



A GENERATION AHEAD,
today

NW Geysers
Enhanced Geothermal System
Demonstration Project

Seismicity Analysis
01 Sept 2011 to 05 March 2013

Prati 32 Injection Well
Prati State 31 Production Well



Craig Hartline Senior Geophysicist Calpine Corporation

C L E A N M O D E R N E F F I C I E N T F L E X I B L E P O W E R G E N E R A T I O N

The Geysers

Location of Northwest Geysers EGS Demonstration

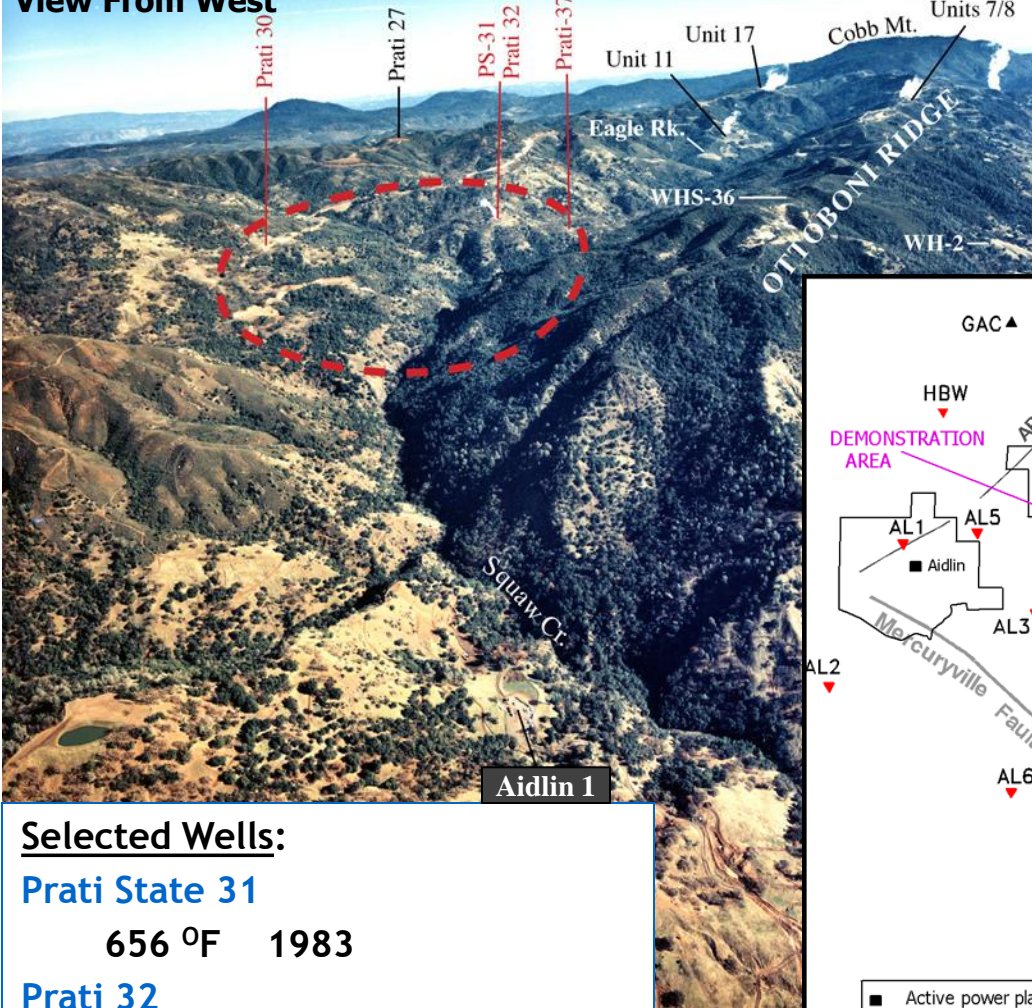
Principal Investigator: Mark Walters; Calpine Senior Geologist

Julio Garcia; Calpine Manager Geothermal Production Analysis

Craig Hartline; Calpine Senior Geophysicist



View From West



Selected Wells:

Prati State 31

656 °F 1983

Prati 32

600 °F 1985

750 °F 2010 - Deepened

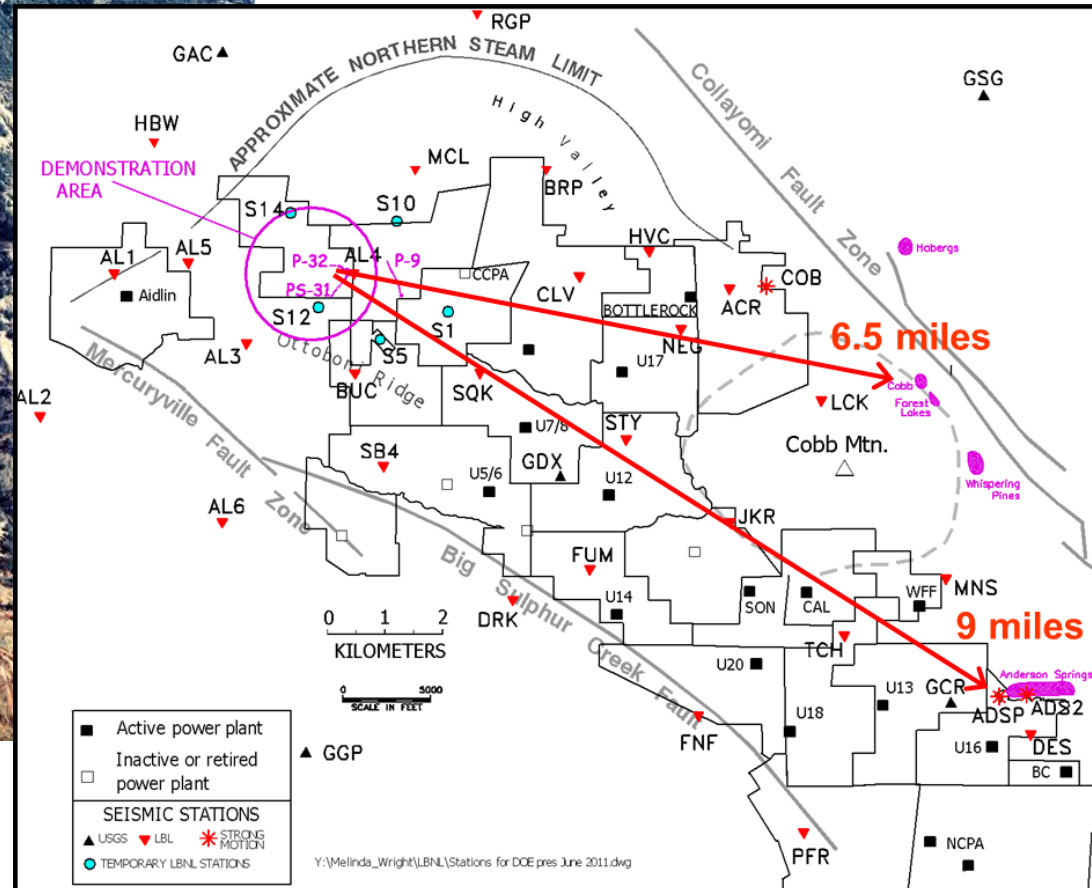
NW Geysers explored in 1980's

Relatively high concentrations of:

Non-condensable gas

Corrosive chloride gas

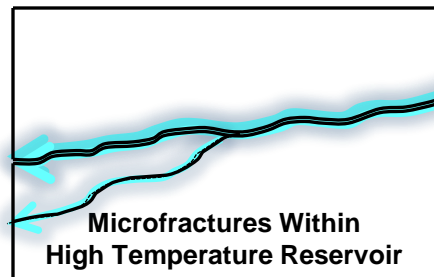
Technology and innovation ...



The Geysers

Northwest Geysers Enhanced Geothermal System Demonstration

Location and Technique

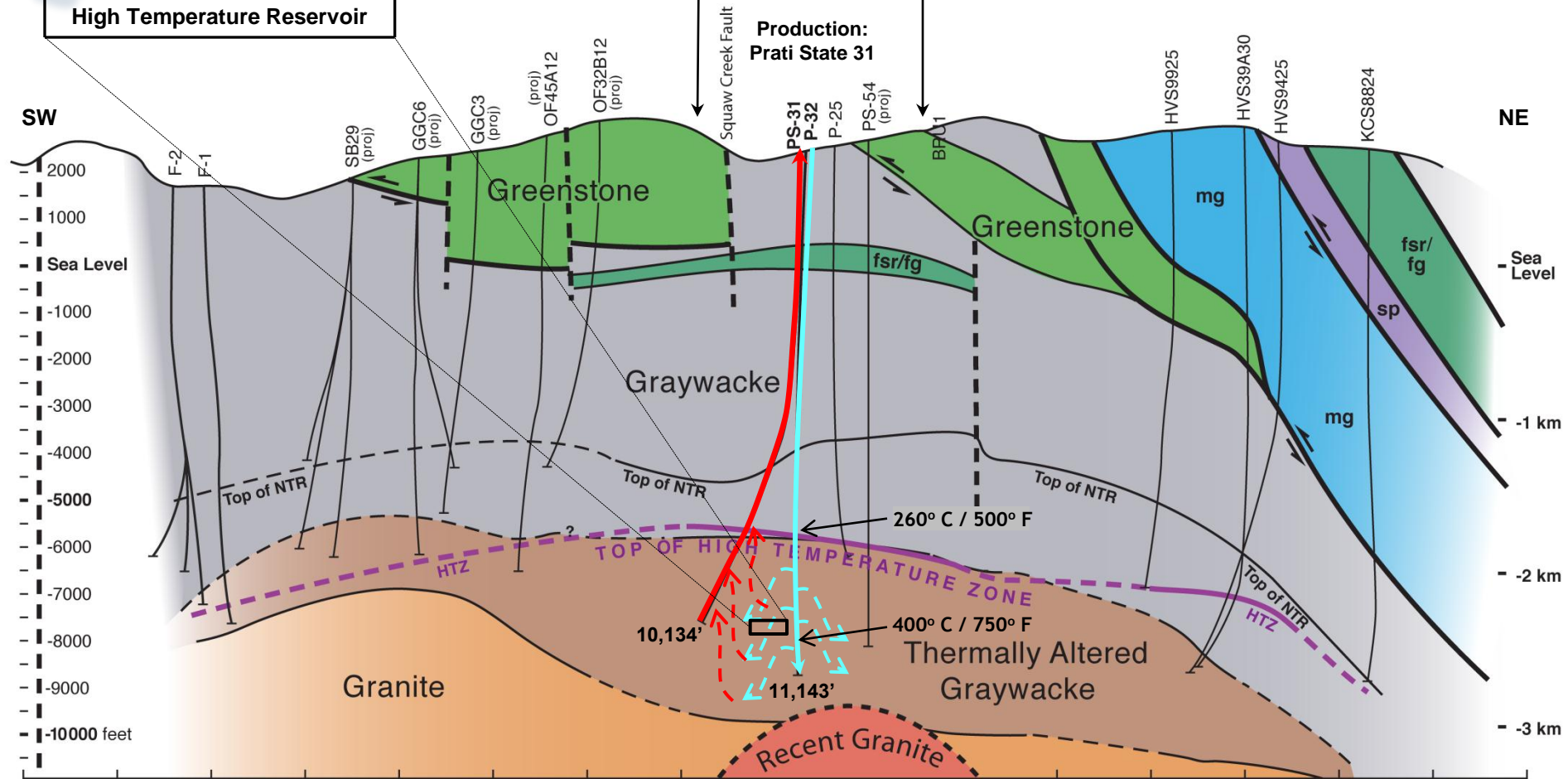


**EGS
Demonstration
Area**

**Injection:
Prati 32**

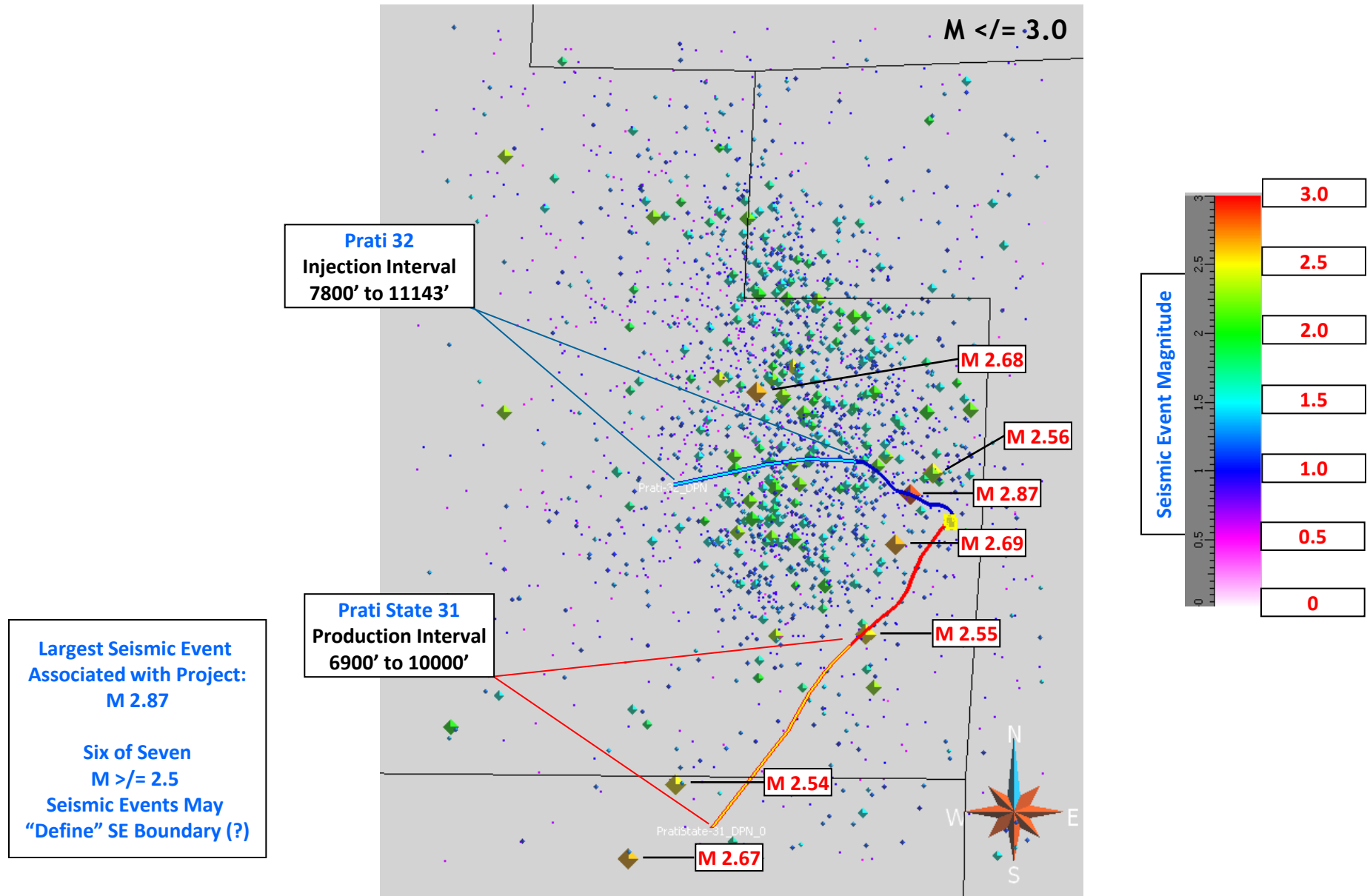
**Production:
Prati State 31**

**Estimated Injection-Derived Steam:
Additional 5 MW @ 500 gpm injection
Power for approximately 5,000 homes**



Seismicity Analysis: 01 September 2011 to 05 March 2013

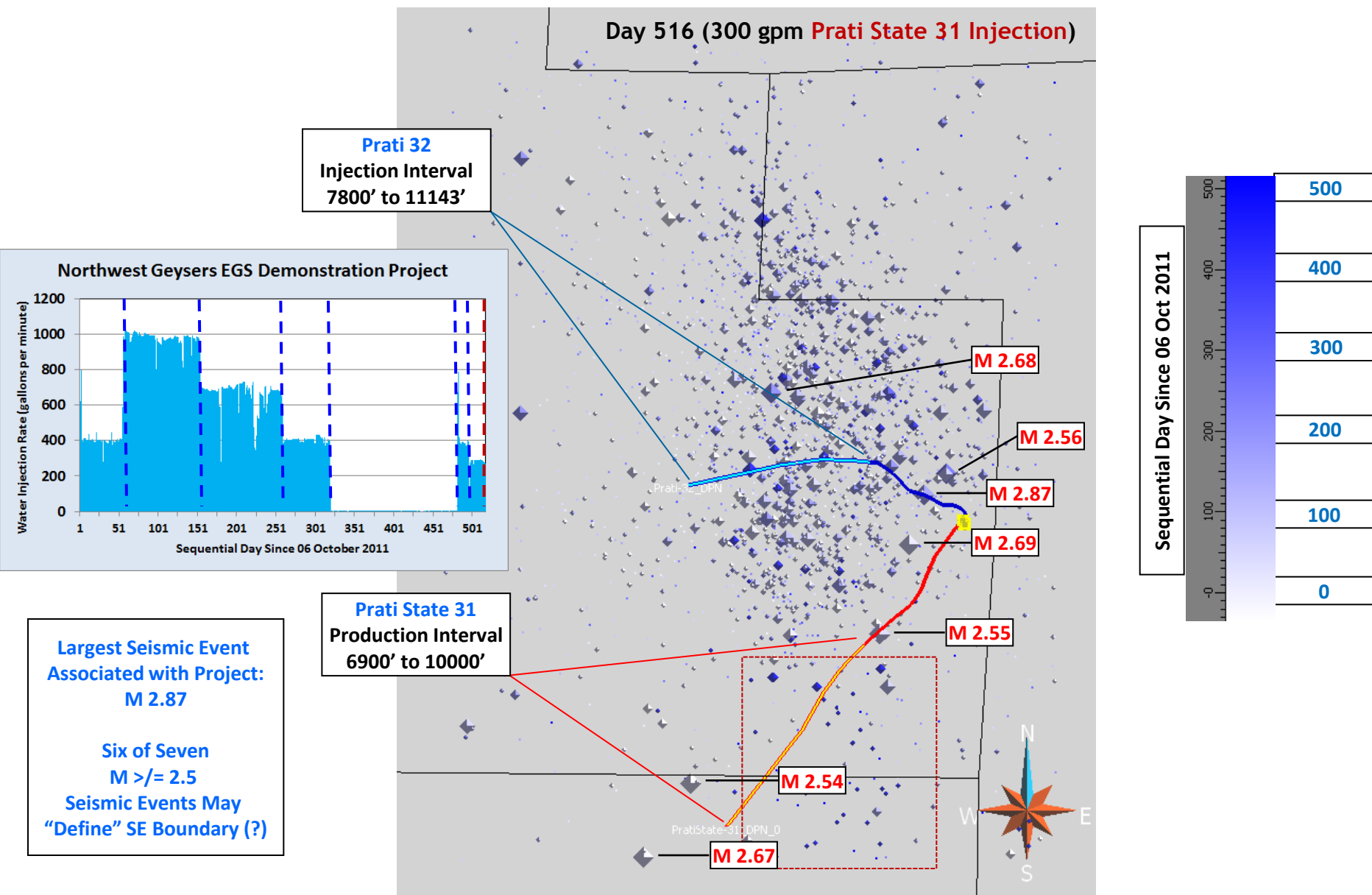
LBNL database events with ErH (horizontal error) and ErZ (vertical error) less than 1 km



Calpine NW Geysers EGS Demonstration

Seismicity Analysis: 01 September 2011 to 05 March 2013

LBNL database events with ErH (horizontal error) and ErZ (vertical error) less than 1 km



Calpine NW Geysers EGS Demonstration

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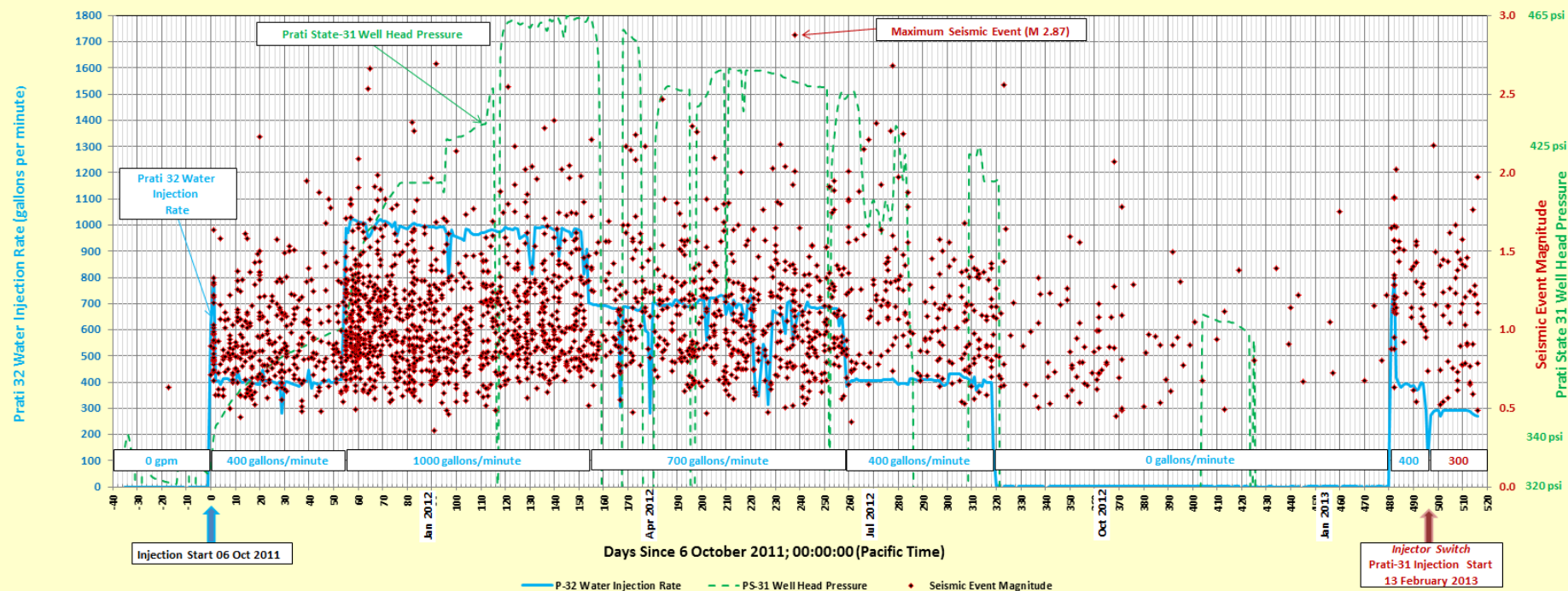


2343 Seismic Events
7 Events > M 2.5
0 Events > M 3.0

Calpine NW Geysers Enhanced Geothermal System Demonstration

Prati 32 Water Injection - 06 October 2011 through 05 March 2013

Seismicity Hypocenters with Horizontal and Vertical Positioning Errors of ≤ 1 km

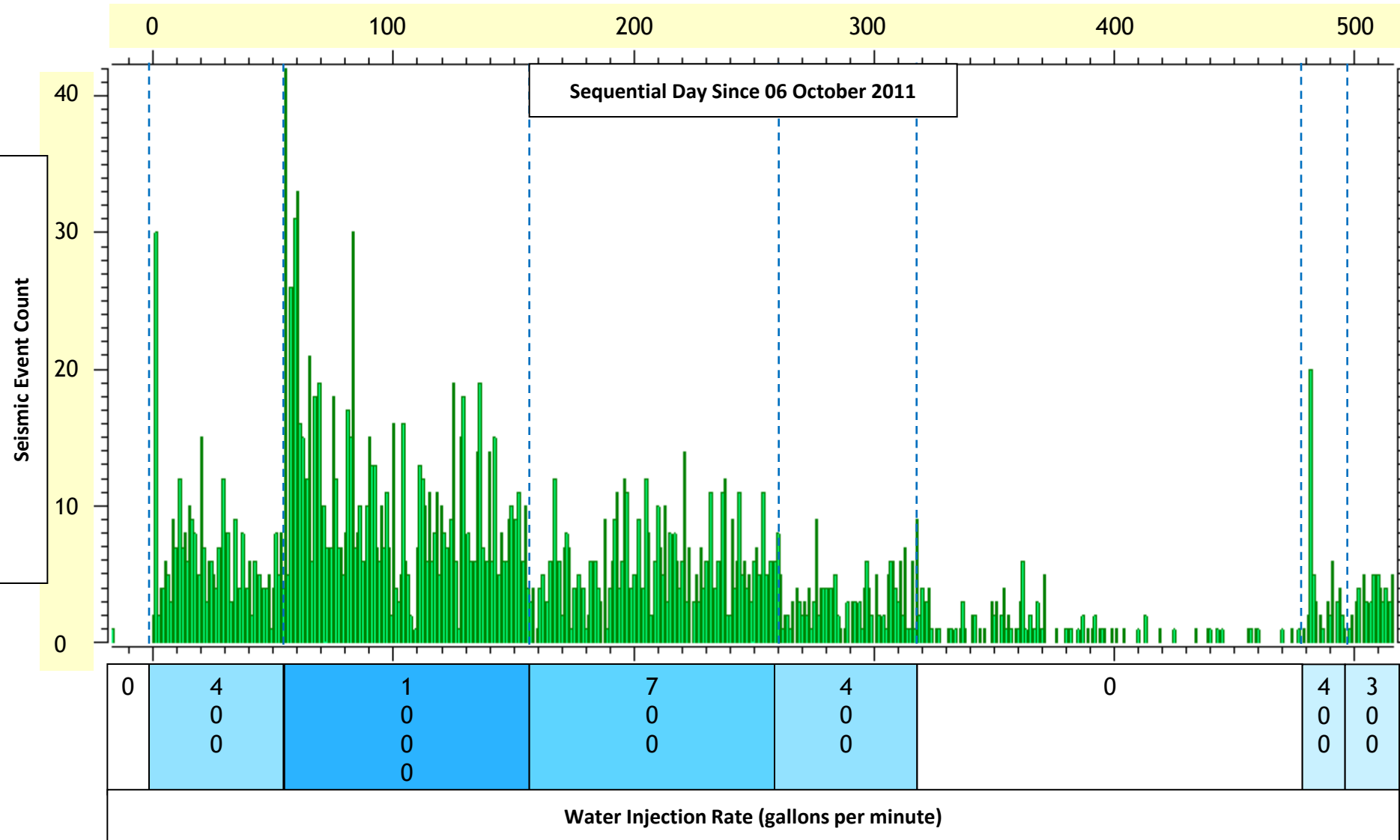


Seismic Event Frequency Declined During the Shut-in Period, Returned to Previous Levels with Injection Restart

Calpine NW Geysers EGS Demonstration

Seismicity Analysis: 01 September 2011 to 05 March 2013

LBNL database events with ErH (horizontal error) and ErZ (vertical error) less than 1 km

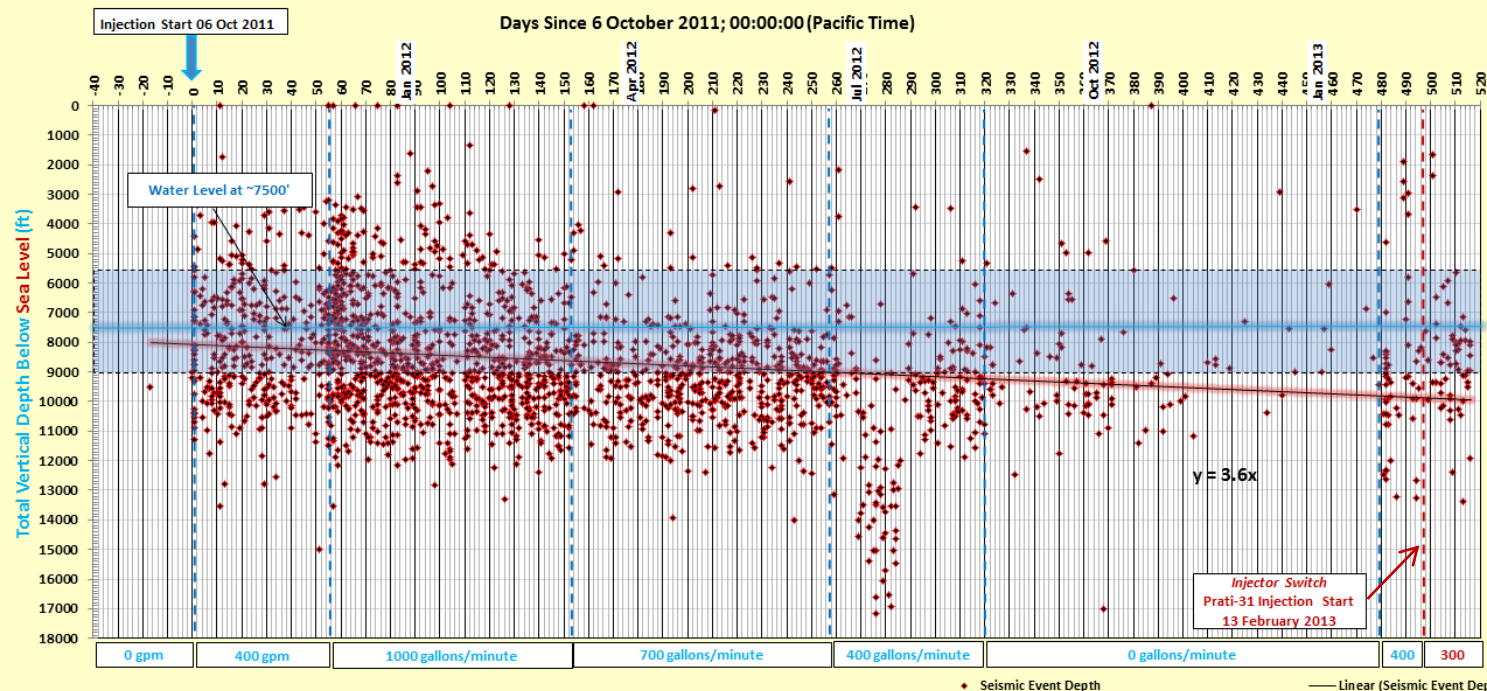


Seismic Event Frequency Tends to Decrease with Continued Injection at a Constant Flow Rate

2343 Seismic Events

NW Geysers Enhanced Geothermal System Demonstration Prati 32 Water Injection - 06 October 2011 Through 05 March 2013

Seismicity Hypocenters with Horizontal and Vertical Positioning Errors of ≤ 1 km

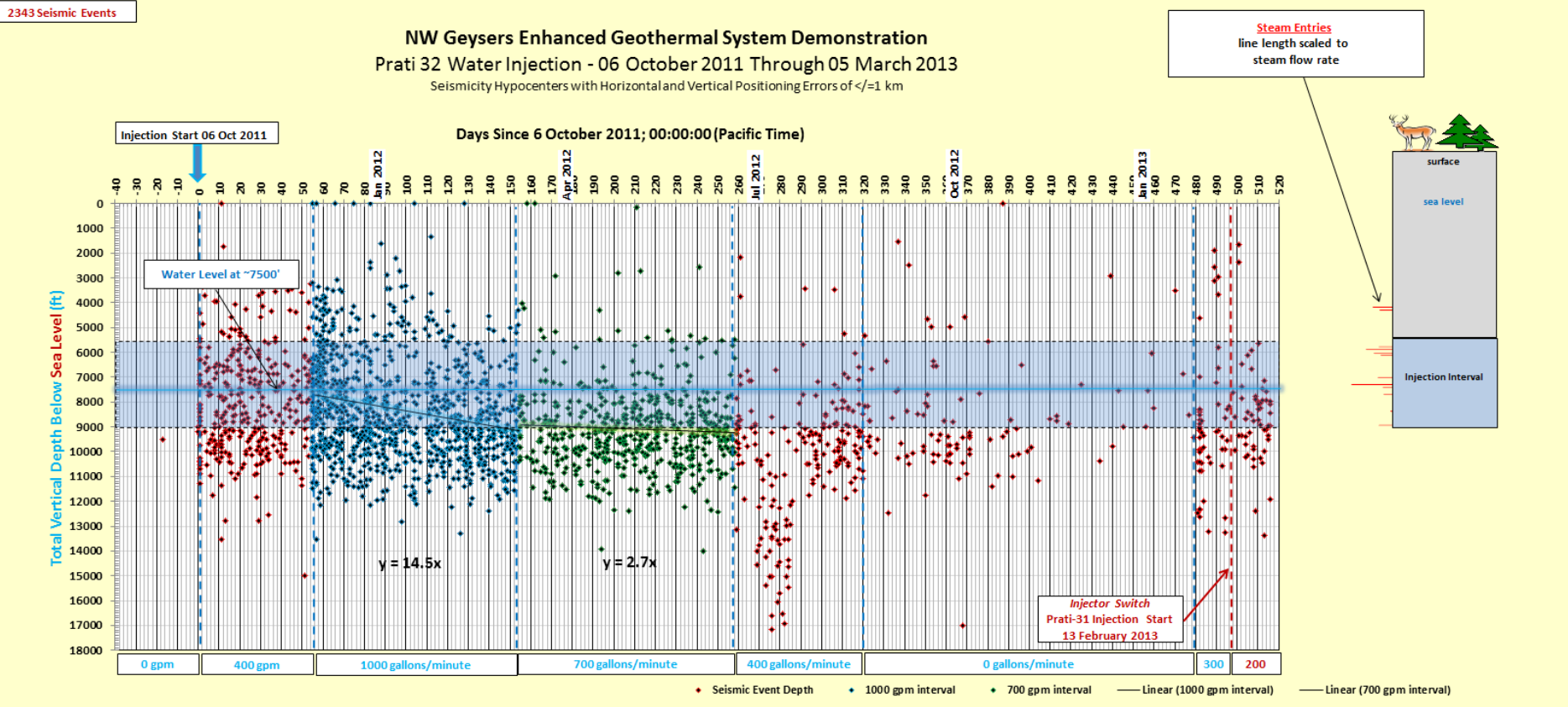


The Center of Seismicity Has Generally Trended Downward During The Injection Period
(at an average of ~3.6 feet/day or ~1900 feet since program initiation)

Calpine NW Geysers EGS Demonstration

Seismicity Analysis: 01 September 2011 to 05 March 2013

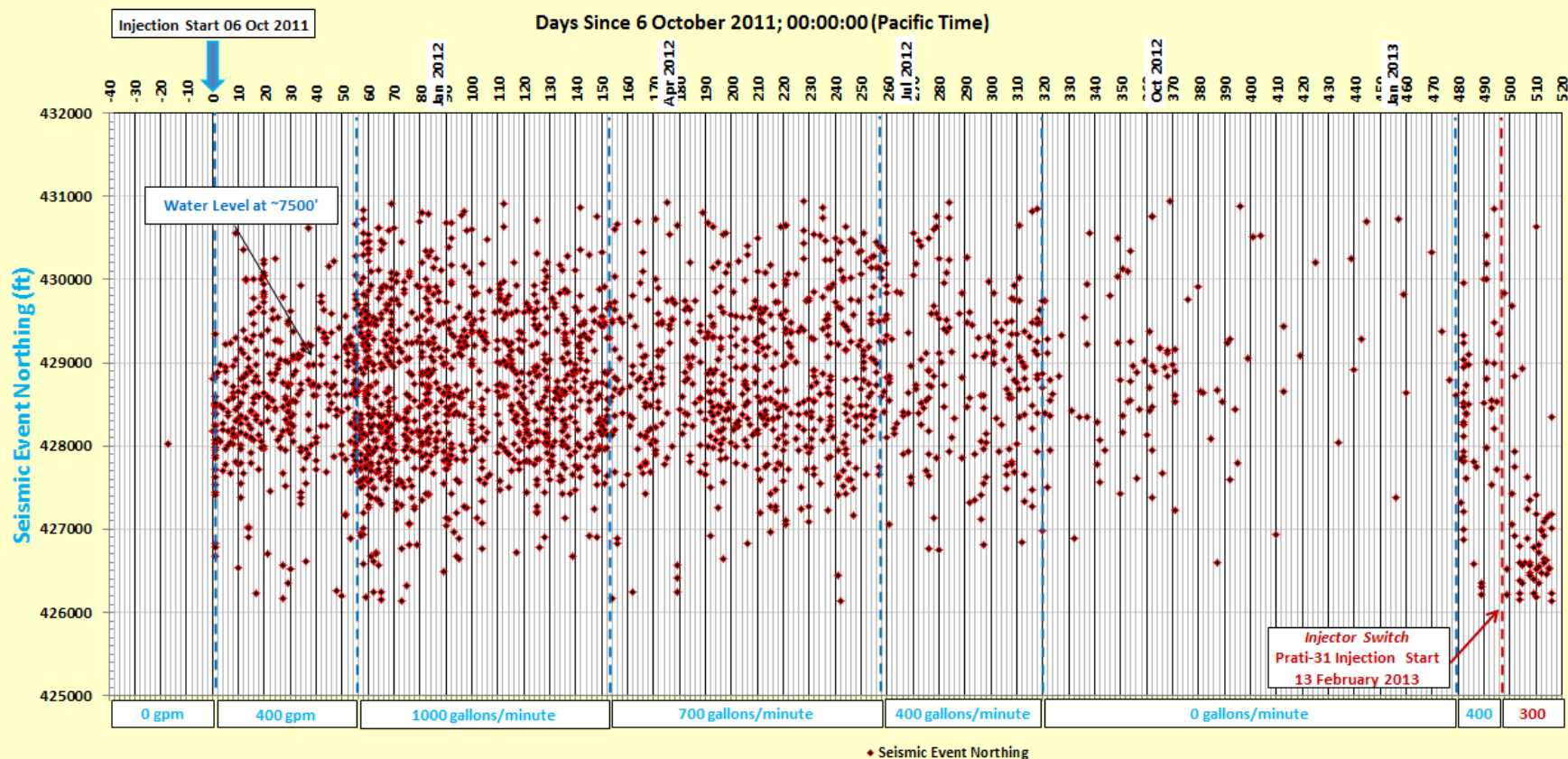
LBNL database events with ErH (horizontal error) and ErZ (vertical error) less than 1 km



The Rate of Downward Movement of the Center of Seismicity is Somewhat Dependent on Injection Flow Rate

2343 Seismic Events

NW Geysers Enhanced Geothermal System Demonstration Prati 32 Water Injection - 06 October 2011 Through 05 March 2013 Seismicity Hypocenters with Horizontal and Vertical Positioning Errors of ≤ 1 km

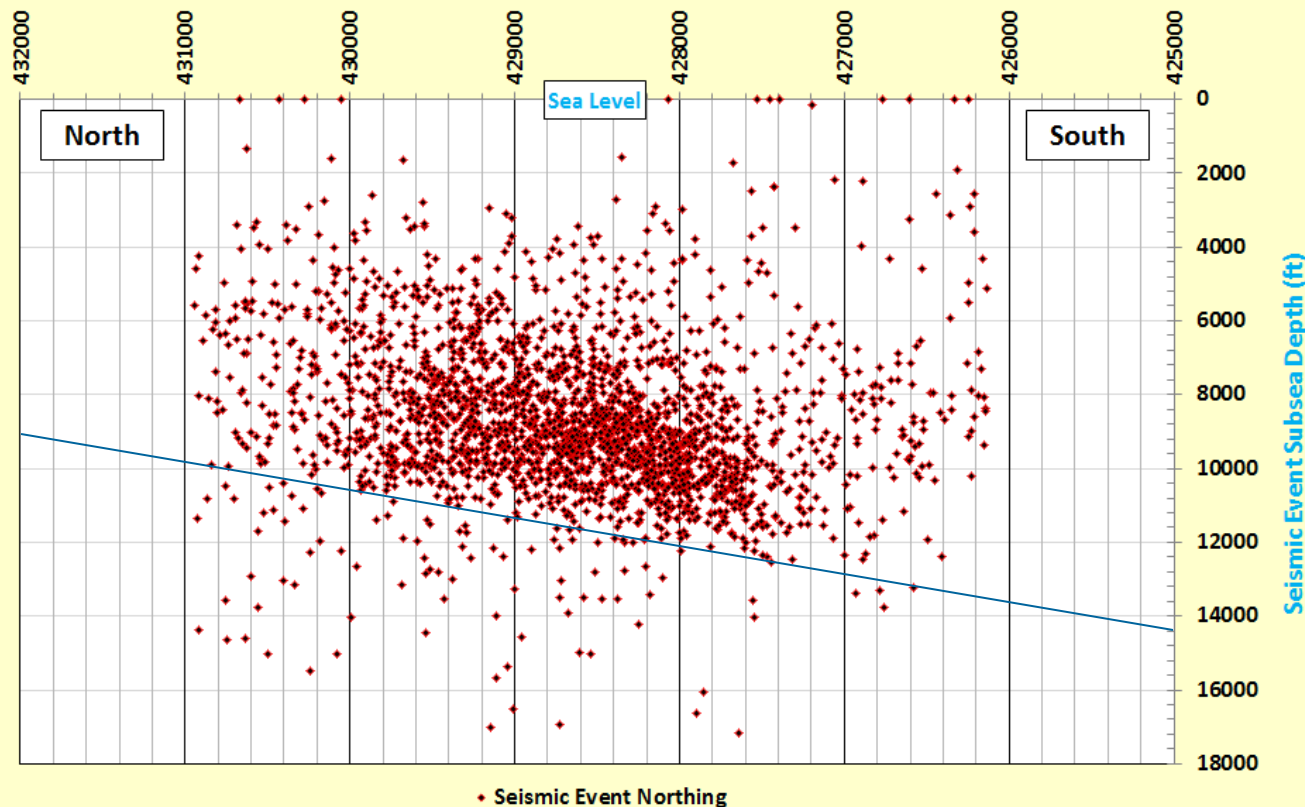


The seismicity center shifted to the south with the transition of injection from Prati 32 to Prati State 31

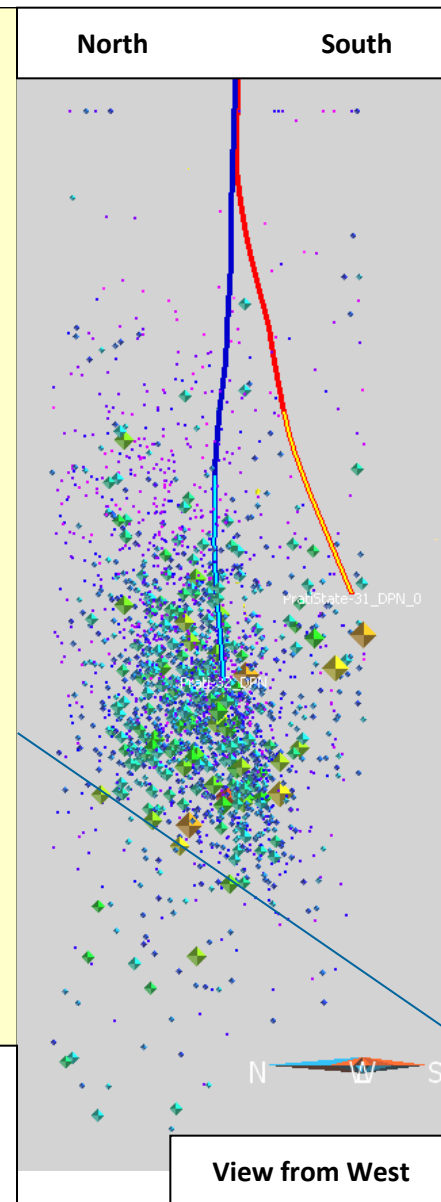
2343 Seismic Events

NW Geysers Enhanced Geothermal System Demonstration Prati 32 Water Injection - 06 October 2011 Through 05 March 2013 Seismicity Hypocenters with Horizontal and Vertical Positioning Errors of ≤ 1 km

Seismic Event Northing (ft)



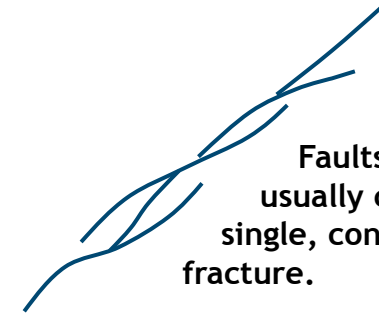
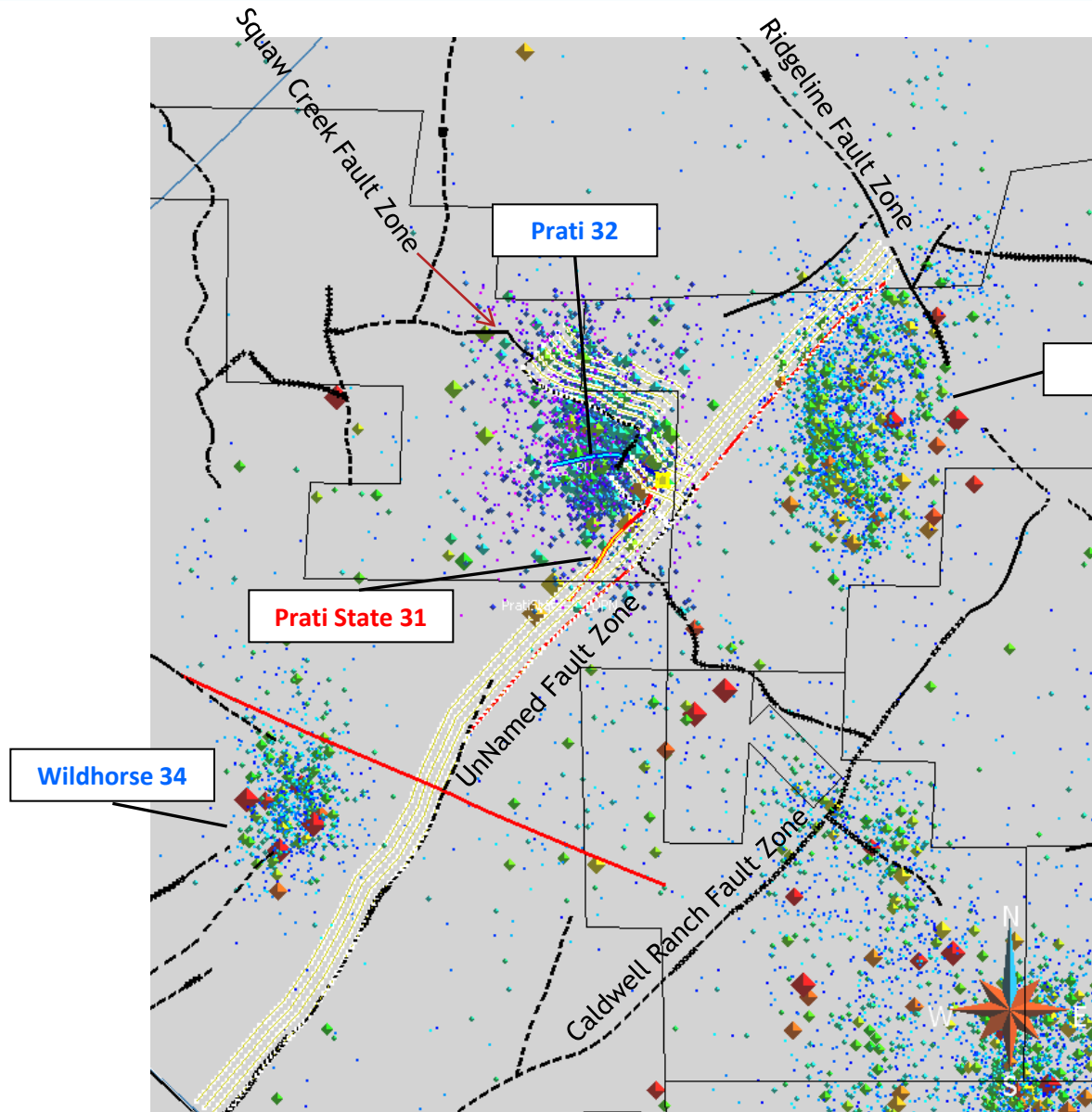
• Seismic Event Northing



There appears to be an inclined “base” to the main seismicity cluster.
Four events of ~ M 2.25 are aligned with this base (fault zone?)

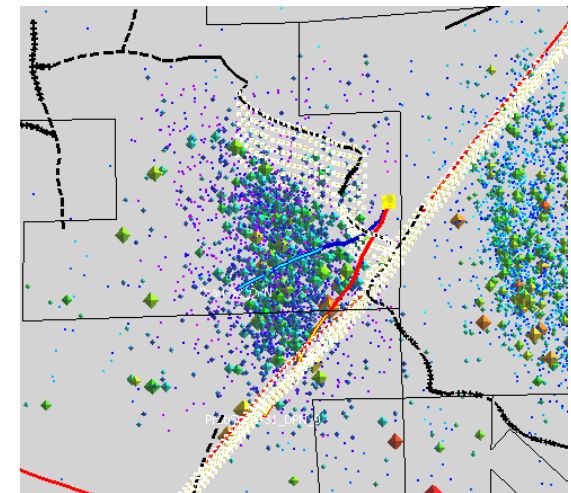
Seismic Monitoring Advisory Committee

Calpine 3D Visualization and 3D Model Building



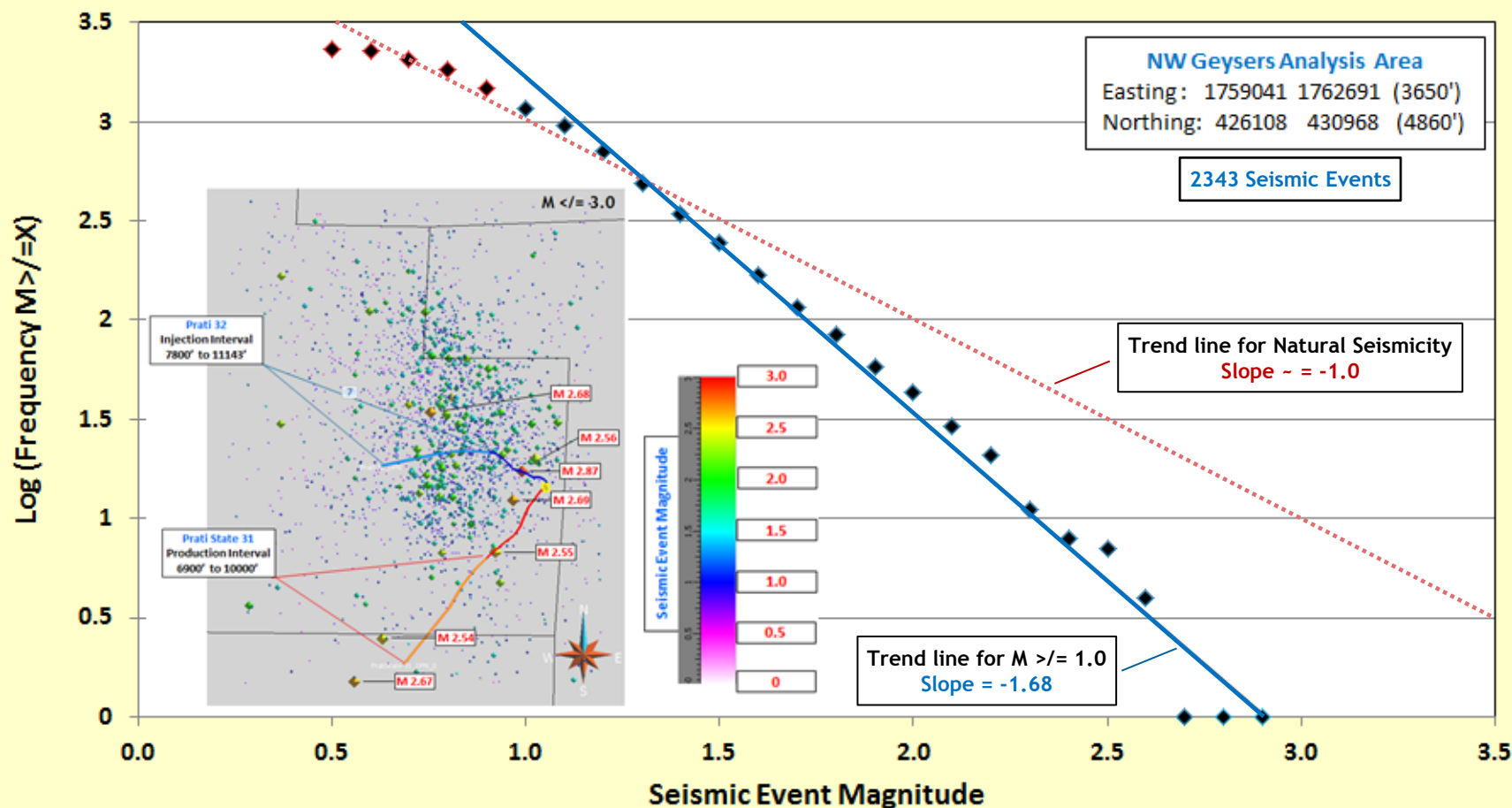
Faults do not usually consist of a single, continuous fracture.

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



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

Calpine NW Geysers Enhanced Geothermal System Demonstration Prati 32 Water Injection - 06 October 2011 through 05 March 2013 "Beta Plot" - Event Magnitude vs. Log (Frequency of Events $M \geq X$)



Calpine NW Geysers EGS Demonstration

Seismicity Analysis: 01 September 2011 to 05 March 2013



Negligible Strong Motion Instrument Responses at Anderson Springs and Cobb From Maximum Seismic Event (M 2.87)

20120531_053126_COB-03432_EF081 COB 05/31/2012/ 05:31:26.000

HNE 1.484894 0.019180 0.590780 0.054566 0.008896 HNN 1.281621 0.021821 1.063913 0.045667 0.008398 HNZ 0.818167 0.010188 0.395494 0.036799 0.004547

20120531_053129_ADSP-03433_FF1239 ADSP 05/31/2012/ 05:31:26.000

HNE 1.718394 0.022286 0.600226 0.034296 0.008010 HNN 1.366358 0.019826 0.484243 0.029602 0.010503 HNZ 0.998494 0.011479 0.185820 0.014799 0.004931

Magnitude 2.87 Event

31 May 2012, 05:31:26 UTC

Anderson Springs:

Geometric Mean (Horizontal Components):

$1.53 \text{ cm/sec}^2 = 0.16\%$ of gravitational acceleration

Modified Mercalli Intensity: I

Not Felt; No Potential Damage

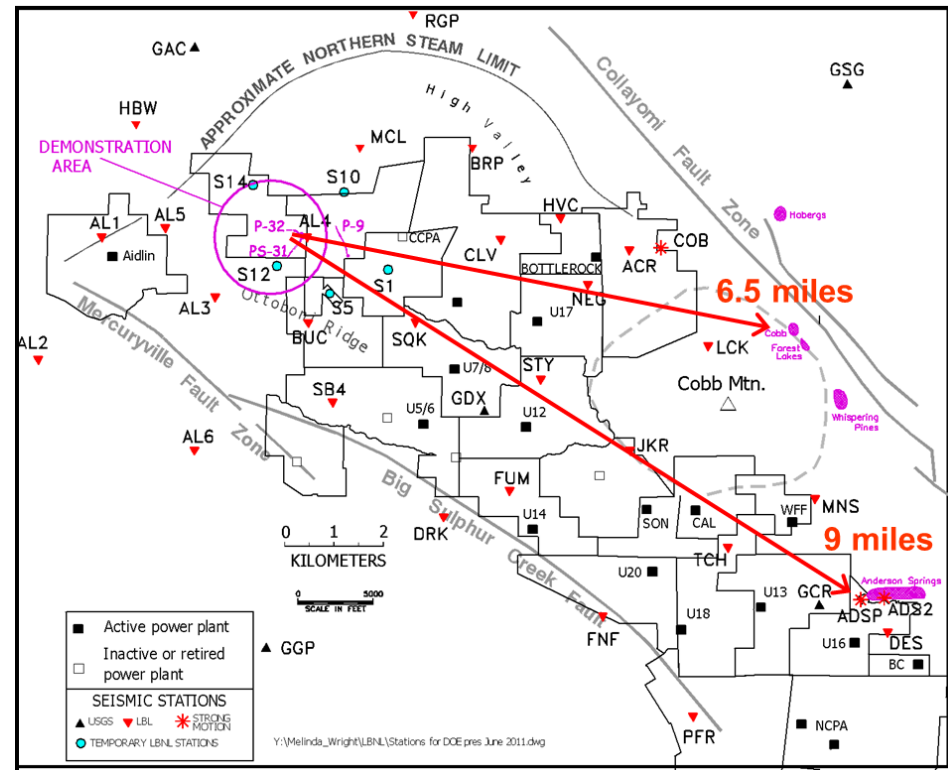
Cobb:

Geometric Mean (Horizontal Components):

$1.38 \text{ cm/sec}^2 = 0.14\%$ of gravitational acceleration

Modified Mercalli Intensity: I

Not Felt; No Potential Damage



Perceived Shaking	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	None	None	None	Very Light	Light	Moderate	Mod/Heavy	Heavy	Very Heavy
Peak Acceleration (% of g)	< 0.17	0.17 - 1.4	1.4 - 3.9	3.9 - 9.2	9.2 - 18.0	18.0 - 34.0	34.0 - 65.0	65.0 - 124.0	> 124.0
Peak Velocity (cm/sec)	< 0.10	0.1 - 1.1	1.1 - 3.4	3.4 - 8.1	8.1 - 16.0	16.0 - 31.0	31.0 - 60.0	60.0 - 116.0	> 116.0
Modified Mercalli Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X

Northwest Geysers Enhanced Geothermal System Demonstration

A Successful Research Collaboration with the U.S. Department of Energy



- Prati State 31 and Prati 32 were recompleted as a production-injection well pair in September 2011 (respectively).
- Injection into Prati 32 began on October 6, 2011 and has been continuously monitored.
- Continuous injection of water at rates of 400, 700 and 1000 gallons per minute into 750°F rock at a depth of 11,000 feet.
- A microseismicity “cloud” began to form almost immediately with the Prati 32 water injection.
- An Enhanced Geothermal System has been created in hot dry rock. The evidence for this comes from the analysis of:
 - Microseismicity data
 - Isotope data
 - Temperature data
 - Pressure data
 - Prati State 31 flow response
- A connection has been established between the deep, hot-dry rock reservoir and the overlying normal temperature reservoir.

