How good are results from small scale injection tests?

A comparison of results from two testing methods in deep bedrock at a Canadian arctic site.

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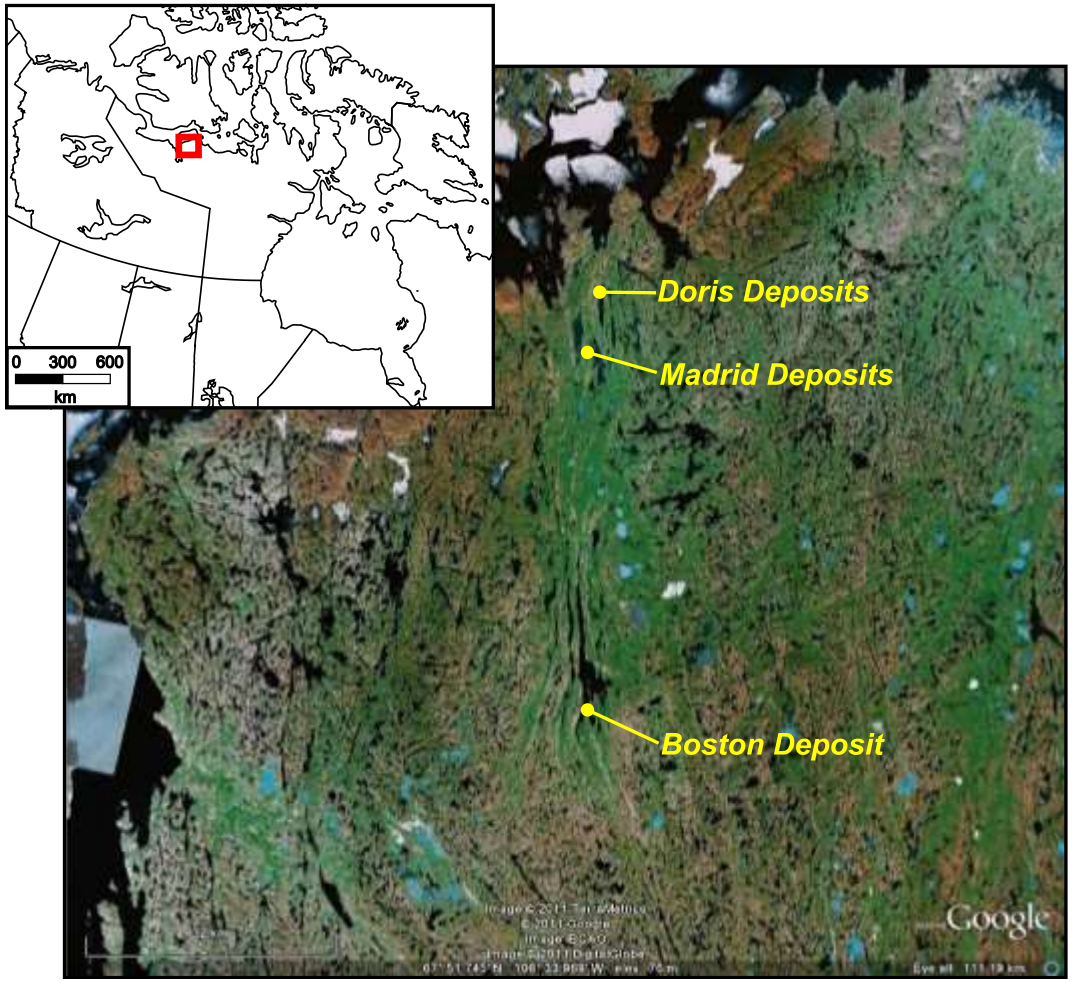
Introduction

- Hydrogeologists never have a perfect understanding of hydraulic conductivity, at least not at the beginning of a project
- Traditionally greenfields projects utilize small scale test methodologies (i.e. packer testing)
- However, can we effectively assess aquifer uncertainties using only these small scale methods?

- Large-scale testing methods at the artic mine site were utilized in an order to assess this uncertainty and gain a better understanding of the distribution and magnitude of hydraulic conductivity (K)

Regional Setting / Logistical Challenges

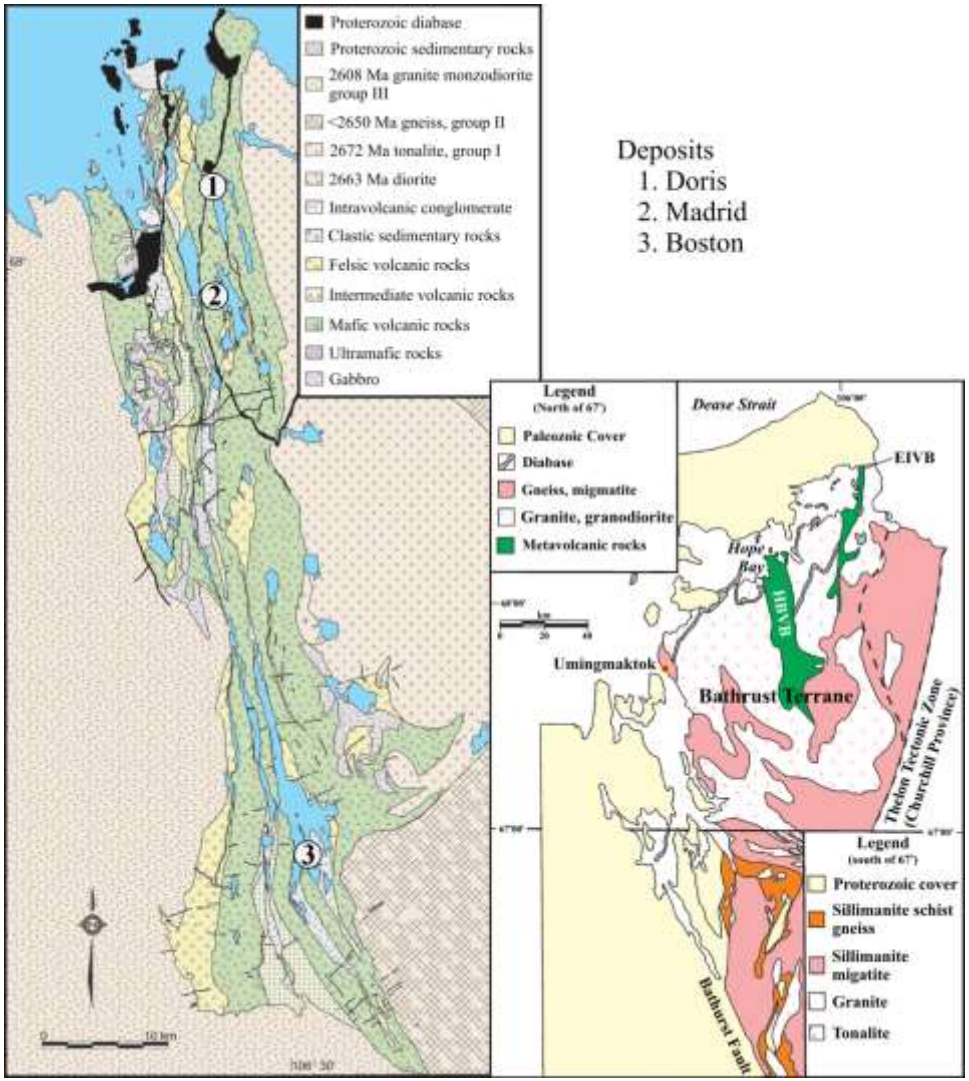
- Study site located within Nunavut along Artic Ocean
- Extremely cold climate
- Deposits located beneath regional lakes
  - Majority of testing conducted during winter months
- Saline water conditions



Mayer (2011)

Regional Geology

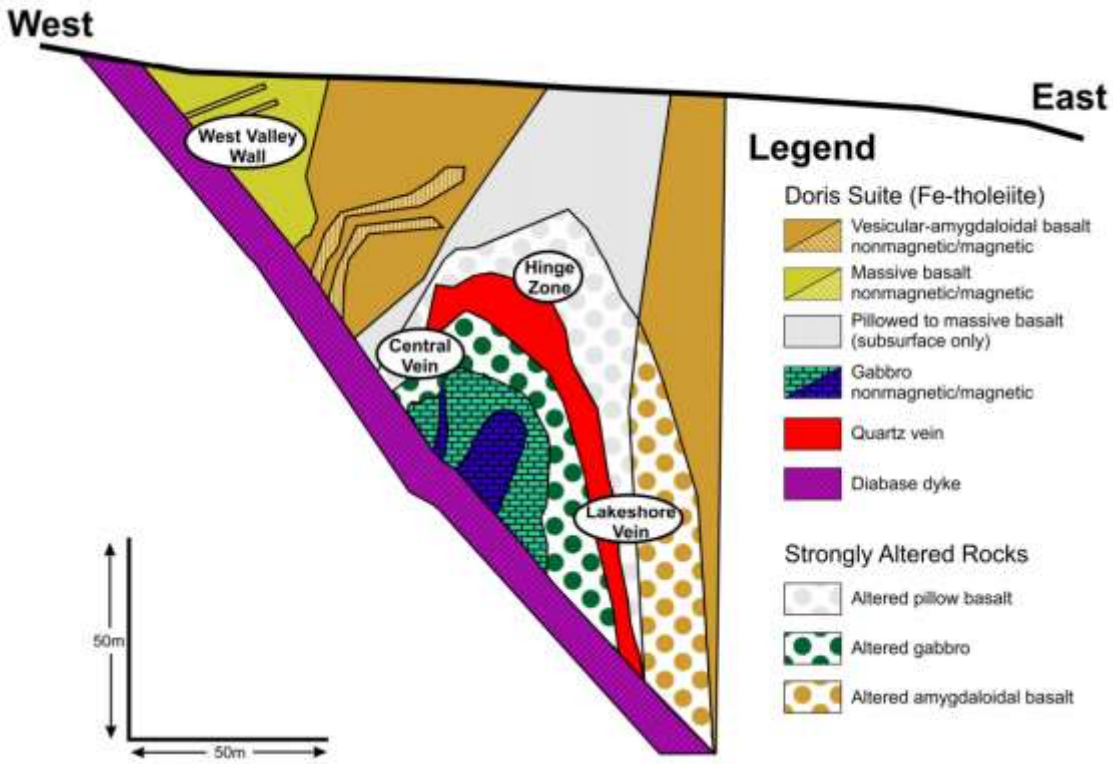
- North-south striking Hope Bay volcanic belt
  - Within northeastern Slave Structural Province
- Greenstone-hosted quartz-carbonate vein deposit
  - Dominated by:
    - Pillowed Mg-rich tholeiitic basalt
    - Basaltic andesite
    - Fe-rich tholeiites
  - Interlayed with:
    - Intermediate felsic volcanic rocks
    - sedimentary rocks



Modified from Sherlock and Sandeman (2003)

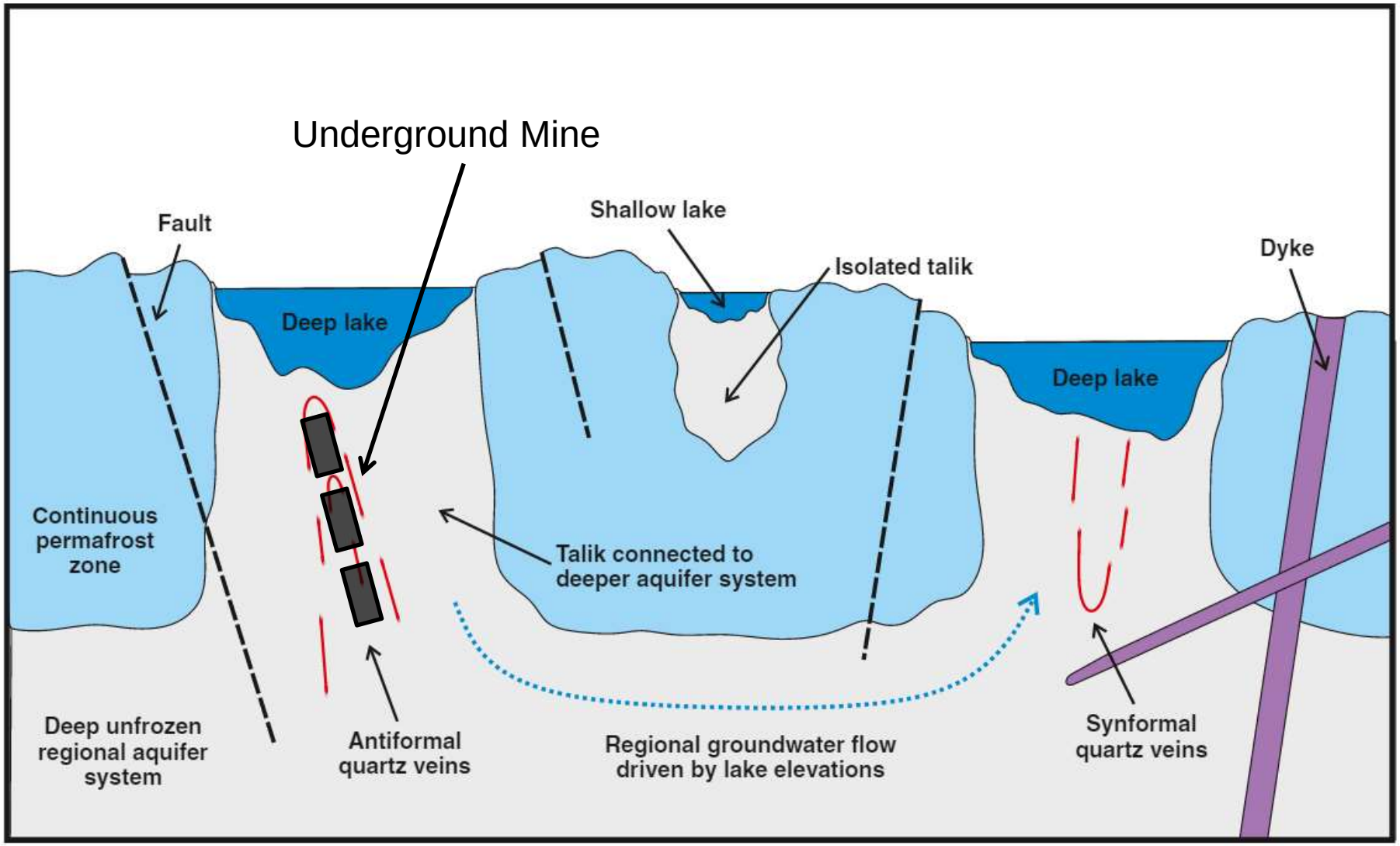
Local Geology: Doris Deposit

- Succession of mafic meta-volcanics
  - Groundwater flow is predominantly fracture controlled
- Geology is locally folded within a doubly plunging upright anticline
- Increased fracturing observed near hinge zone
  - Zone is also associated with increased quartz veining
- Cross-cut by localized diabase intrusions
  - Dykes are more competent then surrounding meta-volcanics



Mayer (2011)

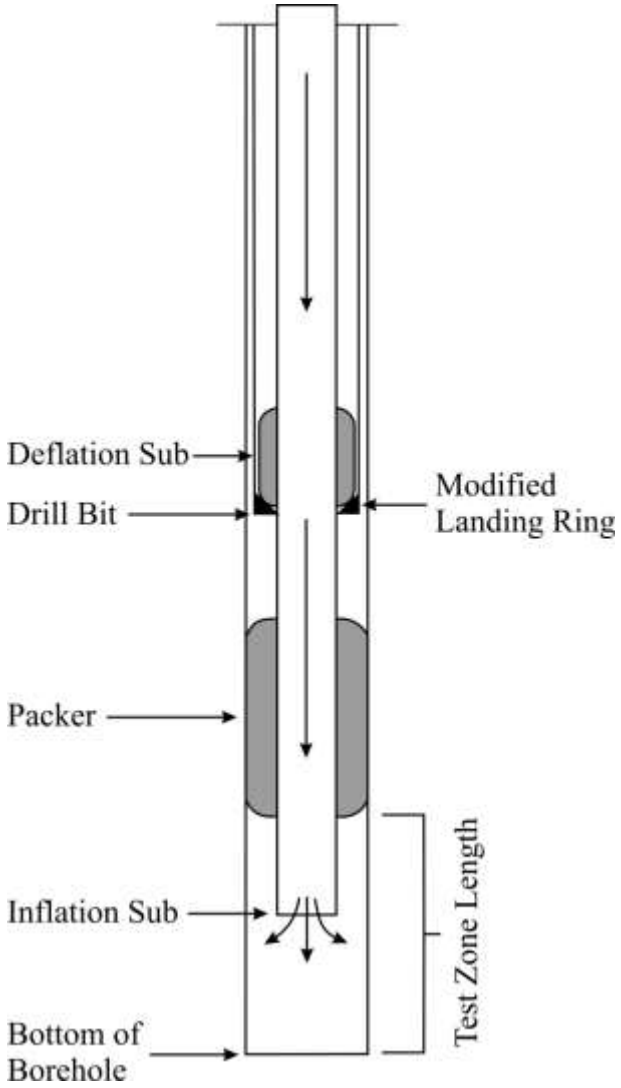
Conceptual Model



Modified from Mayer et al. (2014)

Hydrogeological Testing

- Phase One:
  - Packer testing (56 short test)
    - 10 to 30 mins
    - Isolated, small-scale injection tests
  - Thermal monitoring
  - Deep Westbay multi-level wells
- Phase Two:
  - Long term injection test
    - 14 hours
    - Packer-isolated injection zone
    - Monitored from Westbay multi-level well

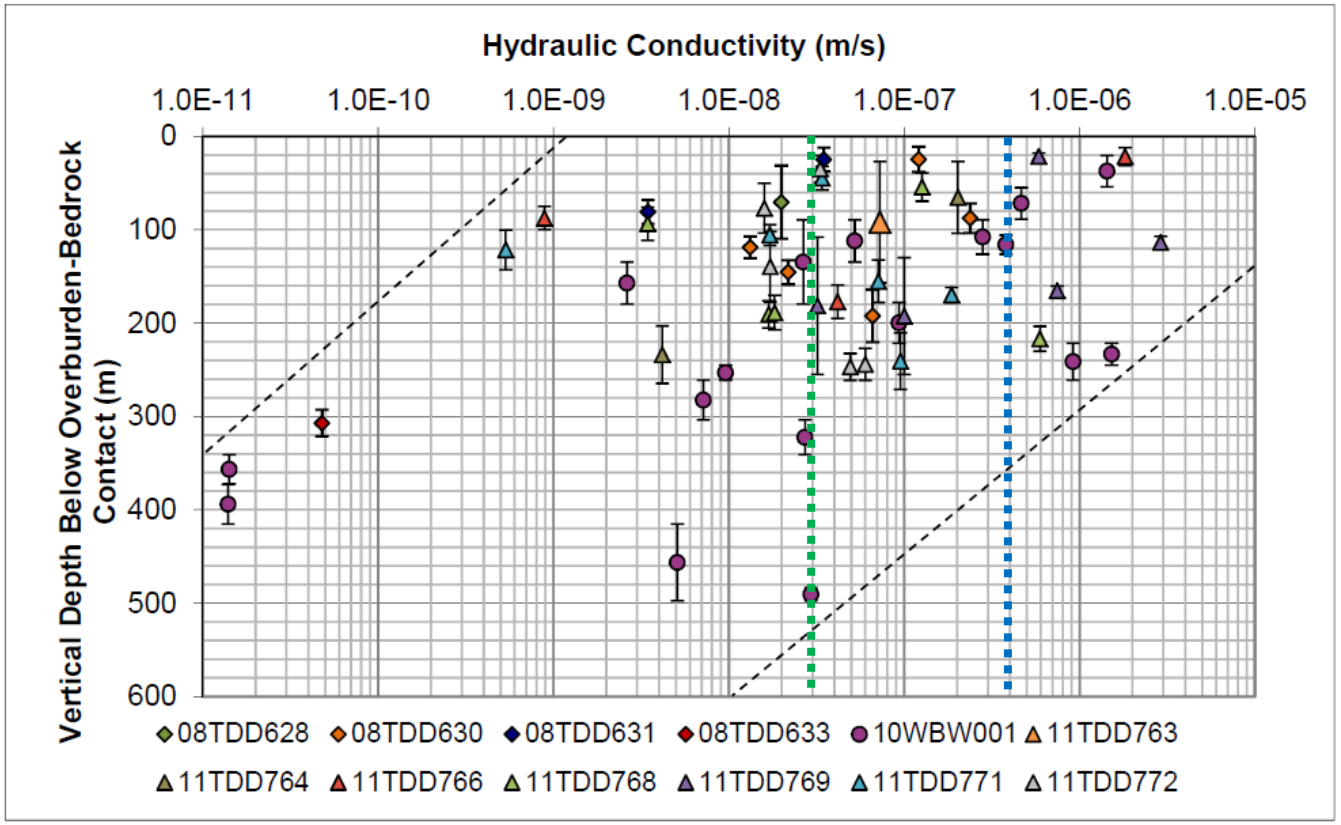


Mayer (2011)

Phase One

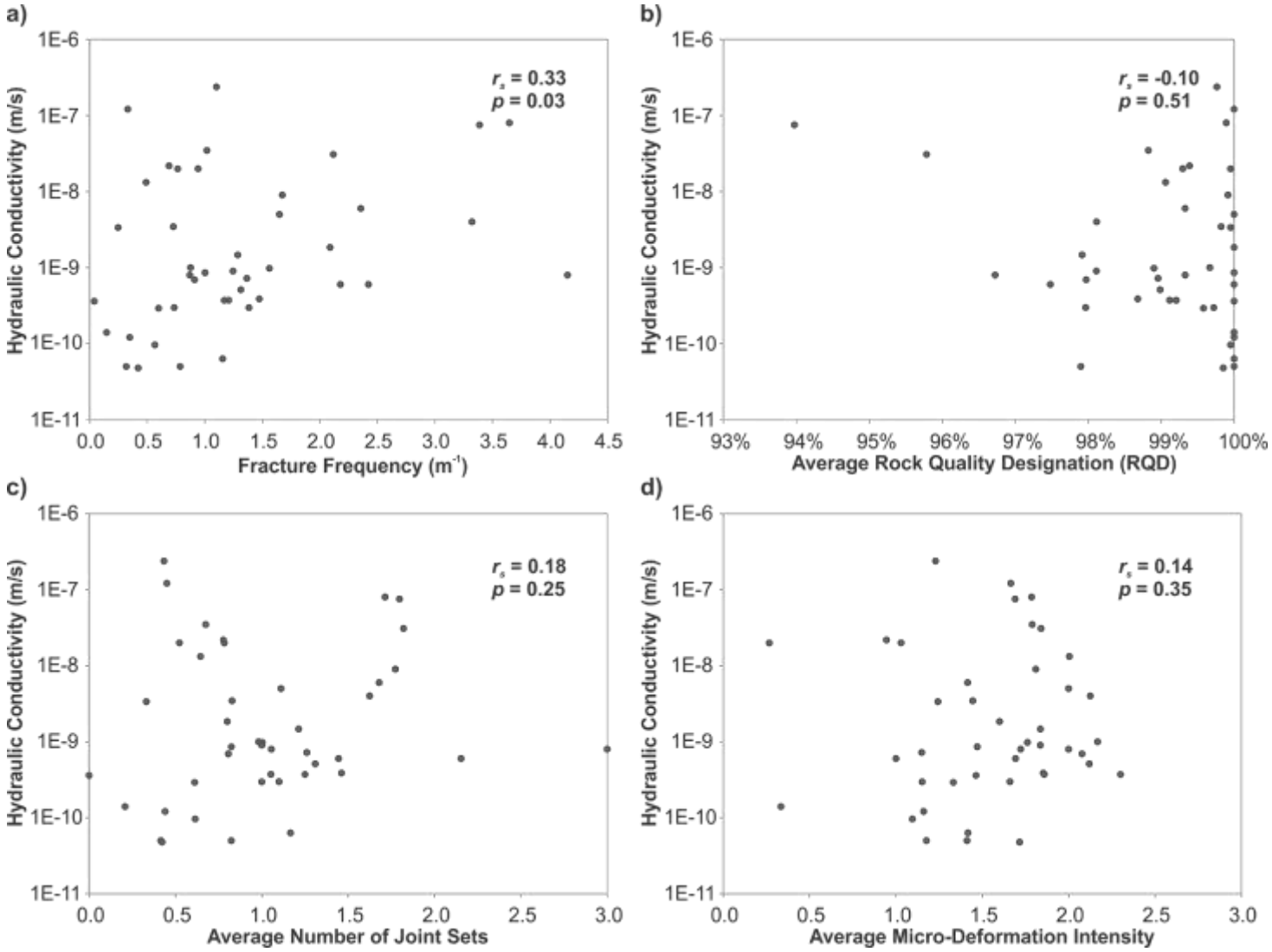
Small-Scale Packer Isolation Tests

Small Scale Testing (Isolated Packers)



Geometric Mean	Arithmetic Mean
3e-8 m/s	4e-7 m/s

Geotechnical Comparisons



Mayer et al. (2014)

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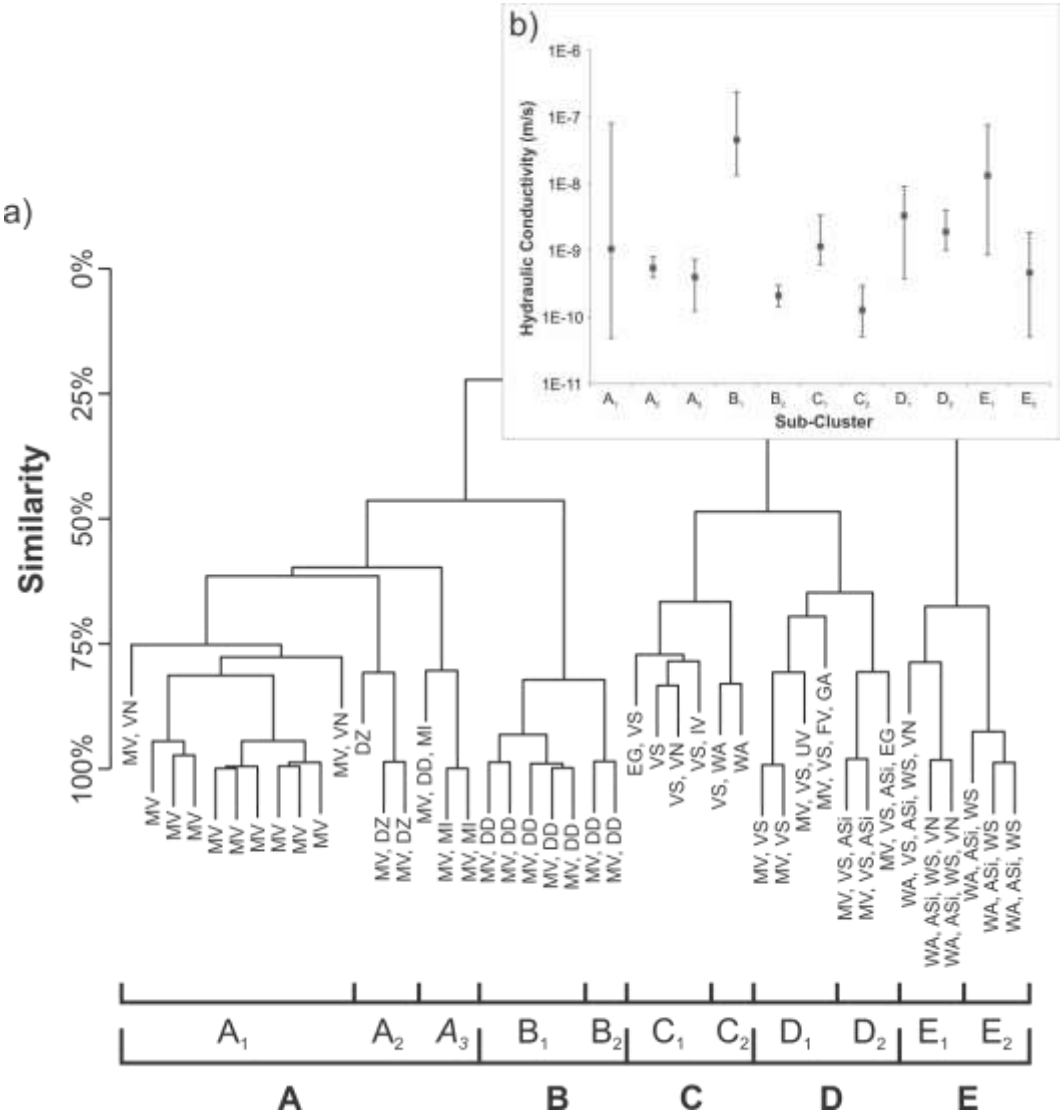
Multivariate Statistics



Mayer et al. (2014)

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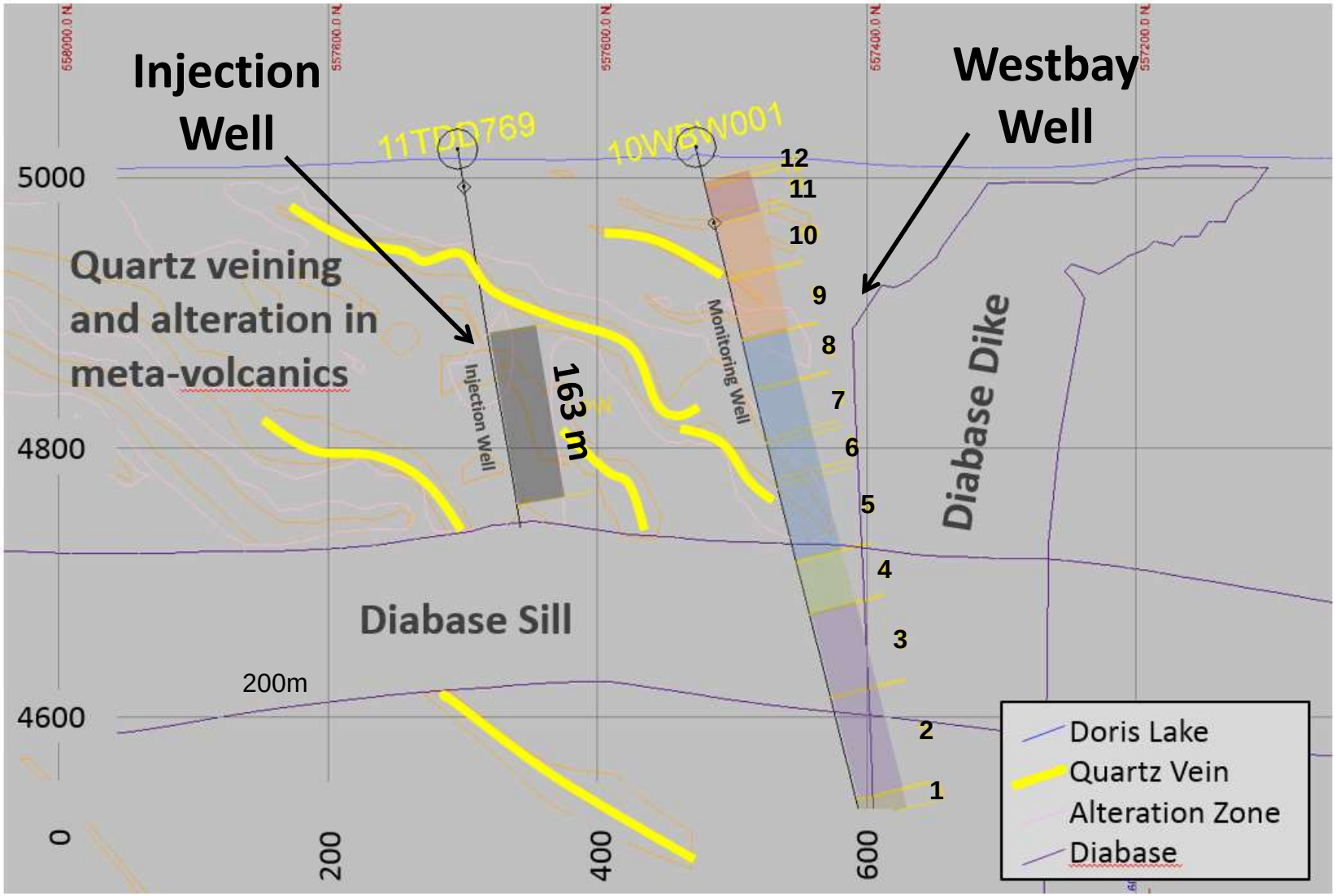
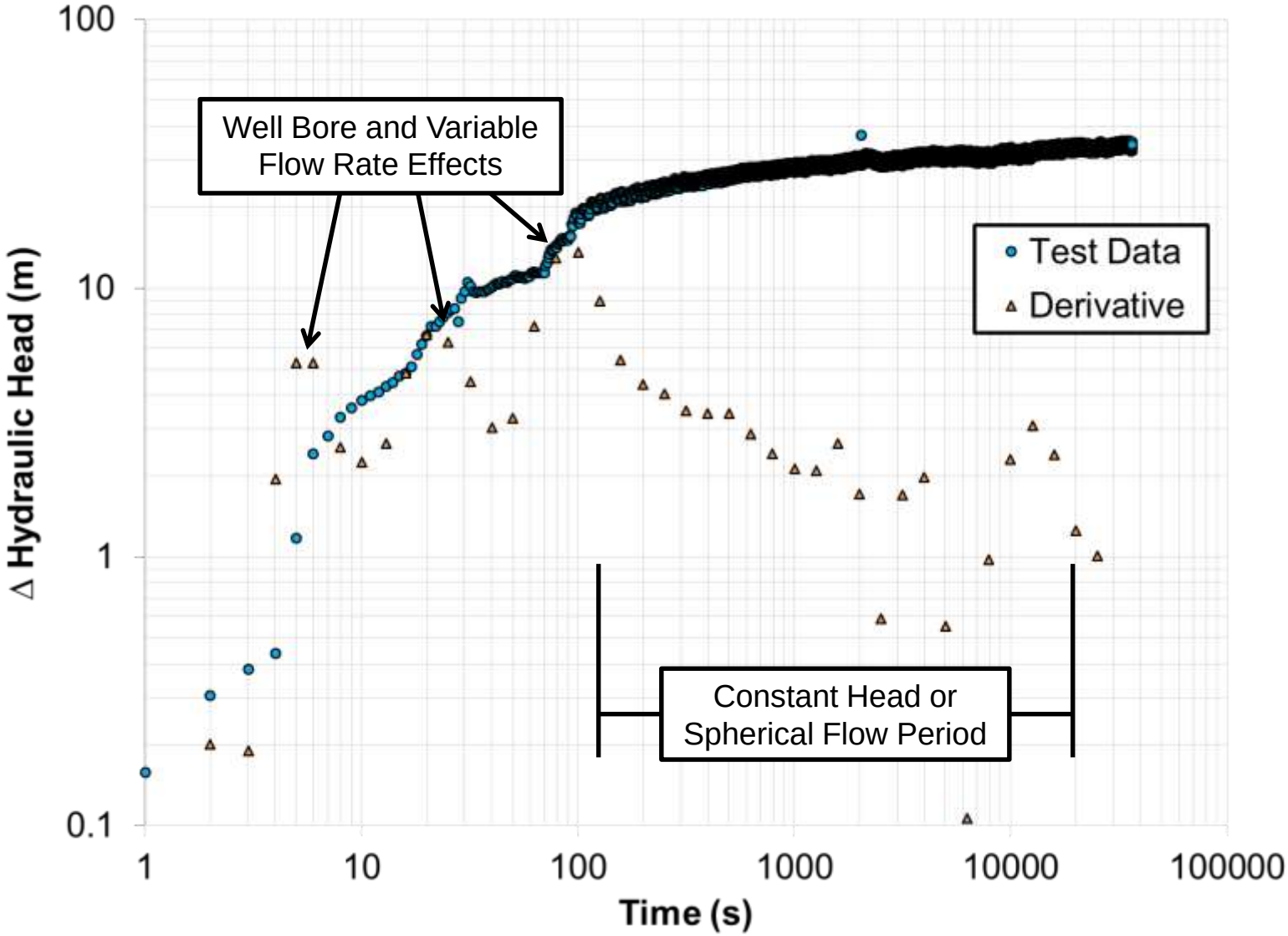
Phase Two

Long-Term Injection Test

Large Scale Injection Test



Injection Well



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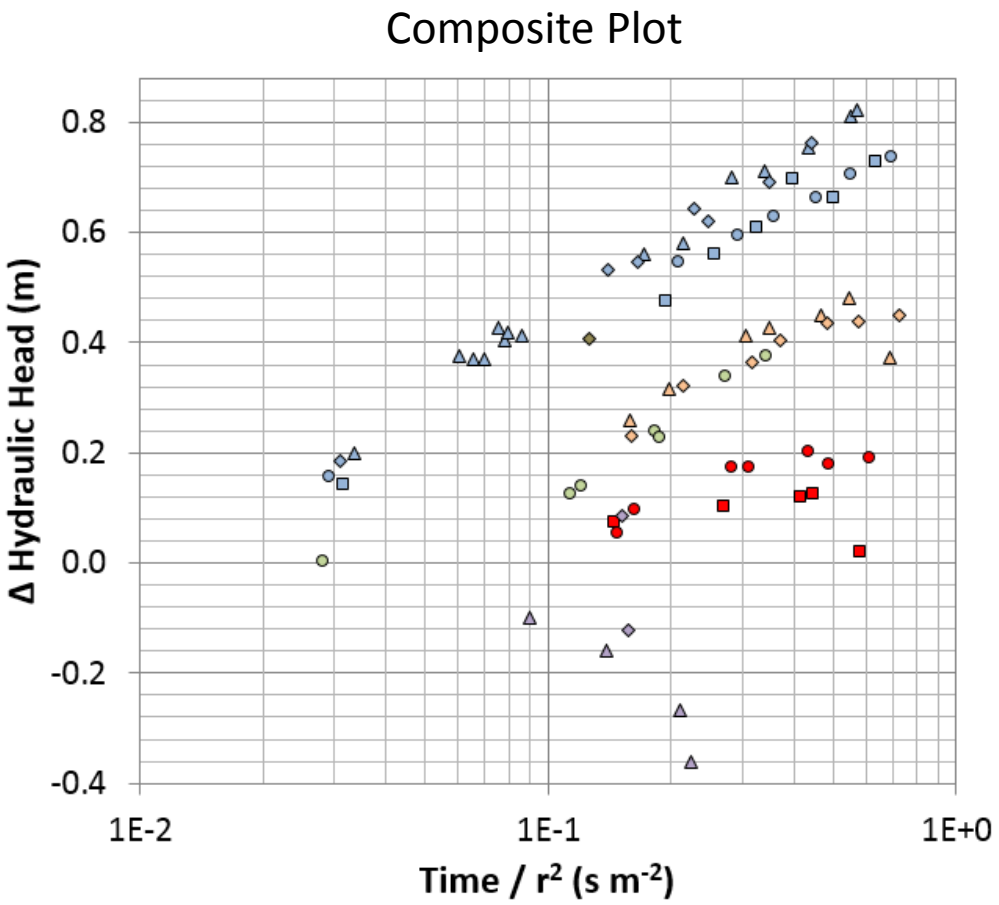
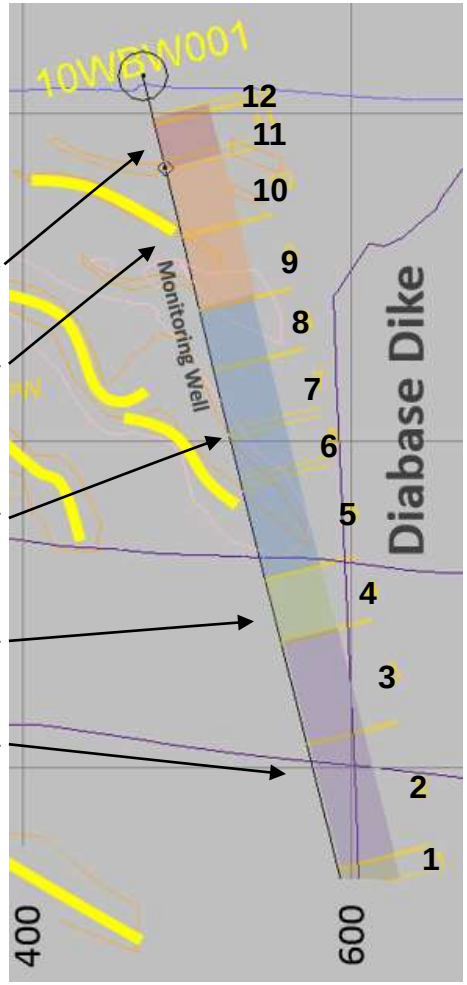
Westbay Well Observations



- Zone 12: 26.5 mbgs
- Zone 11: 41.0 mbgs
- Zone 10: 77.3 mbgs
- Zone 9: 120.5 mbgs
- Zone 8: 161.4 mbgs
- Zone 7: 198.2 mbgs
- Zone 6: 233.4 mbgs
- Zone 5: 278.9 mbgs
- Zone 4: 326.8 mbgs
- Zone 3: 377.3 mbgs
- Zone 2: 446.3 mbgs
- Zone 1: 490.0 mbgs



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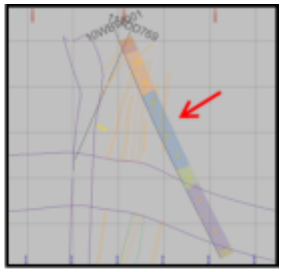
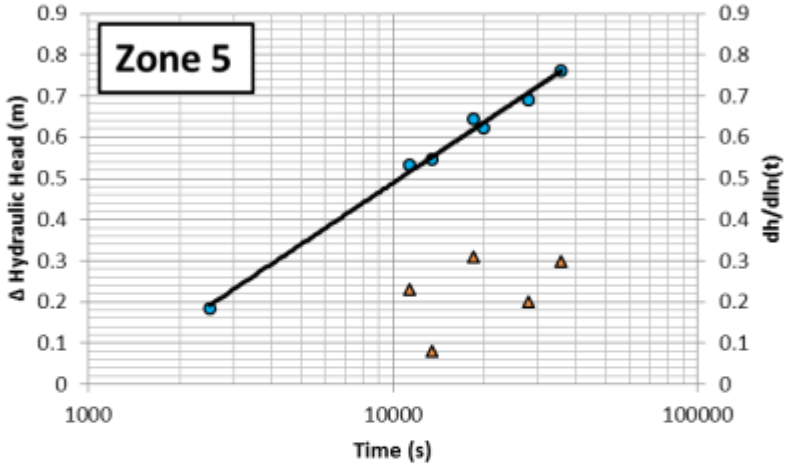
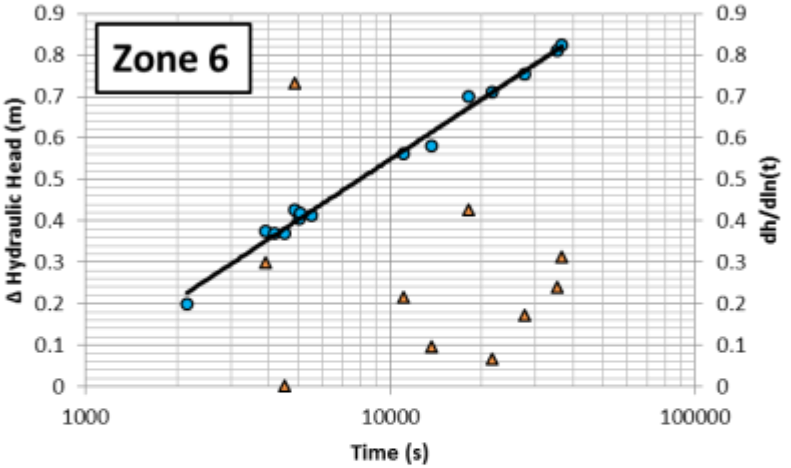
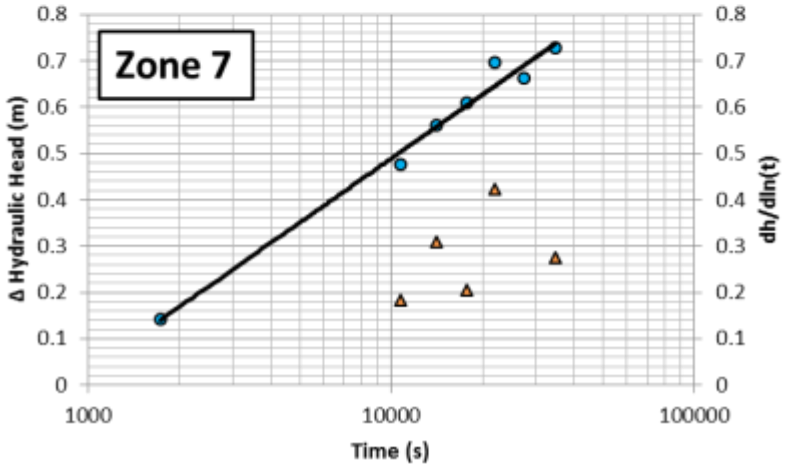
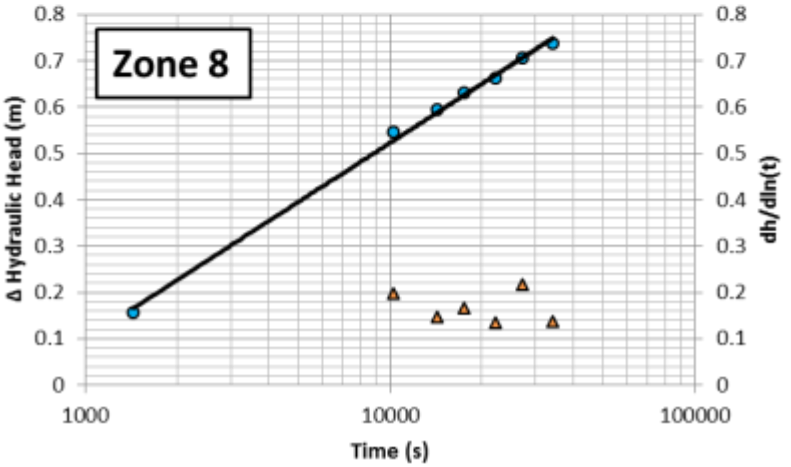
Central Aquifer











Test Data Derivative

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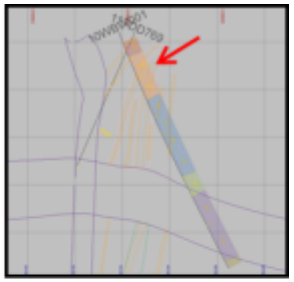
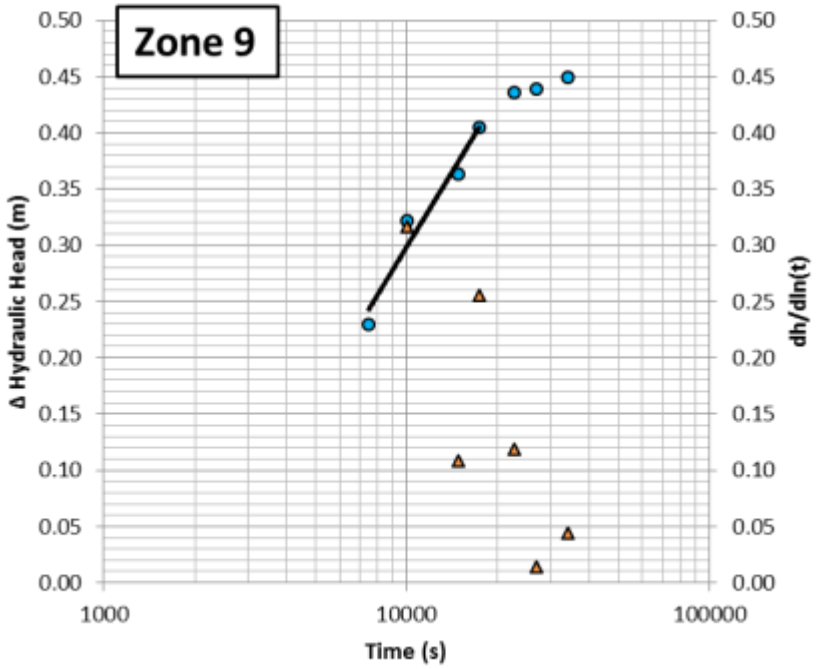
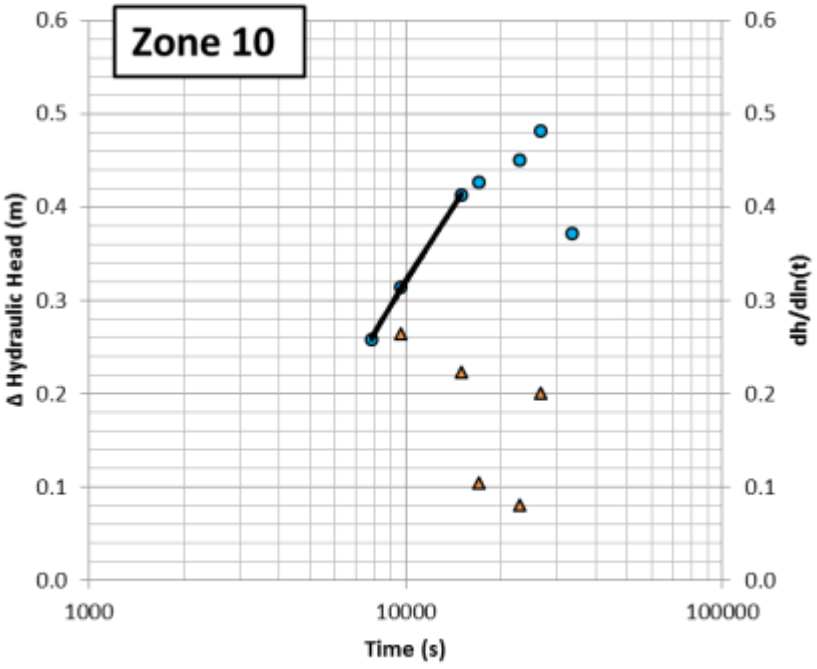
Upper Aquifer







Test Data Derivative

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Comparison of Small vs. Large Scale Tests

Small Scale		*Large Scale*
Geometric	Arithmetic	
3e-8 m/s	**4e-7 m/s**	**3e-6 m/s**

Comparison is not without it's challenges:

- Large scale testing indicates an two orders of magnitude larger K than suggested by packer testing average
- This is consistent with published literature which suggest fractured systems are disproportionally controlled by highest K features

What does this all mean?

Conclusions/Final Thoughts

How often are we getting “blinded” by our methods?

- Under-estimation of large-scale behaviour using small-scale tests

Analytical models and even numerical models require some sort of average K value for the zones or domains being assessed

- Is this even appropriate for fracture rock hydrogeology?
- How can we utilize traditional analysis method if an appropriate REV does not exist?

In theory, all the test data is good but:

- We need to understand limitations,
- Interpret with regard to lithology and structure,
- Assess reasonable worst case scenarios considering these factors.

We’ll never be “right” but we can get better at managing “wrong”