RemTech 2022

Fractured Bedrock Characterization in the Foothills of Alberta – Old Sites, New Ideas

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RemTech 2022

- Introduction
- Geophysical Logging
- Core Analysis
- Borehole and Well Testing
- Summary

Acknowledgements: Deanna Cottrell, Alex Haluszka, Louis-Charles Boutin, Natalie Lippa

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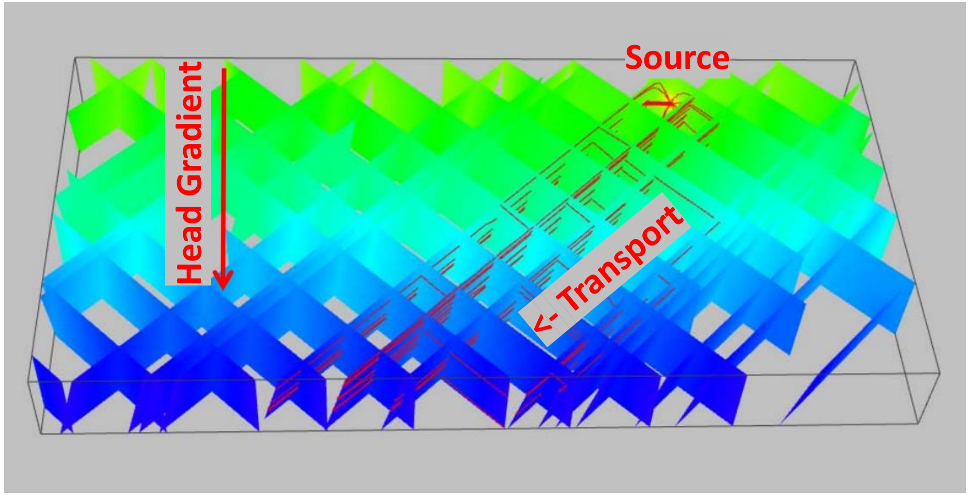
Contaminant Transport and Fate

Key Questions:
Where?
How Fast?
What Concentration?

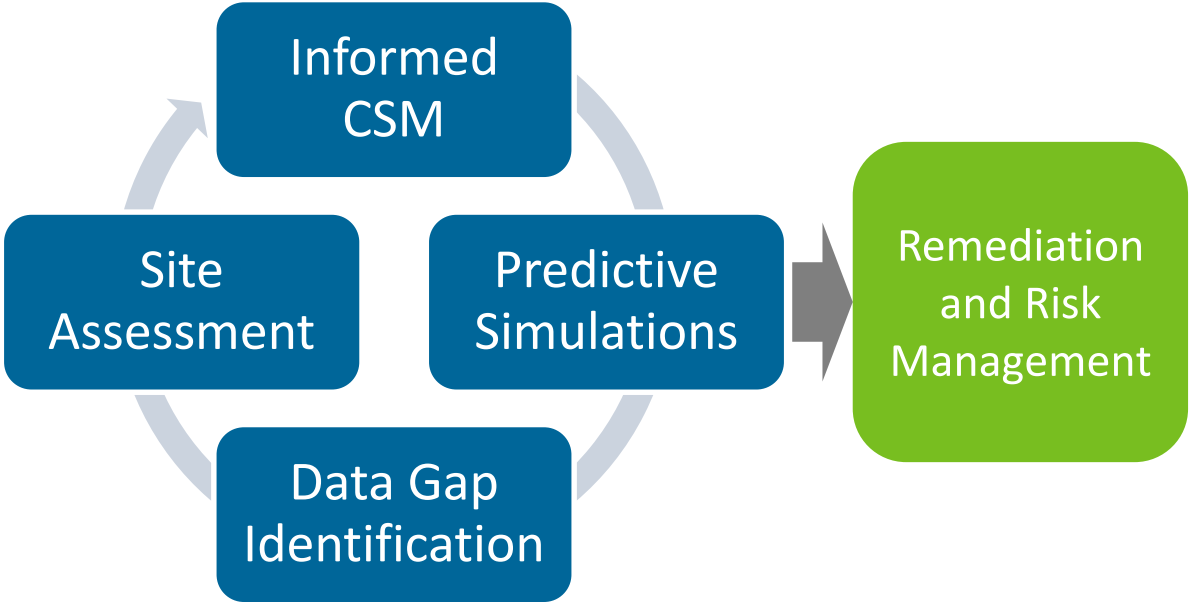
- Contaminant loading into fractured porous bedrock
- Head gradient controls general plume direction
- Preferential flow paths through fractures
- Fracture and matrix porosity
- Diffusion into porous bedrock matrix



Reference: Fractured Bedrock Field Methods and Analytical Tools, Golder 2010

Why do we care?

- Decisions on risk management and remediation
- Remediation can be complex and expensive
- Site assessment methods that inform Conceptual Site Model



Fractured Rock – Key Parameters

- What parameters influence contaminant transport?

Parameter	Key Questions
Orientation	Where?
Spacing/density/frequency	How fast?
Aperture	How Fast?
Hydraulic conductivity/permeability	How Fast?
Porosity (fracture vs. matrix)	Concentration? How fast?

➡ We need to use site assessment techniques that evaluate these parameters

Alberta Foothills Oil & Gas Sites

Age **Generalized Stratigraphy** **(Unit Name: Description)**

QUATERNARY

Q a. — Till, alluvium, colluvium, landslide, debris of nearby bedrock
a. glacier

PALEOCENE and EOCENE

P_{Pa} — PASKAPOO FORMATION: sandstone, fine to coarse grained, locally massive, cliff forming, buff weathering; shale; carbonaceous shale; siltstone; conglomerate; rare coal seams; shell beds

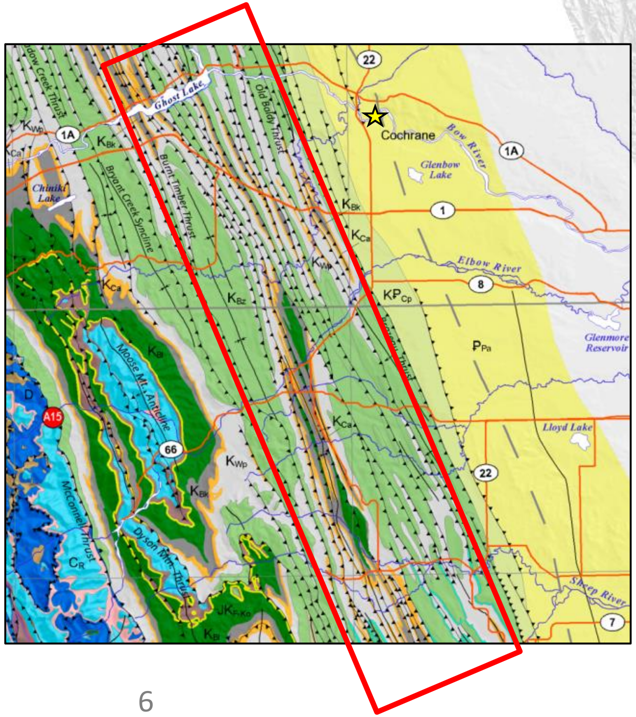
UPPER CRETACEOUS and PALEOCENE

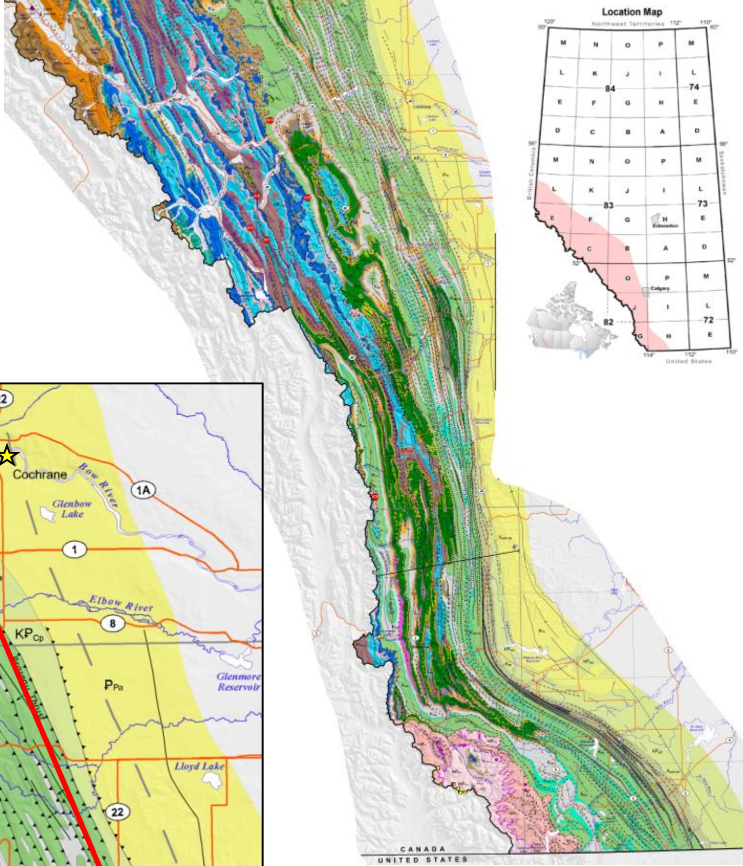
KP_{Cp} — COALSPUR FORMATION: shale, grey to olive-green coaly shale, siltstone, sandstone, numerous thin bentonite beds in the lower part, and coal seams of the Coalspur Coal Zone in the upper part
Entrance Conglomerate Member: conglomerate with chert, rare volcanic, limestone, and phyllite pebbles; sandstone

UPPER CRETACEOUS

K_{Bz} — BRAZEAU FORMATION
Upper part: mudstone, siltstone; sandstone, greenish grey; bentonite; thin coal seams towards the top
Lower part: sandstone, siltstone, laminated; mudstone, olive green; conglomerate, granule to pebble sized, chert and quartzite, plant debris; bentonite beds towards the top

K_{Wp} — ALBERTA GROUP
WAPIABI FORMATION
Nomad Member: mudstone, dark grey, rubbly, rusty weathering; carbonaceous mudstone, greyish green; interbedded sandstone, fine grained, greyish green; thin, chert-pebble conglomerate at base
Chungo Member: sandstone, fine to coarse grained; argillaceous siltstone, dark grey; shale, greyish green, coal at top
Hanson Member: 'concretionary shale' consisting of mudstone, dark grey; argillaceous siltstone; sideritic concretions
Thistle Member: 'platy shale' consisting of mudstone, dark grey; interbedded with siltstone, thin, indurated; bentonite
Dowling Member: 'concretionary shale' consisting of mudstone and siltstone, dark grey; sideritic concretions, orange weathering; chert-pebble and -cobble conglomerate at base
Marshybank Member: concretionary mudstone; sideritic concretions, isolated or horizons; sandstone, fine grained; argillaceous siltstone; massive to cross-bedded; silty concretions, orange-red weathering
Muskiki Member: silty shale, dark grey, rusty weathering; siderite concretions, dark bluish grey, reddish-brown weathering; chert-pebble and -cobble conglomerate at base

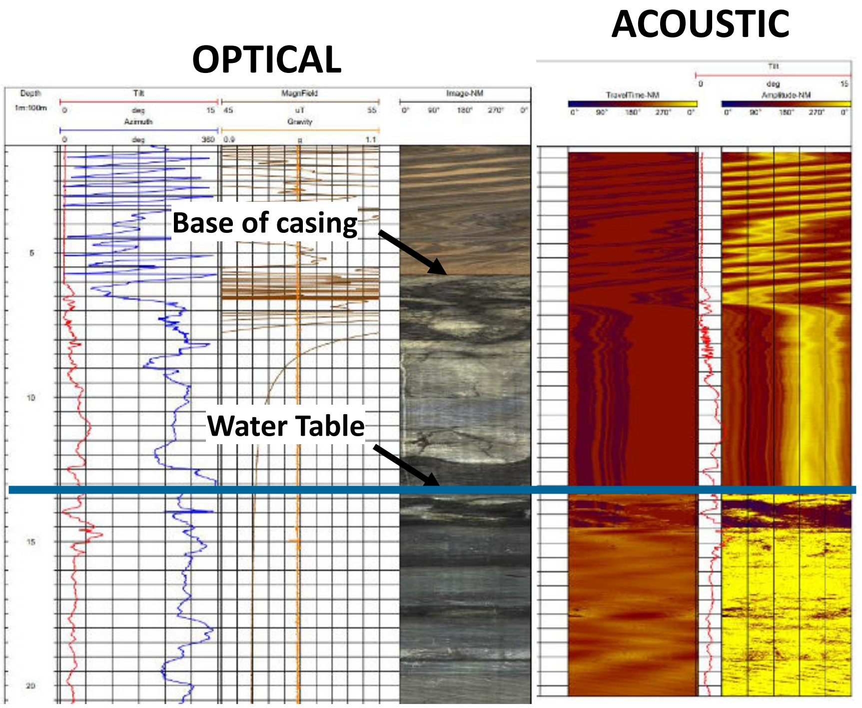




Reference: AGS, 2013 Map 560

Borehole Image Logging

- Acoustic for below fluid level
- Optical for clear water/above fluid level
- Oilfield - more advanced acoustic and resistivity based options



Where?

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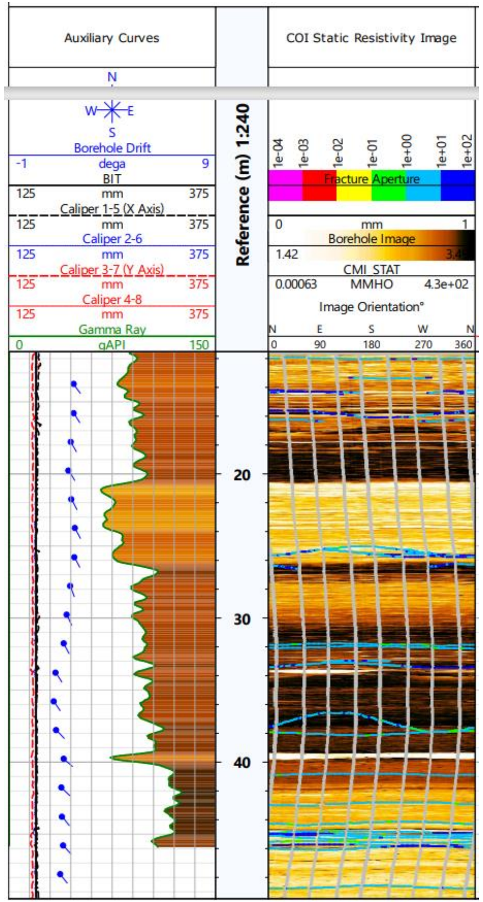
Borehole Image Logging

- Acoustic for below fluid level
- Optical for clear water/above fluid level
- Oilfield - more advanced acoustic and resistivity based options

RESISTIVITY



Where?

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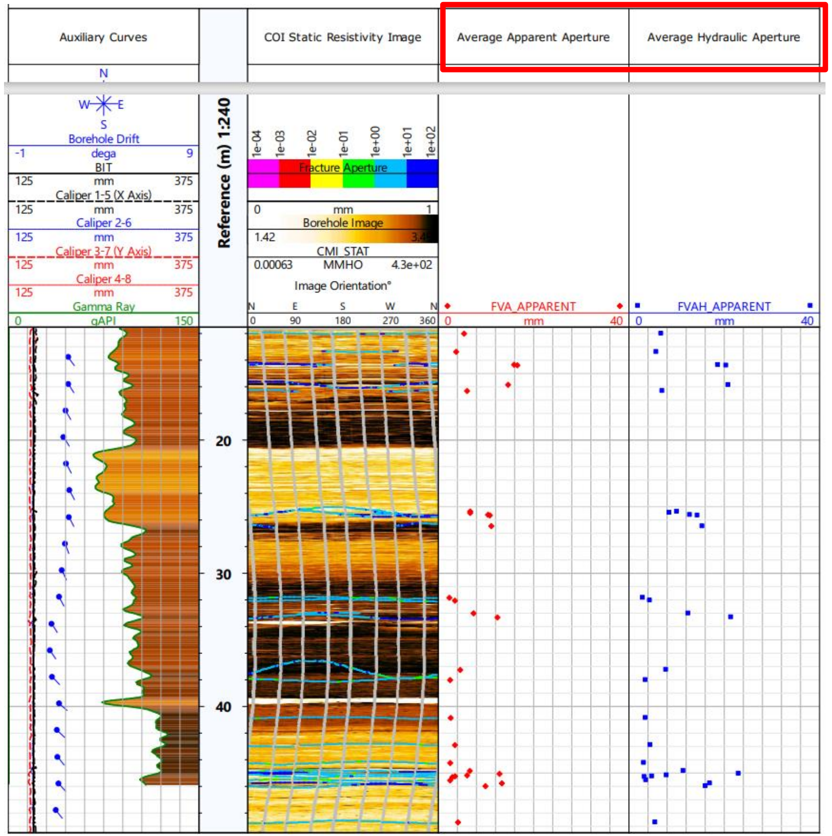
Borehole Image Logging



- Method to estimate mechanical and hydraulic aperture from electrical image logs

Fracture apertures from electrical borehole scans

S. M. Luthi* and P. Souhaité‡

ABSTRACT

Three-dimensional finite-element modeling was performed to investigate the response to fractures of the Formation MicroScanner (Mark of Schlumberger), which records high-resolution electrical scans of the borehole wall. It is found that the equation

$$W = cAR_m^bR_{x0}^{1-b}$$

describes, over two orders of magnitude of resistivity contrasts between borehole mud and the formation, the relationship between fracture width W (in mm), formation resistivity R_{x0}, mud resistivity R_m, and the additional current flow A caused by the presence of the fracture. A is the additional current which can be injected into the formation divided by the voltage, integrated along a line perpendicular across the fracture trace. Coefficient c and exponent b are obtained numerically from forward modeling. Tool standoffs of up to 2.5 mm and fracture dips in the range from 0° to 40° were found to have an insignificant effect on the above relation.

A three-step approach to detect, trace, and quantify fractures is used. Potential fractures in Formation MicroScanner images are detected as locations where conductivity exceeds the local matrix conductivity by a statistically significant amount. Integration over a circular area is performed around these locations to gather all excessive currents; this integral is then geometrically reduced to approximate the line integral A. Line sharpening and neighborhood connectivity tests are done to trace the fractures, and apertures are computed for all fracture locations.

Results from a well into basement in Moodus (Connecticut) show that the method successfully traces fractures seen on Formation MicroScanner images. The resulting fracture apertures range from 10 µm to 1 mm. For the wider fractures there is acceptable agreement with apertures obtained from Stoneley wave reflection measurements. This unique and novel technique for characterizing fractures in wellbores has a very low detection threshold of around 10 µm and resolves fractures as little as 1 cm apart. Furthermore, it provides azimuthal orientation of the fractures.

How Fast? What Concentration?

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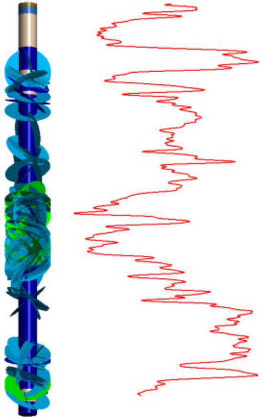
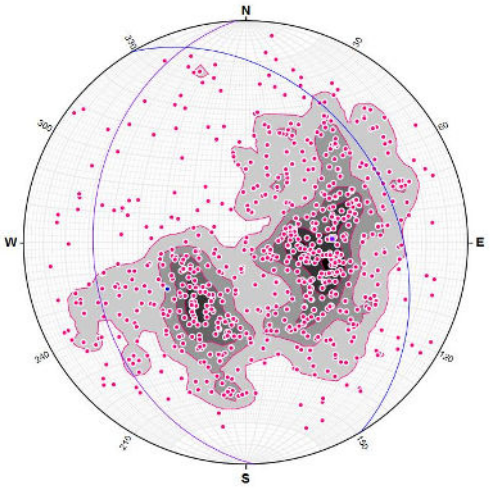
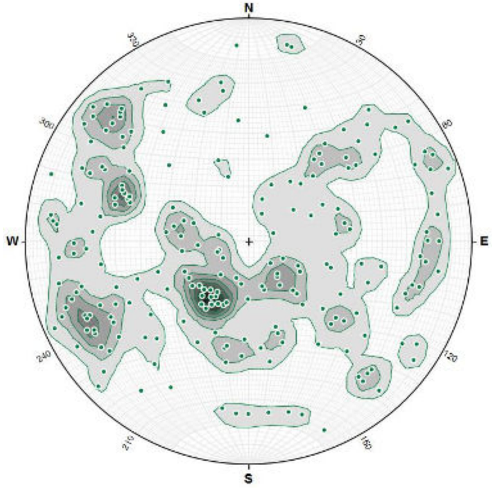
Fractures Sets - Orientation



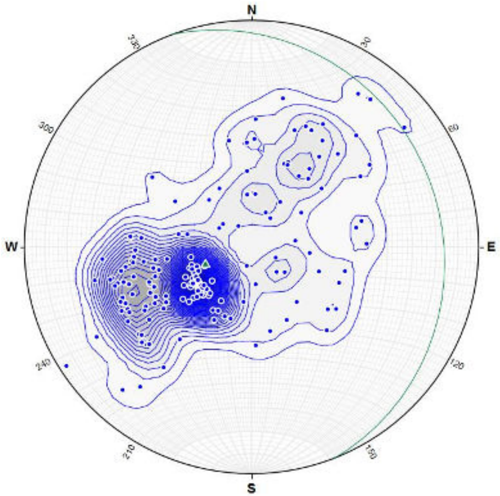
Open Fractures



Closed Fractures



Bedding

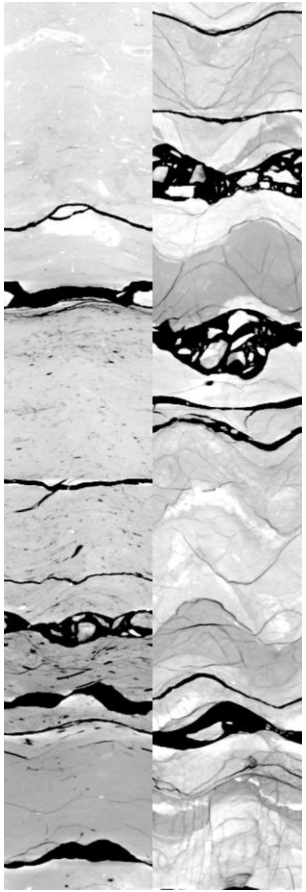


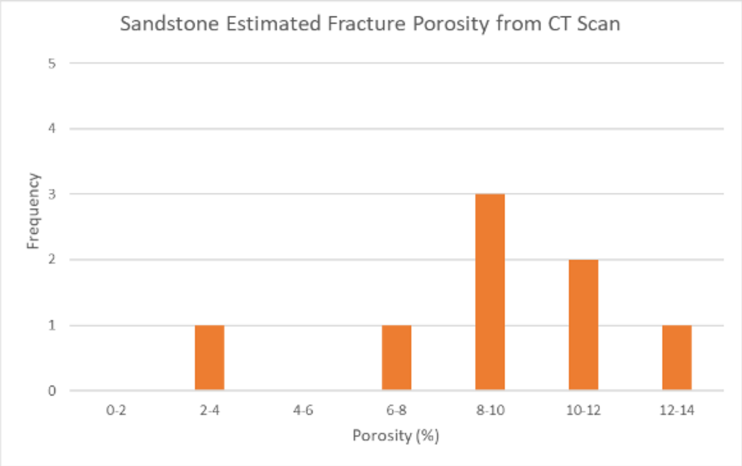
- Most orientation data comes from image logs but can come from oriented core

Where?

Core - CT Scan

- Validation of core recovery/quality
- Estimate of fracture porosity
- Core handling critical and calculated fracture porosity can be biased high





How Fast? What Concentration

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Core Analysis

- Core can be oriented so that fracture orientations can be obtained; this is more expensive
- Unoriented core can be analyzed for other properties like fracture frequency, porosity, and permeability

Core – Laboratory Testing

- Plugs = matrix porosity and permeability
- Full Diameter = matrix + fracture permeability and porosity
- Characterization of anisotropy
  - At borehole scale

Core Plug

Well	Sample Depth	Permeability to Air (OB: 800psi)	Ambient Porosity	AR Bulk Density	Grain Density
	m	mD	fraction	g/cc	g/cc
3B	24.75	0.0129	0.053	2.588	2.691
2A	43.14	0.00215	0.032	2.607	2.677
2A	69.26	0.00198	0.022	2.642	2.686
4B	56.26	0.00281	0.028	2.613	2.674
4B	87.27	0.00166	0.033	2.603	2.669
4B	94.77	0.00373	0.068	2.533	2.681
4B	113.65	0.00480	0.069	2.534	2.660
4B	114.28	0.00209	0.033	2.625	2.687
4B	118.50	0.0120	0.034	2.603	2.676

Full Diameter

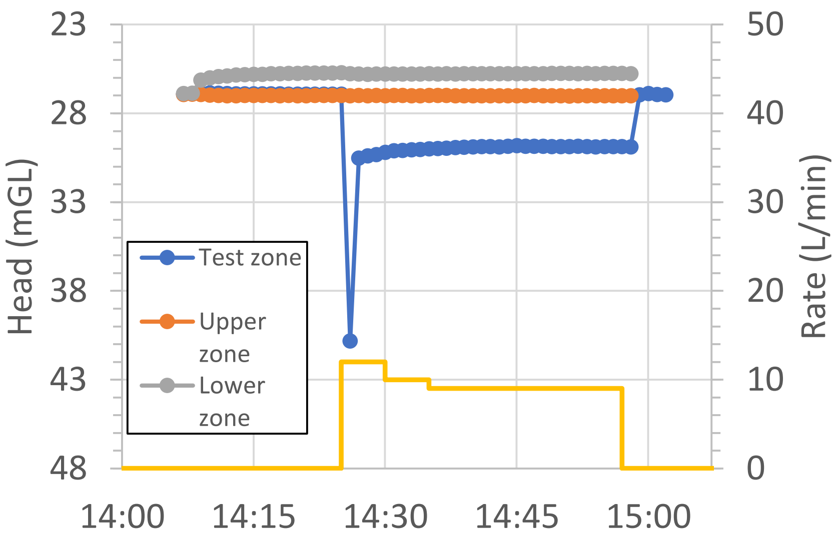
Well	Sample Top Depth	Sample Bottom Depth	Sample Median Depth	Permeability to Air (OB: 400psi)			Ambient Porosity	AR Bulk Density	Grain Density
				K_{HMax}	K_{H90}	K_V			
	m	m	m	mD	mD	mD	fraction	g/cc	g/cc
2A	29.68	29.82	29.75	4910.	1010.	0.0810	0.038	2.588	2.671
2A	40.94	41.09	41.02	748.	314.	0.00209	0.021	2.639	2.685
2A	43.24	43.39	43.32	13.9	5.95	0.0112	0.038	2.603	2.692
2A	60.41	60.53	60.47	4790.	2430.	0.0108	0.048	2.597	2.705
2A	67.00	67.10	67.05	3040.	1900.	0.0215	0.051	2.569	2.687
2A	69.58	69.73	69.66	1960.	1550.	0.00679	0.031	2.624	2.695
4B	58.20	58.35	58.28	690.	459.	0.0590	0.024	2.638	2.695
4B	59.45	59.57	59.51	3630.	3050.	0.192	0.050	2.568	2.694
4B	110.78	110.89	110.84	4630.	3690.	0.0746	0.041	2.628	2.718

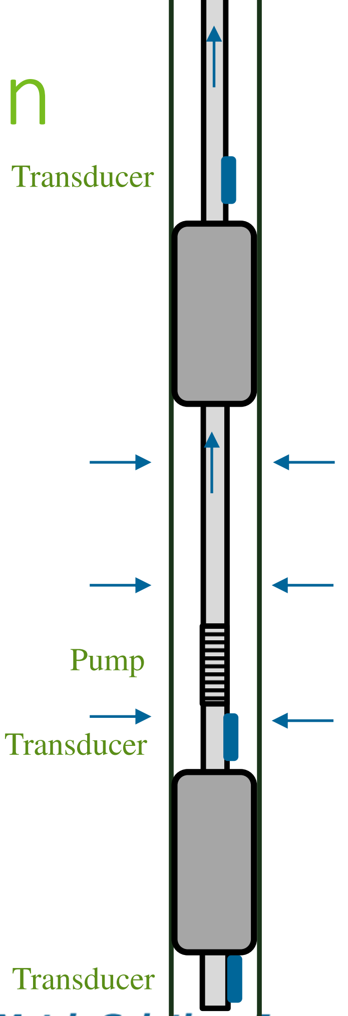
2. Box 56 – shale/siltstone – 1x open single fracture (bedding plane parallel)

How Fast? What Concentration?

Borehole Packer Testing – Zone Isolation

- Evaluate:
  - Hydraulic conductivity (K)
  - Groundwater quality
- Monitor nearby wells
- Zones selected based on:
  - Drilling info
  - Geophysics/image logs



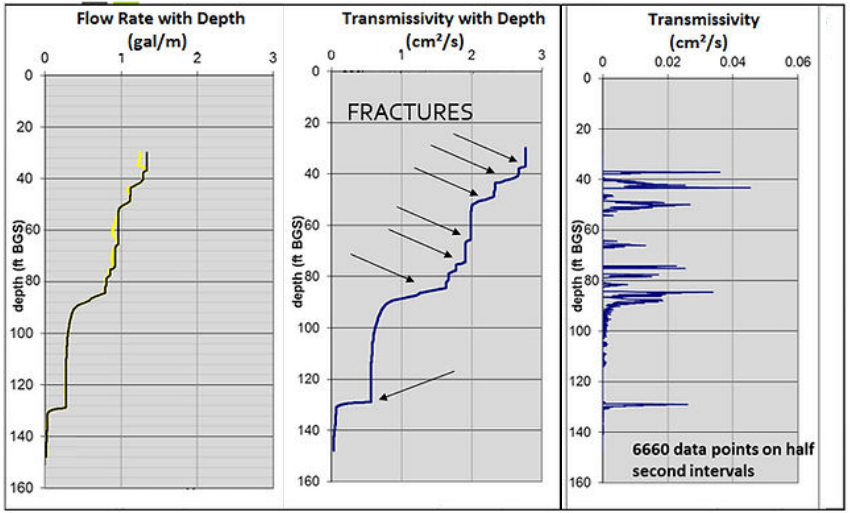


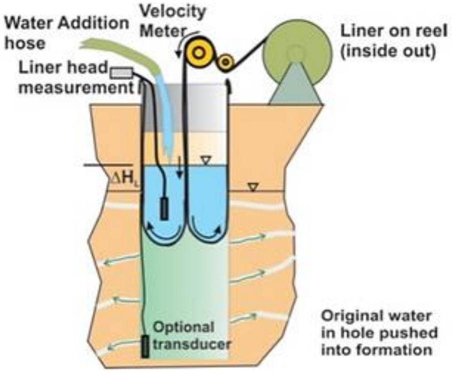
How Fast?
What Concentrations?

Borehole Profiles

- Transmissivity Profile:
  - High resolution measurement of **hydraulic conductivity**
  - Identify hydraulically active fractures

FLUTe Flexible Liner Underground Technologies
Environmental Innovation





Where?
How Fast?

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Borehole Profiles

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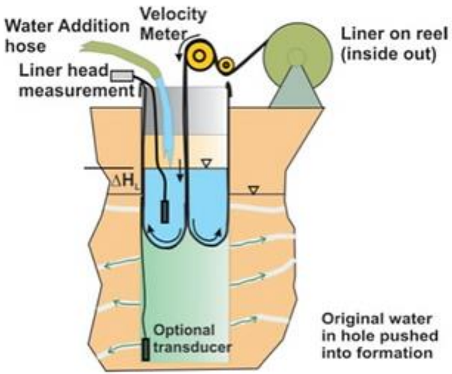
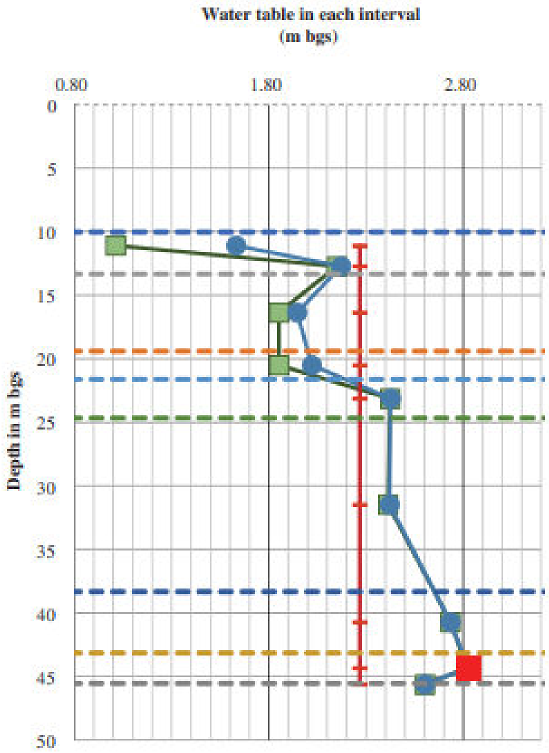
- Reverse Head Profile:
  - Determine **hydraulic head** in specific intervals
  - Vertical gradients





Where? How Fast?

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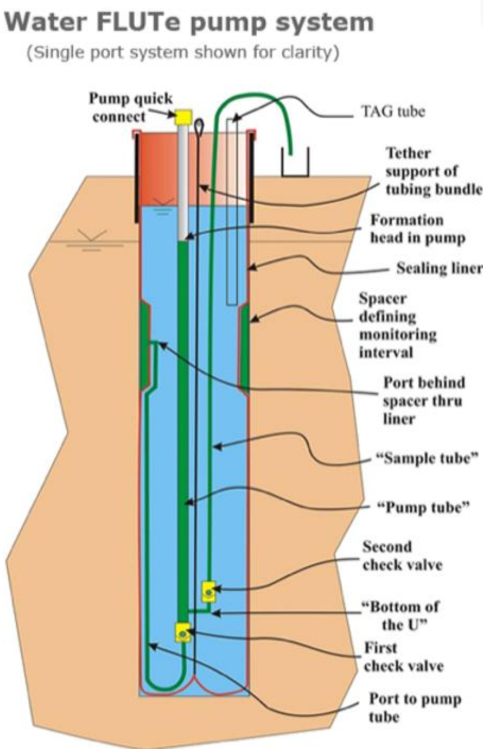
Multi-Level Wells



- Water FLUTe:
  - Sampling ports (groundwater quality)
  - Optional pressure transducers

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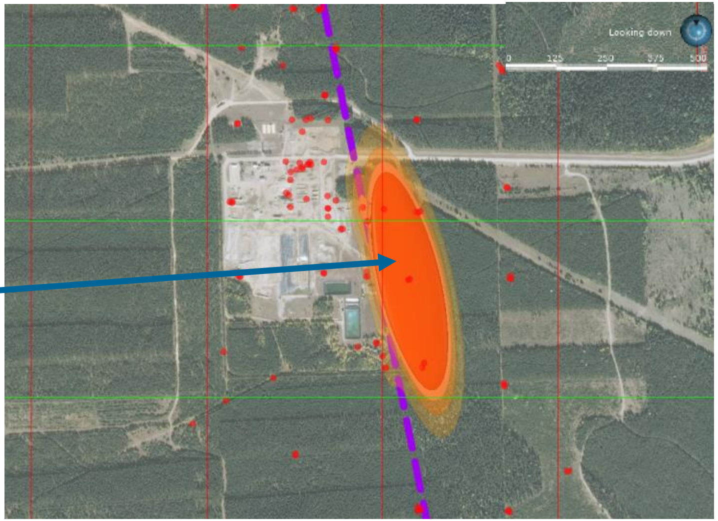
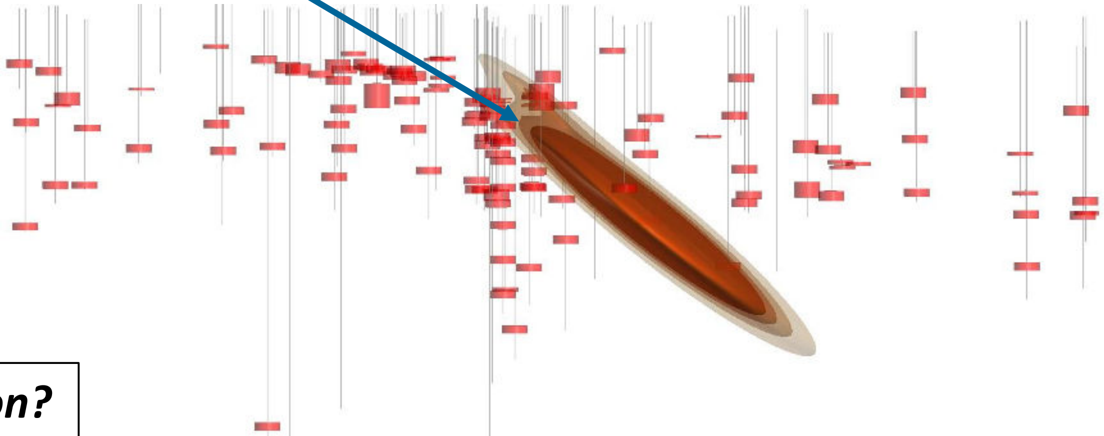
Anisotropic Drawdown in a Pumping Test

3D Interpretation
of hydraulically connected
fracture network from
monitoring well network



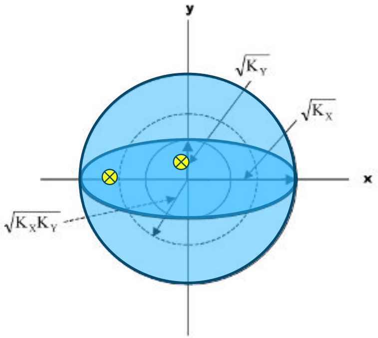
Monitoring well screen interval
and FLUTe multi-level ports



Where? How Fast? What Concentration?

Anisotropic Drawdown in a Pumping Test

- Options to analyze:
  - Numerical model
  - Simplified analytical approaches



groundwater

Technical Note/

A Distance–Drawdown Aquifer Test Method for Aquifers with Areal Anisotropy

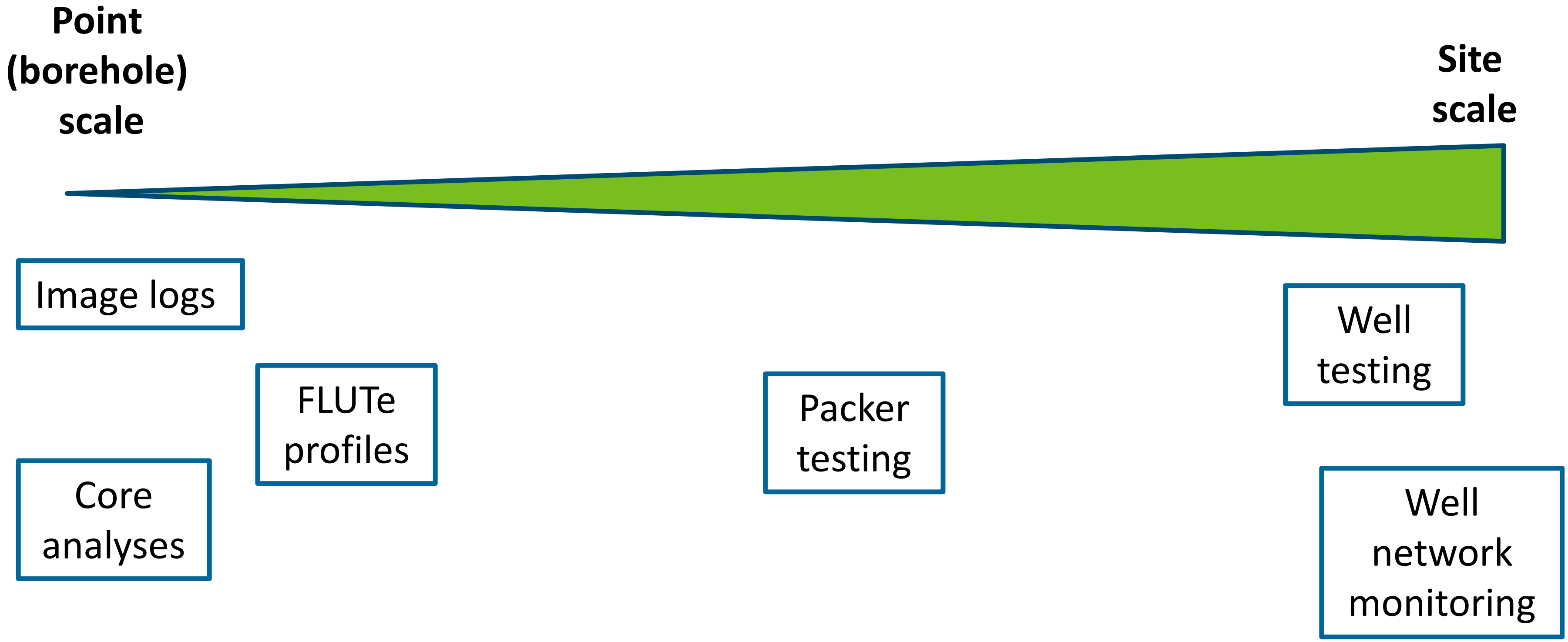
by Robert D. Mutch Jr.[1,2]

Abstract

A new distance-drawdown method for aquifers with anisotropy on the horizontal plane is presented. The method uses scalar transformation to convert to an equivalent, isotropic medium, thus permitting application of the Cooper-Jacob Method. The method is applicable to cases where at least one ellipse of equal drawdown can be delineated but can also be applied where no ellipse can be discerned from the data. In the latter case, a least-squares regression approach can be employed to estimate the orientation and magnitude of the anisotropy. The regression R^2 value provides a quantitative assessment of the degree to which the drawdown data are indicative of a systematic areal anisotropy in the aquifer or whether the data simply reflect natural aquifer heterogeneity. In addition to confined aquifers, this methodology, like the Cooper-Jacob Method, is also applicable to unconfined aquifers either before the onset of delayed drainage or following the completion of delayed drainage provided that the u value meets the recommended criterion.

Where? How Fast? What Concentration?

Scale Considerations



Summary

- Flow and transport in fractured bedrock is inherently complex, may require significant effort and different approaches to characterize.
- Filling data gaps in conceptual site model.
- Various field characterization techniques for different stages
- Validate results with different methods and scales

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