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Newberry EGS Demonstration

Project Officer: Lauren Boyd
Total Project Funding: $43.8 m
April 22, 2013

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AltaRock Energy

EGS Demonstration Projects

Relevance/Impact of Research

Project Objective: Demonstrate the development and operation of an Engineered Geothermal System

Project Site: NWG 55-29, TD 3067 m, BHT 331ºC

Phase 1 (2009-11): Complete site investigation, permitting and planning with historical data review and baseline data gathering

Phase 2.1 (2012): Install Microseismic Array

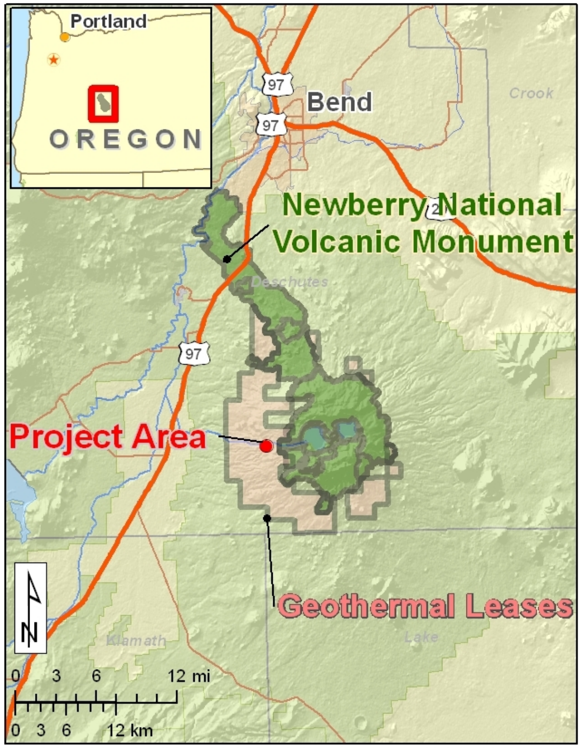
Create EGS reservoir around NWG 55-29.

Stimulate at **least three fracture zones** using diverter technology.

Phase 2.2-2.5 (2013-14): Drill **two production wells** into seismically mapped fracture network

Test well connectivity, productivity and reservoir characteristics.

Phase 3 (2014): Develop conceptual modeling of commercial-scale EGS wellfield and power plant.



Innovation 1: AltaRock TZIM Technology

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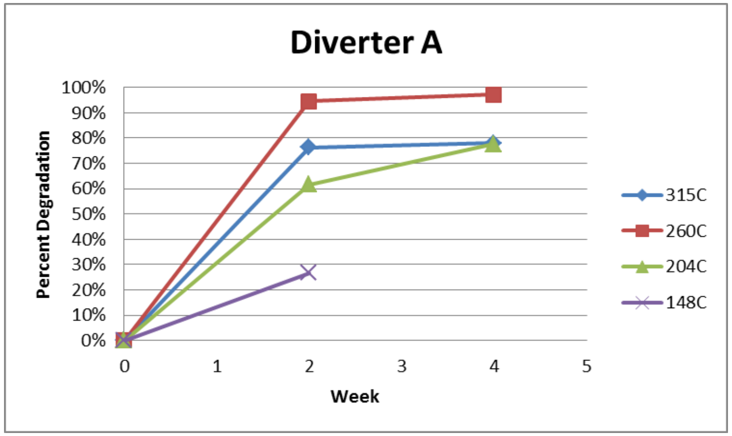
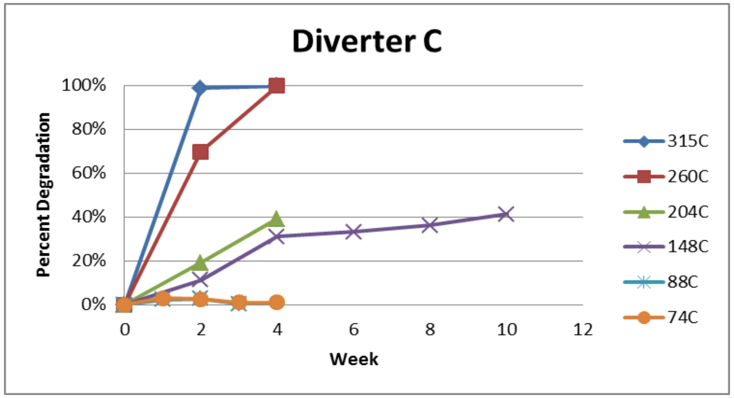
Challenge: Low flow per EGS well

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

- Non-mechanical zonal isolation material
- No rig required during treatment
  - Major cost savings
  - Reduces operational risk
  - Create fractures in succession without moving packer and waiting on rig
- Breakdown products are non-hazardous
- A suite of materials developed that degrade with time and temperature
  - Lab tested from 74°C-315 ° C



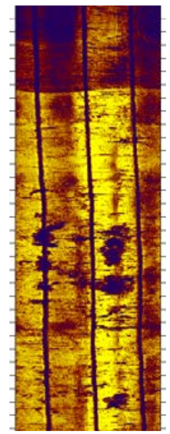


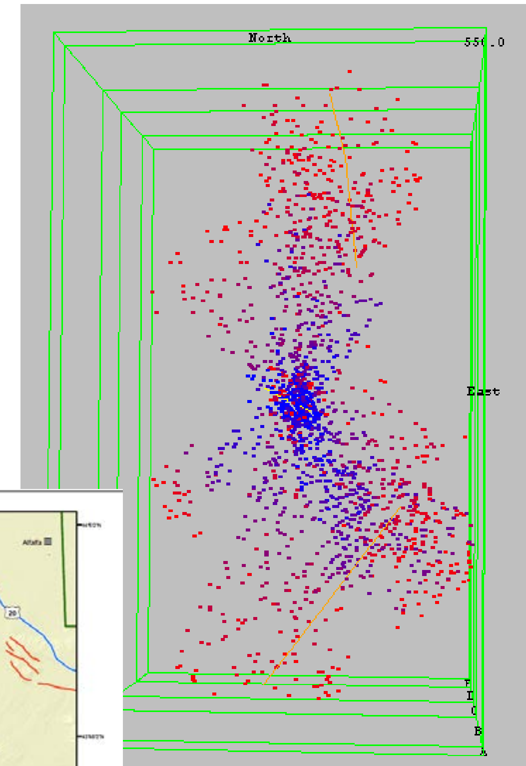
Innovation 2: EGS Characterization tools

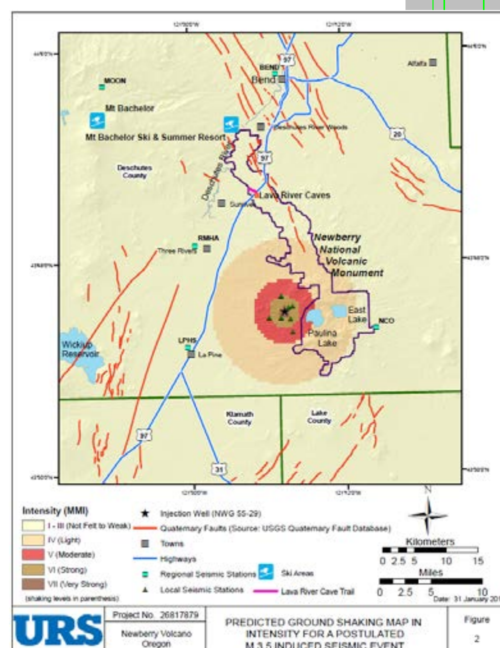
Challenges: Predicting induced seismicity, mitigating seismic risk, and characterizing EGS reservoir

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
- Combination of conservative and non-conservative tracers injected to assess surface area and temperature of stimulated zones.





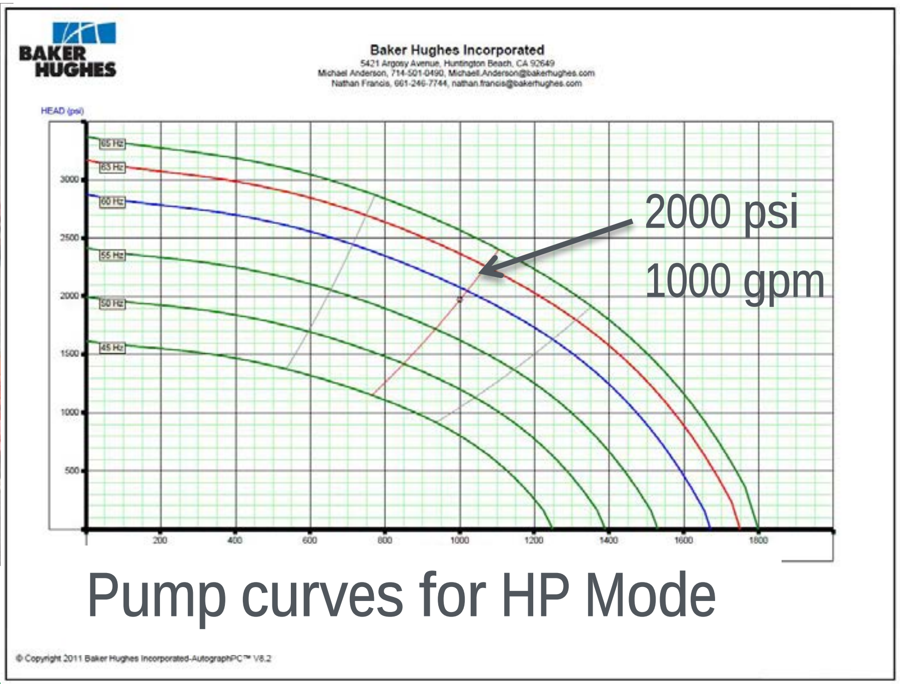


Innovation 3: Stimulation pumps

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

Milestone/ Technical Accomplishment	Date Completed
Phase 1 Planning Report Submitted	August 26, 2011
Stage Gate Passed	November, 2011
Environmental Assessment Submitted	December 20, 2011
BLM and DOE Issue Finding of No Significant Impact	April 5, 2012
Phase 2.1 Begins	April 5, 2012
MSA Acceptance	August 29, 2012
Stimulation Begins	October 16, 2012
Demobilization for Winter Complete	December 20, 2012
Phase 2.1 Report	In Progress (April 2013)

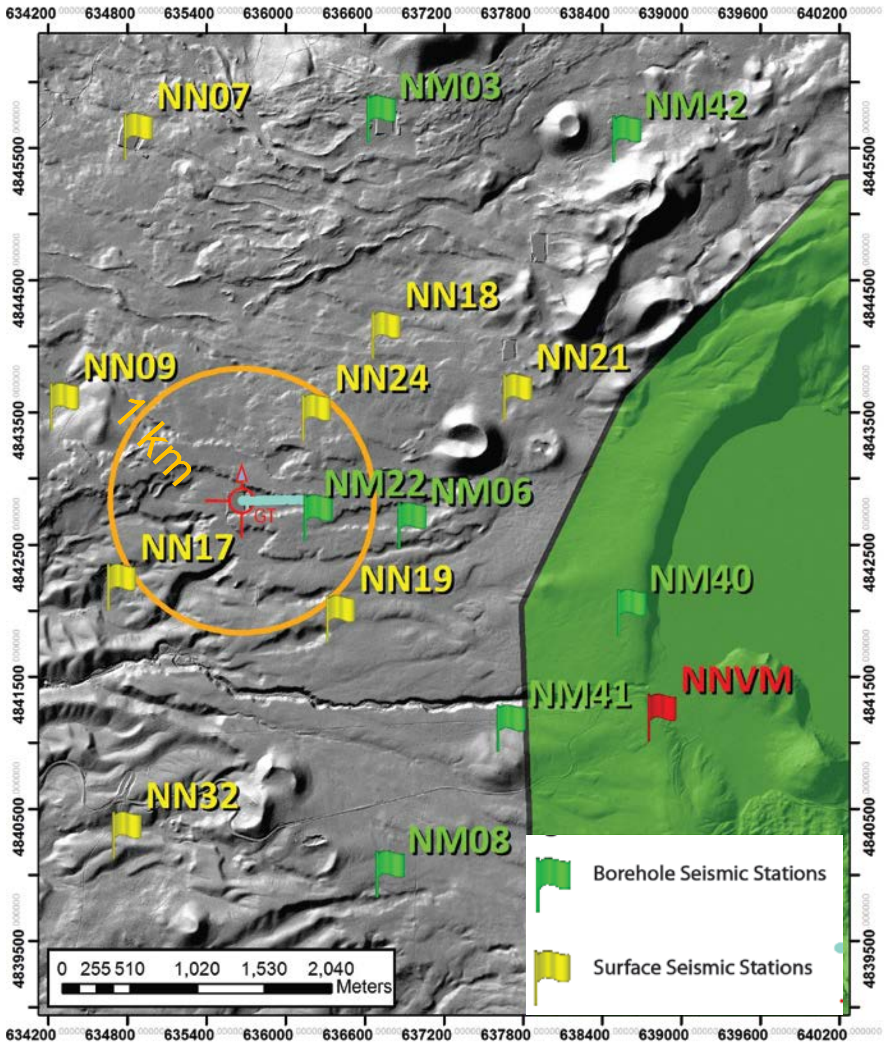
Mapping EGS with Microseismic Array

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)



MSA Installation: May – August 2012

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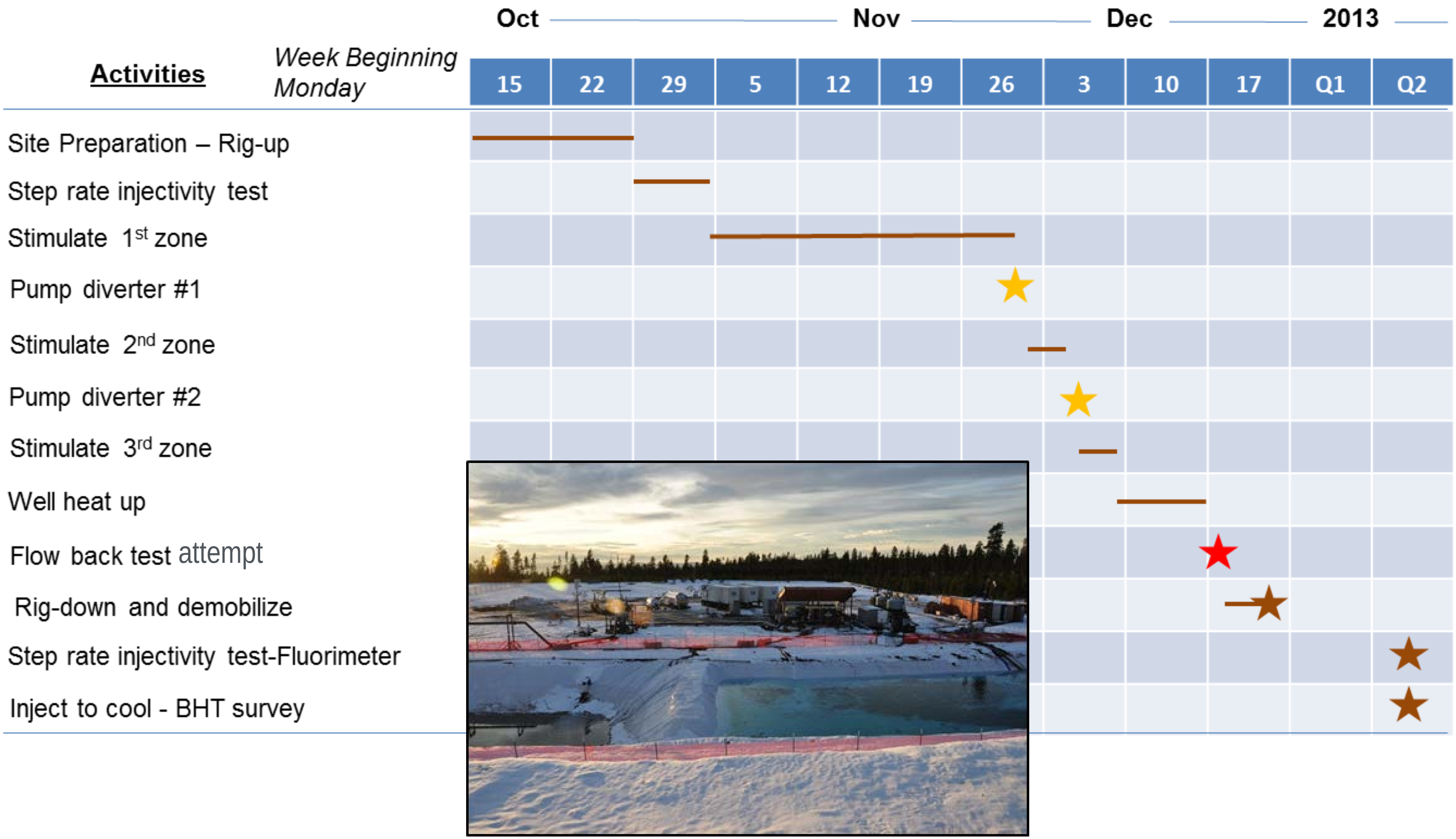
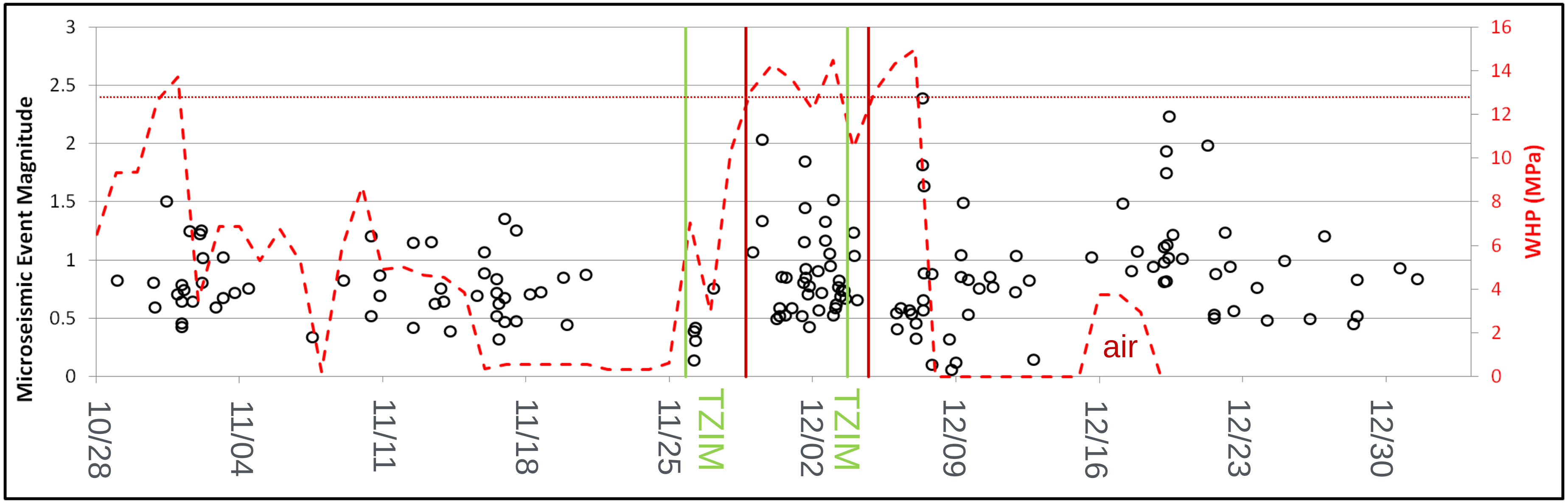
- **Boreholes drilled to get below to water table**
  - 4 existing BH (one deepened)
  - 4 new BH drilled 210-250 m
  - Average 11 drilling days each
  - 3 months total
- **BH geophones**
  - with hole locks for orienting sensors
  - to enable source mechanism calculations.
- **Surface instruments at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

Stimulation of NWG 55-29

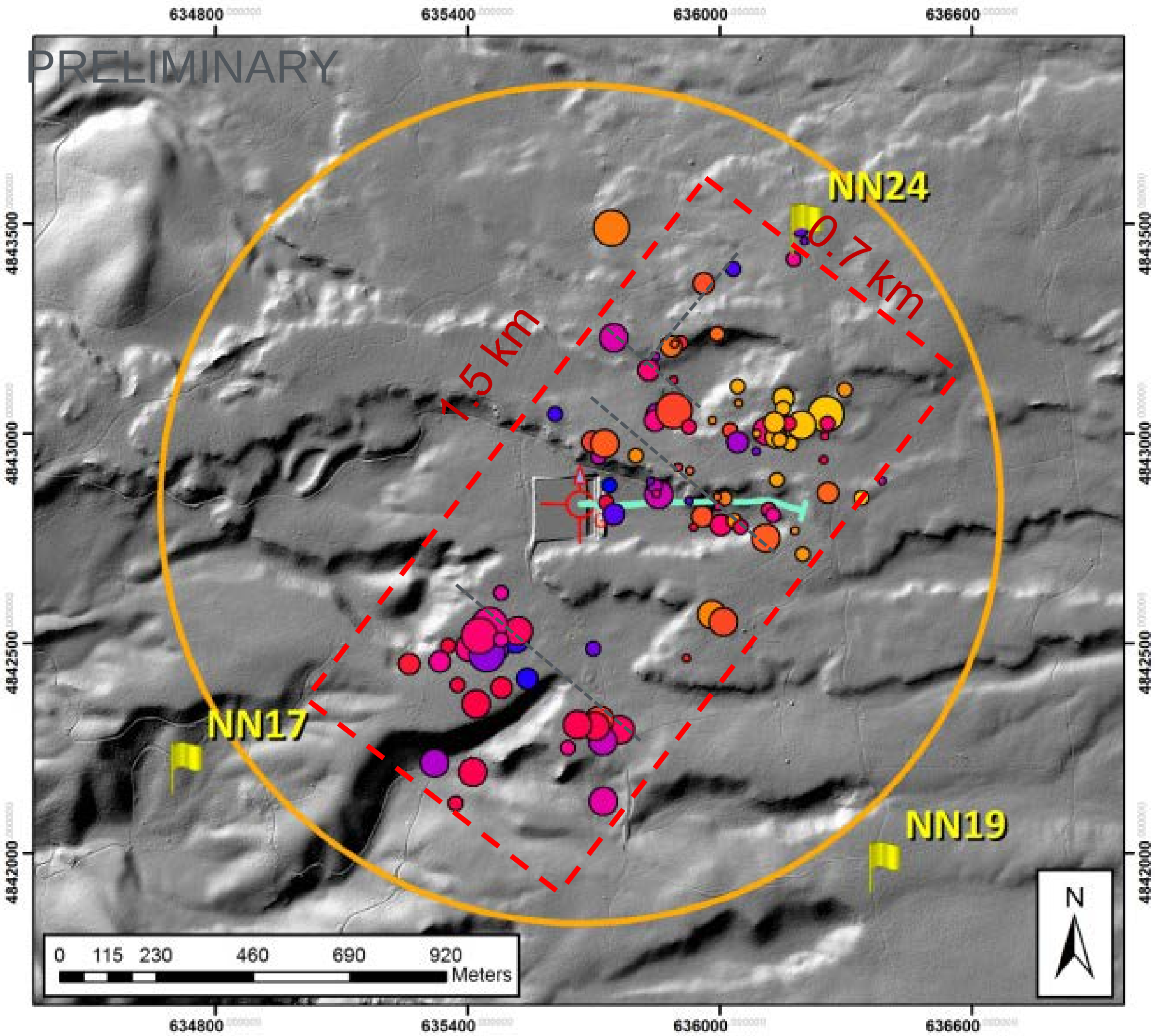


Stimulation pressures and seismicity rates



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

EGS Reservoir Created: Map View



EGS Reservoir

- Elongate NE-SW
- 1.5 x 0.7 km
- $V_{stim} \approx 1.5\ km^3$
- NW-SE lineaments

Stimulation Depths

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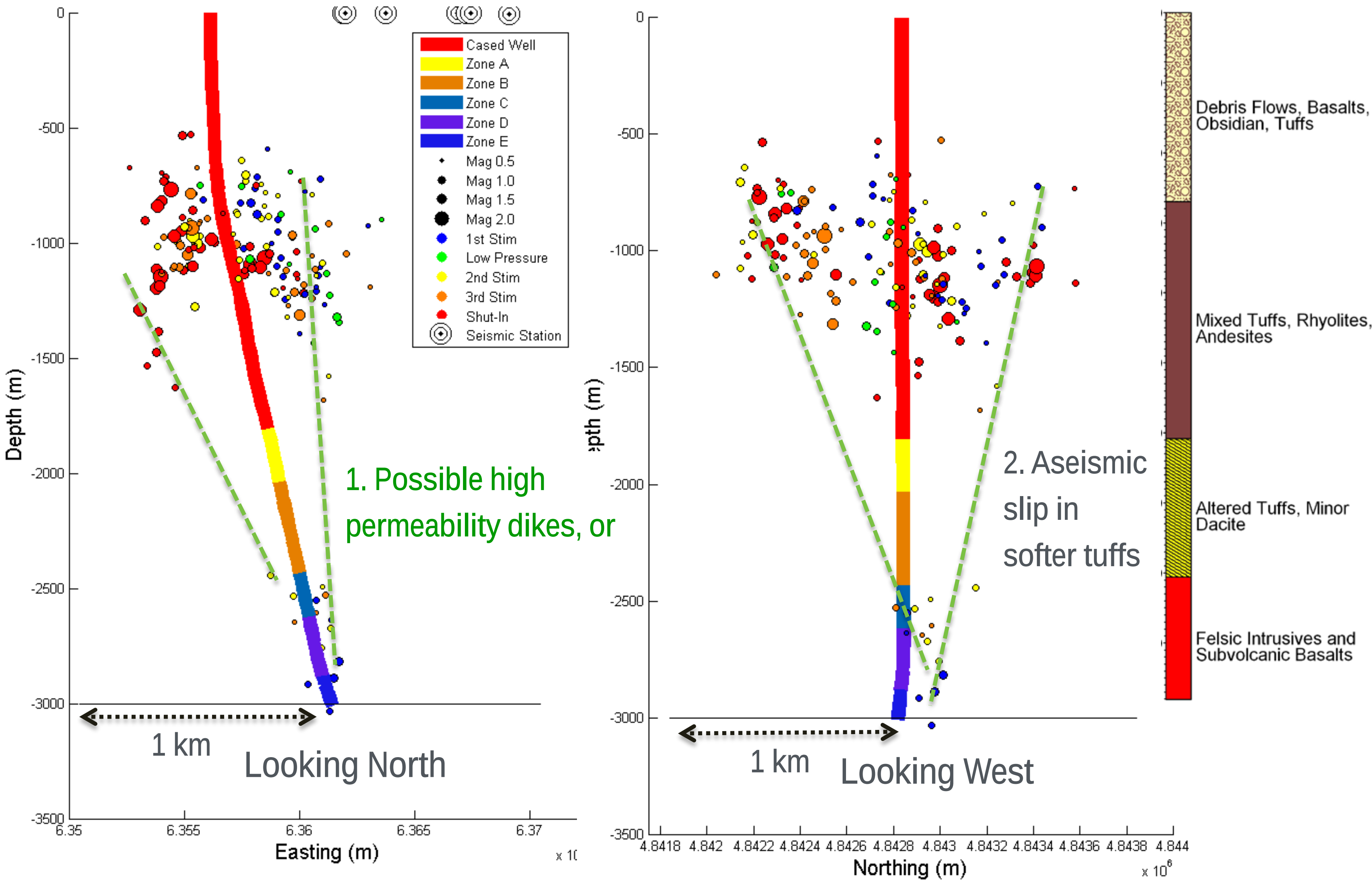

Stage 1 DTS Results in Open Hole

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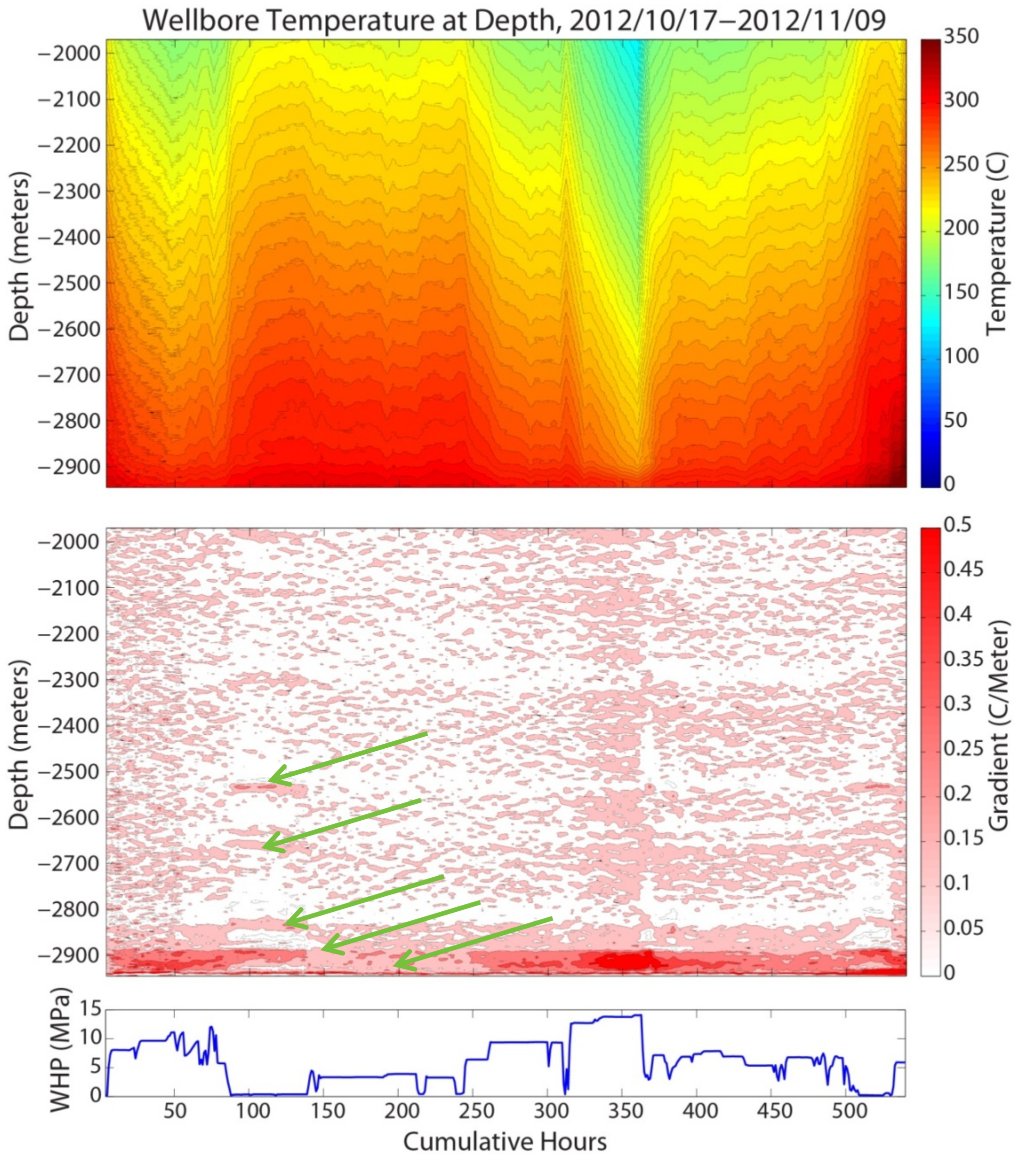
- Two or more permeable zones between 2880 and 2950 m take majority of the injected fluid at start
- Darker red color after higher pressures indicates improvement – zones take for fluid and therefore cool more
- Stimulated at pressures above 12.5 MPa
- Other small permeable zones exist around 2550m, 2670m and 2850m
- DTS #1 failed on Nov. 9
- DTS #2 lowered on Nov. 25 but only reached 2105m before likley settling on ledge, just 130 m into open hole



Temperature and stimulation depths

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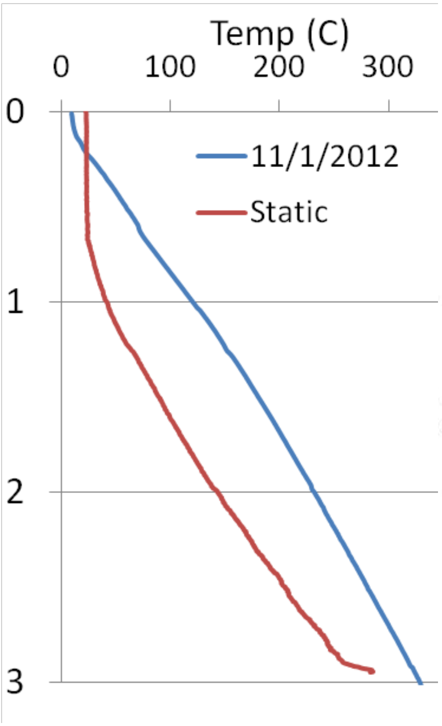

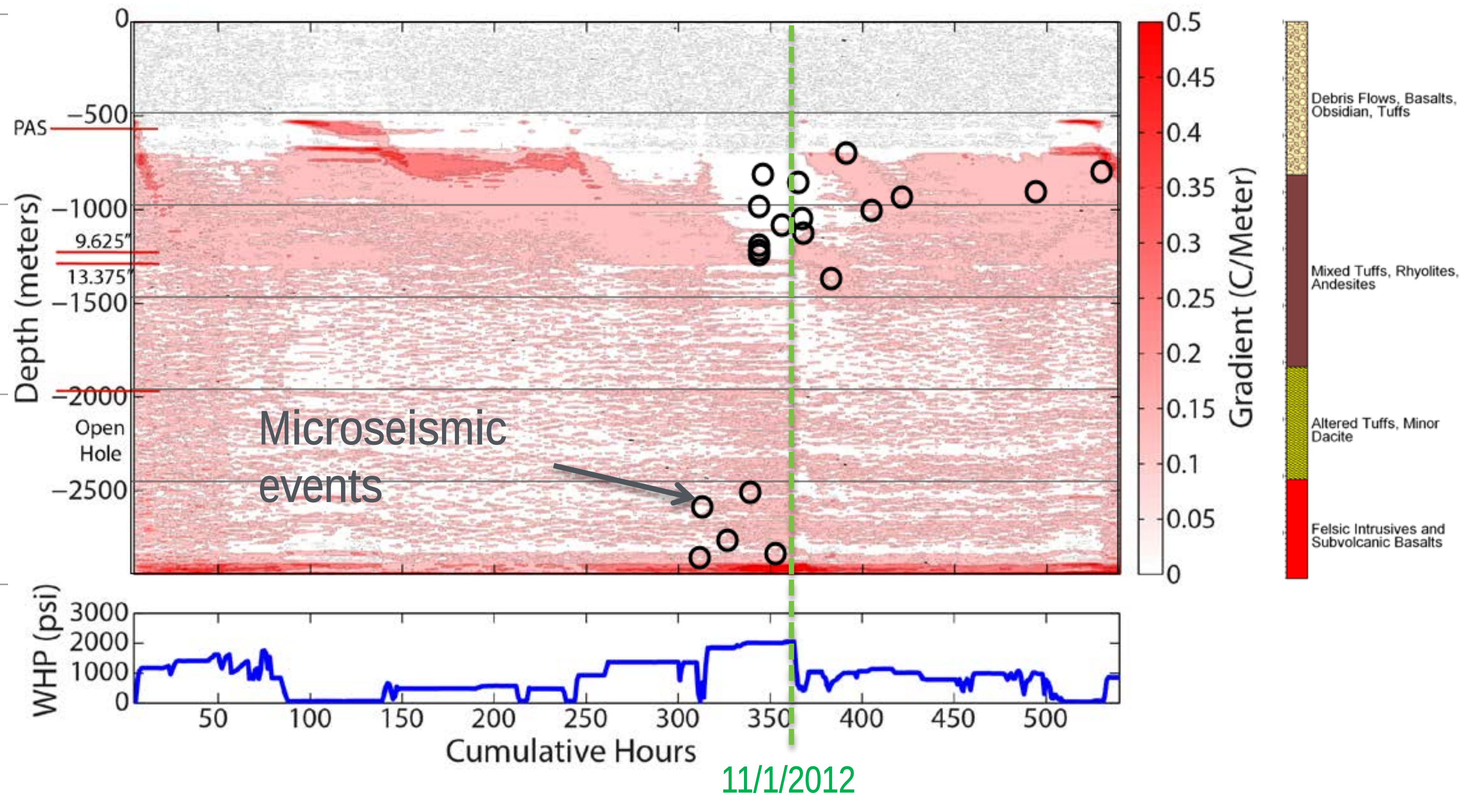

- Although seismicity occurred above depth of 1500 m bgs, temperature profiles and gradients over 550 hour period indicate majority of fluid exited below 2500 m depth.

WHP, Flow and Injectivity

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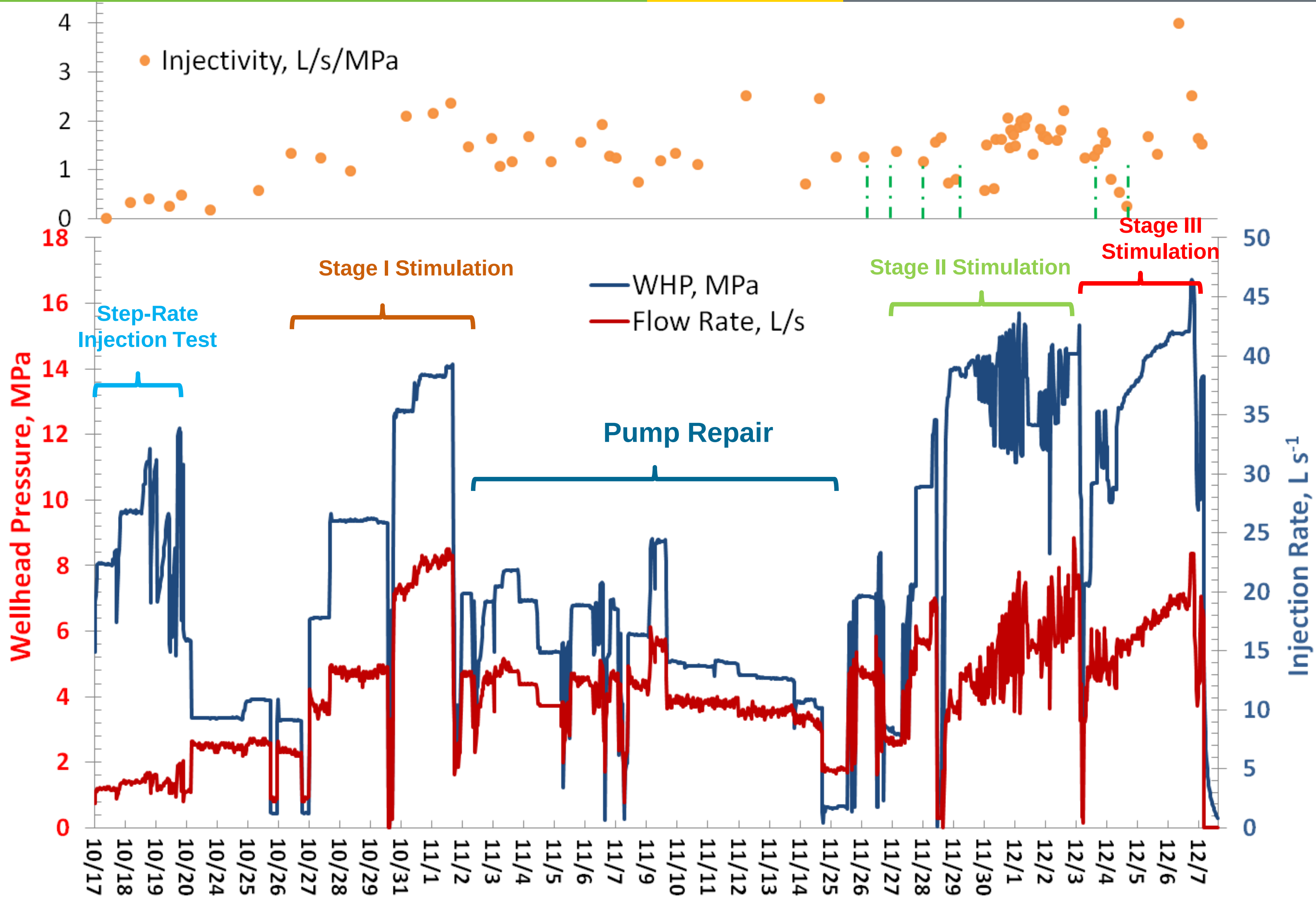
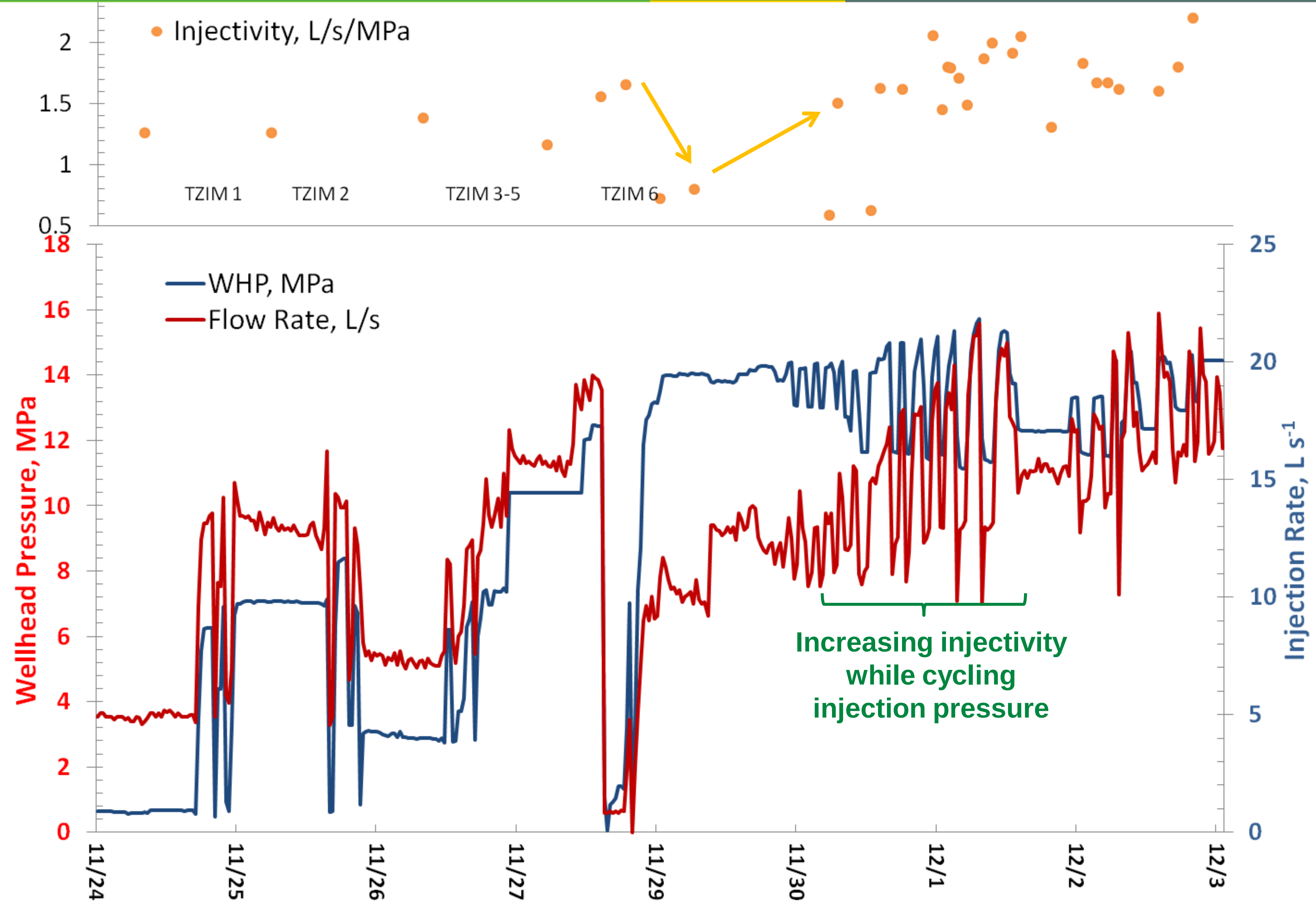


TZIM and Stage II



Stage III and shut-in

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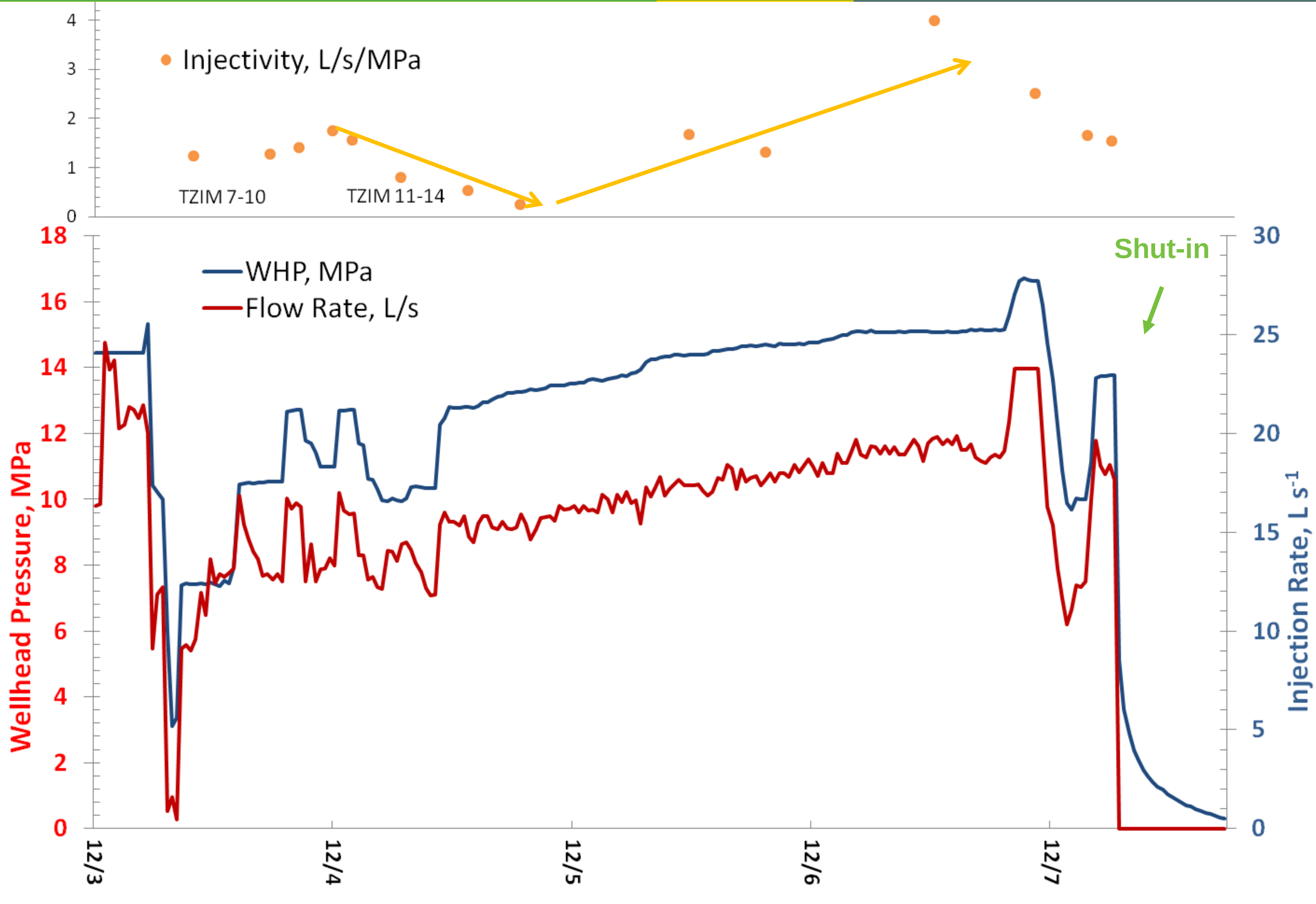
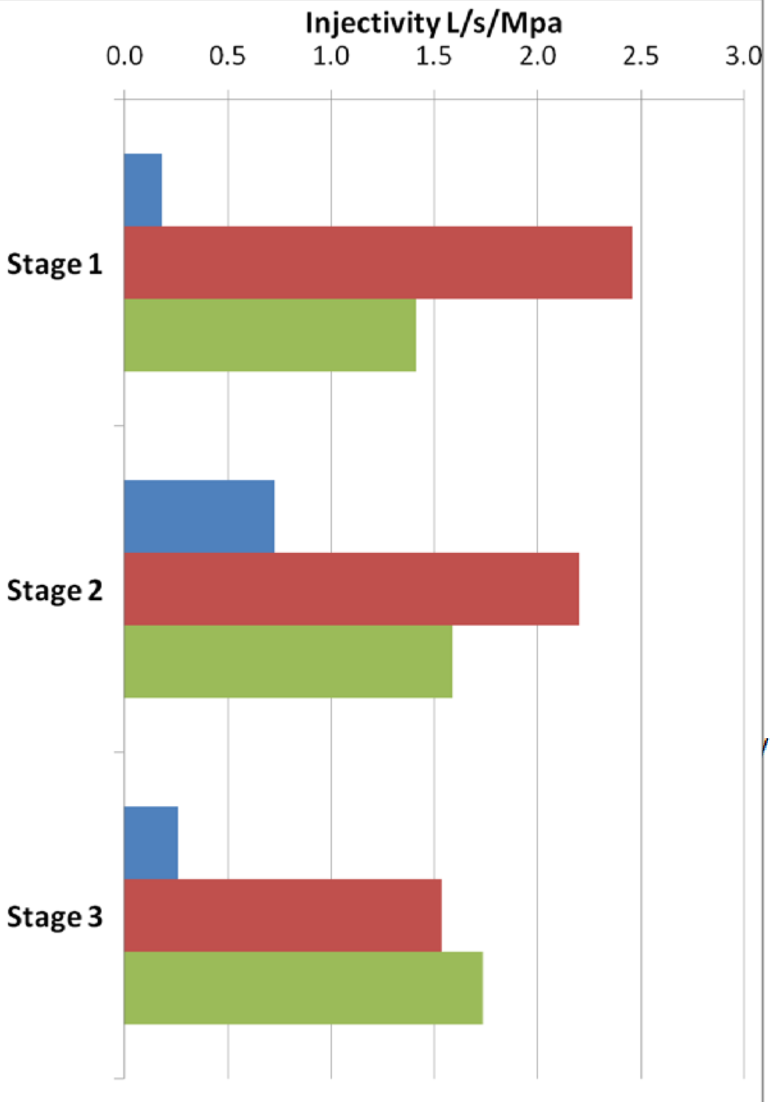


Multizone Stimulation Results



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

Future Directions

- Finish Phase 2.1 report and pass DOE Go/No-Go
- Possible flow test and fluid sampling for tracer returns/geochemical sampling
  - Collaborators: LBNL, LANL, INL, EGI/Utah, NETL/OSU
- Conduct post TZIM degradation injectivity and fall-off analysis
- Low-amplitude seismic emission analysis: vert. array of 12 geophones in 6 holes
- ExPro-video run to 2105 m (6900 ft) (check ledge and possible fish)
- BHTV and fluorimeter run (requires inject-to-cool)
- Design well course from stimulation seismicity
- Drill first production well (Q3/Q4 2013)
- Stimulate production well, if needed - conduct 7-day connectivity test
- Plan and drill second production well (2014)
- Conduct 30-day multi-well connectivity test

Milestone or Go/No-Go	Status & Expected Completion Date
Post-stimulation Stage Gate	Report in progress: Complete Q2 2013
Post-stimulation well tests	Planning: Complete June 2013

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
  - Accelerated procurement and installation
  - Winter weather starting in October
  - Pump breakdowns
  - Interpretation of shallow seismicity (in progress)

Project Management

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Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
4/1/2010	4/1/2010	9/30/2014	9/30/2014

Budget:

Federal Share	Cost Share	Planned ExpensesTotal	Actual Expenses to 12/31/2012	Value of Work Completed to Date	Funding needed to Complete Work
$21,450,000	$22,358,461	$43,717,304	$9,288,281	80%	$34,429,023

Collaborative projects

- K. Rose/NETL/OSU: Novel use of 4D Monitoring Techniques to Improve Reservoir Longevity and Productivity in Enhanced Geothermal Systems
- Ghassemi/OkU: Geological and Geomechanical Framework for the Analysis of MEQ in EGS Experiments
- P. Rose/ EGI-UU: Tracers: Fracture Evolution following Hydraulic Stimulation within an EGS Reservoir
- Waibel/Davenport: Validation of Innovative Exploration Technologies for Newberry Volcano
- O'Connell/WLA-Fugro: Noise and Coda Correlation Data into Kinematic and Waveform Inversions With Microearthquake Data for 3D Velocity ...
- Templeton/LLNL: Matched field processing for EGS

Additional Info: Publications

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Forum and Date	Paper Title	Authors
GRC 2010 - Presentation and Publication	Newberry Volcano EGS Demonstration	Osborn, Petty, Nofziger and Perry
GRC 2010 - Presentation and Publication	Injection Induced Seismicity and Geothermal Energy	Cladouhos, Petty, Foulger, Julian and Fehler
AGU 2010 - Abstract and Presentation	Stimulation Controls and Mitigation of Induced Seismicity for EGS Projects	Petty, Cladouhos, Osborn, and Iovenitti
GRC 2010 - Presentation and Publication	Development of a Downhole Fluorimeter for Measuring Flow Processes in Geothermal and EGS Wellbores	Rose, Fayer, Olsen, Petty and Bour
Stanford 2011 - Presentation and Publication	Fluid Diversion in an Open-Hole Slotted Liner – A First Step in Multiple Zone EGS Stimulation	Petty, Nofziger, Bour and Nordin
	The role of a stress model in stimulation planning at the Newberry Volcano EGS Demonstration	Cladouhos, Petty, Callahan, Osborn, Hickman and Davatzes
GRC 2011 - Presentation and Publication	Newberry Volcano EGS Demonstration Stimulation Modeling	Cladouhos, Clyne, Petty, Osborn, Nofziger, Callahan, Nordin, Sonnenthal, Davatzes, and Hickman
	Newberry Volcano EGS Demonstration – Phase I Results	Osborn, Petty, Cladouhos, Iovenitti, Nofziger, Callahan and Perry
Stanford 2012- Presentation and Publication	Newberry Volcano EGS Demonstration—Phase I Results	Cladouhos, Osborn, Petty, Bour, Iovenitti, Callahan, Nordin, Perry, and Stern
AGU 2012 - Abstract and Poster	Newberry Volcano EGS Demonstration: Plans and Results	Cladouhos, Petty, Moore, Nordin, De Rocher, Callahan, and Perry
Stanford 2013 - Presentation and Publication	Microseismic Monitoring of Newberry Volcano EGS Demonstration	Cladouhos, Petty, Nordin, Moore, Grasso, Uddenberg, Swyer, Julian, and Foulger
	Improving Geothermal Project Economics with Multi-zone Stimulation: Results from the Newberry Volcano EGS Demonstration	Petty, Nordin, Glassely, and Cladouhos

Additional Info: Meeting DOE EGS Program Objectives

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Project Tasks Include All Essential Elements of EGS Development

Phase I (actual)

- Site Selection - surface analysis, well logs and well construction
  - Selected NWG 55-29 from two available, existing full-size bore holes as stimulation candidate and verified excellent well bore conditions.
  - Contributed to Oregon LiDAR Consortium for enhanced surface faulting and topographic imaging.
  - Developed comprehensive local and regional geoscience model based on existing and recent data.
  - Temple/USGS conducted borehole televiewer survey (see supplemental slide)
    - From casing shoe at 6435 ft and 200ºC, to 8860 ft and instrument thermal saturation at 265ºC.
    - Identified 351 fractures and; dominant fracture sets oriented NNE-SSW, dipping 50ºE and 50ºW
    - Clearly defined borehole breakouts, and measured consistent azimuth of minimum horizontal stress, Sh_{min}, oriented at 092º±16.6º, as predicted by initial resource model.
  - Conducted baseline injectivity test, identifying minimum stimulation pressure of 1153 psig
  - Maximum stimulation pressure limited by casing burst rating of 3566 psi
- Reservoir Characterization - downhole instruments and use of data in modeling
  - Installed and calibrated surface seismometers; designed borehole seismometer network
  - Texas A&M measured cuttings and core rock properties
  - LBNL constructed native state THMC model
  - Compiled AltaStim fracture model of stimulation plan

Additional Info: Meeting DOE EGS Program Objectives (cont'd)

Phase II (actual)

- Reservoir Creation - establish permeability maintain open cracks with hydroshearing
  - Stimulate injection well using chemical diverters.
  - Monitor fracture growth using focused surface- and borehole-deployed MSA.

Phase II (planned)

- Reservoir Validation - fracture imaging tools
  - Repeat borehole televiewer to assess effects of hydroshearing
  - Inject tracers and execute single-well flow test methods to measure fracture volume and fluid velocity
  - Use distributed temperature sensing to identify flow zones in injection and production
- Interwell Connectivity - tools to ensure that suitable flow path connects wells, such as tracers
  - Conduct two-well and three-well connectivity tests
  - Analyze conservative and non-conservative tracers to assess effective fracture volume, fluid velocity, etc.
  - Conduct dual-well stimulation, if necessary

Phase III (planned)

- Reservoir Scale-Up and Sustainability - tools for selecting additional locations for wells, and long-term operation and maintenance of an economic EGS installation
  - Calibrate numerical models with real EGS performance data
  - Forecast reservoir performance over typical plant and field design life
- Energy Conversion – suitable energy conversion systems
  - Build conceptual model of commercial-scale power plant and wellfield
  - Estimate capital and operating costs of conceptual system