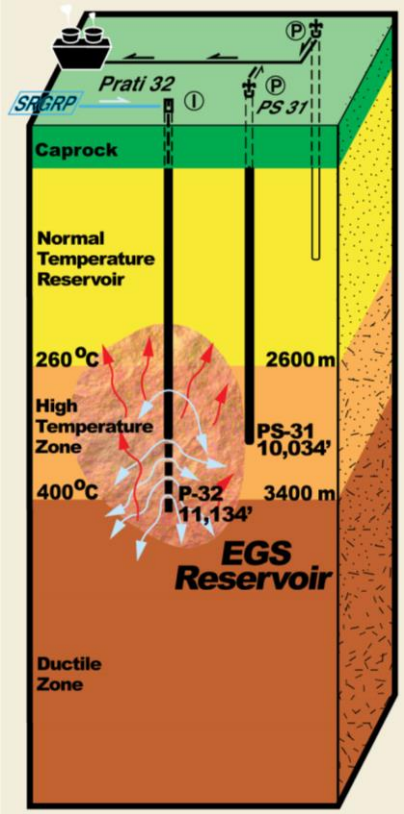


Prati State 31 and Prati 32 Production-Injection Well Pair

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

Project Officer: Lauren Boyd

Total DOE Project Funding: $6.25 million

May 12, 2015

2:00 p.m. – 2:30p.m.

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

Presenter: Julio Garcia

Track 4 - EGS 2

Relevance/Impact of Research

The technical objective of the NW Geysers EGS Demonstration is to demonstrate that injecting relatively cool water directly into deep, hot dry rocks is a viable mechanism for creating a distributed network (or “cloud”) of fractures.

The central premise is that shear reactivation offers an alternative to hydraulic fracturing mechanisms. Specific mechanisms for stimulation addressed in this project include thermal contraction, shear reactivation, and low pressure perturbations in a critically stressed high temperature reservoir (HTR).

Relevance of this project to the Geothermal Technology Office Goals:

- An EGS capable of producing 5 MW was created in the NW Geysers;
- Community acceptance was gained for this EGS project; and
- The injection of meteoric water at relatively low rates and low injection pressures can stimulate hot dry rock below, and at the margins of, hydrothermal systems.

Scientific/Technical Approach

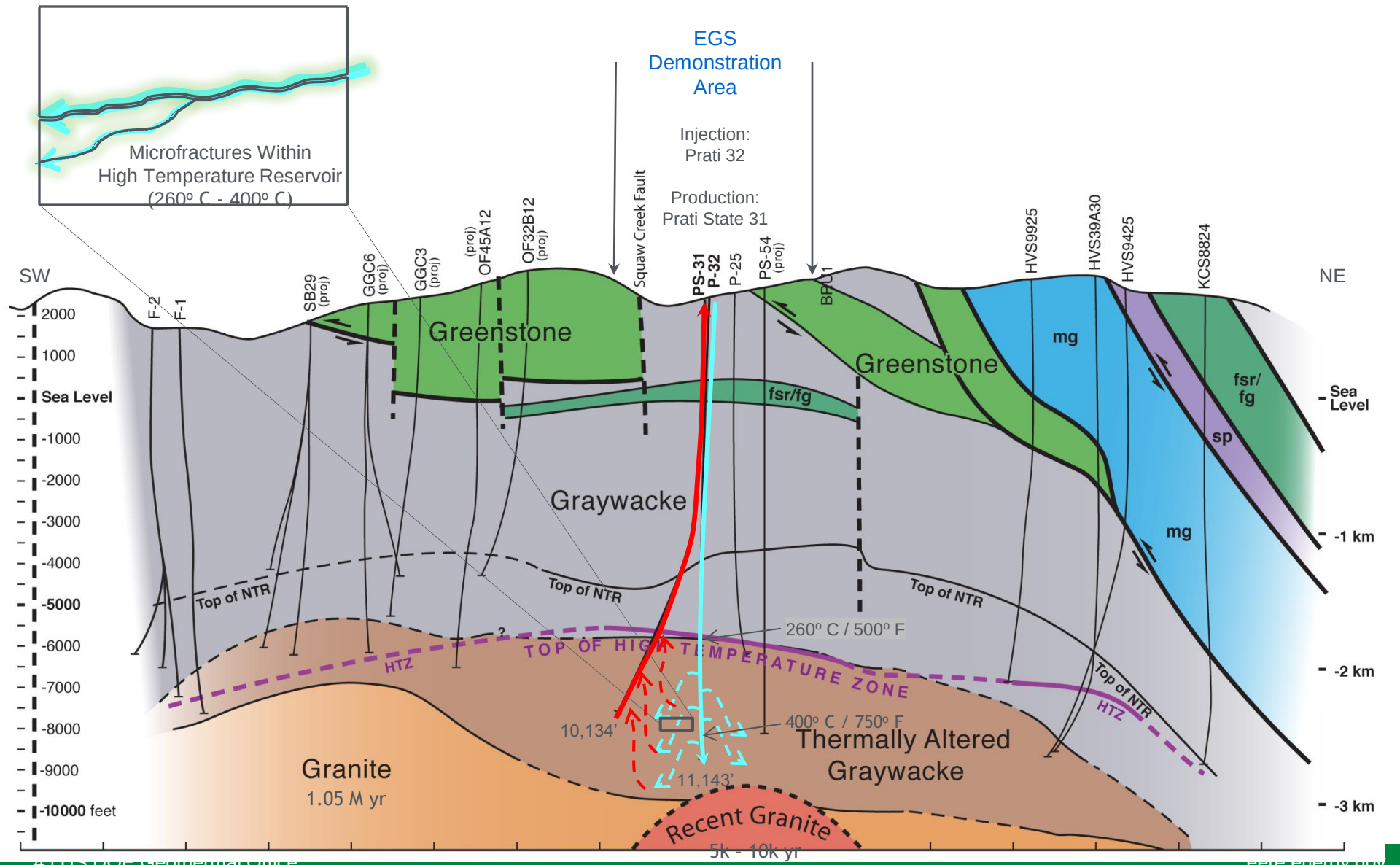
- Santa Rosa Geysers Recharge Project (SRGRP) water is tertiary-treated wastewater and is injected into Prati-32 (P-32) under a vacuum (~ -0.8 bar).

- A blank liner in P-32 directs water through the Normal Temperature Reservoir (NTR) and into the High Temperature Reservoir (HTR) which is 500 ^{o}F (260 ^{o}C) to 750 ^{o}F (400 ^{o}C).

- Temperatures conductively increase at 10 ^{o}F/100 ft (182 ^{o}C/km) in the HTR and the native fluids are connate and partially magmatic in origin. The HTR rocks are not isotopically exchanged with meteoric water, unlike the NTR which is the injection target elsewhere at The Geysers.

- Key issues for future direction of project in Phase III :
  - Mitigate corrosive, chloride-bearing steam;
  - Further define the permeability volume of the created network of distributed fractures through seismicity analysis;
  - Determine the sustainability of the stimulated reservoir volume; and
  - Analyze changes in the geochemistry of injection-derived steam over time.

Scientific/Technical Approach



Accomplishments, Results and Progress

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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 in HTR 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 during 4 month period 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 was shut-in on Feb. 13, 2013 following 70 days of production due to a shallow casing leak caused by chloride corrosion.

2013 - 2017

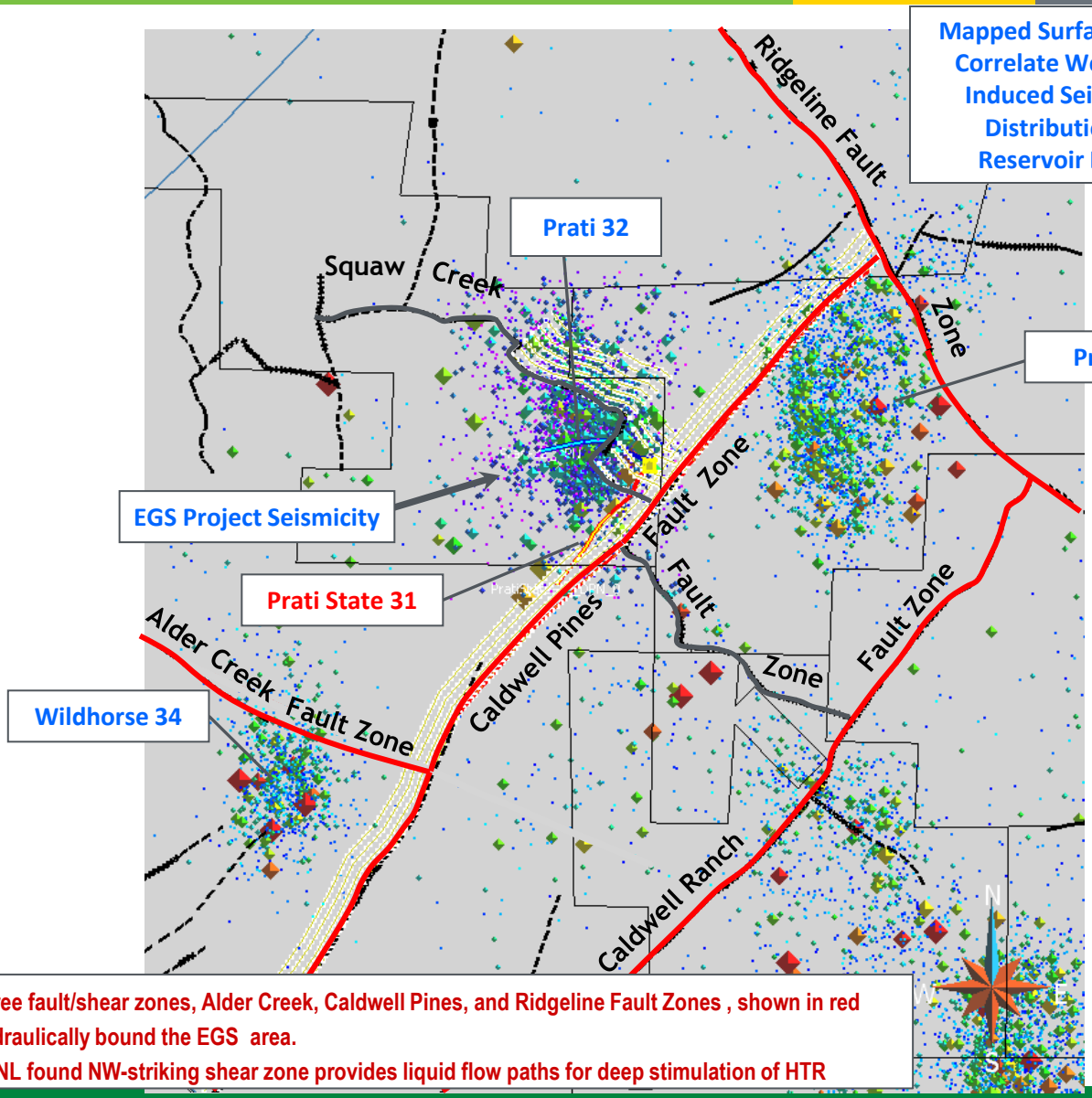
Phase 3: Long Term Monitoring

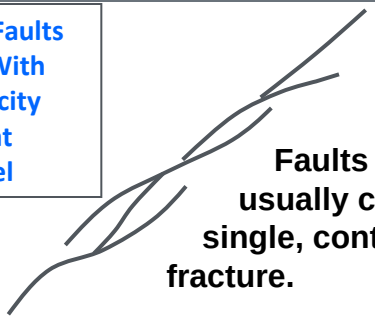
Obtain a no-cost time-extension to 2017 beyond the original December 2014 project completion.

Repair PS31 in Spring 2016 with 4000' of corrosion-resistant liner.

Monitor PS-31 production to:

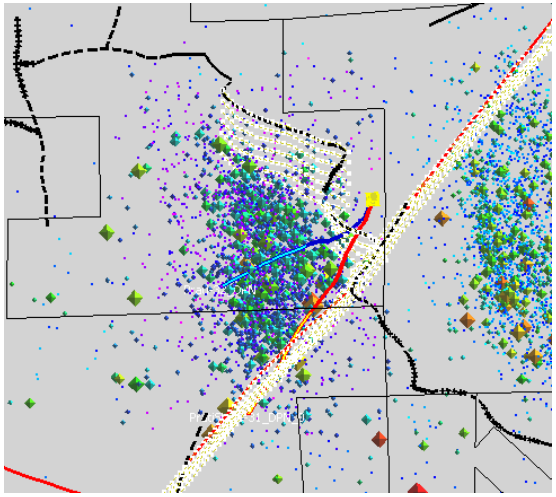
- *Determine sustainability of stimulated HTR reservoir volume.*
- *Further define permeability volume through seismic monitoring and possibly geomechanical modeling by LBNL.*
- *Determine changes in geochemistry of injection-derived steam with time.*
- *Study induced seismicity patterns*





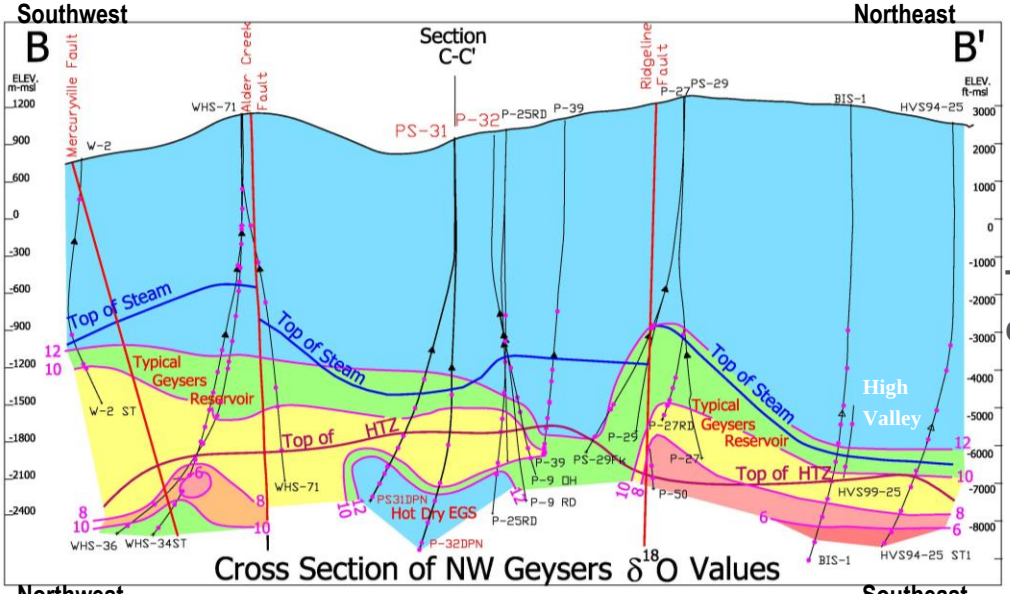
Faults do not usually consist of a single, continuous fracture.

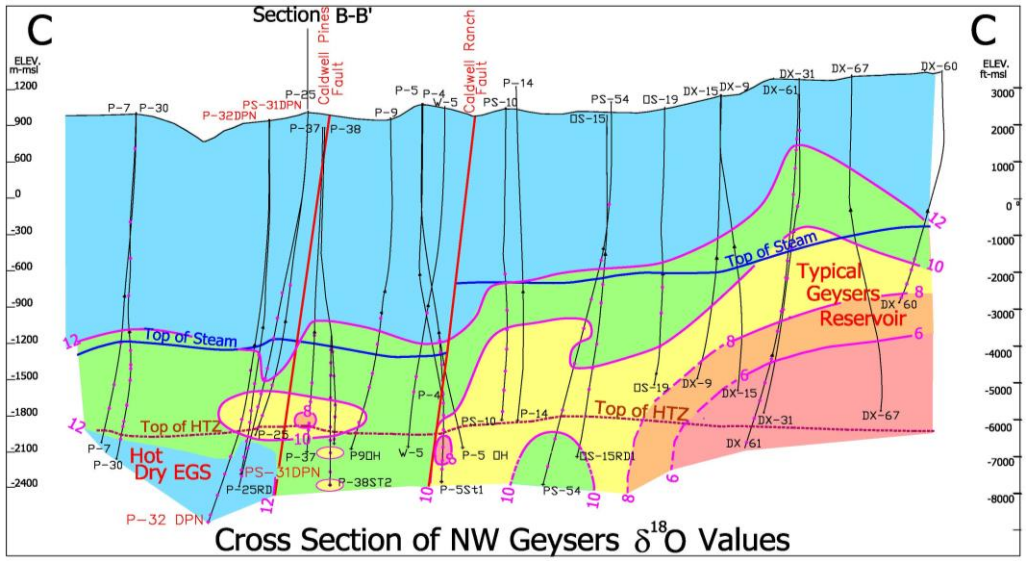
Geologists use the term fault zone when referring to a zone of complex deformation



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

- Three fault/shear zones, Alder Creek, Caldwell Pines, and Ridgeline Fault Zones , shown in red hydraulically bound the EGS area.
- LBNL found NW-striking shear zone provides liquid flow paths for deep stimulation of HTR





The $\delta^{18}O$ values in the EGS reservoir rock are unexchanged with meteoric water and are in the same range as the caprock to the typical Geysers reservoir.

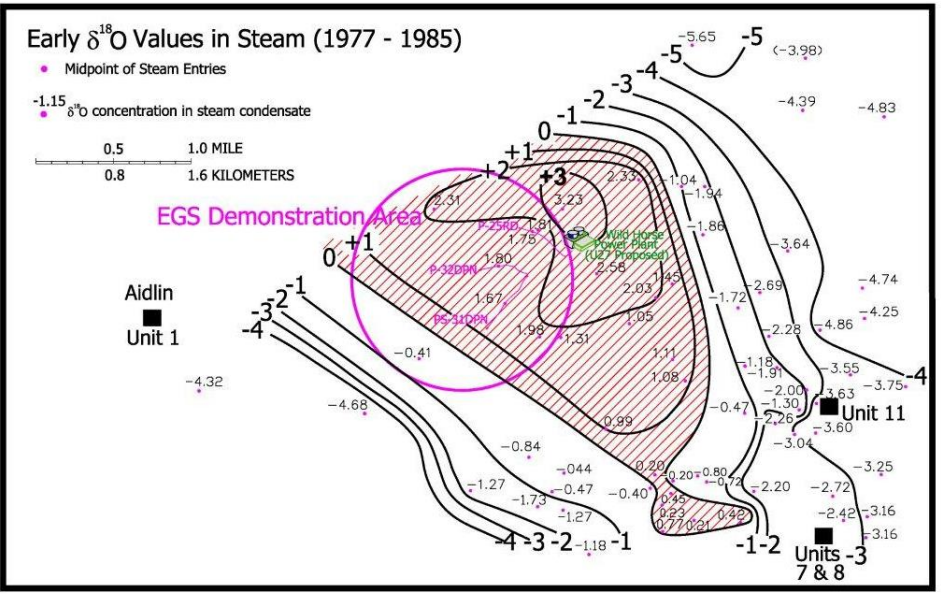
Temperature gradients in the HTR are conductive: 10 °F/100ft (182 °C/km

Supercritical temperatures 750 °F (400 °C) exist in EGS. The physical state of the water **molecule bonds** in a well-accepted structural model at these super critical temperatures is not yet available.

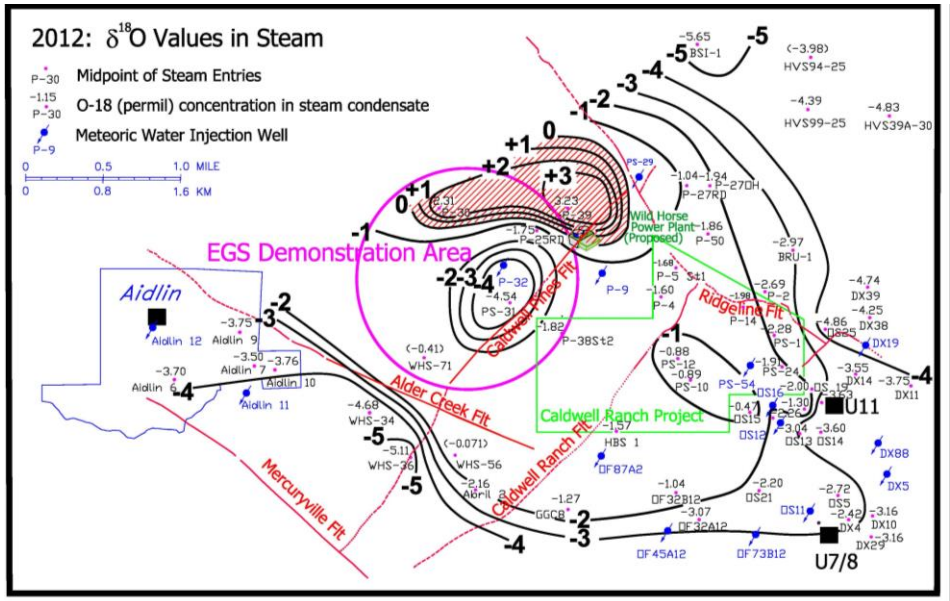
The $\delta^{18}O$ values throughout the typical Geysers reservoir rock and the high temperature reservoir in the High Valley area (above) systematically decrease with depth from +12 to +4 $\delta^{18}O$ *(per mil)*.

We conclude the EGS reservoir is in hot, dry rock and is not part of a hydrothermal system.

Isotopic Analysis of Steam Condensate



Steam initially produced northwest of the Caldwell Ranch Fault originated as connate water with $\delta^{18}O$ values of 0 per mil *(SMOW)* to +3 per mil.



The injection of meteoric water from the SRGRP project has flushed the connate water from EGS Demonstration and the adjacent Caldwell Ranch Project areas

The injection of meteoric water from SRGRP has flushed the connate water from EGS Demonstration and the adjacent Caldwell Ranch Project areas since Calpine re-opened the abandoned wells in the former CCPA steam field in 2009 and began SRGRP injection.

Accomplishments, Results and Progress

Seismicity Analysis / 3D Visualization of the Development of the Seismic Volume during First Year of SRGRP injection in Prati 32

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Weeks Since Injection Start: 52

Prati State 31
Production Interval
6900’ to 10000’

Seismic Event Magnitude
0.5 1.0 1.5 2.0+

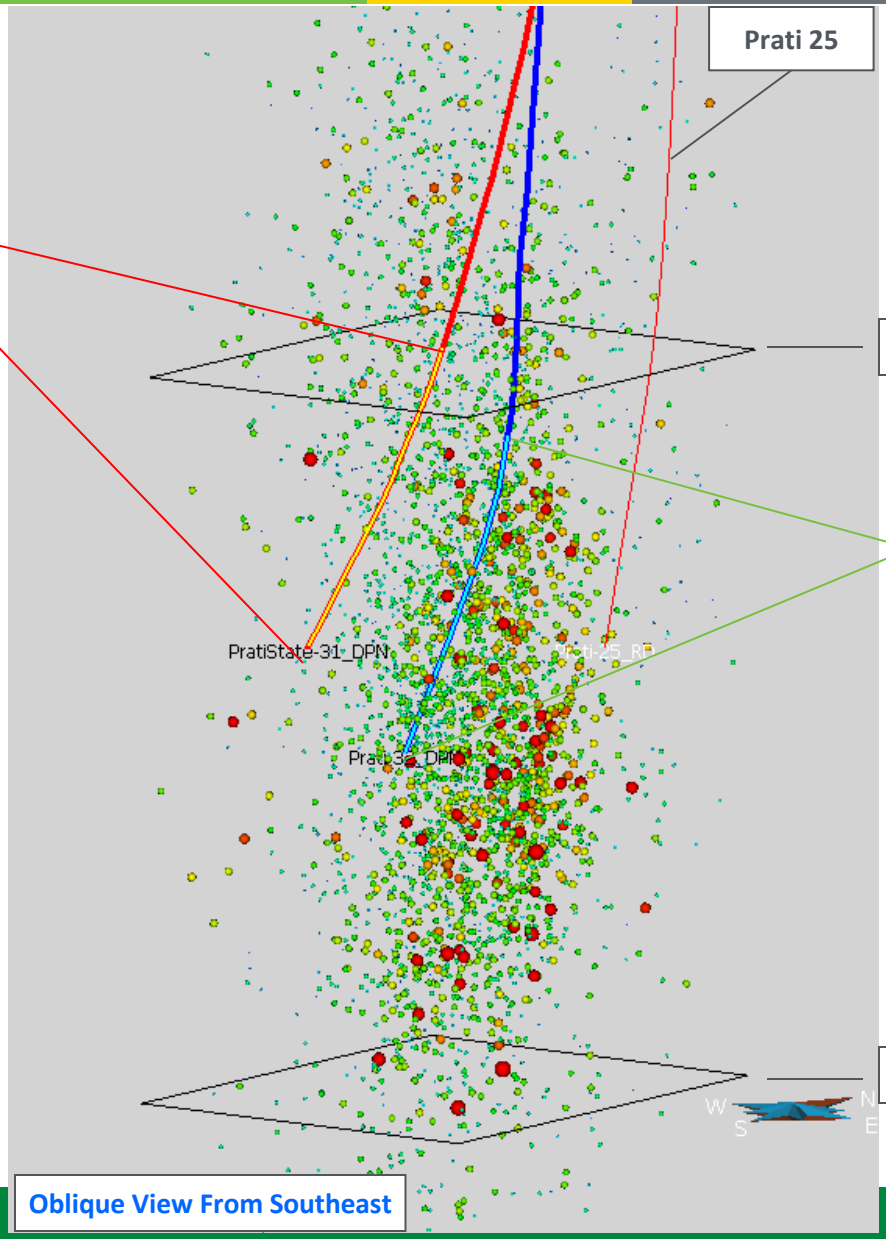
Area NW Geysers
Detailed Seismicity Analysis

Easting Range
1759041 – 1762691
= 3650’ East-West

Northing Range
426108 – 430968
= 4860’ North-South

Longitude Range
-122.8459 to -122.8333 degrees

Latitude Range
38.8336 to 38.8471 degrees



Oblique View From Southeast

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Seismicity Analysis / 3D Visualization of the Seismic Volume around P-32 from Different Viewing Perspectives

Prati State 31
Production Interval
6900' to 10000'

Prati 32
Injection Interval
7800' to 11143'

Seismic Events
06 October 2011 – 31 March 2015
Magnitude Scale
0.5 1.0 1.5 2.0+

Area NW Geysers
Detailed Seismicity Analysis

Easting Range
1759041 – 1762691
= 3650' East-West

Northing Range
426108 – 430968
= 4860' North-South

Longitude Range
-122.8459 to -122.8333 degrees

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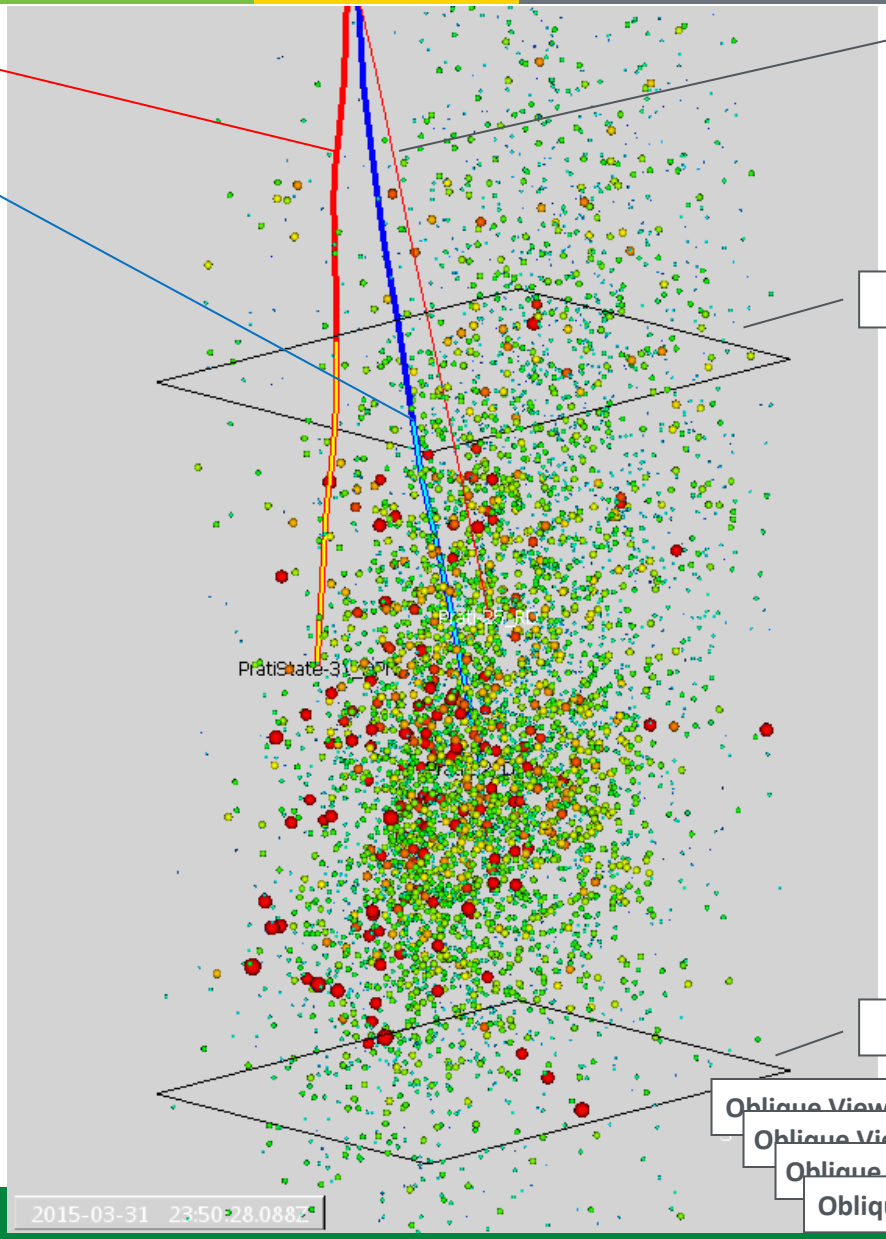
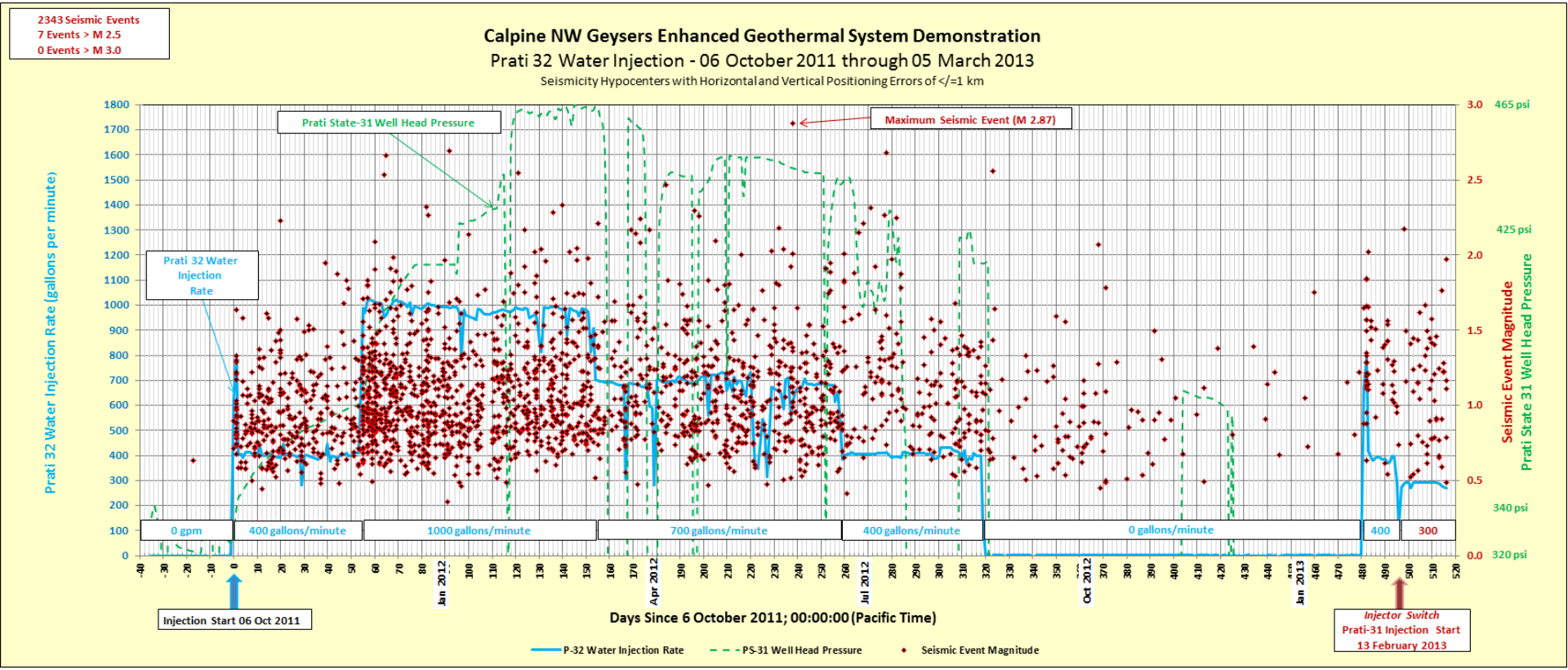
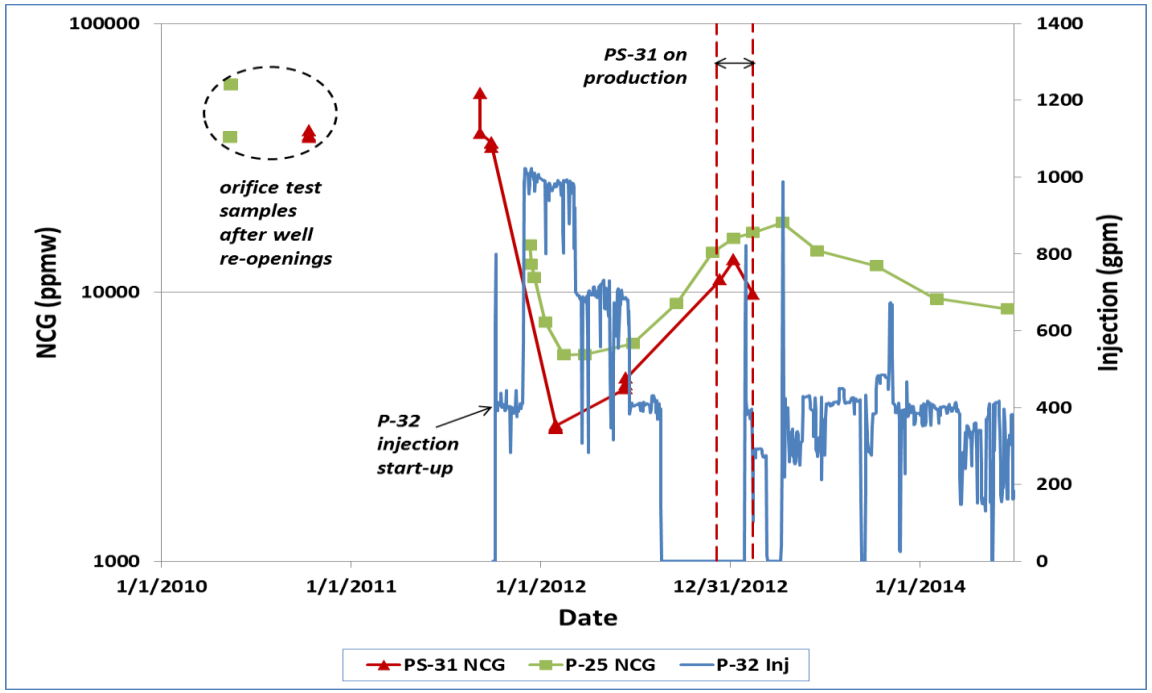


Accomplishments, Results and Progress



Injection rate correlates with microseismicity and static wellhead pressure. The highest injection rates at Prati-32 result in the highest frequency of microseismic events and highest wellhead pressures at PS-31. Note the few microseismic events during the period of no injection in P-32.

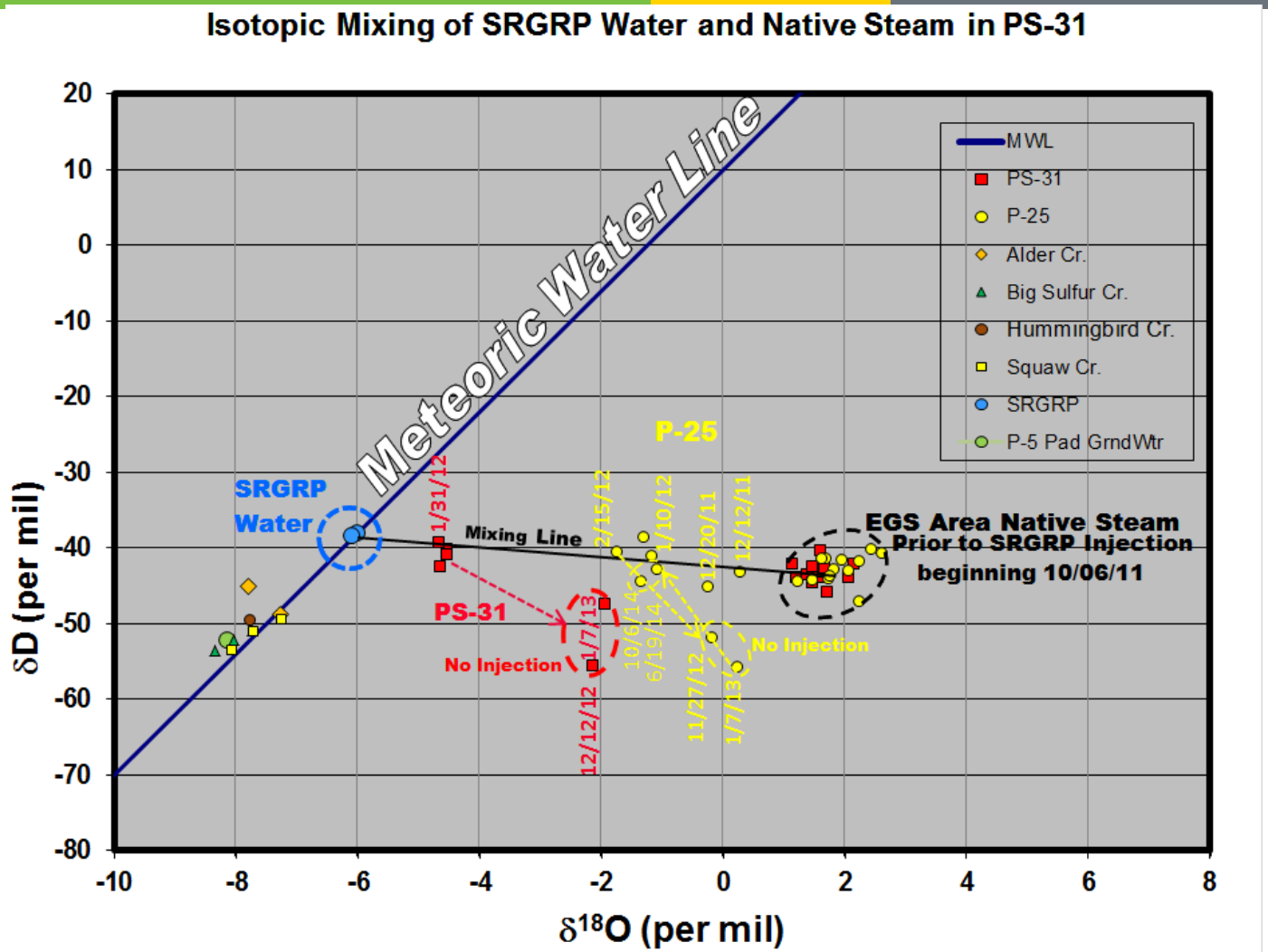


PS-31	NCG	H2S	Cl
Orifice Testing	Wt%	ppmw	ppmw
10/13/2011	4.5	1386	135
09/7/2011	4.7	1299	31
9/29/2011	3.5	1077	3.6
01/31/2012	0.32	545	27-123
06/14/2012	0.46	628	0.67-15.3
Production			
12/12/2012	1.1	767	13.5
01/7/2013	1.3	808	23
02/13/2013	1.3	808	23

NCG concentrations initially decreased about 90% in PS-31 after P-32 injection began in Nov. 2011.

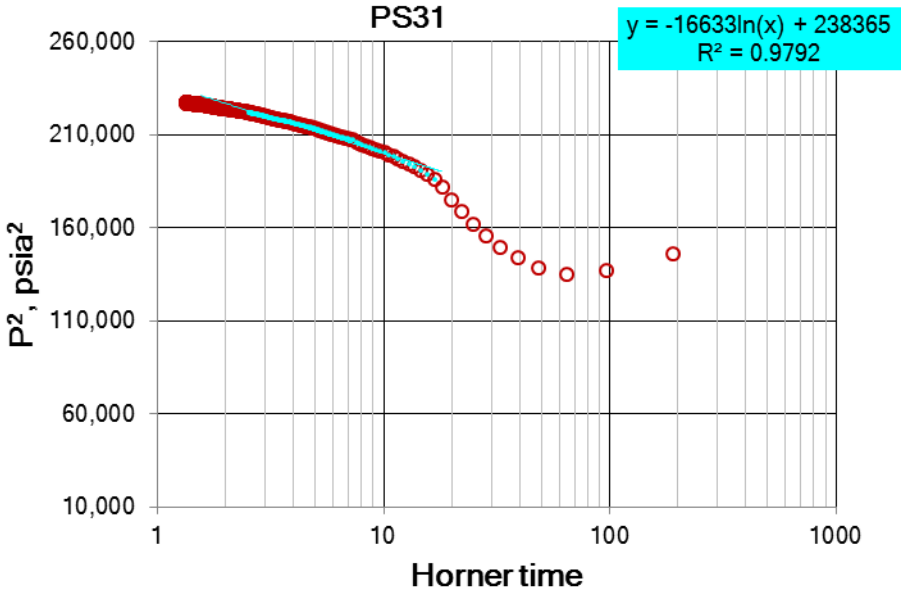
After P-32 injection began in Nov. 2011, P-25 NCG concentrations decreased more than 75% by Dec. 2014.

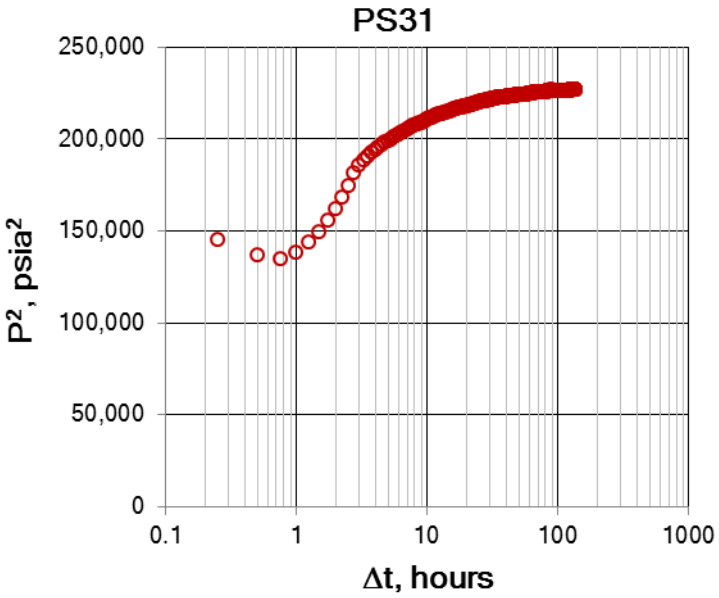
Corrosive chloride concentrations in the EGS producers has not decreased since P-32 injection began. As a result, a near-surface hole in the PS-31 casing developed after only 70 days from the start of production. Calpine believes that dry steam paths may still extend from the high temperature zone into the overlying NTR.



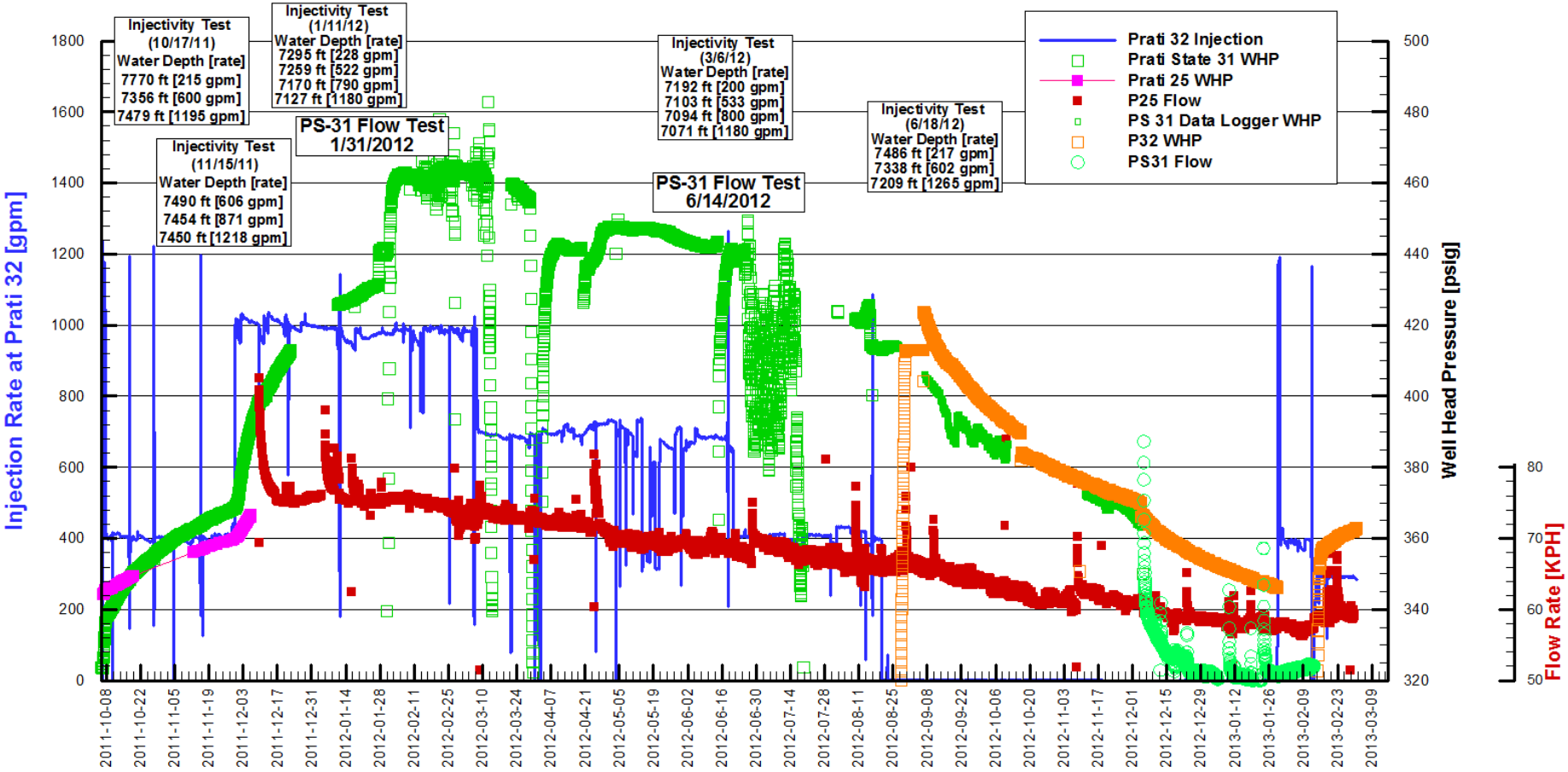
^{18}O and deuterium are natural tracers in the EGS. Prati State 31 steam was 80% IDS from SRGRP water and Prati 25 was 50% when Prati 32 injection stopped in Aug. 2012. The percentage of IDS in PS-31 dropped to 50% and 20% in P-25 during a no injection period in P-32. The IDS percentage increased to 40% IDS in P-25 after P-32 injection re-started.

PS-31 Steam Well Build-up Test Analysis January 13, 2012





Pressure Transient analysis indicates that the fracture permeability of PS-31 increased from a value of 22,000 md-ft (6.6 Dm) on January 13, 2012 to 42,300 md-ft (12.7 Dm) 7 months later.



P-32 injection and well head pressures at PS31 and P25

Future Directions

PS-31 was shut-in after 70 days of production due to a leak caused by accelerated chloride corrosion in near-surface carbon steel casing.

- **Stainless steel duplex alloy (2507) and titanium Grade 12 are being evaluated as a tieback liner to 4000 ft depth in PS-31.**
- **Calpine is planning to install an alloy liner in PS-31 in 2016.**

Phase III, long-term monitoring, will continue into 2017 and determine the sustainability, changes to the microseismic volume, and geochemical changes during production.

Cooperation with Lawrence Berkeley National Laboratory (LBNL) through Phase III of the project will continue. Calpine recommends additional geomechanical modeling by LBNL to determine the permeability volume created by the EGS stimulation.

Production test reports, injection test reports, microseismic analyses, isotopic data for rocks and fluids, geochemical data, and copies of selected illustrations, maps and sections will be submitted to the geothermal data repository in 2015.

Calpine and LBNL submitted two papers for publication in late 2015 in a special edition of Geothermics:

- Garcia, J., Hartline, C., Walters, M., Wright, M., Rutqvist, J., Dobson, P.F., and Jeanne, P., (submitted January 12, 2015), The Northwest Geysers EGS Demonstration Project, California: Part 1: Characterization and Response to Injection, Geothermics, Special EGS Issue.
- Rutqvist, J., Jeanne, P., Dobson, P.F., Garcia, J., Hartline, C., Hutchings, L., Singh, A., Vasco, D.W. and Walters, M., (submitted January 12, 2015), The Northwest Geysers EGS Demonstration Project, California, Part 2: Modeling and Interpretation, Geothermics, Special EGS Issue.

Mandatory Summary Slide

- Although the EGS project is capable of producing 5 MW of new steam in addition to the native steam, it cannot because of pipeline interference until a new generation unit is constructed.
- Seismic analysis of microseismic hypocentral locations indicates a distributed network of fractures (“cloud”) has developed in a reservoir compartment bounded by an orthogonal set of NW-SE and NE-SW shear zones. The frequency of microseismic events is directly related to the injection rate of P-32.
- The EGS Demonstration Area is 6.5 miles and 9 miles distance to the nearest communities of Cobb and Anderson Springs, respectively. Consequently the largest seismic events induced by P-32 injection, including a 3.74 event, cause “light” perceived shaking with “no potential for damage” (as defined by the Modified Mercalli Intensity scale) in these communities.
- SRGRP water injection into the EGS project area has flushed the original connate water from the HTR in the EGS reservoir and has significantly lowered the concentrations of noncondensible gas and stable isotopes in injection-derived steam.
- Higher temperature modeling capabilities are needed for the accurate representation of water at super critical temperature conditions in the EGS reservoir. Updated Equations-of-State models for water in low permeability rock at super critical temperatures are needed for future geomechanical modeling of the EGS project.