# *Revisiting the Karst Continuum Concept in the Great Valley*

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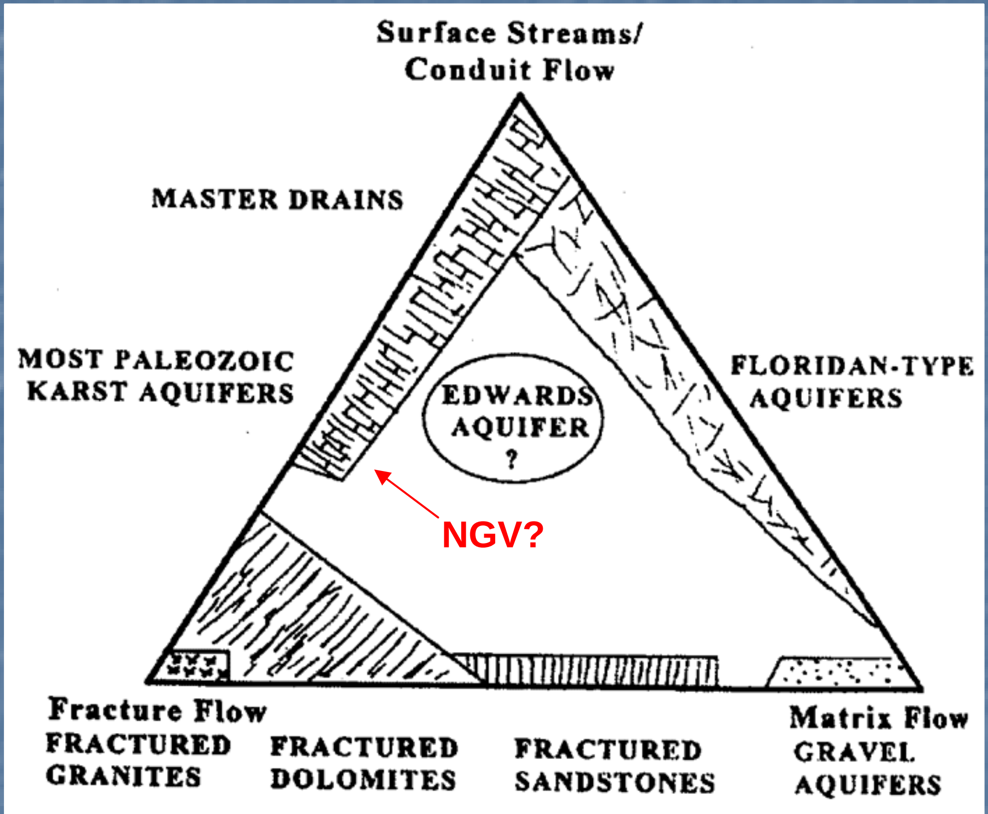
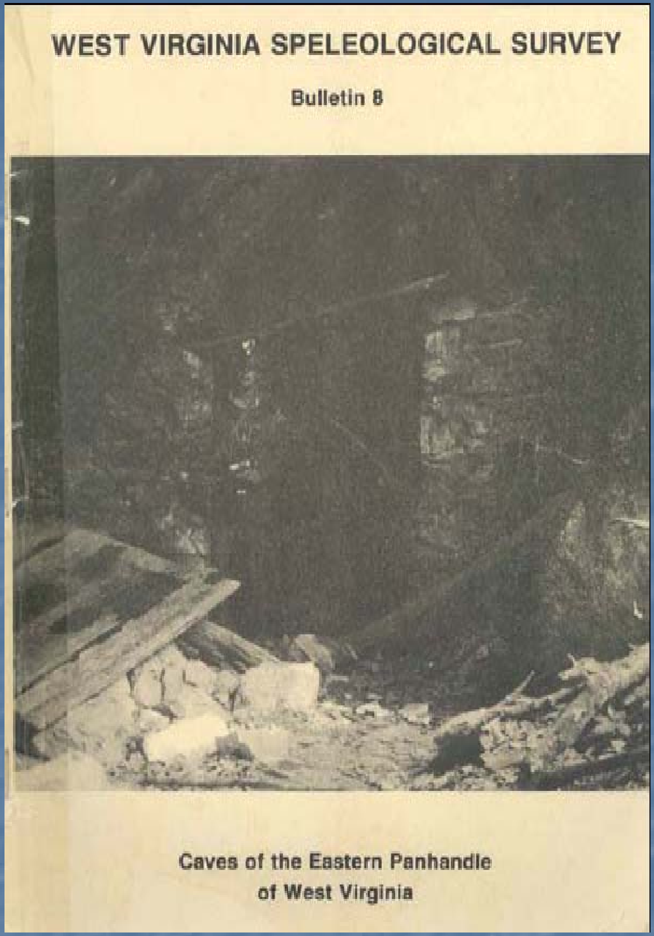
# Karst Continuum Model



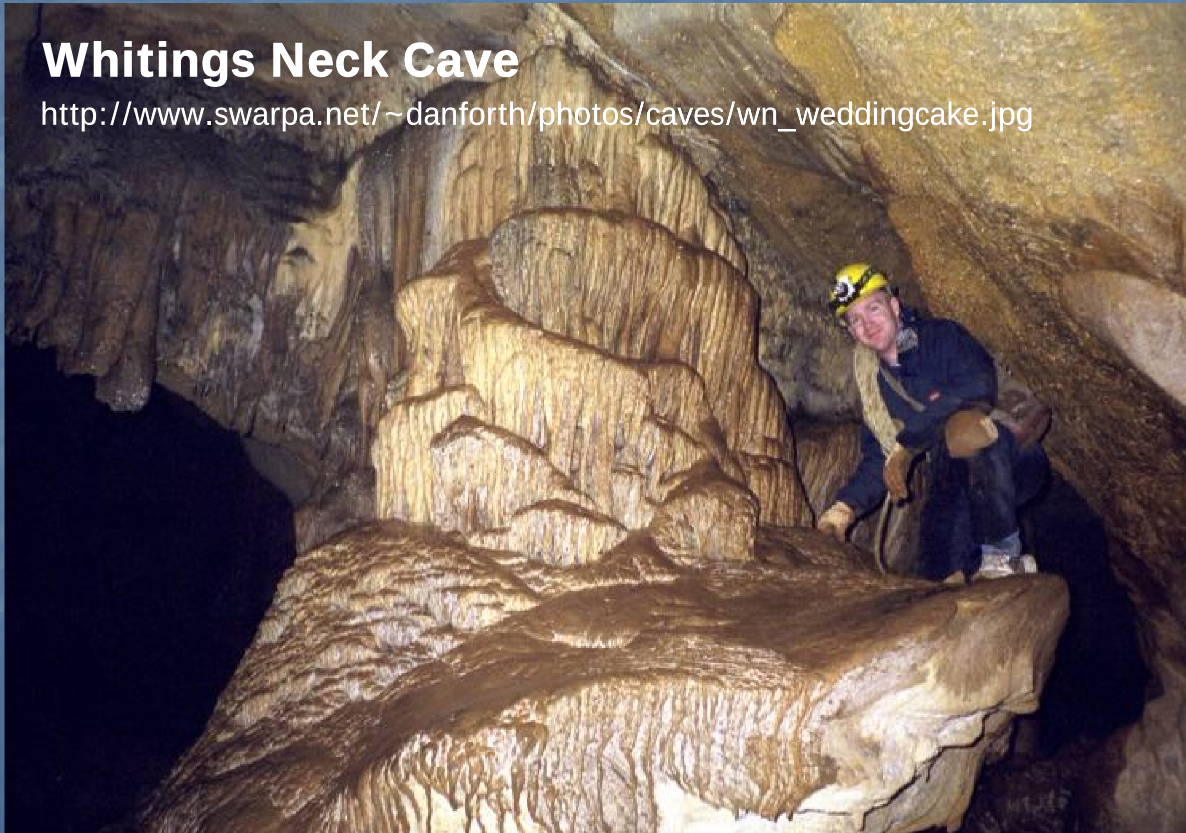

modified from White and White (2001)

# Karst Continuum Model




## CAVES OF THE EASTERN PANHANDLE

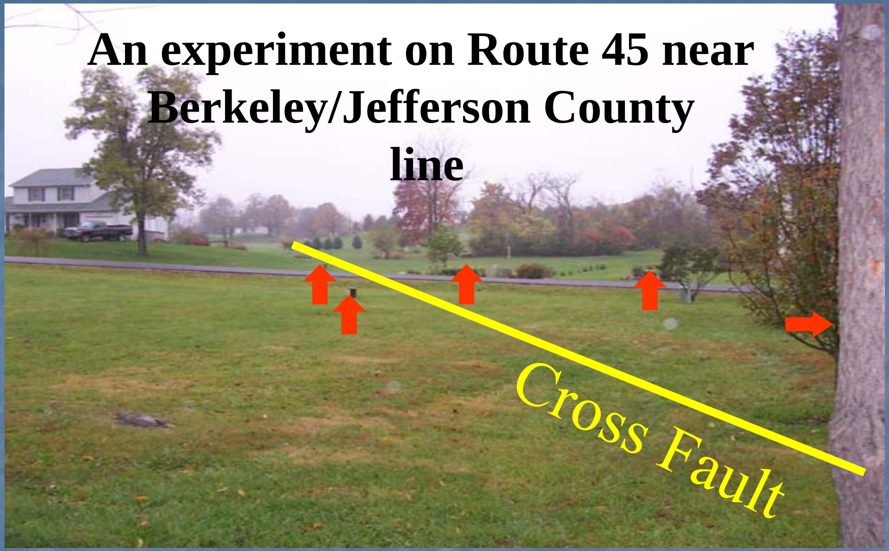
- Not that many caves
  - 42 known caves in Jefferson County
  - 48 known caves in Berkeley County
- Most are short and not of hydrological interest



# Outline - Conceptual Evolution

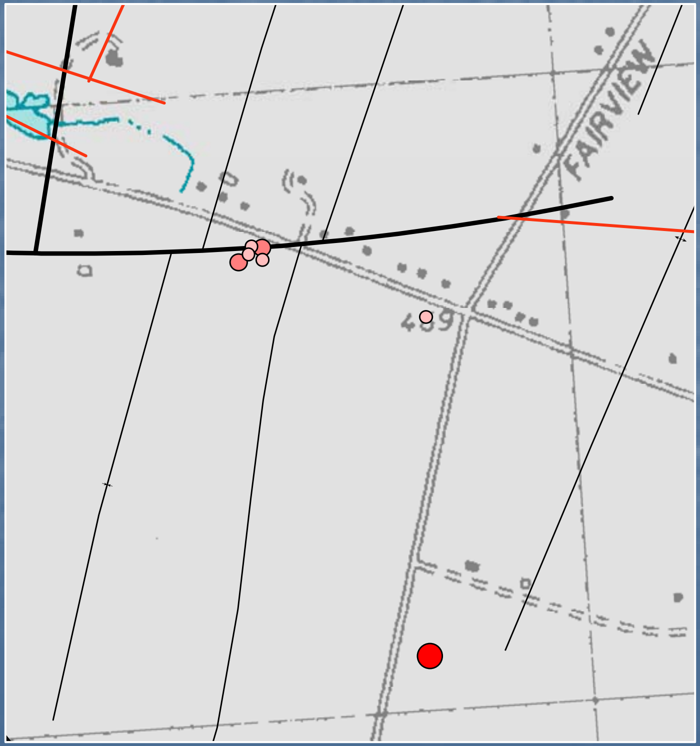
- Review of initial county projects and identification of preferred flow paths
- Review of GV Forum 2005 discussion on gradients in karst
  - Insights provided by review comments
- Karst heterogeneity
  - Systematic variation
  - Can we have karst without conduit dominance?
- Movement towards numerical validation of conceptual models
  - Transport characteristics

# Initial Project Results




## Drill Now

Cross faults
Complex folds
Cross strike fractures
Beekmantown Group




- Features/flowpaths may not have a surface expression.
- Data in addition to surficial mapping is necessary.

# Role of Structure – Directional Gradients (GV 2005)

**Hypothesis: Sinkholes and high capacity wells can be used as indicators of preferential subsurface flow paths (McCoy and Kozar, in review)**

**Sinkholes**

**Folds**

Synclines
Anticlines
Overturned Synclines
Overturned Anticlines

**Topography**

Hilltop
Valley

**Fracture orientation**

Strike parallel
Strike perpendicular

**Faults**

Longitudinal
Strike-slip

**Wells**

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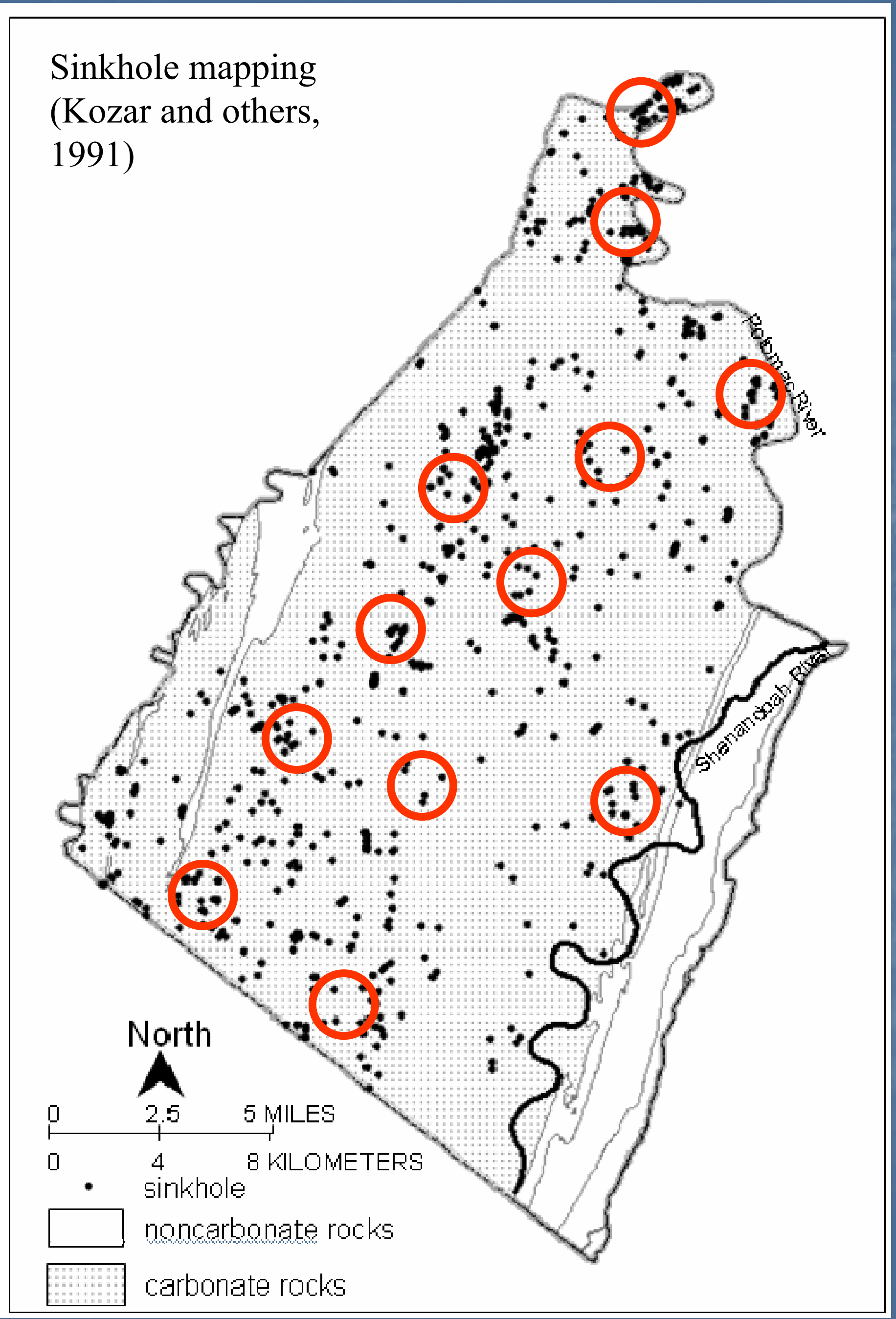
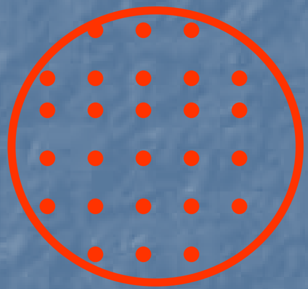
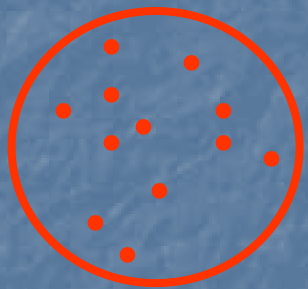
# A more rigorous approach




Grid-aligned



Random



# A more rigorous approach

| Orientation, in degrees | Observed frequency, in percent | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Potomac River Drainage | | | | Opequon Creek Drainage | | | | Shenandoah River Drainage | | | | |
| | Random sinkholes | Grid-aligned sinkholes | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 | Sample 6 | Sample 7 | Sample 8 | Sample 9 | Sample 10 | Sample 11 | Sample 12 | Theoretical distribution |
| 0-180 | 12 | 25 | 18 | 18 | 6 | 13 | 9 | 20 | 16 | 9 | 33 | 33 | 60 | 16 | 16.7 |
| 30-210 | 20 | 12 | 21 | 5 | 13 | 13 | 9 | 27 | 16 | 27 | 33 | 33 | 0 | 16 | 16.7 |
| 60-240 | 10 | 12 | 21 | 18 | 44 | 21 | 30 | 13 | 21 | 9 | 0 | 17 | 0 | 21 | 16.7 |
| 90-270 | 22 | 25 | 18 | 23 | 31 | 29 | 30 | 13 | 21 | 9 | 0 | 8 | 0 | 16 | 16.7 |
| 120-300 | 19 | 12 | 12 | 14 | 6 | 13 | 9 | 7 | 11 | 27 | 0 | 0 | 10 | 21 | 16.7 |
| 150-330 | 17 | 12 | 12 | 23 | 0 | 13 | 13 | 20 | 16 | 18 | 33 | 8 | 30 | 11 | 16.7 |
| $\chi^2$ | 6.67 | 13.5 | 5 | 14 | 88 | 13 | 33 | 15 | 4 | 24 | 98 | 58 | 176 | 4 | ---------- |
| Interpretation | ---------- | ---------- | random | both | oblique | oblique | oblique | parallel | random | parallel | parallel | parallel | parallel | random | ---------- |

# Role of Structure – Inferences on Gradients

**Hypothesis 2: Sinkholes and high capacity wells are indicators of vertical gradients (McCoy and Kozar, in review)**

Downward movement of water is implied by the vertical direction of development for most sinkholes in the area (Jones, 1973)

Faults constitute permeable zones that drain fractures, sinkholes, conduits and move water to discharge points at springs (Hobba et al., 1972)

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**Are free convection or forced convection possible reasons to explain vertical gradients driving flow towards the surface?**
**-Guest Editor of *Environmental Geology***

Free Convection is heat transfer due to density driven flow. Warm waters rise, cooler waters sink.

Forced convection is the transfer of heat by another mechanism, commonly flow gradients from recharge to discharge

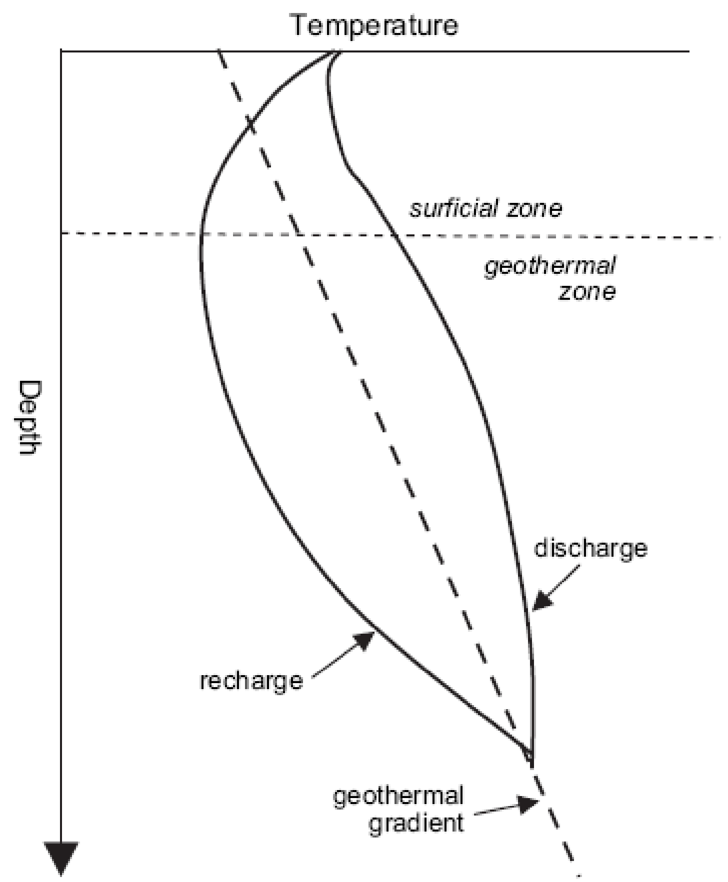


Figure 2. Schematic temperature profiles showing deviations from the geothermal gradient caused by surface warming in the surficial zone and convection in the geothermal zone. Recharge (downward movement of ground water) results in concave upward profiles, whereas discharge (upward movement) results in convex upward profiles. (Modified from Taniguchi et al. 1999a.)

Anderson (2005)

**Are free convection or forced convection possible reasons to explain vertical gradients?**
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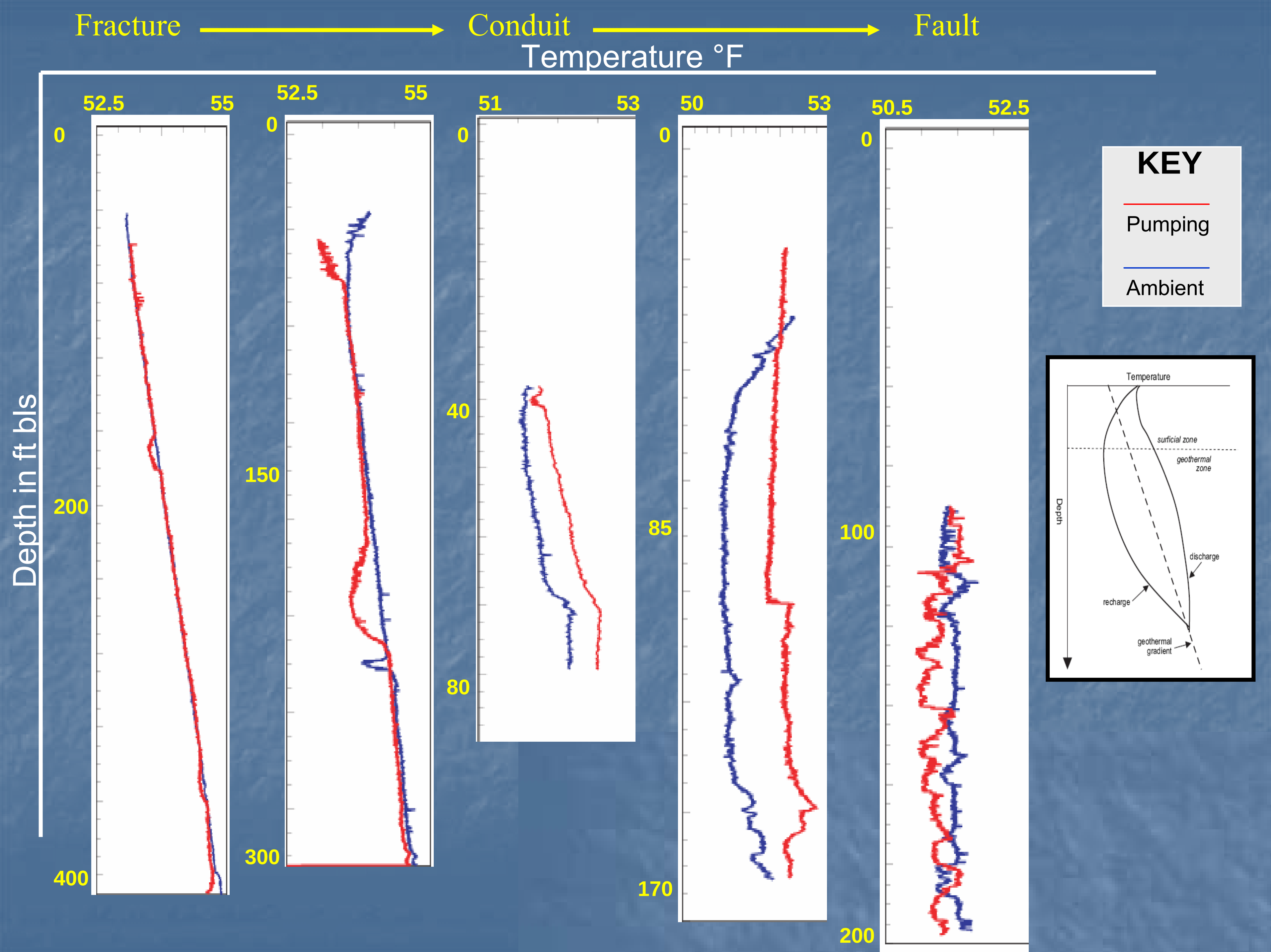

Fracture
Conduit
Fault
Temperature °F
Depth in ft bls
52.5
55
0
200
400
52.5
55
0
150
300
51
53
0
40
80
50
53
0
85
170
50.5
52.5
0
100
200
KEY
Pumping
Ambient
Temperature
surficial zone
geothermal zone
Depth
discharge
recharge
geothermal gradient

# Inferences from drilling

**MUDDY BOOTS SCALE**

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**Thick saprolite**

**Difficult well completion**

**Turbid, unusable water**

***Are fault zones telling us something about karst genesis and conceptualization in the Great Valley?***

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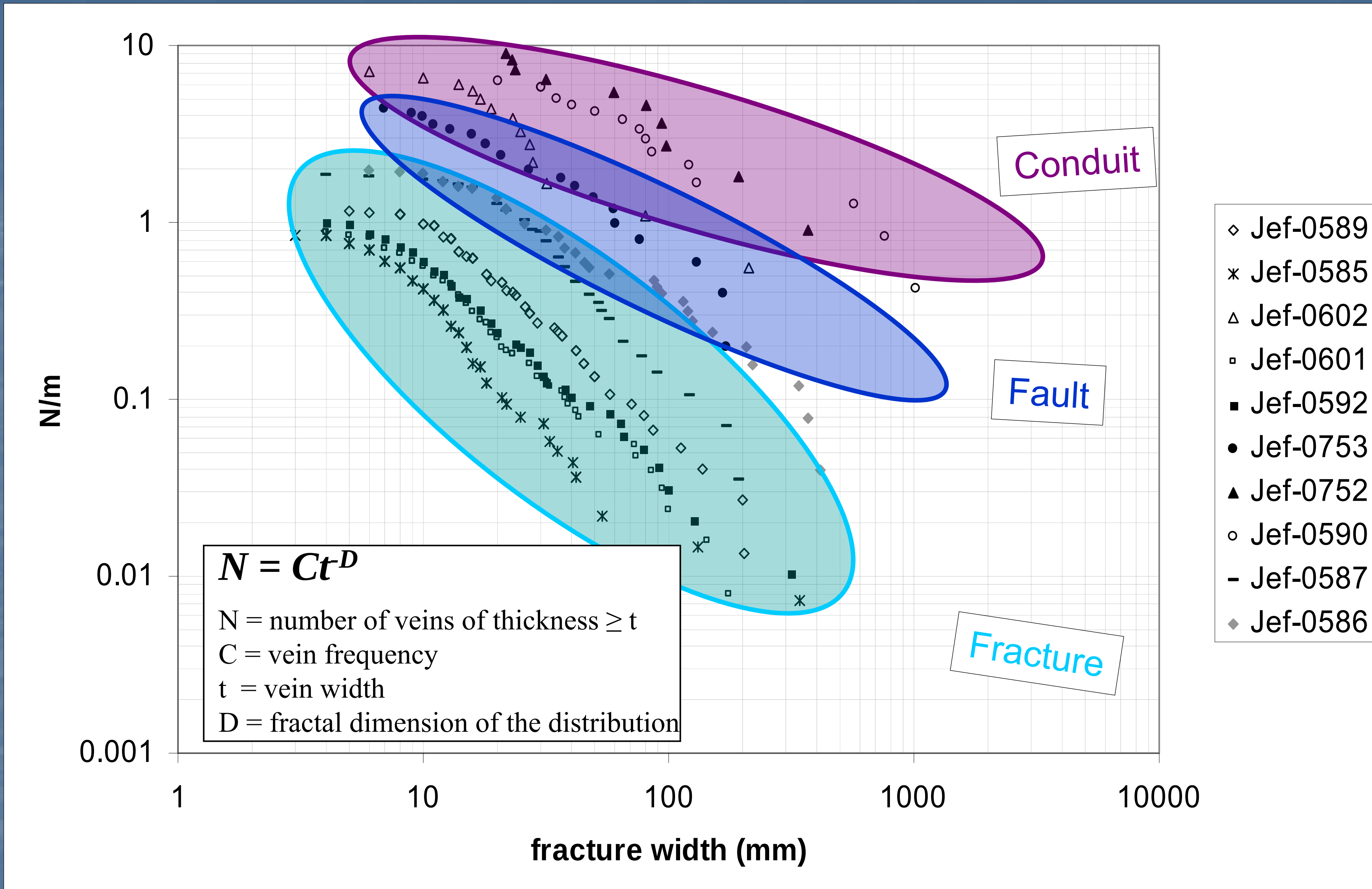


Roberts, S., Sanderson, D.J., and Gumiel, P., 1999, Fractal analysis and percolation of veins. *In* McCaffrey, K.J.W., Lonergran, L., and Wilkerson, J.J., (eds) *Fractures, Fluid Flow, and Mineralization.* Geological Society, London, Special Publications, 155, 7-16.

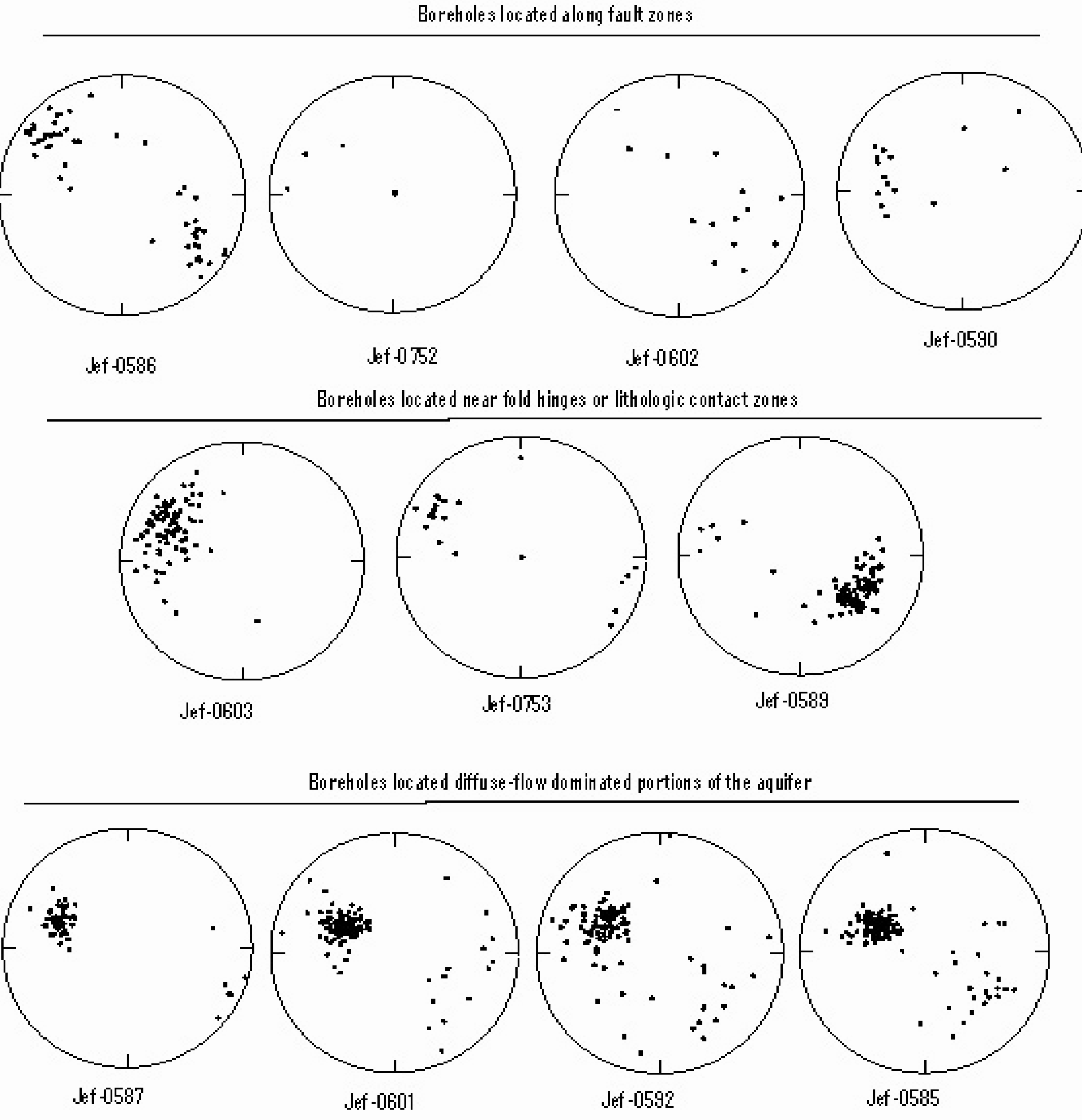


**Figure XX.** Schmidt equal-area stereonet projections of poles to planes of fractures projected in the southern hemisphere for 11 boreholes at the Leetown Science Center, Leetown, West Virginia.

Orthogonal Fracturing

**Faults**

**Karst zones**

**Fold Hinges or Lithologic Contacts**

**Fracture-Flow**

Bed-limited permeability

Deformation

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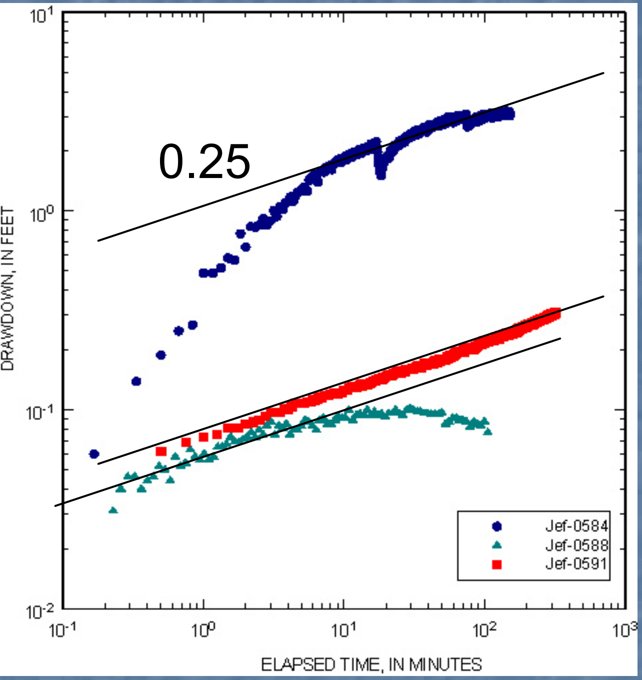
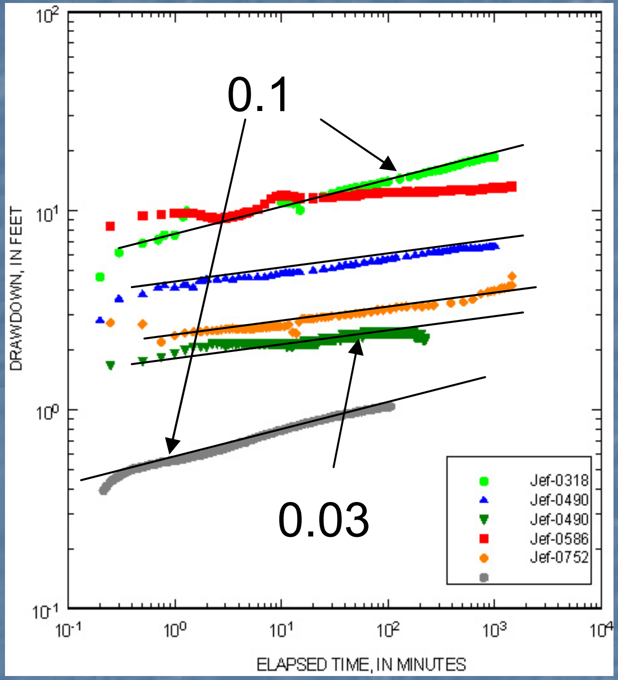
## Time-drawdown data

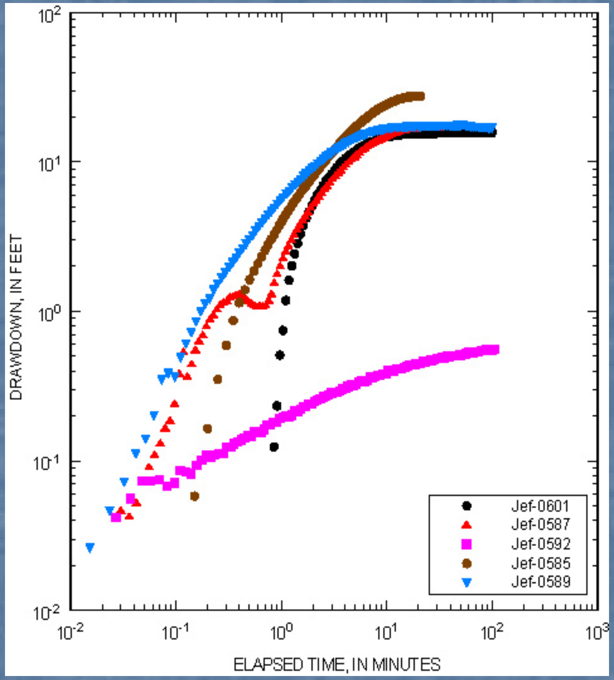
Conduits




Faults




Fractures




**Small drawdown (~1 ft max)**
**0.25 slope**

**Small drawdown (~10 ft max)**
**0.03 – 0.1 slope**

**Large drawdown (>10 ft max)**
**Leaky aquifer response**

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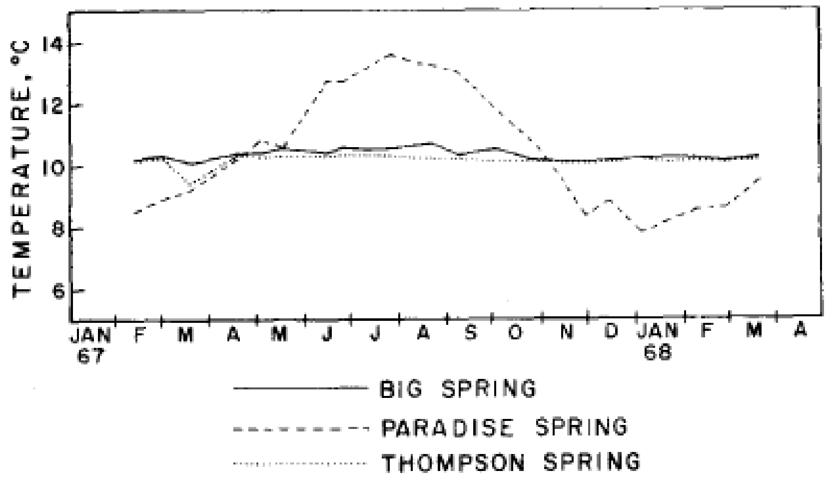



Fig. 11. Seasonal variations in temperatures of three springs in the Spring Creek Basin.

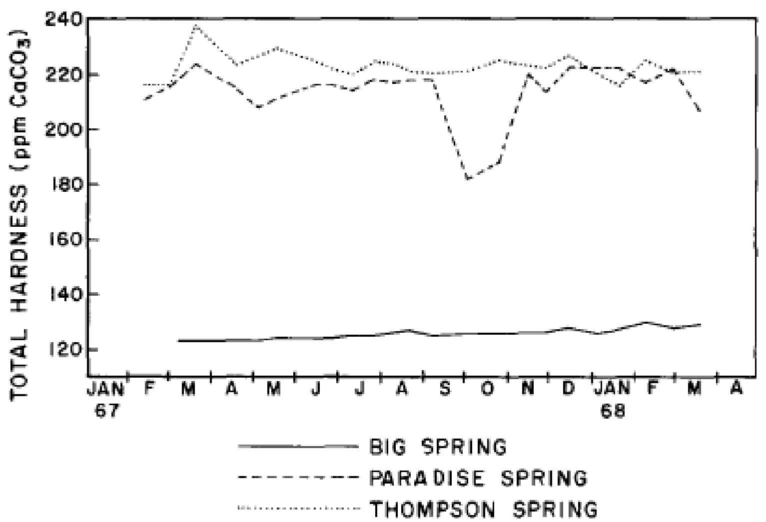


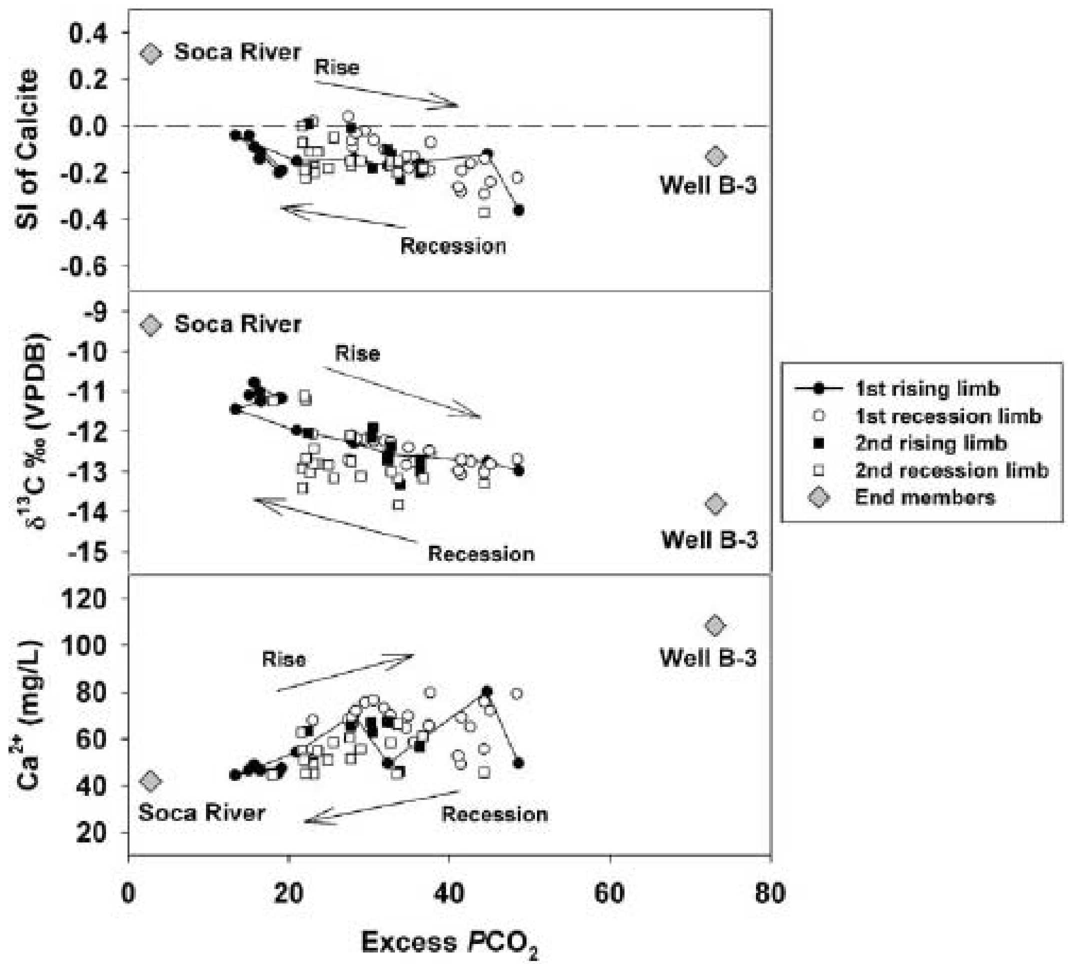

Fig. 14. Seasonal variations in total hardness of three springs in the Spring Creek Basin.

# Inferences from springs

Shuster and White (1971)

# Inferences from wells

Fig. 11 Carbonate chemistry evolution of well B-4 during storm events of 2000. The correspondence of increasing $PCO_2$, lower SI of calcite, lower $\delta^{13}C_{DIC}$, and greater $Ca^{2+}$ concentrations during the rising limb of the storm events indicates increased contributions from epikarstic water




Doctor et al (2006)

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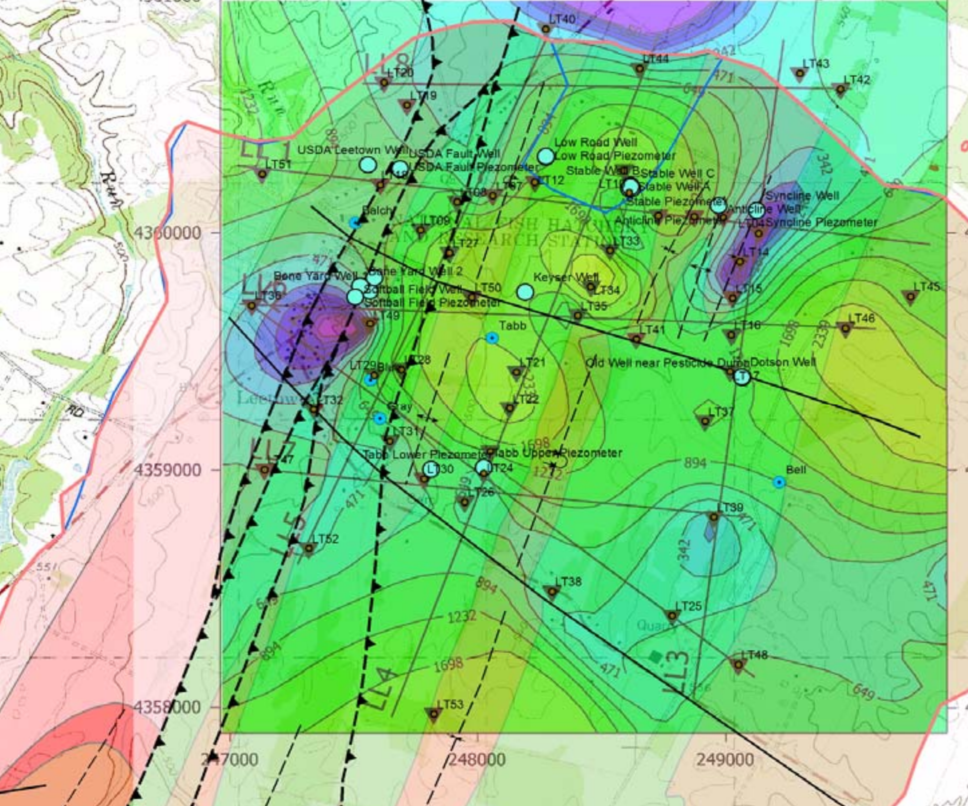
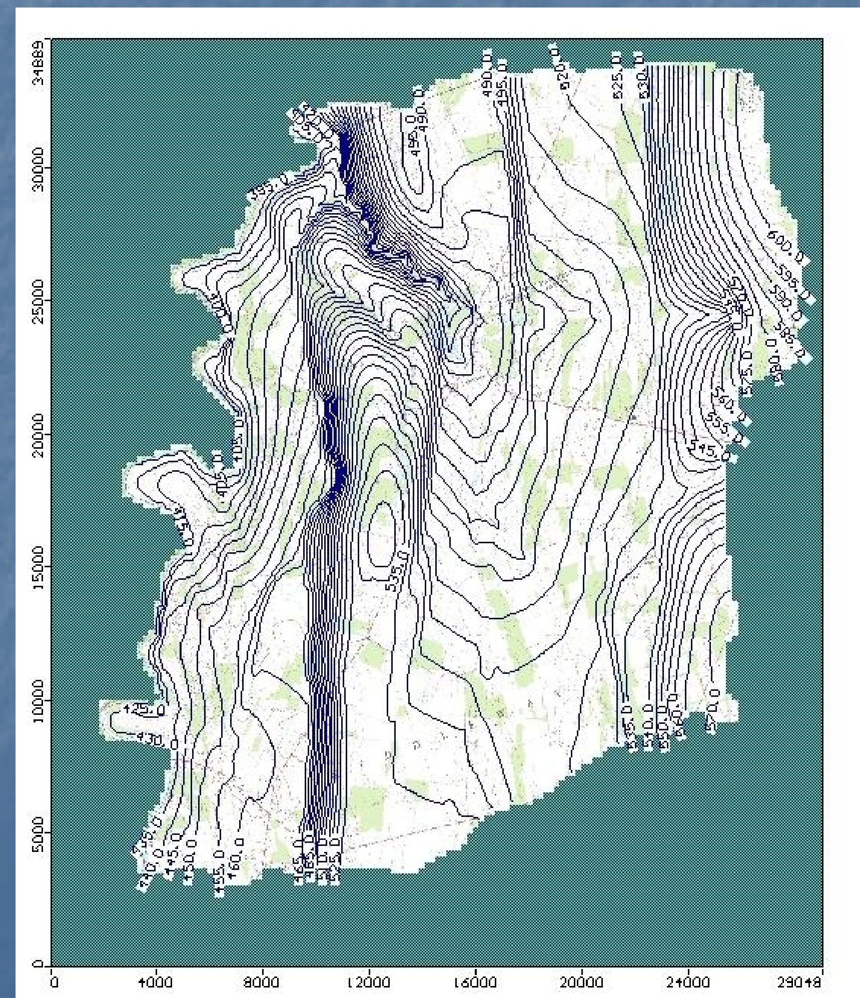


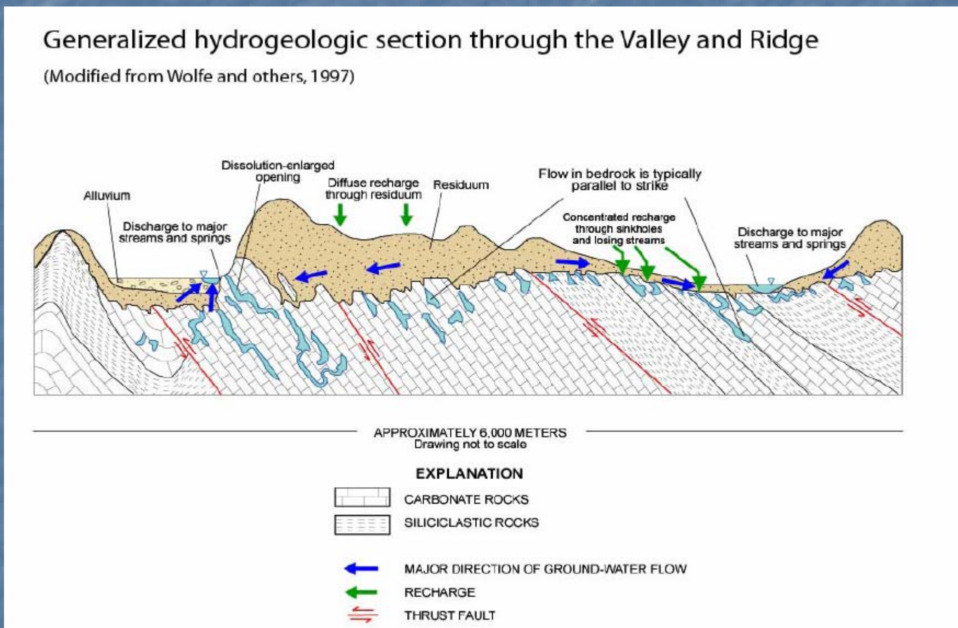

# What are the implications of systematic differences between fractures, faults, and conduits?

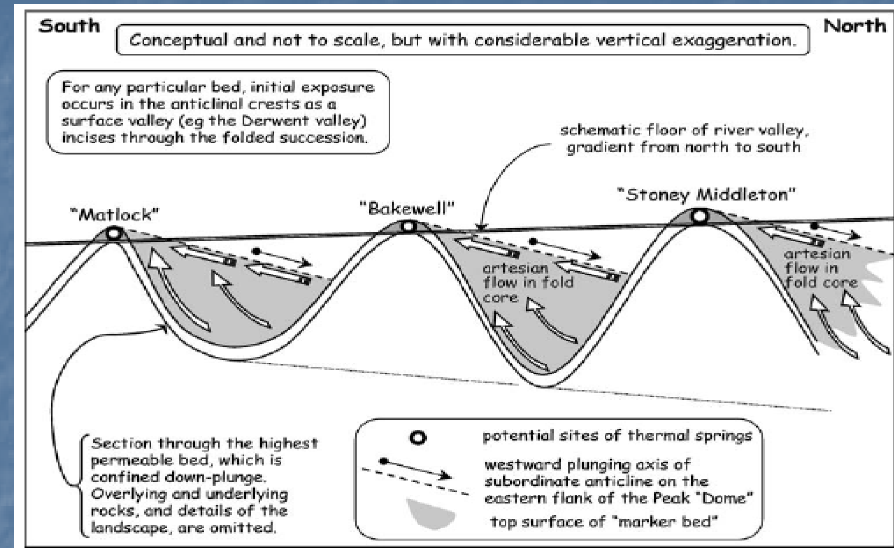
Kozar et al., in review




## Transport characteristics inherent to aquifer health

# Moving from Conceptual to Numerical Evaluation




Gunn et al., 2006

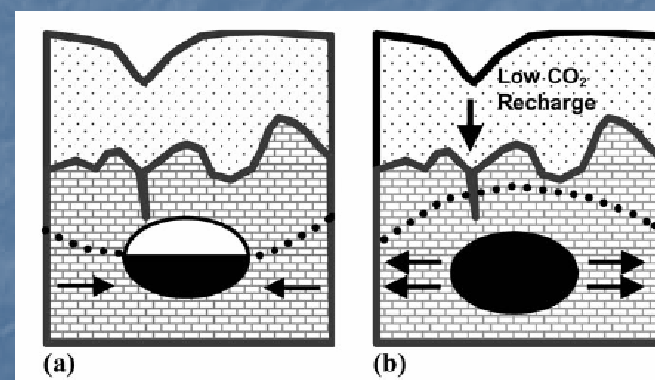



Fig. 8 Conceptual model for recharge in a karst aquifer

modified from Vesper and White (2004)

# Heat as a tracer…in karst

3742 BENDERITTER ET AL.: FLOW CHARACTERIZATION THROUGH HEAT TRANSFER EVIDENCE

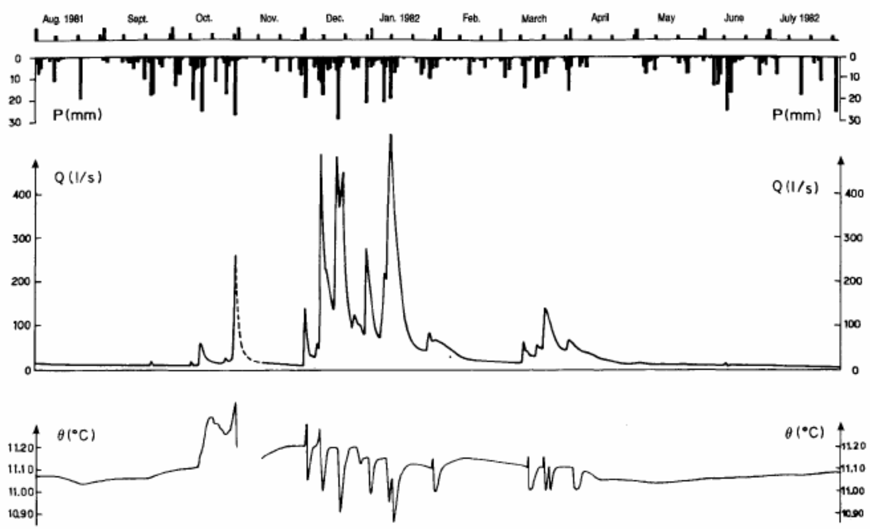



Fig. 1. Daily rainfall, flow rate, and temperature at the outlet during the 1981–1982 annual cycle.

Benderitter and Roy (1993)

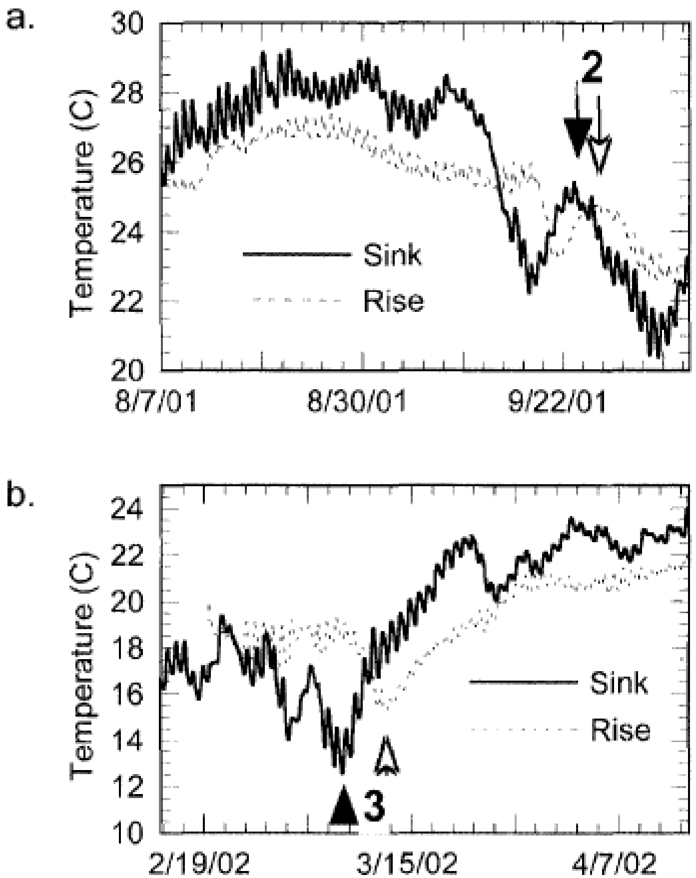



**Figure 4.** Example of correlation of temperature data, showing the temperature measurements at the River Sink and River Rise for the (a) September 2001 event, and (b) March 2002 event. Arrows show traced temperature signals at River Sink (filled) and River Rise (open).

Screaton et al. (2004)

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## Direction of future hydrogeologic investigations

(1) Are current conceptualizations of GV karst adequate to address non-conduit influence on water availability and aquifer health?

(2) Are recent trends in fractured rock applicable to in non-conduit portions of karst aquifers?

(3) What transport characteristics can be assessed from quantitative observations of non-conduit flow processes?

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**In the Great Valley, there is great variation in the size AND the relative importance of conduits in the hydrology of the aquifer.**

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