

Site Characterization Using Physical and Chemical Methodologies

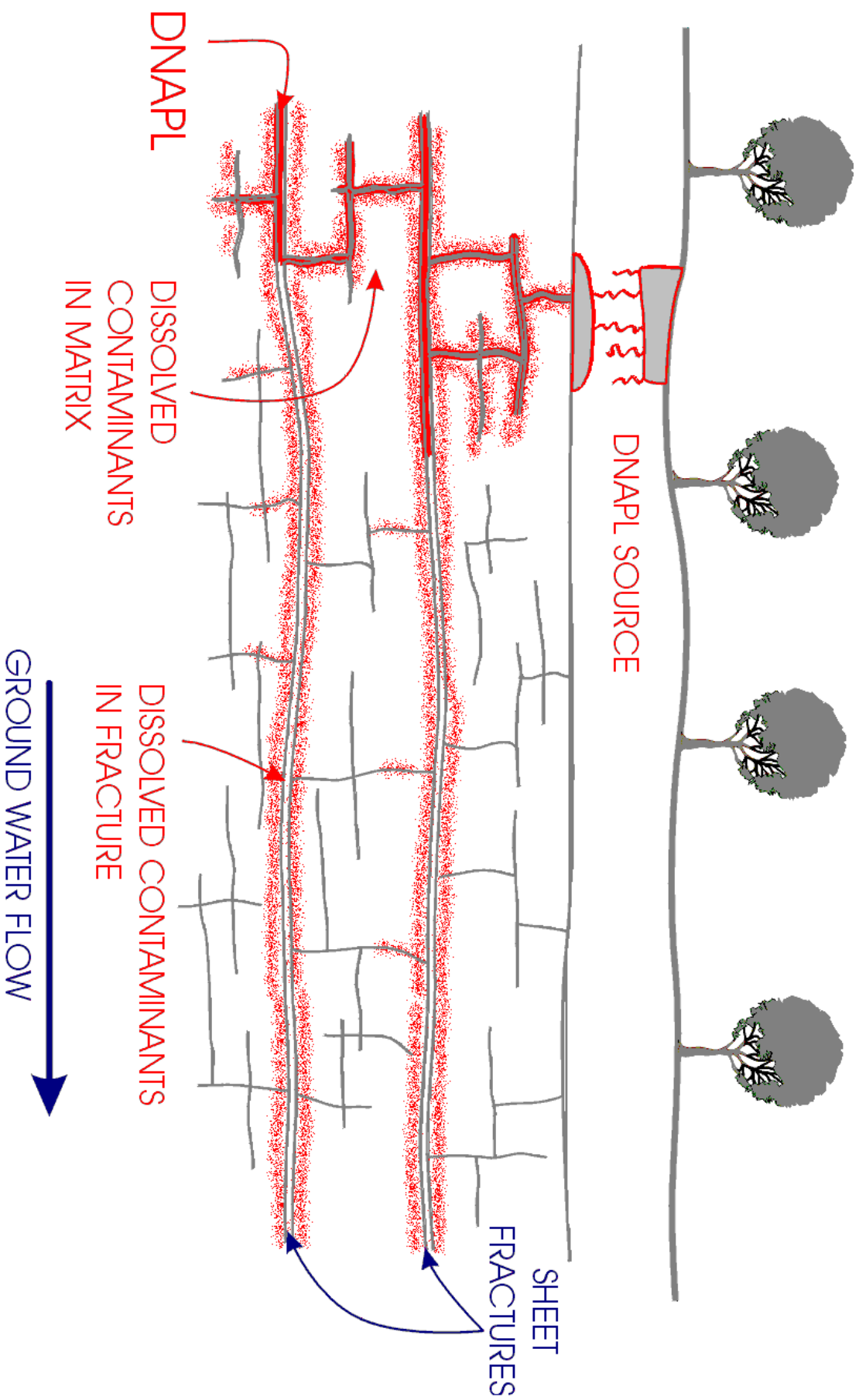
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EPA Fractured Bedrock Workshop





Conceptual Model Development

- Transport through discrete fracture pathways
- Pathway inter-connectivity
- Groundwater velocity
- Matrix diffusion
- Vertical fractures
- Modeling

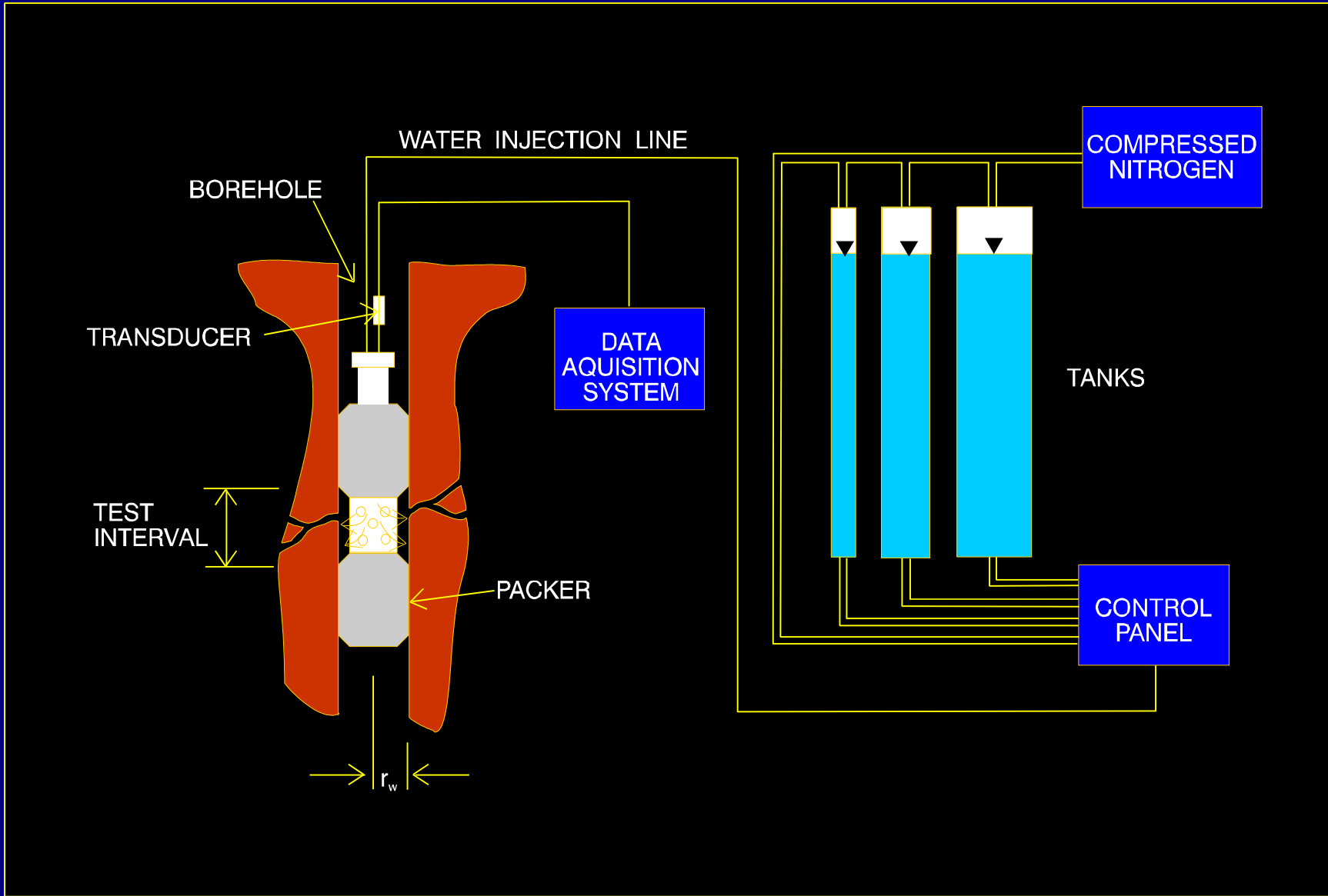
Discrete Fractures

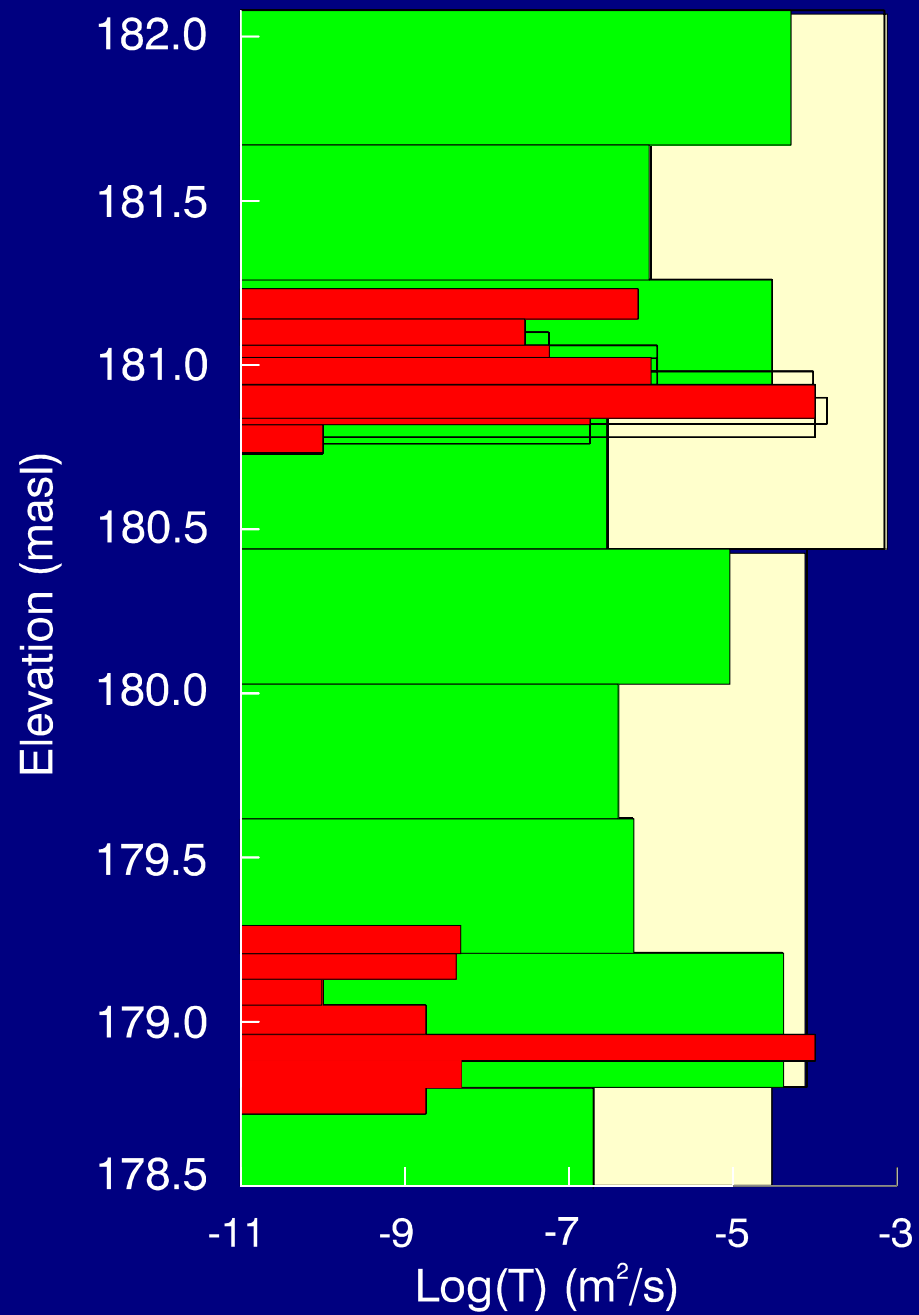
- Very difficult to obtain hydraulic properties of specific fractures
- Geophysics is of limited use
- Measure hydraulics directly using an interval testing method
- Mean fracture spacing and scale play a significant role



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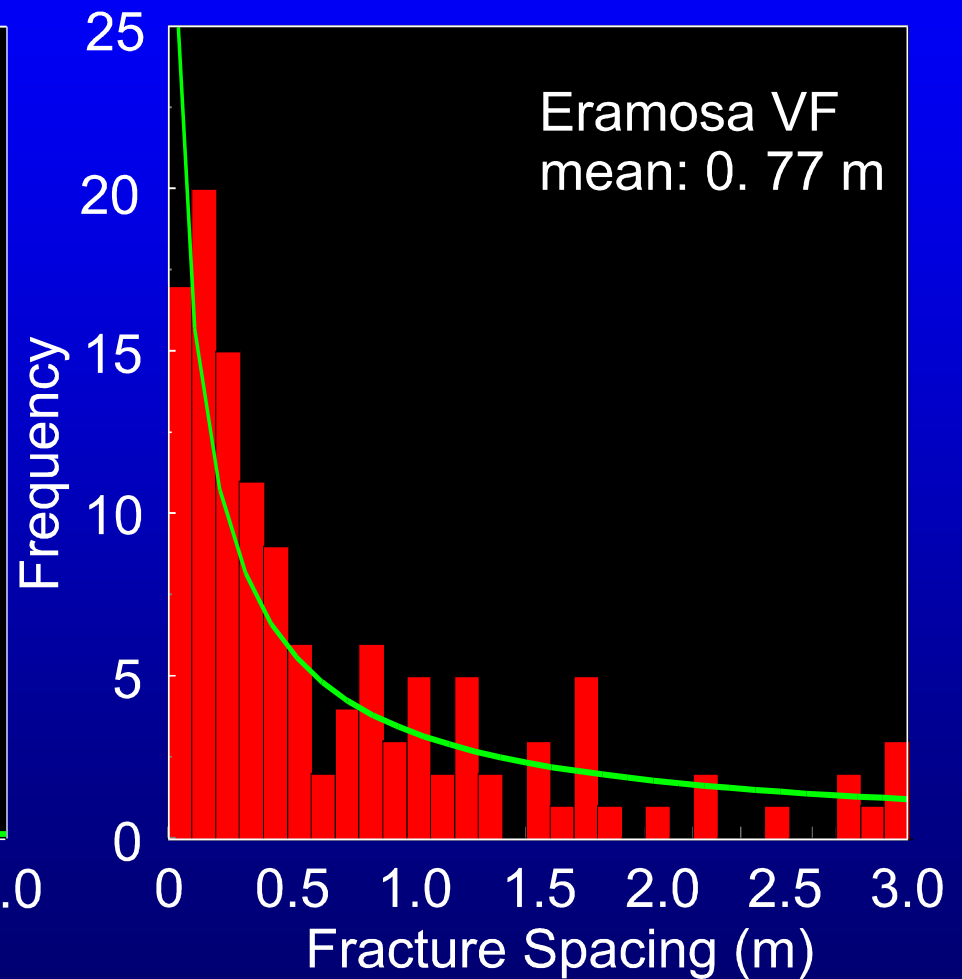
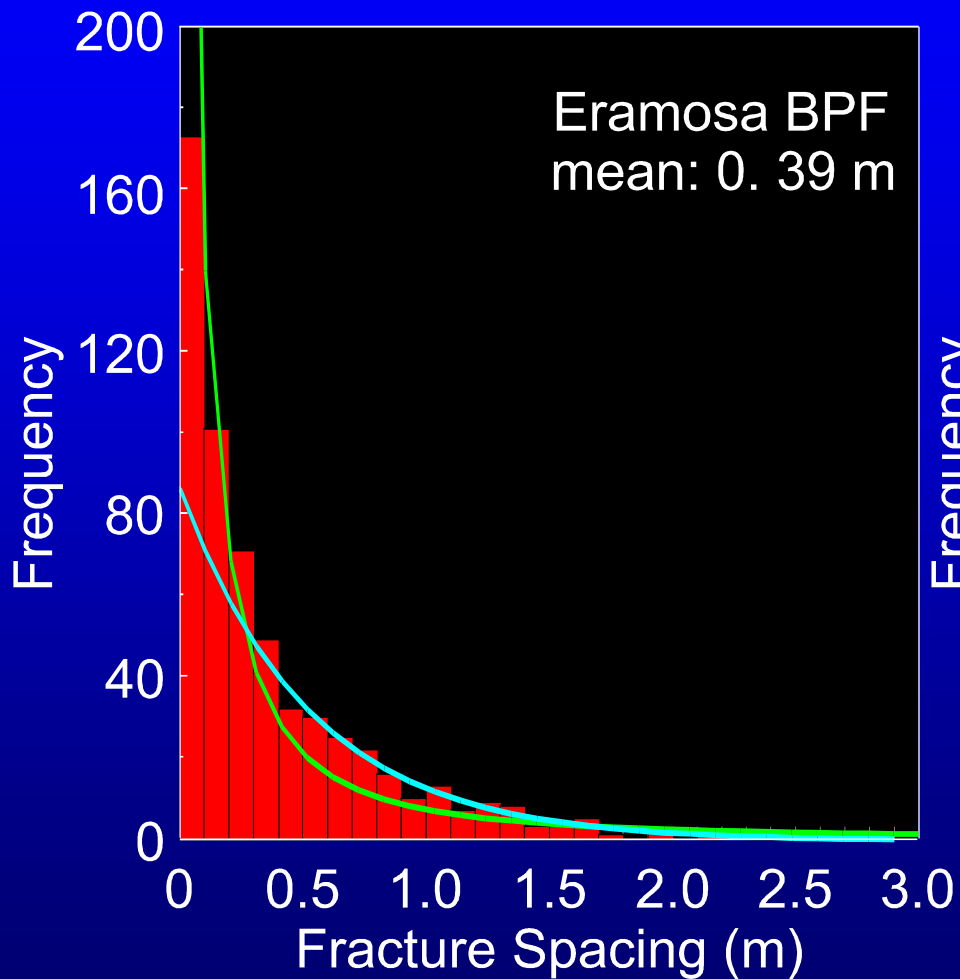


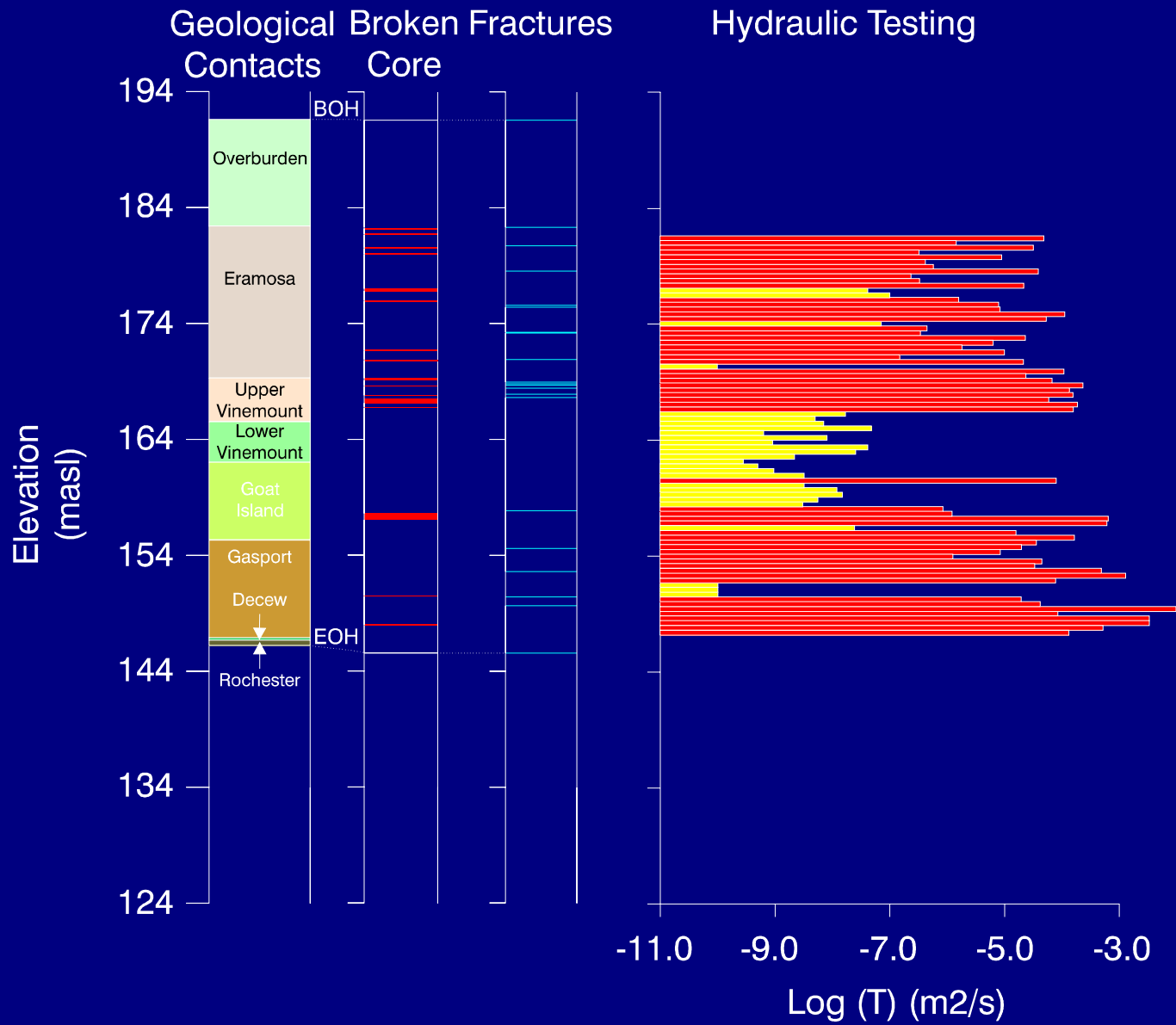


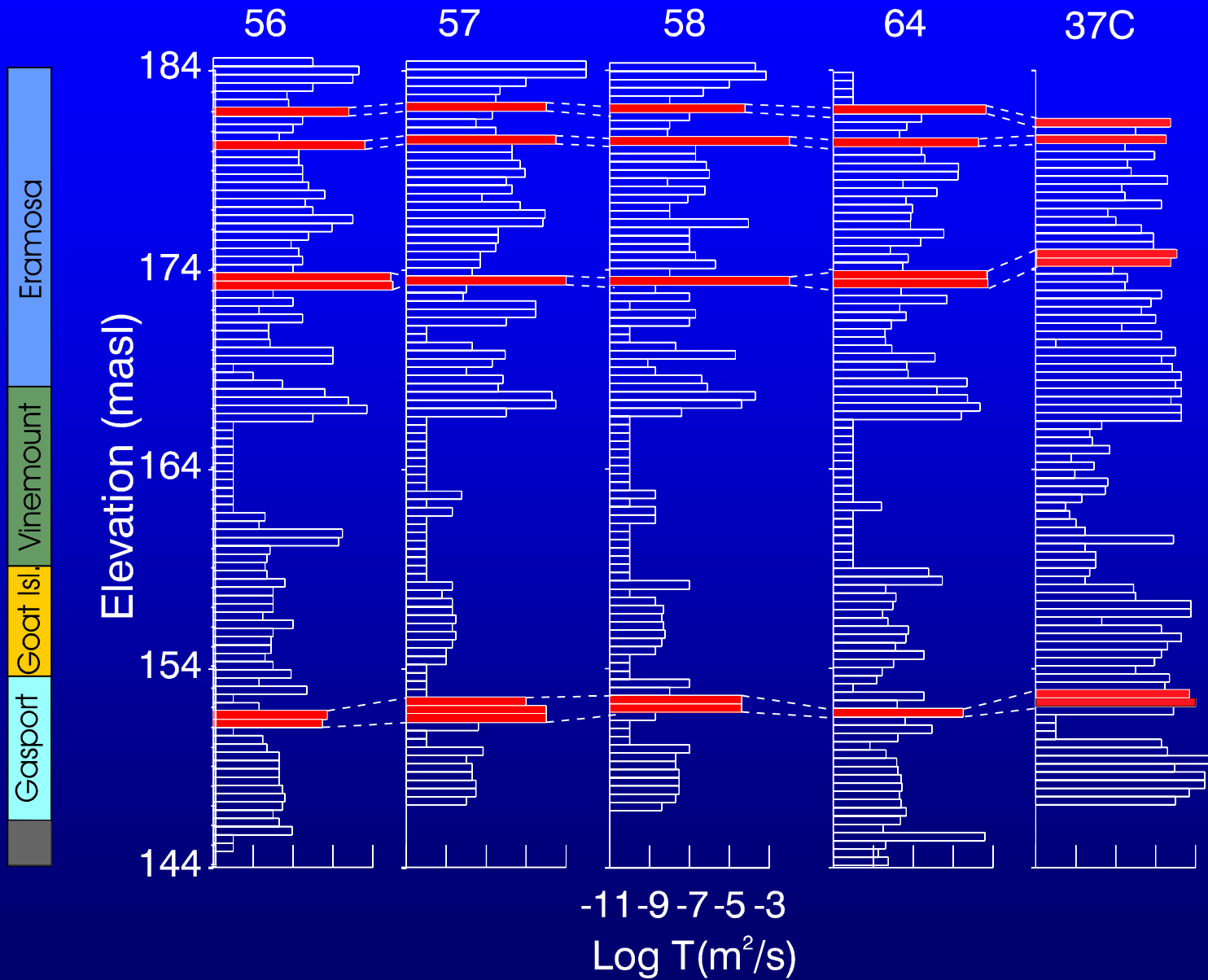


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Fracture Spacings







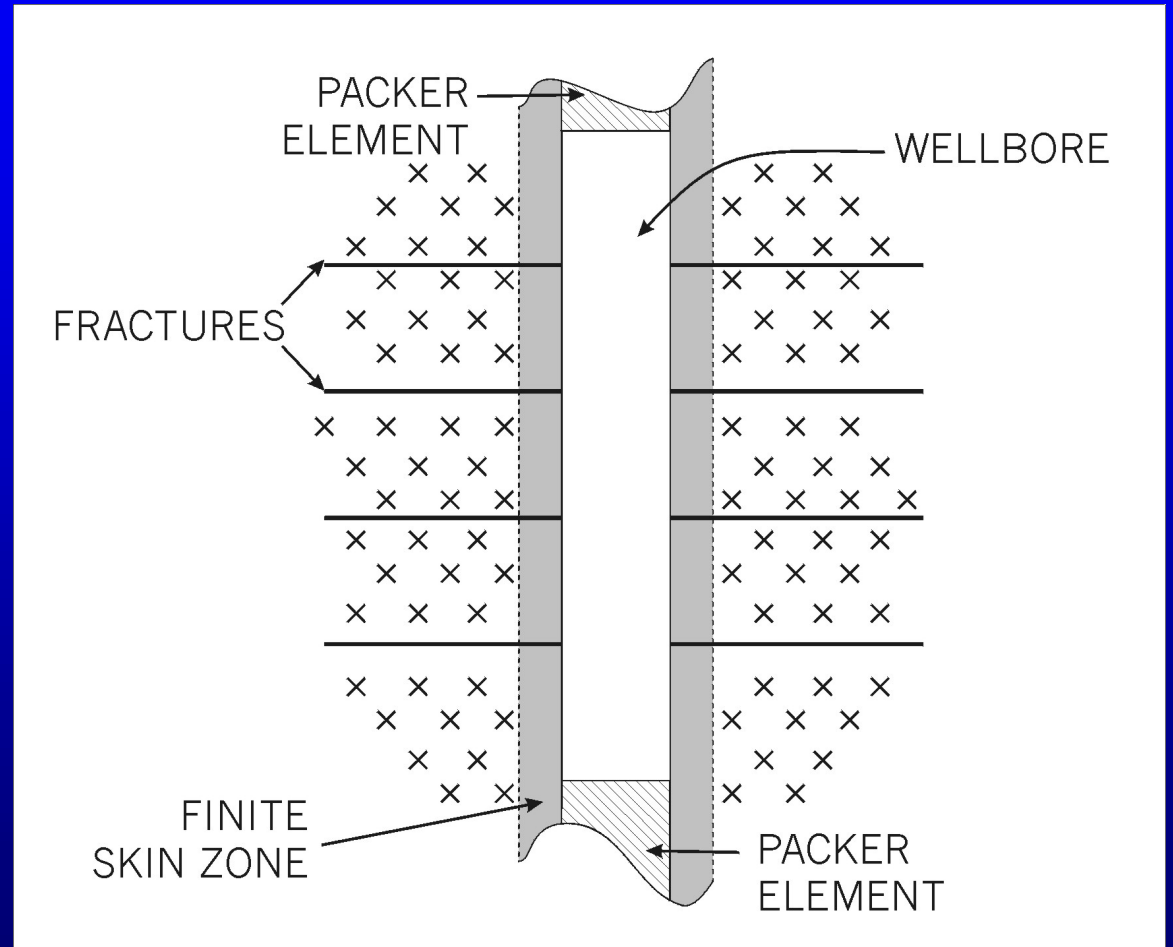
Groundwater Velocity

- Proportional to the square of the fracture aperture (cubic law)
- Darcy's Law does not work
- Must know discrete fracture properties to predict velocity

Example

Four Fractures,
6-m interval

$$T=4 \times 10^{-5} \text{ m}^2/\text{s}$$



Example

- Estimate velocity via Darcy's Law using T , $i=0.001$ and assuming a porosity of 1% = **0.06 m/day**
- Equivalent single fracture aperture is $410 \mu\text{m}$, thus velocity calculated using cubic law = **8.5 m/day**

Example

- Assume fractures contribute evenly, aperture of each is then $257 \mu\text{m}$
- Using the cubic law, the true velocity in each fracture is **3.4 m/day**
- Detailed hydraulic testing results help this calculation immensely

Groundwater Velocity

- Measurement of hydraulic gradient another difficulty with velocity calculations
- Gradient often limited by “critical neck” at the network scale
- May be safest to use estimate of regional gradient and not direct measurement

Point Dilution Results from Smithville

Fracture	Depth (m.b.c.t.)	Aperture (microns)	N	v (m/day)	dh/dx
1	13.1	592	2	36-49	0.002-0.003
2	15.1	953	2	247-284	0.002-0.006
3	19.1	604	1	2	0.0001
4	19.9	638	1	4	0.0002
5	49.9	416	1	66	0.008

Hydraulic Head

- Very powerful information from which to infer connectivity
- Need hydraulic head over entire borehole (not just a discrete zone)
- Requires multi-level completions – the more discrete intervals the better

Example

Isolate intervals
using packer
elements

Measure hydraulic
head in each
interval

Packer

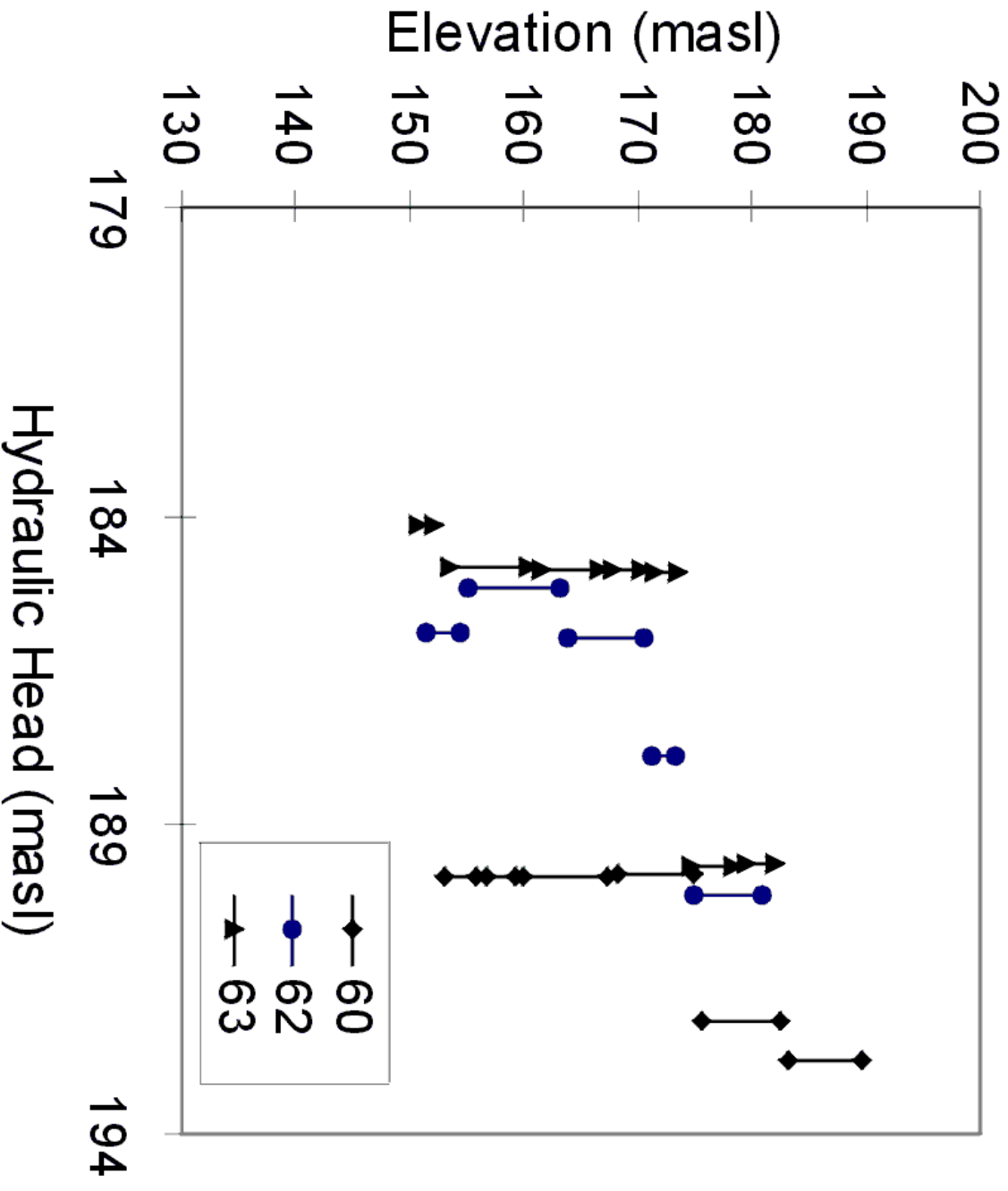


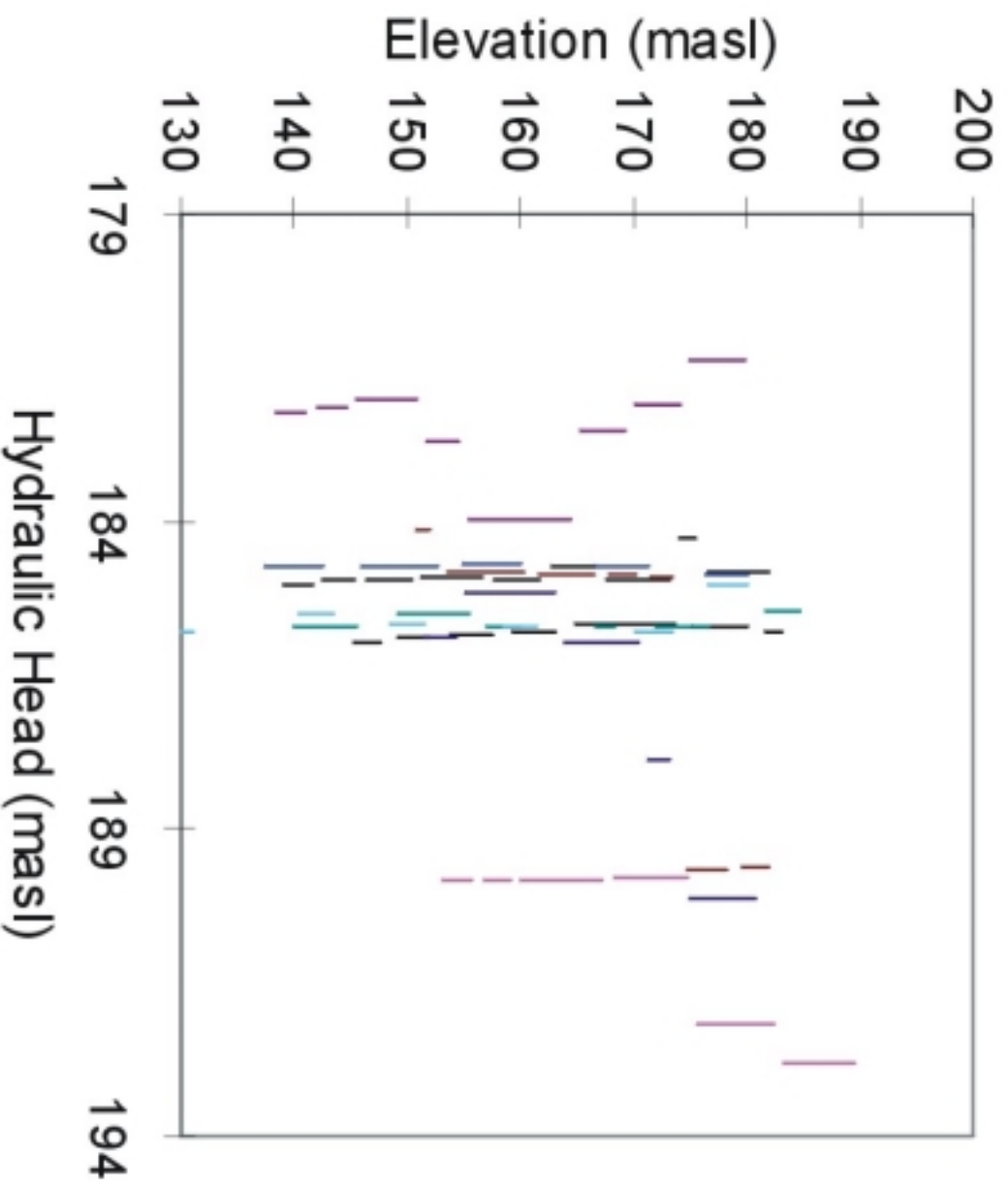
40 m borehole

8 isolated
intervals

82% of
borehole
accessible







Interpretation of Hydraulic Head

- Two laterally-continuous flat lying fractures separated by 0.8 m vertically
- Difference in hydraulic head between the two fractures of 2.0 m
- Two boreholes 15 m apart

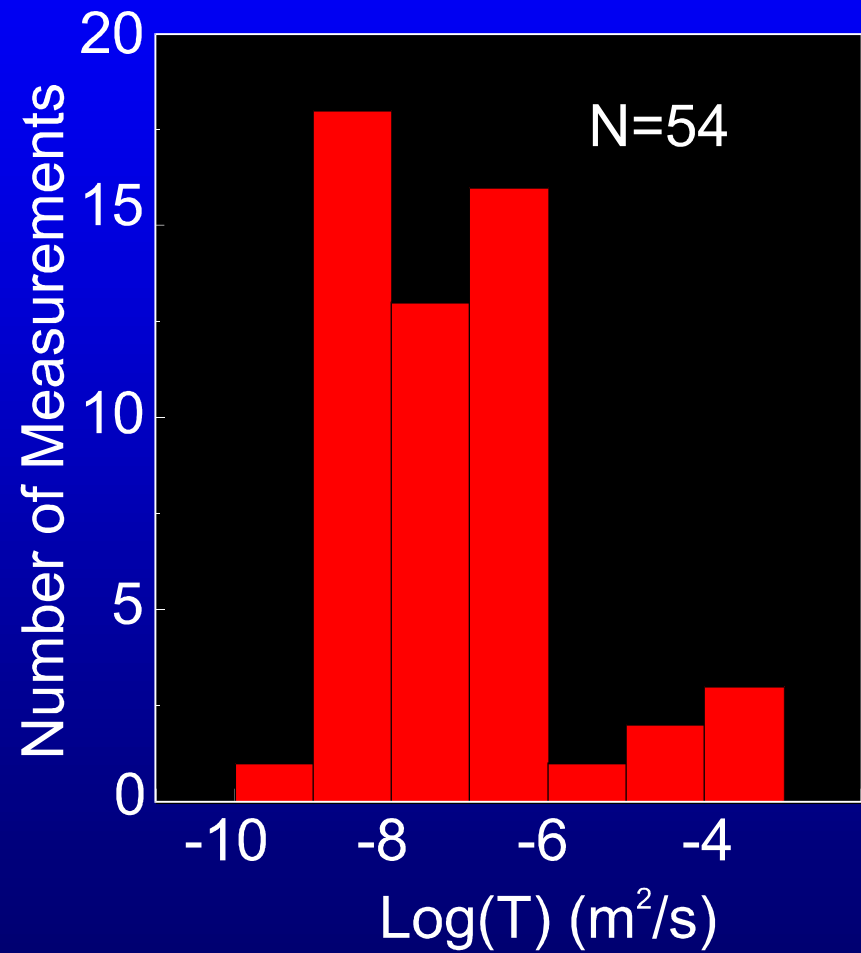
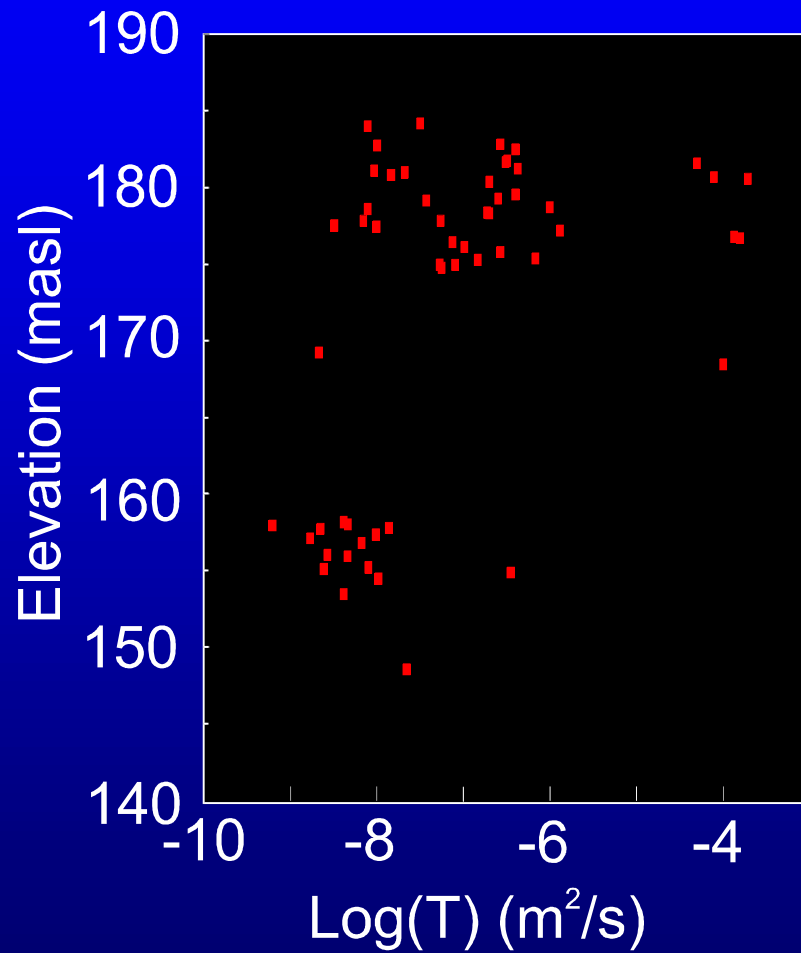
Borehole	APERTURE (μm)	
	Upper Fracture	Lower Fracture
1	135	<10
2	<10	210

- Presumed hydraulic gradient = 0.13
- Real hydraulic gradient = 0.0015

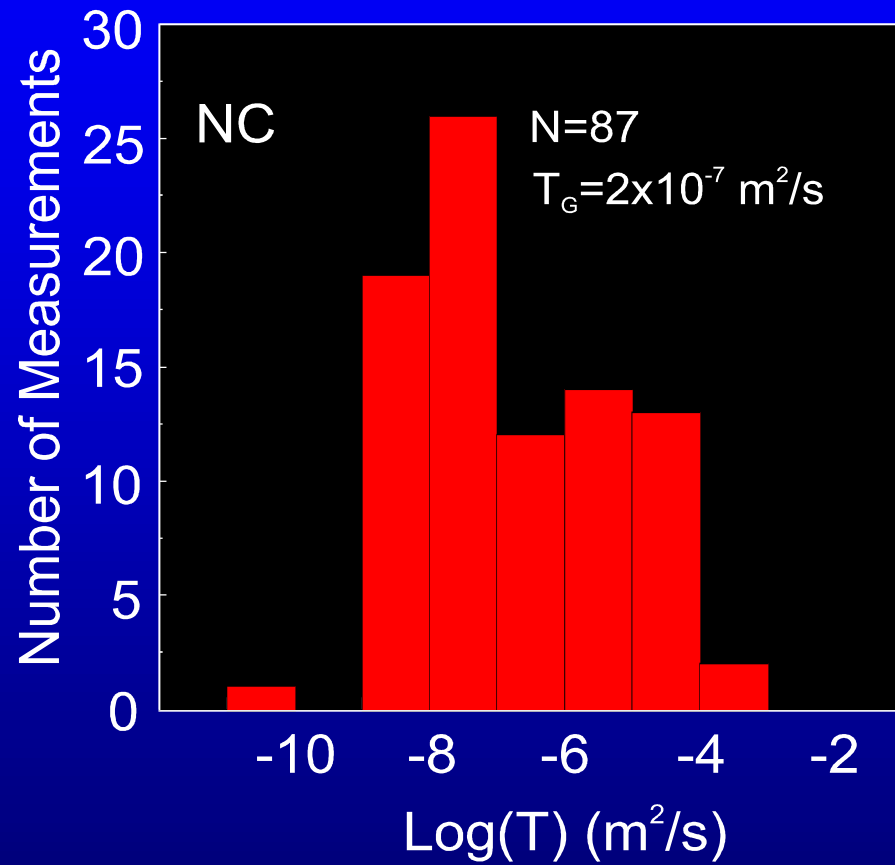
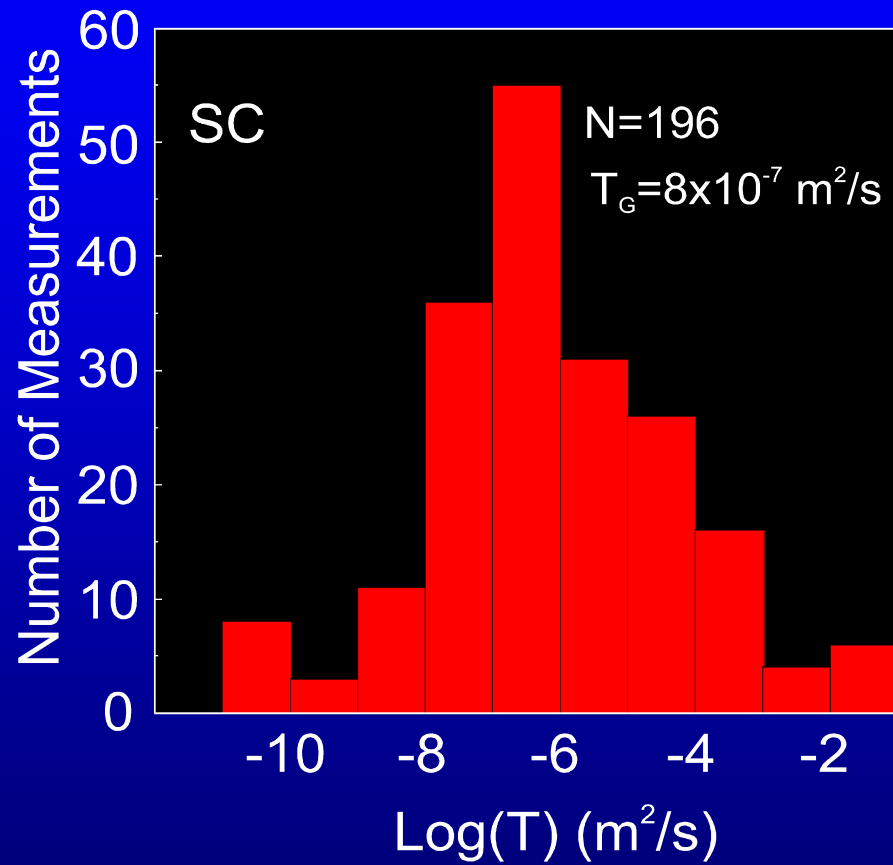
Vertical Fractures



Vertical Fracture Transmissivity



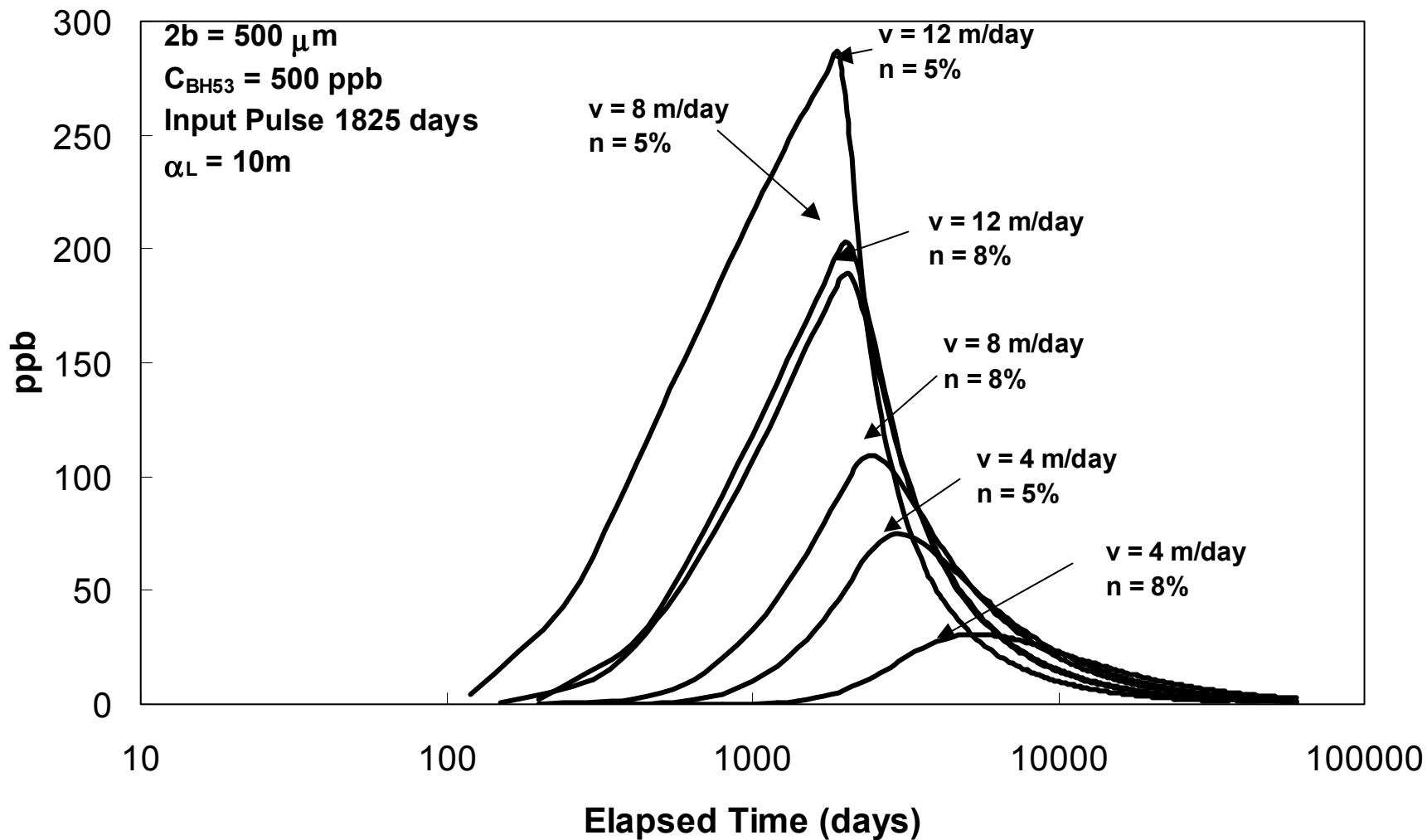
Eramosa Transmissivity



Modeling

- Once the discrete pathways are discovered, use a pathway model that accurately simulates the transport processes
- Analytical models can be easily used for this
 - Choose an appropriate aperture and fracture spacing

Estimated TCE Concentration at 20 Mile Creek



Conclusions

- Major discrete fracture pathways must be identified
- Use hydraulic head to determine inter-connectivity
- Estimate groundwater velocity using cubic law
- Use angle drilling to identify vertical fractures
- Simple pathway modeling (including matrix diffusion) very powerful tool