Multiple Zone Stimulation of EGS Wells – Key to Reservoir Optimization

Geothermal Energy Utilization Associated with Oil and Gas Development

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Outline

- Introduction ð Geothermal & EGS Power
- EGS Lessons Learned
- Current Stimulation Technology
- Reservoir Optimization
- Temporary Diverters
  - Benefits
  - Design
  - Application
- GETEM Modeling Results
- Description of Operations
- Outcome & Conclusions


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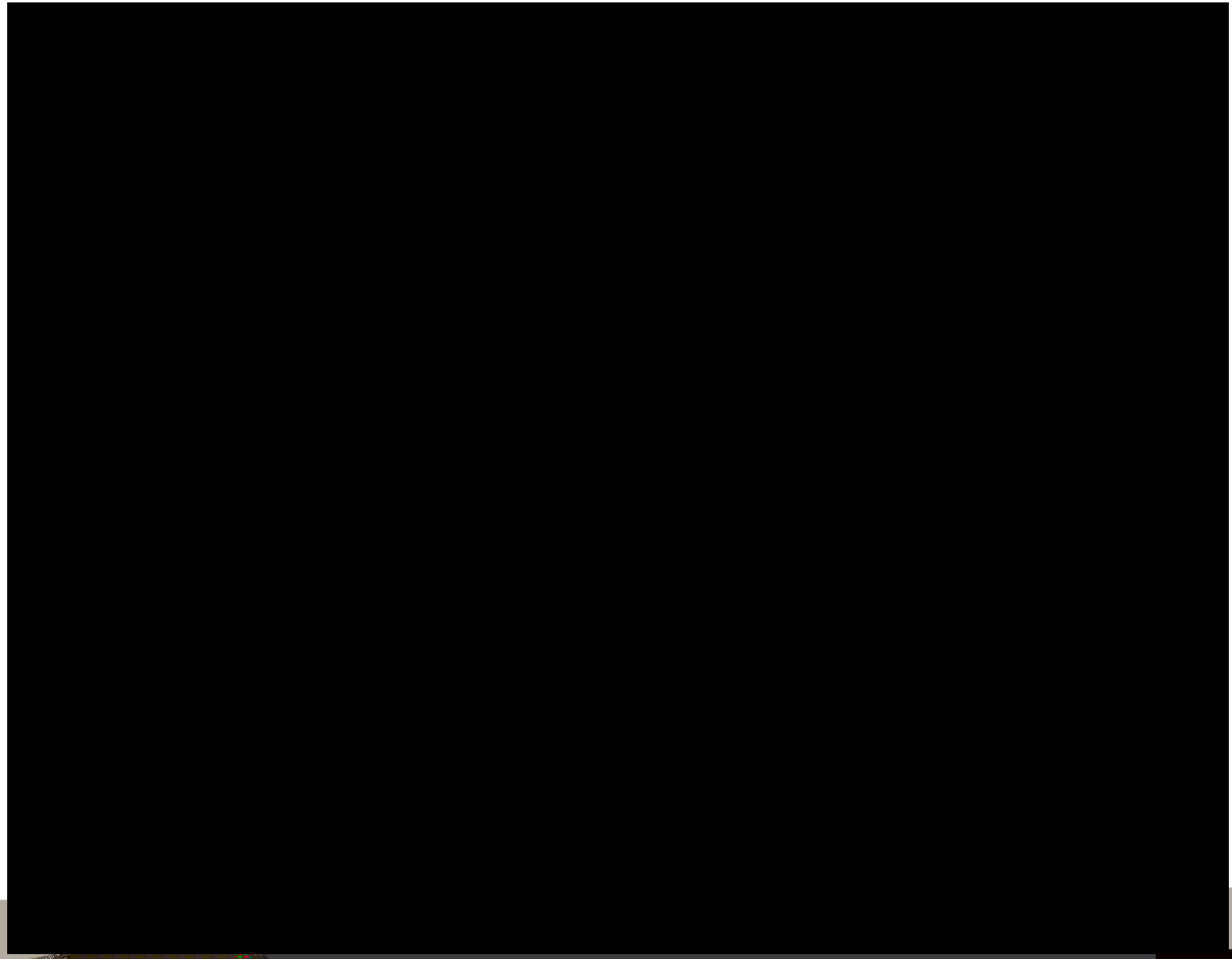
Heat Stored in Rock



Worldwide EGS Lessons Learned

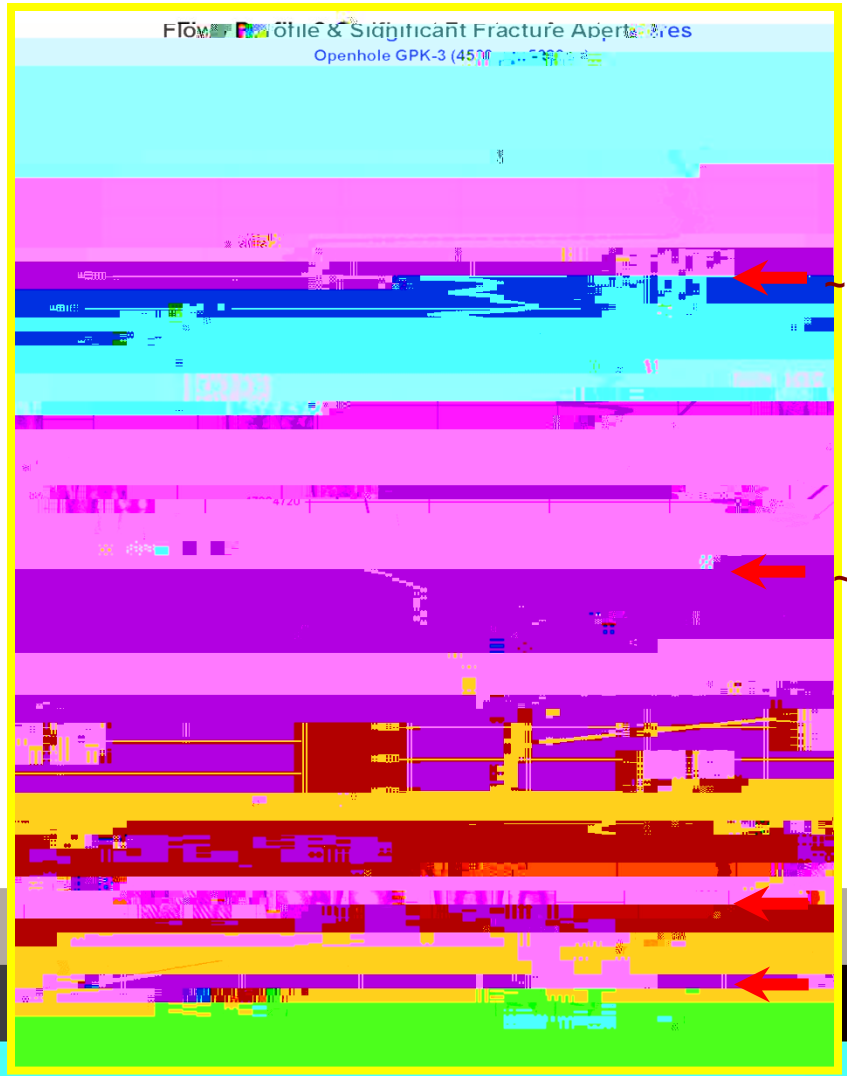
Project	Timeline	Deformation Mode on Fractures	Thermal Output (MWe equiv)	Problems encountered
Fenton Hill				

Worldwide EGS Lessons Learned

- First well needs to be drilled and stimulated in order to design the entire system
- Stimulation is through shearing of pre-existing fractures instead of creating new tensile fractures
- High flow rates with long path length are needed
- Need technology for multiple zone stimulation
  - We currently do not have reliable open-hole packer for zonal isolation

Current Stimulation Technology

- Inject fluid from the surface
- Most permeable zone in well takes fluid and is stimulated
- Remaining zones only take limited amounts of fluid.
- Increasing flow by increasing injection pressure risks induced seismicity



Reservoir Optimization

Single Fracture Network

Limitations of Single Fracture

- Flow through a single stimulated fracture network provides minimial heat exchange area
- Flow rates are then limited by the maximum injection pressure which will extend fractures
  - Increase the rate of cooling at the production well
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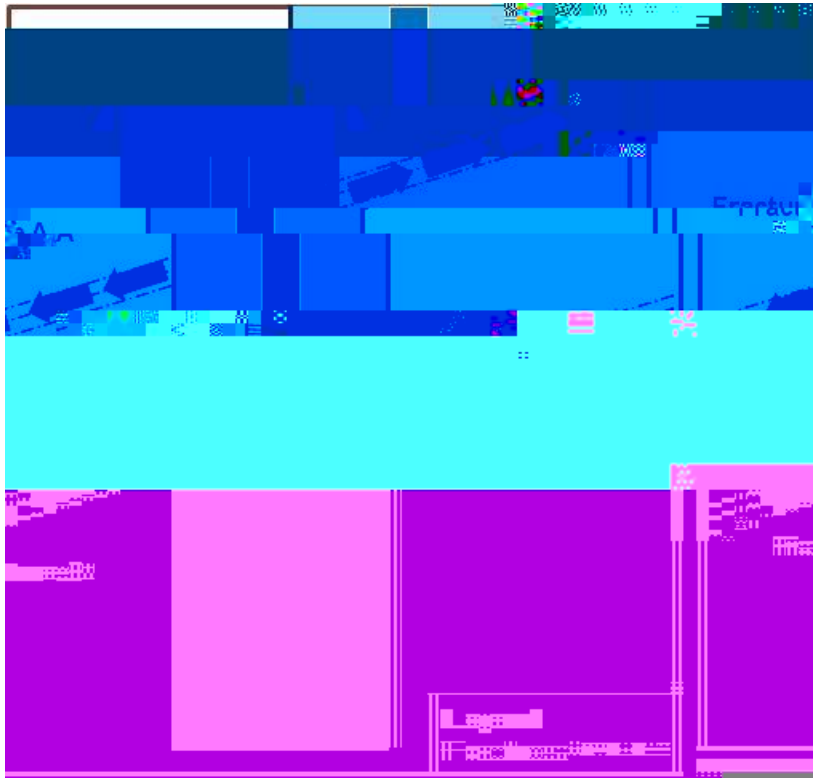
Reservoir Optimization

Benefits of Multiple Fractures

- Multiple fractures allow for flow through two or more fracture networks
- More rock heat exchange area is contacted
- Pressure drop through system is reduced allowing higher flow rates
- Additional flow will allow for greater production on a per well basis

Multiple Fracture Network



GETEM Modeling Results

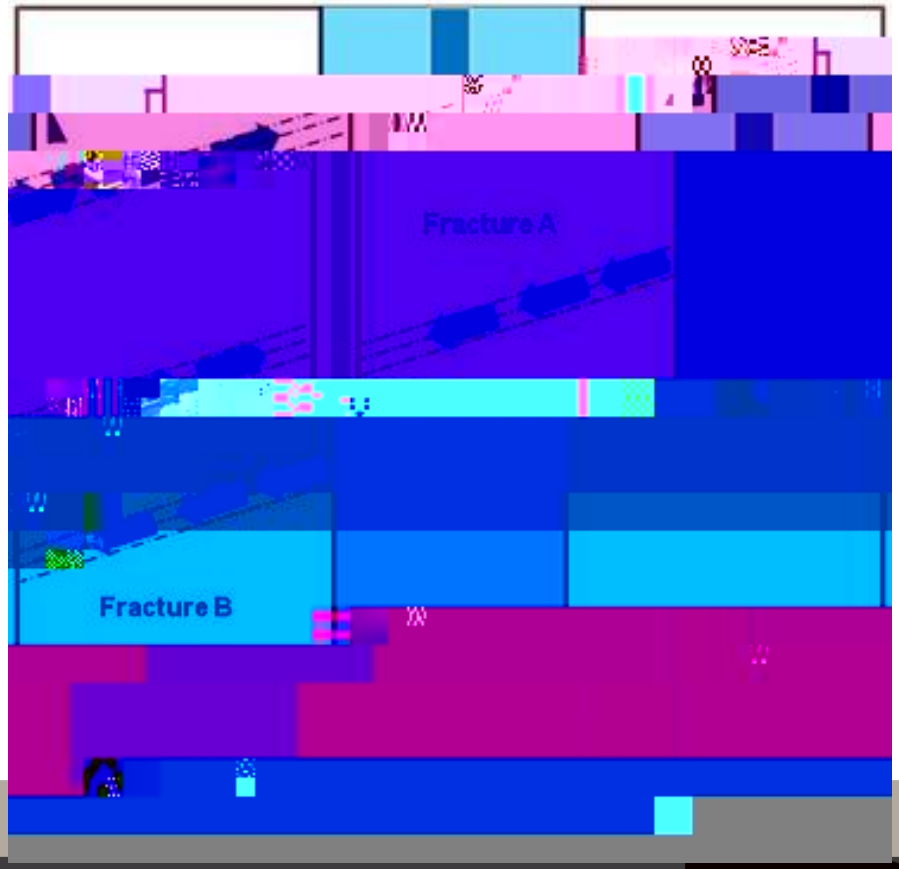
- Inputs
  - 30 kg/sec base flow
  - 4 km depth well
- Results
  - Flash system had 40% reduction in power cost
  - Binary system had 50% reduction in power cost

Flash/Binary	Temperature (° C)	Improvement	Cost of Power 2010 (cent/kw)

Temporary Diverters

Diverter Sealing Zone

Degraded Diverter



AltaRock Proprietary Temporary Diverters

Design

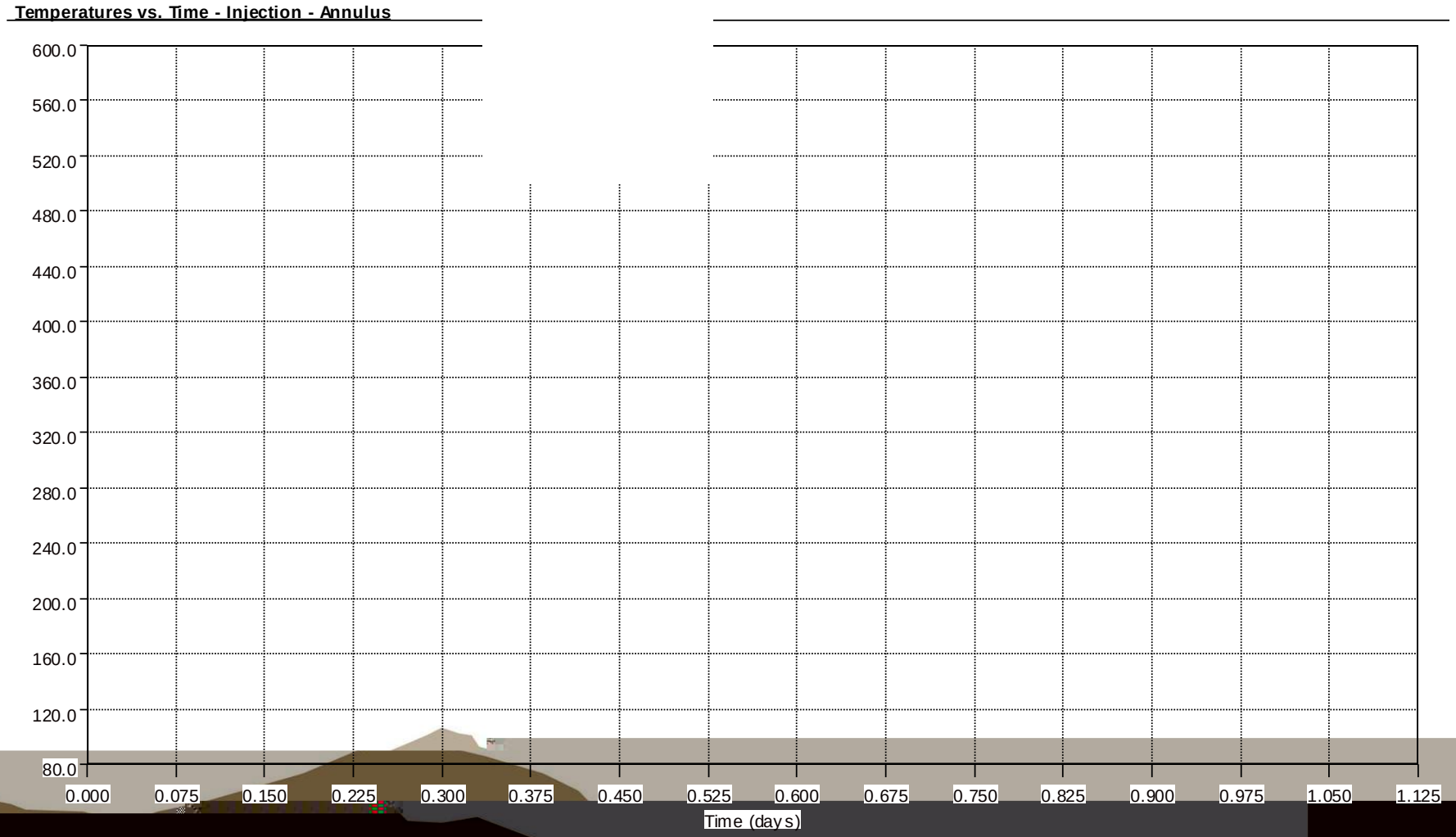
- Particle size distribution of material that will allow for packing and sealing of fracture
- Remain in place and withstand differential pressure during 2nd stimulation
- Degrade to non-damaging products after stimulation as well heats back up
- Require instruments in hole during treatment to monitor and verify that diversion has occurred

Benefits

- Increased production reduces cost of power production
- No Rig required during treatment
  - Major cost Savings
  - Reduce Operational risk
  - Create fractures in succession without moving packer and waiting on rig
- Can be used even when slotted liner is in place
  - Cannot use mechanical isolation like packers in well with slotted liner

Temperature Modeling

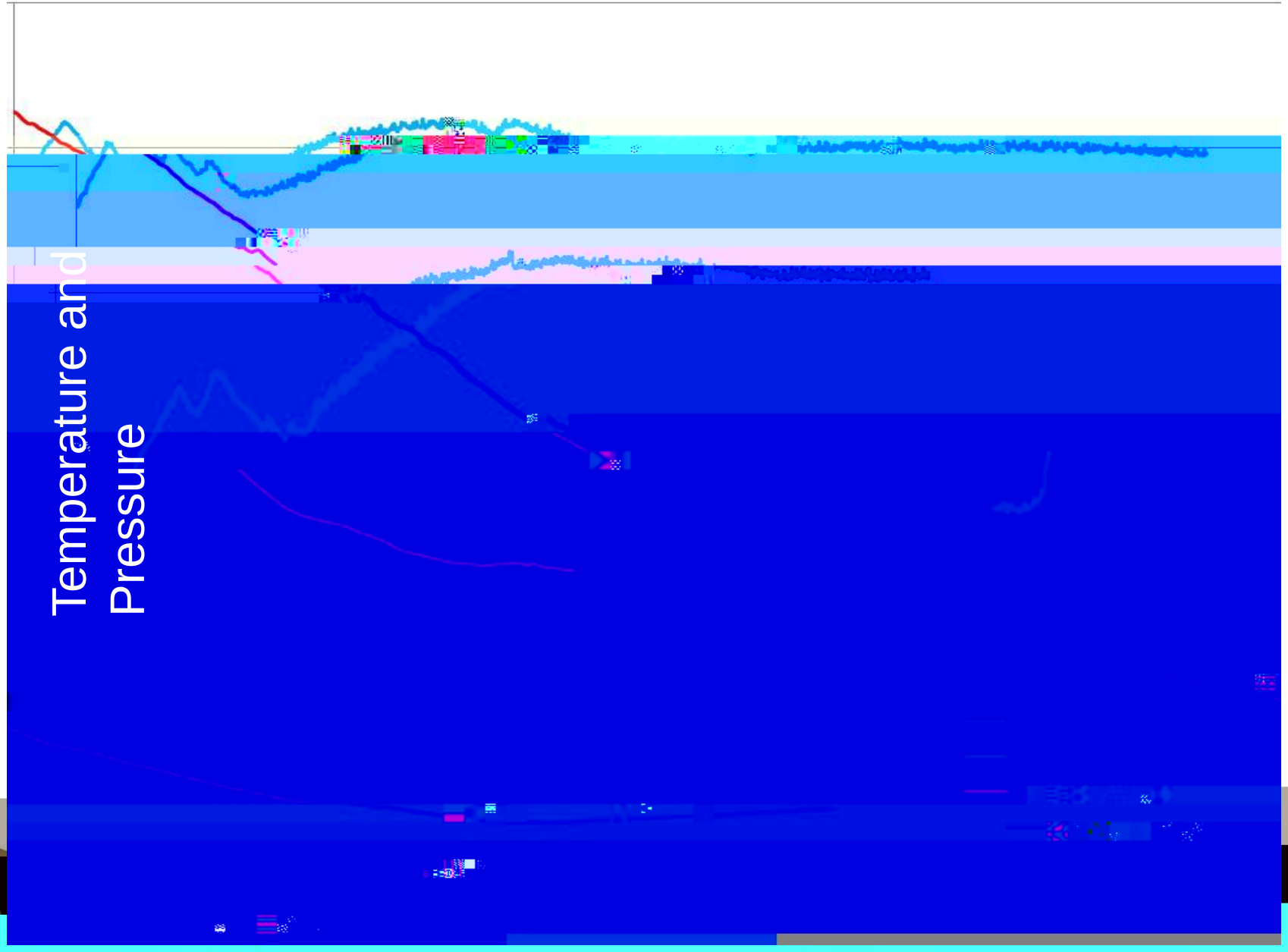
Thermal Cooling from Injection ð 10 bpm



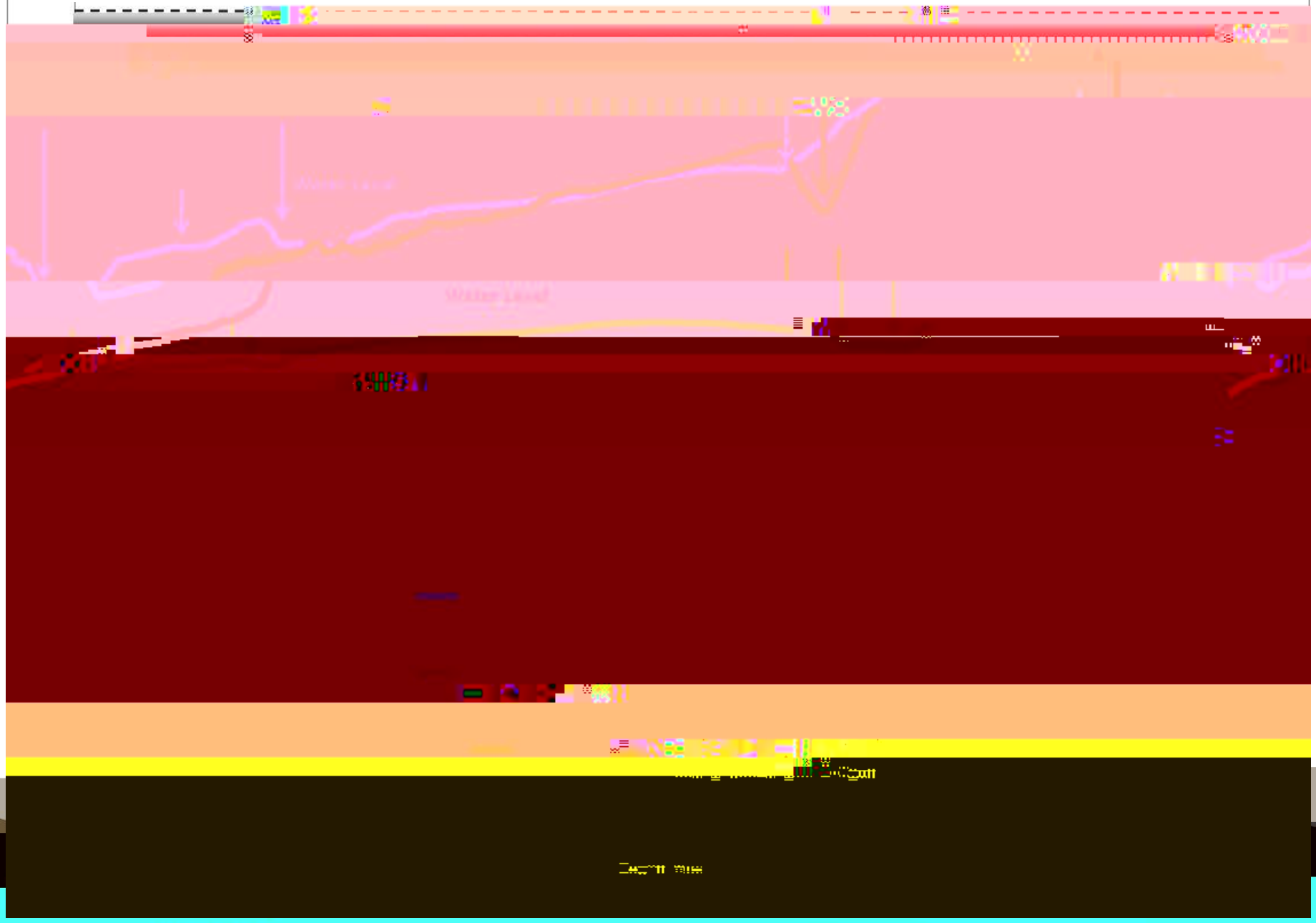
Diverter Test No.1

- Injected water into well prior to the diverter test
- Multiple rates of 150, 300, and 500 gpm
- Measured temperature at bottom of hole

Diverter Test No.1 T & P vs. Time Monitomtted@504



Diverter Test Temperature vs. Depth Monitoring



Injection Pressure Comparison

Outcomes & Conclusions ð Test No.1

- The first field trial of AltaRock Proprietary Diverter successful
- Highly permeable fractures temporarily sealed
- The presence of a slotted liner with ı ó slots did not pose a problem
- Injection profile in well could be modified temporarily
- Fluid could be pushed deeper into the wellbore
- Finally, transmissivity calculations (kh) before and after the test imply full degradation of the diverter material ð value held steady at 55,000 md-ft.

Tracer Test Results ð Test No.2

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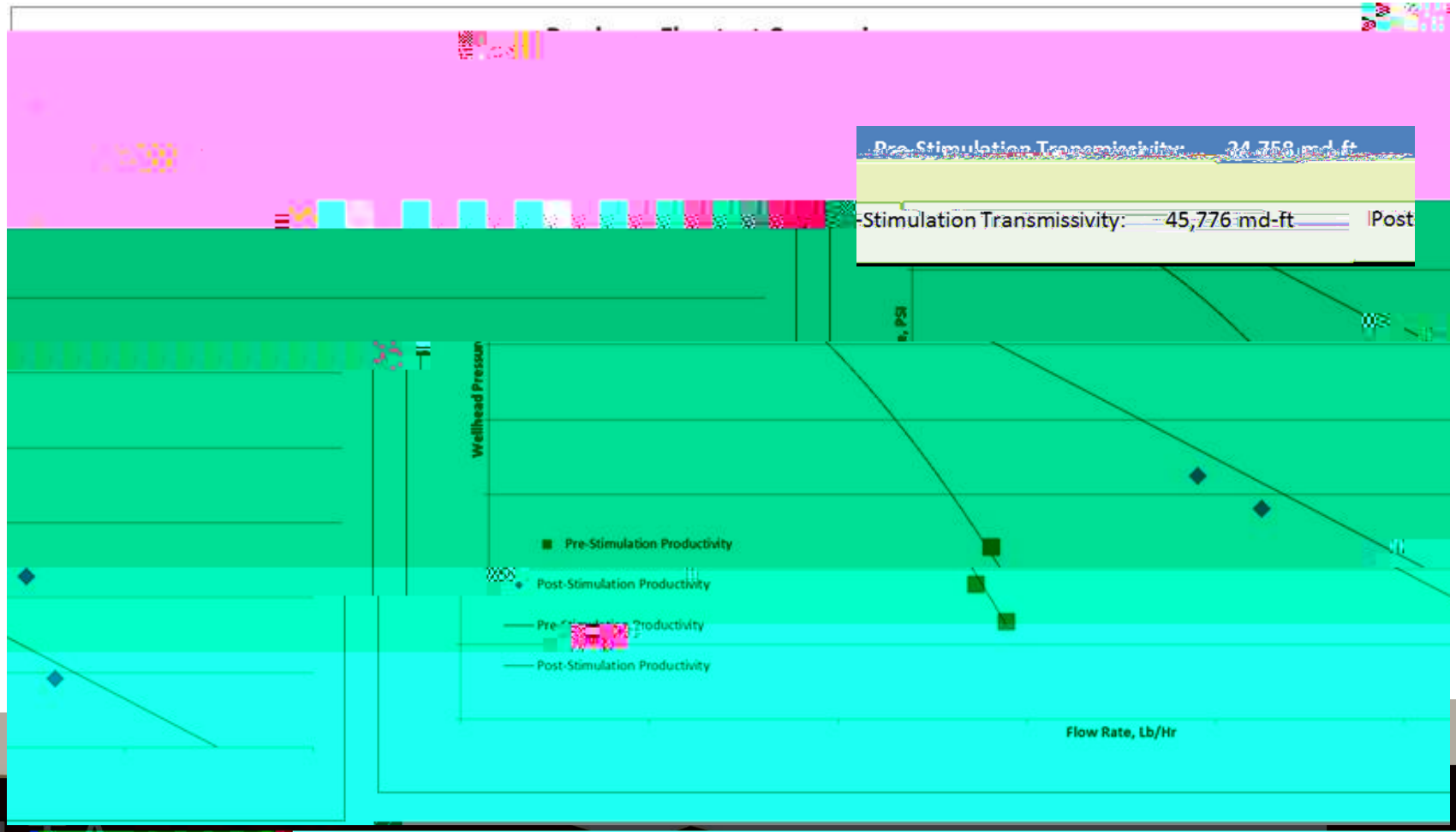
Flow Test Results - Test No.2



Outcomes & Conclusions ð Test No.2

- Successful diversion and stimulation (tracer tests)
- Improved long term production
- Improved permeability due to stimulation (Transmissivity)
- Enhanced production from deeper interval

Conclusions

- AltaRock Proprietary Chemical Diverters have potential to greatly reduce the cost of EGS power and to enhance production of hydrothermal production wells
  - Increase power production on a per well basis
  - GETEM modeling indicates up to 50% or more reduction in power costs
- Field tests provide support of concept of using chemical diverters to temporarily divert flow in actual wells
  - Even with slotted liners already in place

Questions?