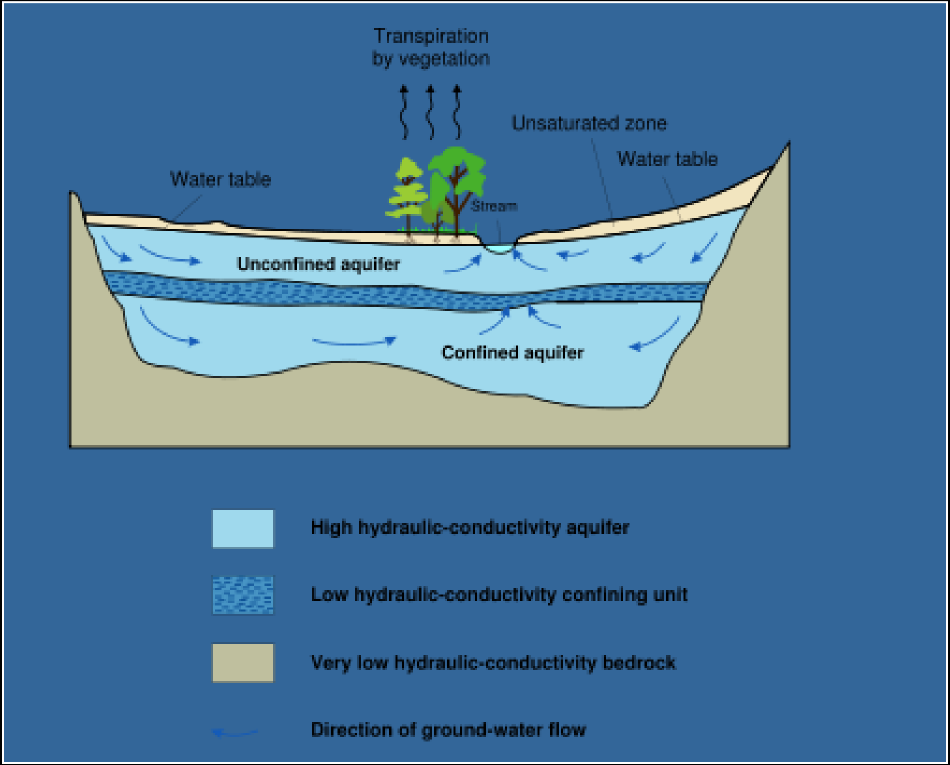




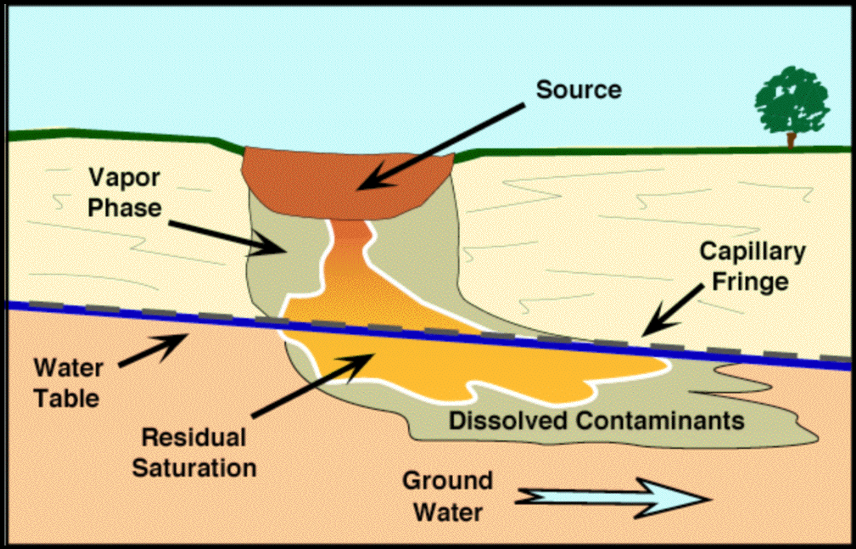
- Water follows very torturous flow paths
- Flow velocities on the order of cm to m/day

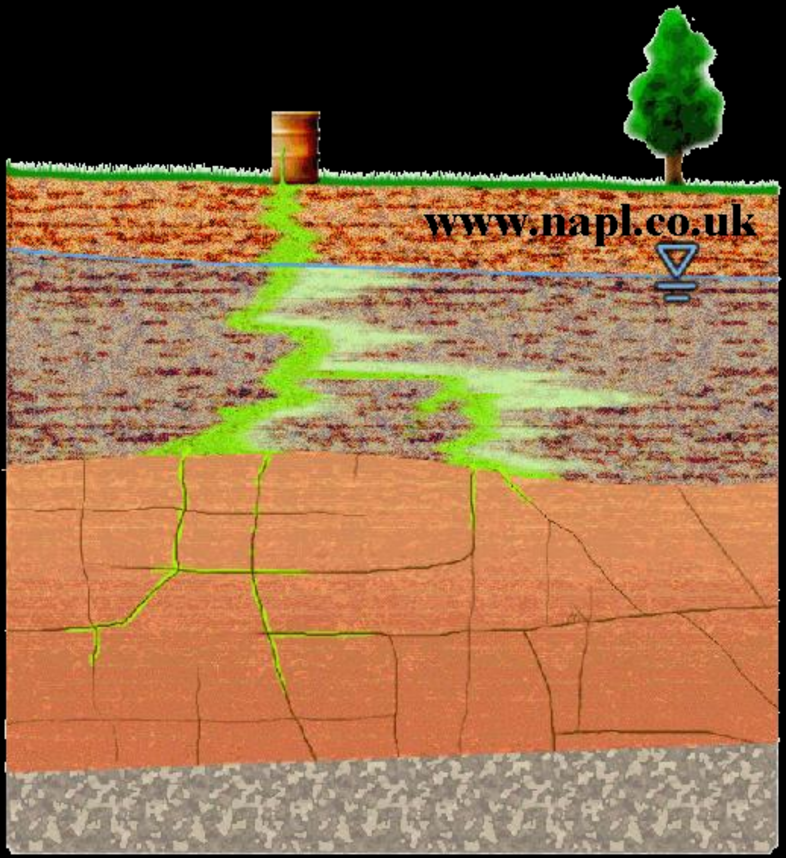
CLASSIC AQUIFER

- How does all of this fit together?
- Generically: “Sand and gravel aquifers”
- General geology classes
- Water infiltrates and slowly moves down gradient
- Generally low flow velocities



REMEDIATION = POSSIBLE





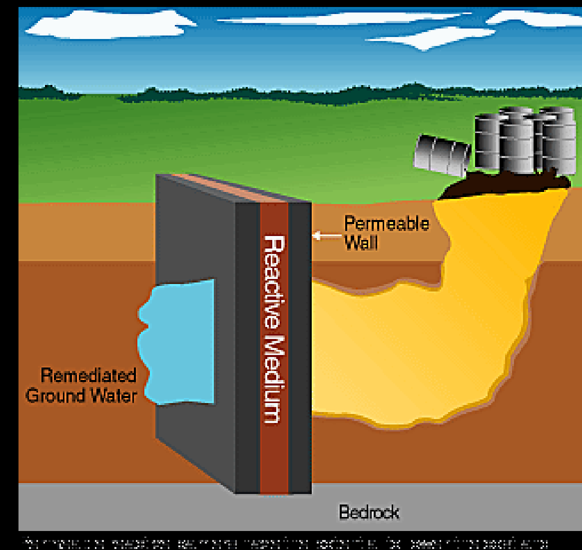
- Flow with groundwater flow direction

- Contaminants travel slowly as a plume

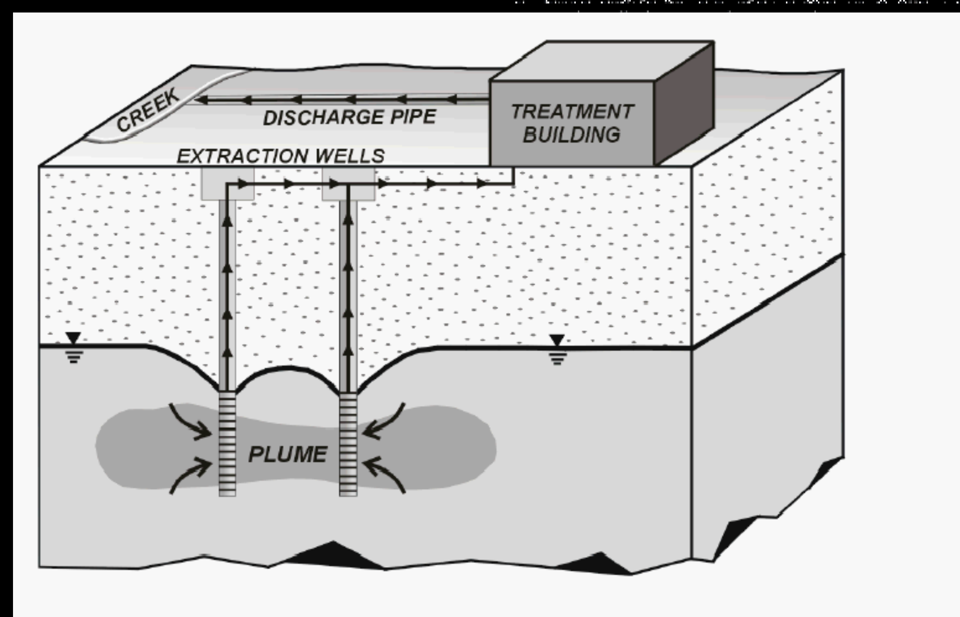
- Soluble
  - Agricultural pollution: fertilizers
- Insoluble
  - Petroleum products

GROUNDWATER REMEDIATION

Reactive Filter



Pump and Treat

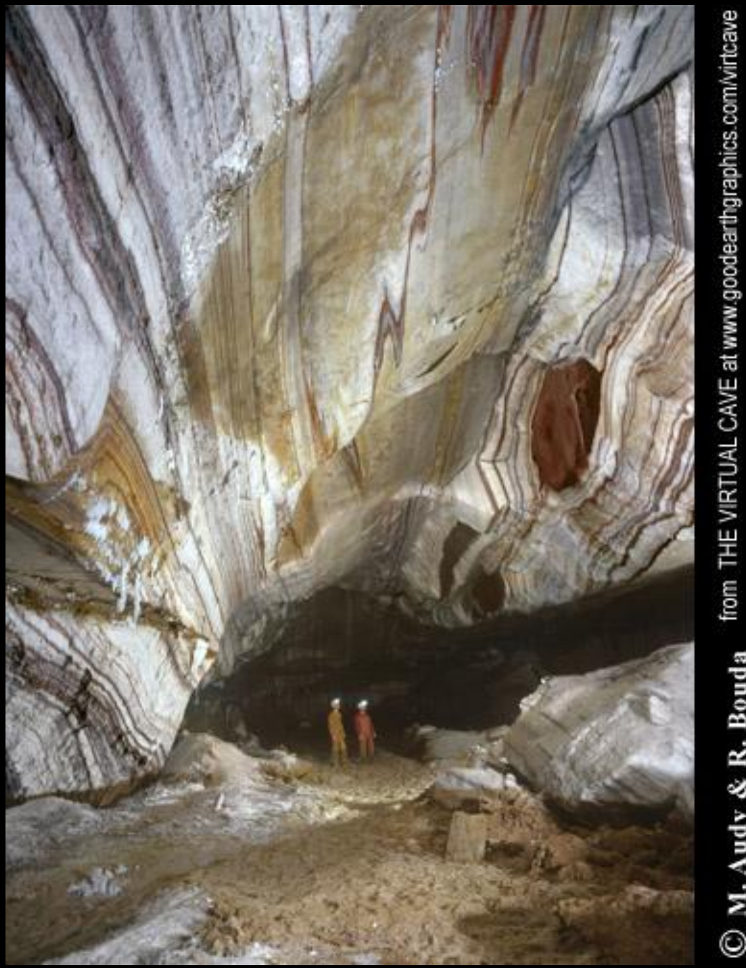


OVERVIEW OF CLASTIC AQUIFERS

- Small pores CAPABLE OF FILTERING WATER
- Complex flow paths through small pores yields LOW FLOW VELOCITIES
- What does this mean for contaminant transport?
- Contaminants can be removed

KARST WATERS INSTITUTE (KWI)

- Karst: “landscape formed by dissolution of soluble rocks”
  - Limestone, dolomites, salts, gypsum, quartzites, more
- 40% of the groundwater used in the U.S. for drinking comes from karst aquifers
- Common of karst: ground subsidence, sinkhole collapse, groundwater contamination, unpredictable water supply



Karst solutioning in a salt dome

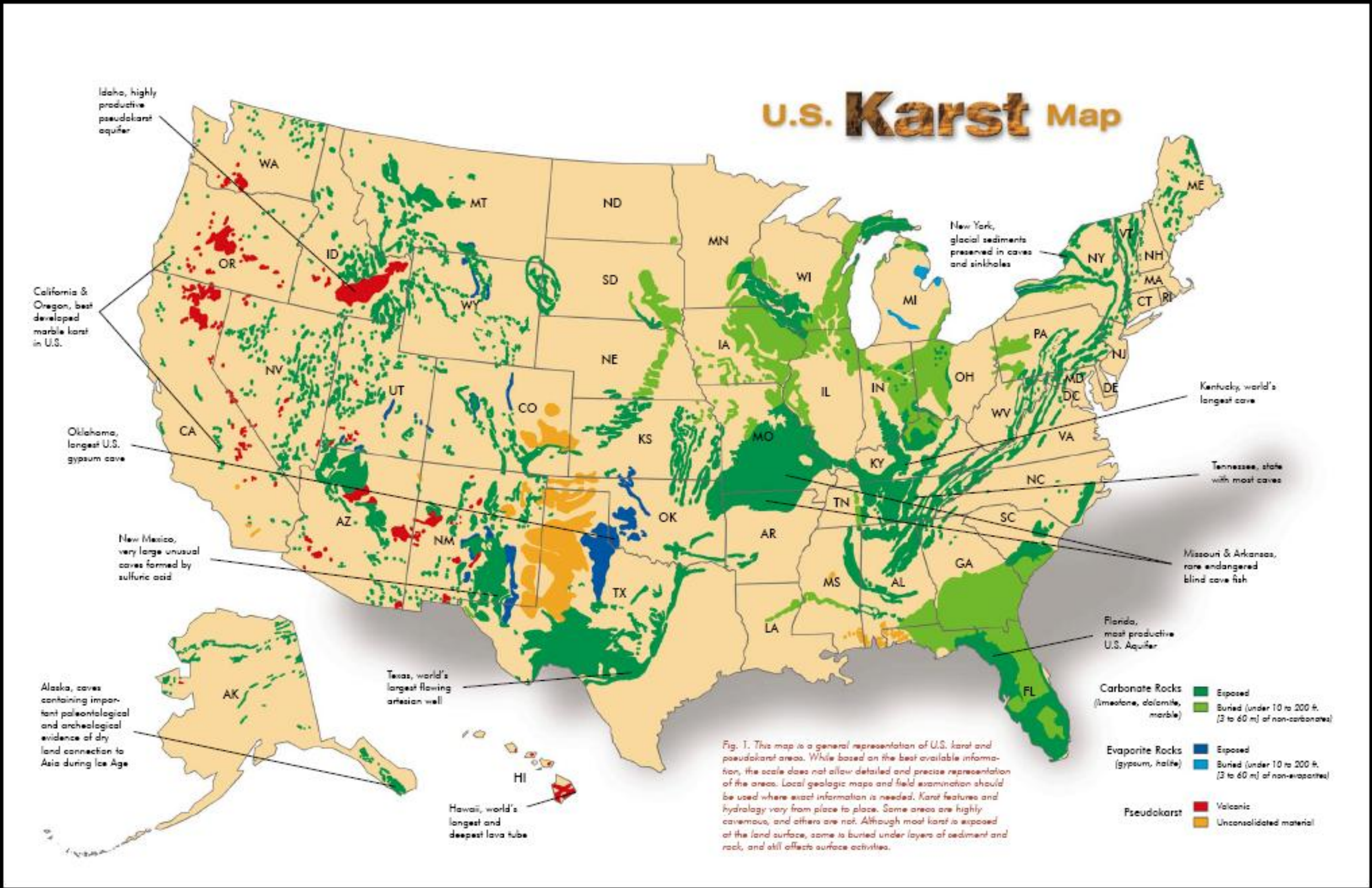
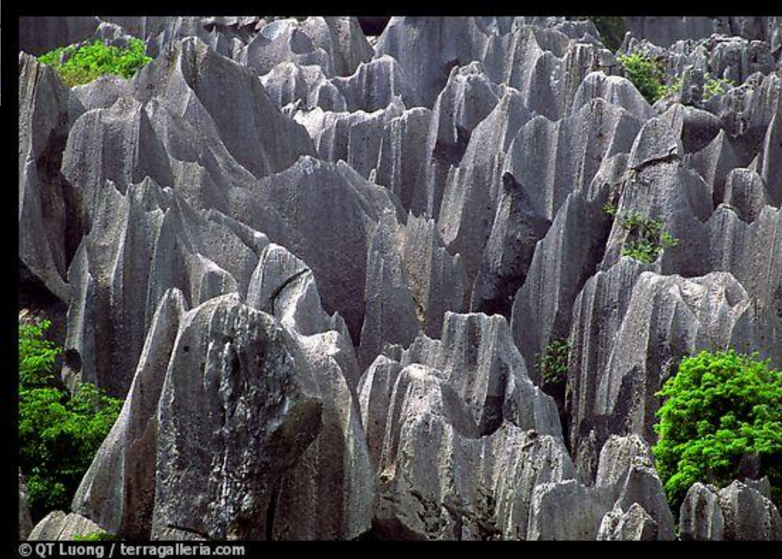


Fig. 1. This map is a general representation of U.S. karst and pseudokarst areas. While based on the best available information, the scale does not allow detailed and precise representation of the areas. Local geologic maps and field examination should be used where exact information is needed. Karst features and hydrology vary from place to place. Some areas are highly cavernous, and others are not. Although most karst is exposed at the land surface, some is buried under layers of sediment and rock, and still affects surface activities.

KARST DISSOLUTION OF EXPOSED BEDROCK

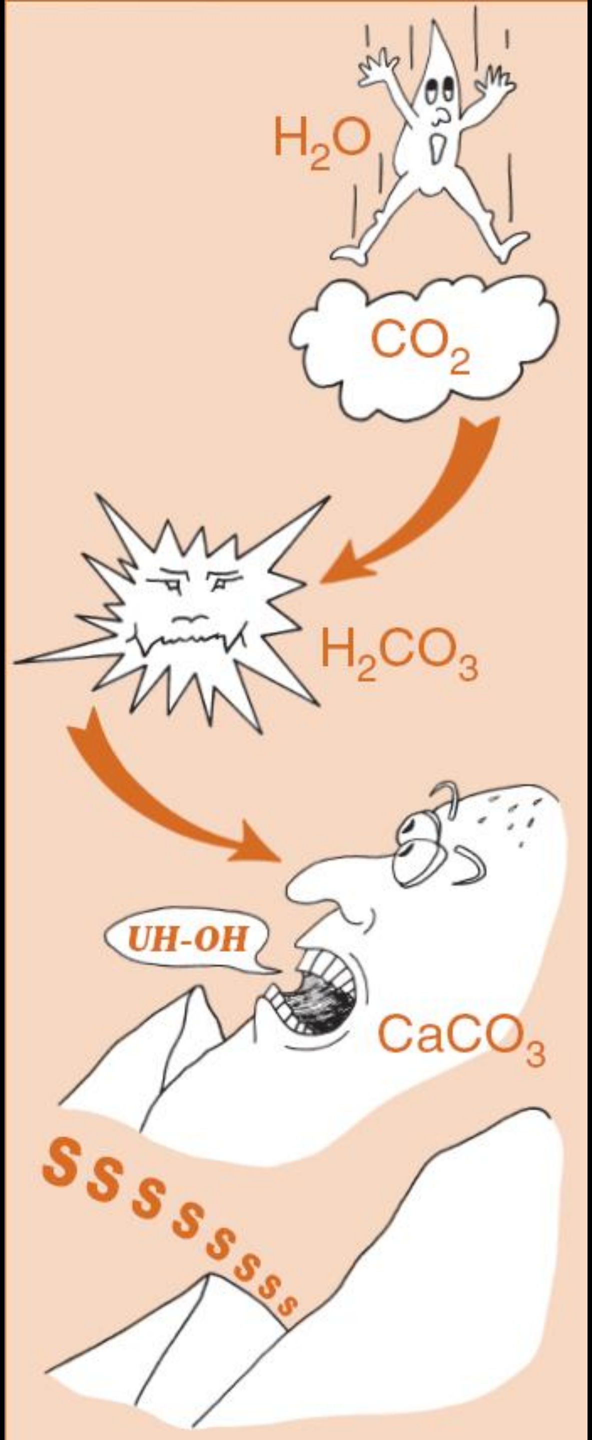
- Basic concept: acidic water dissolves rock
- Reactions are rate limited
- Water quickly enters ground
- Irregularities exploited: fractures, faults, bedding planes



NATURALLY OCCURING ACIDIC WATER

- Rain passes through the atmosphere picking up carbon dioxide
- Soils add more CO_2
- Weak carbonic acid solution:

$$H_2O + CO_2 \rightarrow H_2CO_3$$



CALCITE DISSOLUTION

- Limestone: ($CaCO_3$)
- Dolomite: $CaMg(CO_3)_2$

RESULTS OF KARST DISSOLUTION

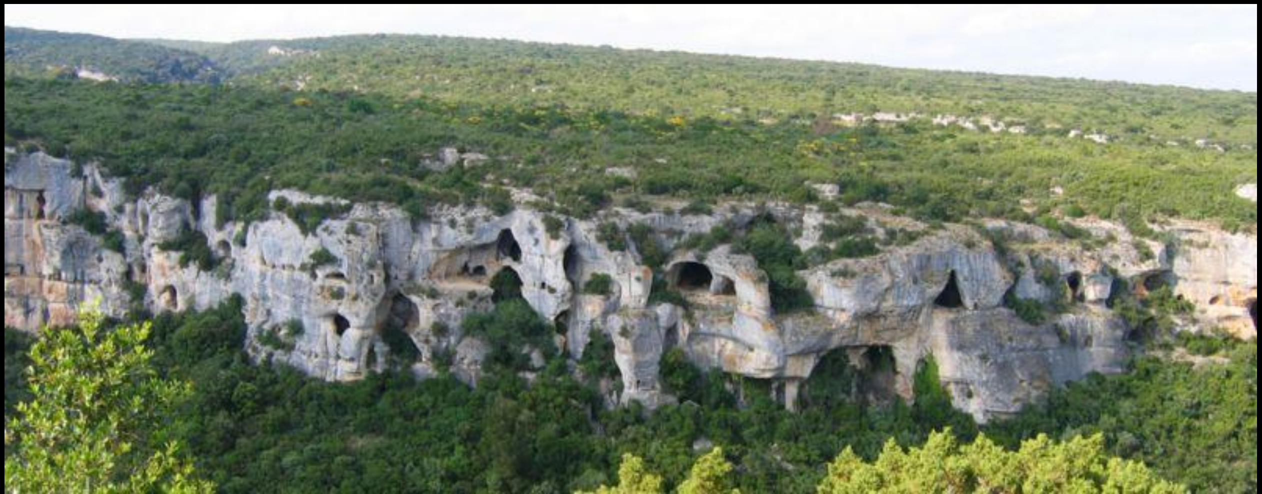
- ‘Aggressive water’ continues to dissolve once underground

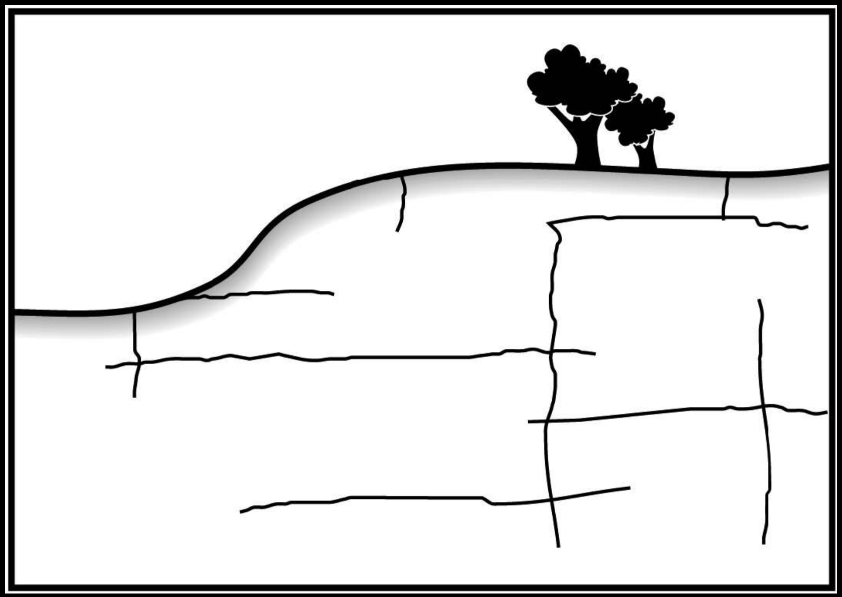
- Water passages enlarged until conduit formation

- Rapid, subsurface flow via conduits

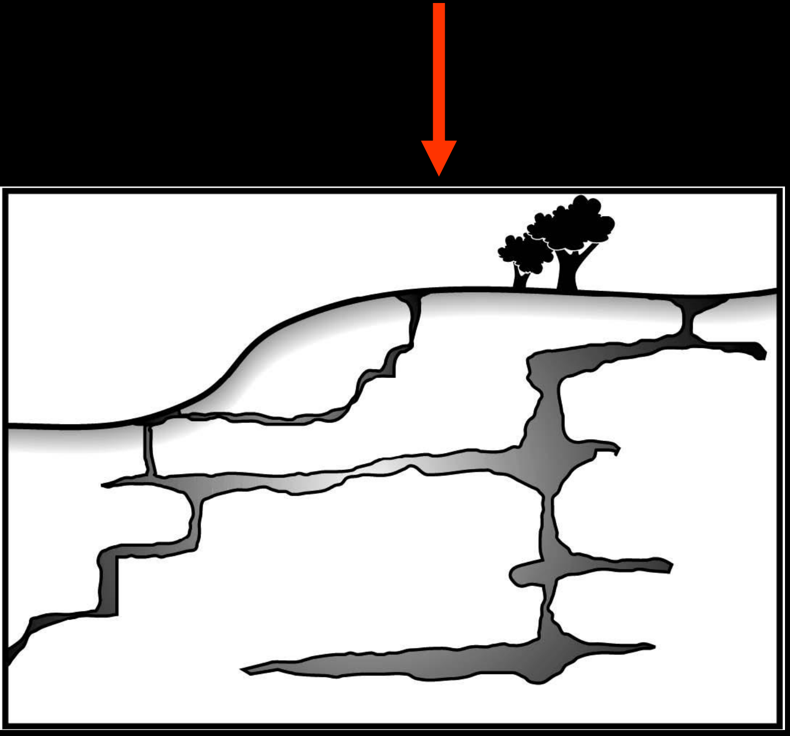
KARST OVERVIEW

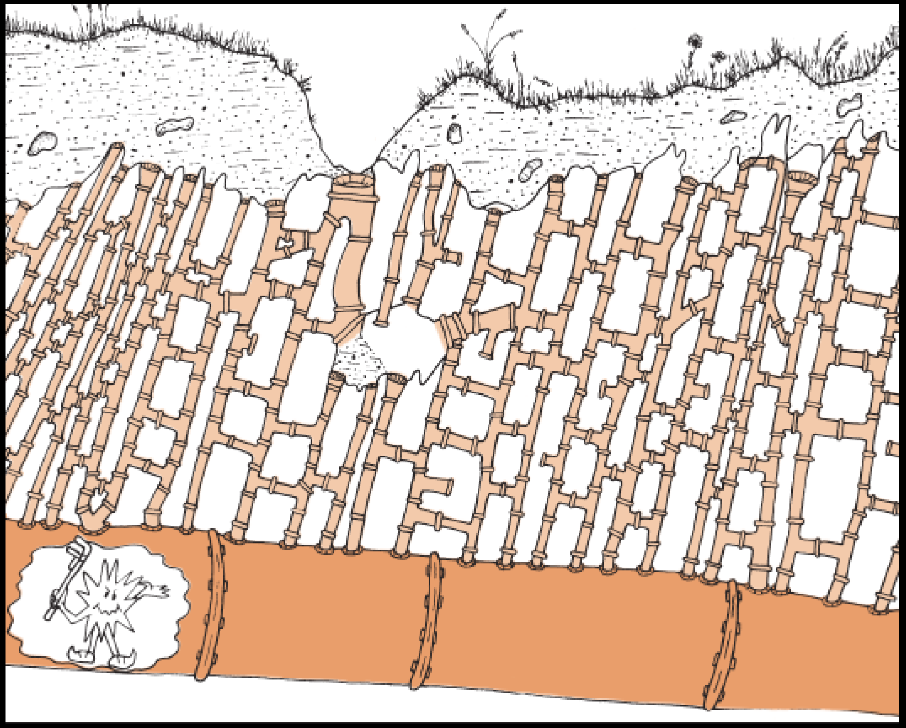
- In the subsurface these conduits feed into each other; dendritic patterns common
- Larger conduits formed
- Large volumes of water transmitted with high flow velocities





FRACTURE CONVERGENCE





Veracruz, Mexico

Veracruz, Mexico

SINKHOLE

- Void dissolved in bedrock
- Soil/rock collapses into underlying void
- Depression formed on surface.
  - Drain may or may not be visible

- Sinkholes indicate void space below

SINKHOLE

- Generic shape is a cone, but can be any shape

- Water is collected and funneled into the subsurface

SINKHOLES

Pennyroyal Plateau, KY

Guatemala

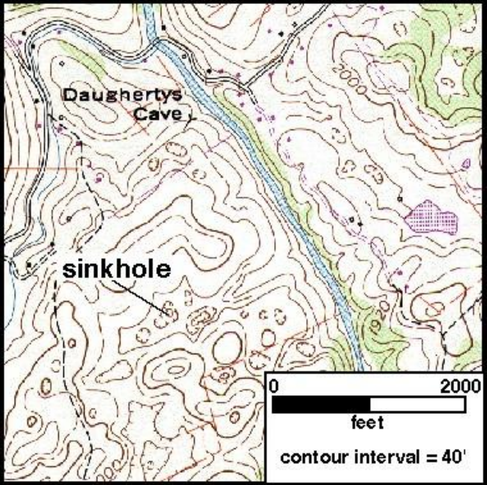
SINKHOLES

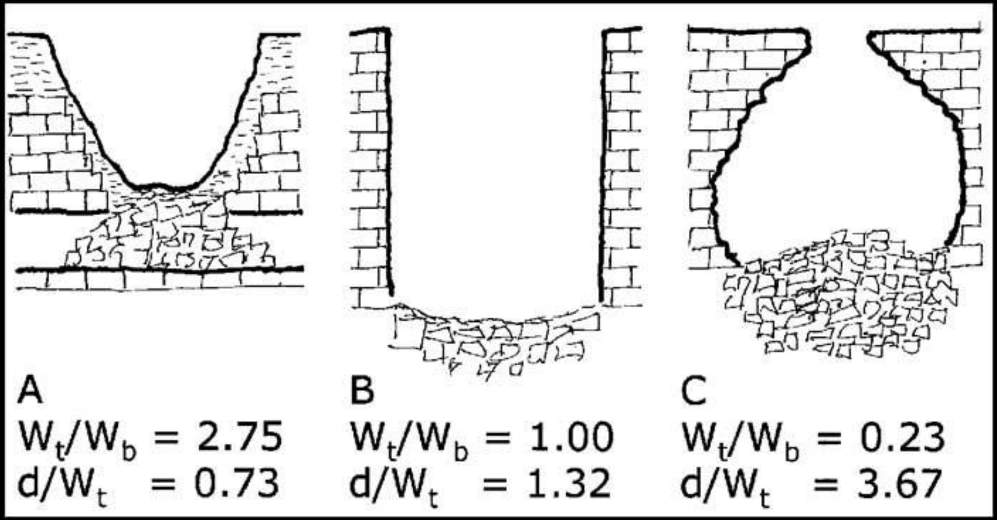
Missouri

Florida

SINKHOLE

- Drain hole at bottom may be plugged with sediment but the connection to the subsurface is still there





PIT CAVES, a.k.a. SINKHOLES

- Pit caves can form by collapse into underlying void
- Underlying void dissolves more and grows in volume
- Collapses again

57m shaft, Alabama

333m shaft, S.L.P., Mexico

SINKING STREAMS

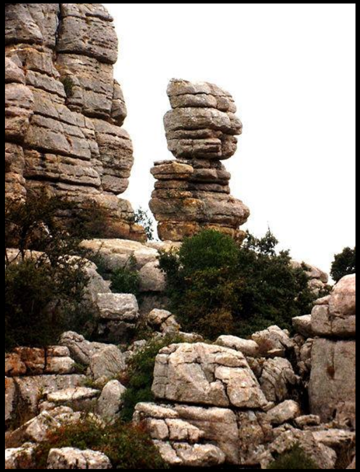
- Water directly recharges aquifer

- Represent points that are very susceptible to rapid contamination of large aquifers

- Seco Creek Sinkhole

El Rio Caha-Bon, Guatemala

SOLUTIONED BEDDING PLANES



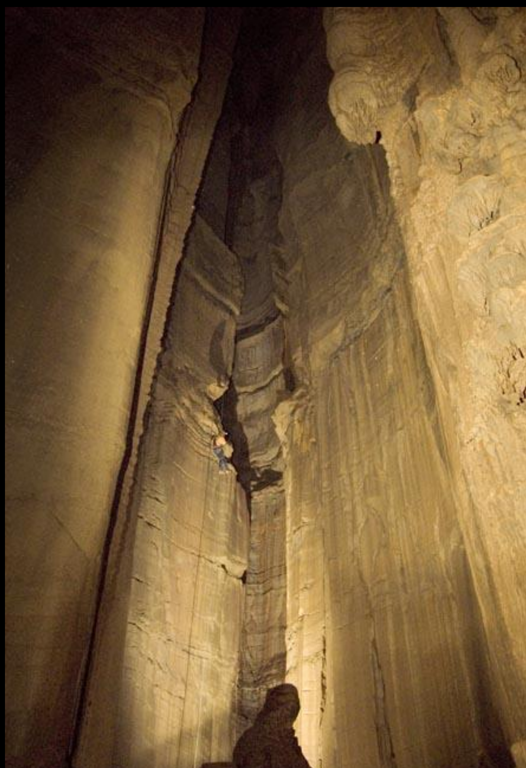
SOLUTIONED BEDDING PLANES

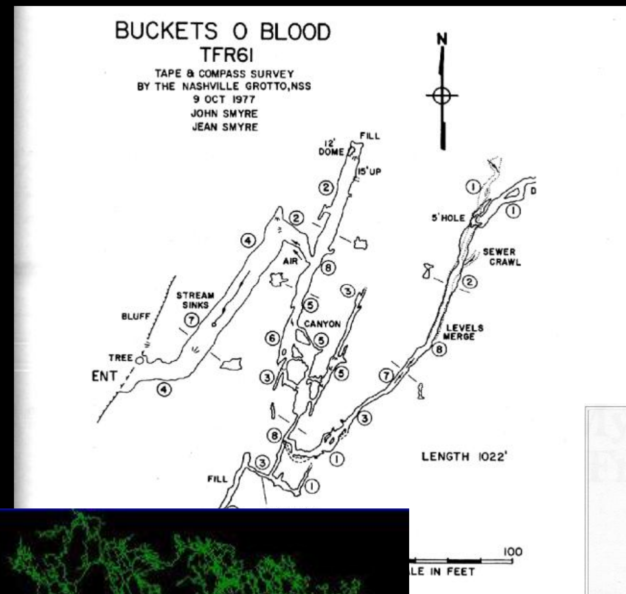
Passages are often lenticular
In cross-section

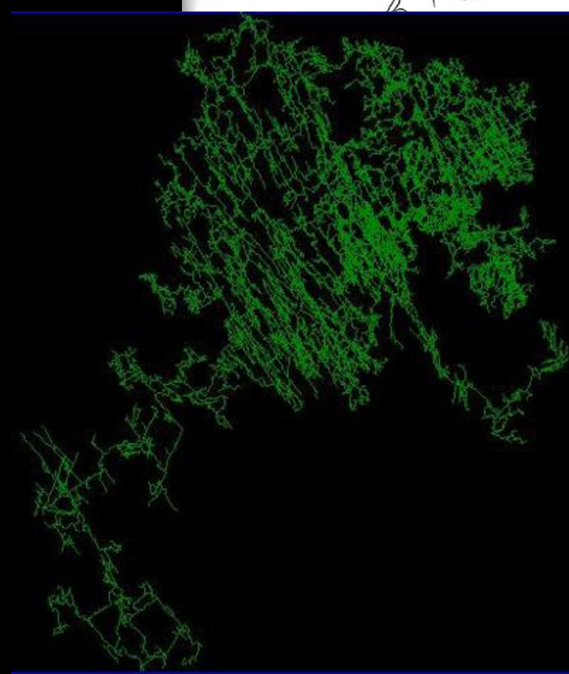
SOLUTIONED FRACTURES AND FAULTS

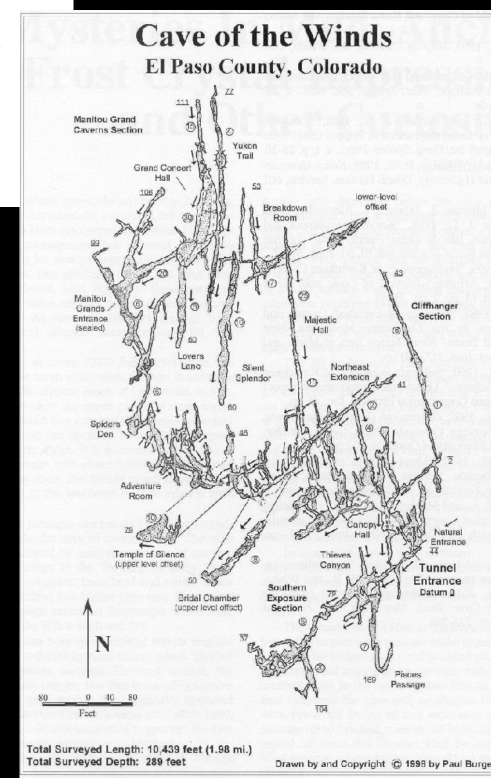
- In the subsurface passages commonly exploit fractures
- Joint controlled passages
- Tend to follow fracture pattern

JOINT CONTROLLED PASSAGES









SPRINGS

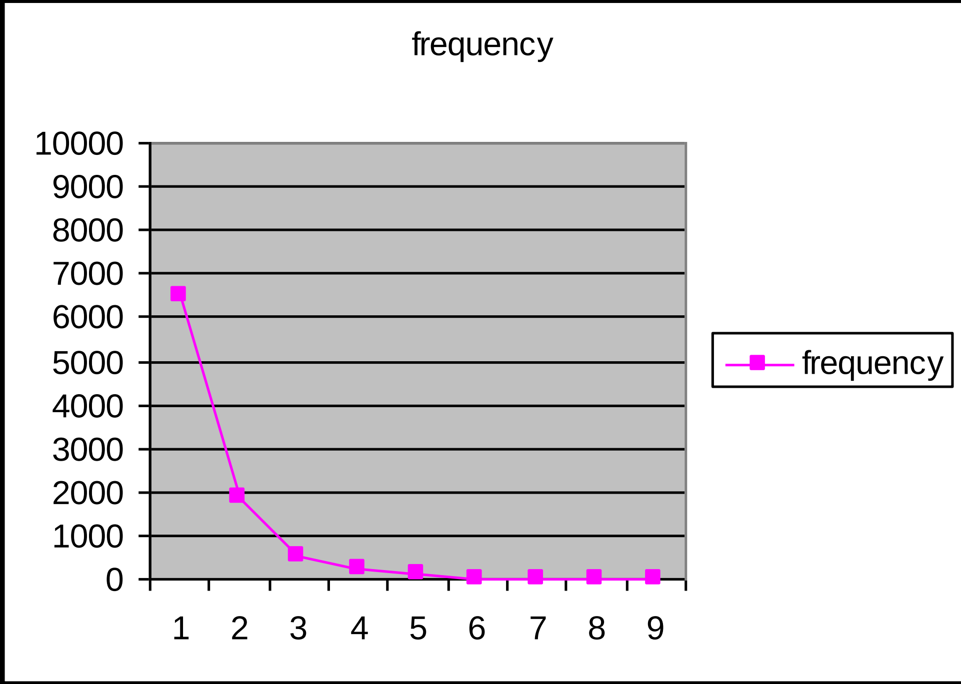
- Where the water table meets the surface

WHAT IS A CAVE?

- Solutioned void that humans can fit into
- Conduit or passage
- Entrance is where passage intersects surface
- **How many passages *do not* intersect the surface?**

CAVES WITHOUT ENTRANCES

- Art Palmer did a semi-log regression
- Plotted number of entrances versus frequency
- If you follow the trend you see that the number of caves without entrances is very high
- AL had <7k known caves; **Palmer’s regression predicted ~100,000 caves**



CAVES

- *Allow us to see what is going on inside the rock*
  - Better view of rock
  - Flowpaths deduced

- Caves tell us how the aquifer reacts to water
  - Flood vs flow

CAVES

- Cave maps offer insight through pattern recognition
  - Dip, regional trends, faults, fractures

- Cave walls contain scallops and other features that indicate flow direction and velocity

WHAT DO THESE KARST FEATURES SHOW US?

- That there are many, many interconnected water carrying passages in karst aquifers
- Only a small portion of them are enterable
  - Enterable passages are caves
- Non-enterable passages are conduits, vugs, cavities or other solutional voids smaller than people
- ***Non-enterable solution features greatly out number enterable features***

AQUIFER COMPARISON

SAND AND GRAVEL

- Small pore size mechanically filters
- Torturous flow paths slow water
- Contaminants don’t travel far
- Remediation possible

KARST

- No filtration takes place
- Fractures and conduits yield fast water velocities
- Contaminants are broadcasted over large distances
- Contaminants gone

WHY TALK ABOUT ALL THESE KARST FEATURES?

- To show that the Edwards Aquifer has the features of a typical karst aquifer

- *and more that make it unique globally among karst aquifers*

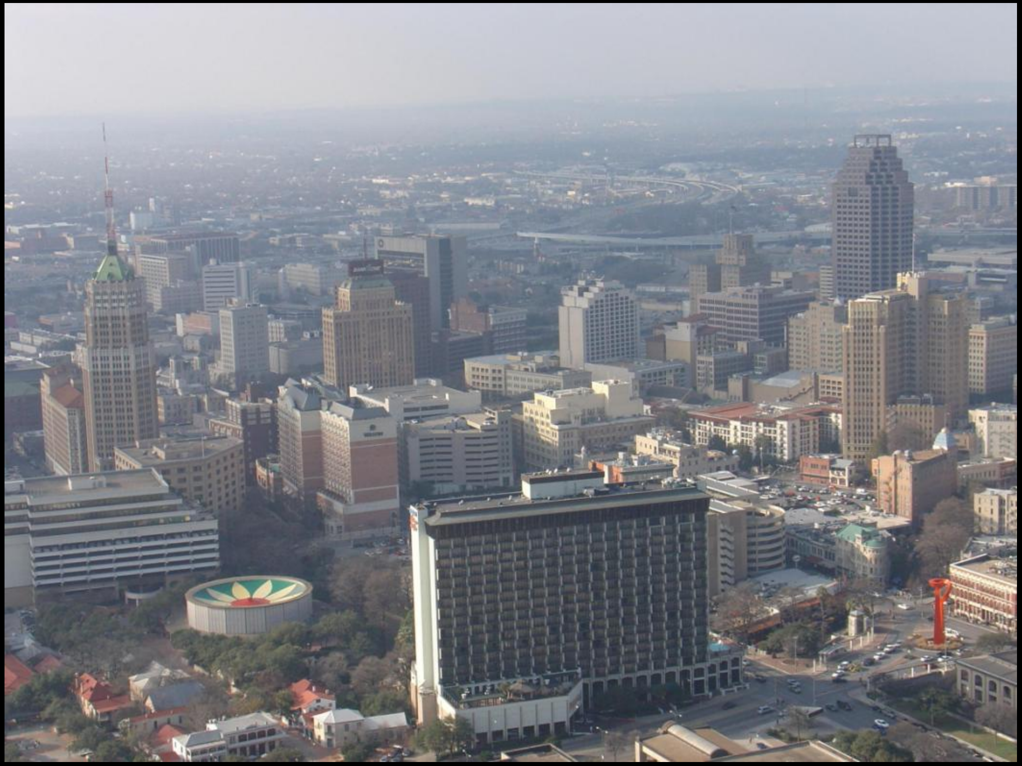
WHAT MAKES THE EDWARDS UNIQUE?

- Incredibly high porosity in the Edwards Limestone
  - Holey rocks
- Highly fractured and faulted rock
  - Permeability increased
- Results in incredibly fast flow rates

WHAT MAKES THE EDWARDS UNIQUE?

- Long, complex flow paths
- Geochemical complexities; bad water line
- Large springs; multiple other springs
- Unique biota

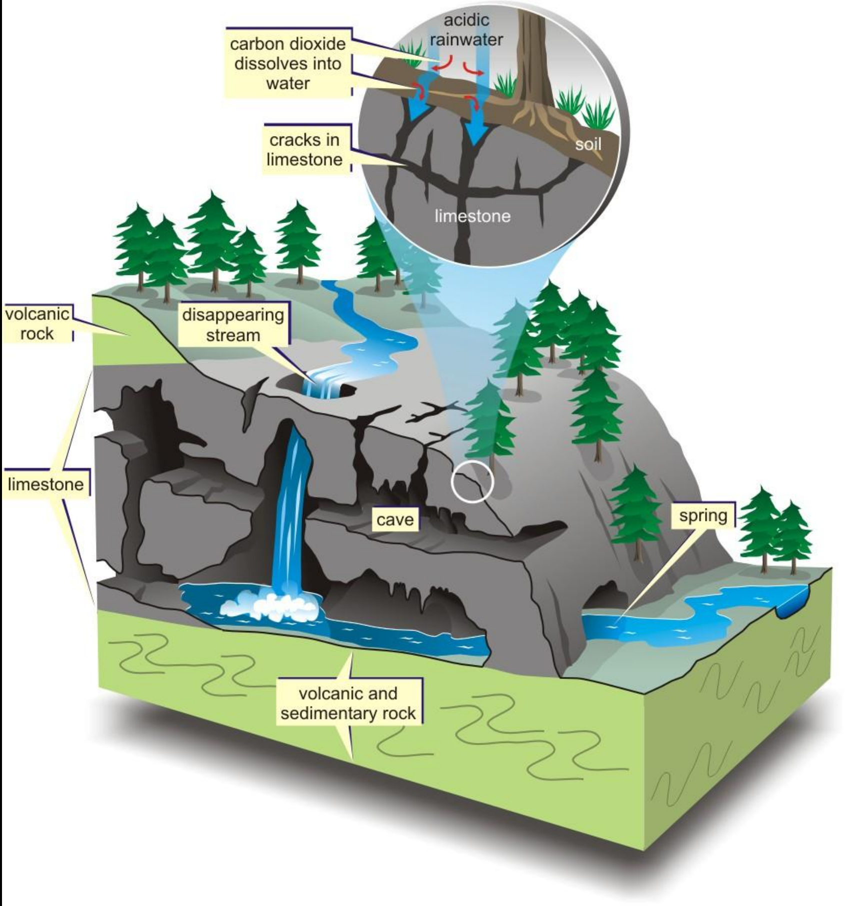
WHAT MAKES THE EDWARDS UNIQUE?



- > 1 million people depend on it for their sole source of water

EDWARDS AQUIFER

- Limestone; interbedded marls, clay layers
- Wikipedia describes it as "one of the most prolific artesian aquifers in the world"
- San Antonio owes its existence to the Edwards—without the aquifer the city might not exist
  - No surface water



EDWARDS AQUIFER

- The aquifer is a very mature karst system

<u>Evidence</u>:

- Thousands of caves and karst features
- Many solutional voids in subsurface
  - Tool drops
- Springs, sinkholes, etc

OUTWARD APPEARANCE

- Rock in each karst area is shaped by the rock and the amount of water it receives
  - Every area has different look

- Factors:
  - Bedding: well bedded vs thinly bedded
  - Rock quality: pure vs impure limestone
  - Amount of rain
  - Contact time between rock and water

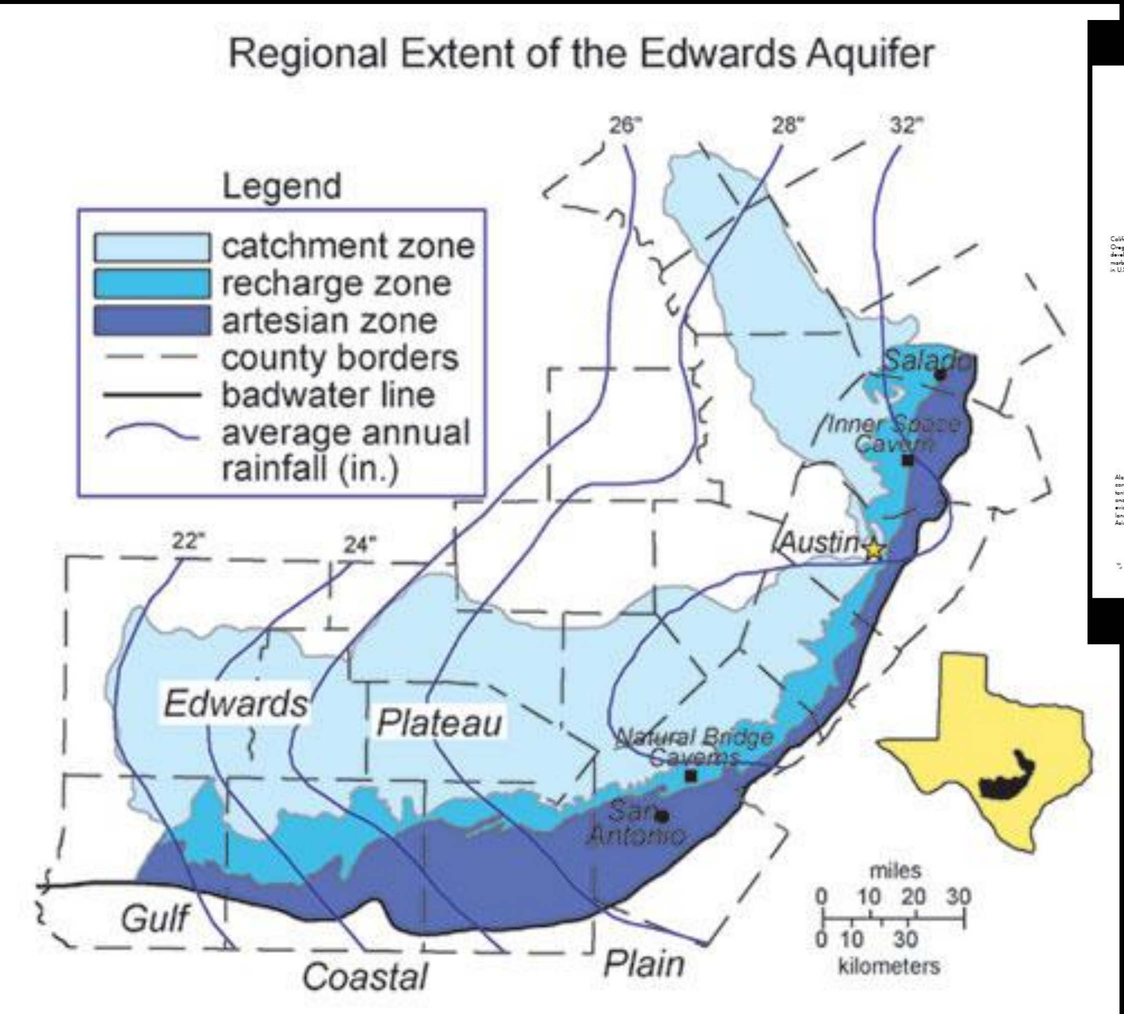
OUTWARD APPEARANCE

- The Edwards is characterized by vugs, large pores, rocks with holes, more
  - We show off the rock's uniqueness

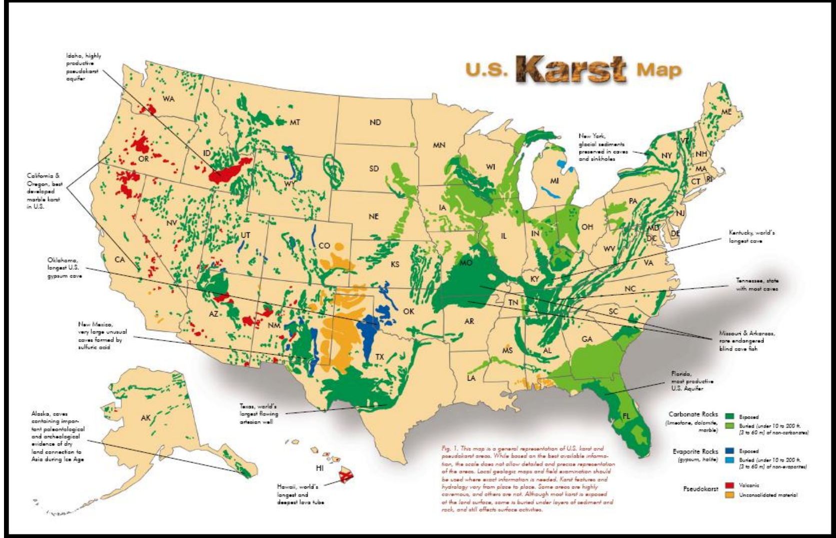
- *No karst in Guatemala, Canada, Mexico, the U.S. looks or behaves like the Edwards*

- *The Edwards Aquifer is an anomaly*

EDWARDS IS A LARGE, COMPLEX SYSTEM



(Musgrove, (2000). Regional aquifer map after Burchett et al. (1986) and Brown et al. (1992); precipitation contours from Larkin and Bomar (1983). The down-dip limit of potable water in the aquifer is defined by the bad water line (1000 mg/l)).



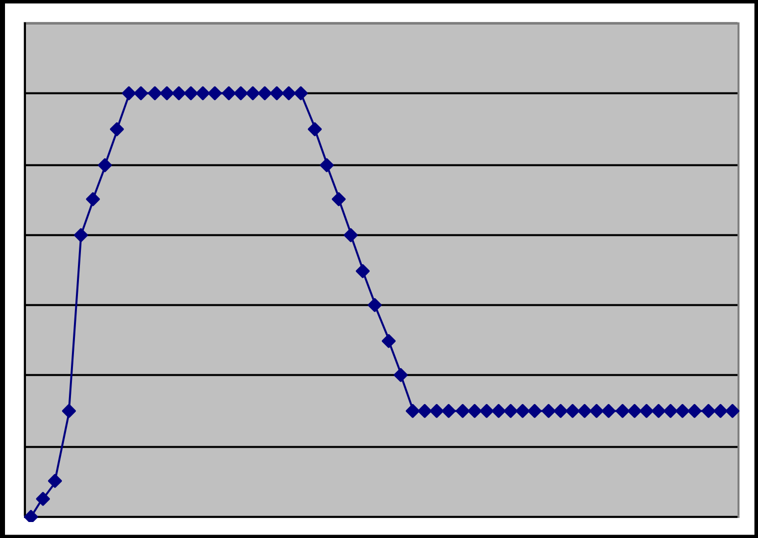
RECHARGE ZONE VS BASIN

•Basin: water in basin to spring

•Edwards: structurally complex; different zones

FRACTURE VS. MATRIX FLOW

- Fracture flow is rapid
- Matrix flow is slow
- Contaminants have initial pulse and then bleed out over long period of time



Chemical as detected at a spring

Why does TX not have subsidence/ sinkhole collapse problems?

- Not enough rain
- Material not being dissolved fast enough
- Most dissolution deep in Edwards

HOWEVER!

- This does not mean that central TX karst is not active!!!
- Major springs, thousands of active caves and other karst features
- No water on the surface---all funneled underground

ORGANISMS

- *No other aquifer in the world has the organism diversity that the Edwards has.*
- No other known karst system has the range of cave adapted insects, fish, and salamanders found in the Edwards.

HOW THE EDWARDS IS SPECIAL

- Very vuggy rock; extremely high porosity
- Fractured/faulted rock concentrates flow
- Very high flow velocities are the result
- Unique organisms

EDWARDS MTYH #1:
“The aquifer filters water”

Muddy water goes in the aquifer and clean water comes out. How can you say the aquifer does not filter?

FILTRATION?

- If I put muddy water in a glass and put the glass in a dark closet for 3 days and then remove the glass has that glass filtered?

Is the water clearer? Yes.

Was it filtered? No.

KARST AQUIFER AS A FILTER

- Does the Aquifer filter? NO!
- Suspended solids DO SETTLE OUT, but they are NOT filtered out!
  - No size exclusion/mechanical filtration occurs
  - Garden hose analogy
- It does NOT filter microorganisms, chemical pollutants

Is this conduit filtering?

KARST AQUIFER AS A FILTER

- Things spilled on recharge/contributing zones jeopardize the entire aquifer
  - Contaminants spilled on them have the potential to contaminate our sole water suppply

- Human activity on the these areas puts the water supply of a million people at risk
  - Once contaminated: Where do we go for water?

2000

- In 2000 there was a diesel spill at a quarry along I-35
- Waters with high VOC levels were detected at San Marcos Springs within 1 – 2 days
- Result:
  - Contaminant moved quickly offsite
  - Large volumes of water affected
  - Wells over a broad area affected

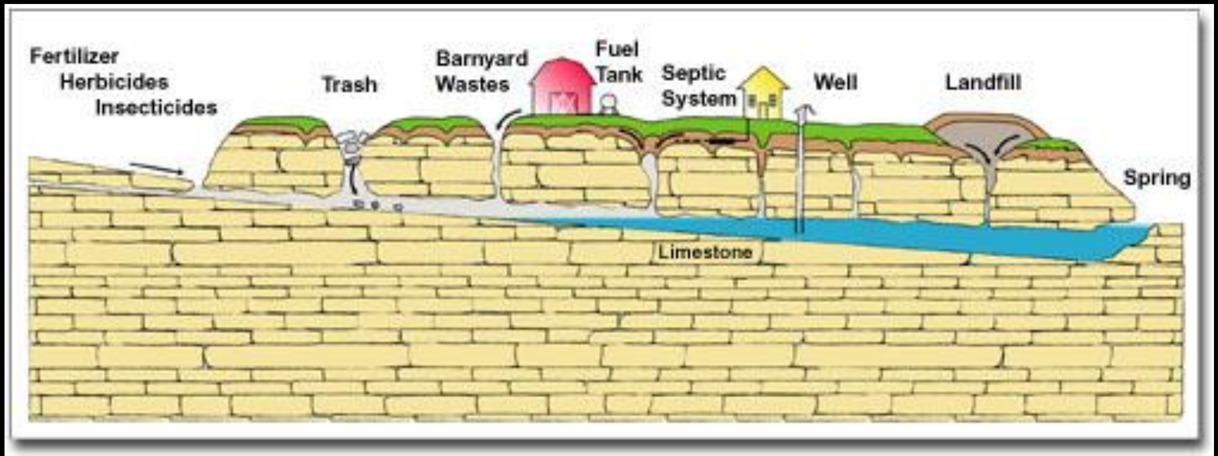
DANGER! HUMAN ACTIVITY OVER THE RECHARGE ZONE

EDWARDS MTYH #2:
“Protecting caves and karst features protects the aquifer”

The law requires me to identify and protect caves and karst features on my site that is on the recharge zone. Protecting point features is enough to protect the aquifer.

EDWARDS MTYH #2: "Protecting features protects the aquifer"

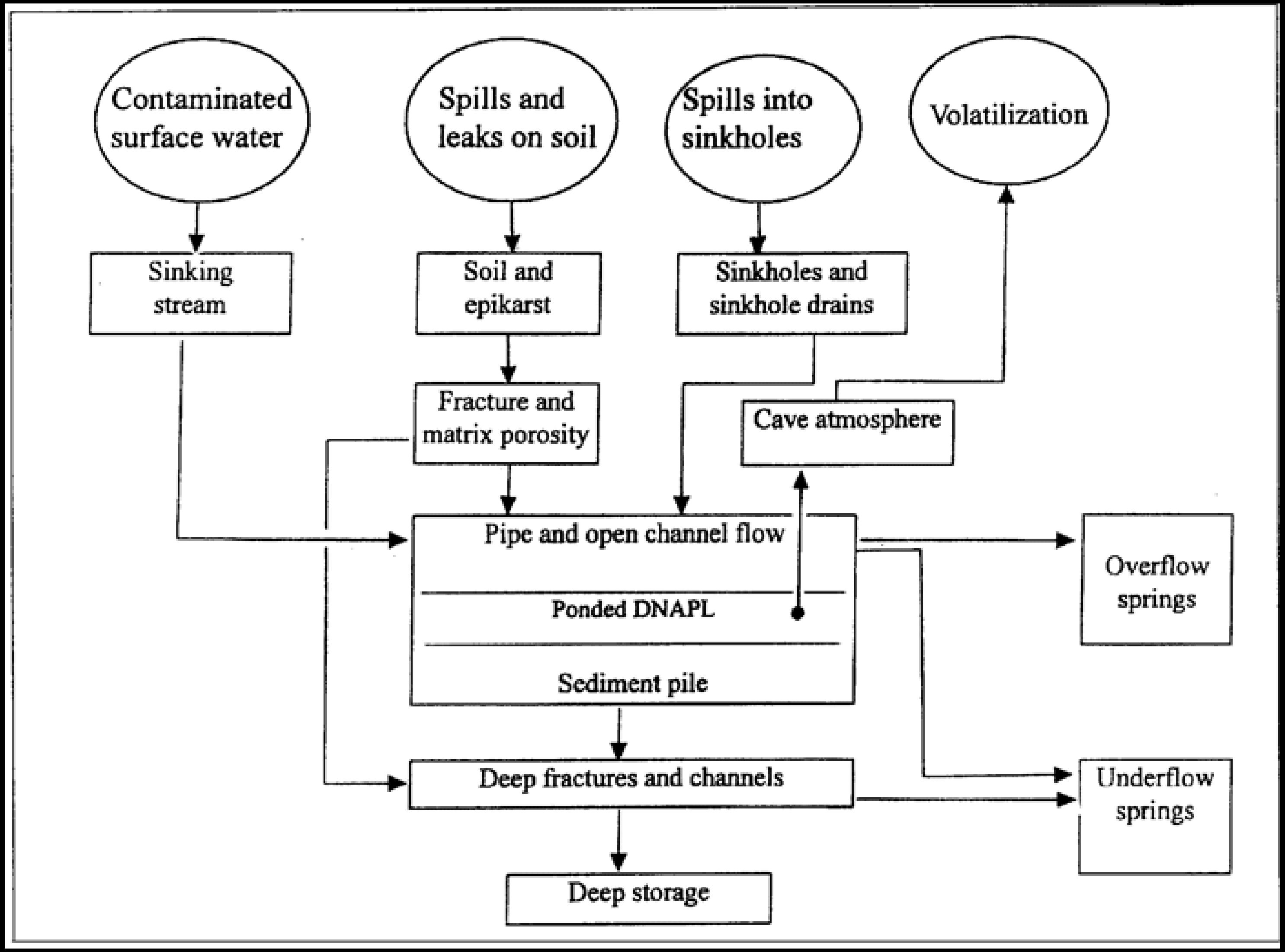
- Protecting features is important
- *Where does water enter a karst aquifer?*
  - *Everywhere!*
  - *Not just at identifiable points*



EDWARDS MYTH #2

- How can we claim our aquifer to be protected if a handful of point features are protected?
- Do all the protected point features account for the volume of water coming out of the springs? NO.
- A great majority of karst features are mantled by soil and go unnoticed
  - Soil mantled fracture
- And they go unprotected

KARST FLOW CHART



Karst-Contaminant Flow Chart

These would not be protected under the Edwards Rules

- *We need to protect large areas, NOT point features*

CONCERNS

- Central TX communities are aware of karst
- Most karst education learned through word of mouth, from tv, reading newspaper articles, etc.

- How many local geologists received karst training? Regulators? Policy makers?

CONCERNS

- The karst here is treated as discrete points in need of protection
  - *The entire area is susceptible and unique.*

- *We shouldn't be identifying point features to protect; we should be identifying large areas to protect.*
  - *Klimchouk*