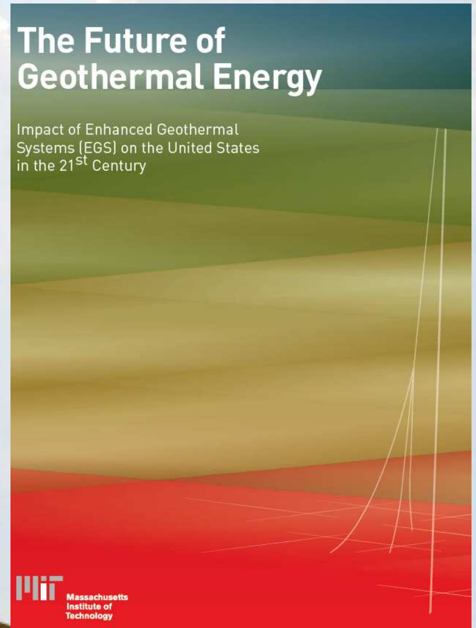
Mitigating Risk Through EGS Technology

Newberry EGS
Enhanced Geothermal Systems
DEMONSTRATION

APEC Geothermal Conference
June 2013

Susan Petty
AltaRock Energy



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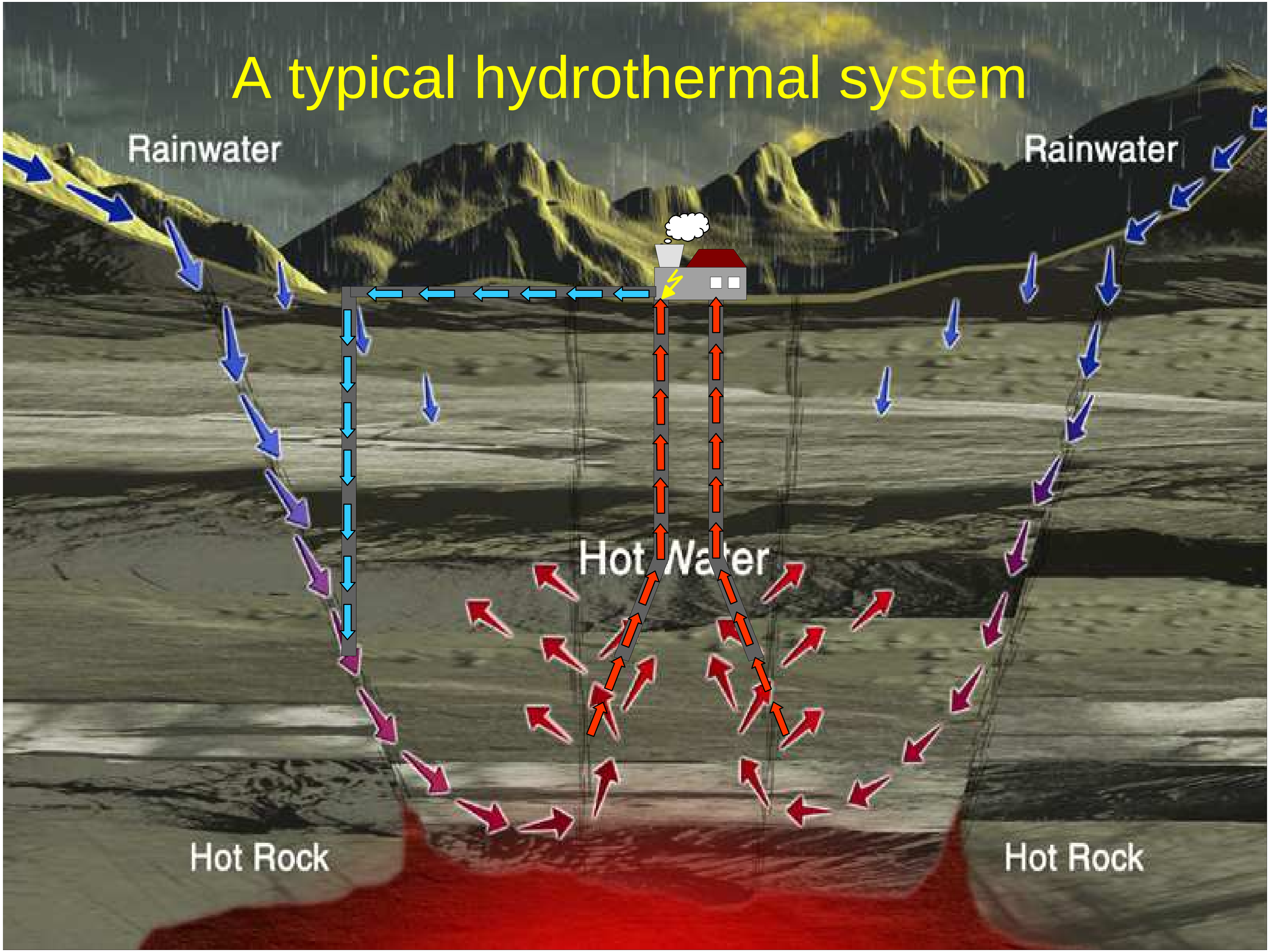
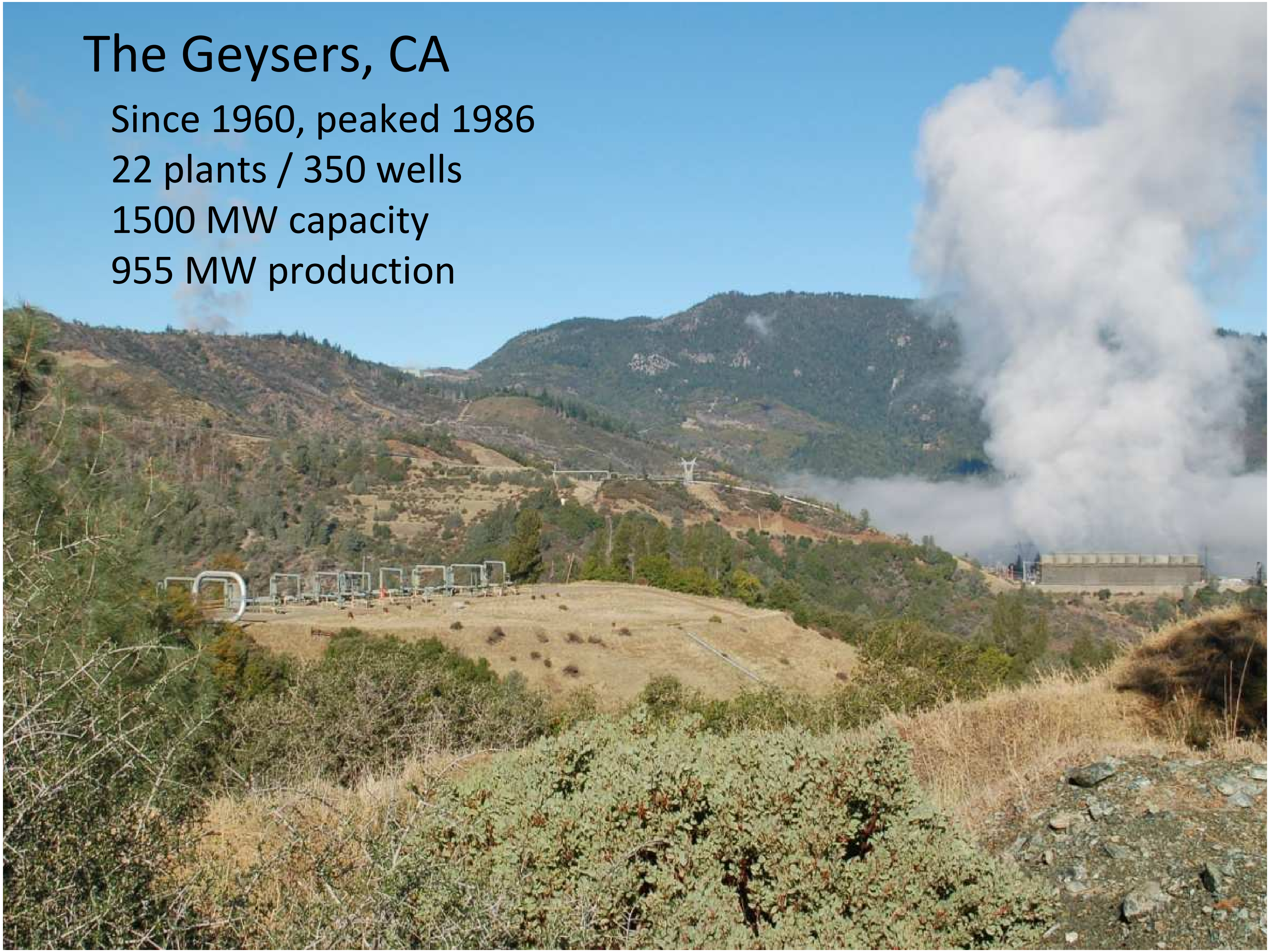
A typical hydrothermal system



The Geysers, CA

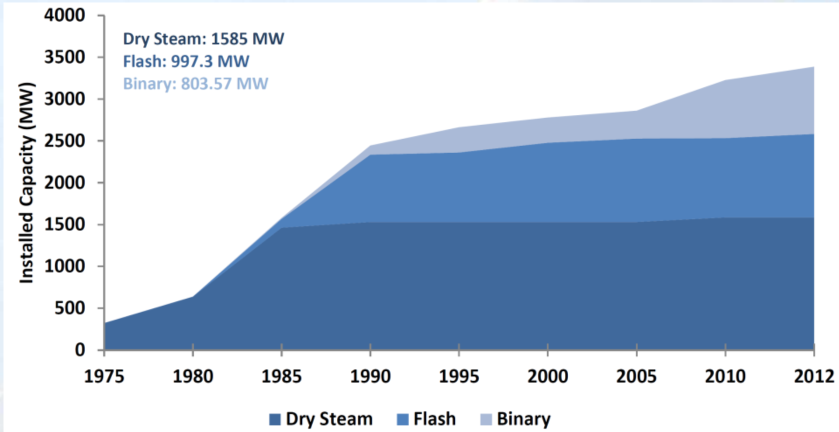
Since 1960, peaked 1986
22 plants / 350 wells
1500 MW capacity
955 MW production



Geothermal Energy: The Baseload Renewable

- Geothermal energy
  - Baseload energy from a renewable resource
  - Large-scale plants have been producing commercial power in the U.S. since the 1960s
- How do we do it?
  - Explore for hot water
  - Need very high permeability
  - Drill producers to get hot water or steam
  - Inject water back into the reservoir to access heat
- Current geothermal capacity
  - World wide >11,000 MW capacity installed
  - US geothermal power capacity is ~3,386 megawatts (“MW”) (0.33% of total U.S. installed operating energy capacity)
  - 175 of known geothermal projects under development, representing ~5,350 MW

U.S. Geothermal Installed Capacity (MW)



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Source: Geothermal Energy Association’s 2013 Annual U.S. Geothermal Power Production and Development Report

Geothermal Potential

Over 3300 MW installed generating ~2400 MW worth of energy. Why?

- Geothermal energy production is based on exploration:
  - Technology was not in place to adequately reduce the exploration and production ("E&P") risk
  - Exploration success the same now as 20 years ago
  - Technology improvements from oil and gas don't translate to geothermal. We are exploring for something different
- Can we translate the oil and gas boom to geothermal?
  - Oil and gas production has been boosted by advances in fracturing technology
  - Multistage fracturing combined with horizontal drilling has accessed the huge untapped resource in tight sediments and shales.
  - Can this technology to be transferred to geothermal?
- Geothermal stimulation history
  - Oil and gas style hydraulic fracturing tried in the 1970s to 2000.
  - Single open fractures with proppants don't create a good heat exchanger
  - Mechanical zone isolation devices don't work in open hole/slotted liner high temperature wells

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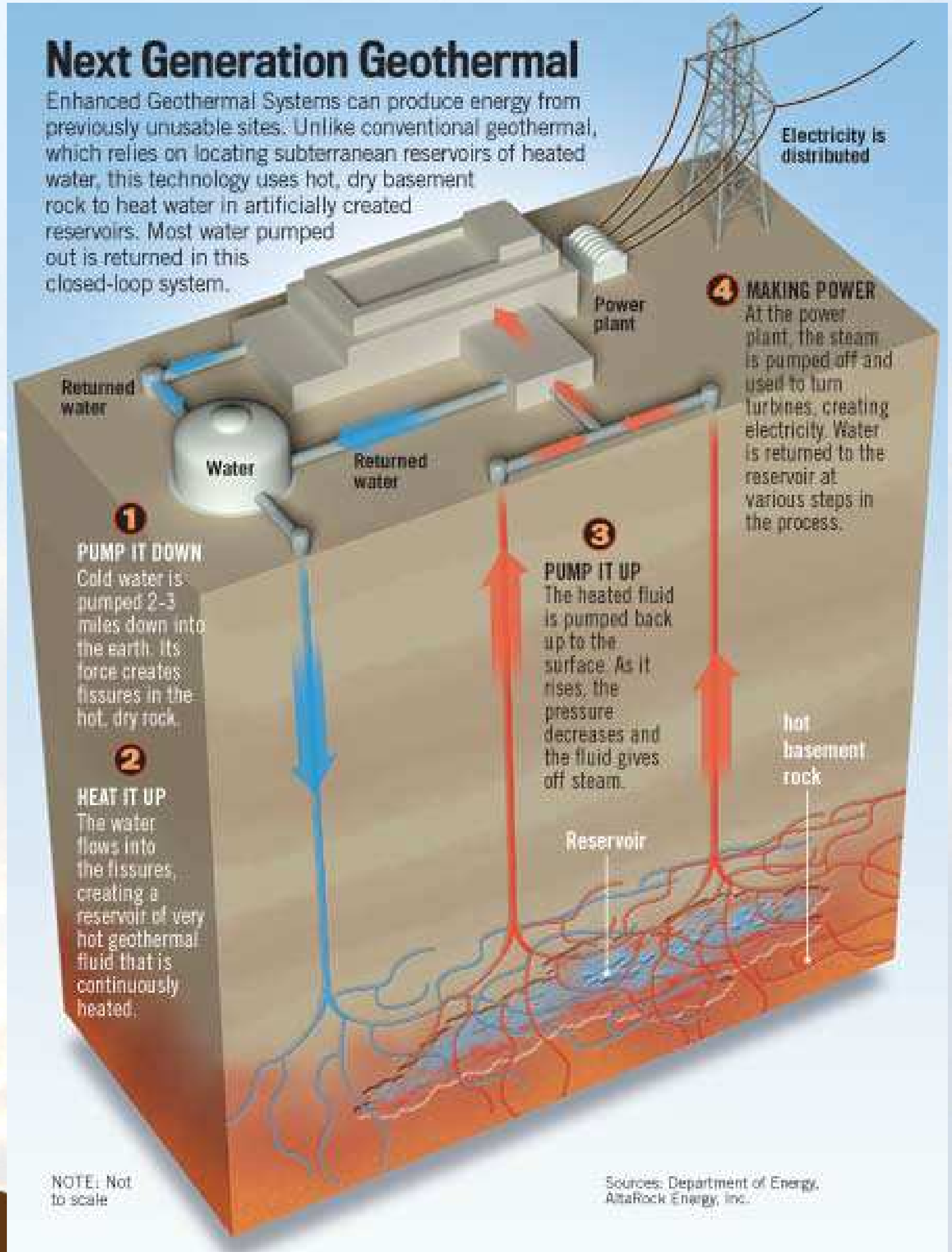
Engineering the Geothermal Reservoir: The Challenges

- *Drill to depths needed to find hot rock*
- *Deep large diameter wells have high cost*
- Stimulation have resulted in low flow rates per producer
- Injection Induced Seismicity
- Water Supply
- Public Relations & Permitting
- = Poor Economics



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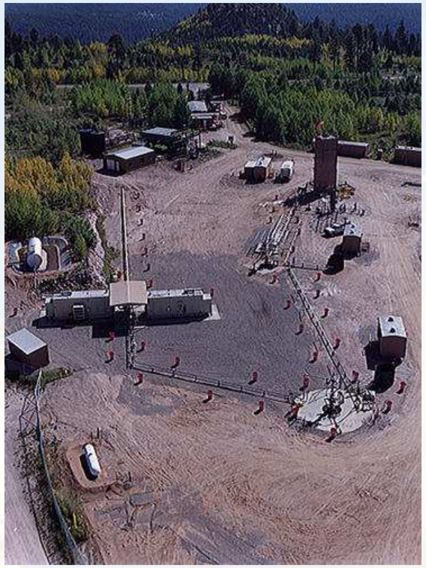
EGS Test Sites

First test of engineered geothermal at Fenton Hill, New Mexico. Hydrofracking doesn't yield a good heat exchanger. Packers fail.



Microseismic monitoring can map fractures.

Rosemanowes Quarry, UK. Hydroshearing yields the best reservoir.

Ogachi – Calderas provide good heat sources, but may have complex and unpredictable stress patterns.

Binary power plant at Hijiori EGS site, Japan. Short circuiting to shallow reservoir resulted in rapid temperature drop

Testing at Soultz EGS test site, France. Large stimulated volumes possible with hydroshearing.

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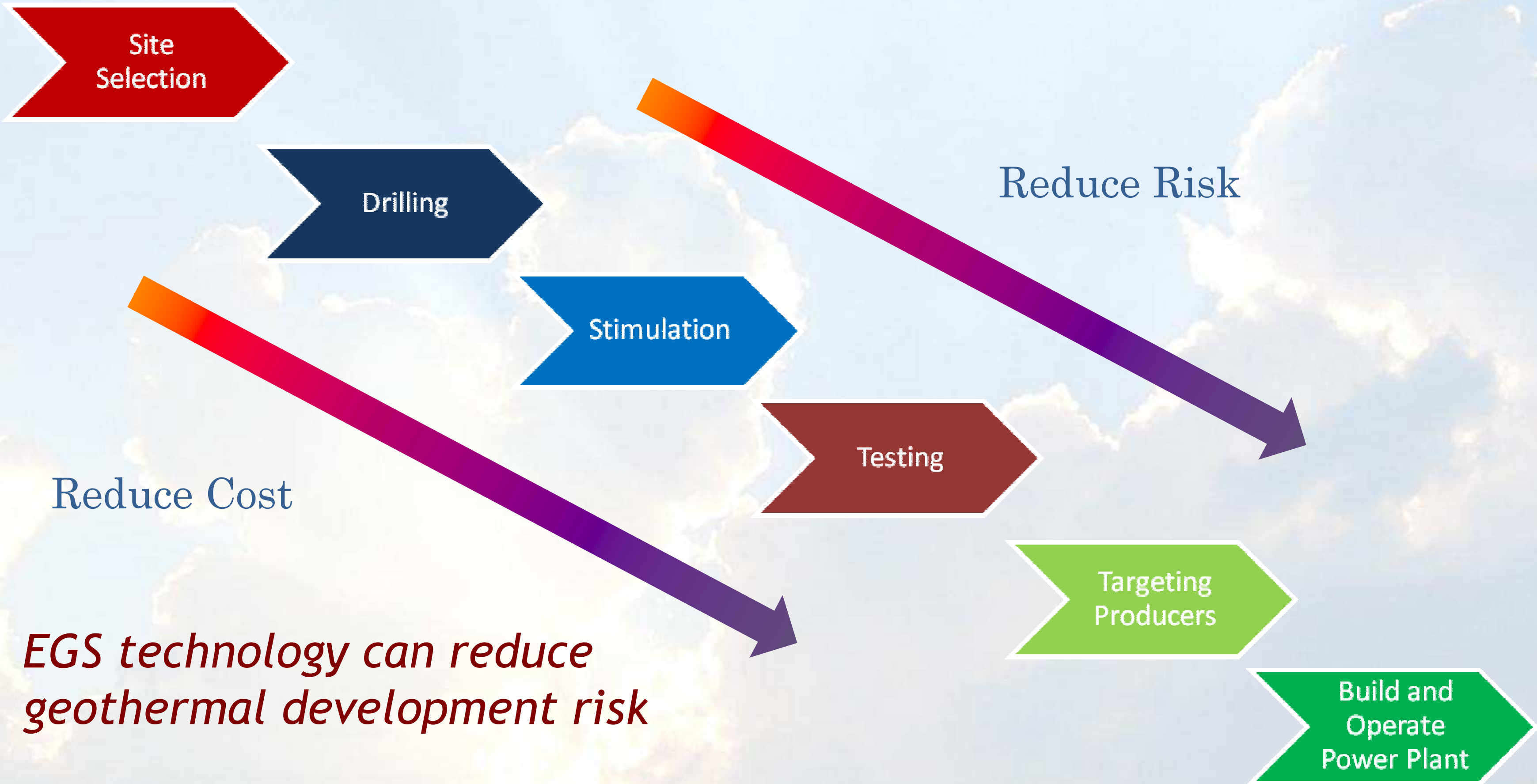
EGS Technology Development Goals



EGS technology can reduce geothermal development risk

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Resource Risk Sensitivity

- Cost of power for current technology base case conditions over a range of resource conditions
  - Conclusion 1 – Only the best sites are economic with today's technology
  - Conclusion 2 – Key resource factors are stress conditions and depth to temperature
  - Conclusion 3 – Depth and temperature trade off in project economics

Case	Cost - P90 (¢/kW)	Cost - P50 (¢/kW)	Cost - P10 (¢/kW)
3 km 300ºC	15	9	7
3.75 km 275ºC	24	15	10
3.5 km 250ºC	27	17	12
3.5 km 150ºC	38	21	13
4.5 km 200ºC	39	24	16
6.5 km 200ºC	156	81	46

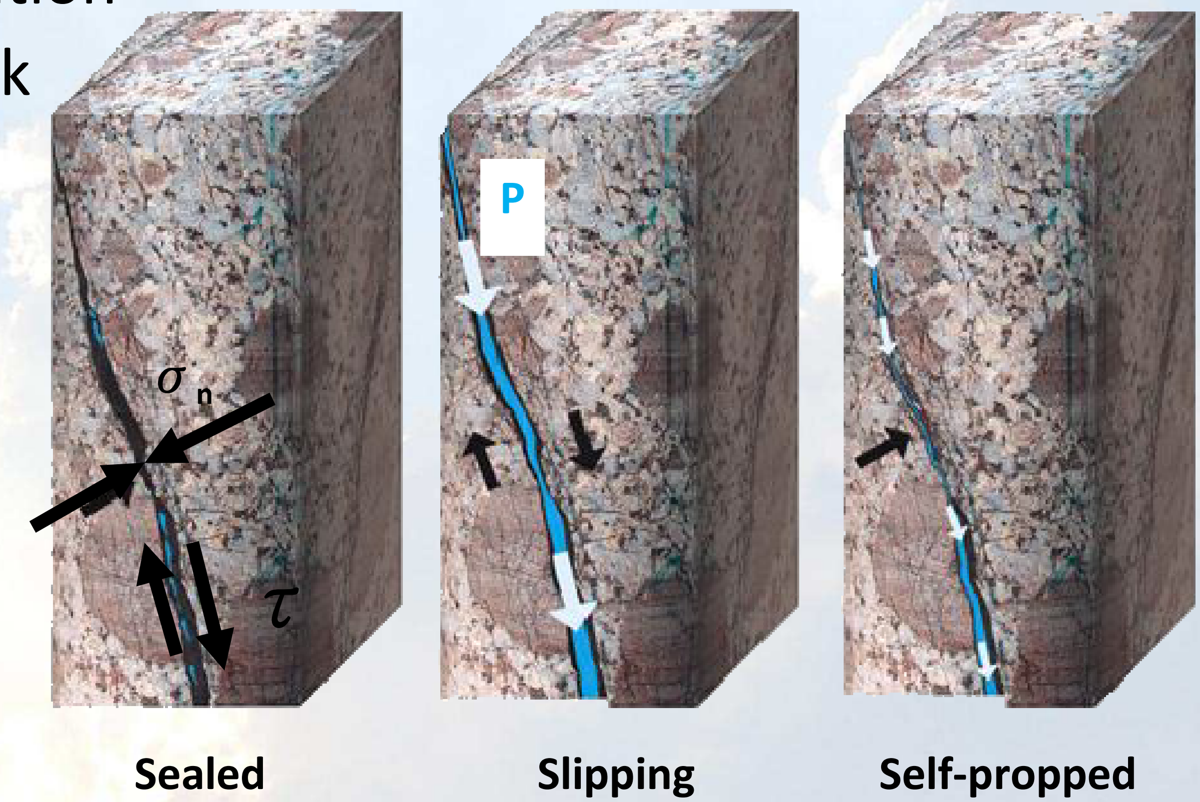
Impact of Technology Improvement On Cost

- Reduction in cost of power with change to major technology variables
  - Conclusion 1 – For all resources, flow per producer is the key parameter
  - Conclusion 2 – Power plant efficiency and temperature decline can impact deep and low temperature resources significantly
  - Conclusion 3 - For deep or low temperature resources well cost and temperature are very important

Case	Higher Flow Per well	Reduce Rate of Thermal Decline	Decrease Production Well Cost	Decrease Injection Well Cost	Increase Power Plant Efficiency	Increase Project Size
3.75 km 275ºC	-45%	-7%	-8%	-1%	-14%	-16%
3.5 km 250ºC	-47%	-7%	-9%	-2%	-18%	-14%
3.5 km 150ºC	-64%	-36%	-13%	-5%	-20%	-16%
4.5 km 200ºC	-56%	-21%	-24%	-17%	-30%	-9%
6.5 km 200ºC	-60%	-12%	-17%	-8%	-22%	7%

Permeability Enhancement in EGS = Hydroshearing (not hydrofracking)

- Hydraulic stimulation
- Impermeable rock
- Shear failure
- Existing fractures
- Open hole
- Low pressure
- Days of pumping @~500-700 gpm
- Total water use:
  ~75 acre/ft



$$\tau > (\sigma_n - P)\,\mu$$

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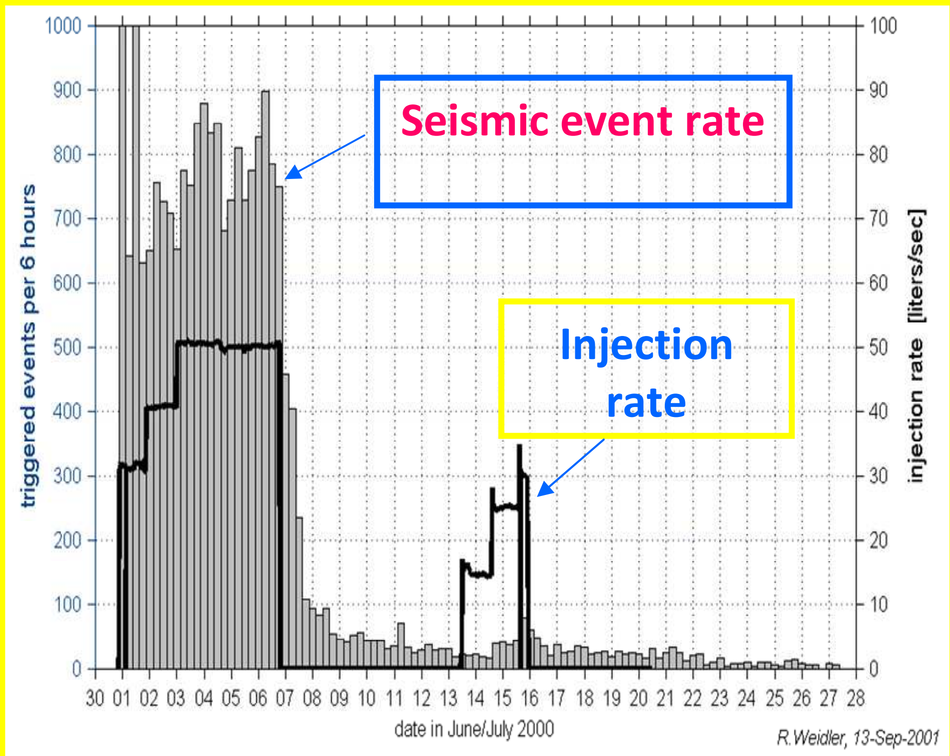
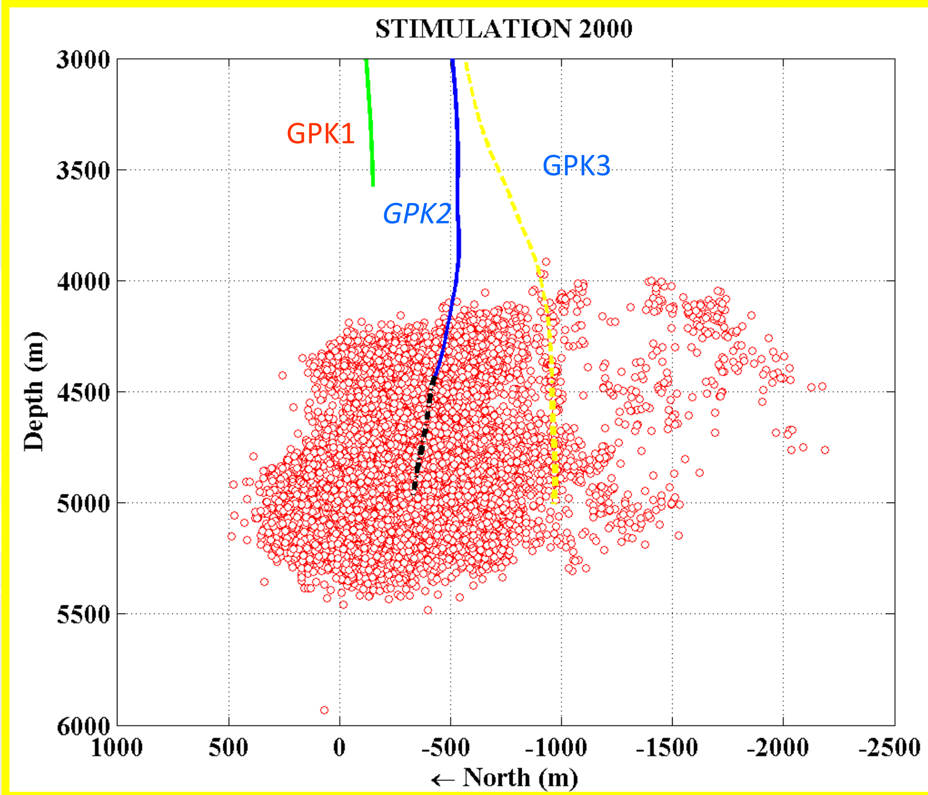
Hydraulic Stimulation of Soultz (France) GPK2 in 2000





Evidence that EGS works!

14,000 located seismic events

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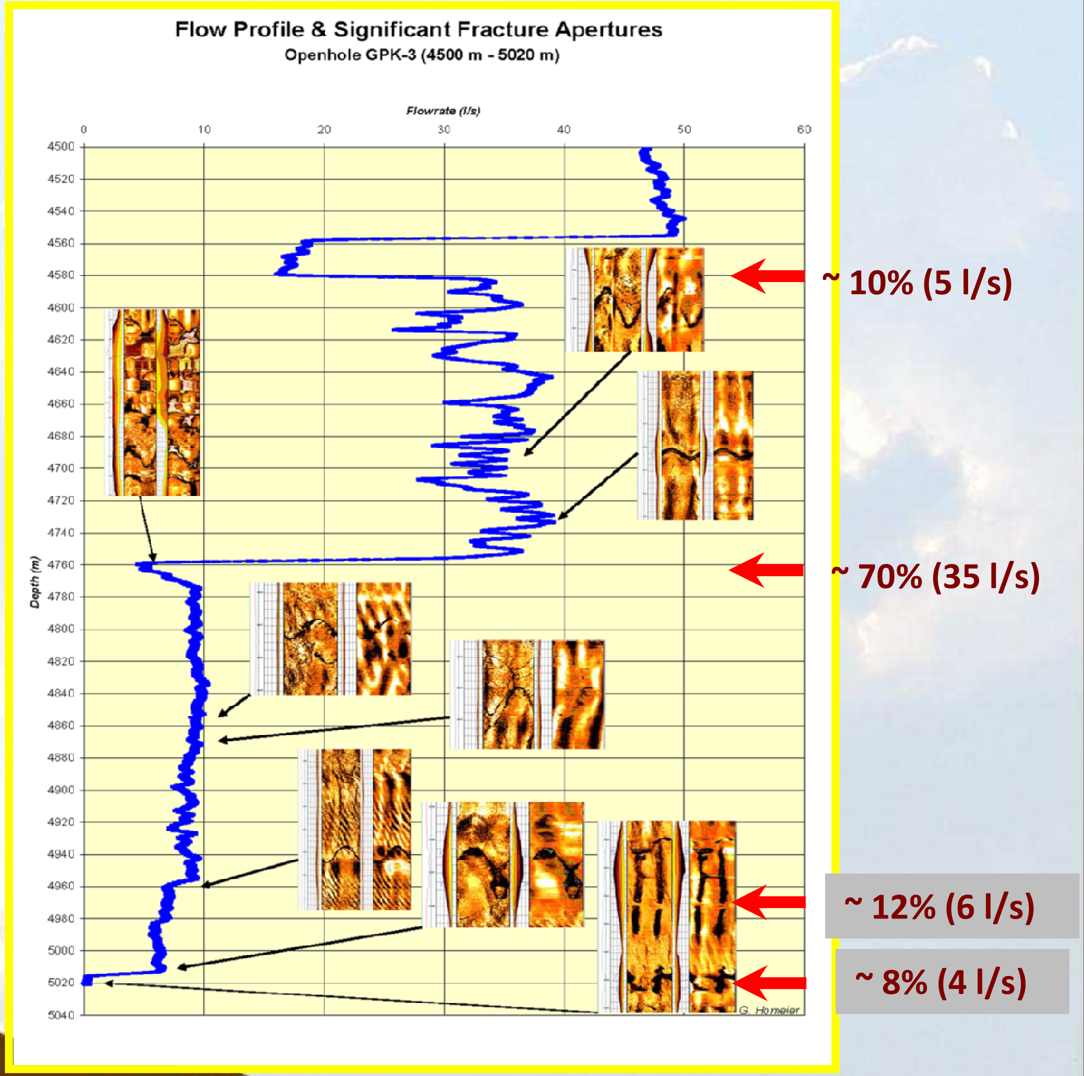
EGS Challenge: "Low" flow rates per well

- Most permeable zone in well takes fluid and is stimulated if pressure can be increased
- Remaining zones only take limited amounts of fluid and are not stimulated
- Increasing flow by increasing injection pressure risks induced seismicity
- Single, dominant zone does not provide sufficient heat exchange or flow-rate
- **Soultz binary plant generates just 1.5 Mw_e**
- 20 l/s ~ 10,000 bbl/day
- If oil = $1M/d



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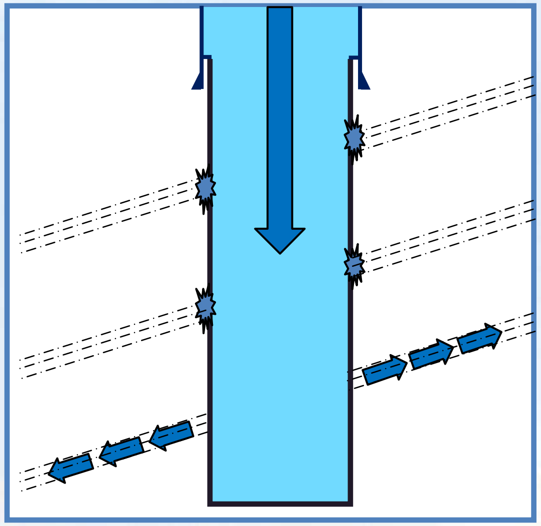
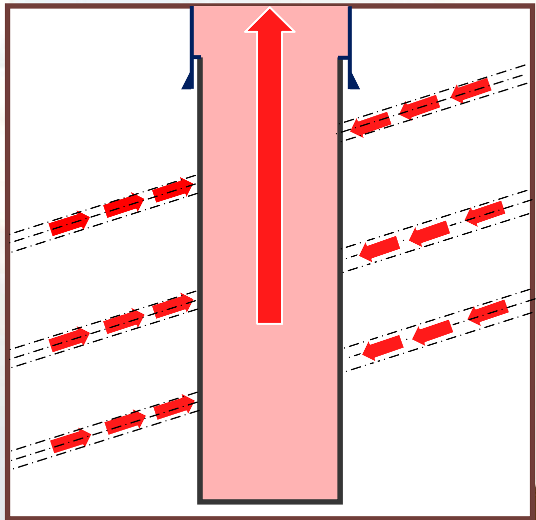
Innovation 1:
TZIM Technology

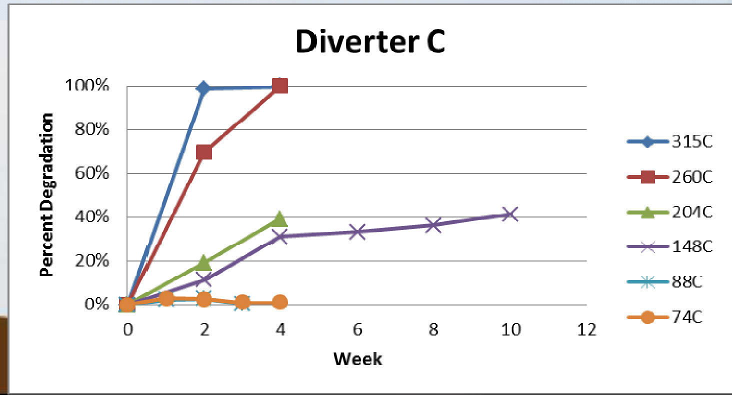


Diverter Sealing Zones



Thermal Degradation

- TZIM = Thermo-degradable Zonal Isolation Materials, AltaVert®
- Pumped as a particulate slurry
- Near neutral density – follows the flow
- Particles packs off near well-bore face
- Various particle size distributions on-site to seal variable fracture apertures
- Downhole instruments monitor fluid exit
- No rig required during treatment



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TZIM Field Demonstration

2010

- Injector improvement
- TZIM blocked shallow zones and forced re-injection fluid deeper in well
- ~200 kW improvement

2011

- Low flow producer stimulation
- Improved overall well transmissivity and long term production flow rates 68%
- 830 kW improvement

2012

- Low temperature producer stimulation
- Opened-up new flow paths in low permeability resource, increased overall production flow rate 30% and temperature
- ~650 kW improvement

2012

- Very hot dry hole
- Created multiple stimulated zones
- Overall reservoir volume created >1.5km^3
- 18X improvement in injectivity

Reducing Cost, Reducing Risk

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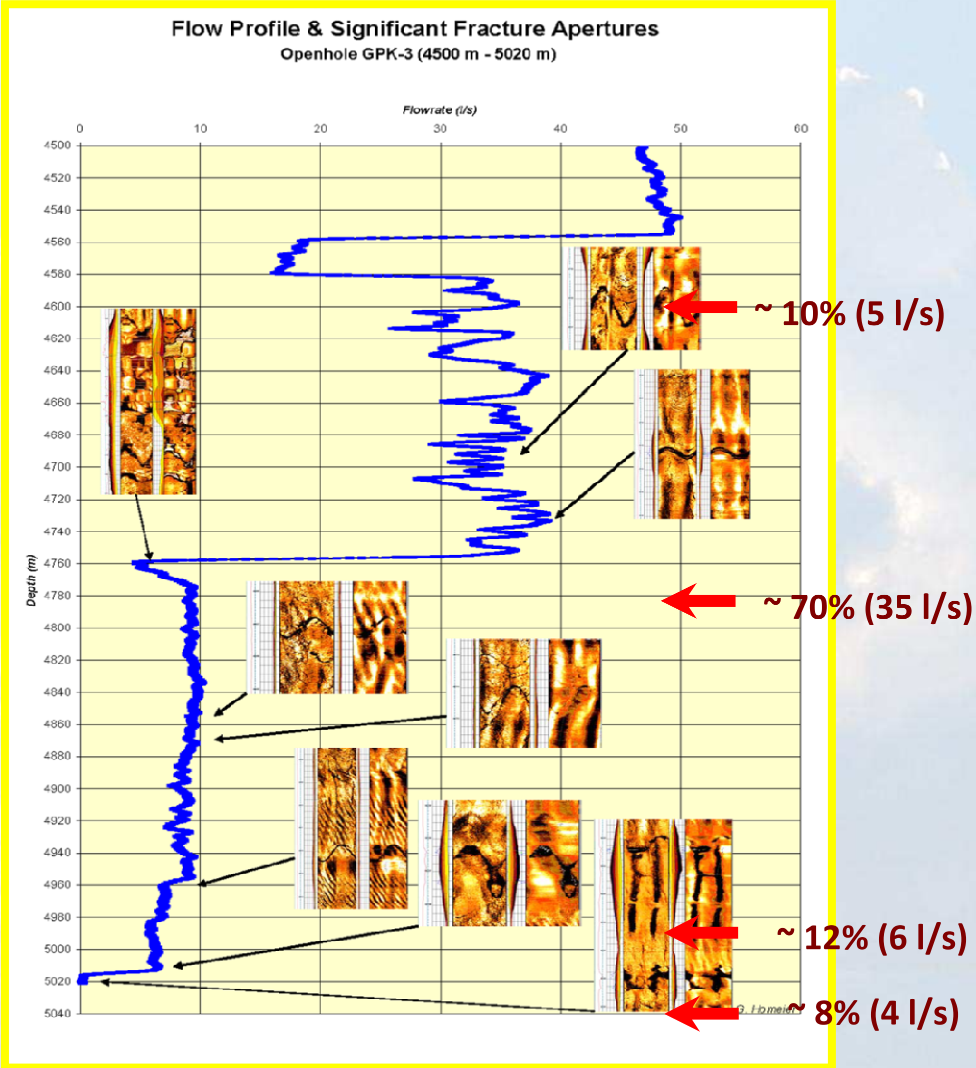
Current Open Hole Geothermal Stimulation Limitations

- Inject stimulation fluid from the wellhead
- Most permeable zone in well takes fluid and is stimulated if pressure can be increased
- Remaining zones only take limited amounts of fluid and are not stimulated
- Increasing flow by increasing injection pressure risks induced seismicity
- Soultz currently generates less than 1 Mw_e



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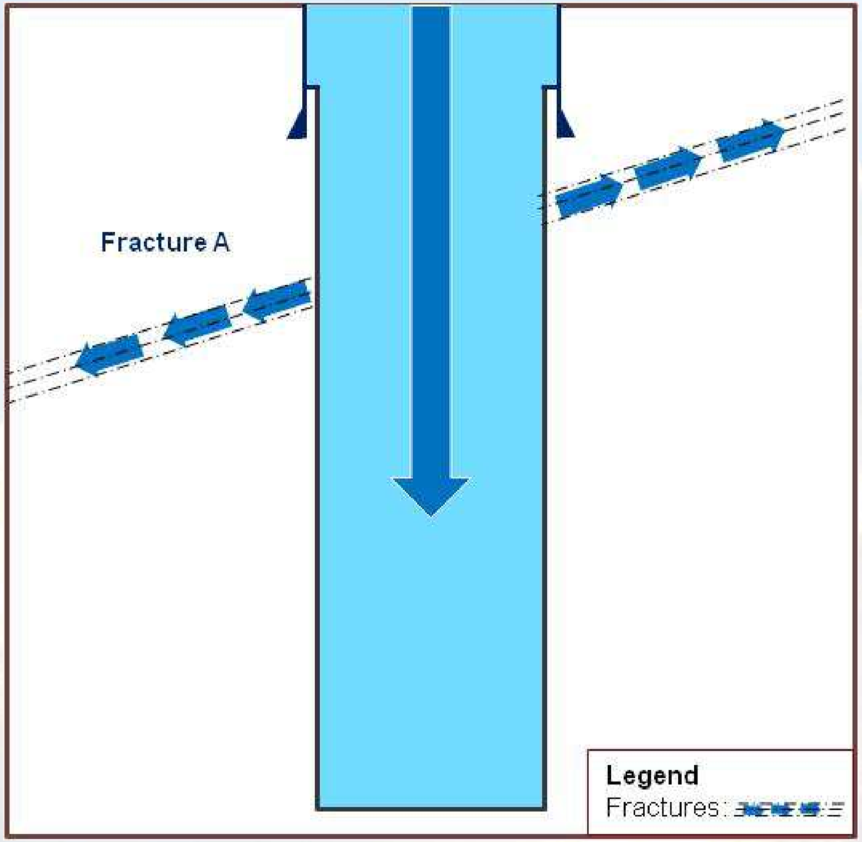
Reservoir Optimization

Single Fracture Network

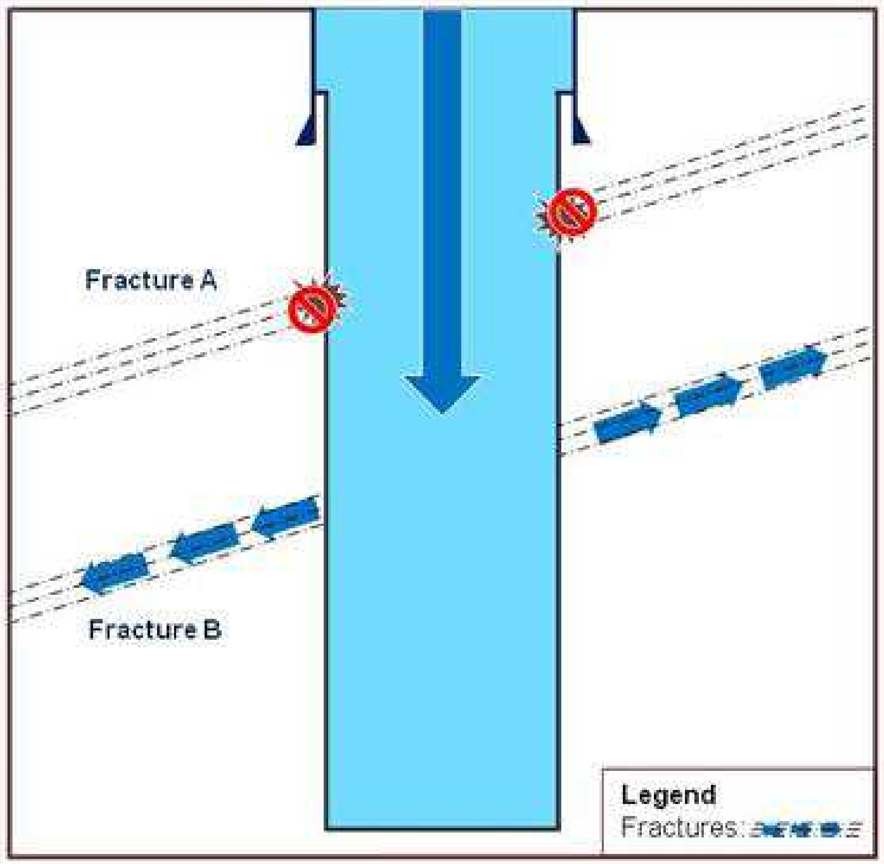


Limitations of Single Fracture

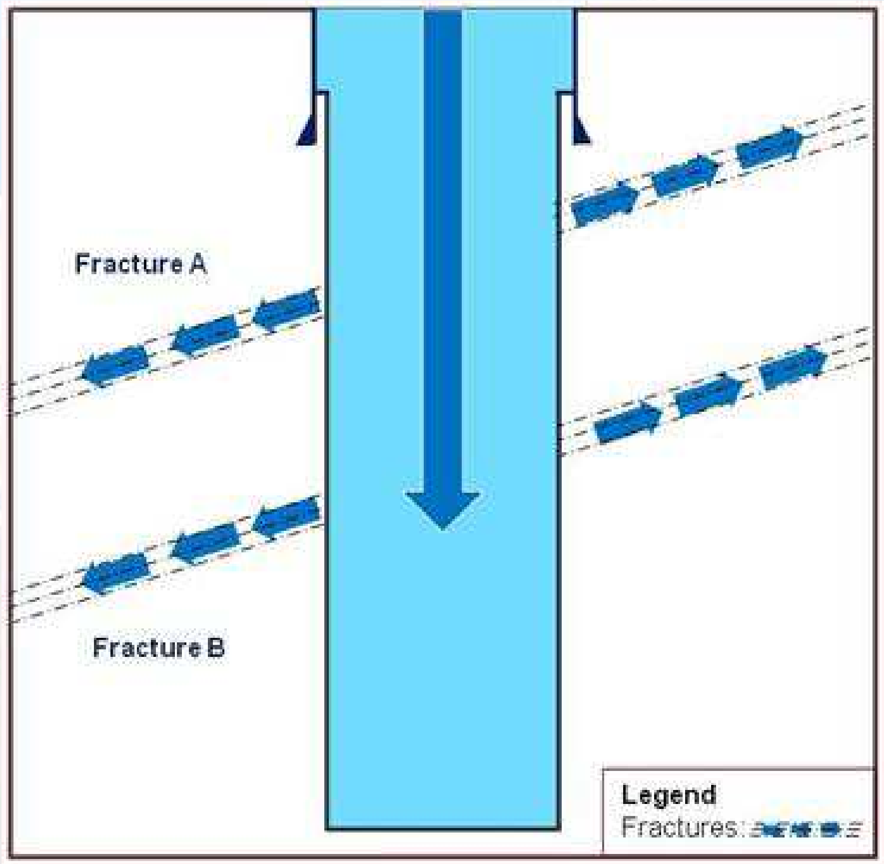
- Flow through a single stimulated fracture network provides minimal heat exchange area
- Production rates are then limited by the single fracture
- Injection rates (in EGS) limited
- Large portions of the reservoir rock intersected by well are left untapped for heat extraction and power production

*Temporary Zonal Isolation Method**

TZIM Sealing Zone



Injector after TZIM degradation



*AltaRock Energy Inc. holds a portfolio of intellectual property, including patents and patent applications protecting its proprietary Thermo-degradable Zonal Isolation Material (TZIM) technology and methods

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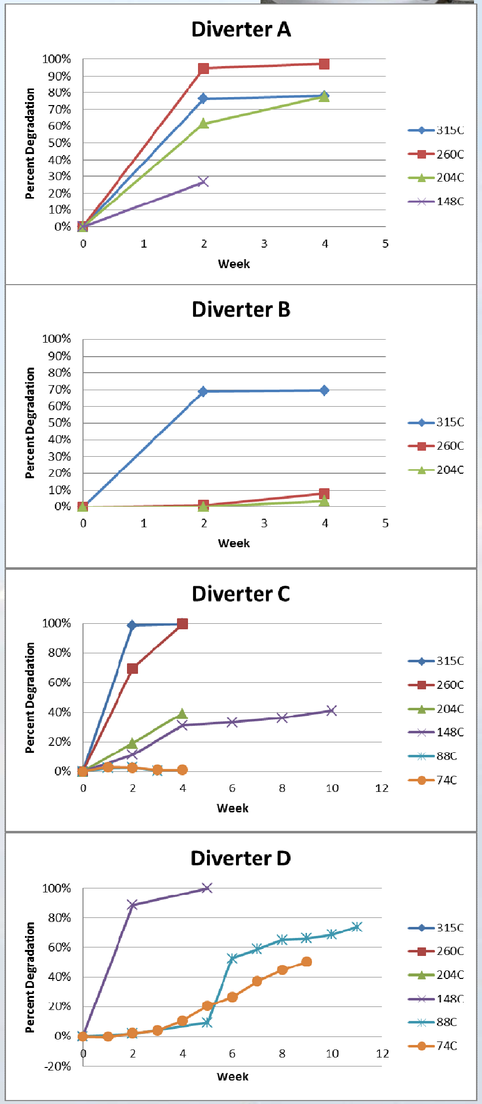
AltaRock Proprietary TZIM Technolog

Benefits of TZIM Stimulation

- Increases production on a per-well basis by stimulating multiple fractures
- Non-mechanical zonal isolation material. No risk of packer or sleeve failure.
- Pumped from surface as a particulate slurry. Forms a particle pack off near the wellbore.
- Solid at temperature of the stimulation fluid. Degrades at rock temperature to a liquid or completely soluble nonhazardous breakdown product.
- No rig required during treatment
  - Major cost savings
  - Reduces operational risk
  - Create fractures in succession without moving packer and waiting on rig
- Can be used even when slotted liner is in place
  - Mechanical isolation methods (i.e. packers) cannot be used in well with slotted liner
- A suite of materials that will degrade with time and temperature post stimulation
  - Lab tested from 74°C-315 ° C
  - Biodegradeable and/or thermally degradable polymers



Sample TZIM degradation testing results
Bour et al, Stanford Geothermal Workshop 2012

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GEYSERS TZIM FIELD TESTS

Multizone Stimulation Using TZIM Diverters Successful

•Goals of injection well stimulation: Stop injection breakthrough from shallow zones. Increase deep hot injection

- Achieved - blocked shallow fractures to stimulate deeper
- Achieved - Stimulate new hot zones to inject deeper

•Goals of production well stimulation: increase well production particularly from deeper reservoir

- Achieved – Increased well output 68% long term
- Achieved - Multiple zones in deep, high temperature resource

Test Outcomes

•Multizone stimulation using diverter improves injection well – Forced water deeper into well to improve injectivity and permeability. Stops injection breakthrough

•Multizone stimulation of production well– Three stages of TZIM diverter

- Two new fractured zones created in hottest part of well. One high temp zone improved.
- Long term improvement of 70% over earlier flow after 6 months. Added 1.22 MW long term to plant output.

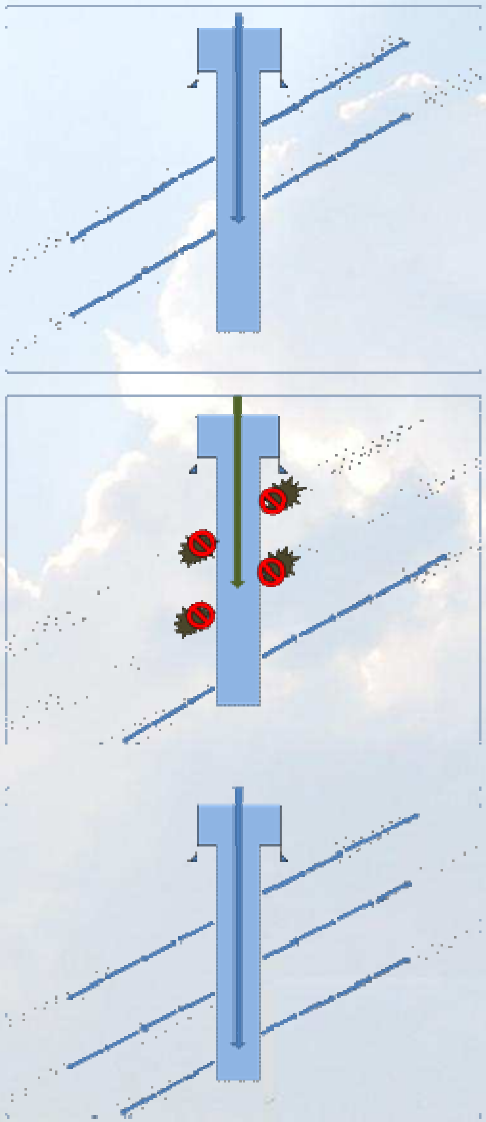
•Slotted liner – Both wells completed with slotted liner. Diverters had to block fractures without clogging slots

TZIM Field Test Concept

Step 1: Inject from surface and stimulate weak zones

Step 2: Pump blocking agent to seal stimulated zones; stimulate next weak zone

Step 3: Blocking agent breaks down with time and heat; all zones stimulated and flowing



COMMERCIAL MULTIZONE STIMULATION

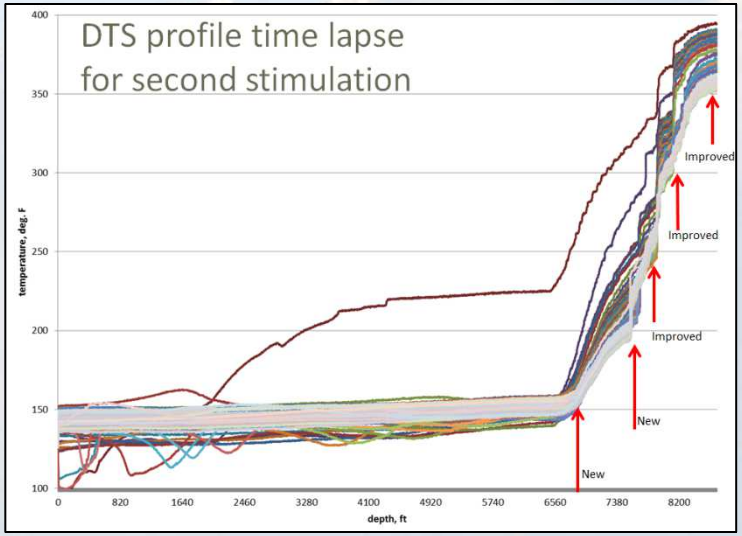
Improvement of Production Well

- **Goals of production well stimulation:** Increase well production particularly from deeper reservoir

- Achieved - **TZIM stimulation** created 2 new zones, stimulated 3 existing zones for estimated **400 kW increased** plant production.
- Achieved - **Two new production zones** in deeper, zones of well
- Achieved - **Existing high temperature permeable zones improved** through TZIM stimulation.
- Achieved - Multiple zones stimulated produce 200 gpm more flow at 30°F higher temp
- Achieved - Overall increase in enthalpy flow rate of over 134%

Injection Optimization

- **Improved injection capacity** in deeper, hotter reservoir through multizone stimulation
- **Increase injection** to deeper hotter zones in field
- **Improved overall plant output** by removing injection limitation
- **Supply pressure support** to production wells through improved injection connection to production without cool water breakthrough



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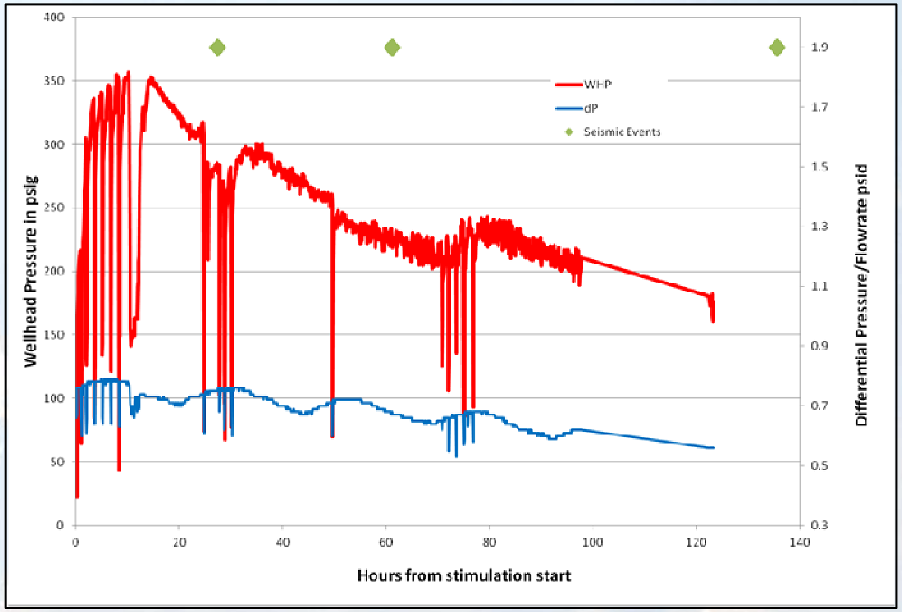
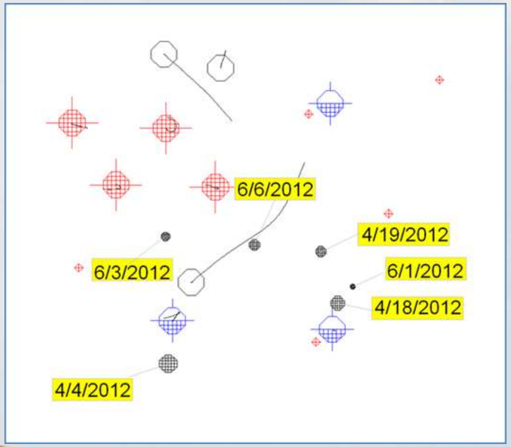
Microseismic Monitoring

- 6 total events mapped during monitoring
- 2 microseismic events occurred during the stimulation
  - Events appear to be the result of stimulation
  - No clear temporal relation to WHP changes
  - ➢ Possibly due to a lag in pressure response in low transmissivity fracture connections between the well and the event epicenters
- 3 events within 2 days after the production or injection pumps were turned off
- 1 event mapped prior to stimulation





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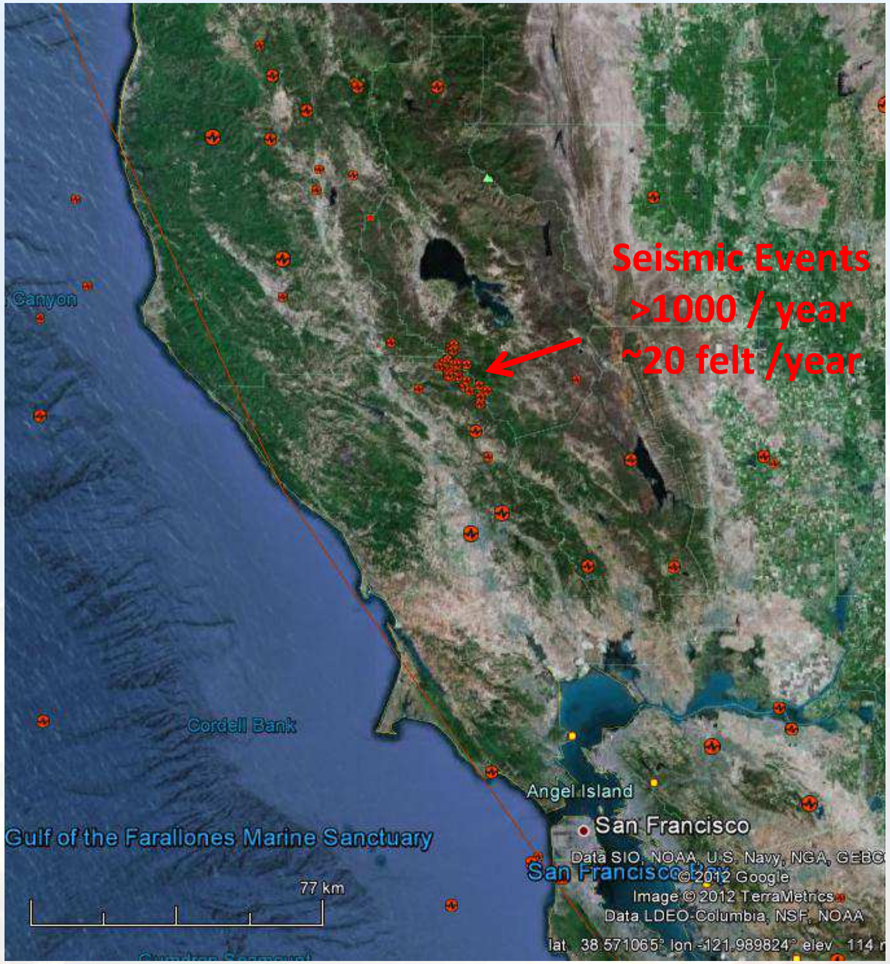
EGS Challenge 2: "Felt" Injection Induced Seismicity



The Geysers
Northern California
1960 -

Deep Heat Mining project
Basel, Switzerland
2005-2009

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A Demonstration of EGS Technology

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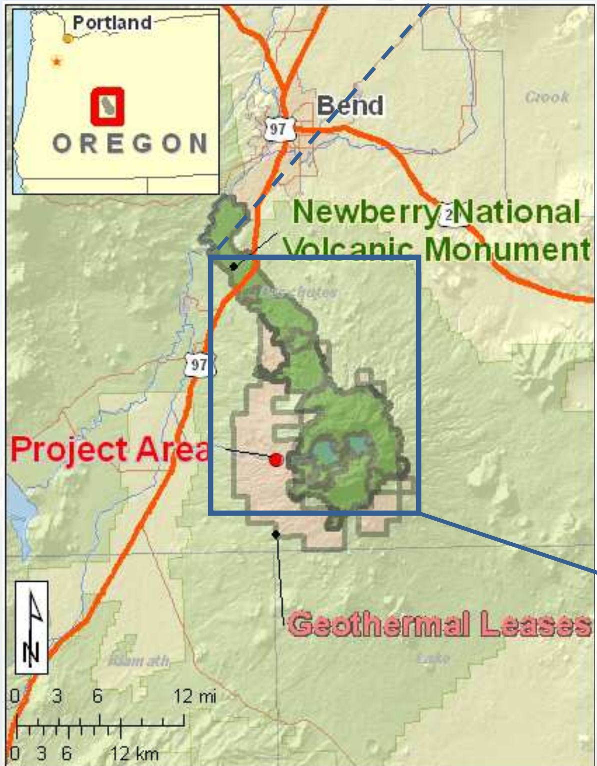
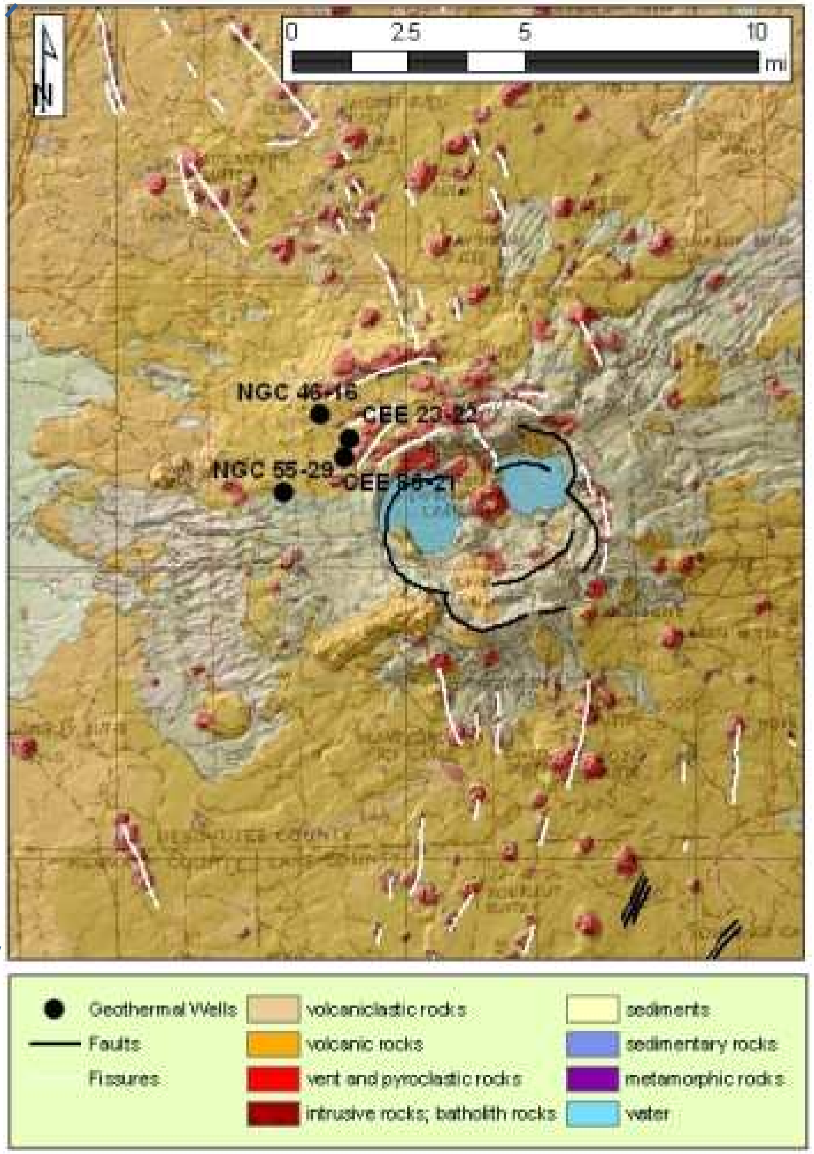
- American Reinvestment and Recovery Act
- AltaRock awarded up to $21.45m as part of total, three phase budget of $43.81m
- Demonstrate recent EGS Innovations at Newberry Volcano for future application across the United States

Newberry Volcano EGS Demonstration

- West flank of Newberry Volcano, OR
- National Forest surface / BLM geothermal leases outside western boundary of monument
- NWG 55-29 drilled to 10,060 ft, >600F





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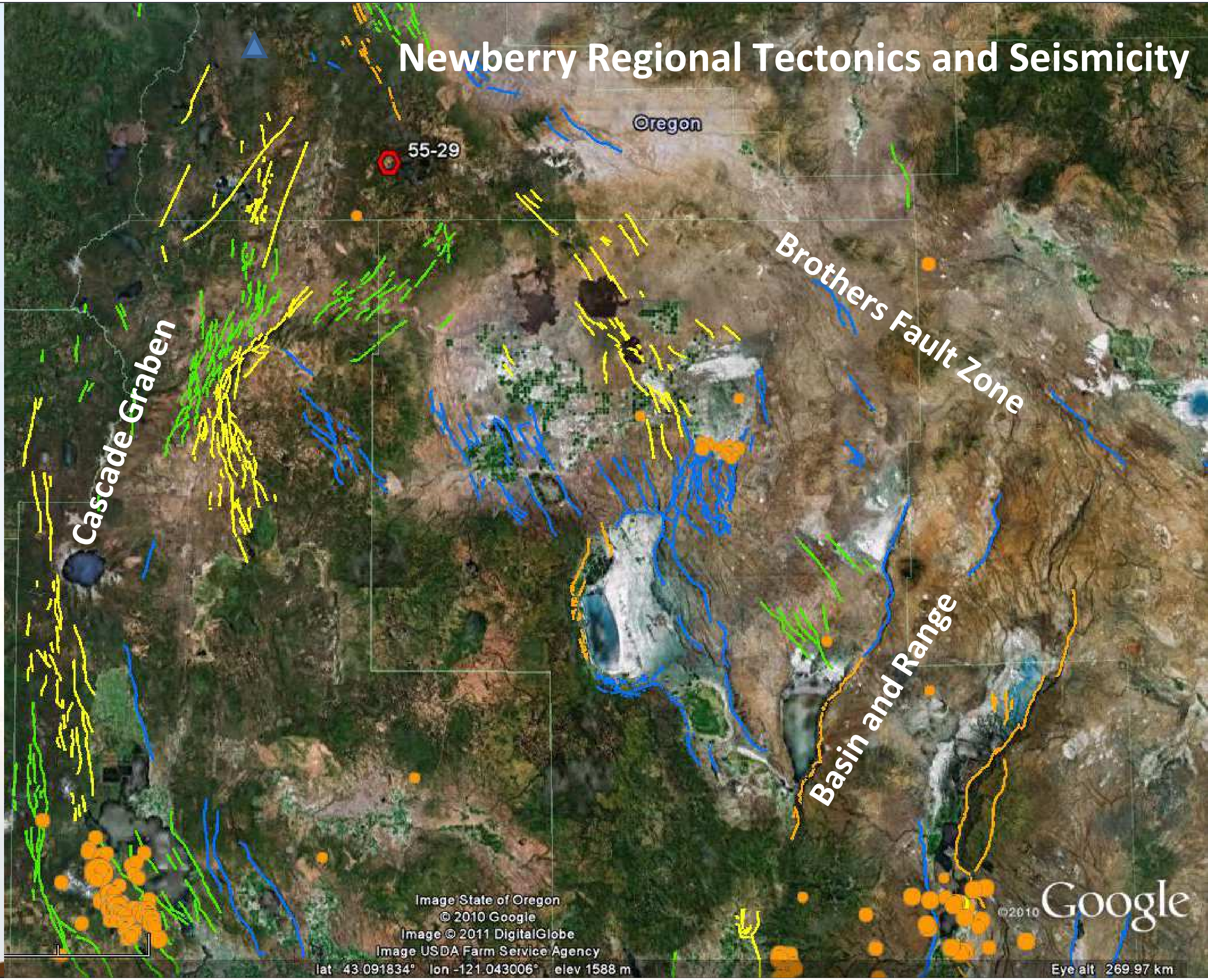
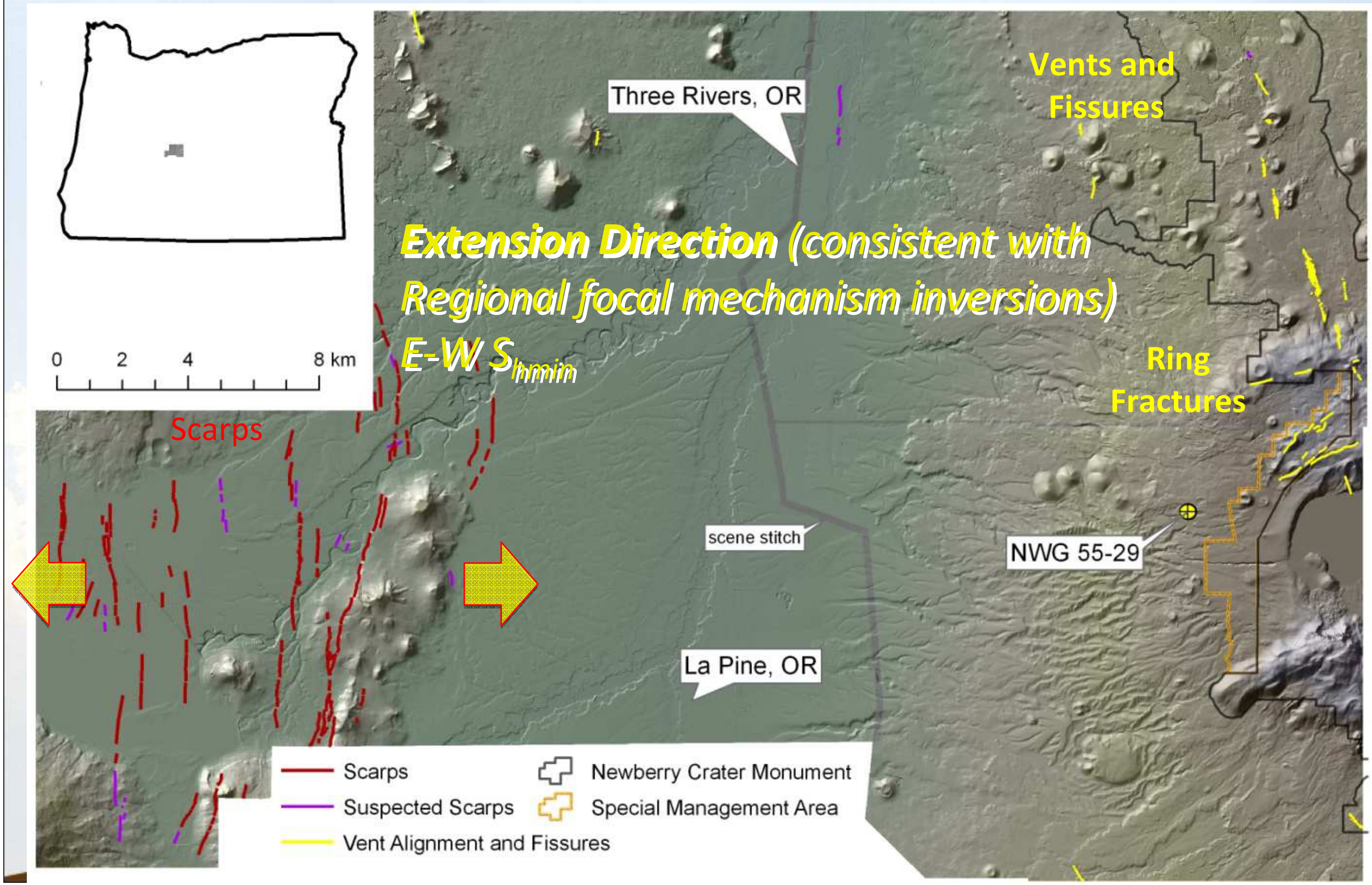
Newberry Regional Tectonics and Seismicity



Oregon LiDAR Consortium: Deschutes and Newberry, summer 2010



Newberry EGS Demonstration Site

view from US hwy 97 north of La Pine

Across the highway – the Cascades

Tools to predict and characterize EGS reservoir

Pre-stimulation

- Lessons learned from previous HDR and EGS projects
- Regional tectonic setting and background seismicity
- LiDAR imagery for local fault and fracture patterns
- Stress and natural fractures in 55-29 using borehole televiewer
- Study of cuttings and equivalent core

During stimulation

- Micro-seismicity

– Locations, extent, volume, failure modes, moment tensors

- Well head pressure and flow rate histories

– Δ Injectivity, bulk permeability, transmissivity

- Tracer tests

– Fracture surface area, flow paths, temperature

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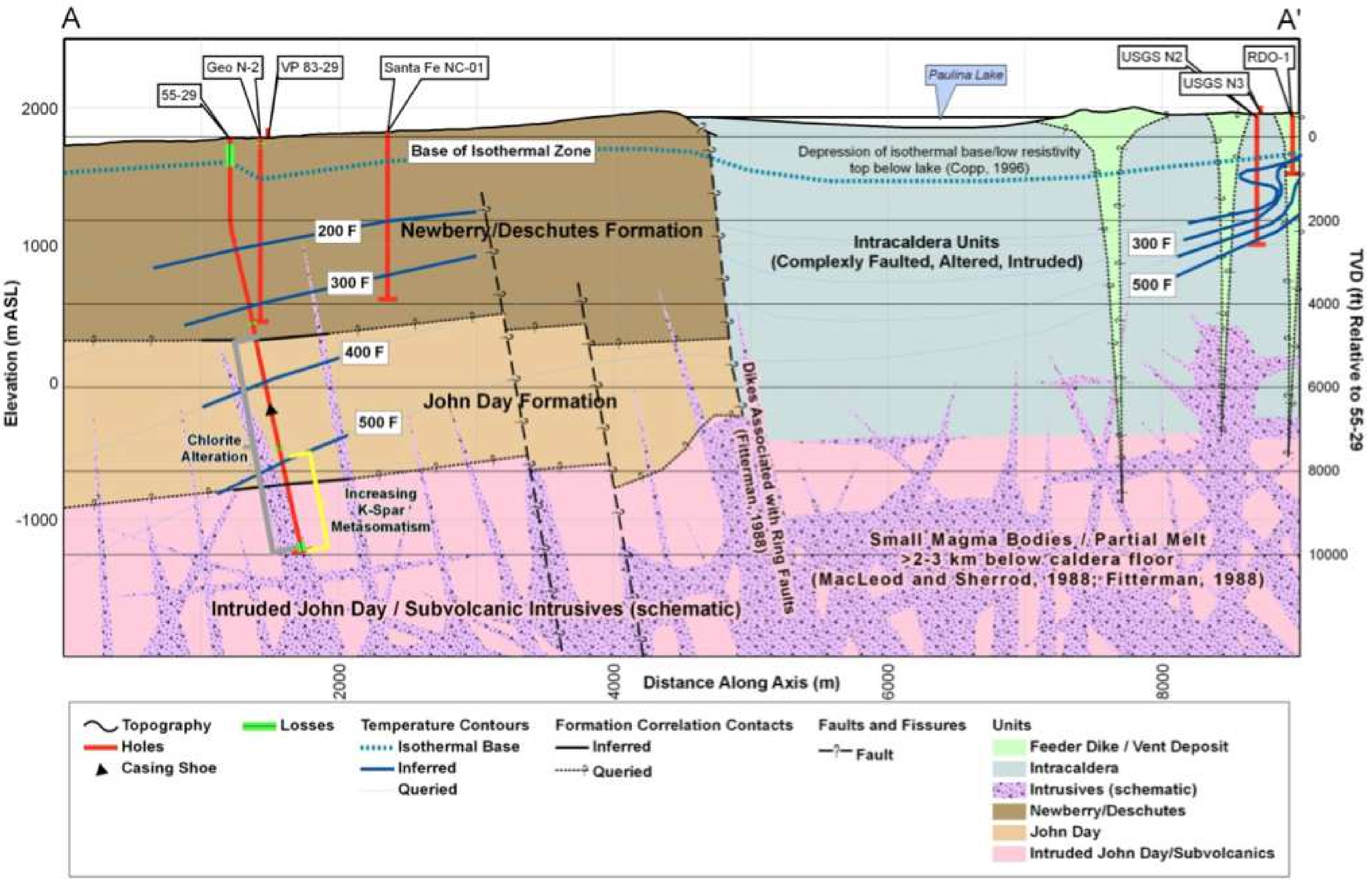
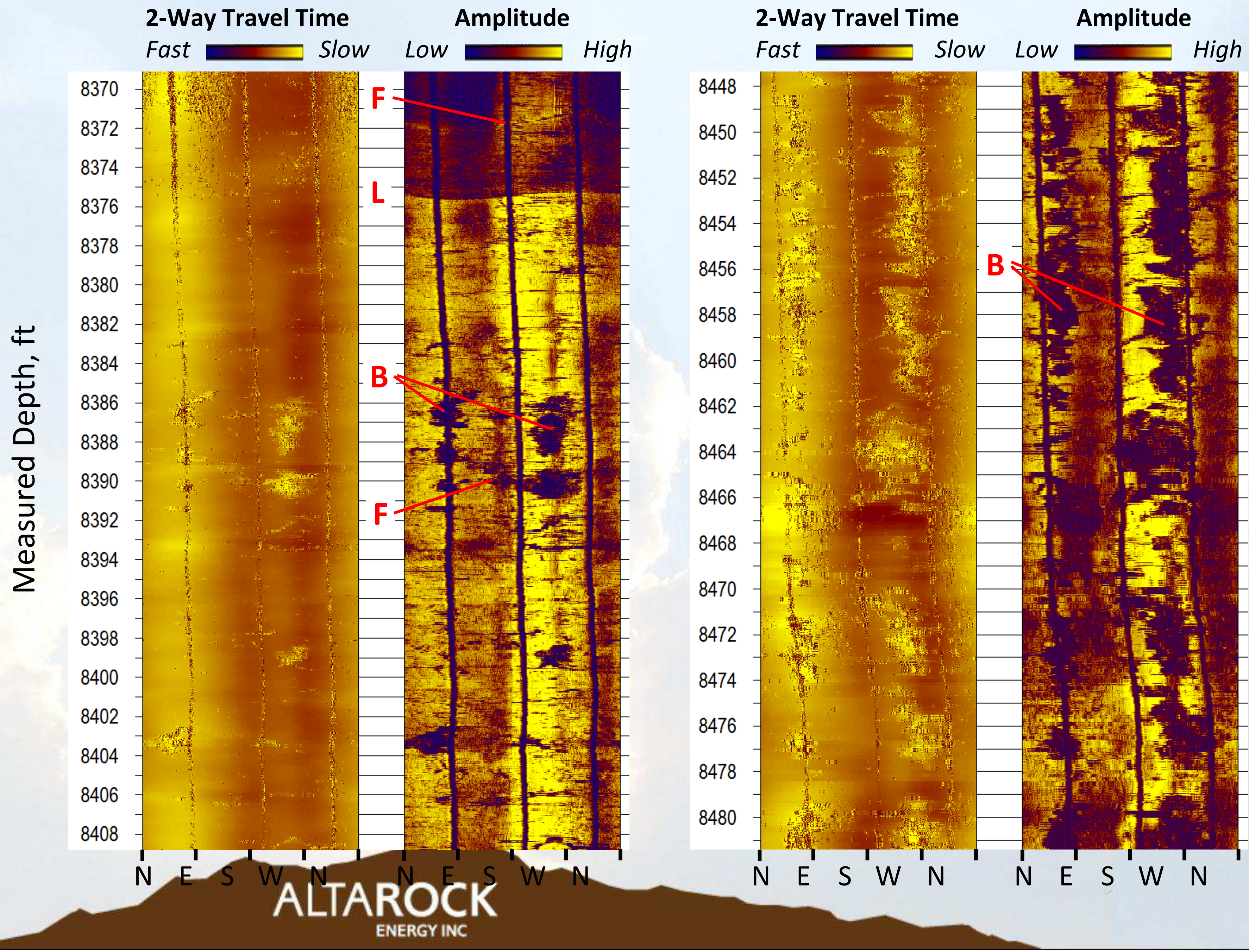
Schematic E-W Cross-section

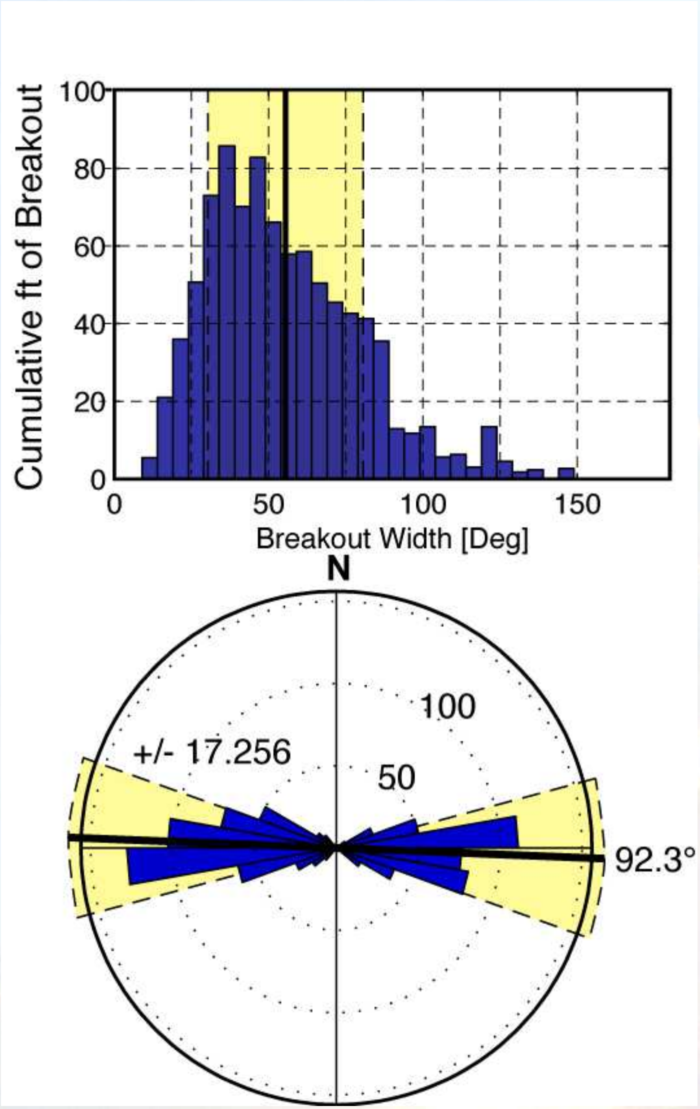


Borehole Televiewer Log: Newberry Well 55-29

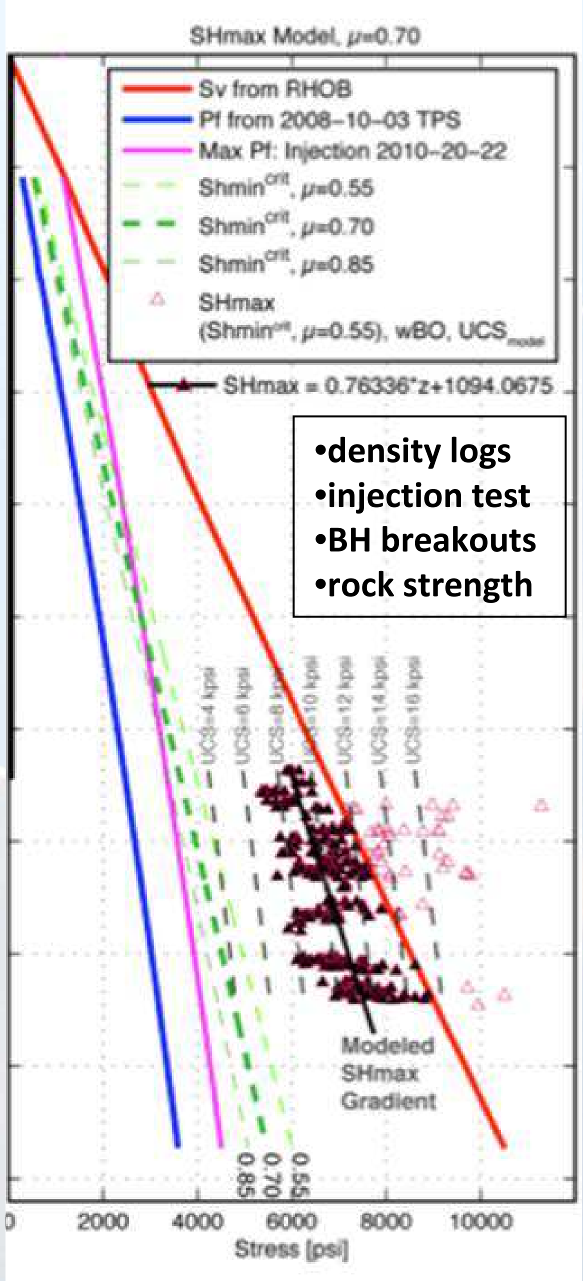


Stress Model

Stress Orientations from BHTV



Profiles of Stress Magnitudes



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Mapping EGS with Microseismic Array

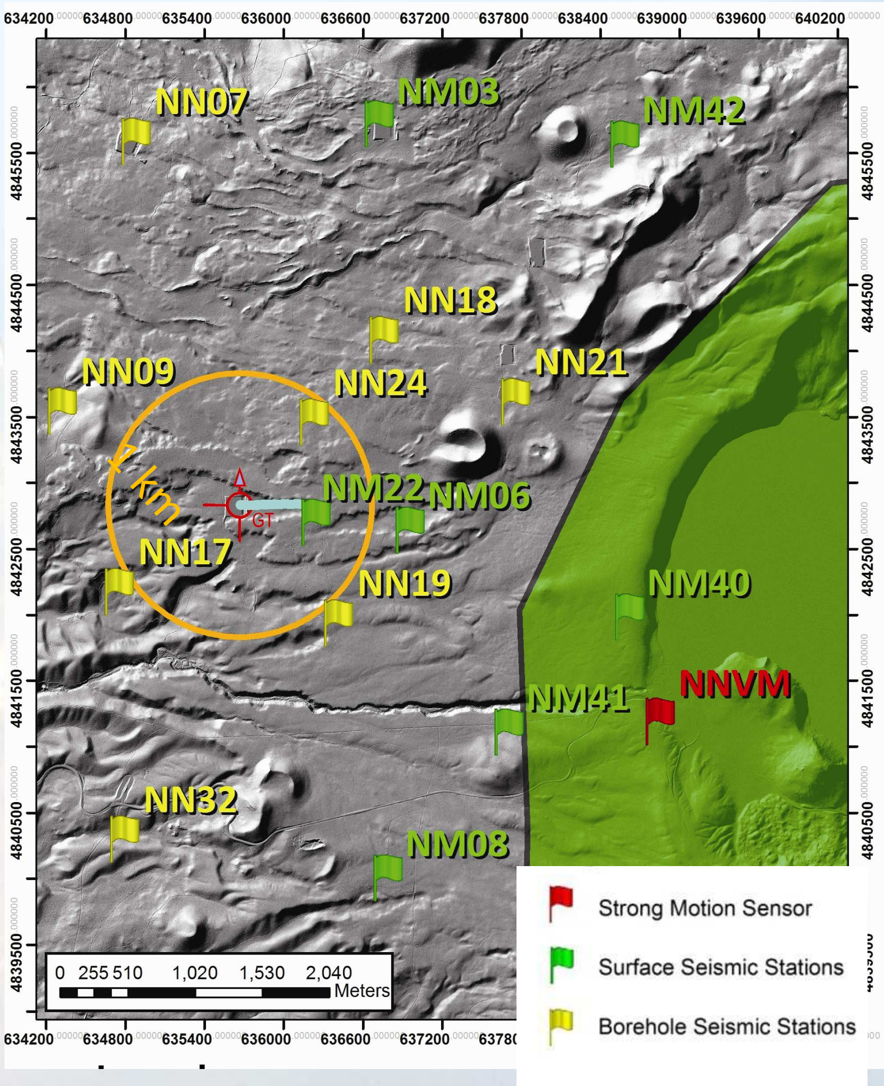
Phase II array

- Replaced Phase I (bkg) array
- 15-stations
- 8 borehole geophones
- 7 surface geophones
- Real-time telemetry

Strong motion sensor

- near Paulina Lake Visitor Center (NNVM)

2 Hz, 3 component geophones



MSA Installation: May – August 2012

- **Boreholes drilled to get below to water table**
  - 4 existing BH (one deepened)
  - 4 new BH drilled 210-250 m
  - Average 11 drilling days each
  - 3 months total
- **BH geophones**
  - with hole locks for orienting sensors
  - to enable source mechanism calculations.
- **Surface instruments at 7 sites**

Induced Seismicity Mitigation Plan: Mitigation Steps

Event Characteristics		Field Operation
• Regulator approval • MSA/SMS active	Start	Initiate stimulation plan Conduct step-rate test
• Event >1 km from well • Shallow (<6000 ft) event • Within 500 m of NNVM	Outlier Alert	Confirm, then apply diverter No flow or pressure increase Assess result for 24 hours
• M 2.0 to 2.6 within 3 km	No Flow Increase	No flow or pressure increase
• M 2.7 to 3.4 within 3 km • PLVC PGA: 0.014 to 0.028 g • MMI: IV (Light, no damage)	Decrease Flow	Reduce flow to reduce P Wait 12 hours
• M ≥ 3.5 within 3 km • PLVC PGA ≥ 0.028 g • MMI: IV (Light, no damage)	Stop Injection – Flow Well	Stop injection Flow to surface (sump)

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55-29 Stimulation Operation 2012

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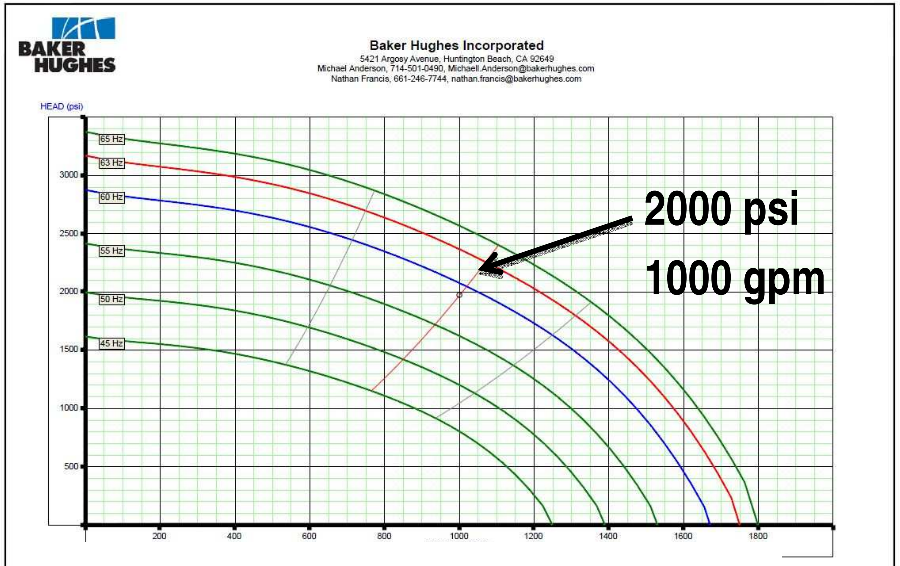
- Setup: September 10 - October 15
- Stimulation: October 16- December 7
- Heat up: December 8-18
- Demob: December 19-22

Innovation: 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

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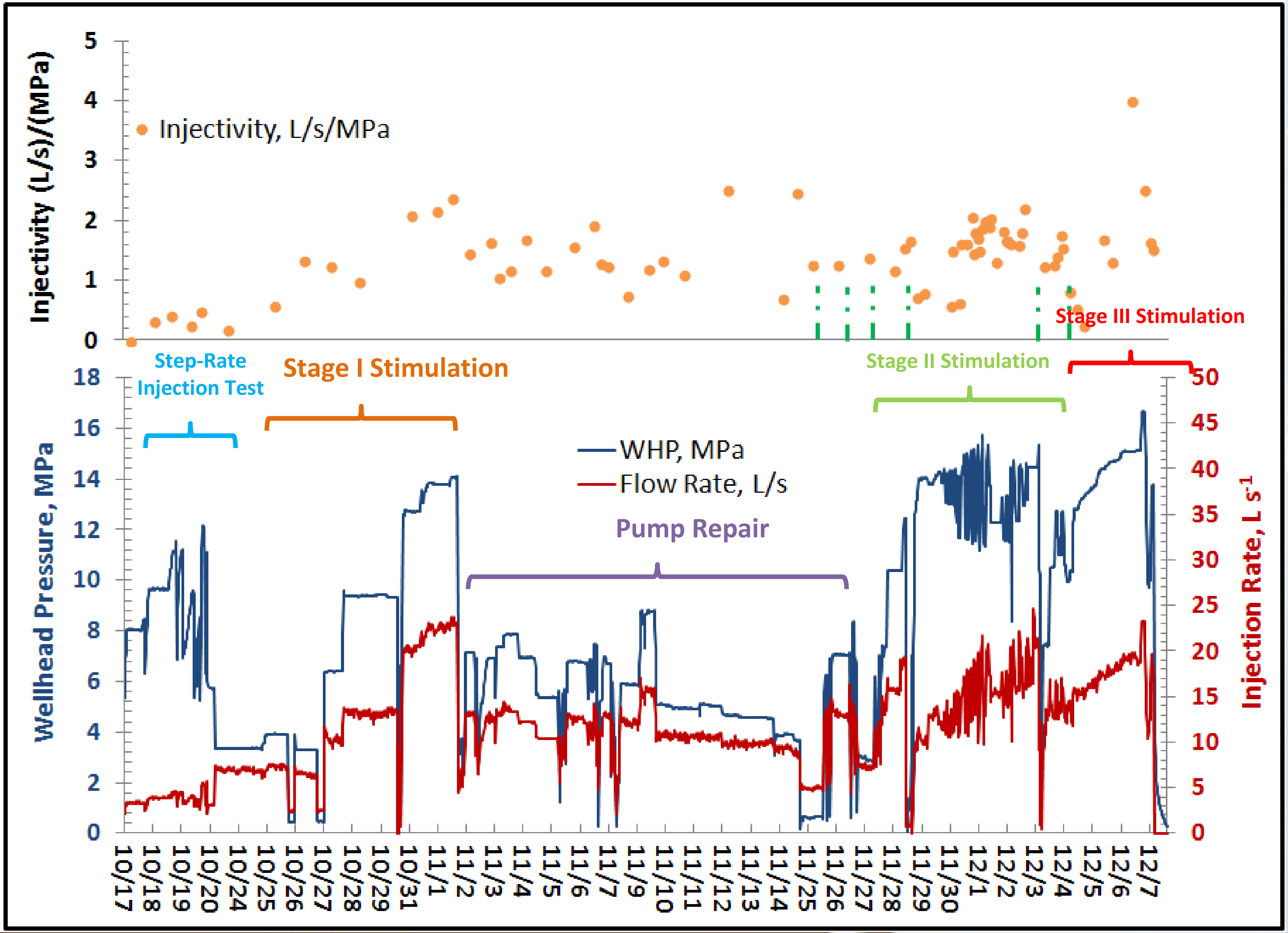
Stimulation History: WHP, Flow and Injectivity



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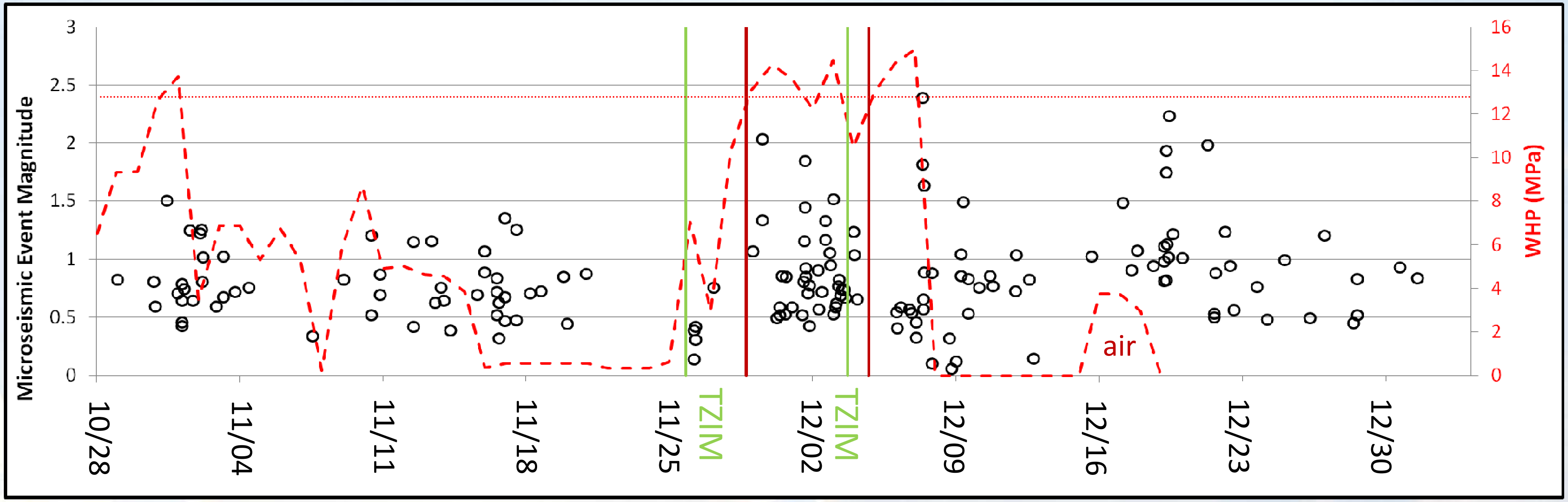
Stimulation pressures and seismicity rates



- Hydroshearing initiated at WHP 12.5 MPa (1800 psi)
- Seismicity continued at lower pressure
- Total 227 locatable events including 22 events in 2013

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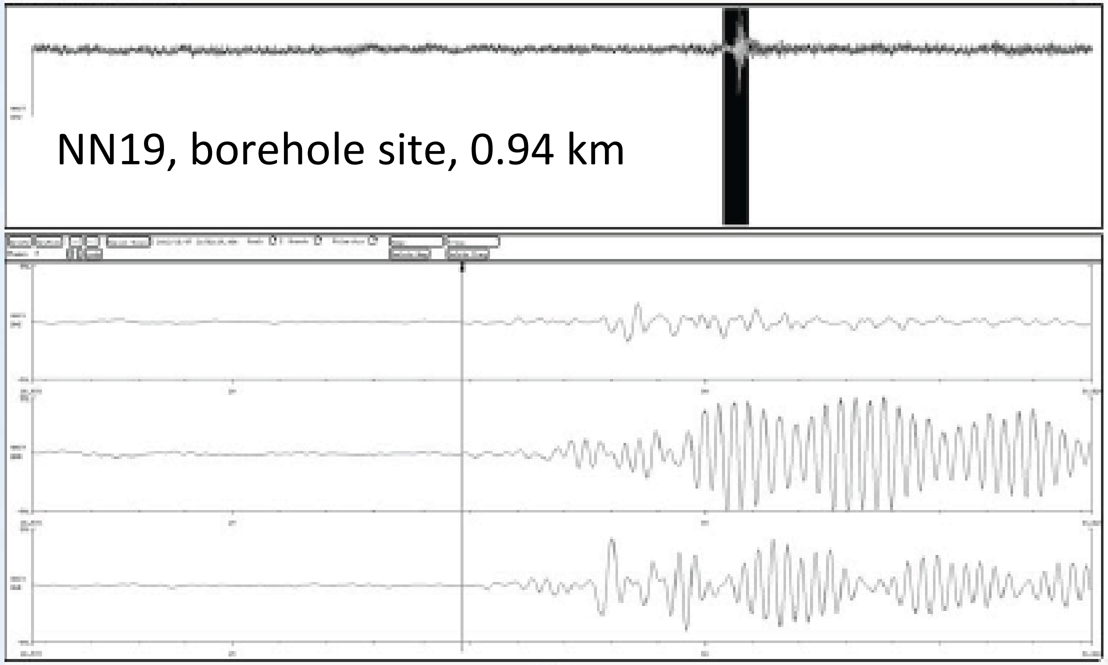
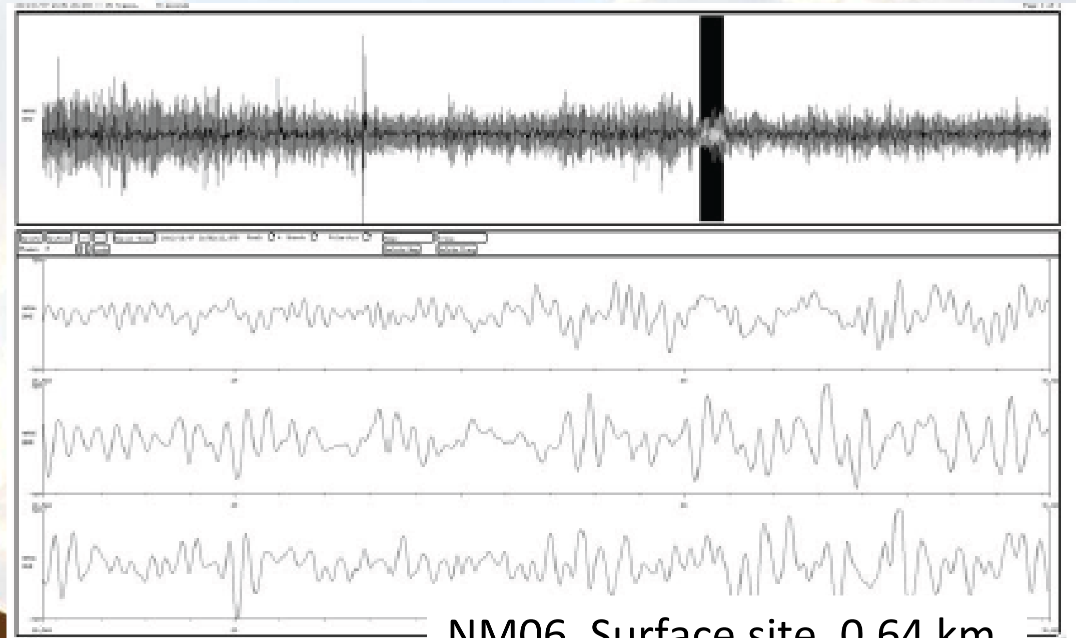
Example seismograms

- 11/07/12
- $M_W = 0.65$
- Z = 970 m bgs



NN19, borehole site, 0.94 km

Station	# P waves	# S waves	Total
Surface stations			
NM03	49	19	68
NM06	53	59	112
NM08	18	8	26
NM22	87	106	193
NM40	8	12	20
NM41	6	5	11
NM42	23	12	35
Borehole stations			
NN07	138	102	240
NN09	199	195	394
NN17	209	198	407
NN18	194	159	353
NN19	212	211	423
NN21	102	59	161
NN24	221	198	419
NN32	158	93	251



NM06, Surface site, 0.64 km

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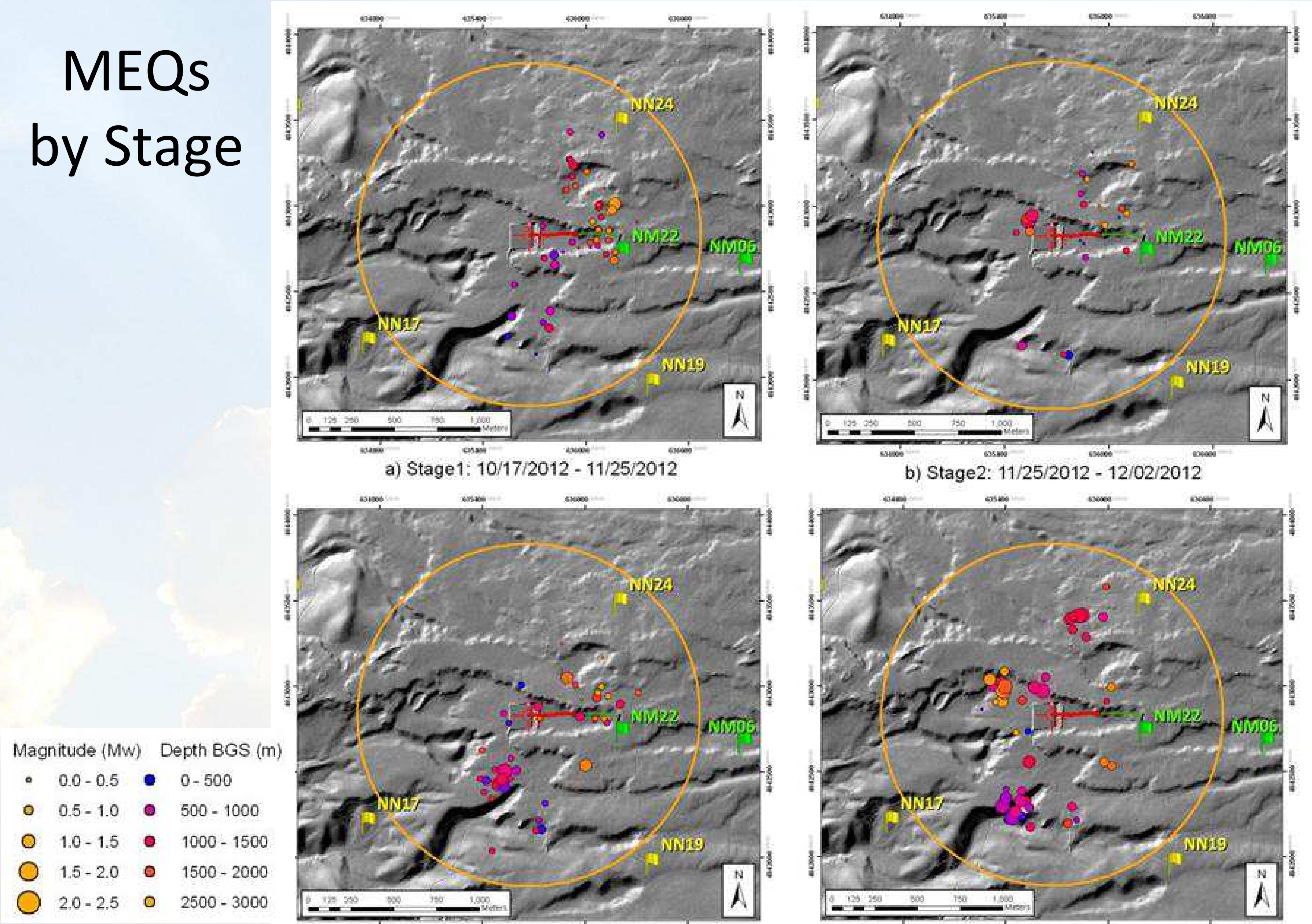
MEQs by Stage



a) Stage1: 10/17/2012 - 11/25/2012

b) Stage2: 11/25/2012 - 12/02/2012

c) Stage3: 12/03/2012 - 12/07/2012

d) Stage4: After 12/07/2012 (Shut-In)

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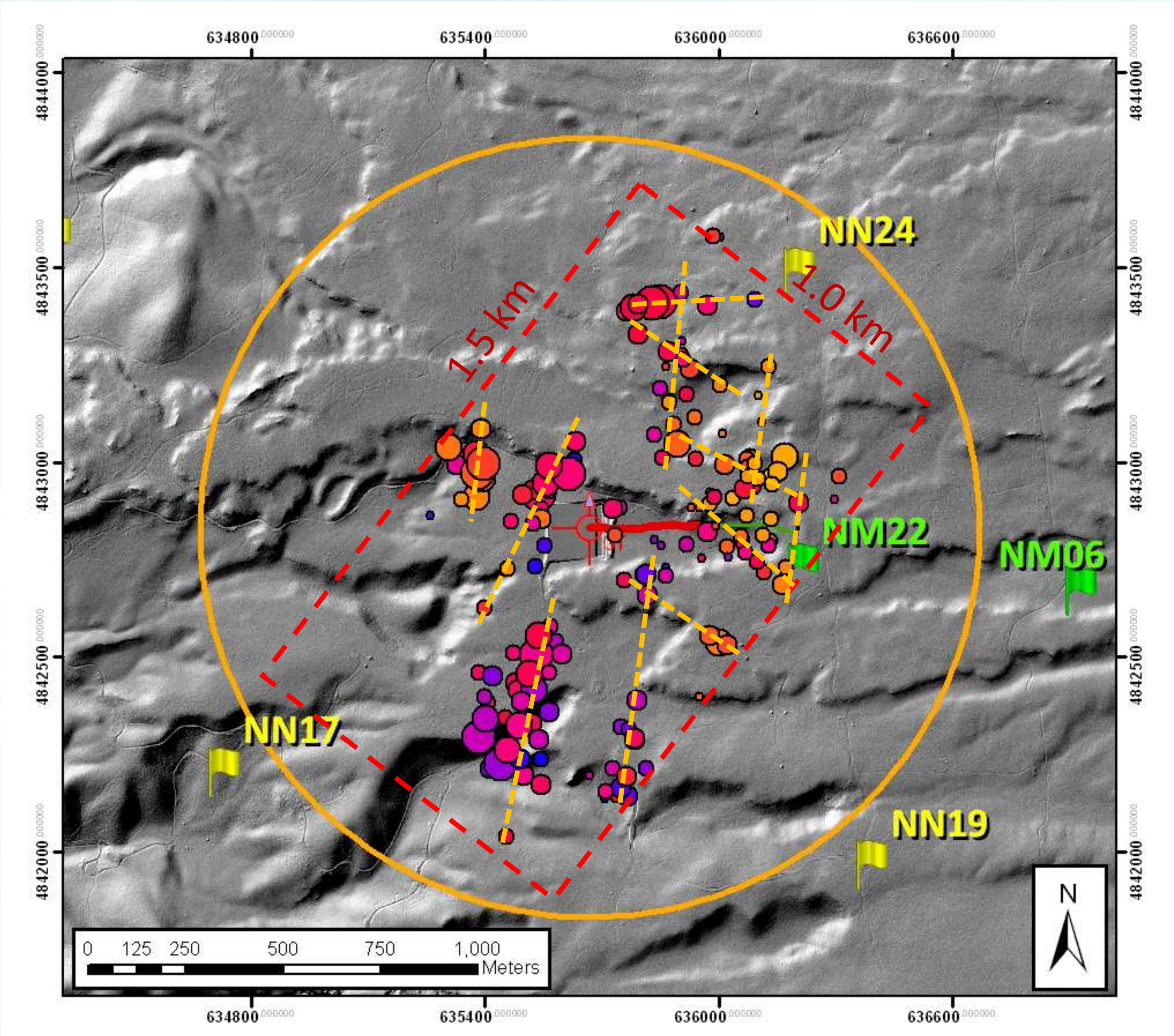
EGS Reservoir Created: Map View



EGS Reservoir

- Elongate NE-SW
- 1.5 x 1.0 km
- $V_{stim} \approx 1.5\ km^3$
- NNE-SSW lineaments

Magnitude (Mw)	Depth BGS (m)
0.0 - 0.5	0 - 500
0.5 - 1.0	500 - 1000
1.0 - 1.5	1000 - 1500
1.5 - 2.0	1500 - 2000
2.0 - 2.5	2500 - 3000

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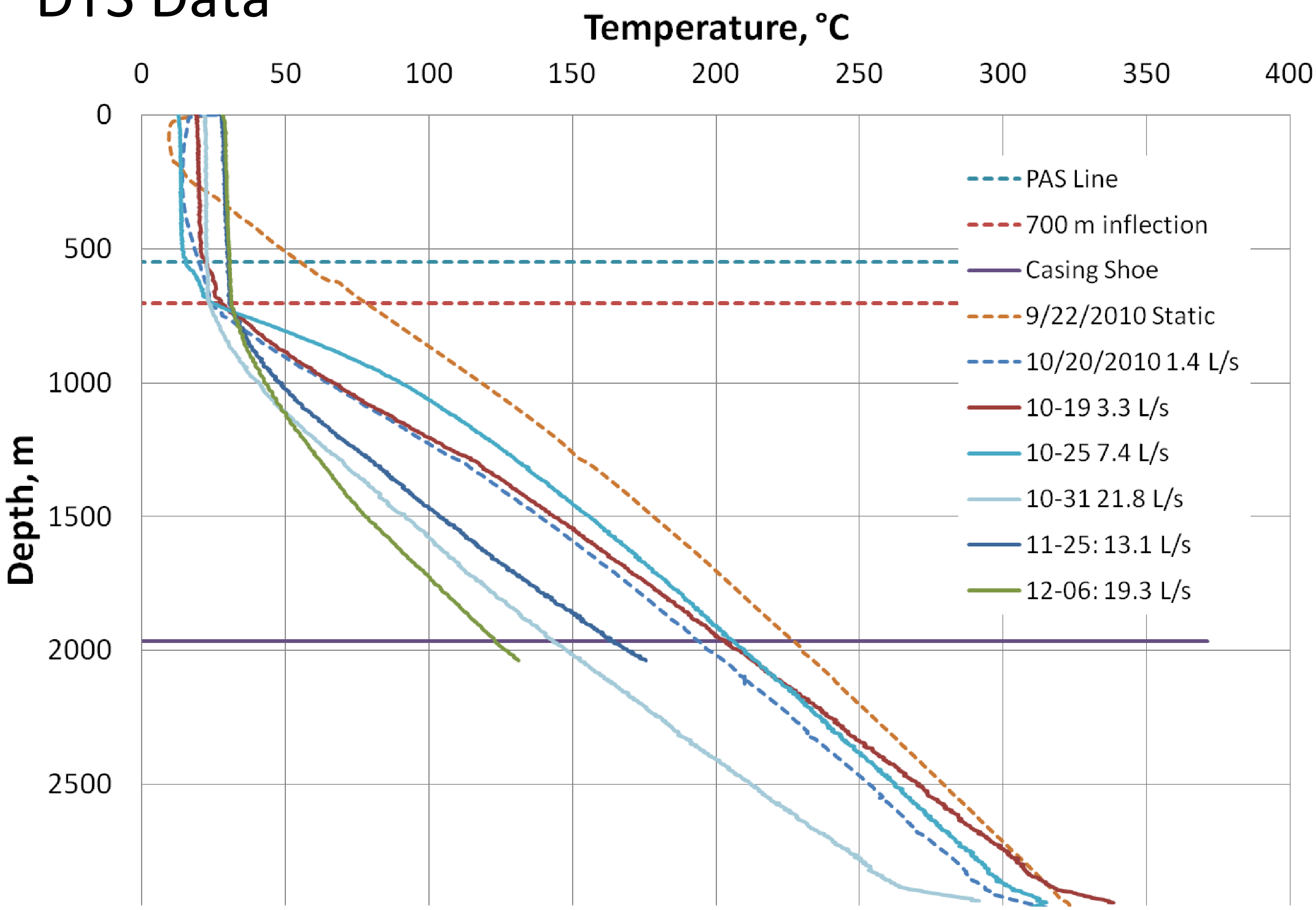
DTS Data



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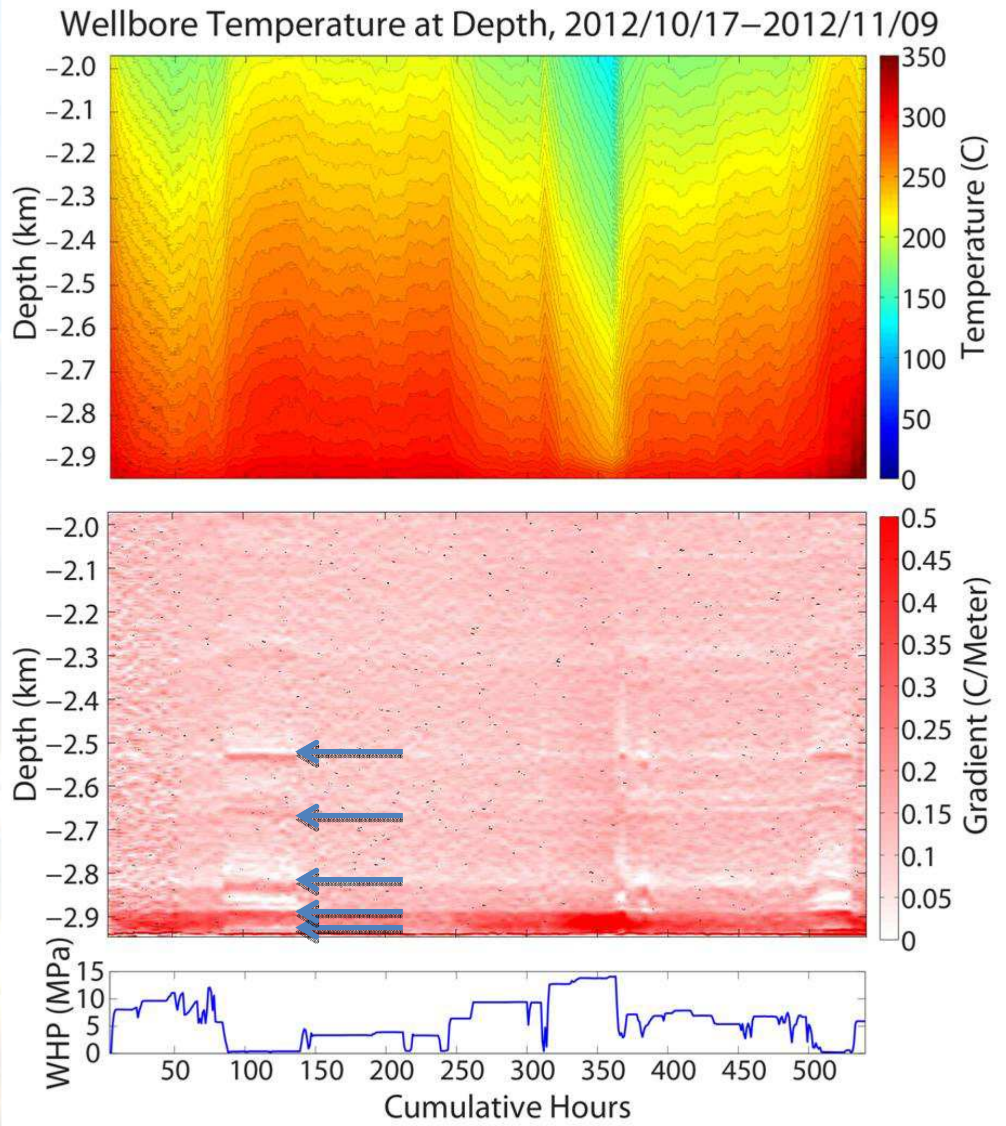
Stage 1 DTS Results in Open Hole

- Two or more permeable zones between 2.88 and 2.95 km take majority of the injected fluid at start
- Darker red color after higher pressures indicates improvement – zones take for fluid and therefore cool more
- Stimulated at pressures above 12.5 MPa
- Other small permeable zones exist around 2.55, 2.67 and 2.85 km
- DTS #1 failed on Nov. 9
- DTS #2 lowered on Nov. 25 but only reached 2105m before likely settling on ledge, just 130 m into open hole



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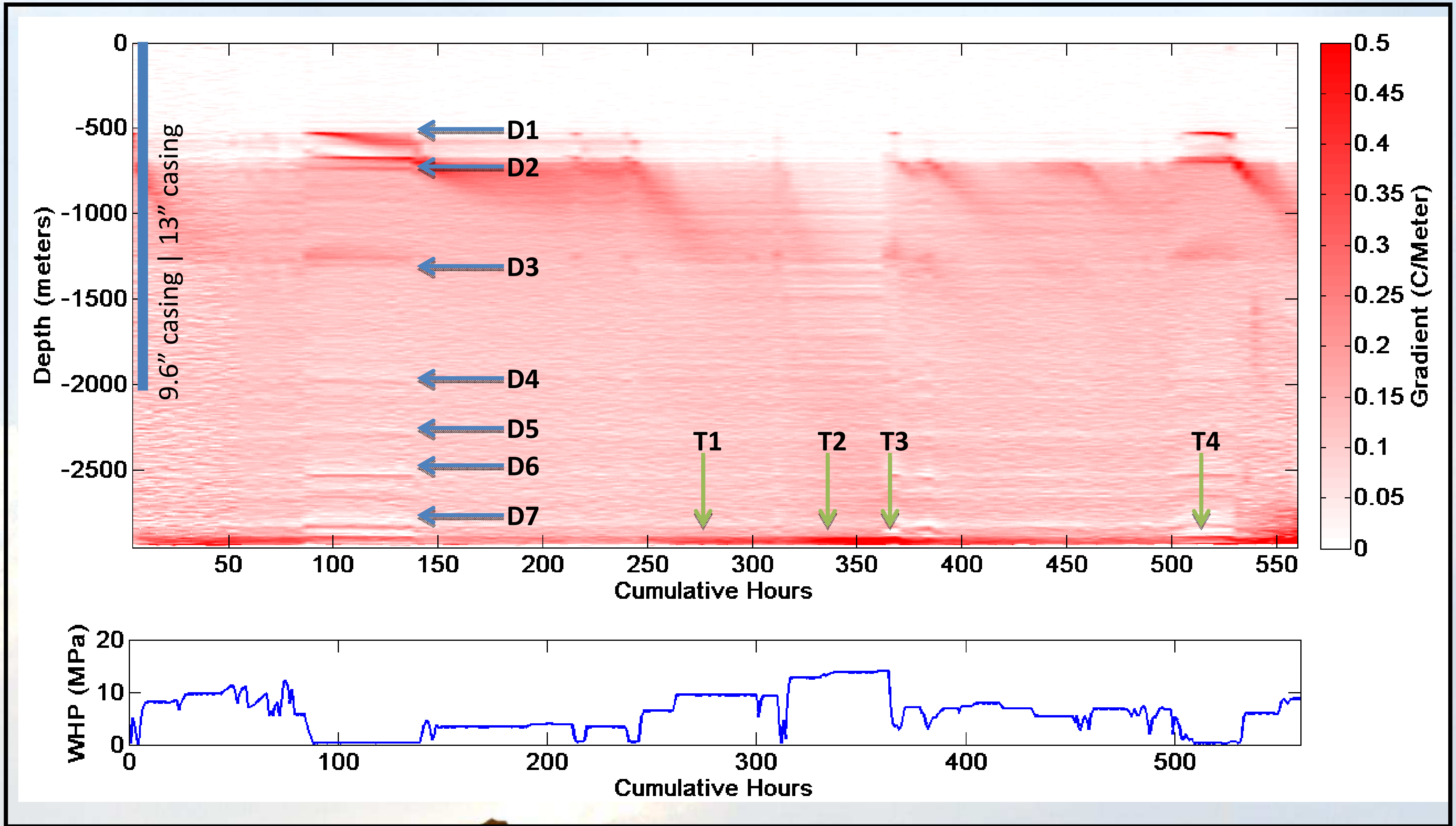
Stage 1 DTS: Complete hole



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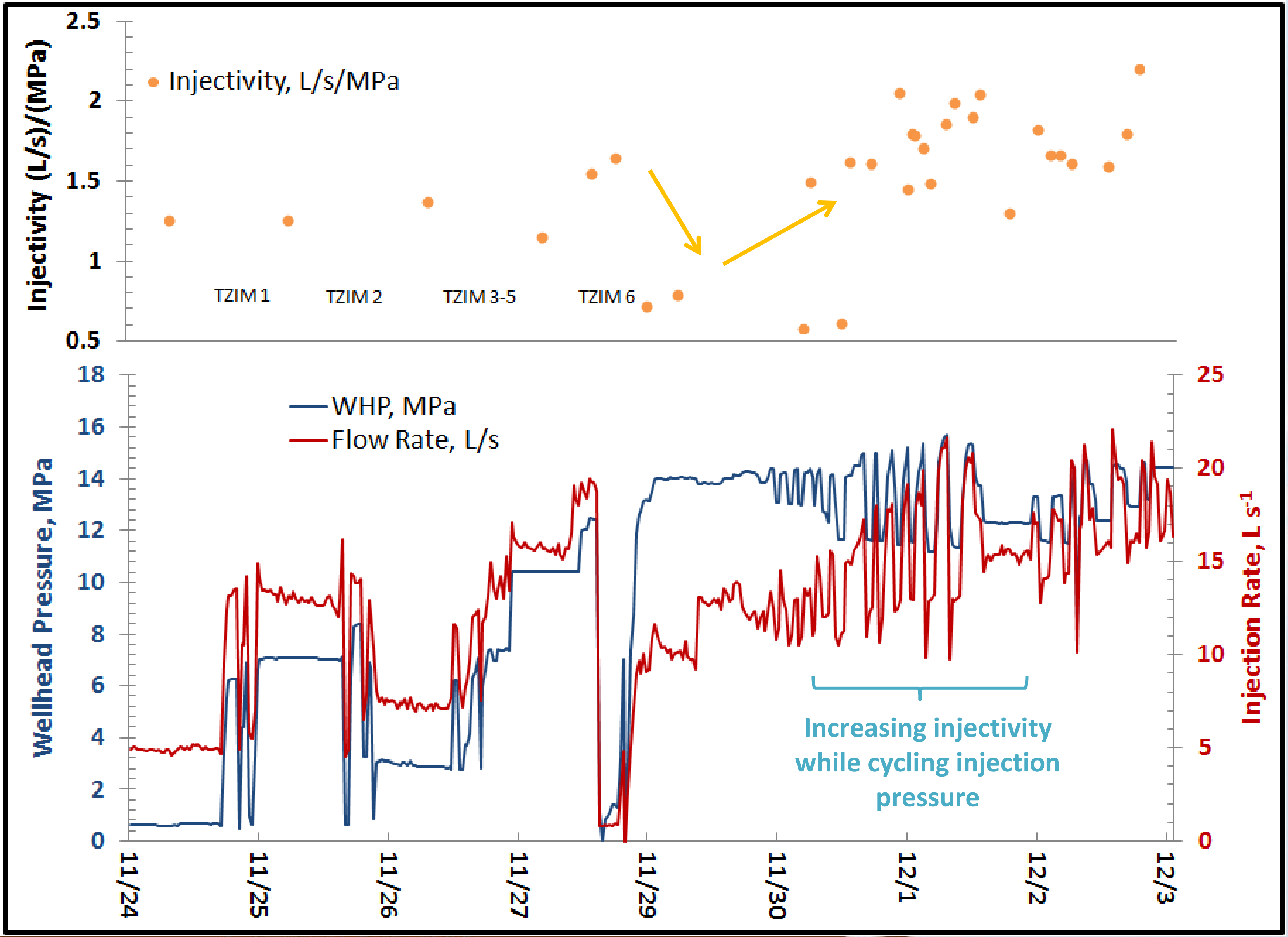
TZIM and Stage II



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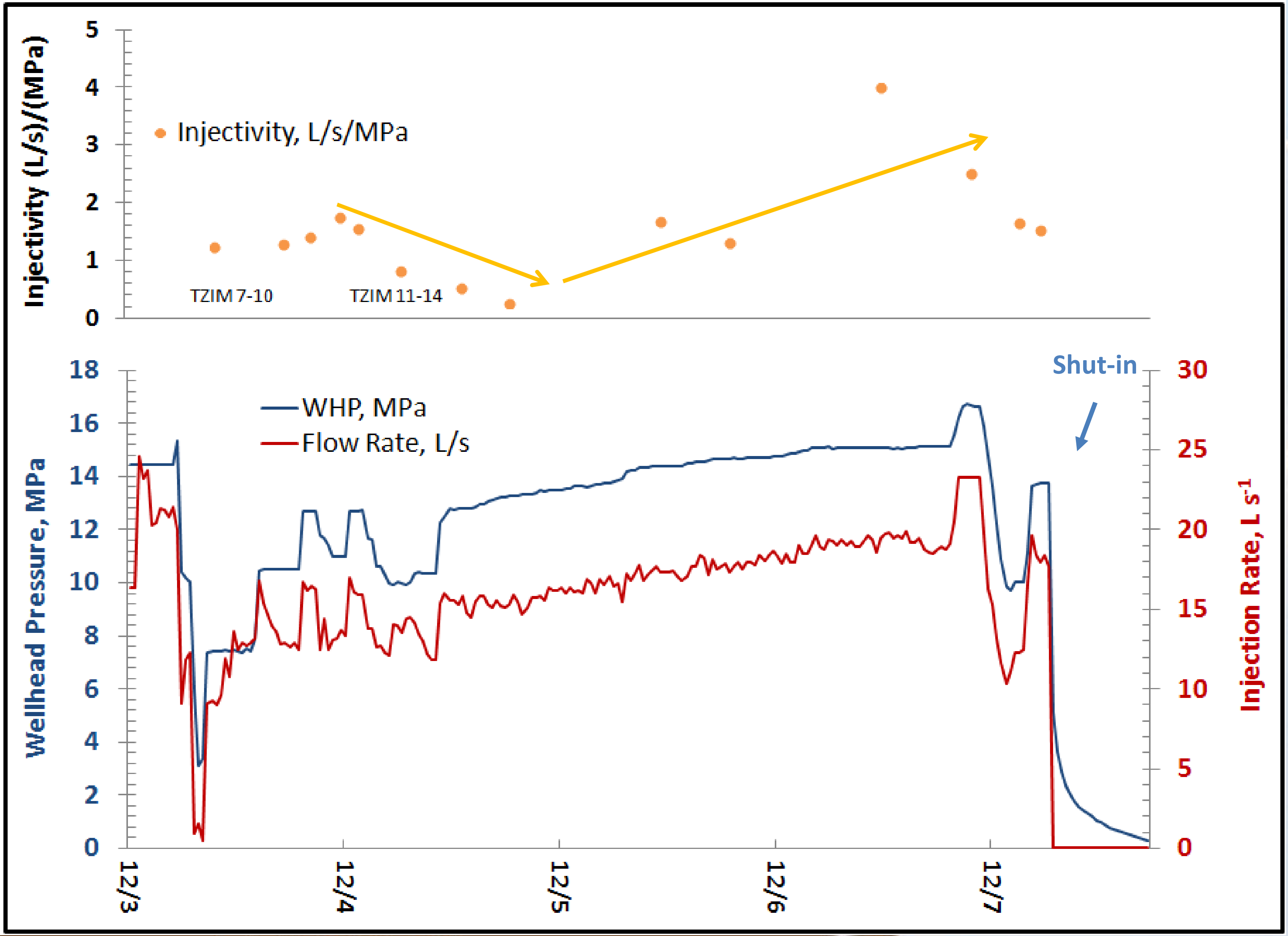
Stage III and shut-in



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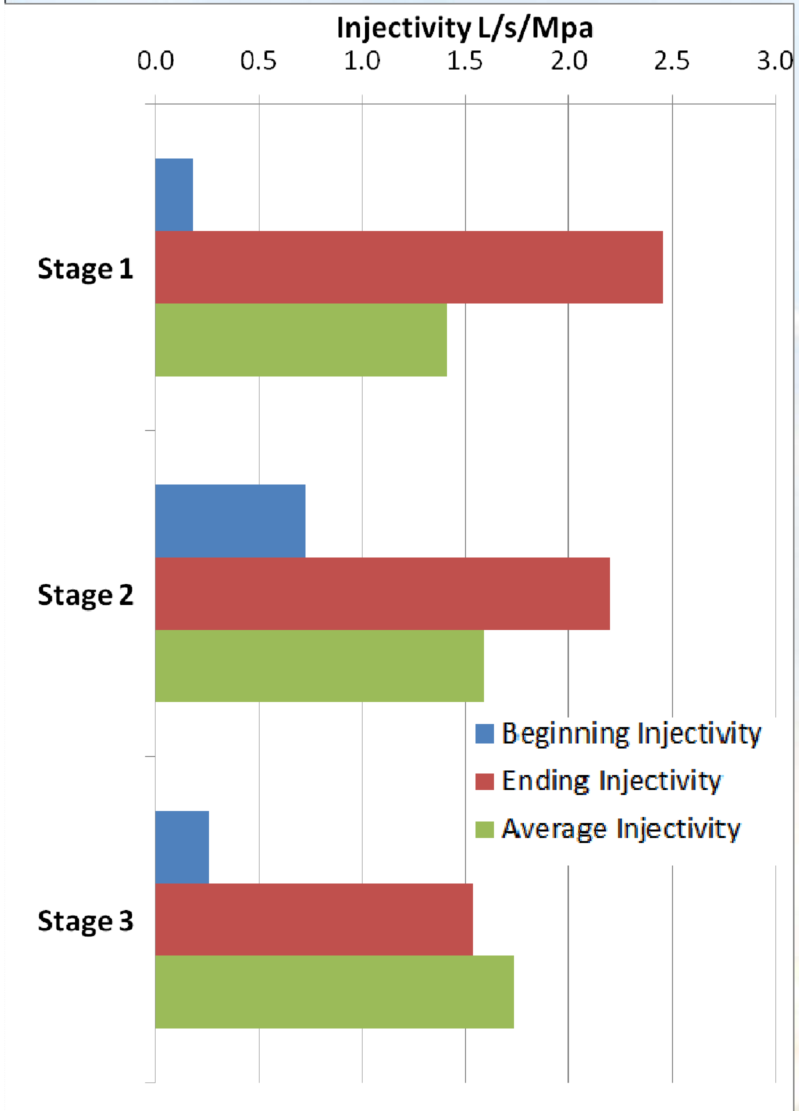
Multizone Stimulation Results



Stage 1 – Deep zones 2880-2950m stimulated

- 10/27/2012-11/2/2012: 27% V_{tot}
- Total HP pumping time – 104 hours
- Maximum WHP 13.8 MPa (2040 psi)

Stage 2 – Pump TZIM 1

- 11/25/2012-12/3/2012: 22% V_{tot}
- Seal permeable zones between 2880-2950 m
- At end of stage zones around 2080 m open up
- Total HP pumping time – 130 hours
- Maximum WHP 15.2 MPa (2200 psi)

Stage 3 – Pump TZIM 2

- 12/3/2012-12/07/2012: 14% V_{tot}
- Seal permeable zones ~ 2080 m
- Total HP pumping time – 101 hours
- Maximum WHP 16.7 MPa (2420 psi)

All Stages – (incl. LP stage 11/3-11/24: 37 V_{tot})

- Total injected volume 41,325 m^3 (11,000,000 gal)
- Maximum WHP 16.7 MPa (2420 psi)
- 227 seismic events located10/29/2012-02/18/2012

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Summary

- In April 2012, after more than two years of permitting and planning BLM & DOE issued FONSIs on stimulation
- Phase 2.1 began with ordering of pumps and MSA equipment followed by extensive field preparations for stimulation
- Seven week stimulation: Oct. 17 – Dec. 7, 2012
- EGS reservoir created with potential volume of 1.5 km^3
- TZIM allowed stimulation of multiple zones
- MSA performed well
- Challenges overcome
  - Fast procurement and installation
  - Winter weather starting in October
  - Pump breakdowns

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Next Steps: Summer 2013

- Flow test and fluid sampling for tracer returns/geochemical sampling
- Post-TZIM degradation injectivity test
- Video camera run to check for:
  - Casing leaks (cause of shallow seismicity?)
  - Shoe integrity
  - Ledge (?) at 2105 m and possible dropped sinker bar
- Post-stimulation BHTV run
- Design well course from stimulation seismicity

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Newberry EGS

Enhanced Geothermal Systems

DEMONSTRATION

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