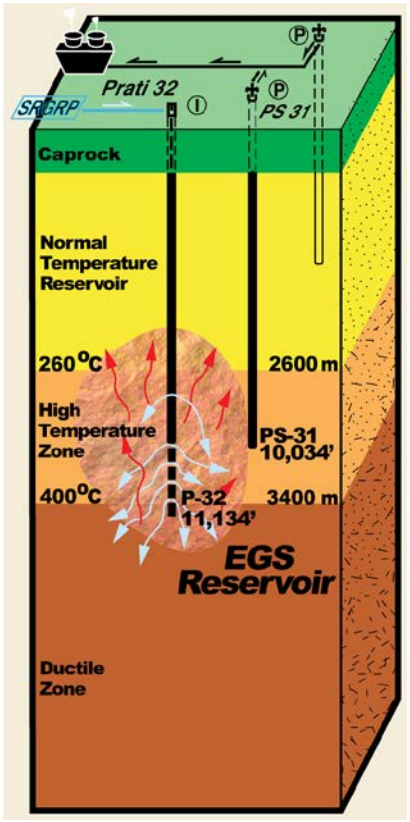
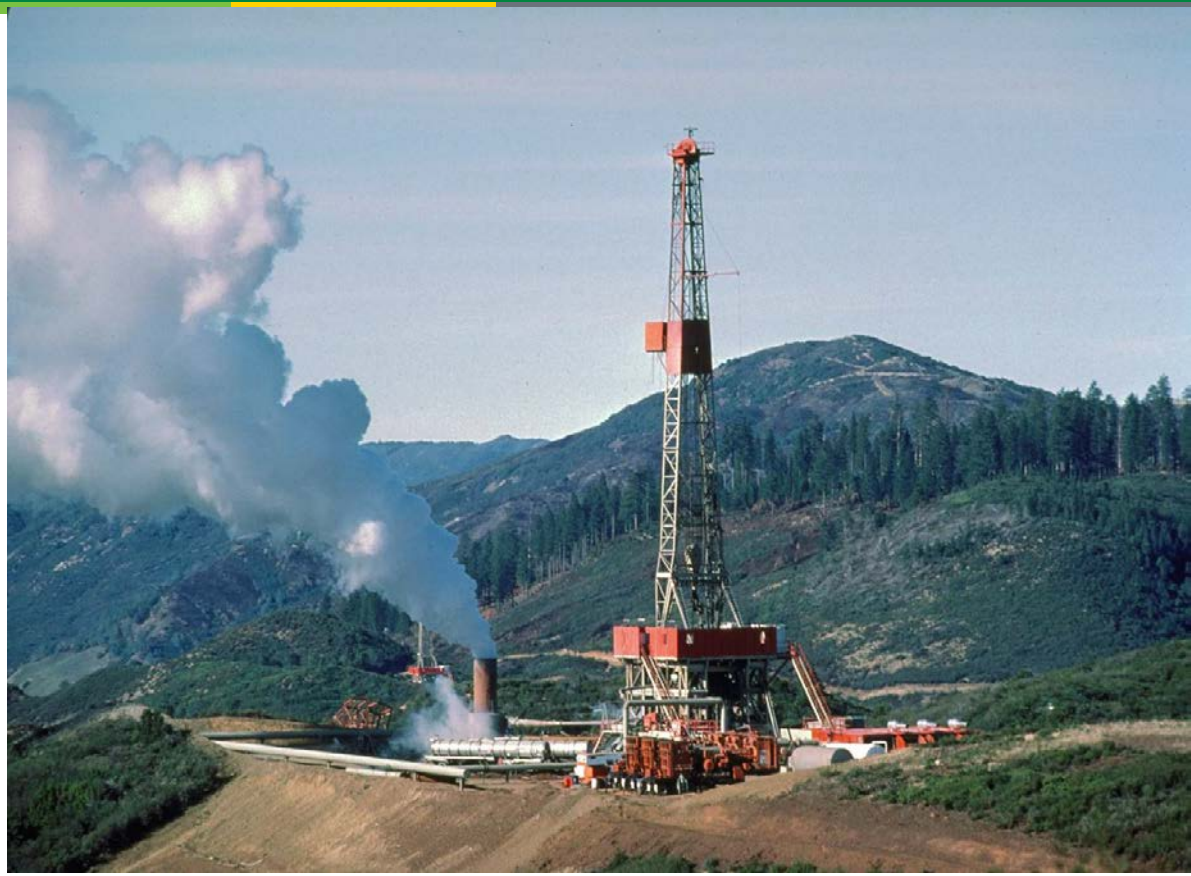




Demonstration of an Enhanced Geothermal System at the Northwest Geysers Geothermal Field, CA

April 22, 2013

Track 2

Principal Investigator:
Mark Walters
Geysers Power Company, LLC ("Calpine")

Relevance/Impact of Research

The Northwest Geysers EGS Demonstration Project has the goal of enhancing the permeability of high temperature, low permeability rocks through the thermal stimulation of fractures.

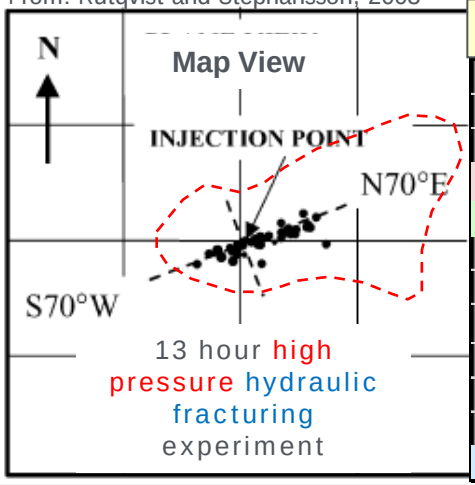
The primary objectives of the NW Geysers EGS Demonstration project and its relevance to the EGS goals of the Geothermal Technology Office Goals are to:

- *Create an Enhanced Geothermal System capable of producing 5 MW.*
- *Gain community acceptance of the EGS project.*
- *Enhance the permeability of hot, low permeability rock by injecting cool water at low pressures to "gently stimulate" thermal fracturing processes.*
- *Significantly lower the noncondensable gas concentrations in the native steam to produce quality, injection-derived steam from the EGS.*

Scientific/Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

From: Rutqvist and Stephansson, 2003

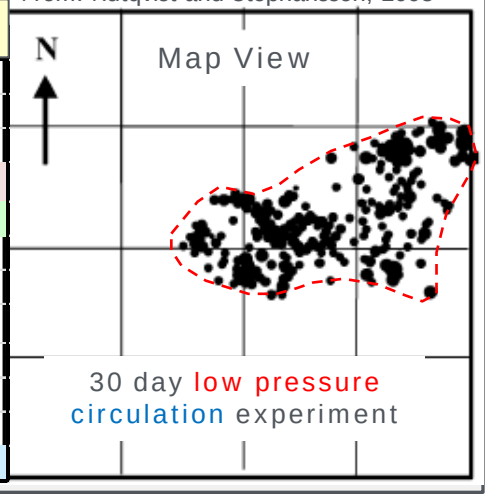


13 hour high pressure hydraulic fracturing experiment

Hijiori Japan Hot Dry Rock Experiments

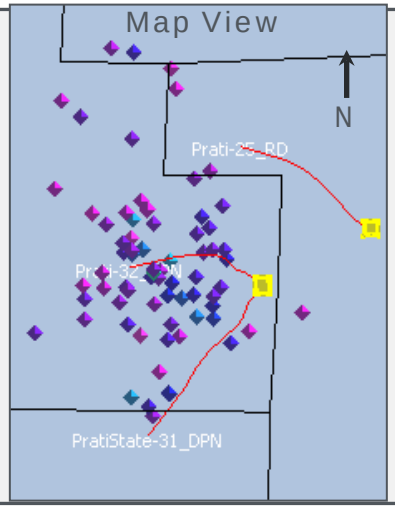
1988 Hydraulic Fracturing		1989 Circulation
250.0	Temperature (°C)	250.0
33.0	Minimum Principle Stress (MPa)	33.0
0.5	Test Duration (days)	30.0
6.2	Maximum Flow Rate (m^3/min)	2.1
16.0	Maximum Wellhead Pressure (MPa)	7.4
1802.0	Well Depth (m)	1802.0
1802.0	Water Column Height (m)	1802.0
33.1	Maximum Reservoir Pressure (MPa)	24.5

From: Rutqvist and Stephansson, 2003



30 day low pressure circulation experiment

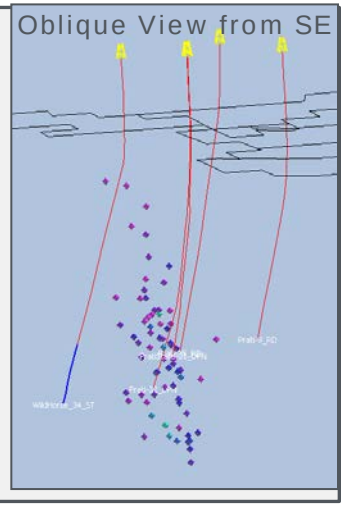
"Gentle stimulation" to create a cloud of fractures through shear reactivation rather than a single fracture zone created by hydraulic fracturing.



Week 1 Seismicity

The Geysers Enhanced Geothermal System Demonstration

10/6/2011 24-Hour Start		2011-2012 Reservoir Stimulation
280.0	Temperature (°C)	280.0
24.0	Minimum Principle Stress (MPa)	24.0
1.0	Test Duration (days)	360.0
4.2	Maximum Flow Rate (m^3/min)	3.0
0.0	Maximum Wellhead Pressure (MPa)	0.0
3396.0	Well Depth (m)	3396.0
1019.0	Estimated Water Column Height (m)	836.0
9.7	Maximum Reservoir Pressure (MPa)	7.9



Week 1 Seismicity

Scientific/Technical Approach

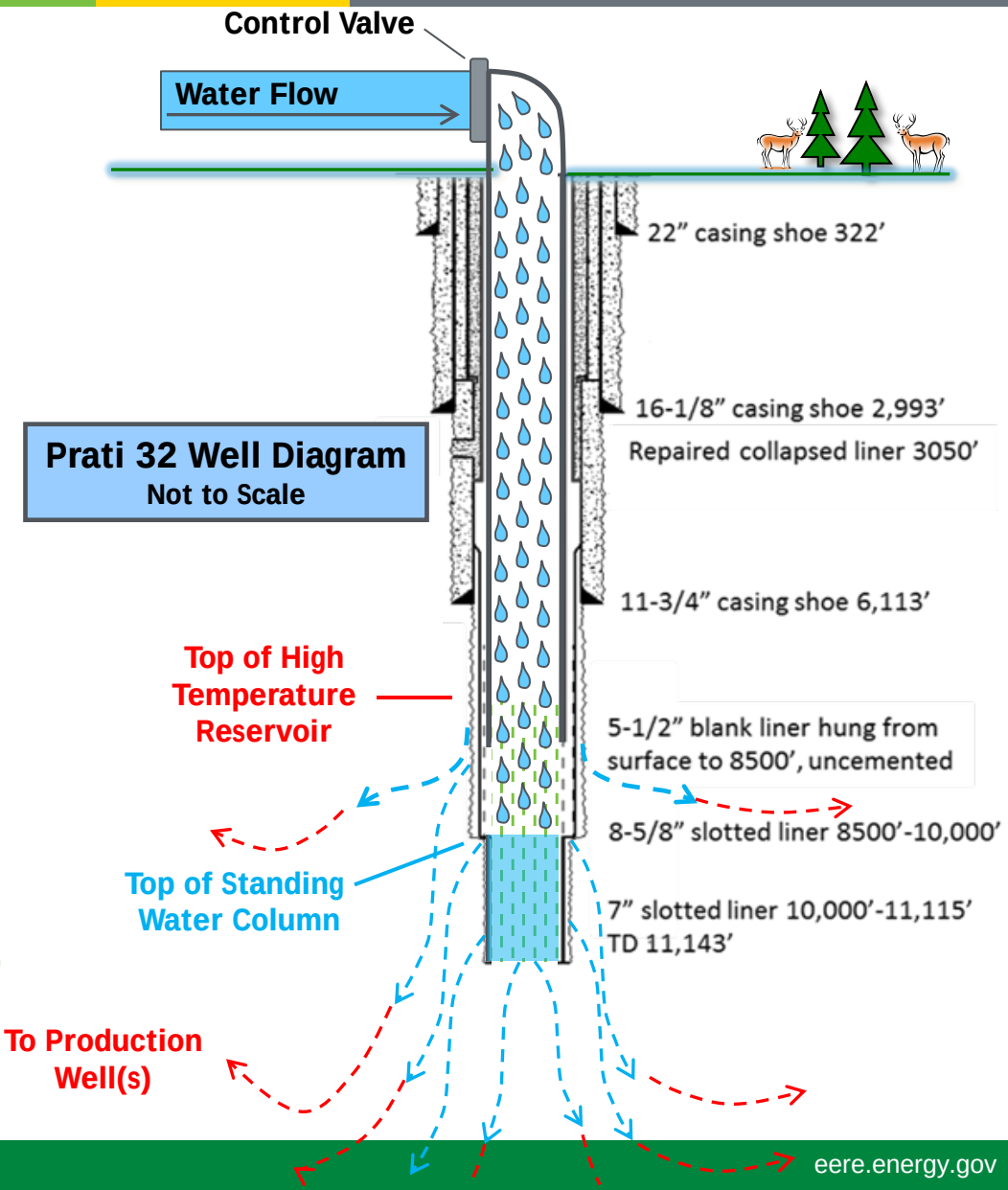
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Our approach to stimulate an EGS

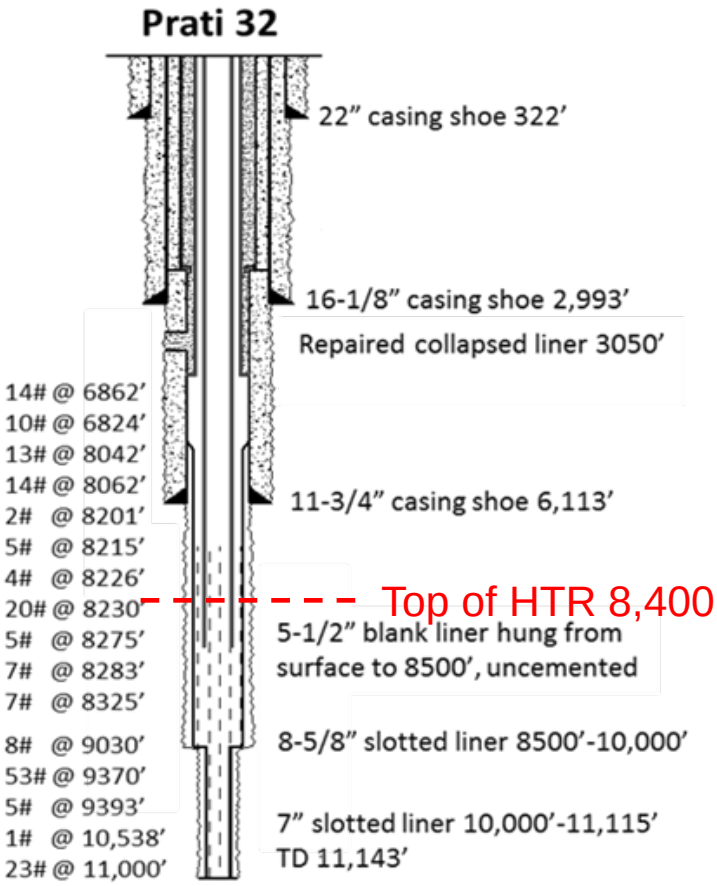
.

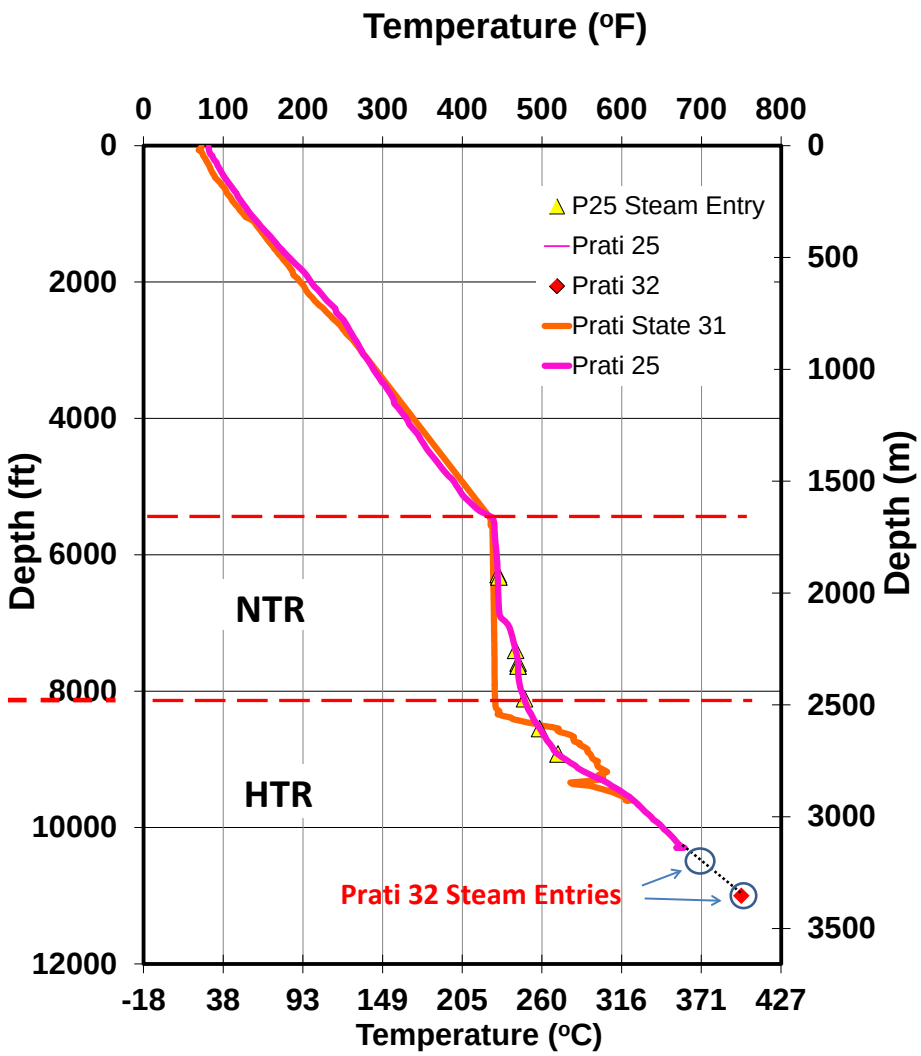
- At P-32, a blank liner is run through the normal temperature reservoir (NTR) so the water is delivered directly to the HTR.
- The high temperature reservoir is below 8400’ in P-32 with convective temperature gradients in the NTR above, and a conductive temperature gradient (10 ^{o}F/100 ft) in the HTR.
- Injected water falls under a vacuum of -13 psig to the bottom of P-32 and forms a water table with a hydraulic head of about 1500 psi at an injection rate of 500 gpm.
- Target rate for long-term injection in P-32 may be in the range of 500 gpm to 700 gpm.

Micro-fracture development at Geysers EGS relies primarily on thermal effects, not pressure effects (as used in hydrofracturing)



Scientific/Technical Approach





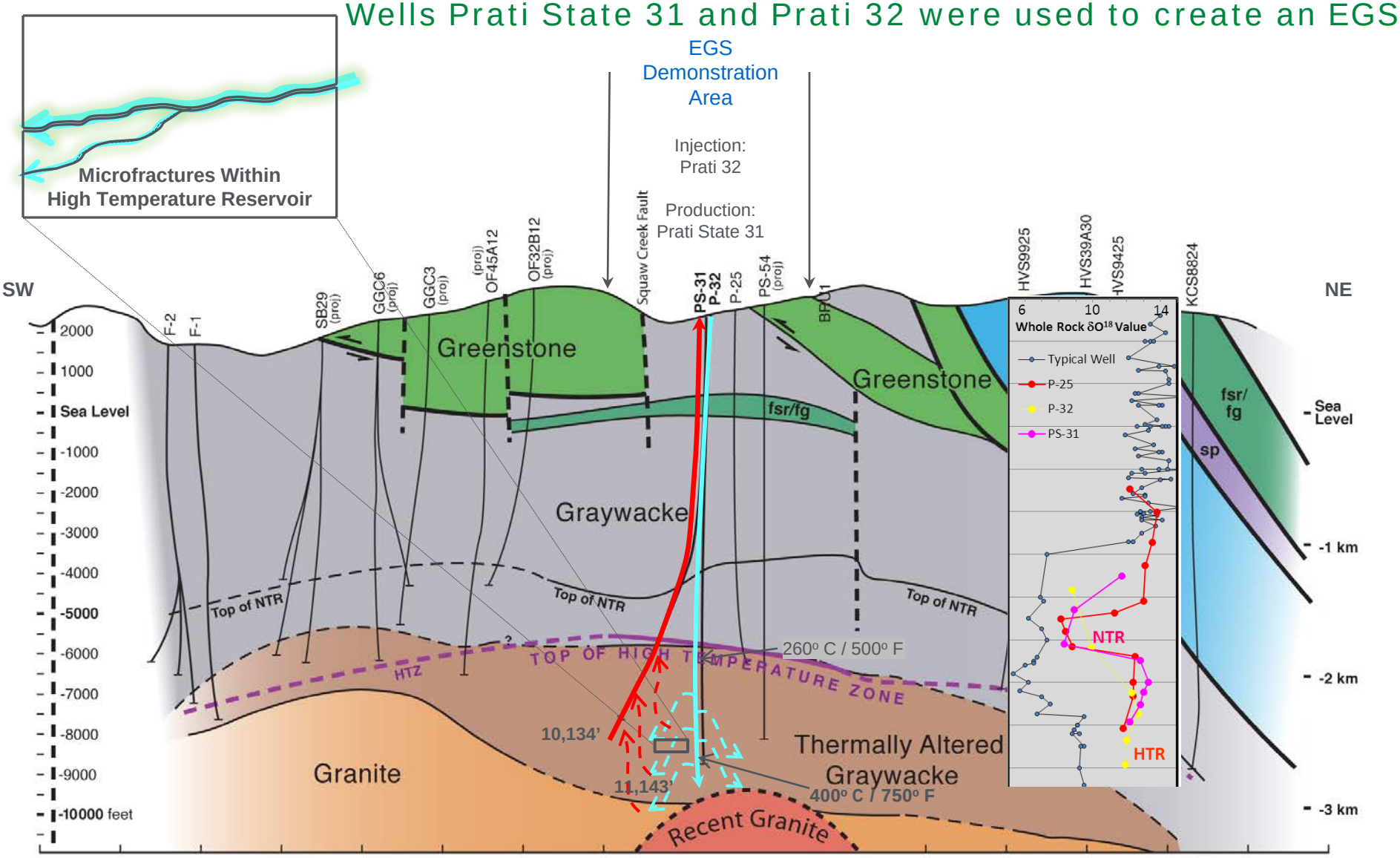
Water is being injected directly into conductively-heated, low-permeability rock with temperatures up to 750 °F (400 °C)

Maximum temperature of 750°F recorded with a Kuster mechanical tool

Scientific/Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Wells Prati State 31 and Prati 32 were used to create an EGS



Accomplishments, Results and Progress

2010-09/2011

Phase 1: Pre-Stimulation

Prati State 31 (PS31) and Prati 32 (P32) recompleted as a production-injection well pair

Identified and characterized a hot (P32: 750 ^{o}F at 11,000 ft) low permeability reservoir for injection

Installed Injection Pipeline

Public Outreach

Established Baseline:

- Flow test
- Static and flowing PTS
- Geochemistry
- Casing Caliper
- Microseismicity

14 additional MEQ stations installed

10/2011-2012
P32 Injection (10/06/2011)

Phase 2: Stimulation (Injection)

Created a cloud of seismic events indicative of three-dimensional volume rather than opening single fracture sets

High NCG gas concentration has been significantly lowered by injection-derived steam.

Changing flow rate at P32 directly affects pressure and steam flow from PS31

Chloride mitigation has not occurred
Developed an EGS field test site that can be used for study stimulation and monitoring technologies:

- *Repeated well logs available under different flow conditions*
- *Continuous reservoir pressure monitoring*
- *MEQ database*

2013
PS31 Production (12/05/2012)

Phase 2: Stimulation (Injection and Production)

Production at PS31 showed a rapid decline without injection at P32

Decreased injection at P32 resulted in increasing NCG in PS31

After re-start of injection at P32, PS31 showed increasing flow rates

PS31 is currently shut-in due to corrosion problems

2013 and Beyond

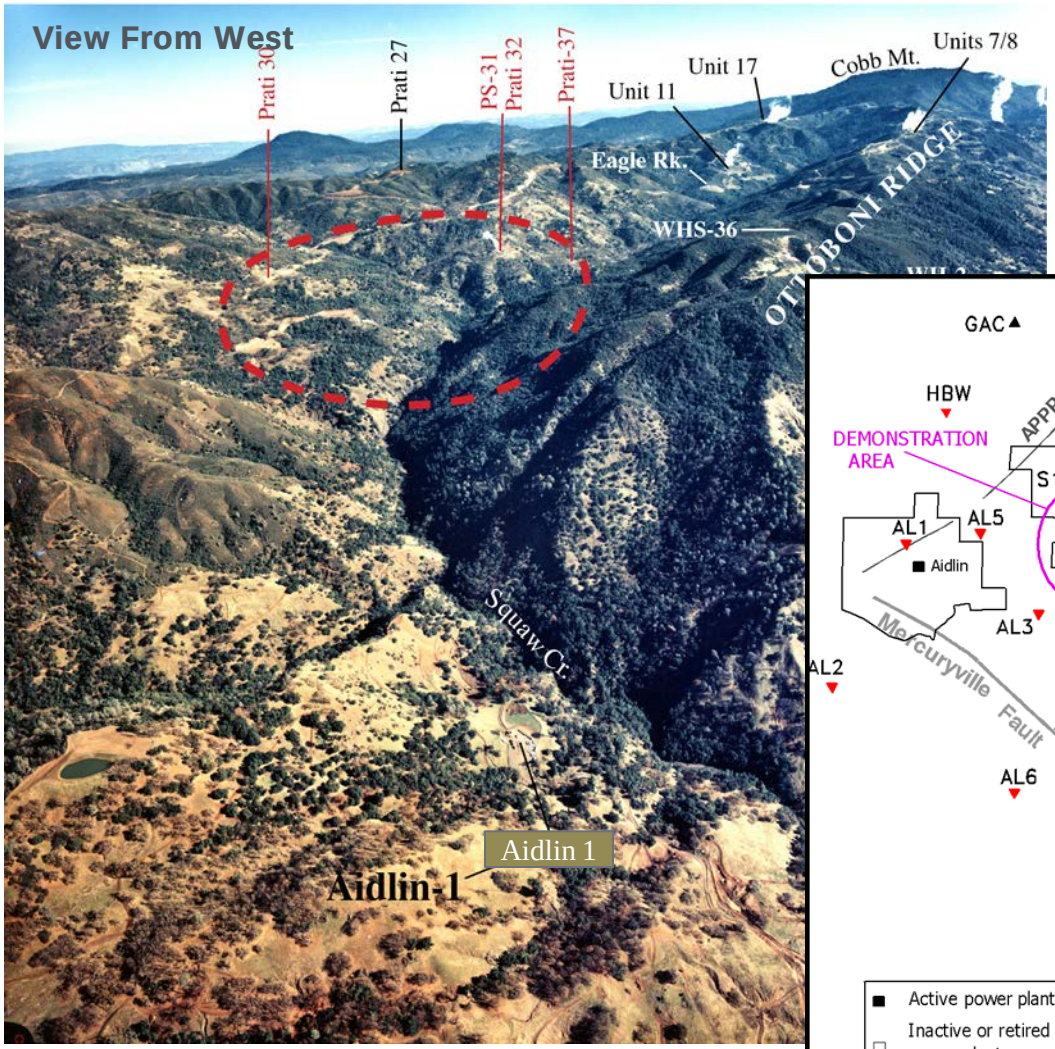
Phase 3: Long Term Monitoring

Repair PS31

Ensure production Sustainability with minimal seismicity

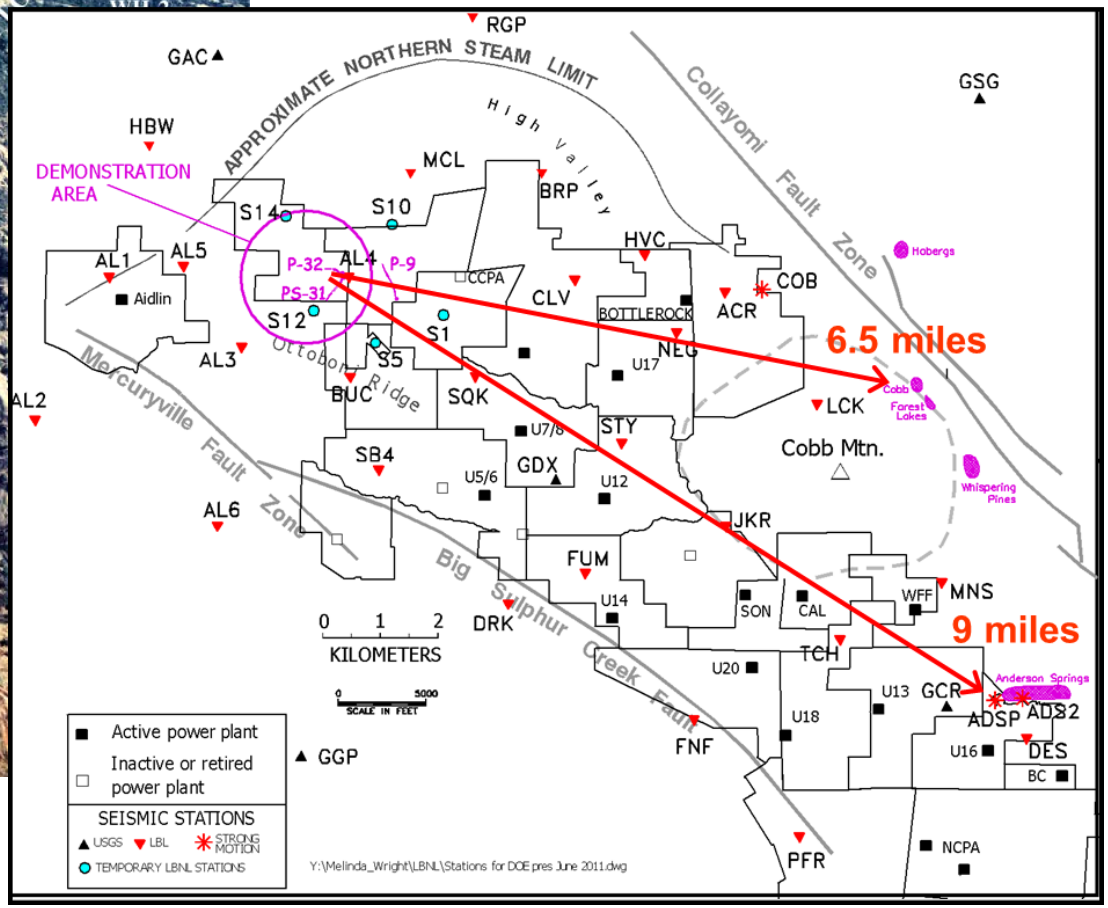
Accomplishments, Results and Progress

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Prati State 31 (PS-31) and Prati 32 (P32) were completed as a production-injection well pair (respectively) in September 2011.

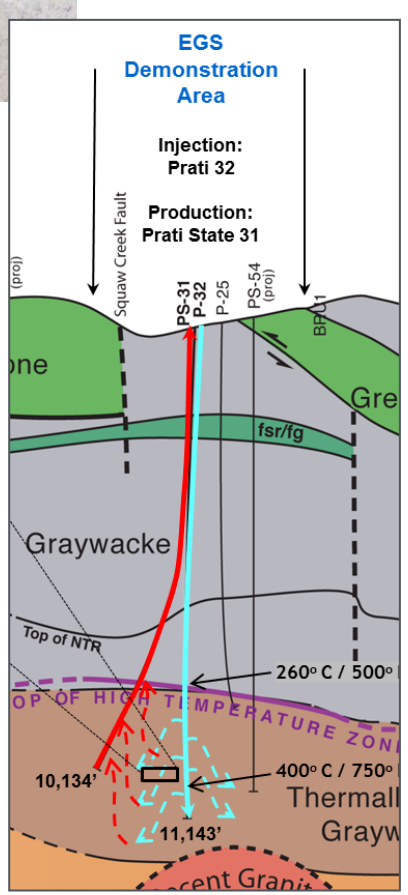
- Obtained public acceptance of the project and local community support
- Negligible strong motion instrument responses at Anderson Springs and Cobb Valley from maximum seismic event (M 2.87)



Accomplishments, Results and Progress

Carefully monitored EGS program:

- *Evaluated system at several injection flow rates*
- *Standing water column height vs. injection rate*
- *Static well head pressure increase in nearby wells*
- *Temperature, Pressure and Temperature Logs*
- *Geochemical analysis of injection and production fluids*
- *Satellite-based InSAR surface deformation analysis*
- *Microseismicity*



Preliminary Well Analysis:

Prati State 31 Producer

- *Well Head Pressure Increased from 323 psi to 465 psi*
- *~90% Non-Condensable Gas Concentration Reduction*
- *~80% of Steam Production was injection derived[1]*
- ***~3.25 MW of Potential Additional Production Capacity***

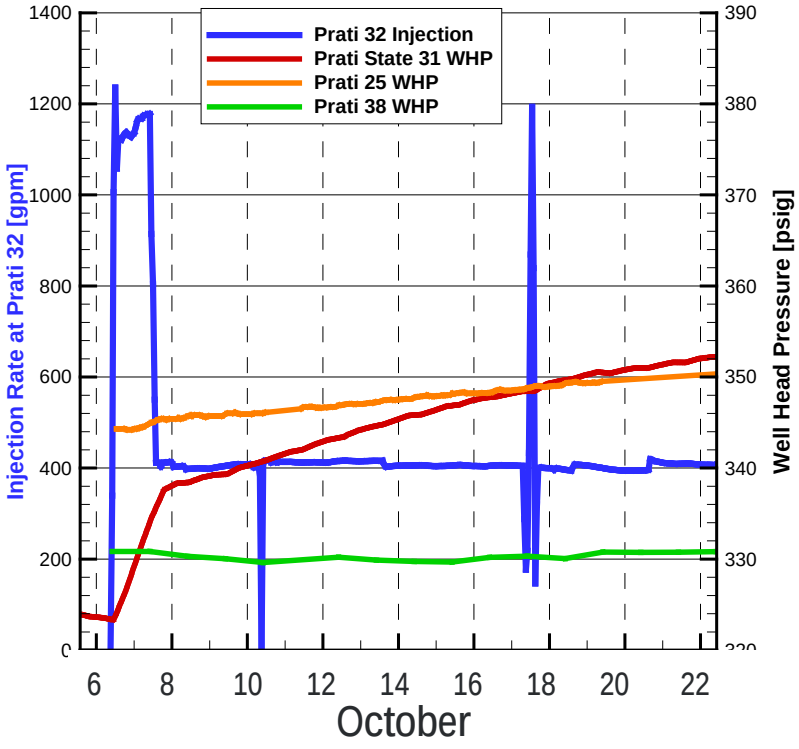
Prati 25 Producer

- *Well Head Pressure Increased from 345 psi to 365 psi*
- *~85% Non-Condensable Gas Concentration Reduction*
- *~45% of Steam Production was injection derived[1]*
- ***~1.75 MW of Potential Additional Production Capacity***

[1] **Isotopic Analysis**

A Total of 5 MW of Potential Additional Production from EGS

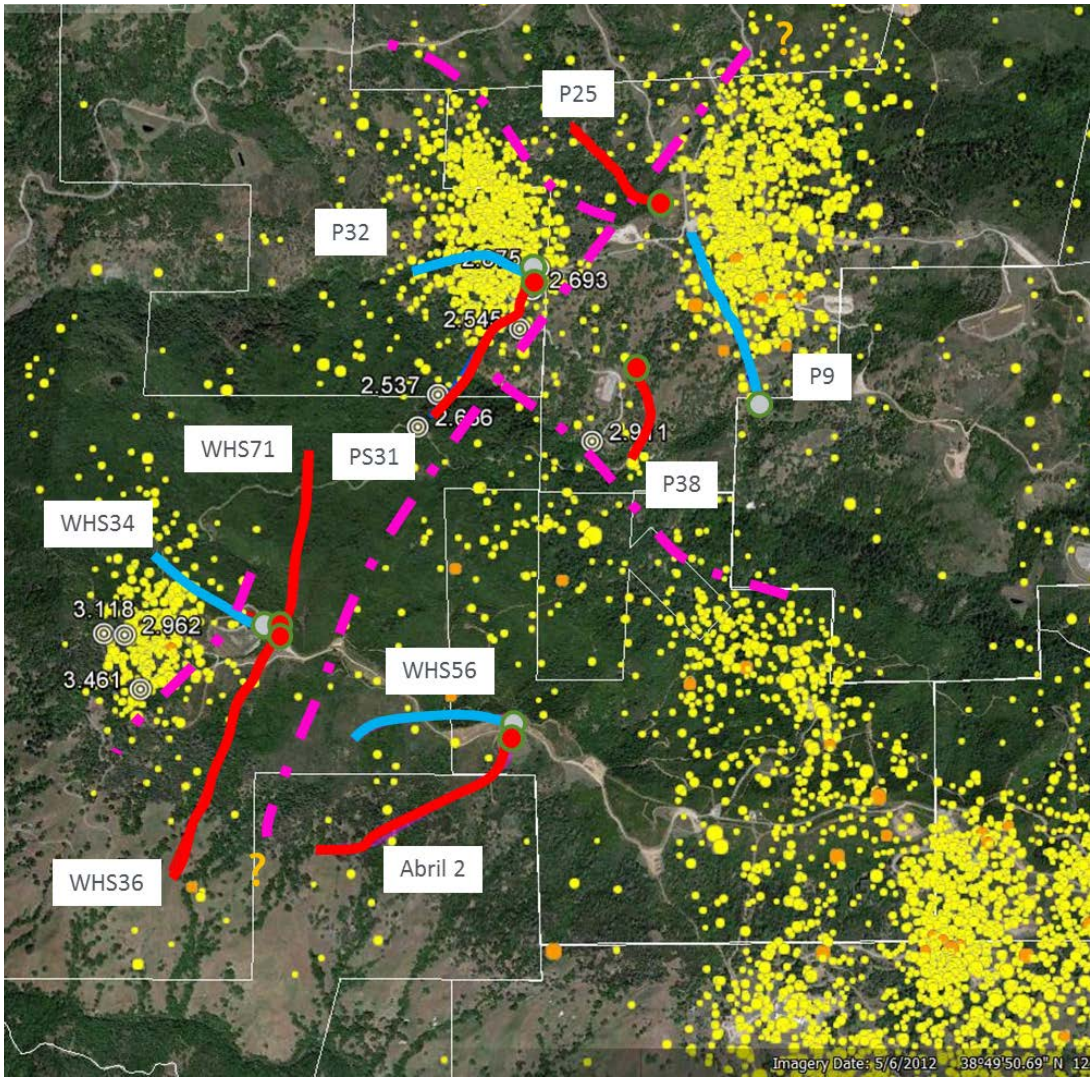
Accomplishments, Results and Progress



Established good communication between P-32 and PS-31 within two weeks

P-32 and PS-31 are partially separated from a convecting hydrothermal system around P-38 by a fault/shear zone

Seismic Events: 01 September 2011 to 30 June 2012

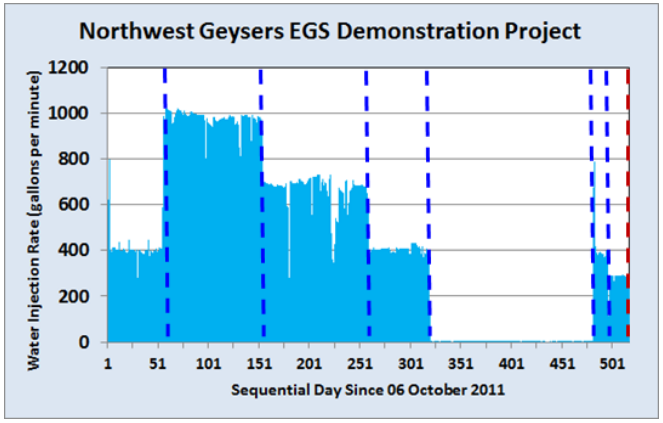


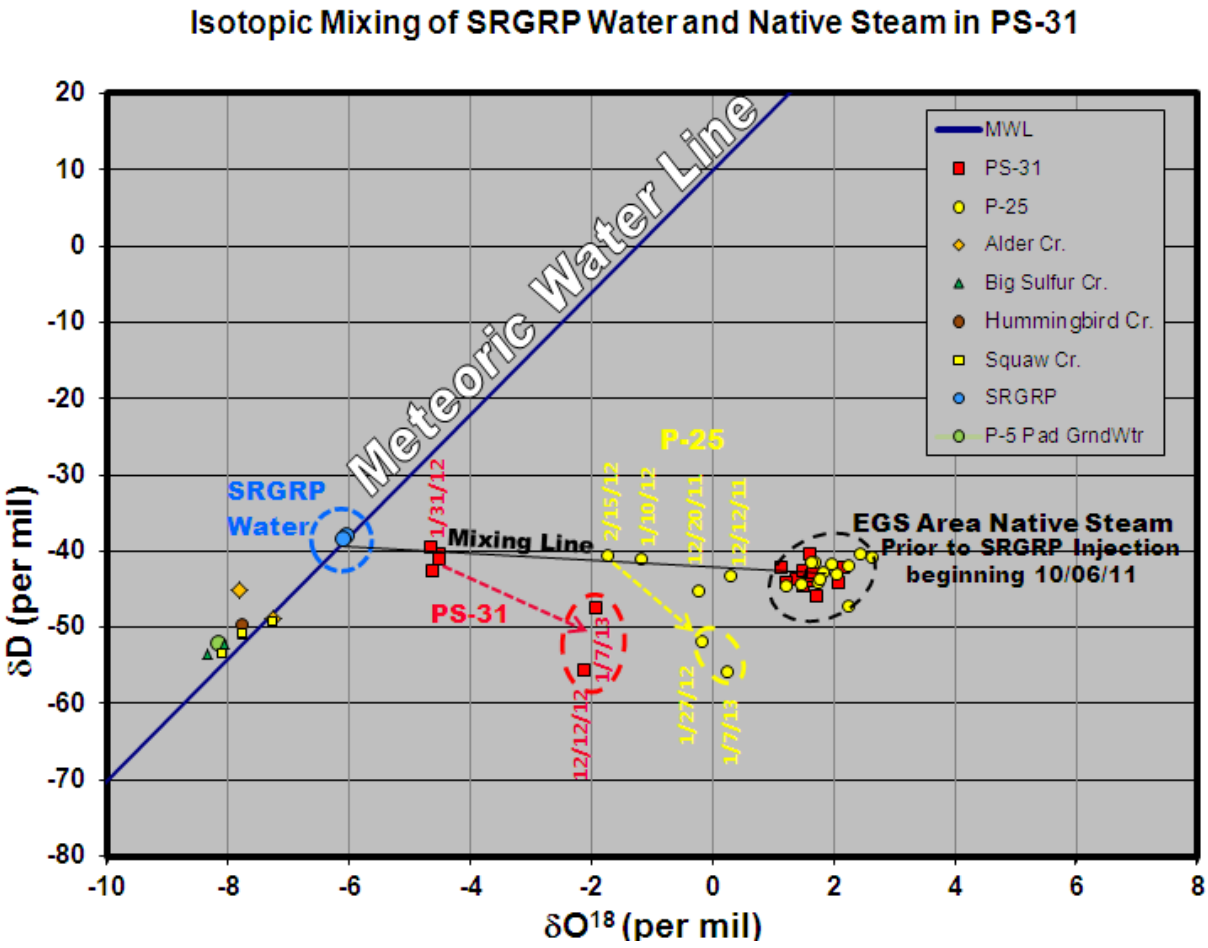
Accomplishments, Results and Progress

P-32 injection caused Injection Derived Steam (IDS) fraction of PS-31 and P-25 to increase to about 80% and 45%, respectively, over an ~5 month period (days 1 through 153).

After P-32 injection ceased in August 2012, the IDS steam fraction from PS-31 and P-25 decreased to about 50% and 20%, respectively, over an ~5 month period (days 320 through 480).

Seismicity Analysis: Days 1 to 520 (06 October 2011 to 05 March 2013)

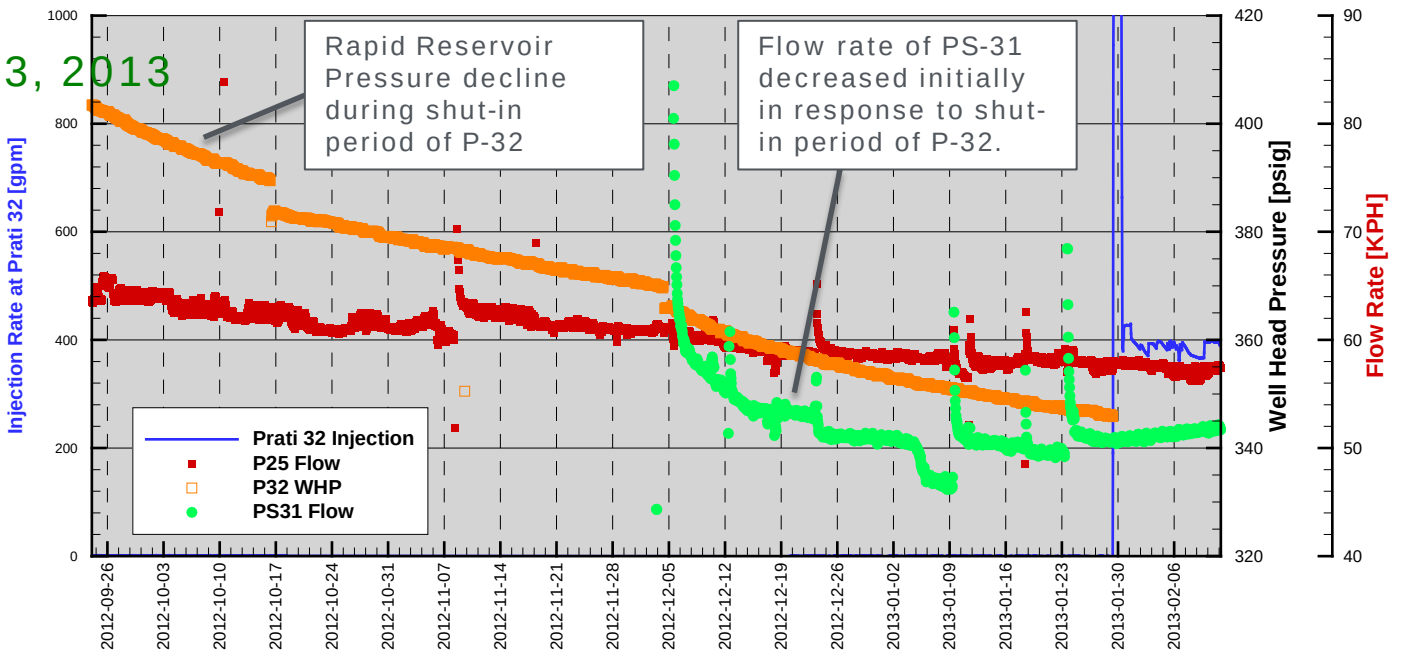




PS-31 Production

Dec. 5, 2012 to Feb. 13, 2013

- Total NCG and H_2S increased significantly after no injection to P-32.
- Cl concentration is not mitigated by injection of meteoric water
- Corrosion rate of about 100 mil/mo. caused leak and damage to top 2500' of PS-31 liner.



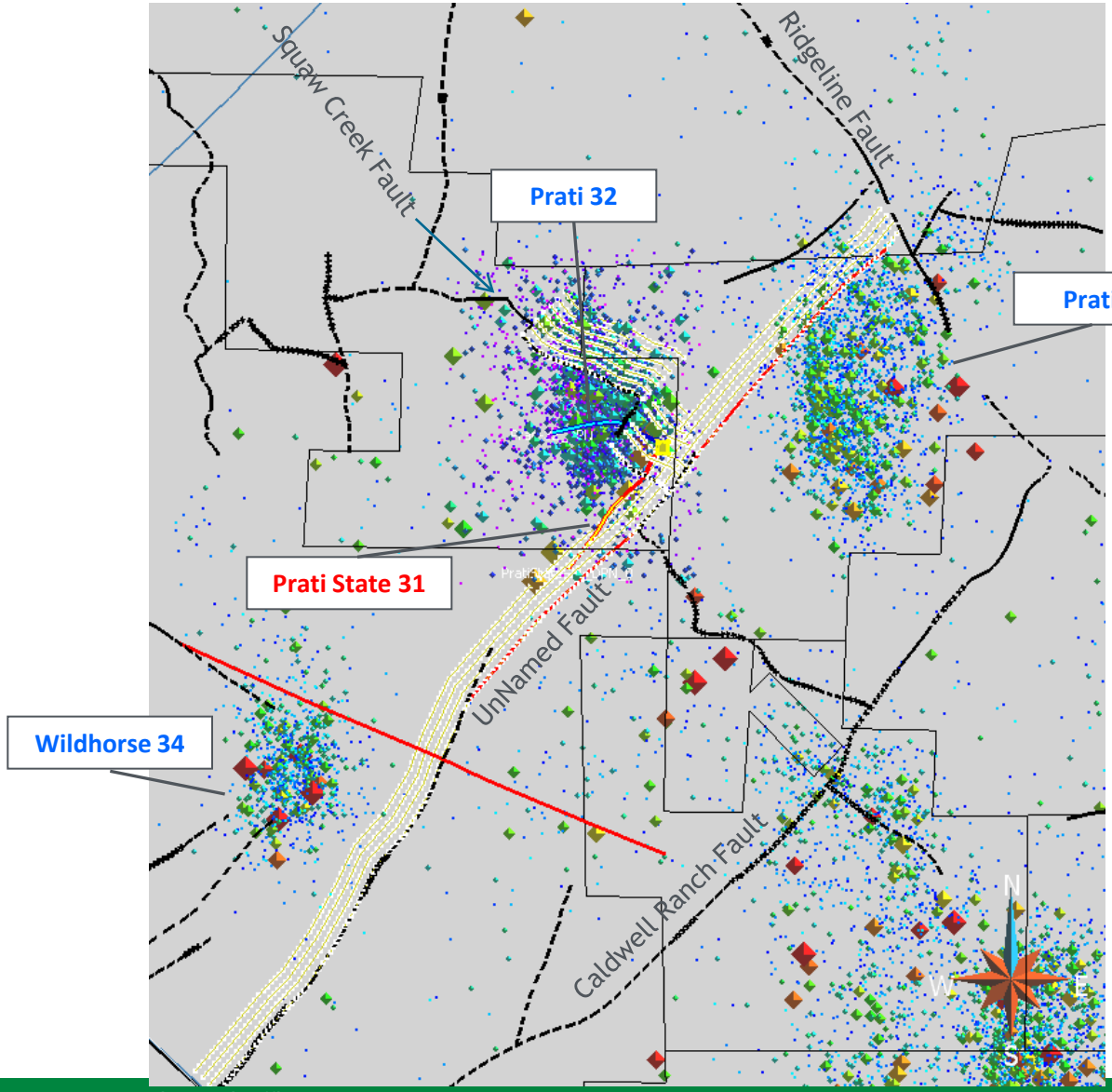
Flow Rate and NCG in PS-31 Steam is directly controlled by injection into P-32

Test prior to October 2011 stimulation

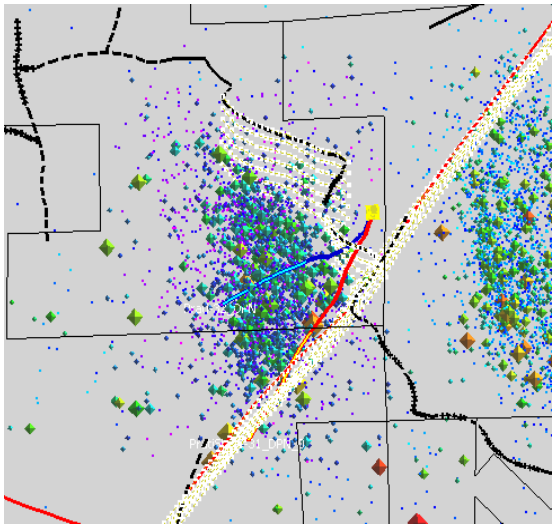
January 31, 2012 test results after 4 mo. stimulation

Production of PS-31 to pipeline February 13, 2013 prior to shut-in

	Flow Testing			Geochemistry		
WELL	KPH (klbs/hr)	WHP (psig)	SIWHP (psig)	NCG (wt.%)	H_2S (ppmw)	Cl (ppmw)
PS-31	55	100	320	3.9	1280	135
PS-31	72	100	465	0.3	550	125
PS-31	51	110	345	1.0	750	23

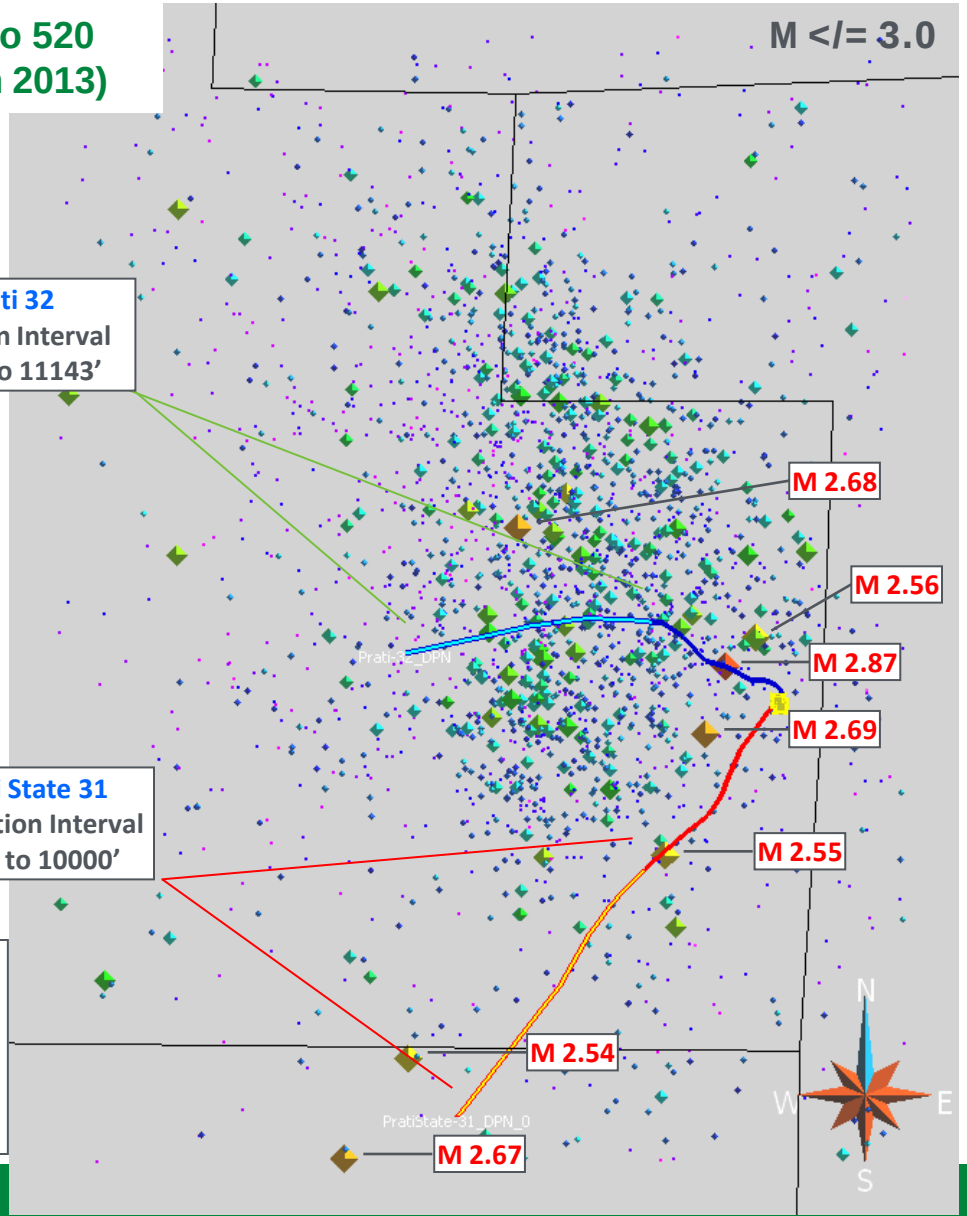


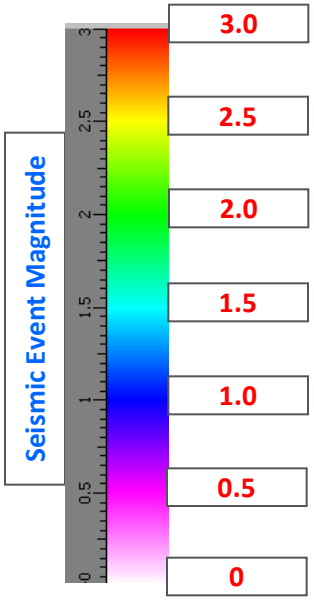
MEQ events associated with surface faults and hydraulic discontinuities in EGS reservoir



Zoom of Prati 32 and Prati State 31 Area
Oblique View (west of vertical)

Seismicity Analysis: Days 1 to 520 (06 October 2011 to 05 March 2013)



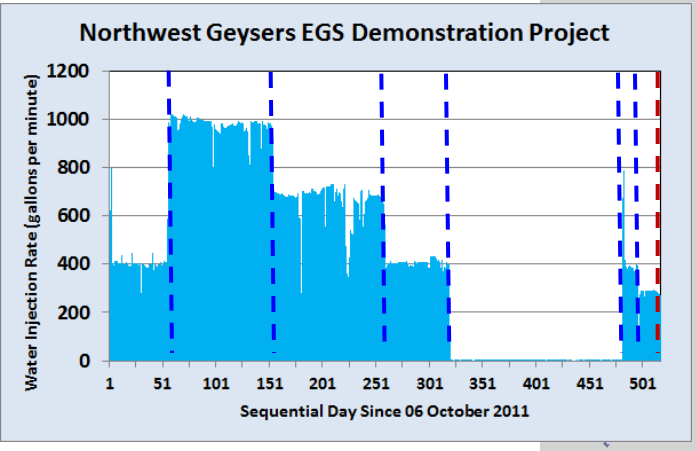


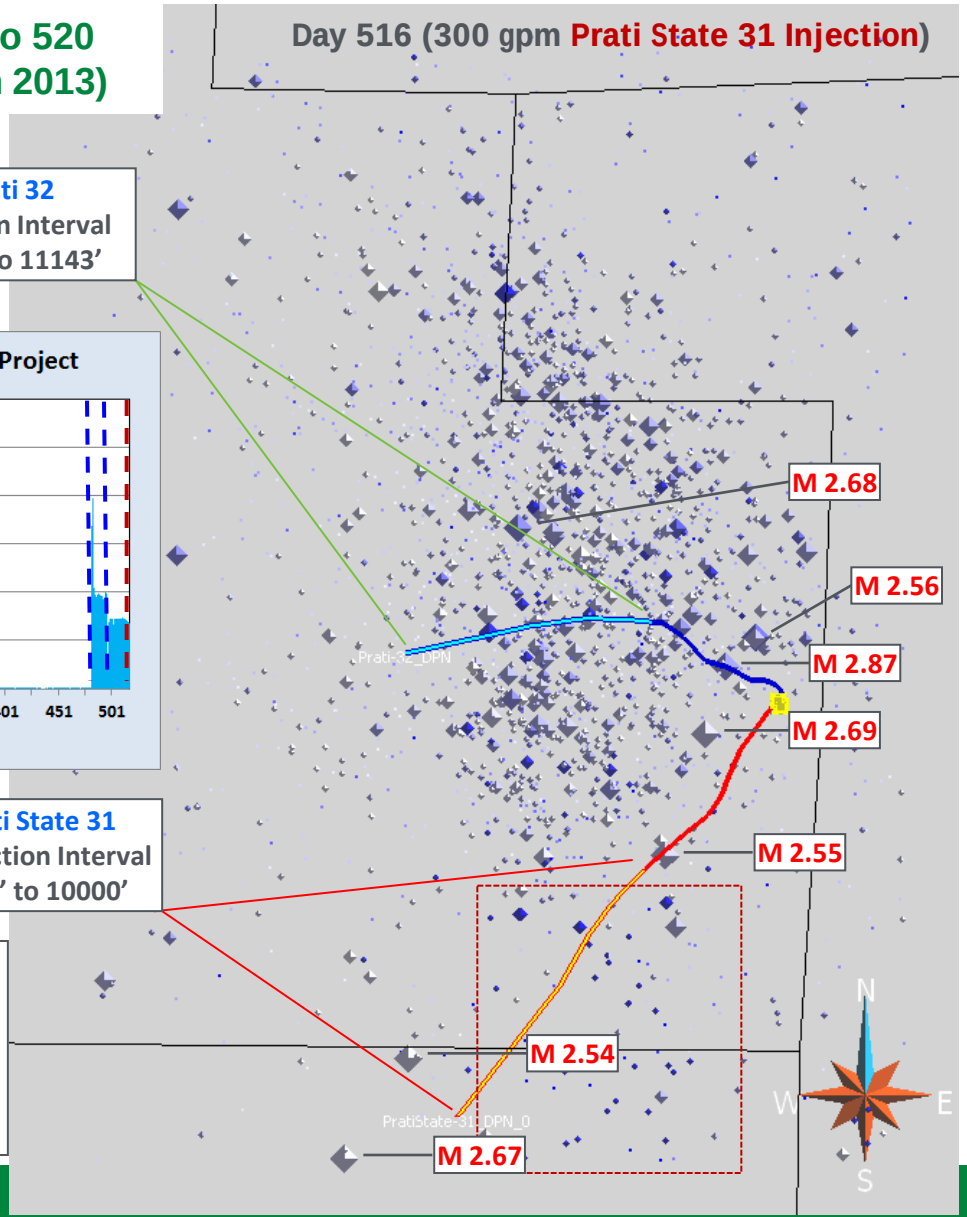
Largest Seismic Event Associated with Project: M 2.87

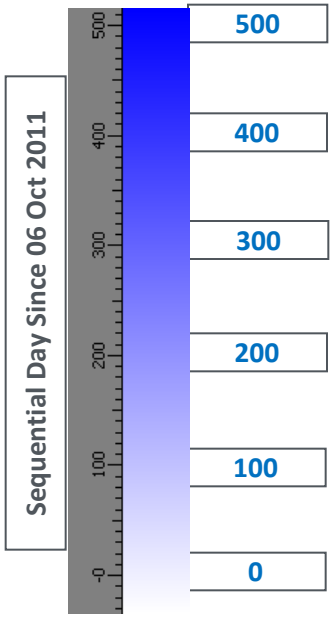
Six of Seven M >/= 2.5 Seismic Events May "Define" SE Boundary of EGS Volume

Seismic Events By Magnitude Range

Seismicity Analysis: Days 1 to 520 (06 October 2011 to 05 March 2013)

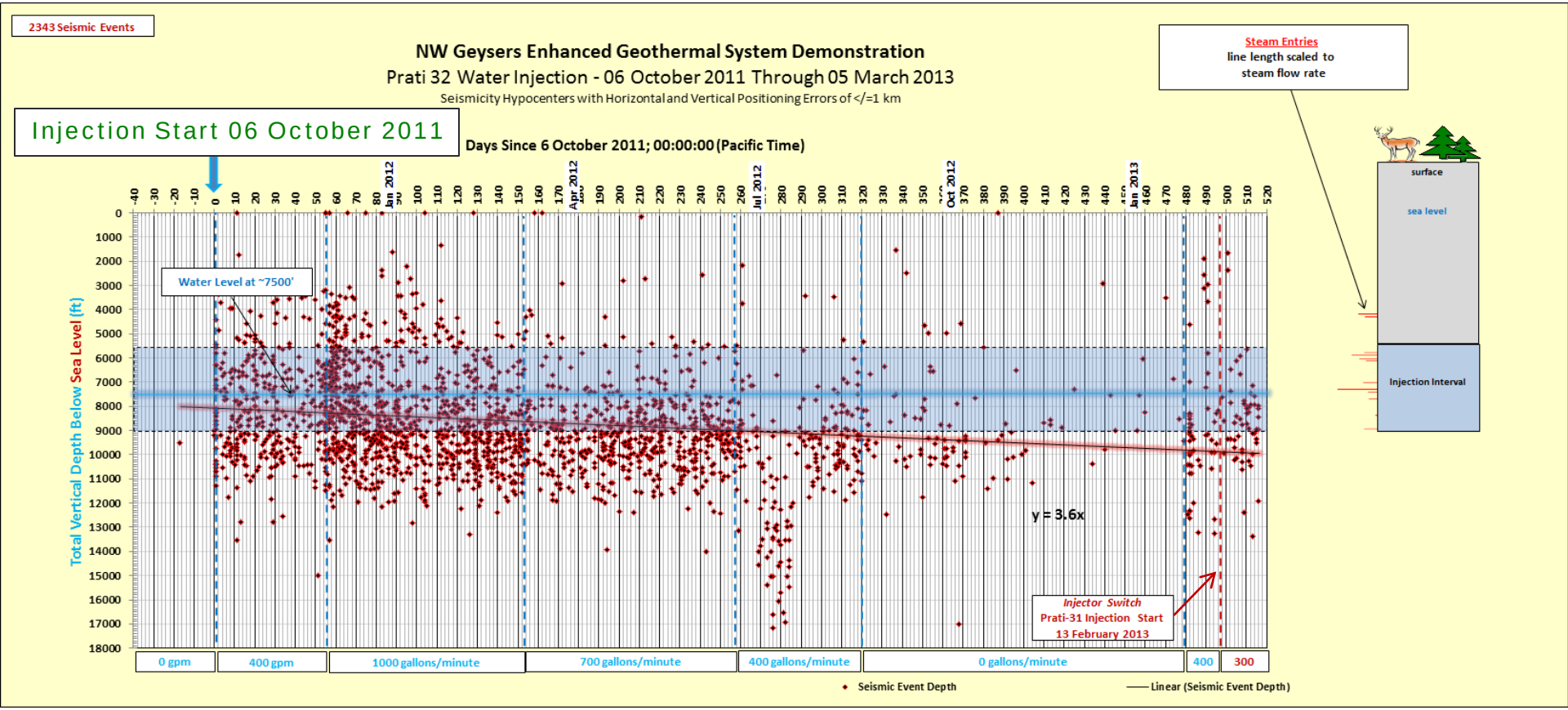






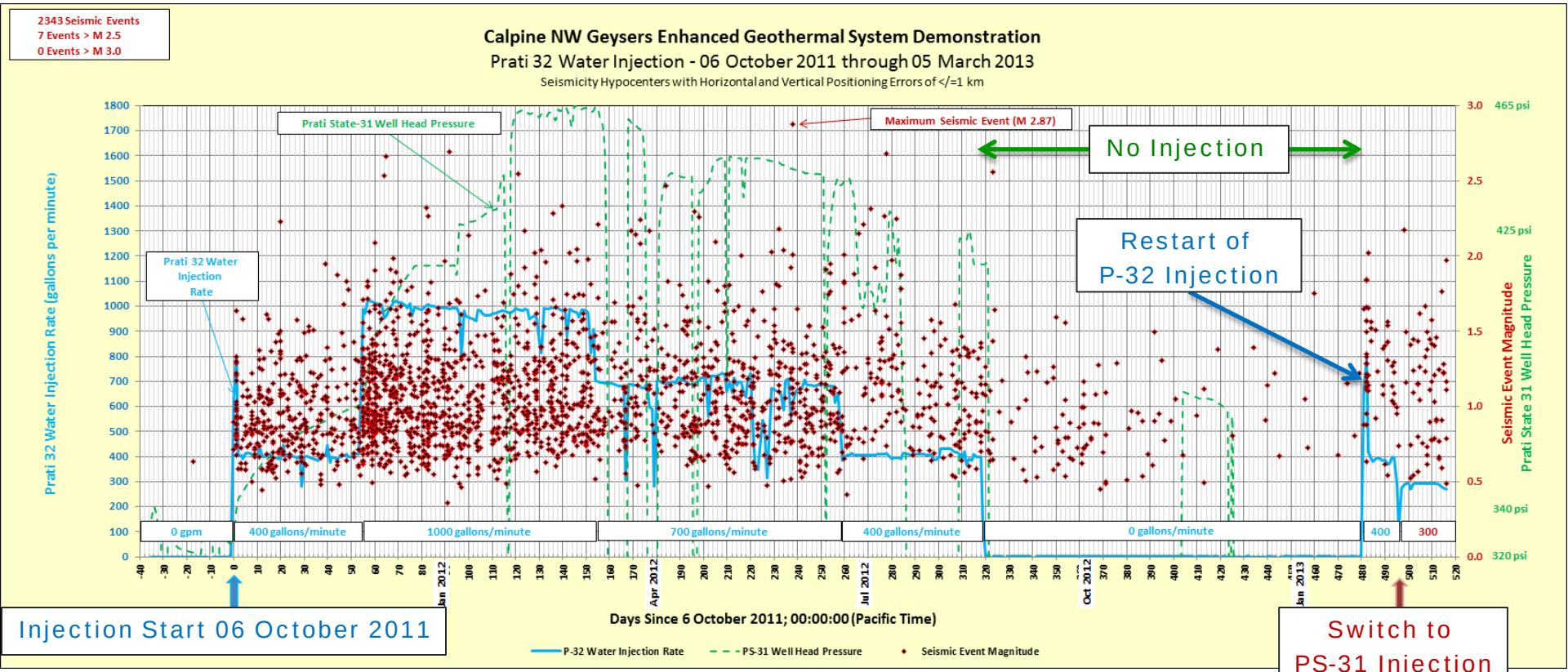
Seismicity Associated with Injection Rate Steps

Seismicity Time-Depth Analysis: 01 September 2011 to 05 March 2013



Seismicity trended downward during injection
at an average of ~3.6 feet/day or ~1900 feet since stimulation began

Seismicity Time-Magnitude Analysis: 01 September 2011 to 05 March 2013



Seismic Event Frequency Declined
With Continued Injection at Each Injection Rate

Future Directions

Until PS-31 is repaired and back into production:

- Continue stimulation of P-32 at pre-determined water injection rates, beginning with a constant rate of 400 gpm.
- Continue monitoring seismicity, geochemistry and flow rates at P-25 production well.
- Monitor the shut-in pressure at the PS-31 wellhead to determine its response to P-32 injection.

After PS-31 is back into production:

- Resume a step-rate Injection schedule at P-32 similar to the Phase 2 stimulation
- Perform well logging and geochemical sampling at PS-31 and injectivity testing at P-32
- Establish optimum injection rate
- Perform tracer experiment study

Milestone or Go/No-Go	Status & Expected Completion Date
Go/No-go for Phase 3 Long-term Monitoring	**April 2013**
Complete Phase 3 monitoring, testing & Reporting	**Fall 2014**

Project Management/Coordination

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

The NW Geysers Demonstration Project is serving as a field testing site per the original plan:

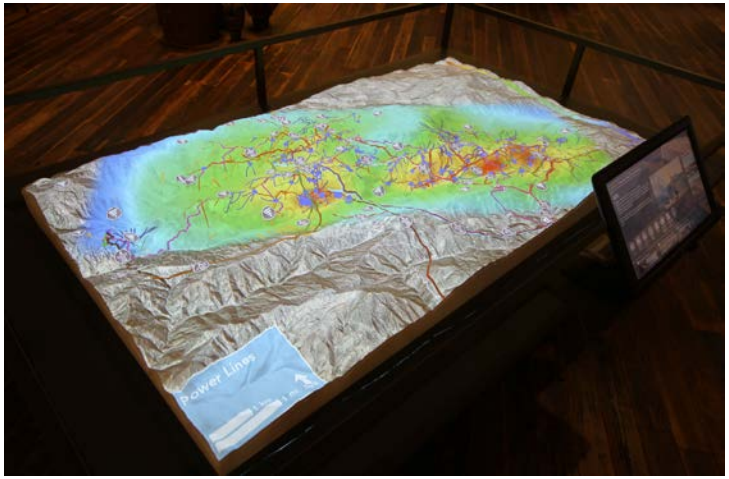
- **Roland Gritto of Array Information Technology has installed a network of broad band accelerometers to understand the ground motion and attenuation of shallow microseismic events.**
- **Pete Rose of EGI is proposing a high temperature tracer test at P-32 once PS-31 is back into production.**

Collaborative research with LBNL:

- **Fracture studies by Pierre Jeanne and Andre Borgia**
- **InSAR Surface deformation studies by Don Vasco**
- **Geomechanical modeling by Jonny Rutqvist**
- **Induced seismicity by Ernie Majer and Larry Hutchings**
- **Noble gases collection and analysis by Mack Kennedy**

Co-operative Support by LBNL:

- **Input to, and support of, EGS exhibit completion at Calpine Visitor Center by Pat Dobson**



Calpine Geysers Visitor opened October 1, 2012.

Mandatory Summary Slide

An Enhanced Geothermal System capable of producing 5 MW was created.

Obtained public acceptance of the EGS project and received local community support.

Prati State 31 and Prati 32 were completed as a production-injection well pair (respectively) into low-permeability, conductively-heated rock with temperatures as high as 400 ^{o}C.

There is good communication between Prati State 31 and Prati 32.

Flow rate and NCG concentrations in Prati State 31 steam are directly controlled by injection into Prati 32.

Plans for producing the EGS steam to a proposed power plant are indefinitely delayed because no PPA from a major utility is available.

Project Management

Timeline:

Planned Start Date	Planned End Date	Actual Start Date	Current End Date
10/1/2008	7/31/2011	2/1/2009	10/31/2014

Budget:

Federal Share	Cost Share	Planned Expenses to Date	Actual Expenses to Date	Earned Value of Work Completed to Date	Funding needed to Complete Work
$6,248,371	$4,472,538	$11,689,332	$13,327,053	$10,504,375	$0

Phases 1 and 2 of the project are complete. The Phase 3 monitoring, testing and reporting portion of the project will be delayed until late Fall of 2013 until the production liner of Prati State 31 is repaired with a high alloy steel or titanium liner.