2009 Portland GSA Annual Meeting (18-21 October 2009)
Paper No. 176-2
Presentation Time: 9:00 AM-6:00 PM

DEPTH EVOLUTION OF FRACTURED ROCK PERMEABILITY IN SHALLOW CRYSTALLINE FRACTURED ROCK AQUIFERS

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Fluid movement and availability in crystalline and heavily metamorphosed rocks is dominated by the secondary porosity generated through fracturing. The distributions of fractures and fracture zones determine permeable pathways and the overall productiveness of these rocks as aquifers. Fractured bedrock in many parts of the world are now being used as sources of water for both drinking and industrial uses. Understanding the sustainability and dynamics of these aquifer systems is crucial for future planning and regulating their use. In this presentation I present the results of a subsurface study of such a region experiencing expanded use of fractured bedrock for aquifers. This field-based study visited 17 wells and logged the distribution of fractures, identified flowing fractures, and hydraulically characterized the rock mass intersecting the borehole. Wells with total depths ranging from 30m to 300m showed trends of decreasing fracture frequency with depth, with hydraulically active fractures showing a similar trend. Of all the fractures encountered, only 4 were deemed to be hydraulically active. Decreases in the number of hydraulically active with depth would have the effect of restricting topographically drive flow systems to near surface regions. Observations of borehole temperature profiles suggest that this is indeed the case with little effects of hydrologically altered profiles below 100m. Mechanisms responsible for permeability alteration include: stress related fracture aperture reduction, reduced frequency of unloading related features, reduction in total fractures creating lower connectivity. Results from this study suggest that active flow systems in these geologic settings are shallow and that fracture permeability outside of the influence of large-scale structures should generally follow a quantifiable decreasing trend with depth.

2009 Portland GSA Annual Meeting (18-21 October 2009)
General Information for this Meeting

Session No. 176
Recent Advances in the Conceptualization, Characterization, and Interpretation of Fluid Movement and Transport Dynamics in Fractured and Karst Aquifers (Posters)
Oregon Convention Center: Hall A
9:00 AM-6:00 PM, Tuesday, 20 October 2009

Geological Society of America *Abstracts with Programs*, Vol. 41, No. 7, p. 465

Challenges and Opportunities for Evaluating Groundwater Resources in Fractured-Rock Environments

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Department of Geology
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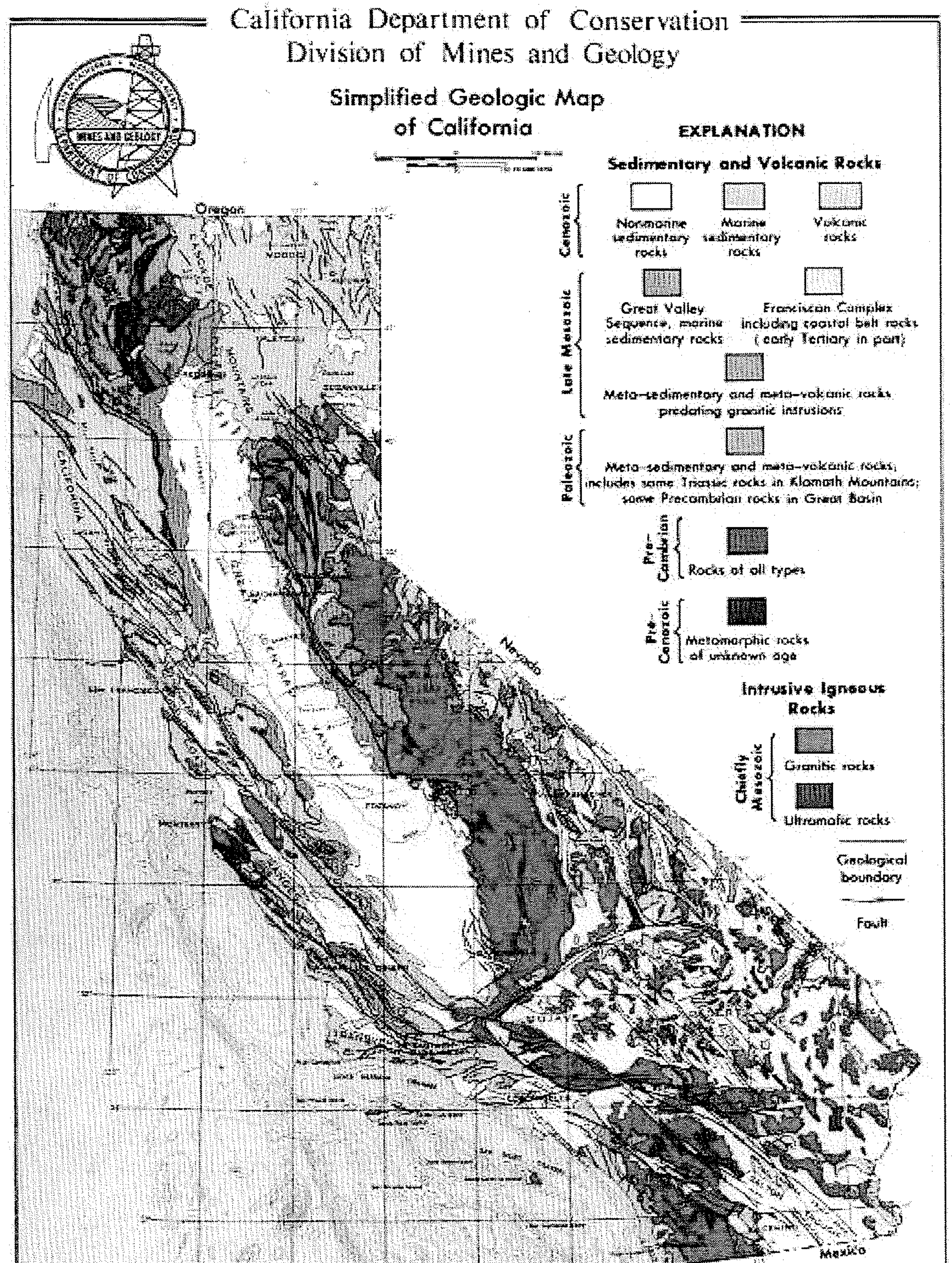
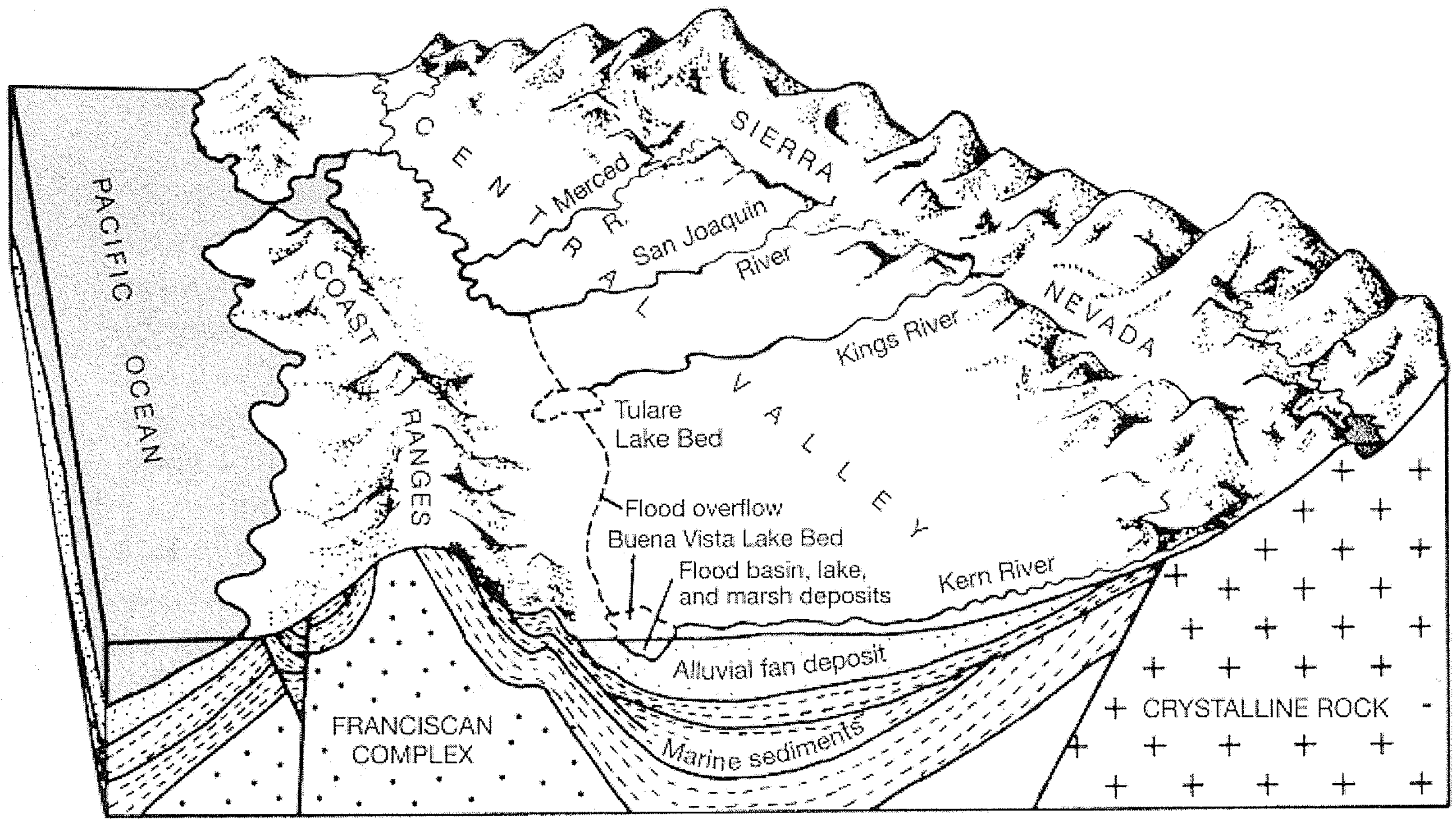
&
James W. Borchers
California Water Science Center
U.S. Geological Survey

Geologic Controls on Groundwater in California



Compiled by USGS and CDMG, 1965.

Where Groundwater Occurs



USGS Professional Paper 1401-C by R. Page, 1986

The Pressing Questions…

- Where are water bearing fractures located?
  - "Where should we drill?"
- What is the sustainable yield of fractured rock aquifers?
  - "How many wells should we allow?"

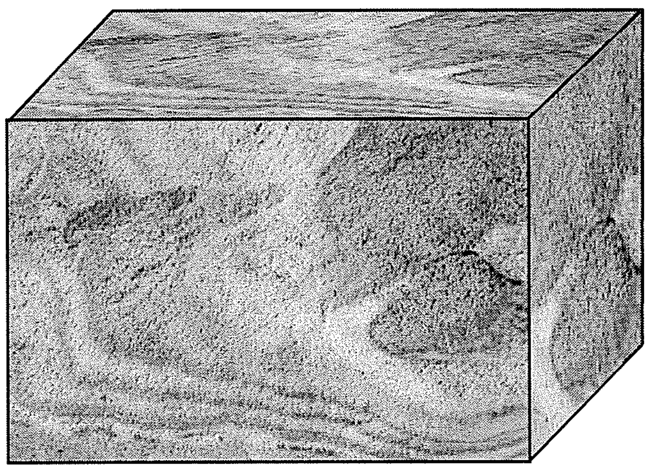
Requires Multidisciplinary, Integrated Approach

Hydrogeology, Geology, Chemistry

With Good Baseline Data

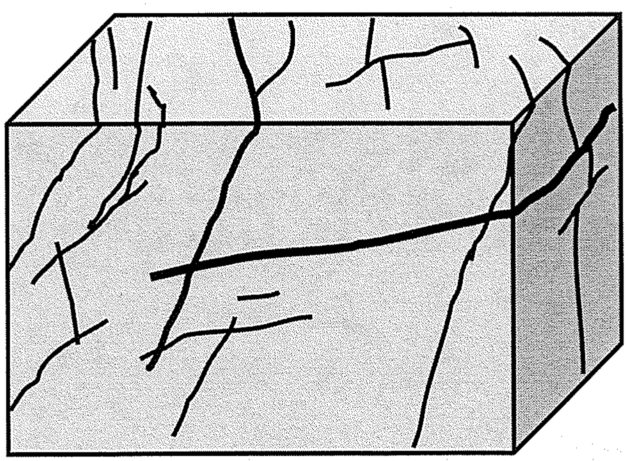
Contrasting Scales of Interest

Porous Media



- $K(\vec{x})$, $S_S(\vec{x})$ continuous
- @ scale of stratigraphic units

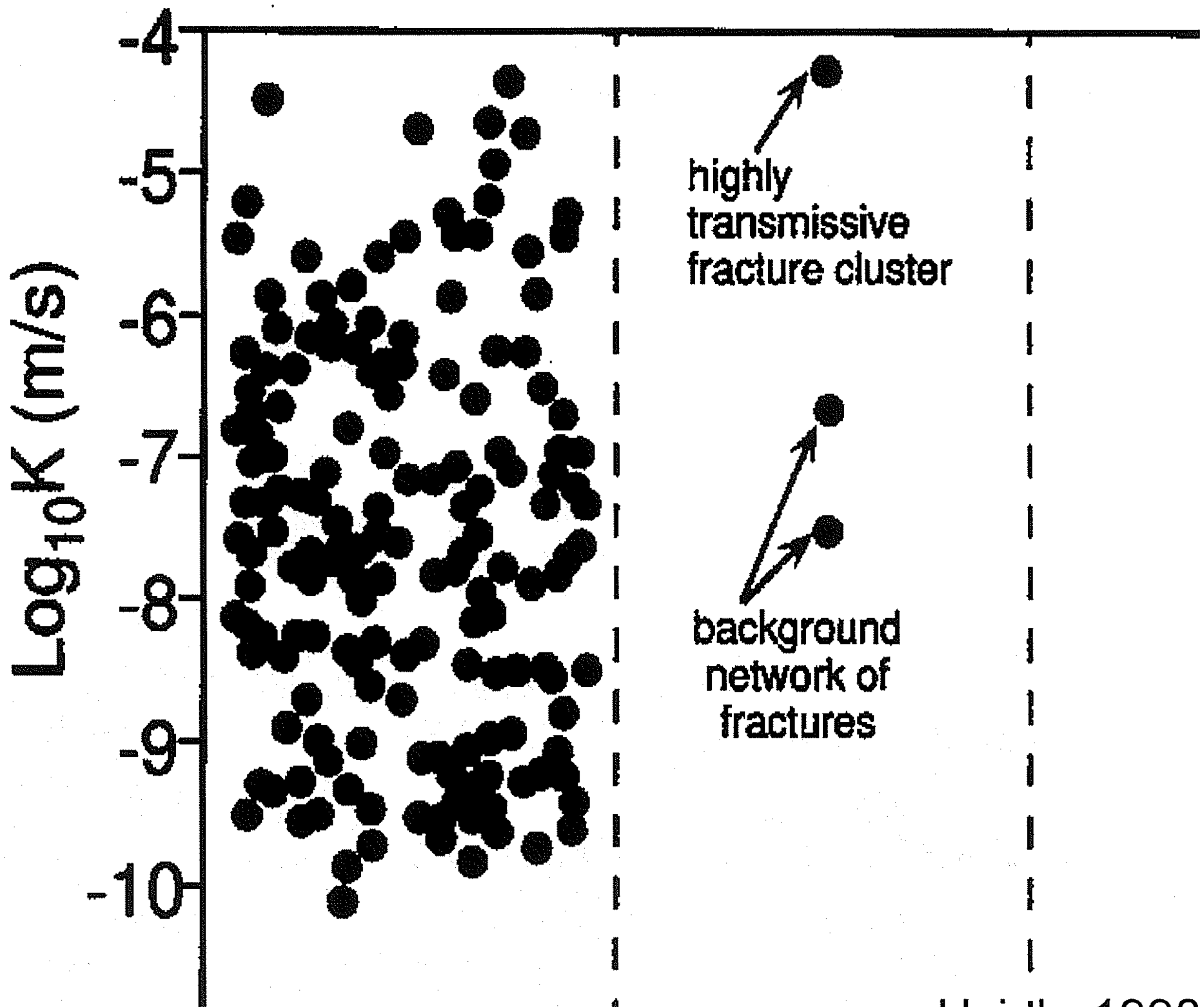
Fractured Media



- $T(\vec{x})$, $S(\vec{x})$ discontinuous
- $T(\vec{x})$ @ discrete fractures
- $S(\vec{x})$ @ geologic units

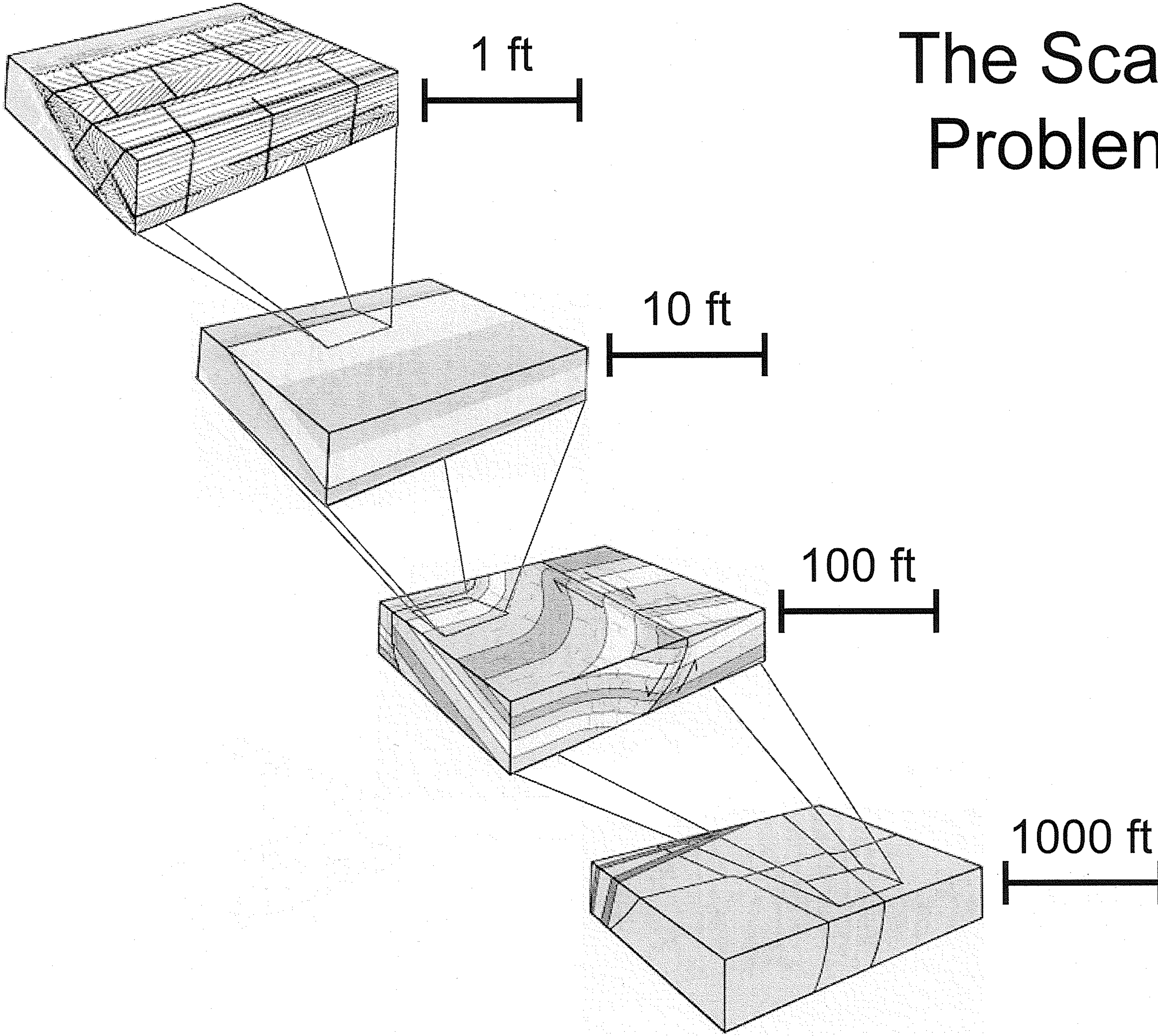

8-8-85
7-37
CS-VFGI-

The Problem of Scale



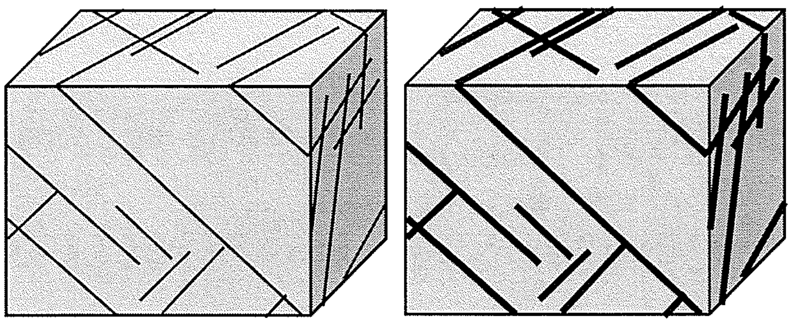
Hsieh, 1998

The Scale Problem

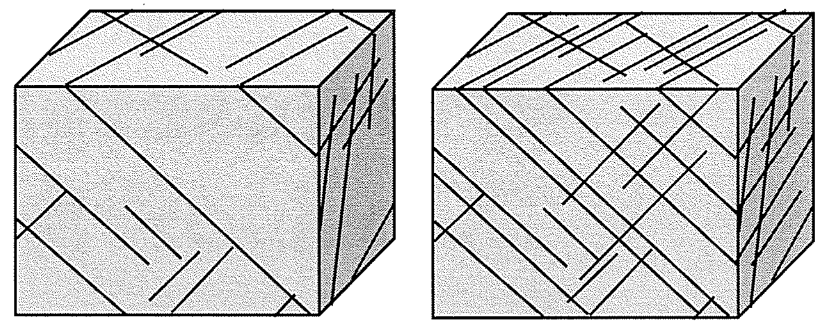


What Affects Flow and Availability of Groundwater In Fractured Rock?

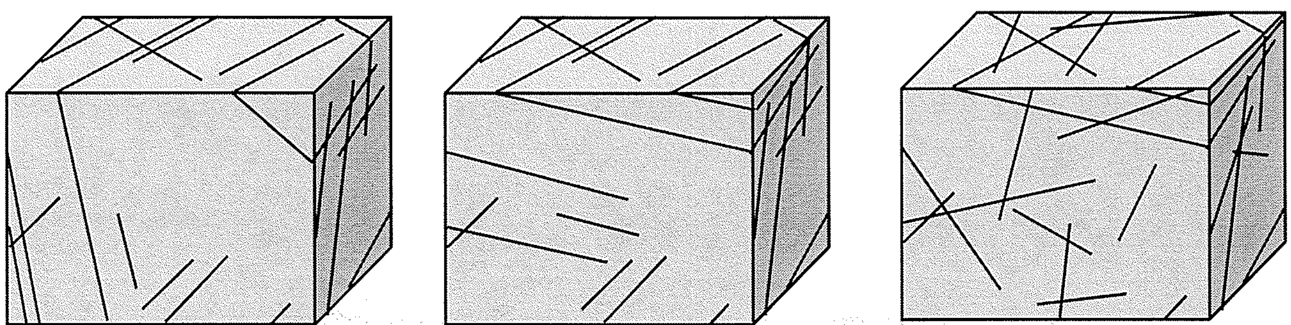
Aperture



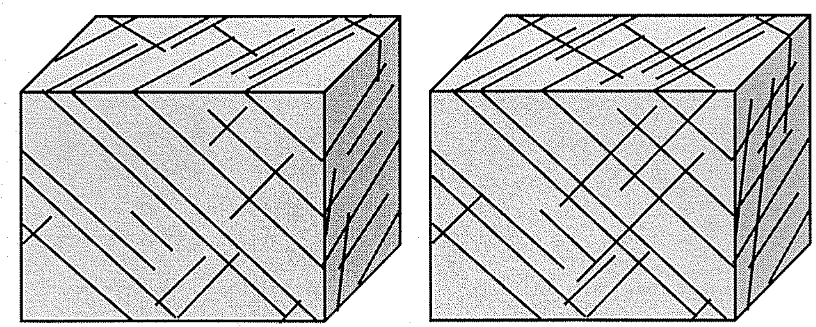
Spacing (Density)



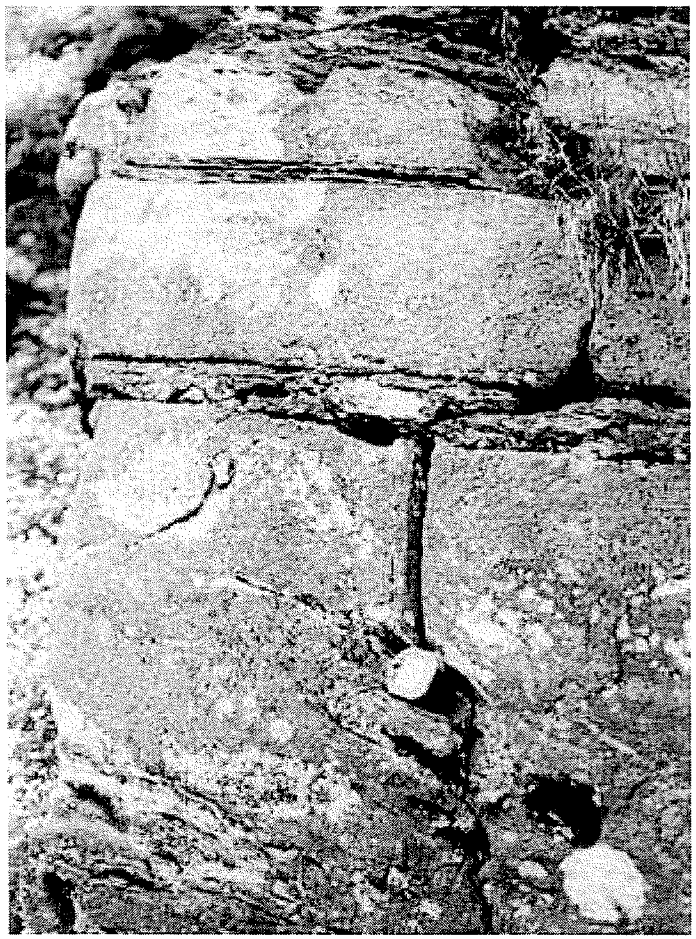
Orientation



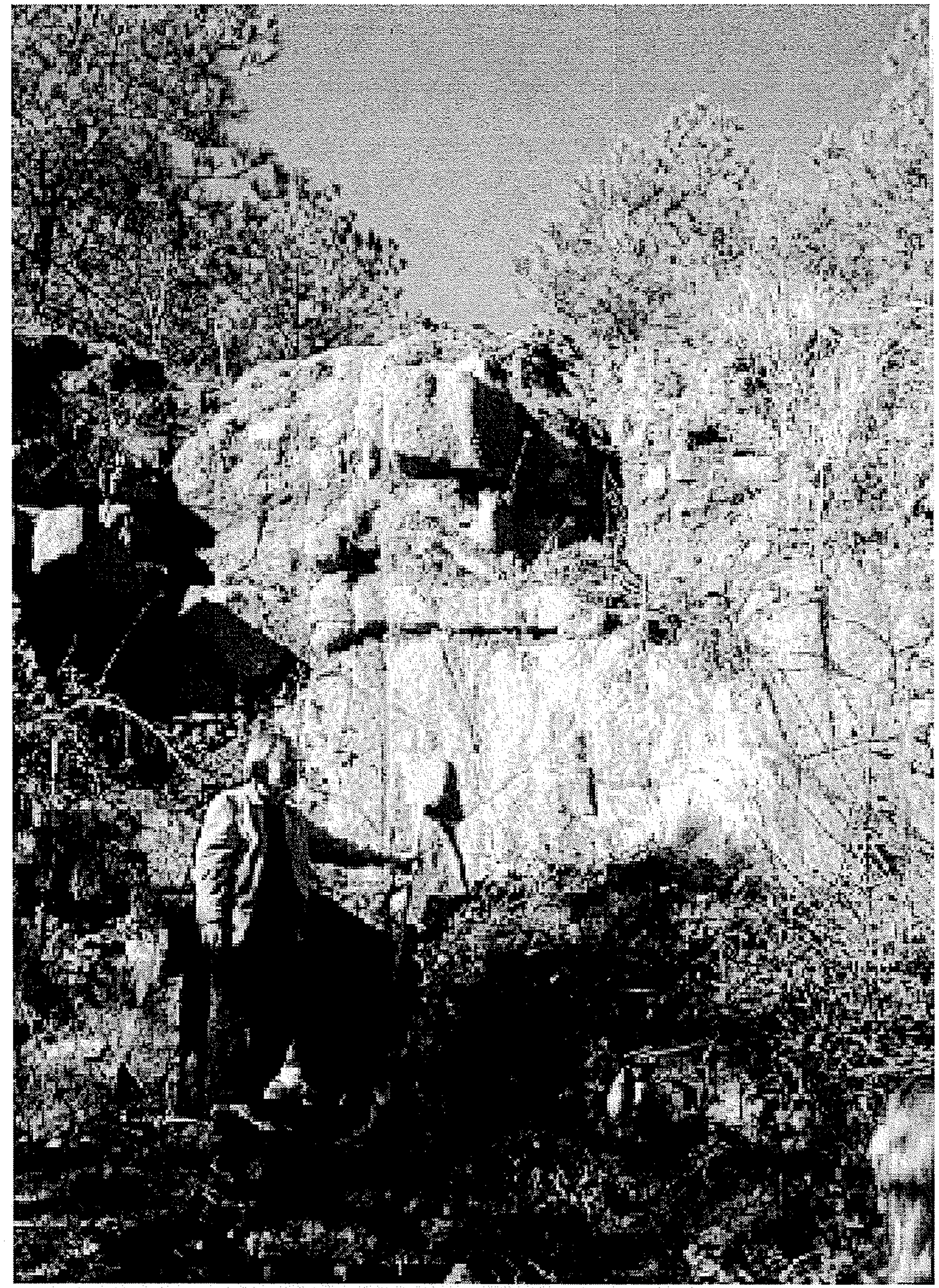
Connectivity



Field Evidence

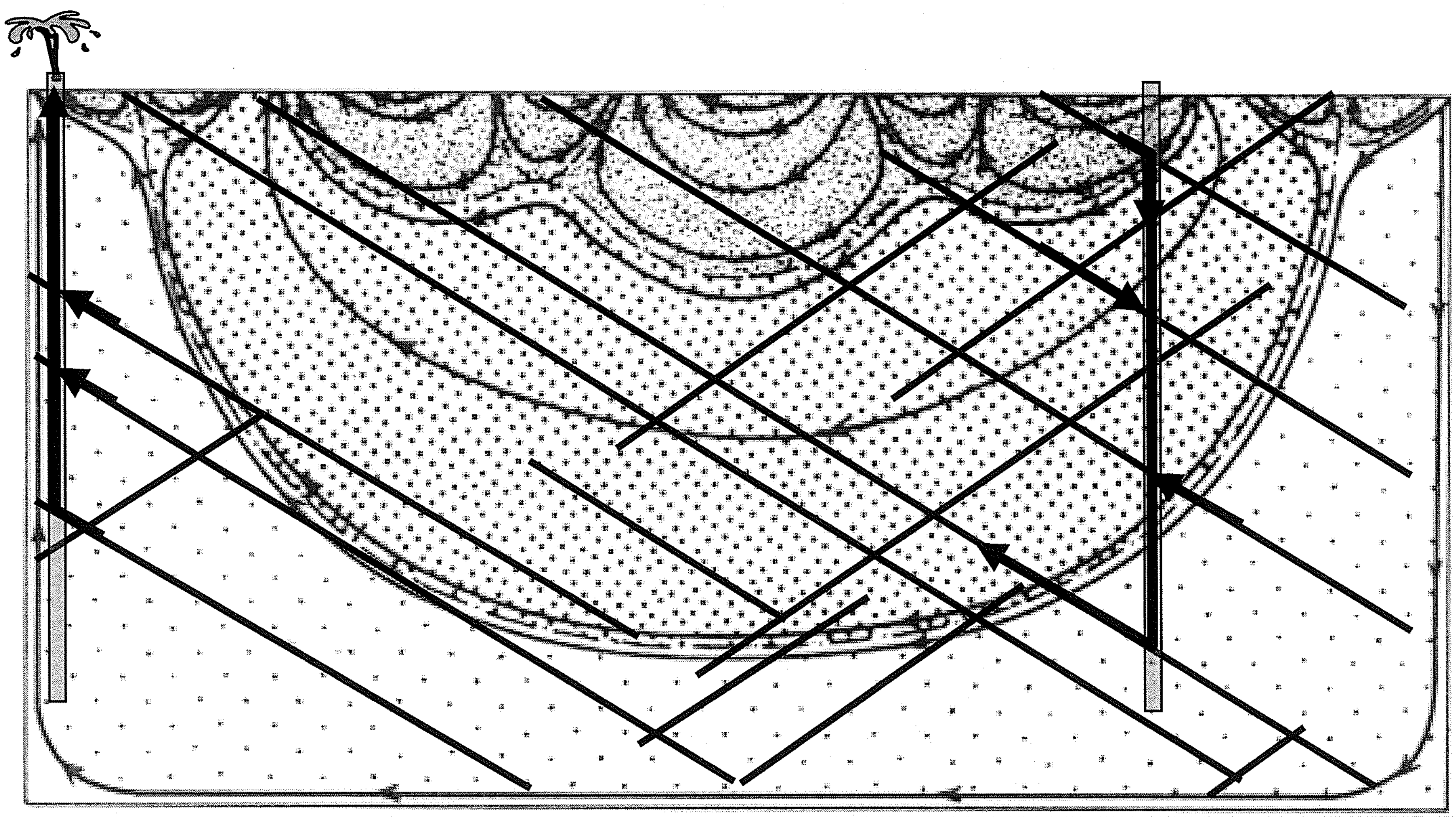


Schultz. A. and Southworth, S. , 2000

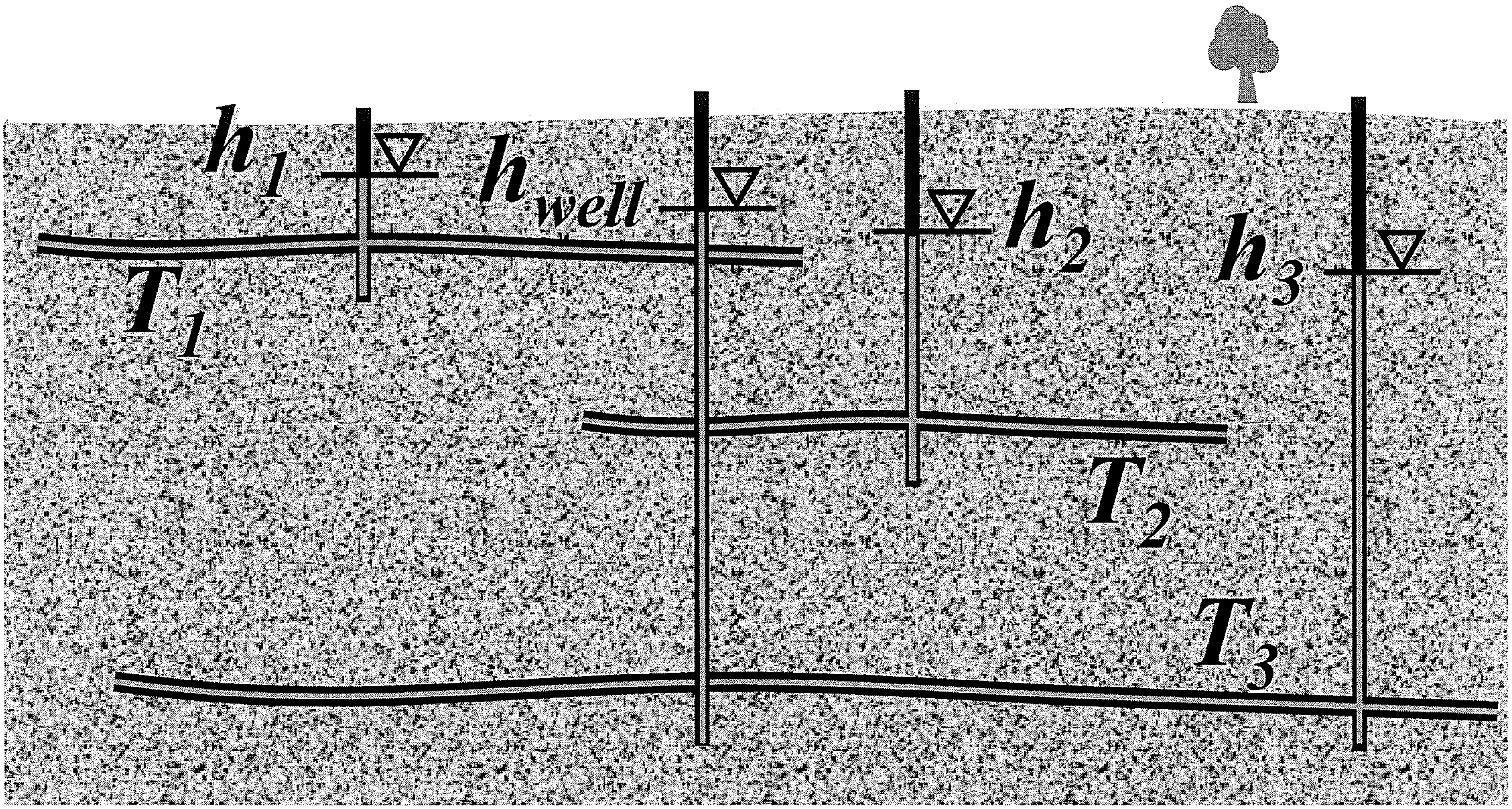


© Doug Hernon, Duke University

Topo driven flow

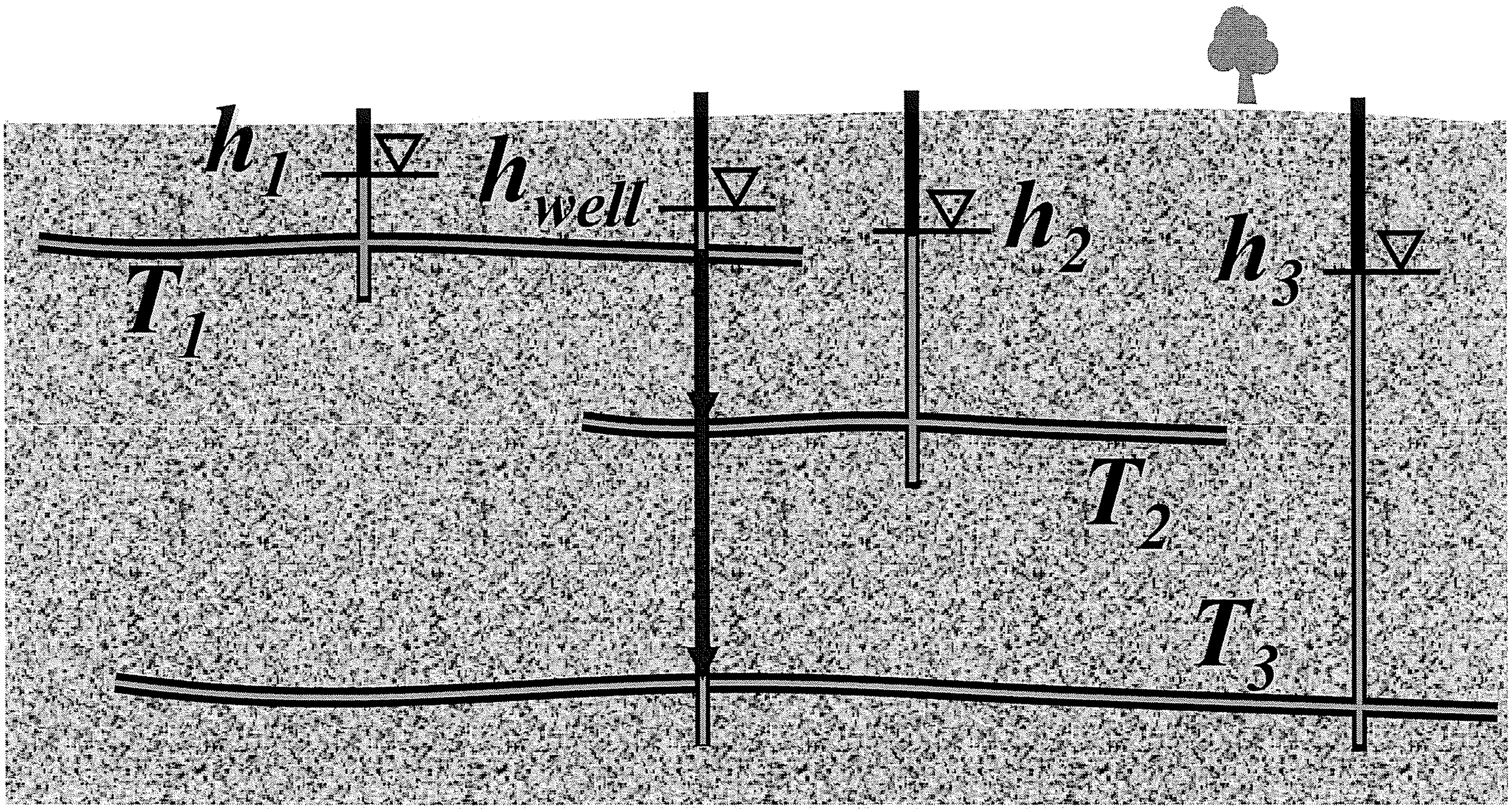


Static head in an open well

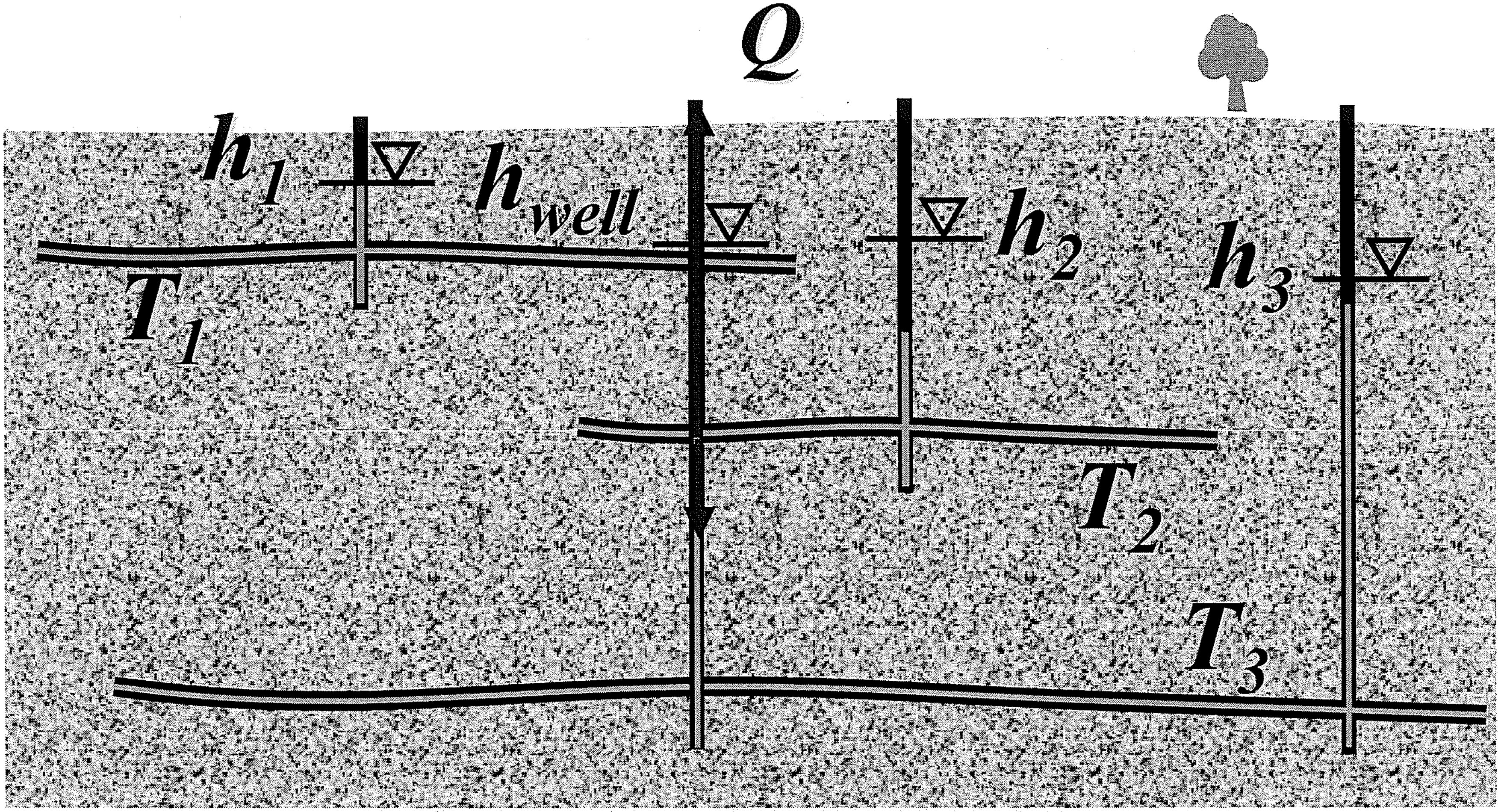


$$h_{WELL} \approx \frac{1}{n}\sum h_i$$

Flow in an open well

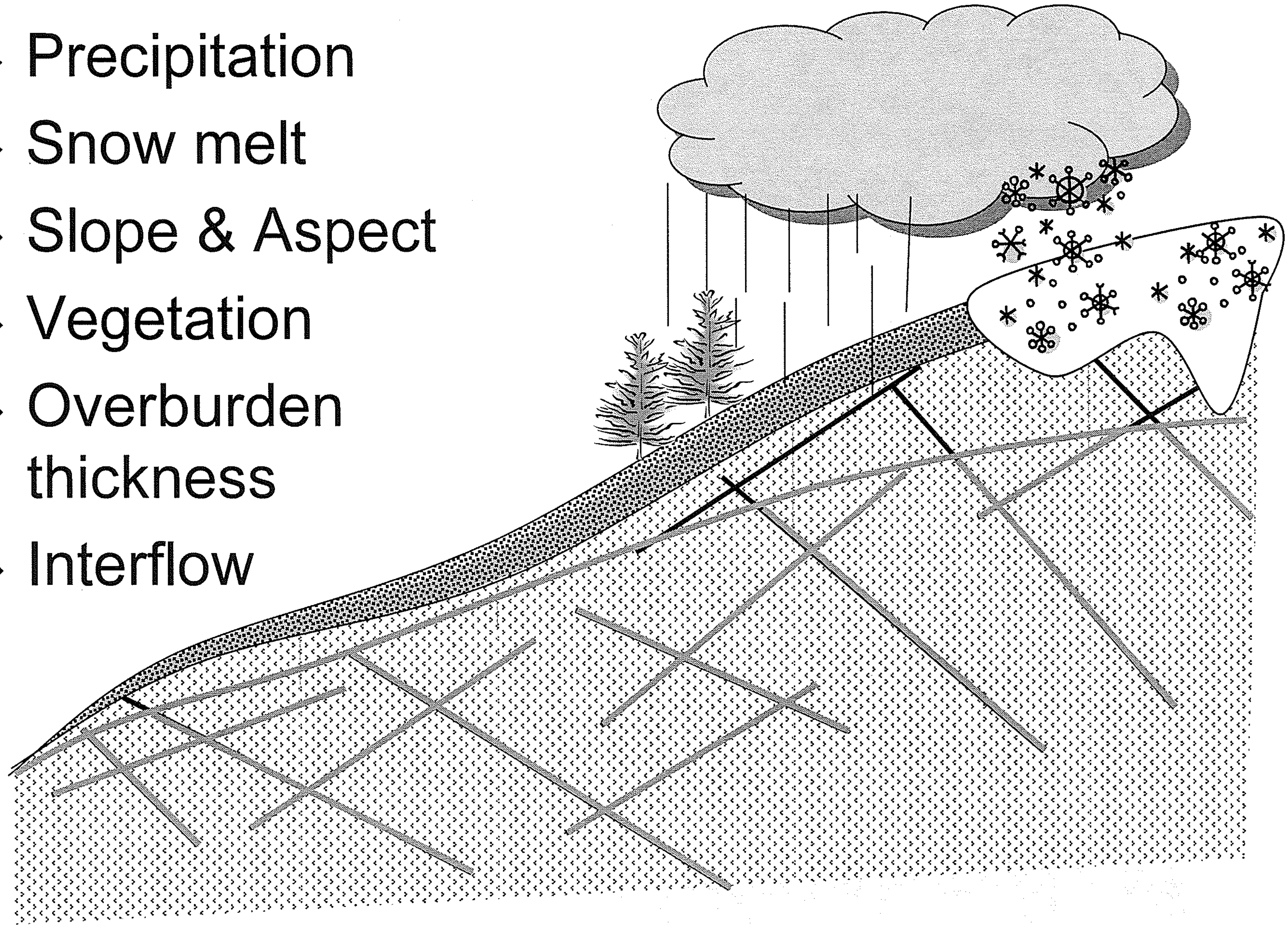


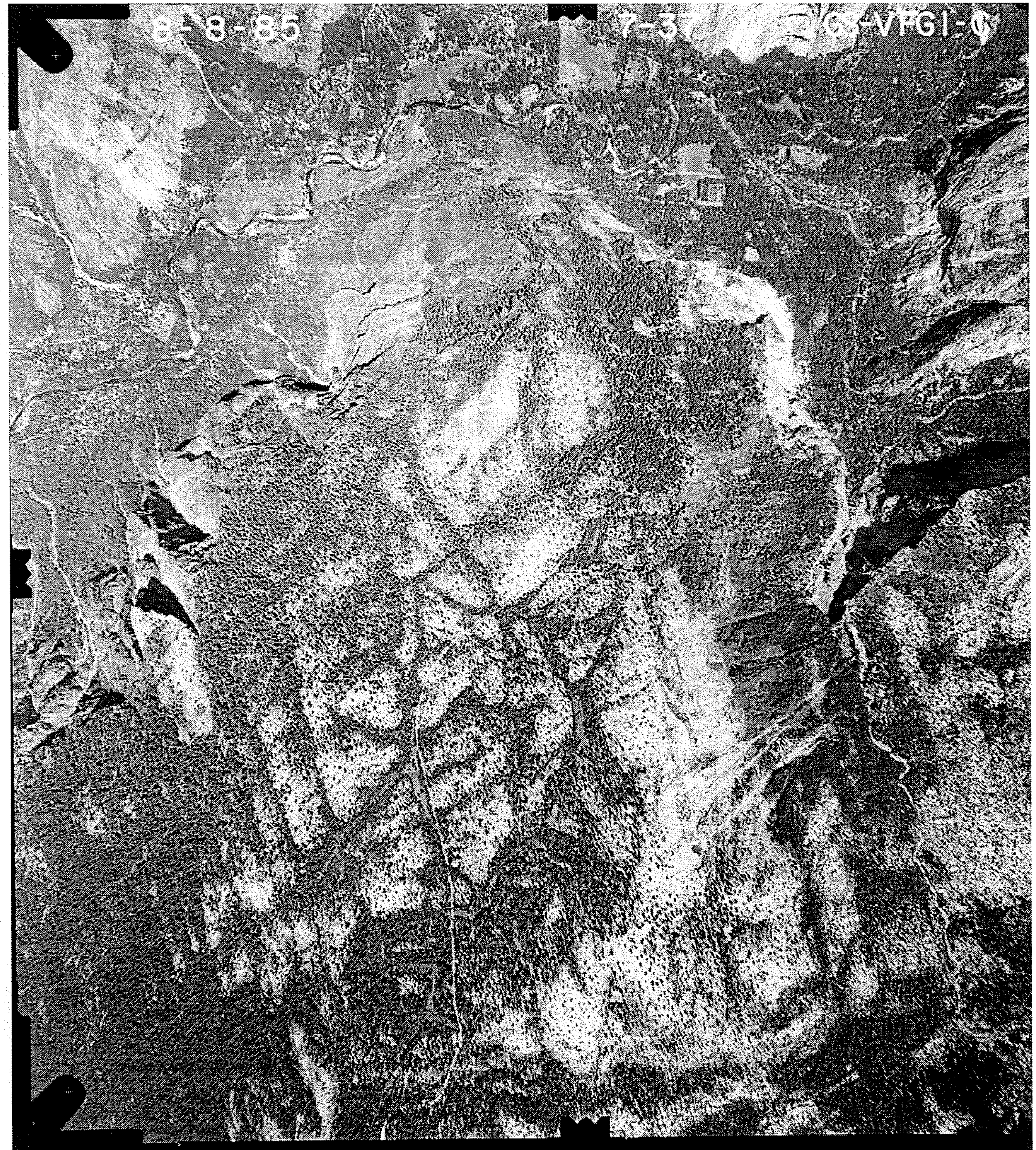
Flow during pumping



Recharge to Fractures

- Precipitation
- Snow melt
- Slope & Aspect
- Vegetation
- Overburden thickness
- Interflow



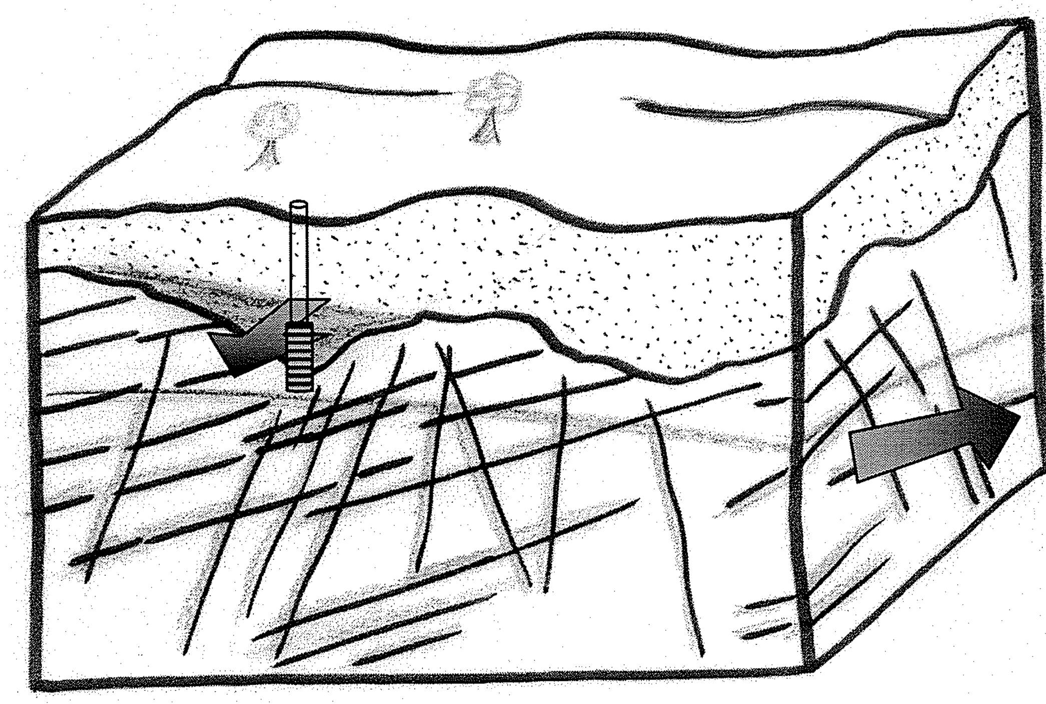


Recharge Variables

- Precipitation
- Snow melt
- Slope & Aspect
- Vegetation
- Overburden thickness
- Interflow

Subsurface Stormflow (Interflow)

- Controlled by bedrock topography
- Direction is independent of groundwater flow
- Intermittently saturated



The Pressing Questions…

- Where are water bearing fractures located?
  - "Where should we drill?"
- What is the sustainable yield of fractured rock aquifers?
  - "How many wells should we allow?"

Requires Multidisciplinary, Integrated Approach

Hydrogeology, Geology, Chemistry

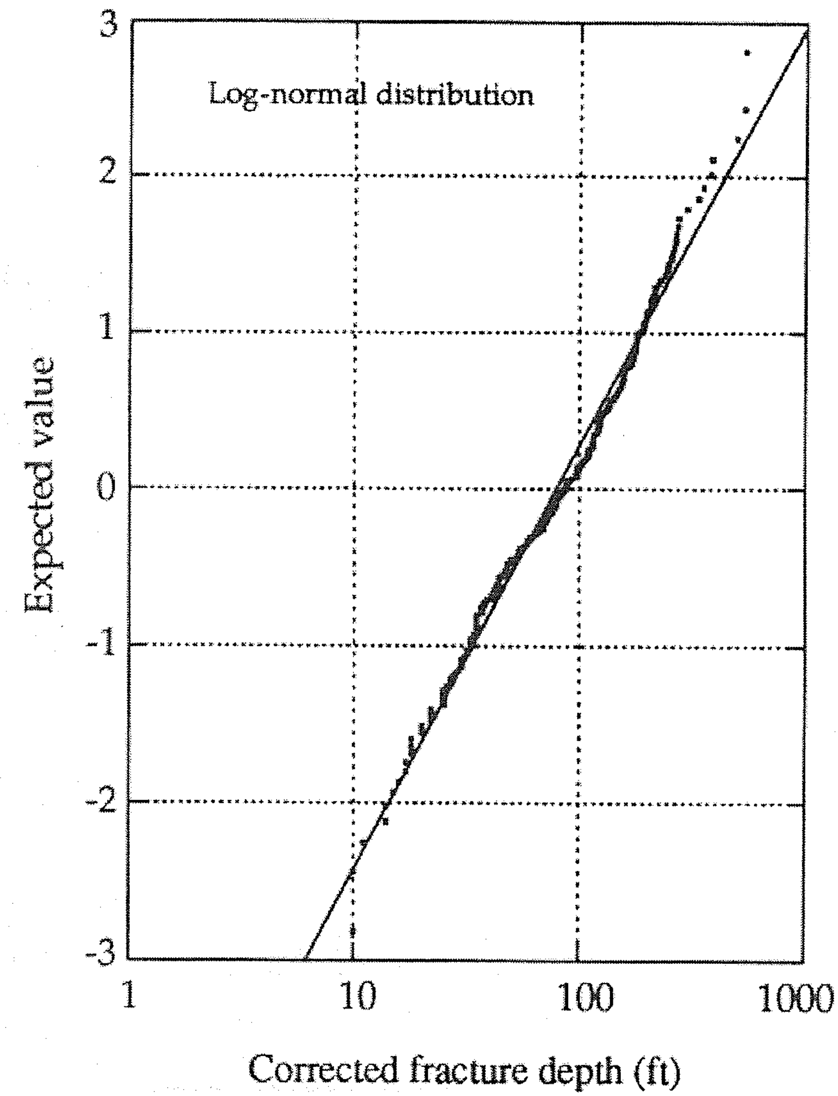
With Good Baseline Data

Detailed Well Inventories

- Location (GPS)
- Elevation
- Total Depth
- **Depth to Water-Bearing Fractures**
- **Overburden Thickness**
- **Total Yield**
- **Yield of Water-Bearing Fractures**
- **Water Quality** (Conductivity & Temperature)

Fracture Depth Distribution

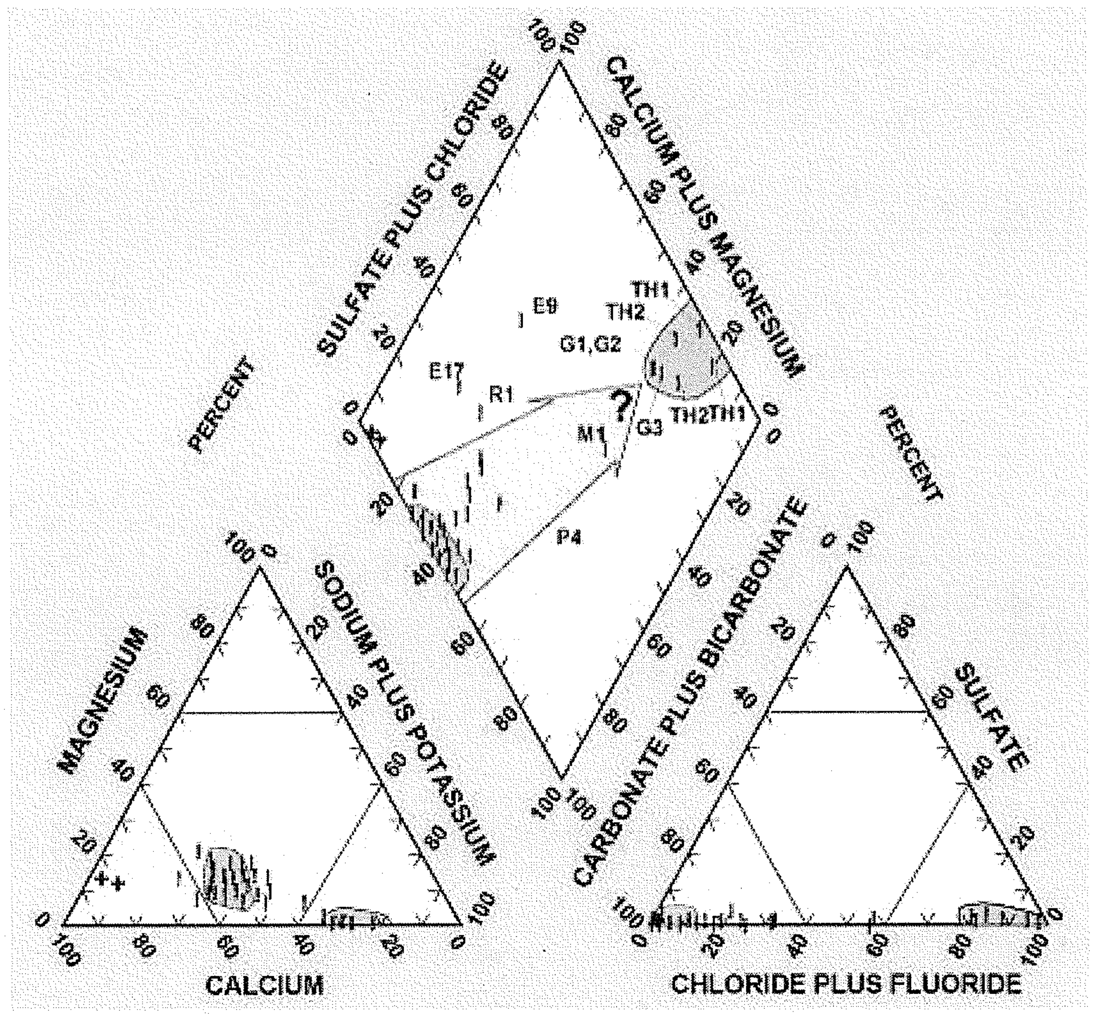
- Probability of encountering a water-bearing fracture with depth



Loiselle & Evans, 1995

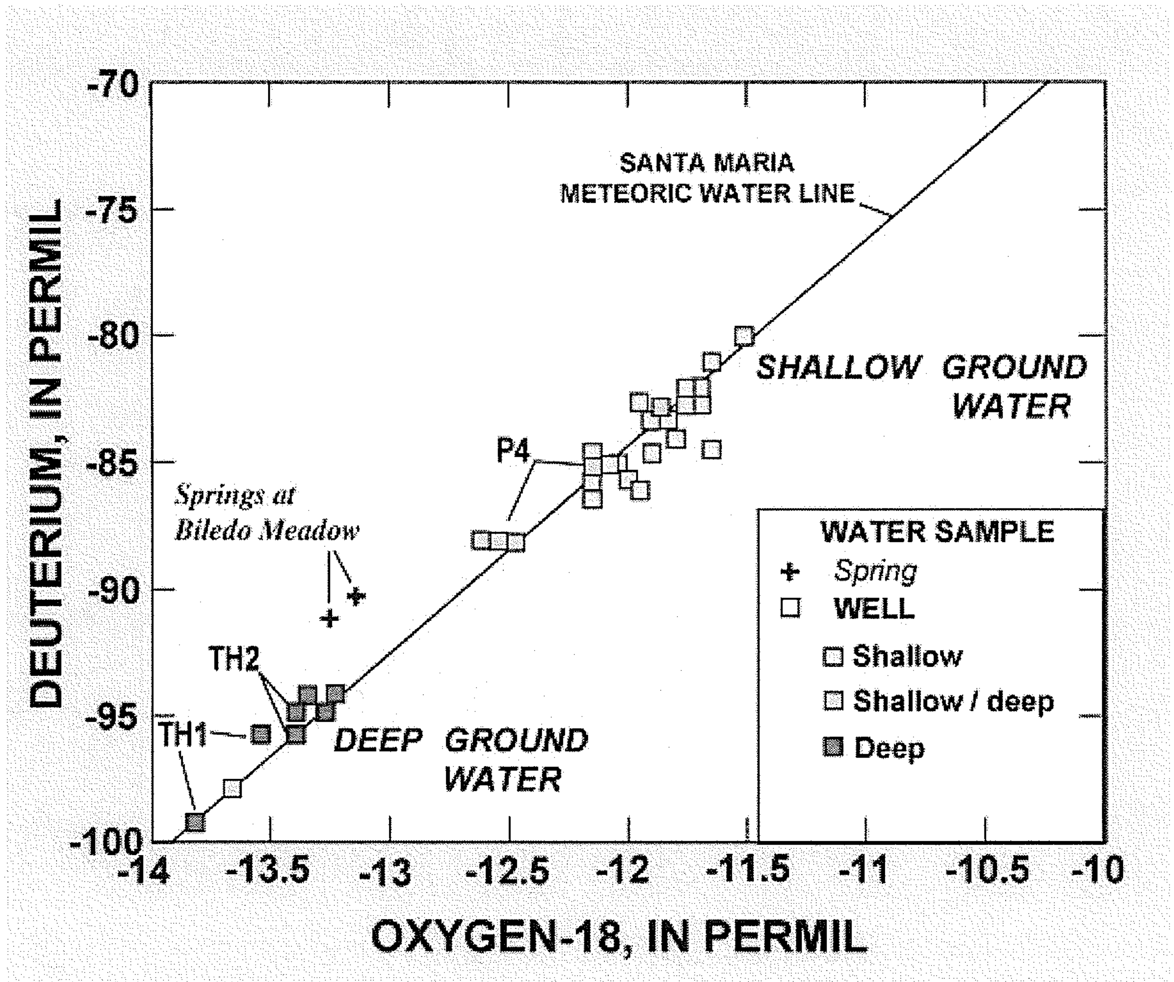
Water Quality Data

- Major Element Chemistry
  - Source Rock & Water-rock Interaction



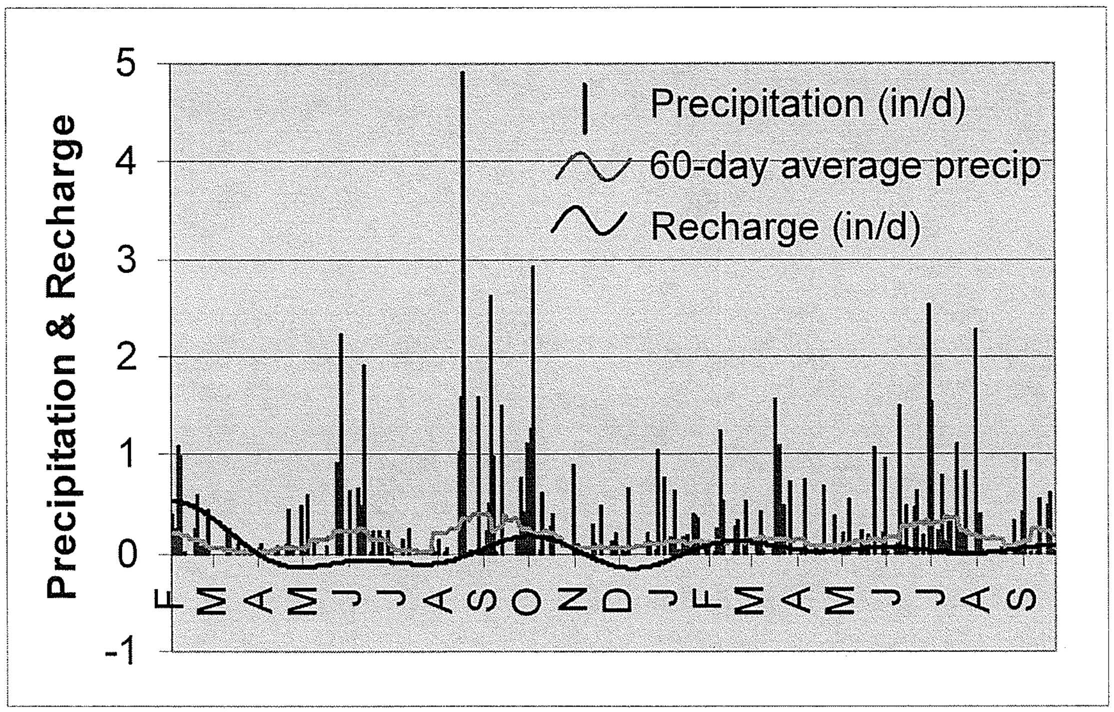
Water Quality Data

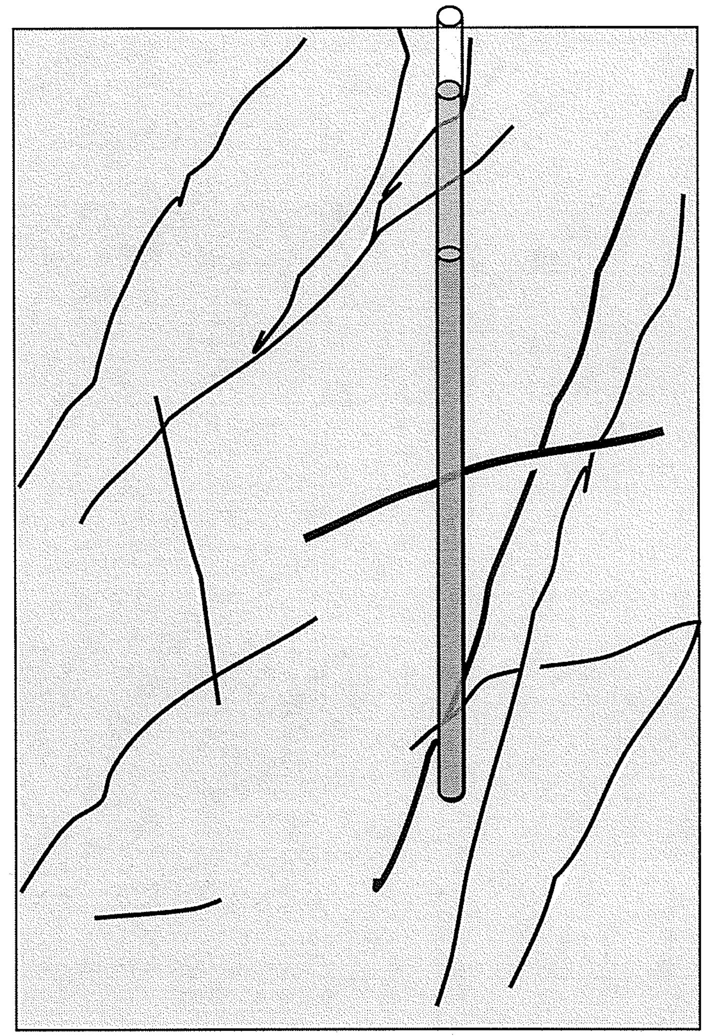
- Trace Element & Isotopic Chemistry
  - Source Identification
  - Flow Path Analysis



Monitoring Seasonal Variations…

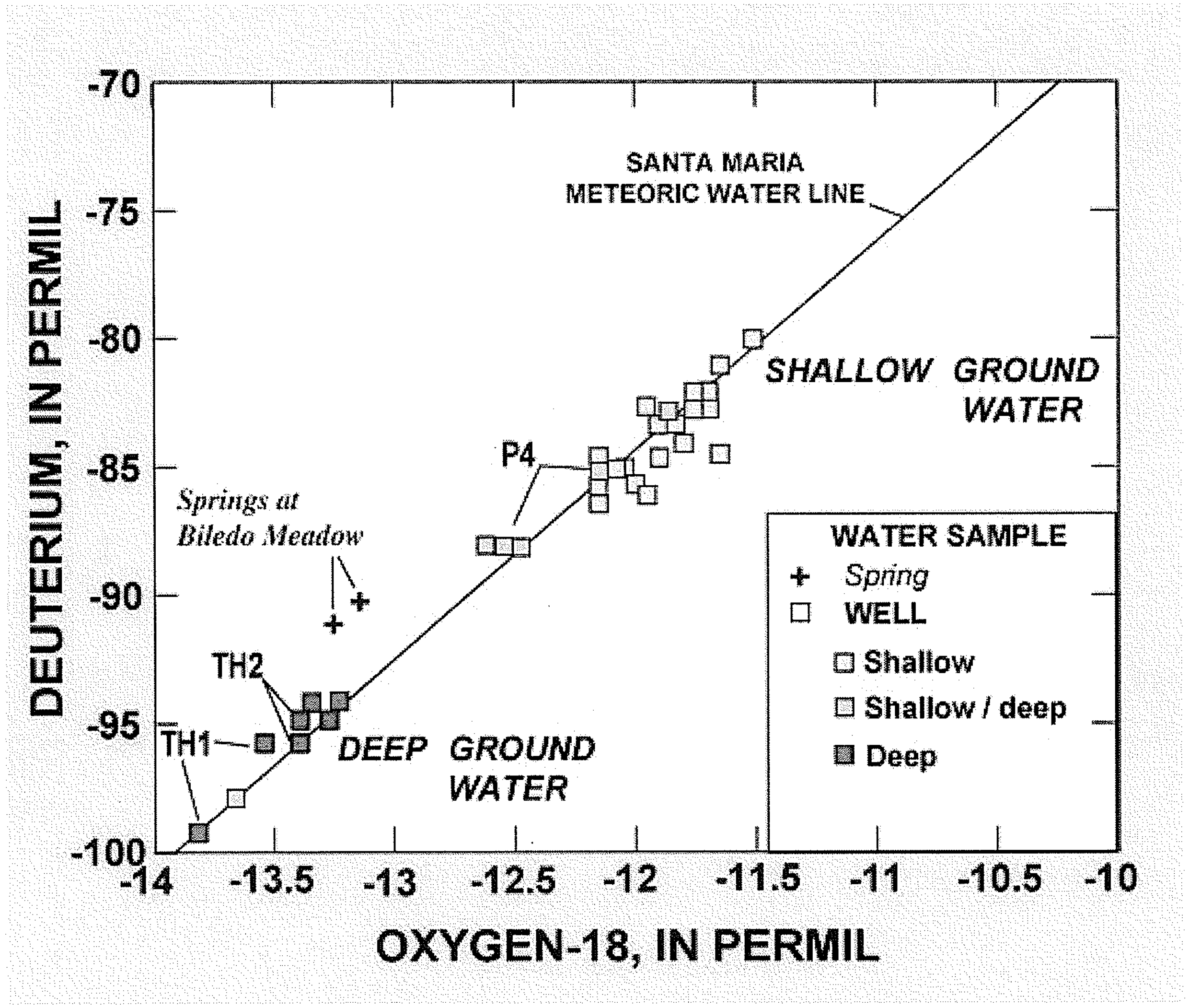
- … in Water Levels



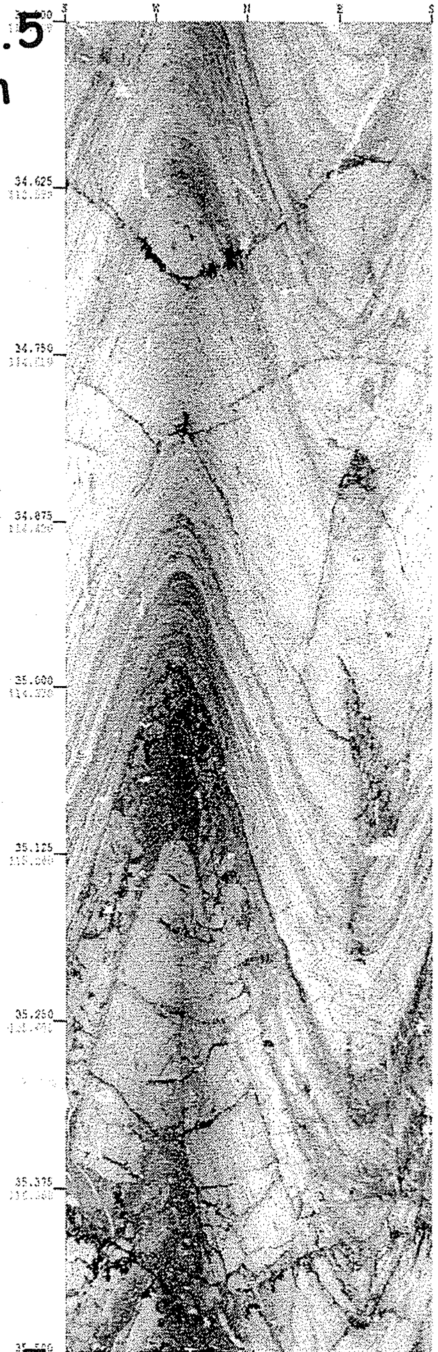


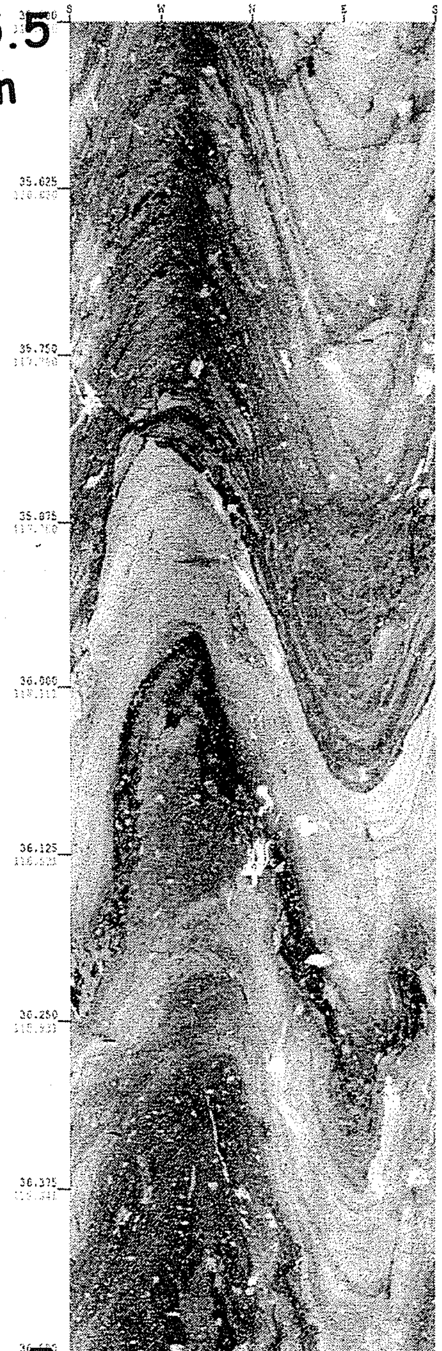
Monitoring Seasonal Variations…

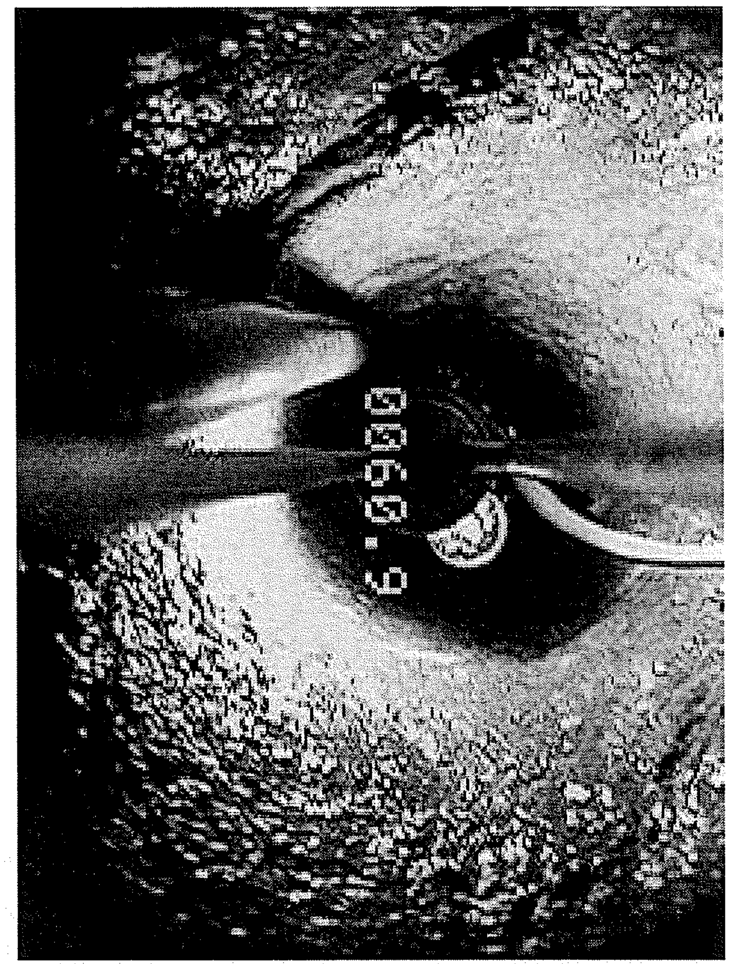
- … in Water Quality

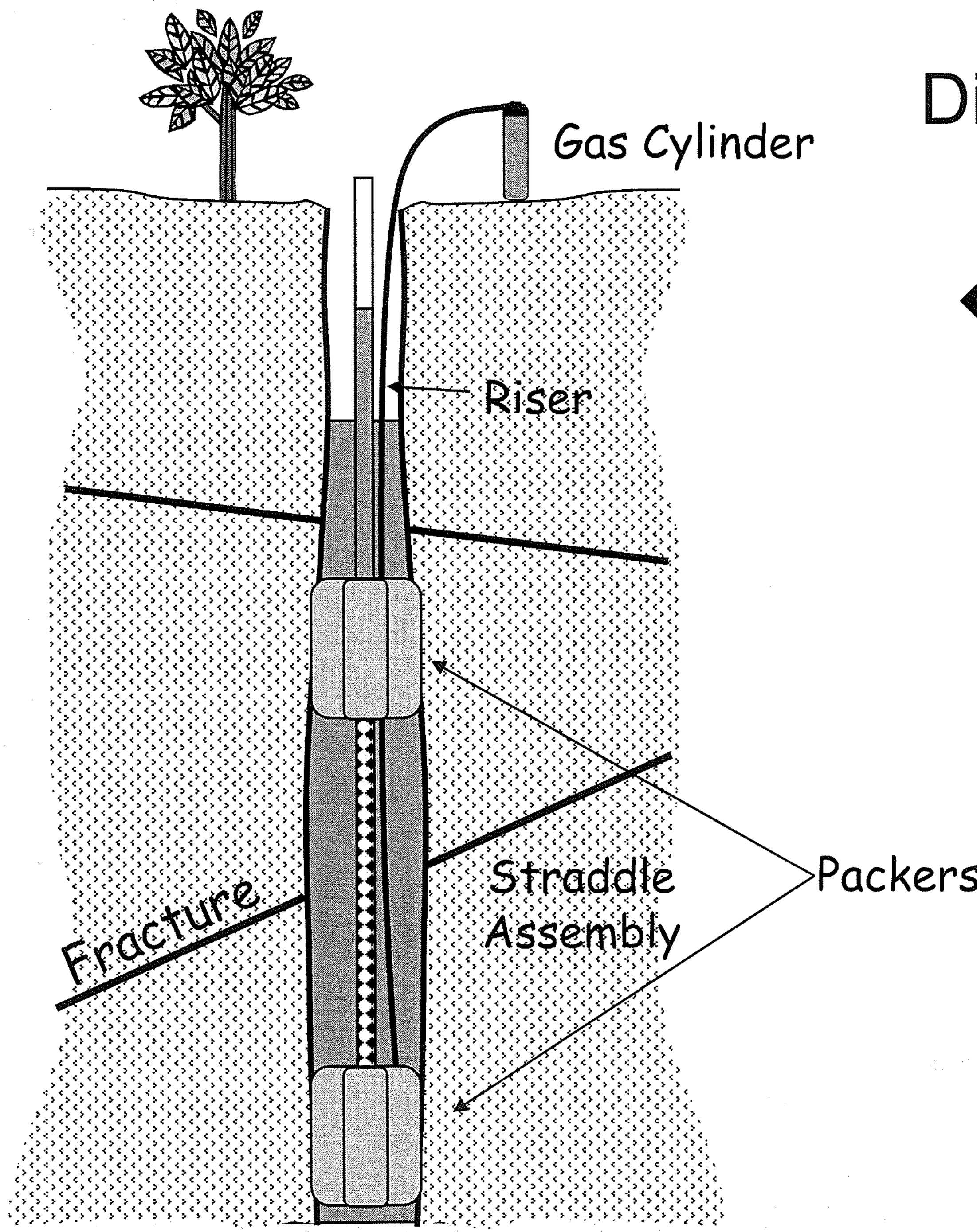


Locate Hydraulically Conductive Fractures





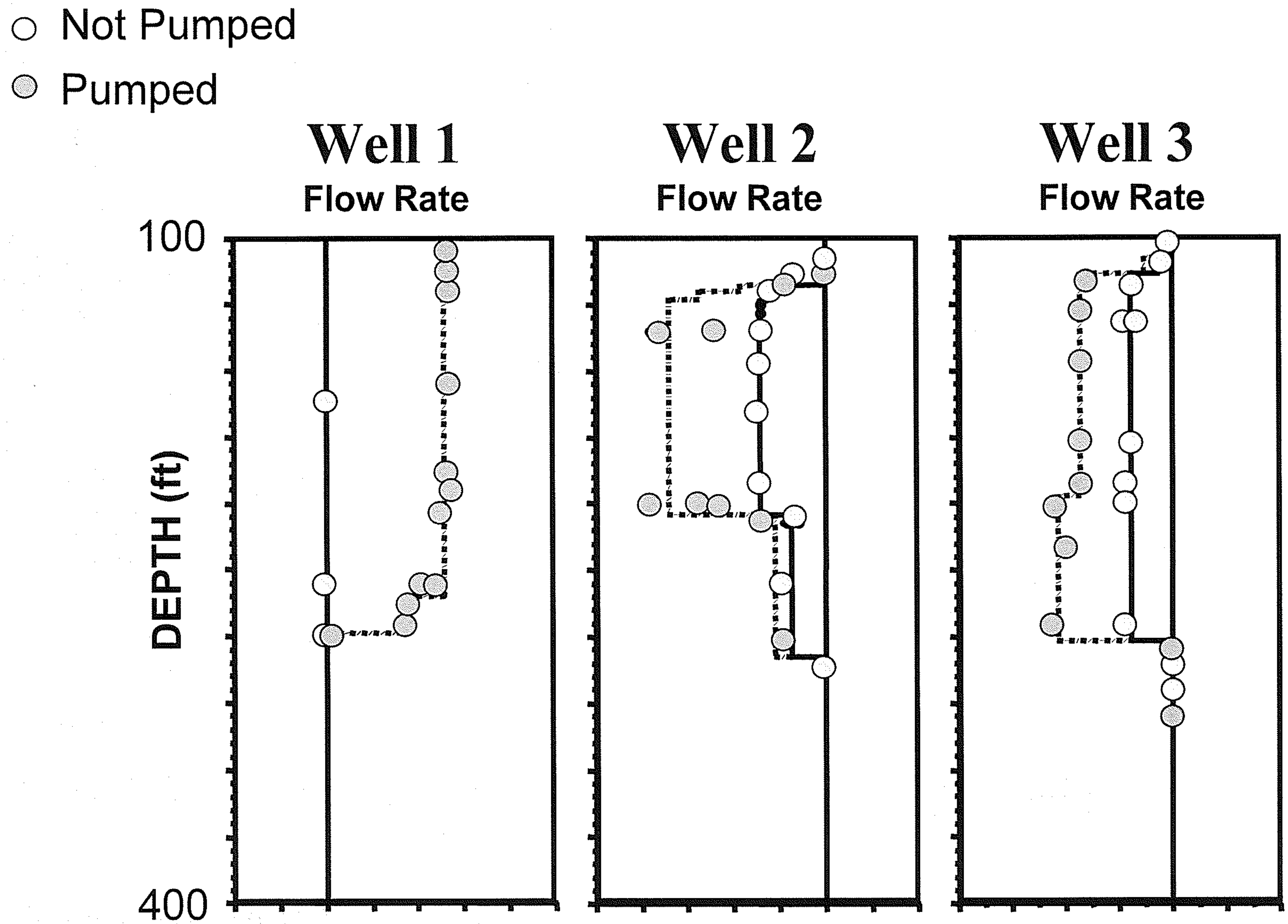




Test & Sample Discrete Fractures

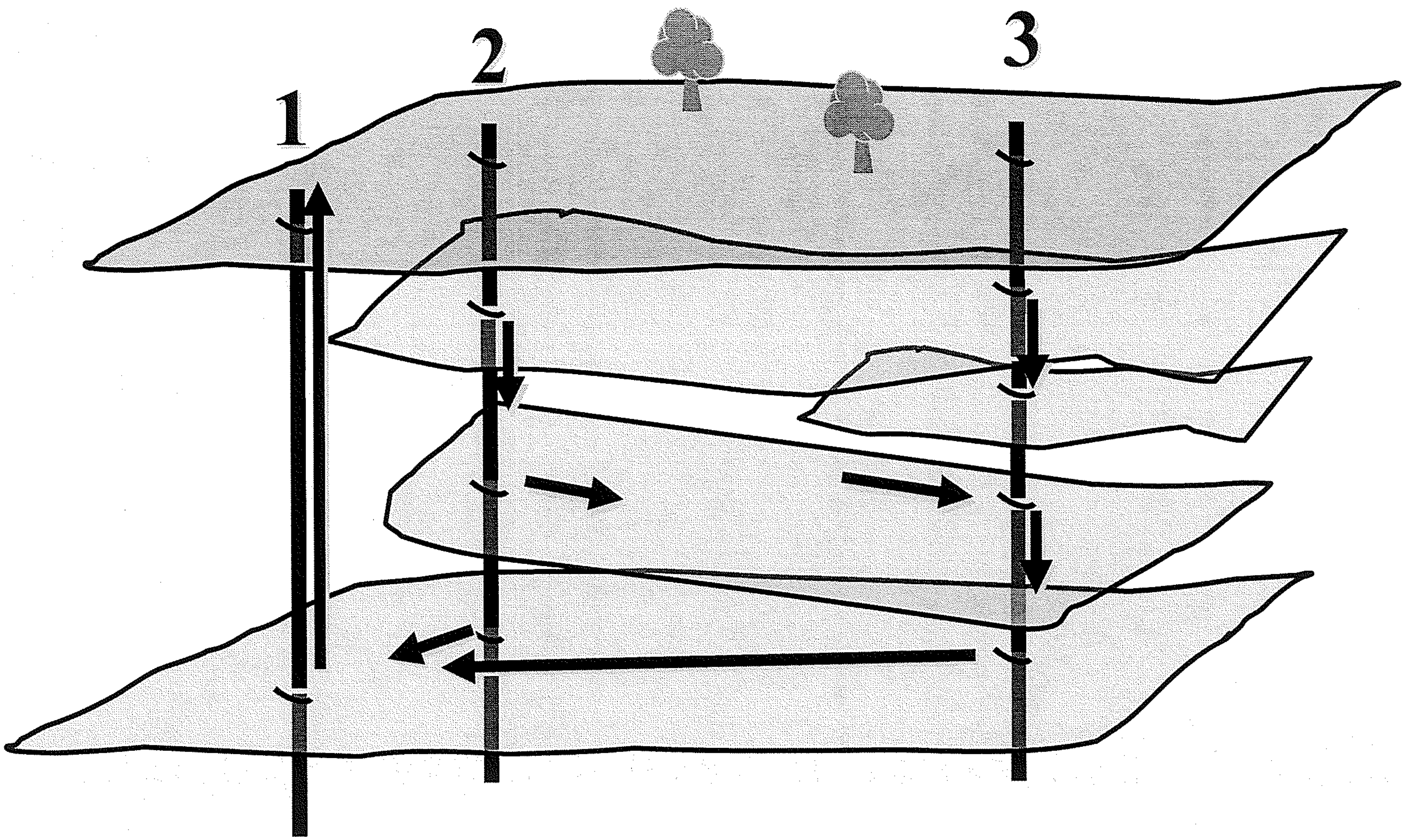
- Packer Tests
  - Isolate interval of borehole for hydraulic testing

Measure Interconnections Between Fractures



Flow Due to Pumping Well 1

Multiple-well Flow Inference Tests



The Pressing Questions…

- Where are water bearing fractures located?
  - "Where should we drill?"

- Use the Geology
- Use the Regional Hydrology
- Determine Likely Recharge Areas
- Expect Large Uncertainties

The Pressing Questions…

- What is the sustainable yield of fractured rock aquifers?
  - "How many wells should we allow?"

- Determine General Pathways
  - Fracture Patterns
  - Fracture Properties
  - Geochemistry
- Conduct Systematic Monitoring
  - We have not even started.