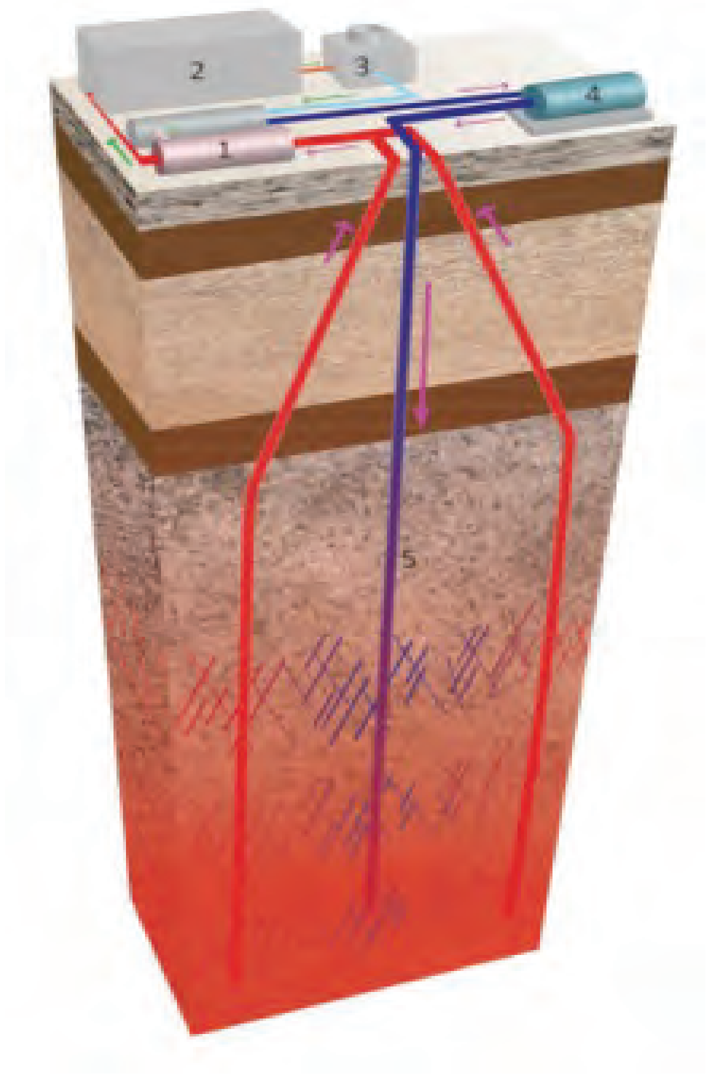
Stimulation Technology: Economics and Application

ALTAROCK™

May 2015



Multiple stimulated zones (5) allow greater flow through the reservoir with higher heat collection from the rock to produce more steam flow in the separators (1) for more power output from the plant (2), less use of cooling water (3) and lower injection pumping costs (4).

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What is EGS?

How does it relate to Stimulation?

What are the different forms of stimulation?

Innovations

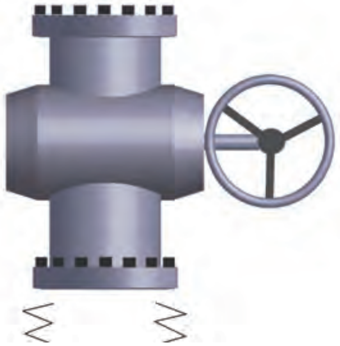
Innovation 1: AltaRock TZIM Technology

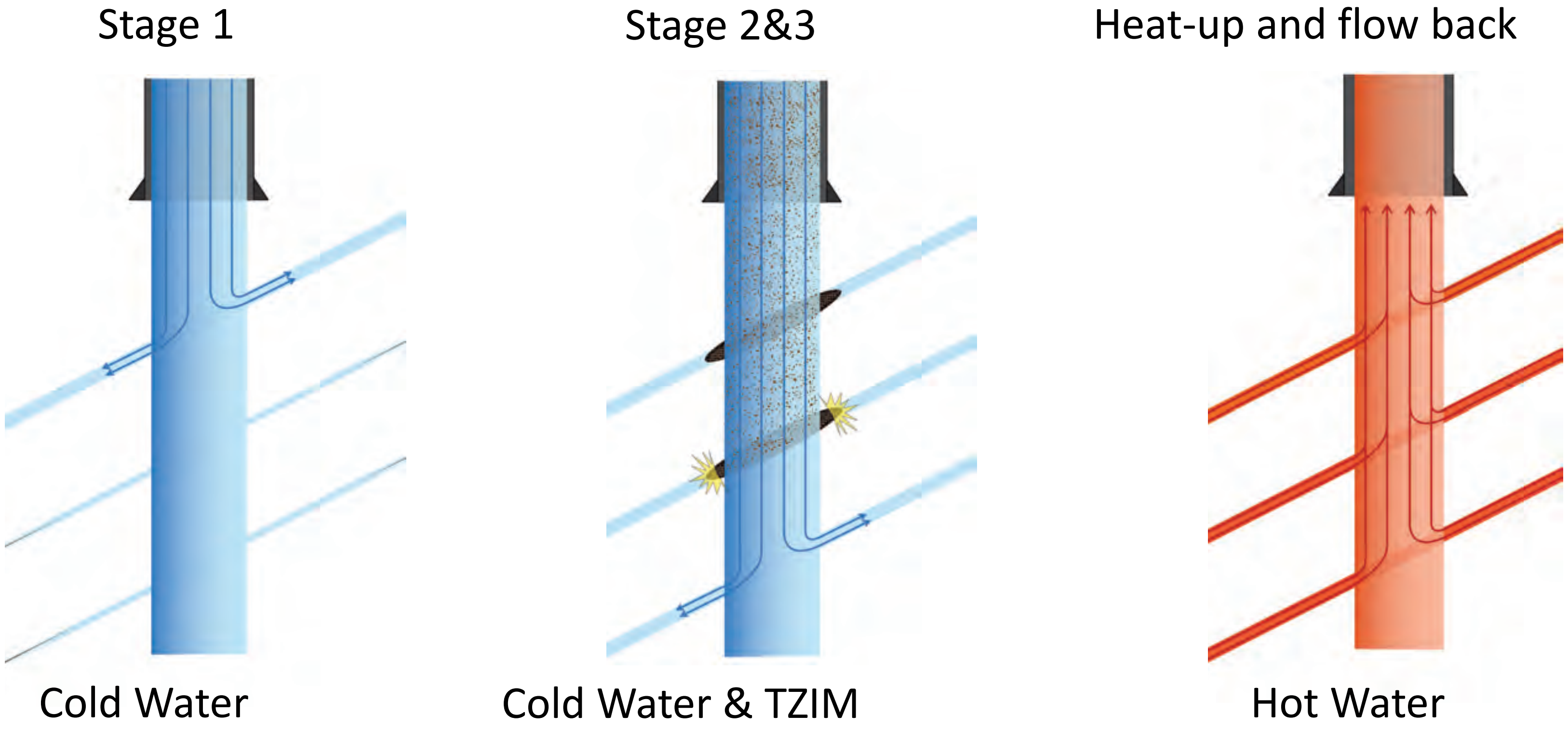
Challenge: Low flow per EGS well Need >75 l/s, >1200 gpm

Solution: Multiple zone stimulation through thermally-degradable zonal isolation materials (TZIM)

- Non-mechanical zonal isolation
- No rig required during treatment
- Non-hazardous breakdown products
- A suite of materials developed that degrade with time and temperature
  - Lab tested from 74°C-315 ° C

Multizone Stimulation and TZIMs



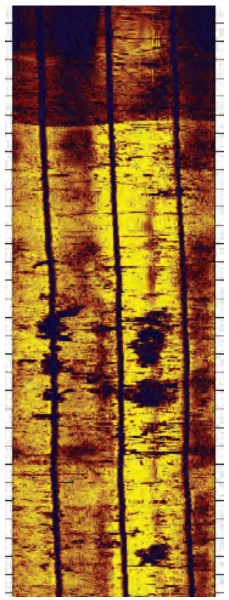


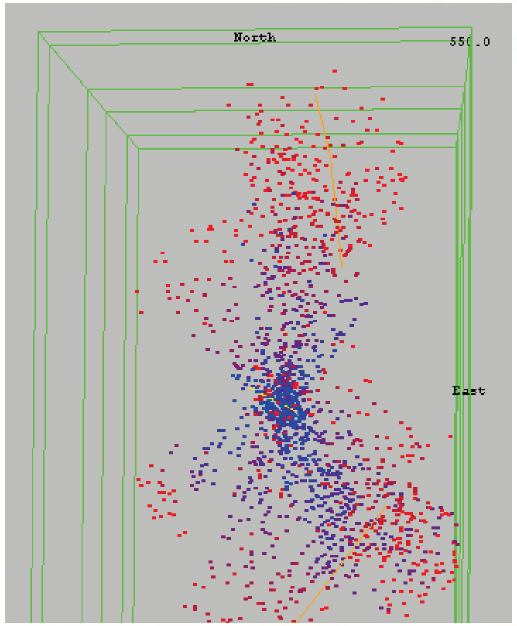
Innovation 2: EGS Characterization tools

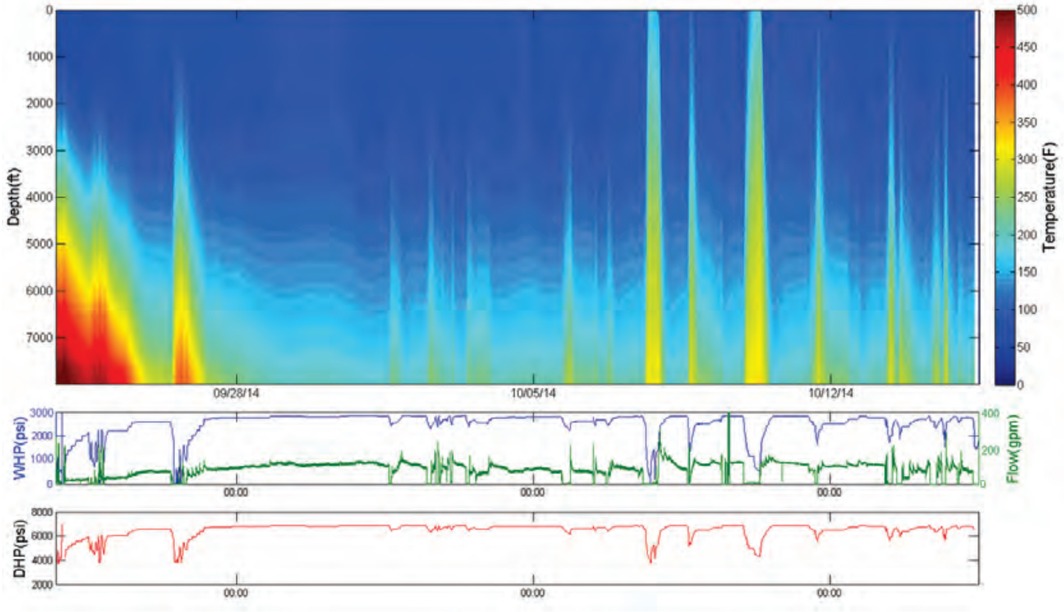
Challenges: Predicting induced seismicity, mitigating seismic risk, and characterizing EGS reservoir

Solutions

- Stress and fracture analysis from BHTV
- Hydroshear model (AltaStim™)
- Induced Seismicity Mitigation Plan to meet 2012 DOE Protocol
- Distributed Temperature Sensing (DTS) system to track zone isolation .







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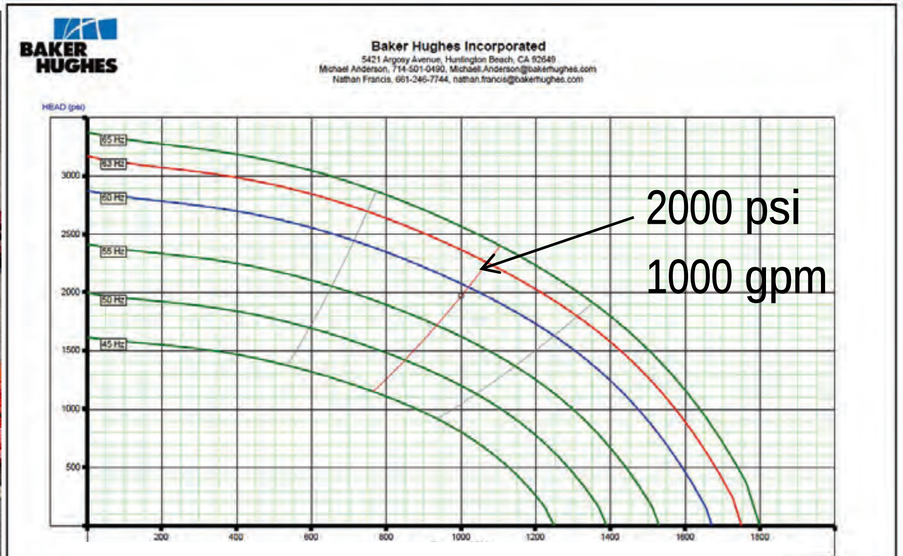
Innovation 3: Stimulation pumps

Challenge: Stimulation pump reliability, suitability, and high rental cost

Solution: Lease-to-own, electric pumps

- Two 14 stage centrifugal pumps connected by 10 inch pipes & four valves
- HP (Newberry) Mode: in series with bypass line to allow sufficient flow to keep pumps cool when injecting to very low permeability wells
- LP Mode: in parallel for ~1000 psi WHP and ~2000 gpm



Pump curves for HP Mode

Economics

Two Scenarios for Improving Geothermal Economics with Stimulation

Infield Stimulation for Improving Existing Projects

- Increase production in existing projects underperforming due to reservoir decline
- Mitigate reservoir cooling from thermal breakthrough by stimulating dry holes
- Increase heat exchange area by creating additional fractures
- Expand projects by stimulating dry holes for production and injection on edges of the field

Stimulation of Dry Holes for Greenfield Development

- Reduce risk associated with exploration and discovery
- Stimulate dry holes to increase drilling success
- Improve output of wells in field through stimulation

Infield Stimulation to Improve Existing Geothermal Projects

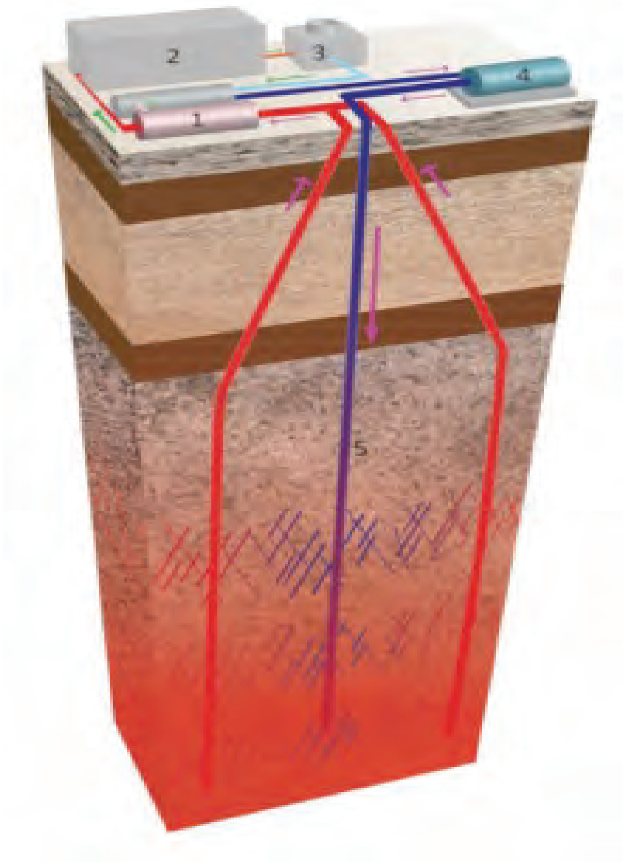
Multizone stimulation reduces dry hole risk, lowers capital costs, and improves production

New Geothermal Well

- **$5-12 million drilling cost**
- Significant exploration risk, with only a 20% success rate for wildcat wells
- Infill and step out wells still have a 50%-72% success rate
- Includes conventional developer risks (permits, PPA, financing, etc.)
- High cost drilling equipment with construction risk
- Renewable power has lower returns than O&G
- Average cost: $2430 / kilowatt*

Stimulation of an Existing Well

- **$0.5-1.5 million stimulation cost**
- Resource is already proven and producing so most developer risks eliminated (permits, PPA, financing, etc.)
- No high cost drilling rigs, risky mechanical equipment
- Renewable energy returns now far *exceed* O&G
- Average cost: $300 – $1000 / kilowatt



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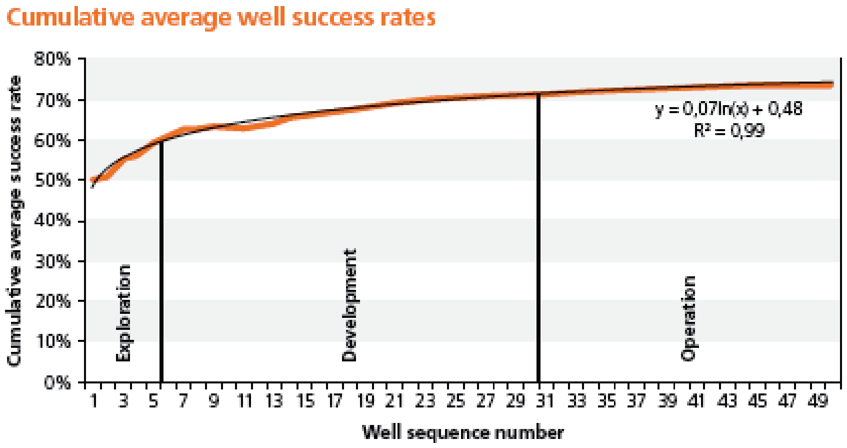
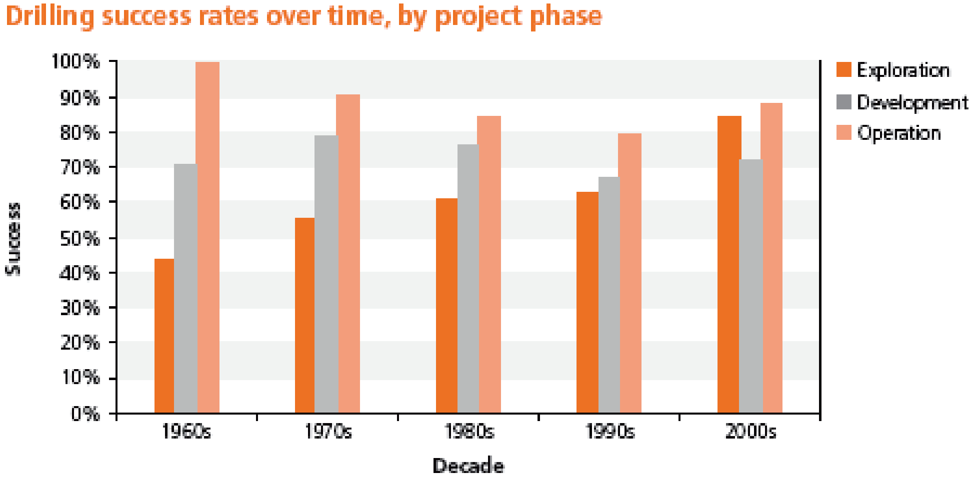
*Source: International Finance Corporation's *Success of Geothermal Wells: A Global Study*

Dry Hole Risk in Geothermal



- Two ways to have a "dry hole": Too low temperature, too low permeability.
- Success improves with stage of development, but not by much.

- Drilling success has improved over time, but not by much.
- We aren't getting much better at exploration.



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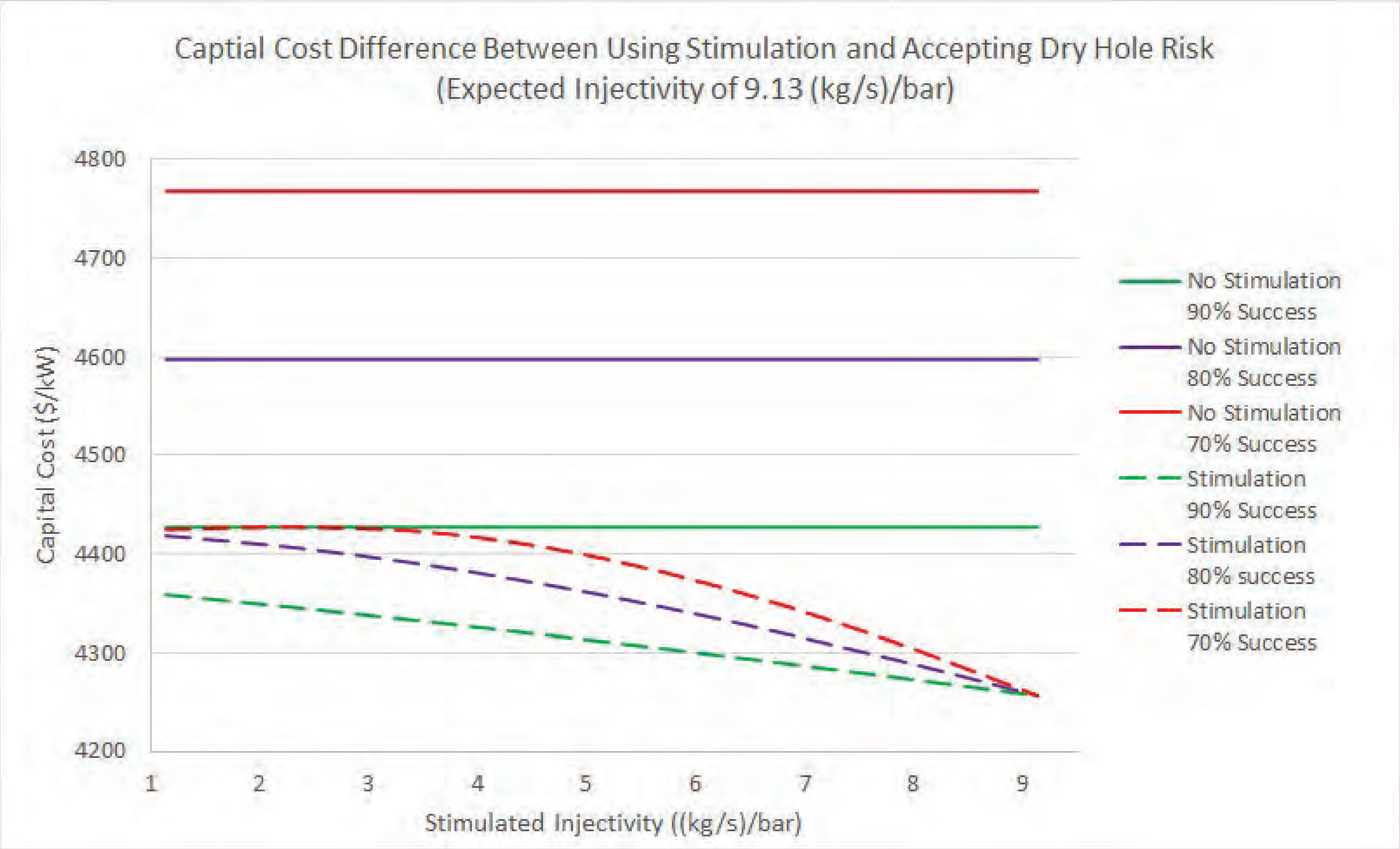
Sensitivity Analysis of the Impact of Stimulation on New Geothermal Development in the Basin and Range

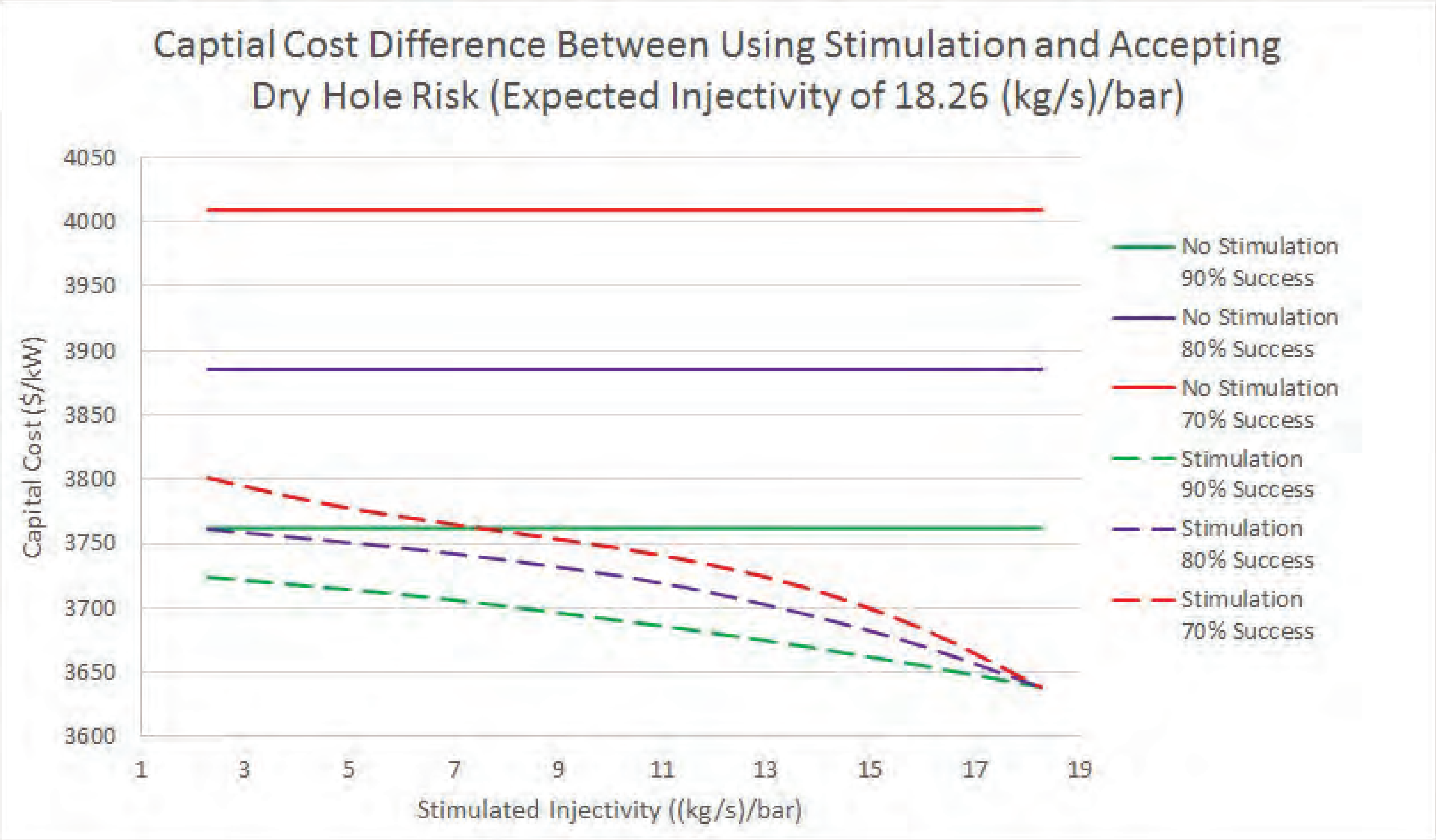
- GETEM model used to compare development with and without stimulation of dry holes
- Assumes Basin and Range development outside currently developed areas
- Temperature gradient is lower than typical commercial geothermal projects (80°C-100°C/km)
- Drilling success is similar to current developments (66% for exploration and 87% for development)
- Permeability is defined by the injectivity, one of the important inputs for GETEM. The expected injectivity for future natural systems will be lower (18 kg/s/bar) than current highly productive systems (36 kg/s/bar
- A range of stimulation outcomes are examined for a range of drilling success rates

Scenario Assumptions	
Temperature of resource is 180 °C	
Geothermal gradient is 64 °C/Km	
Injectivity goes from 0 to 17.5 kg/s/bar	
Productivity is one half of injectivity	
Thermal decline rate is .5%	
Drilling 10 production wells	
Size of plant will be optimized to pumping conditions	
Stimulated injectivty will be modeled at an increase of 25%, 50%, 75% of expected injectivity	

Cost Comparison for Basin and Range Project With and Without Stimulation: Low Initial Productivity/Injectivity



Cost Comparison for Basin and Range Project With and Without Stimulation: Moderate Initial Productivity/Injectivity



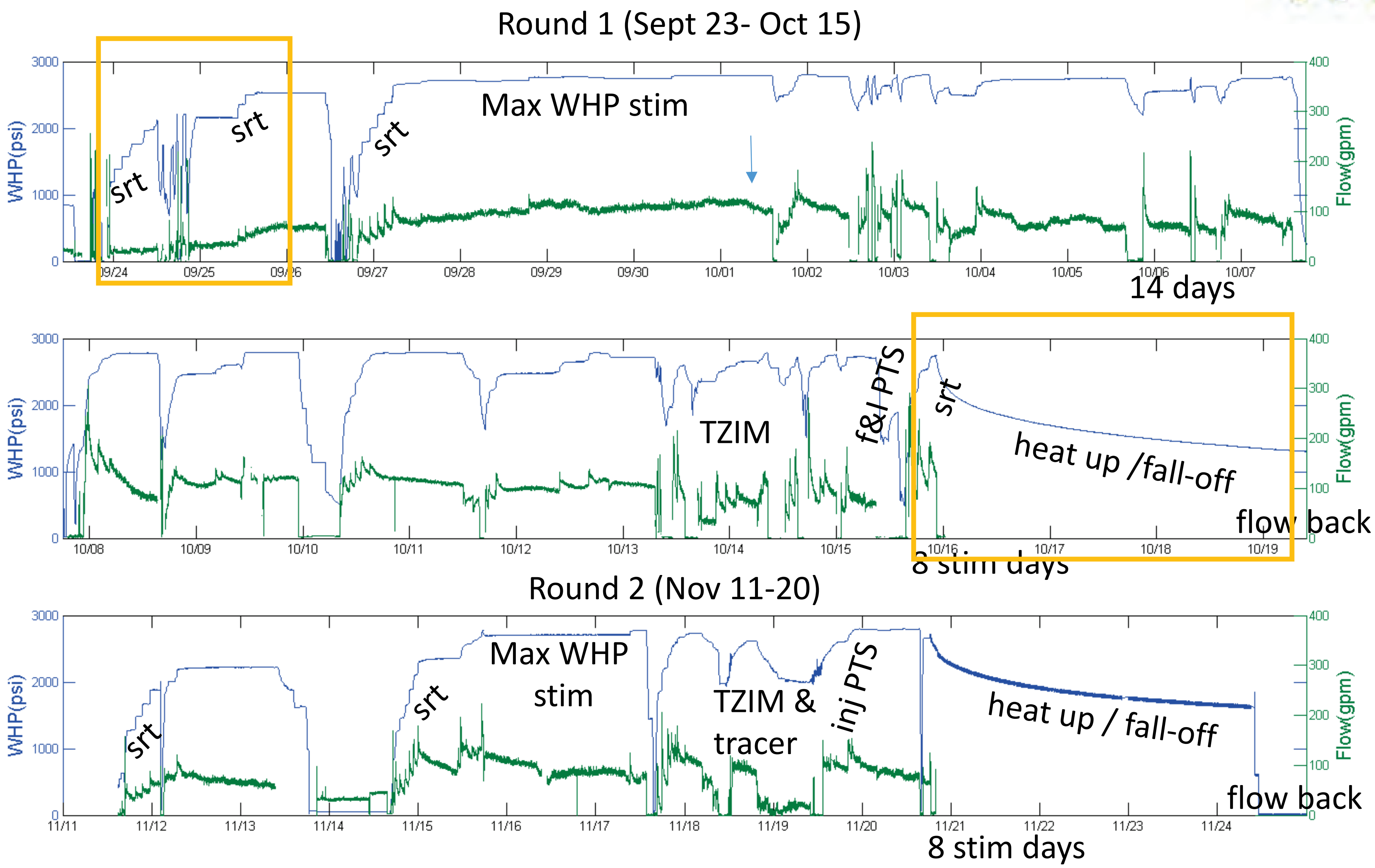
Multizone Stimulation Improves Economics of Geothermal Projects

- Stimulation can improve economics by offsetting lower drilling success rates in future geothermal projects
- Economics of stimulation are valid over a range of injectivity values.
- Infield stimulation may also be a way to mitigate reservoir pressure and thermal decline

Field Testing

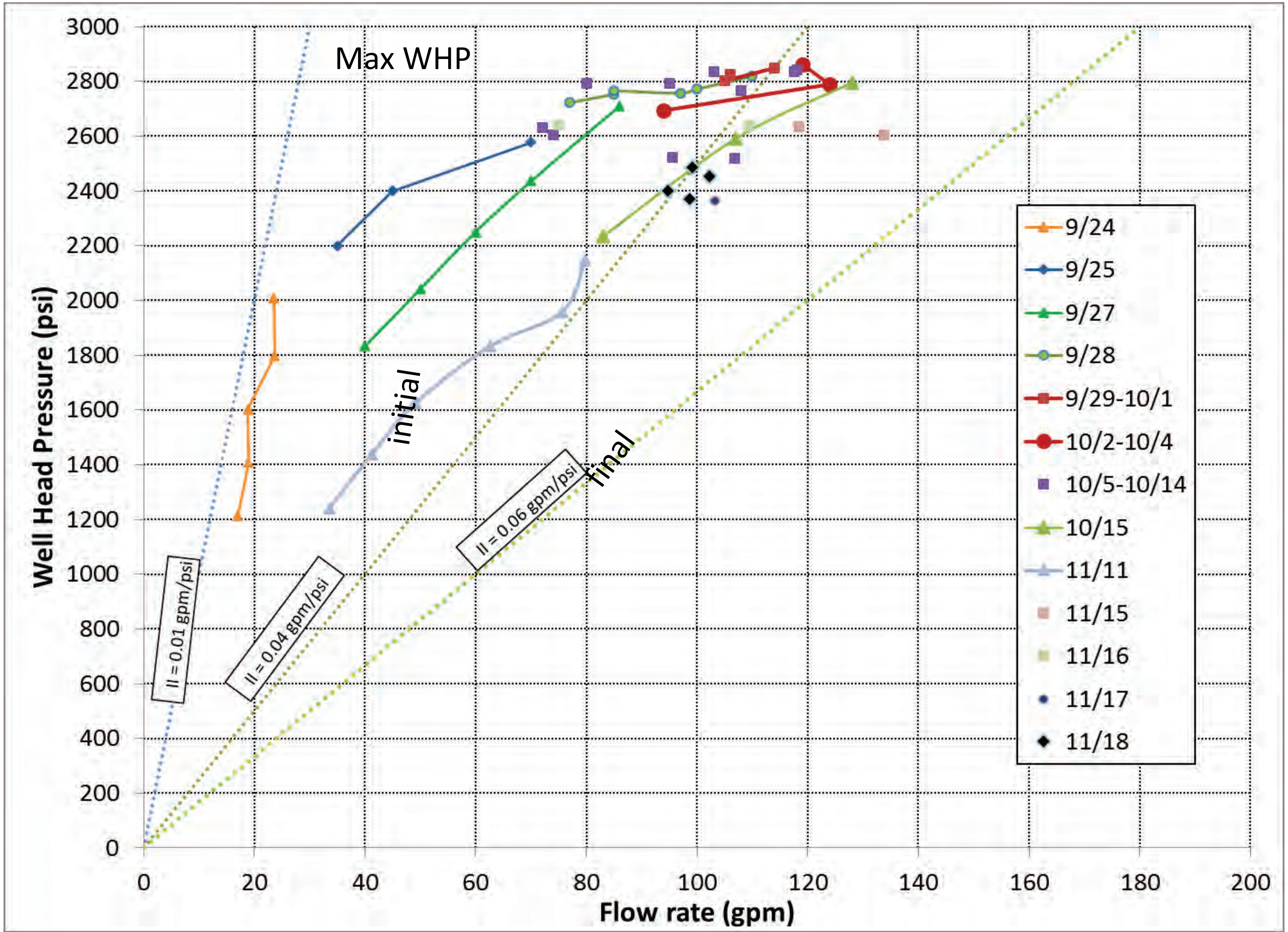
2015 Stimulation Summary

Wellhead pressure and flow rate during stimulation

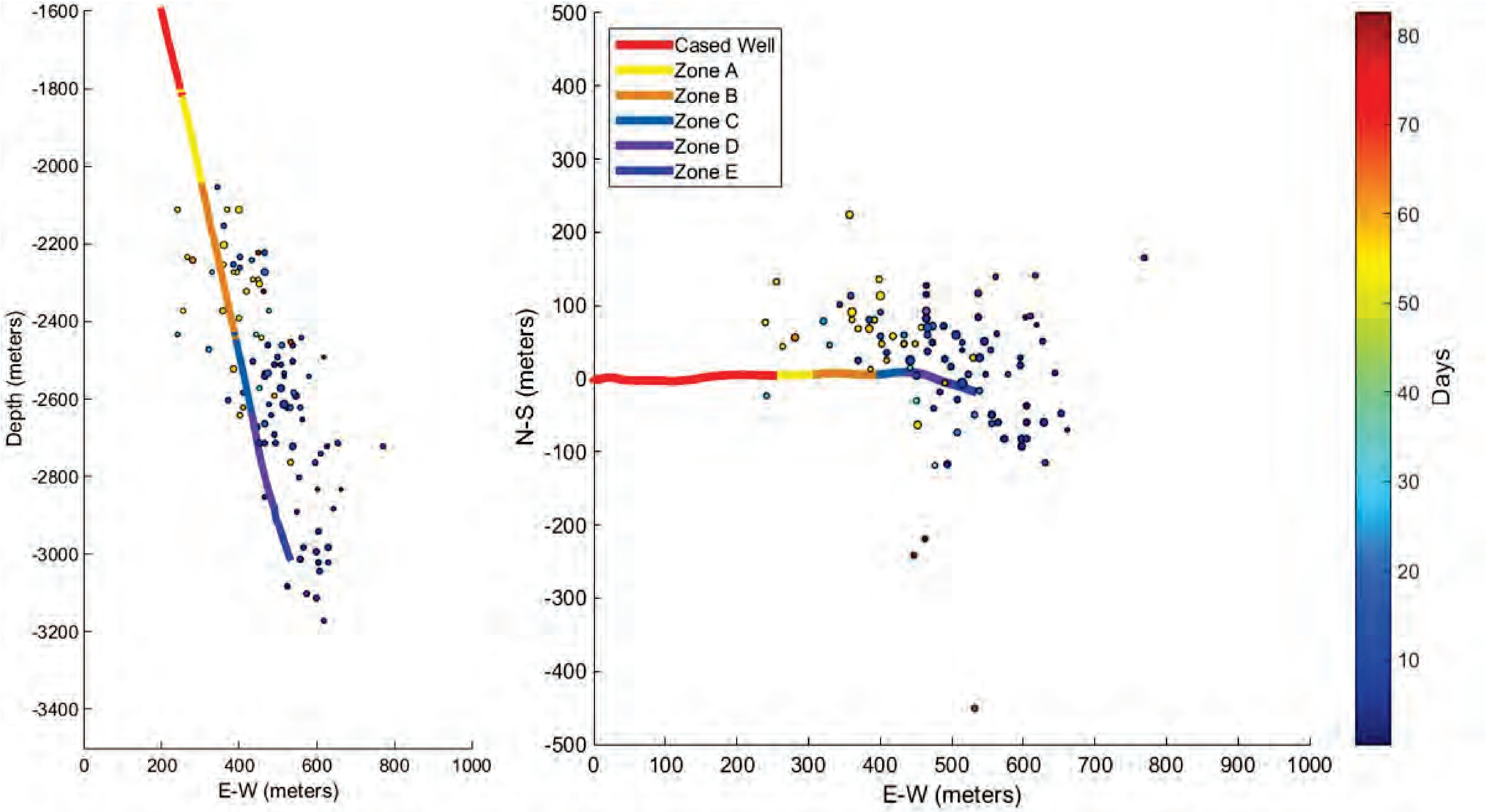


srt = step-rate test

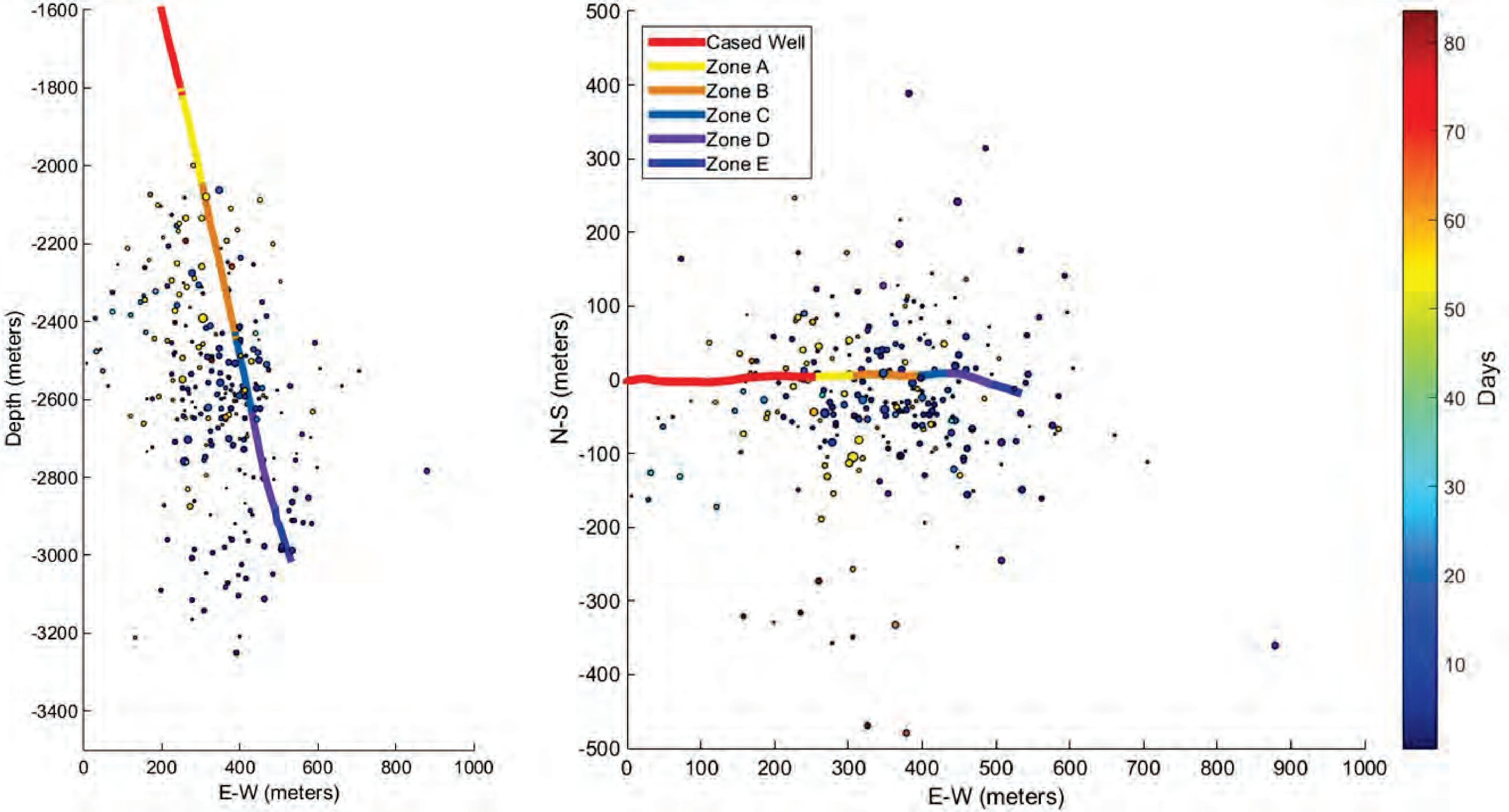
Injectivity Index



Gillian Foulger Moment Tensor Locations



LBNL Re-locations

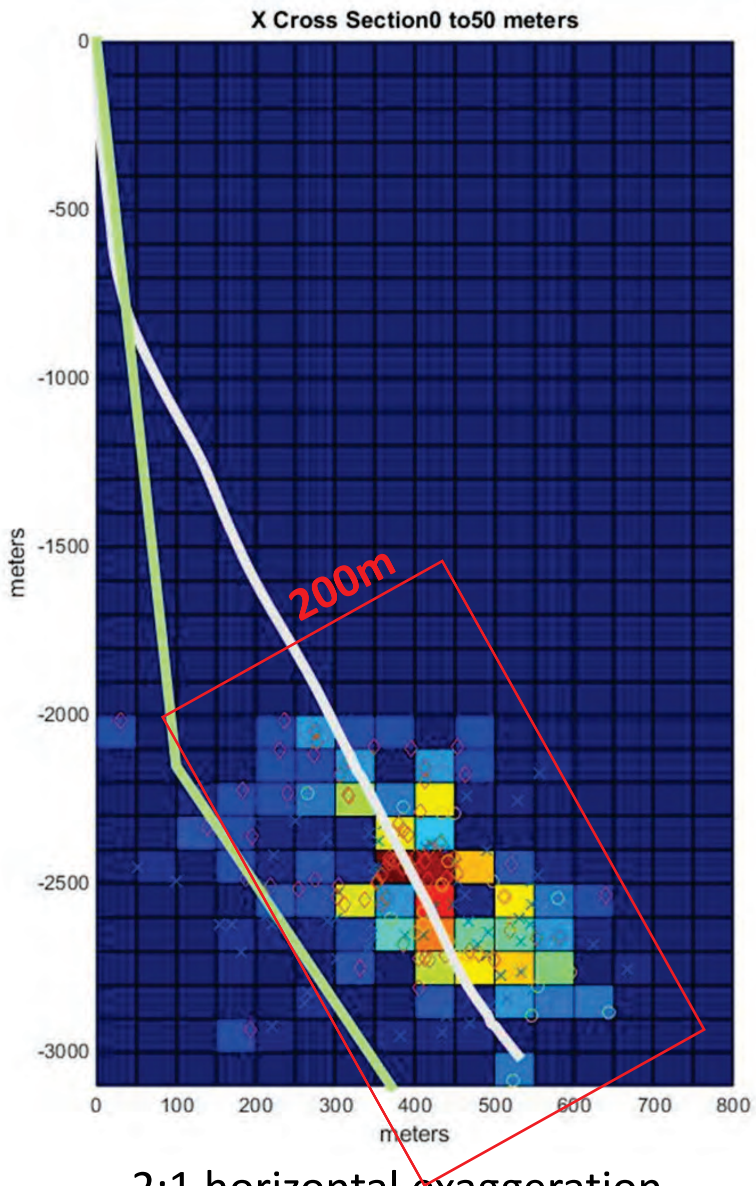


List of event catalogs and their relative weights

Catalog	Number of Events	Weight
ISTI Original Locations	400	10%
LBNL Hand-picked Locations	362	20%
LBNL Relative Relocations	278	30%
Foulger MT Locations	99	40%

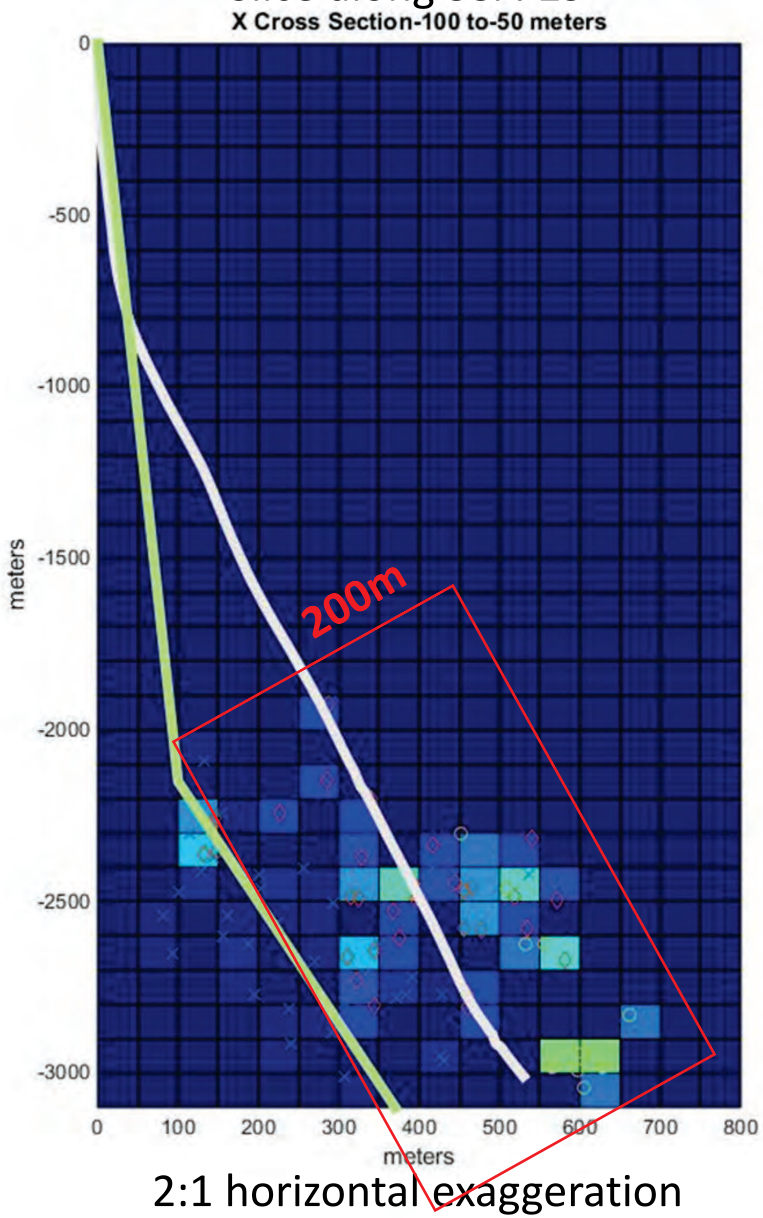
EW Cross-section

Slice along 55-29



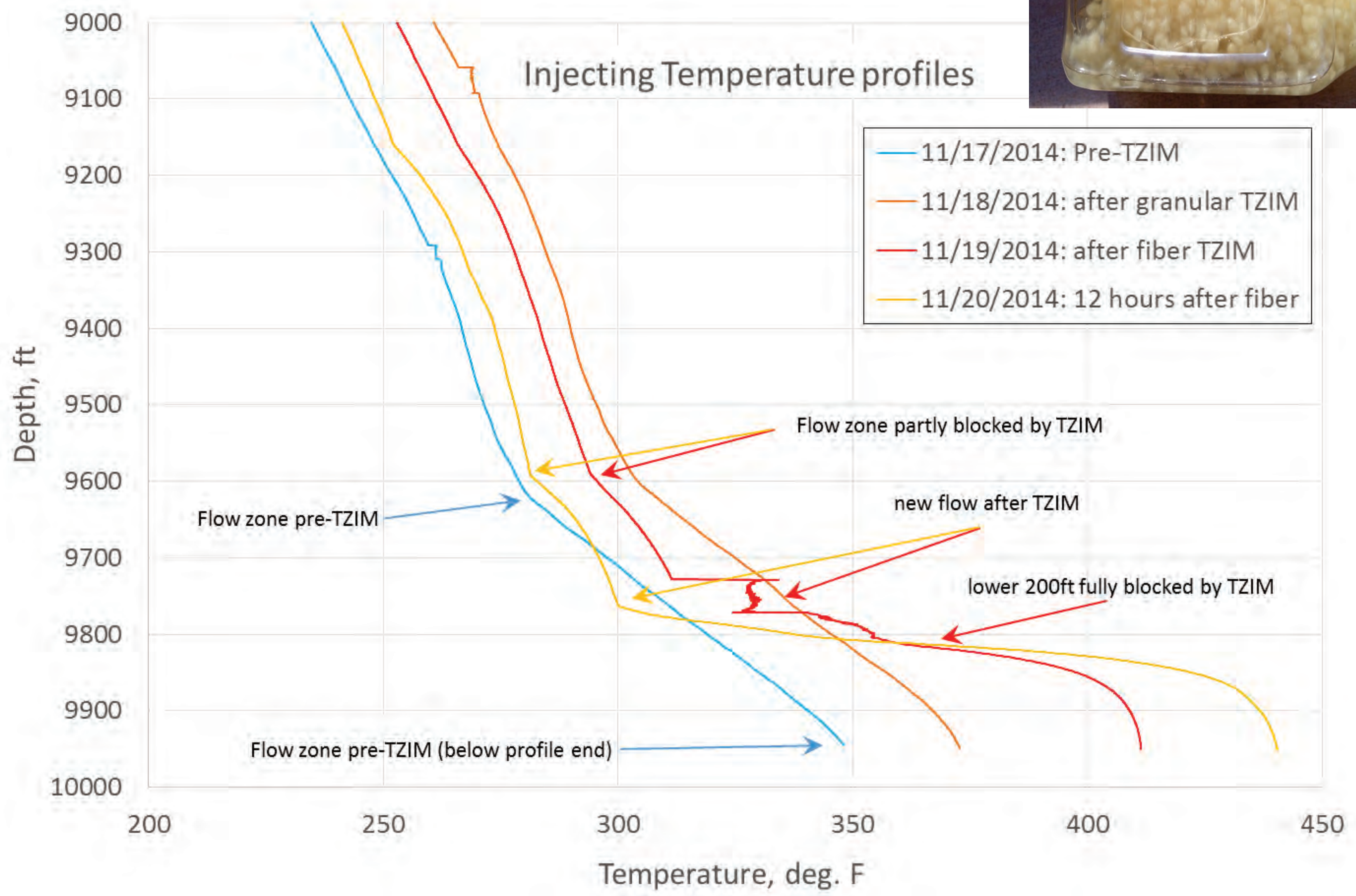
2:1 horizontal exaggeration

Slice along 55A-29

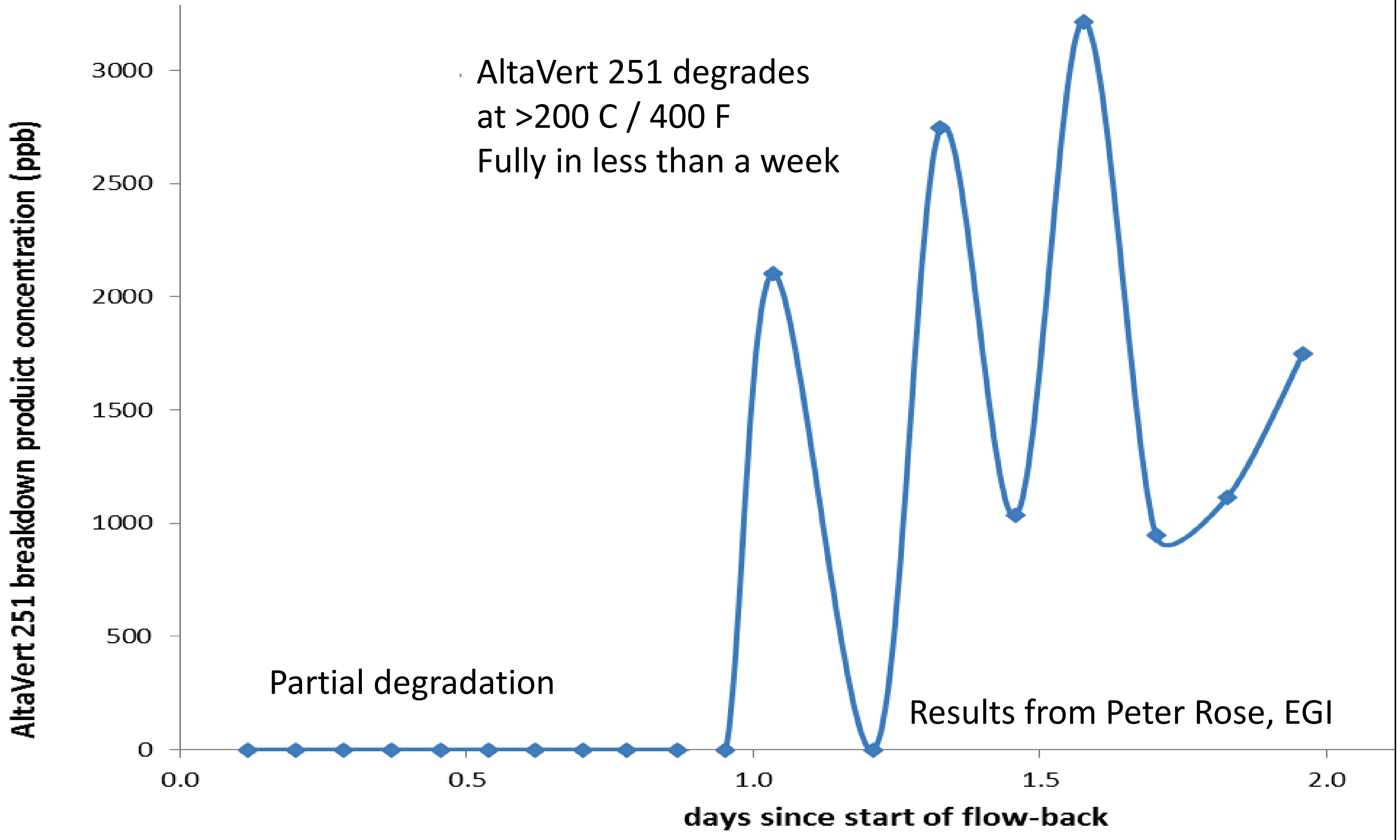


2:1 horizontal exaggeration

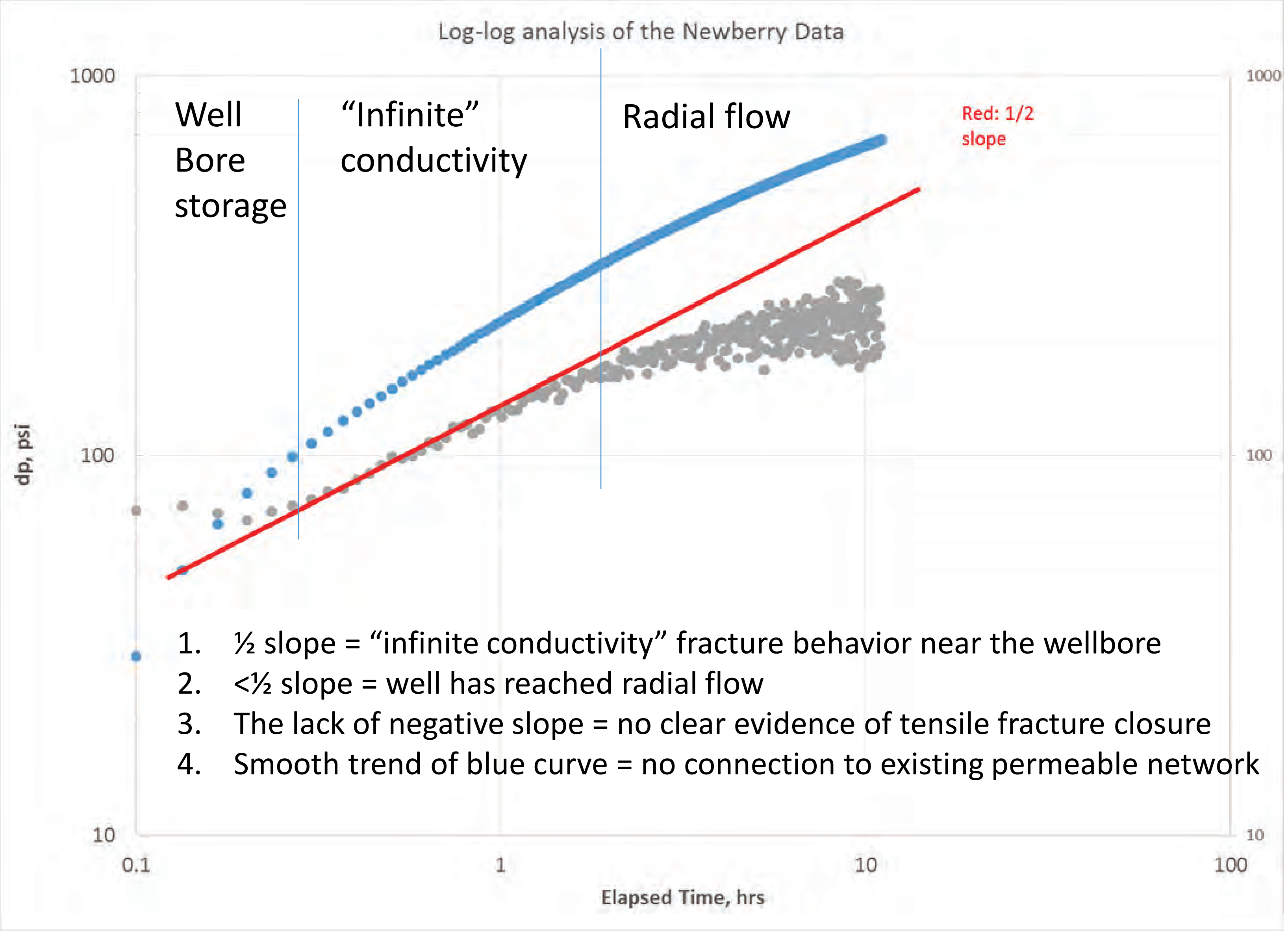
Evidence for TZIM Blocking



Nov. 24-25 flowback: TZIM degradation product



Derivative Analysis of Pressure fall-off



1. ½ slope = "infinite conductivity" fracture behavior near the wellbore
2. <½ slope = well has reached radial flow
3. The lack of negative slope = no clear evidence of tensile fracture closure
4. Smooth trend of blue curve = no connection to existing permeable network

Conclusion

- There is a clear pathway forward for reducing cost using stimulation in existing geothermal fields
- Technology has been proven in EGS Greenfield Demonstration project at Newberry
- Reservoir enhancement techniques potentially applicable to oil and gas wells