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A GENERATION AHEAD, today

Seismic Monitoring Advisory Committee Meeting

11 May 2015
Geothermal Visitors Center
Middletown, California

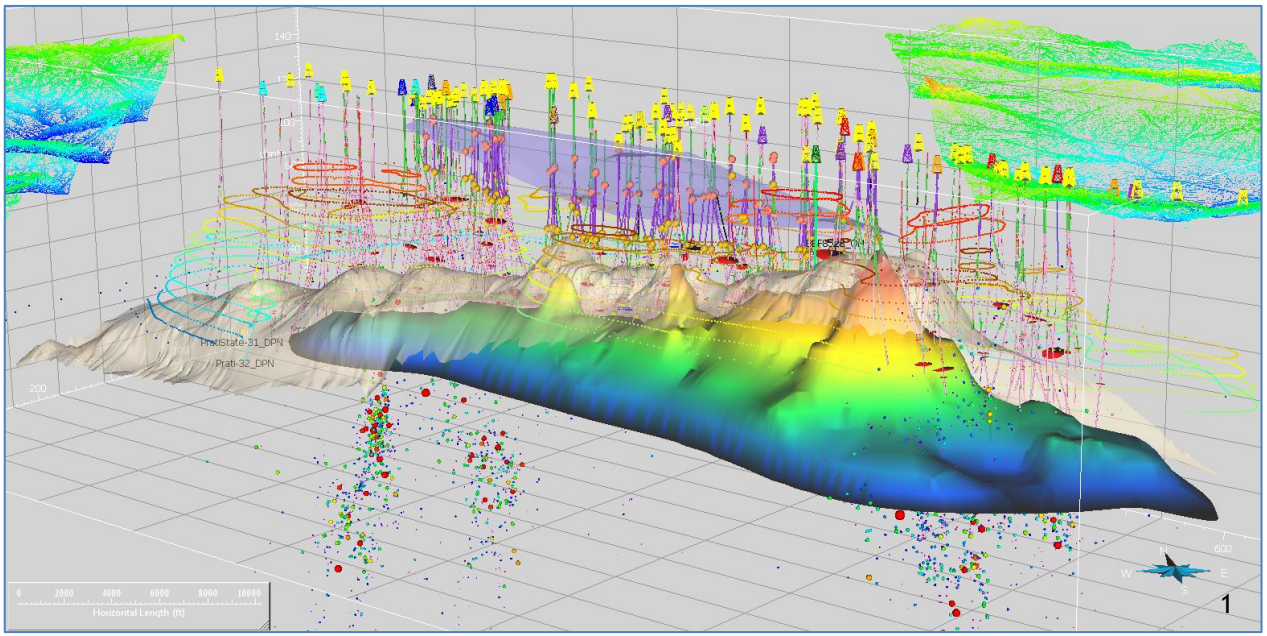
Reporting Period:
01 October 2014 to 31 March 2015

Craig Hartline
Senior Geophysicist
Calpine Corporation

CLEAN MODERN EFFICIENT FLEXIBLE POWER GENERATION

Seismic Monitoring Advisory Committee Meeting
Calpine Presentation Agenda
Reporting Period 01 October 2014 to 31 March 2015

- Seismicity Hotline
- Field-wide Seismicity Analysis
- Yearly Field-Wide Water Injection and Seismicity
- Monthly Field-Wide Water Injection and Seismicity
- Daily SRGRP Water Supply
- Strong Motion Sensor Station Analysis
- Seismicity, Fault Zones and Reservoir Compartmentalization
- 3D Visualization and Structural Model Building
- Additional Seismic Monitoring and Research
- Reference Items



Seismic Monitoring Advisory Committee Meeting
01 October 2014 to 31 March 2015
Seismicity Hotline 1-877-4GEYSER (Toll Free)

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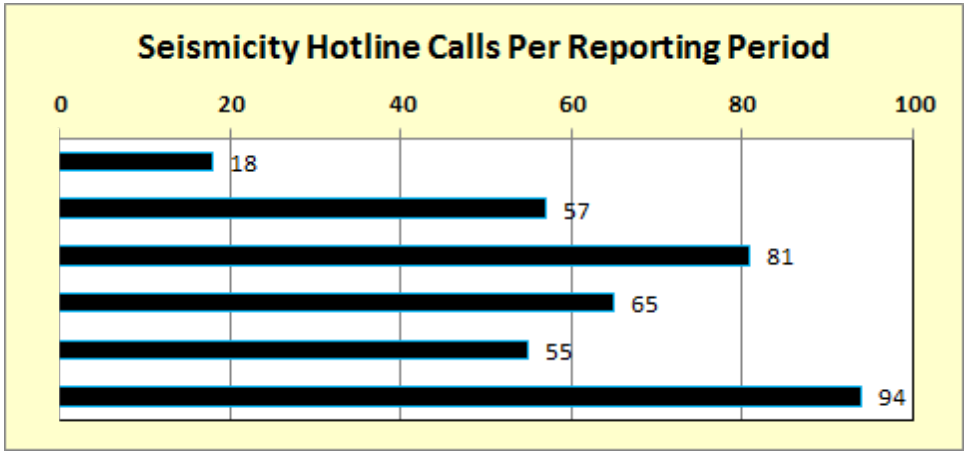
Calls transcribed and reviewed daily.

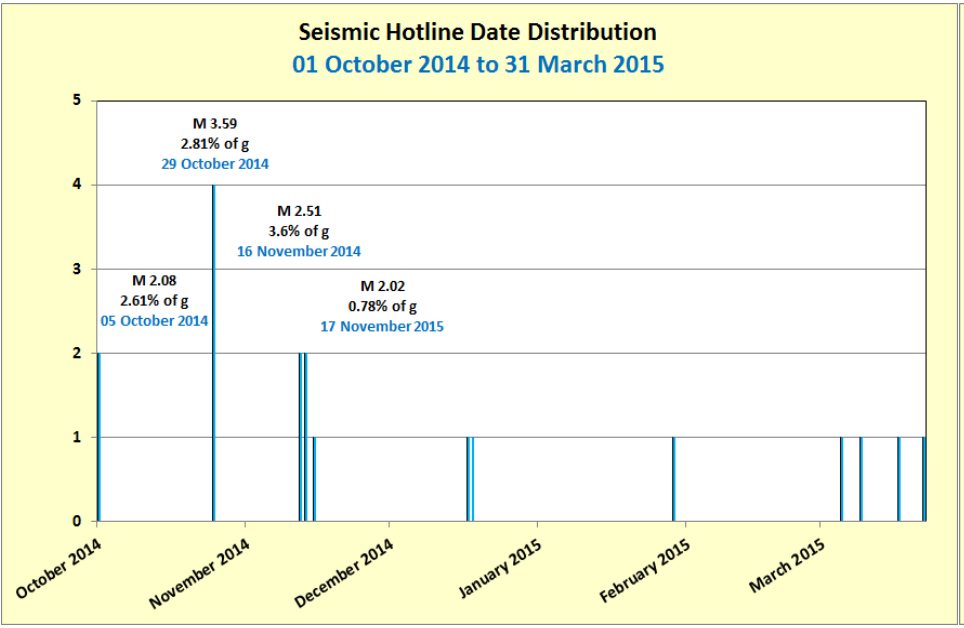
Current Reporting Period

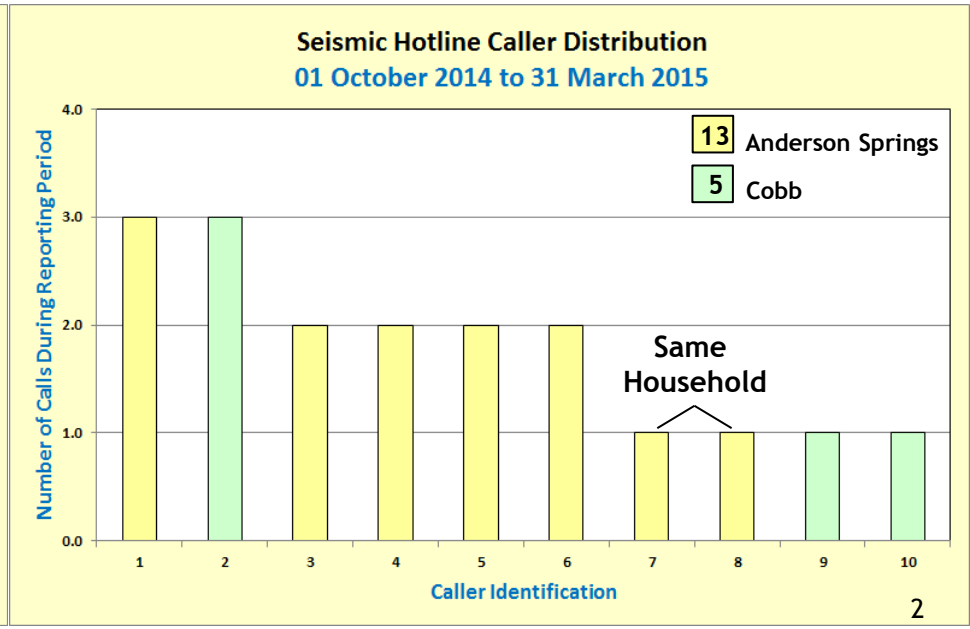
18 calls 01 October 2014 to 31 March 2015

Previous Reporting Periods (most recent at top)

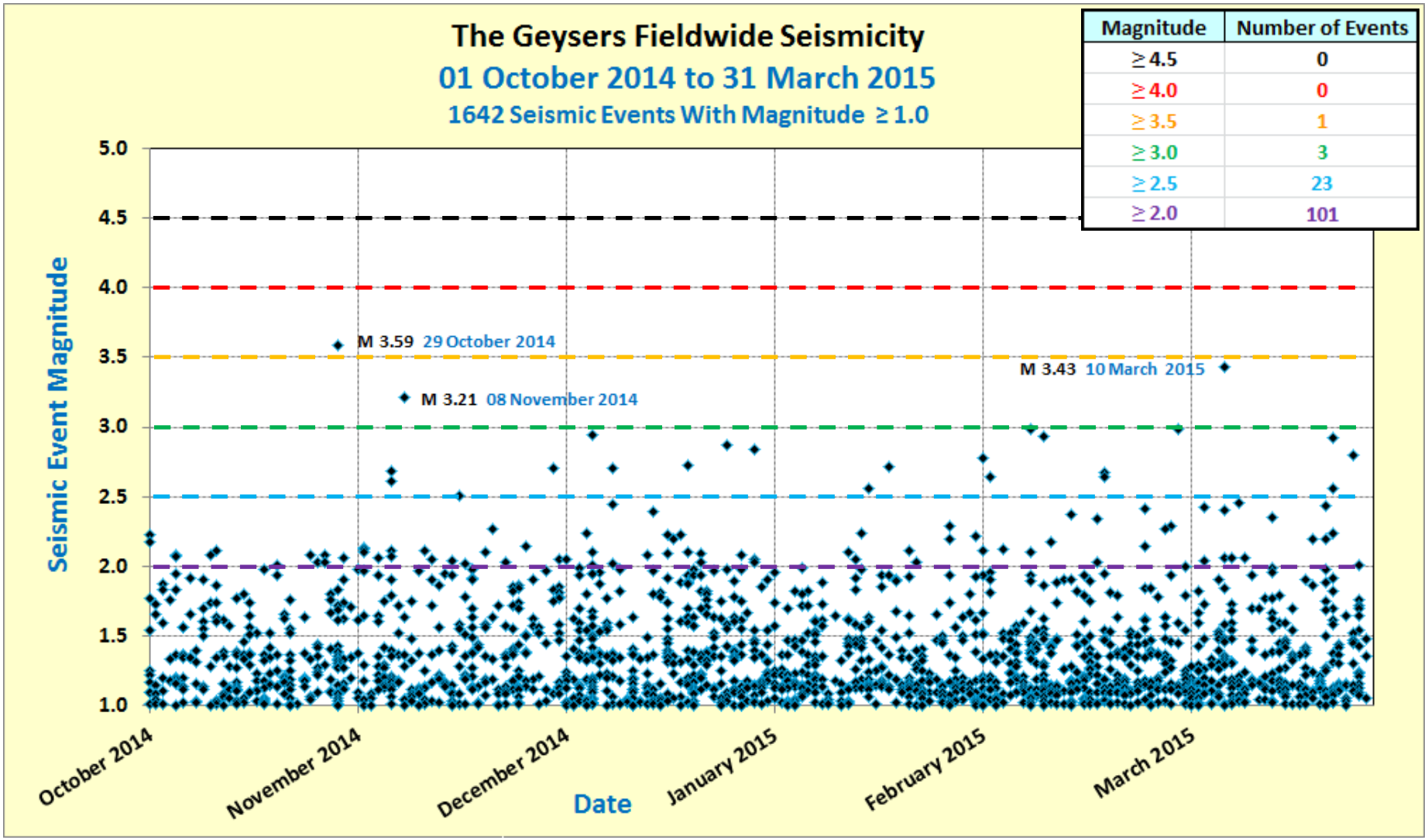
18 calls 01 April 2014 to 30 September 2014
57 calls 01 October 2013 to 31 March 2014
81 calls 01 April 2013 to 30 September 2013
65 calls 01 October 2012 to 31 March 2013
55 calls 01 April 2012 to 30 September 2012
94 calls 01 October 2011 to 31 March 2012



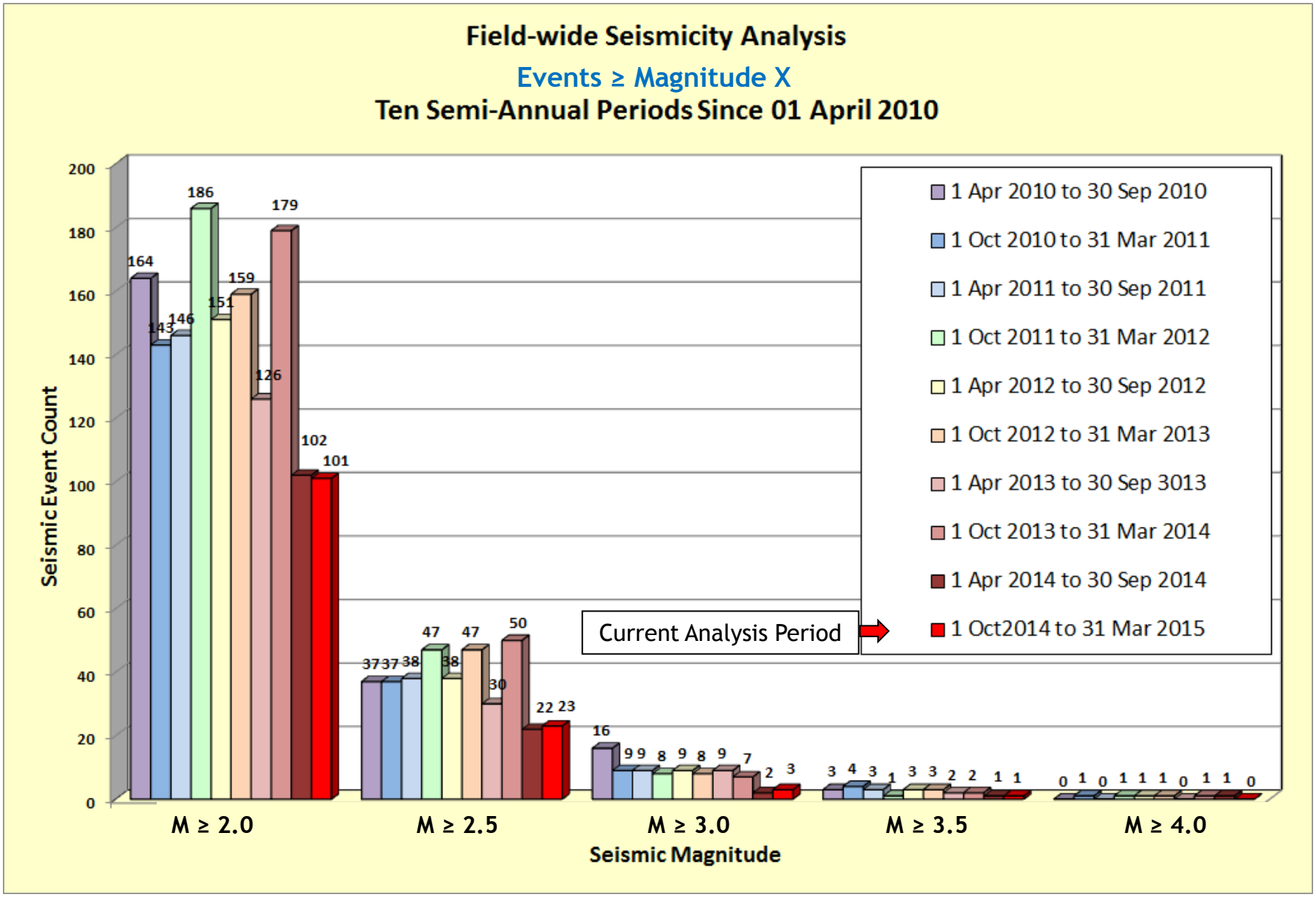




Field-wide Seismicity Analysis
01 October 2014 to 31 March 2015



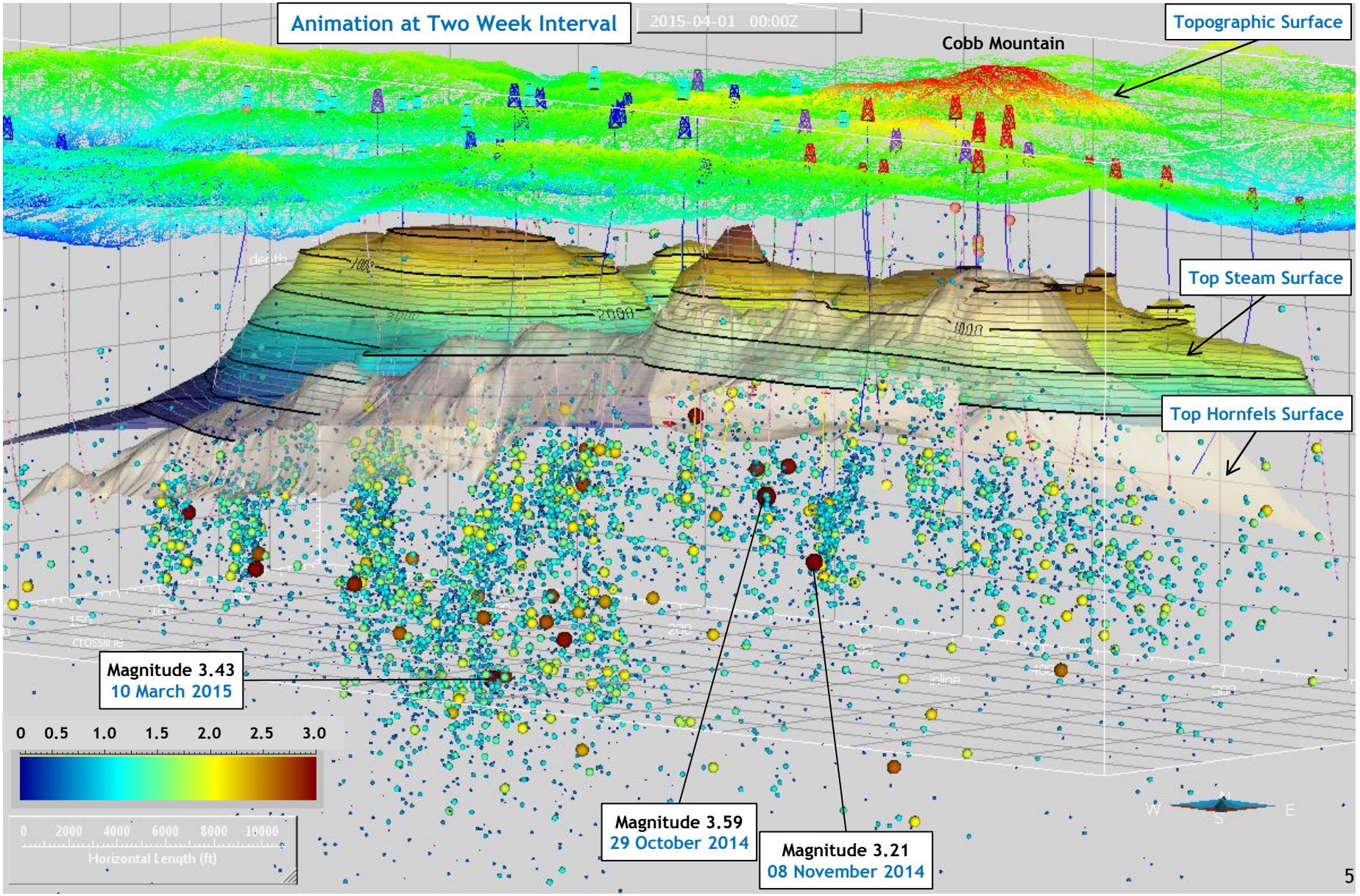
Field-wide Seismicity Analysis
Comparison of Ten Semi-annual Reporting Periods



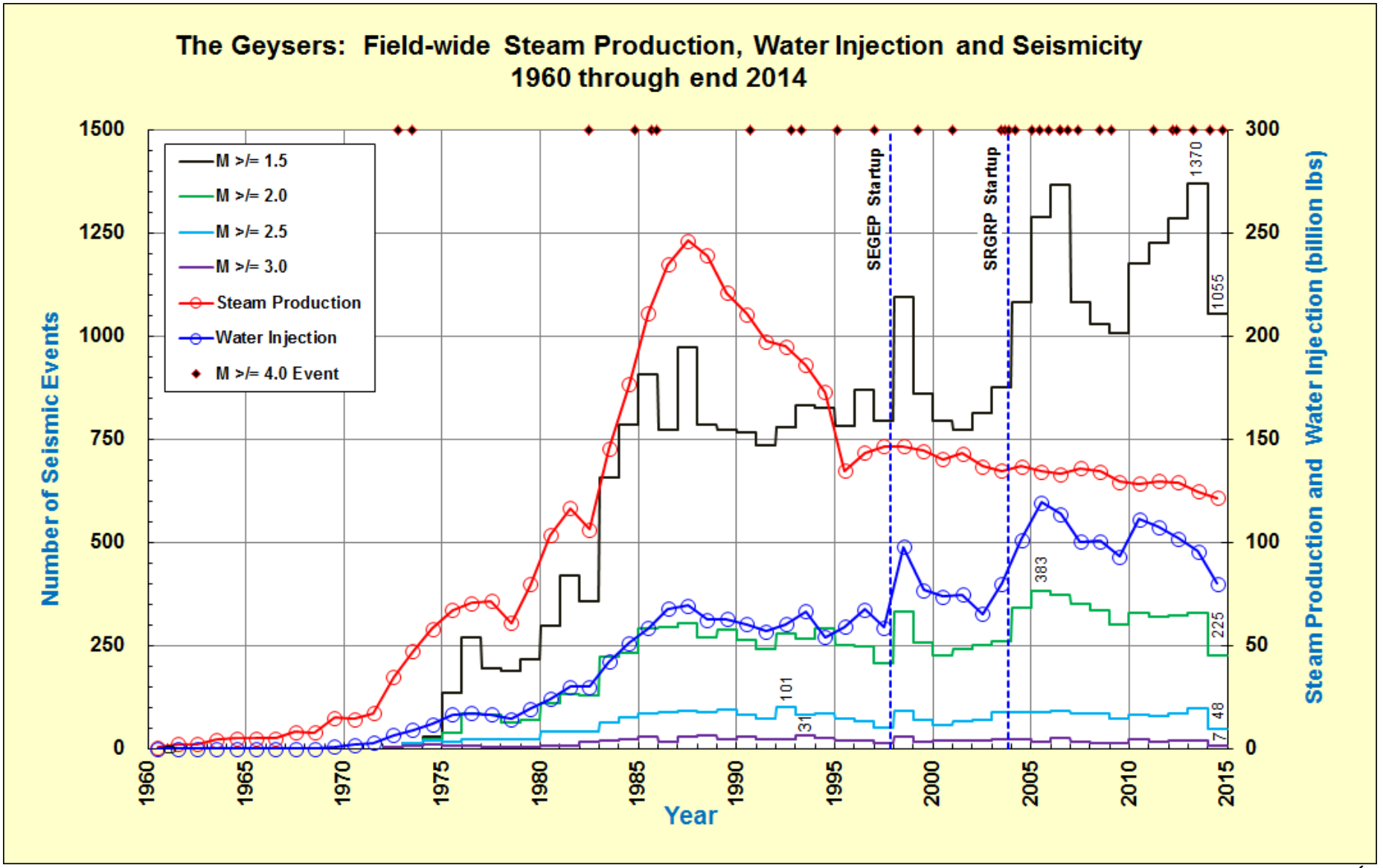
Seismic Monitoring Advisory Committee Meeting

Field-wide Seismicity Analysis

01 October 2014 to 31 March 2015

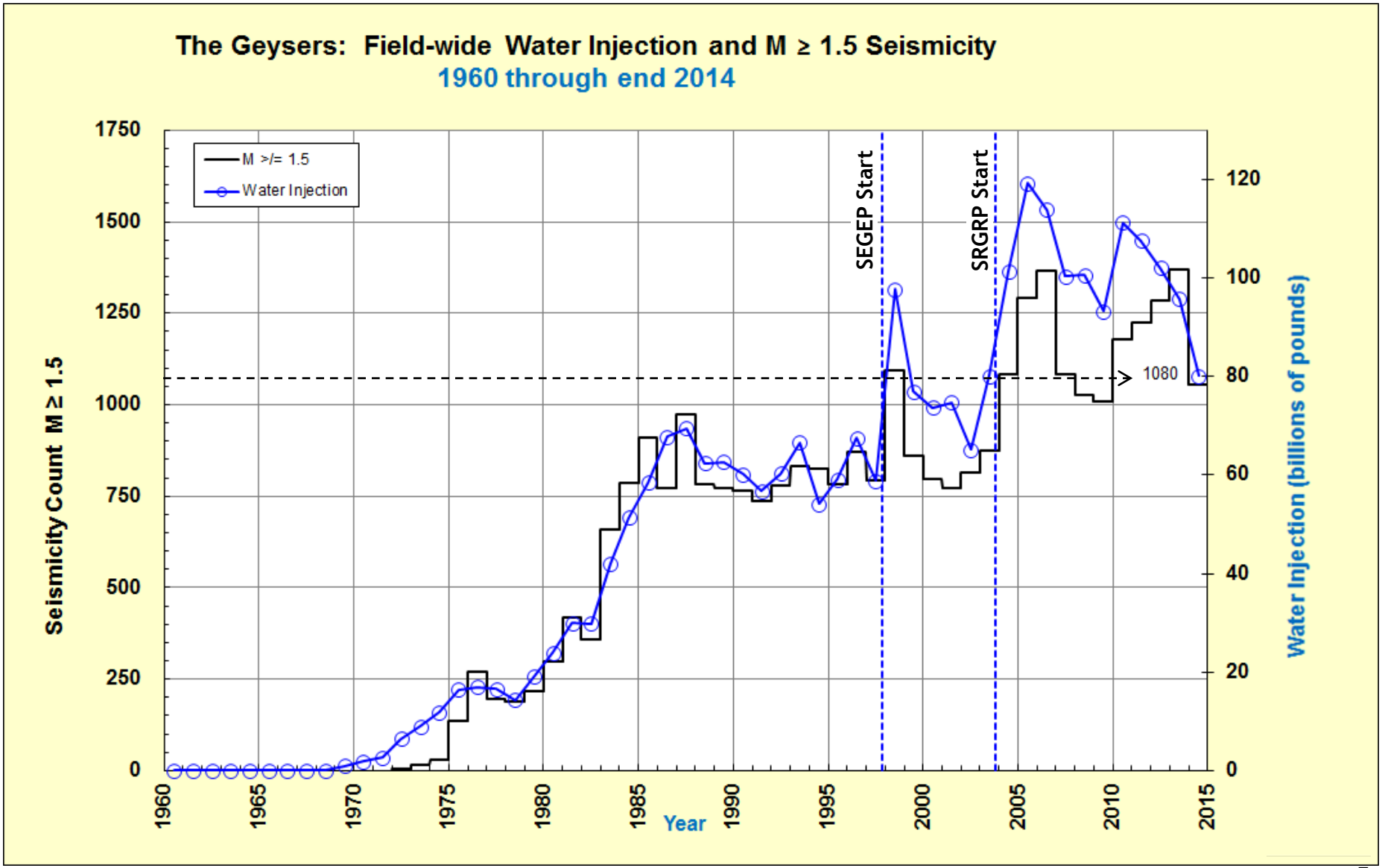


Yearly Field-wide Steam Production, Water Injection and Seismicity 1960 Through End 2014



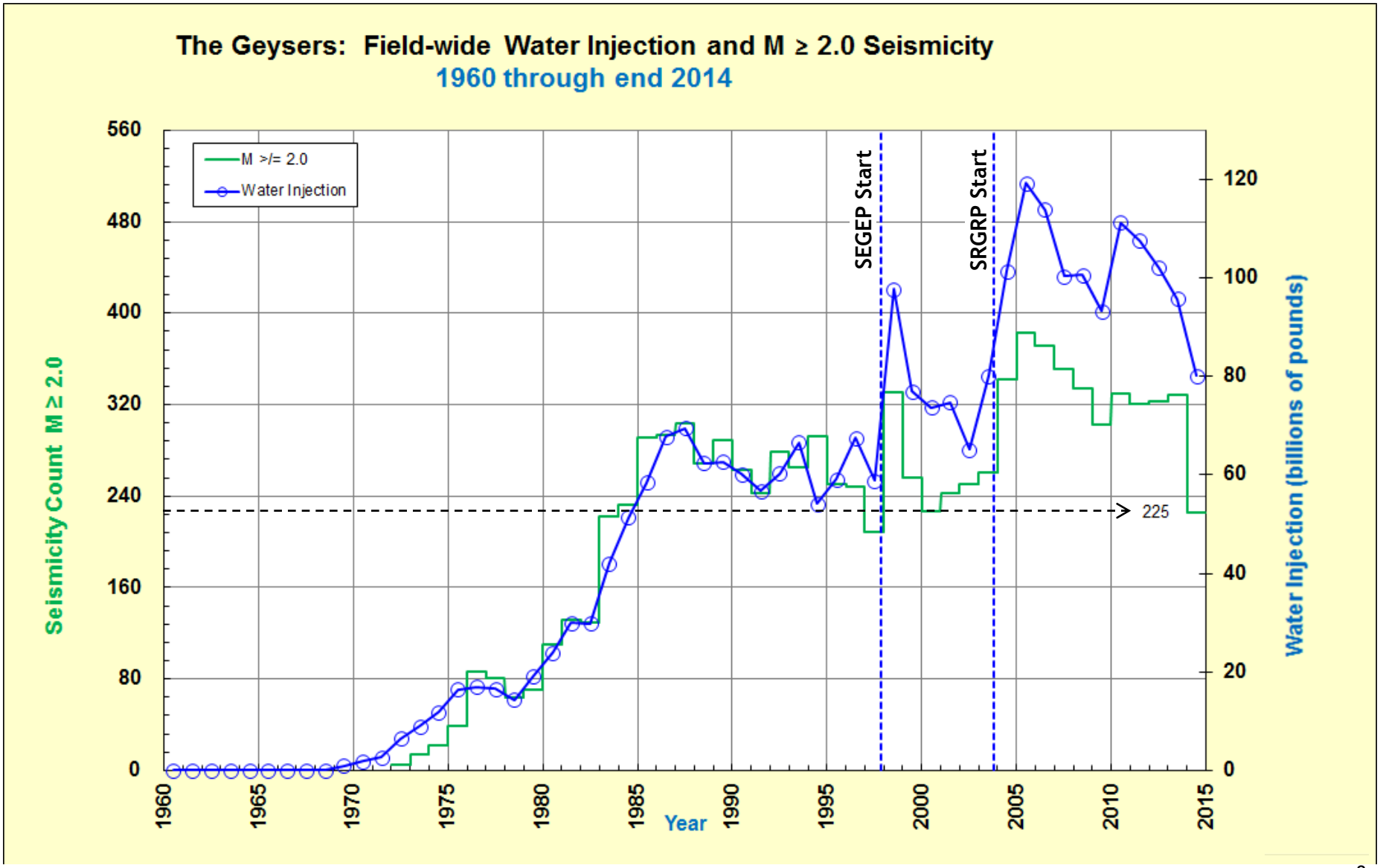
Database: Northern California Earthquake Data Center (NCEDC); UC Berkeley Seismological Laboratory

Yearly Field-wide Water Injection and M ≥ 1.5 Seismicity 1960 Through End 2014



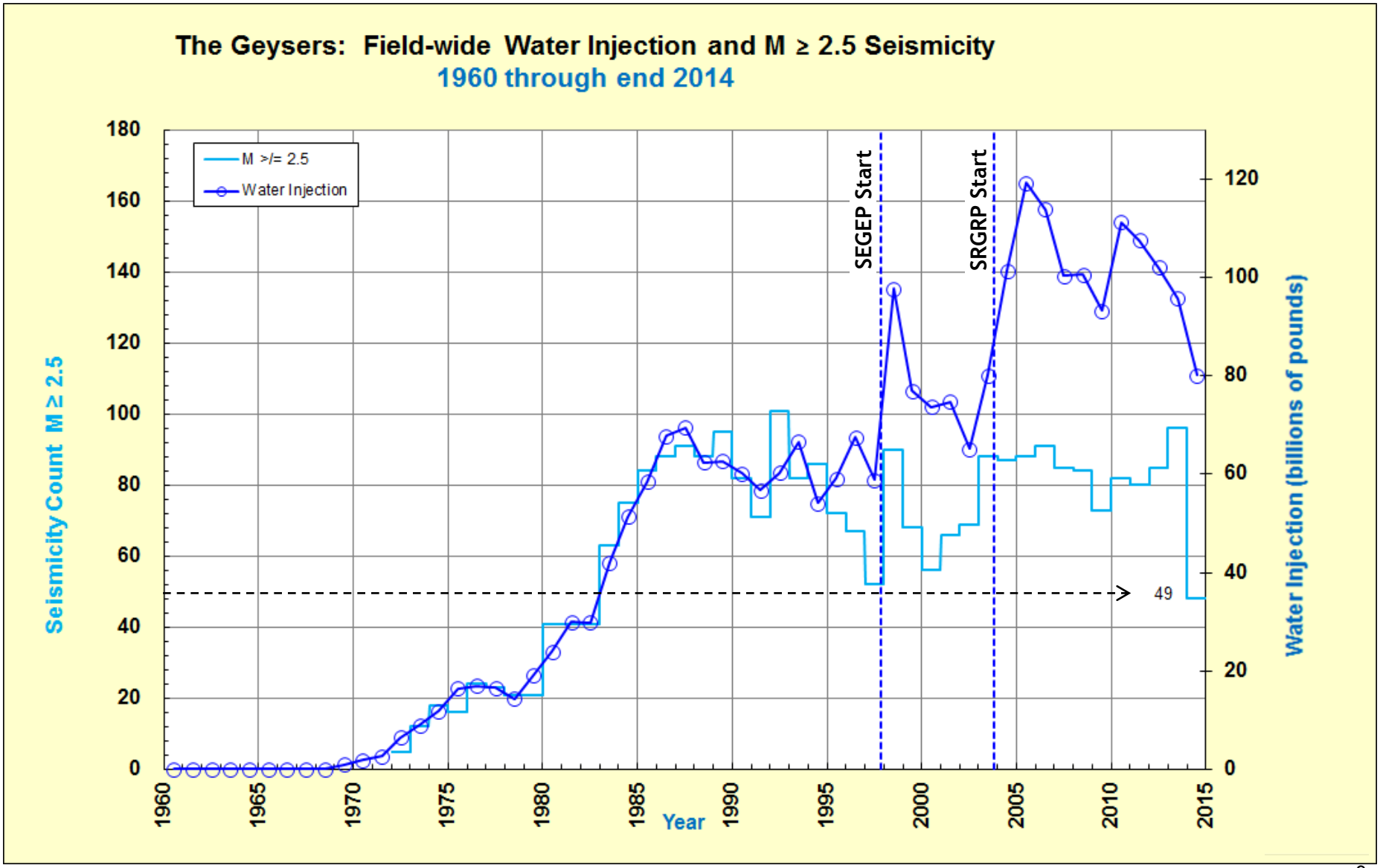
Database: Northern California Earthquake Data Center (NCEDC); UC Berkeley Seismological Laboratory

Yearly Field-wide Water Injection and M ≥ 2.0 Seismicity 1960 Through End 2014



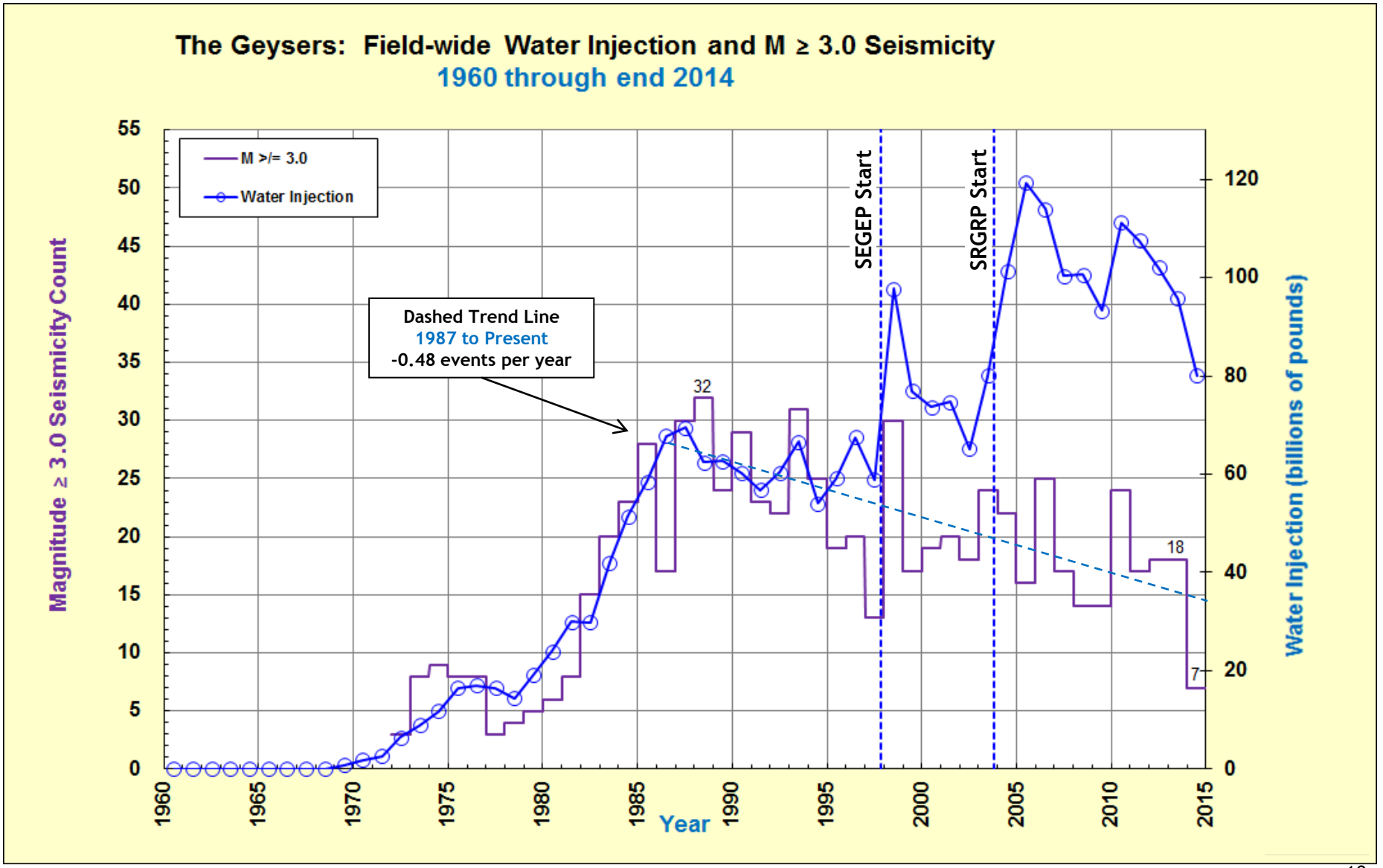
Database: Northern California Earthquake Data Center (NCEDC); UC Berkeley Seismological Laboratory

Yearly Field-wide Water Injection and M ≥ 2.5 Seismicity 1960 Through End 2014



Database: Northern California Earthquake Data Center (NCEDC); UC Berkeley Seismological Laboratory

Field-wide Water Injection and Magnitude ≥ 3.0 Seismicity 1960 Through End 2014



Database: Northern California Earthquake Data Center (NCEDC); UC Berkeley Seismological Laboratory

Seismic Monitoring Advisory Committee Meeting
Field-wide Water Injection Sources and Magnitude ≥ 4.0 Seismicity
Monthly Values from 01 January 2000 to 31 March 2015

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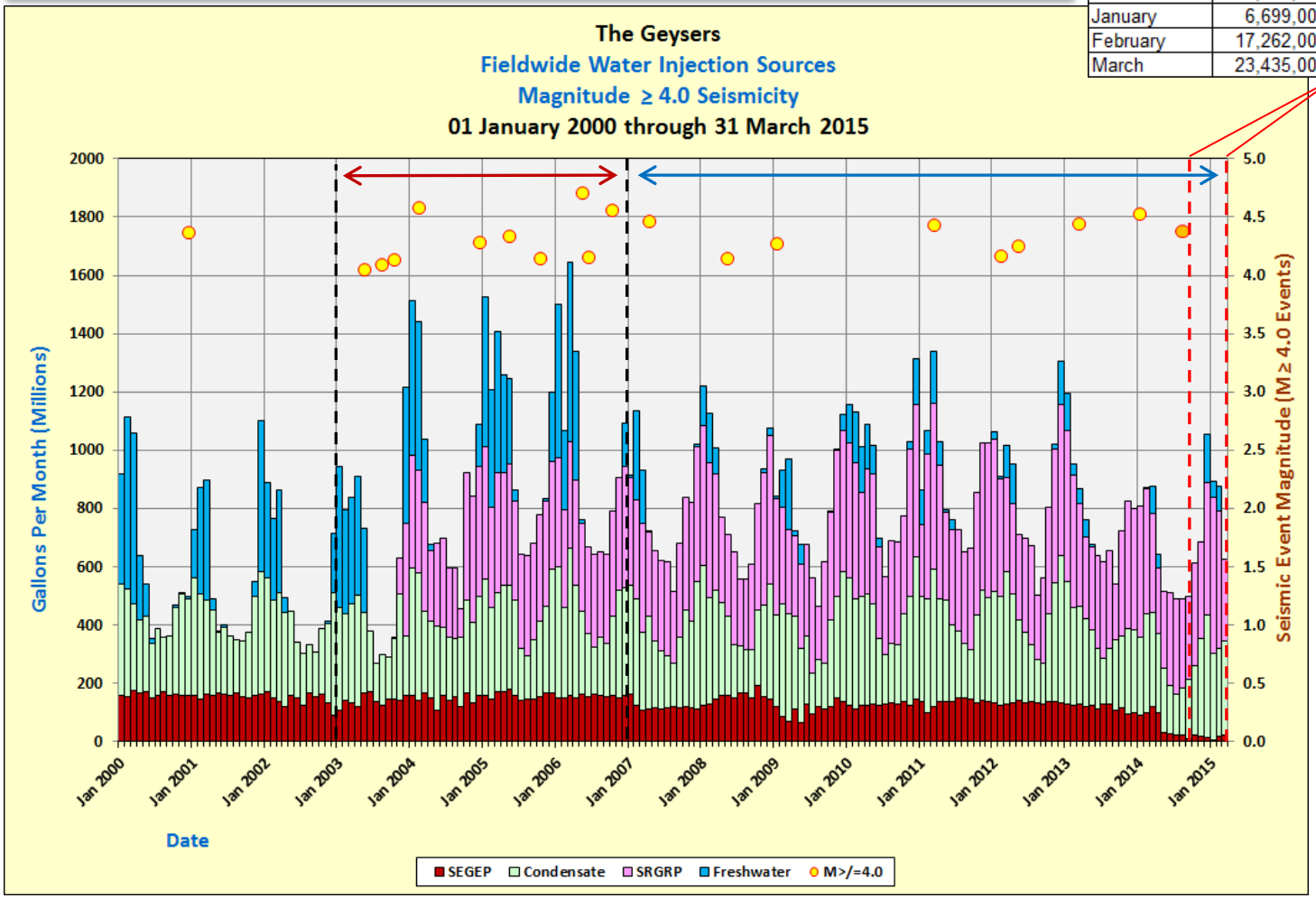
Average Number of Magnitude ≥ 4.0 Events Per Year Significantly Less Than 2003-2006 Peak

Time Period	M ≥ 4.0 Seismic Events	
January 2003 through December 2006	2.50 events per year	10.0 / 4.0
January 2007 through September 2014	1.09 events per year	9.0 / 8.25

Water Supply for Reporting Period (Six Months)

	Water Injection Sources (Gallons)			
Month	SEGEP	SRGRP	Condensate	Fresh Water
October	21,074,000	352,560,000	241,169,367	-
November	20,232,000	334,930,000	331,845,577	-
December	15,142,000	453,430,000	421,254,032	165,772,814
January	6,699,000	537,860,000	295,360,079	55,124,038
February	17,262,000	472,350,000	300,898,483	85,016,733
March	23,435,000	280,620,000	321,545,646	-



Daily Supply of SRGRP Tertiary Treated Waste Water
01 October 2014 to 31 March 2015

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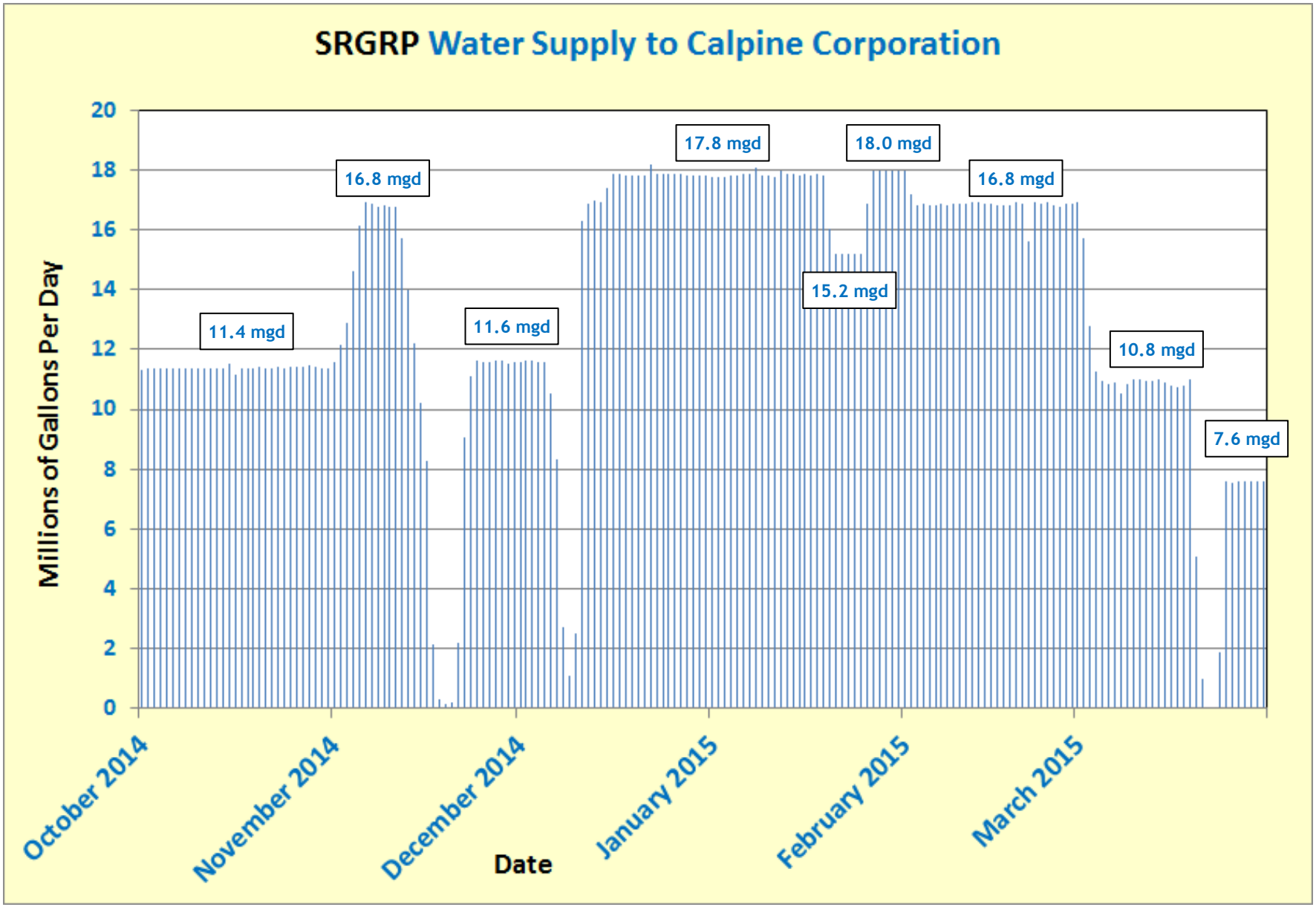

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Cobb Peak Ground Acceleration
01 October 2014 to 31 March 2015

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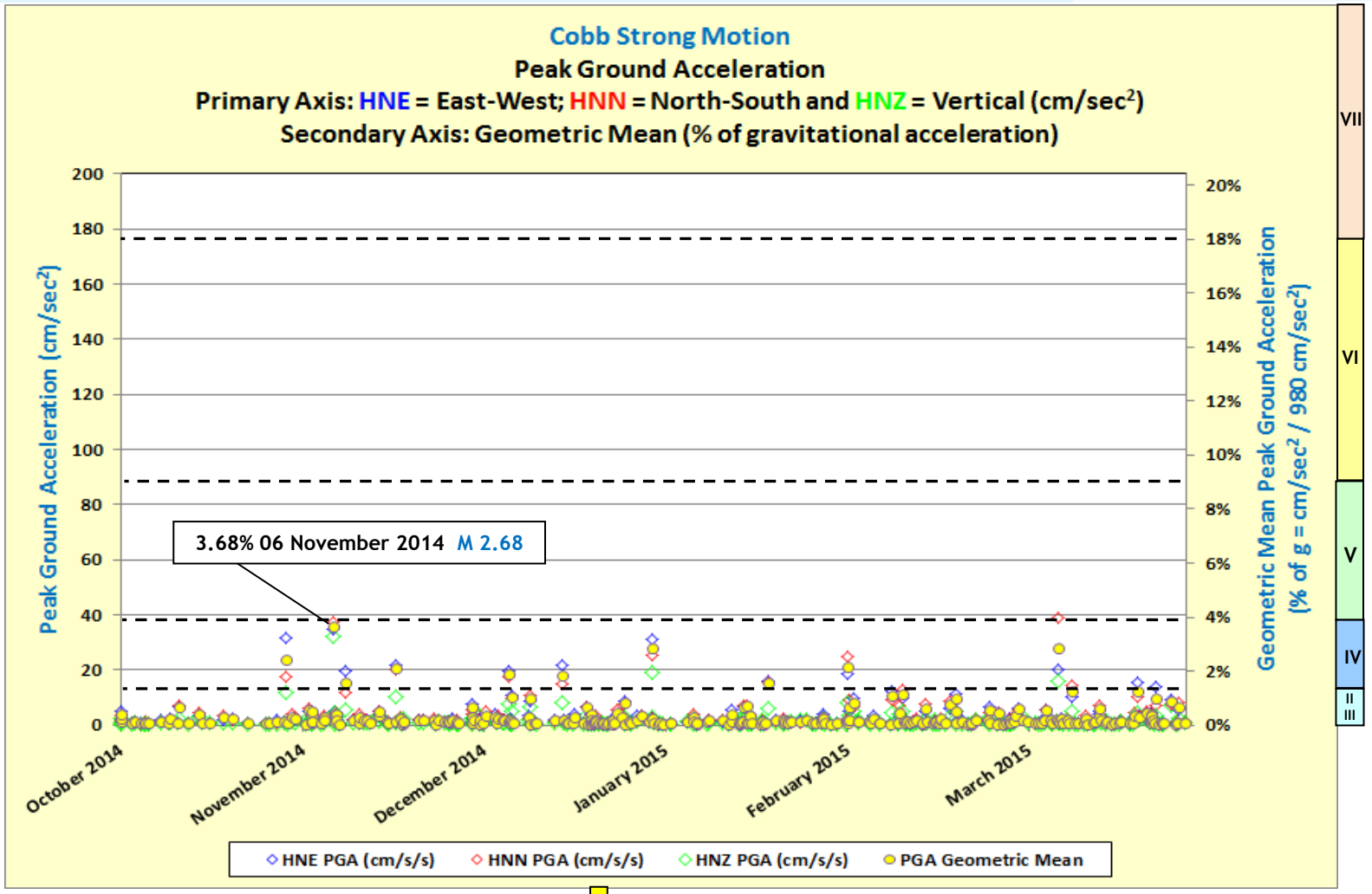
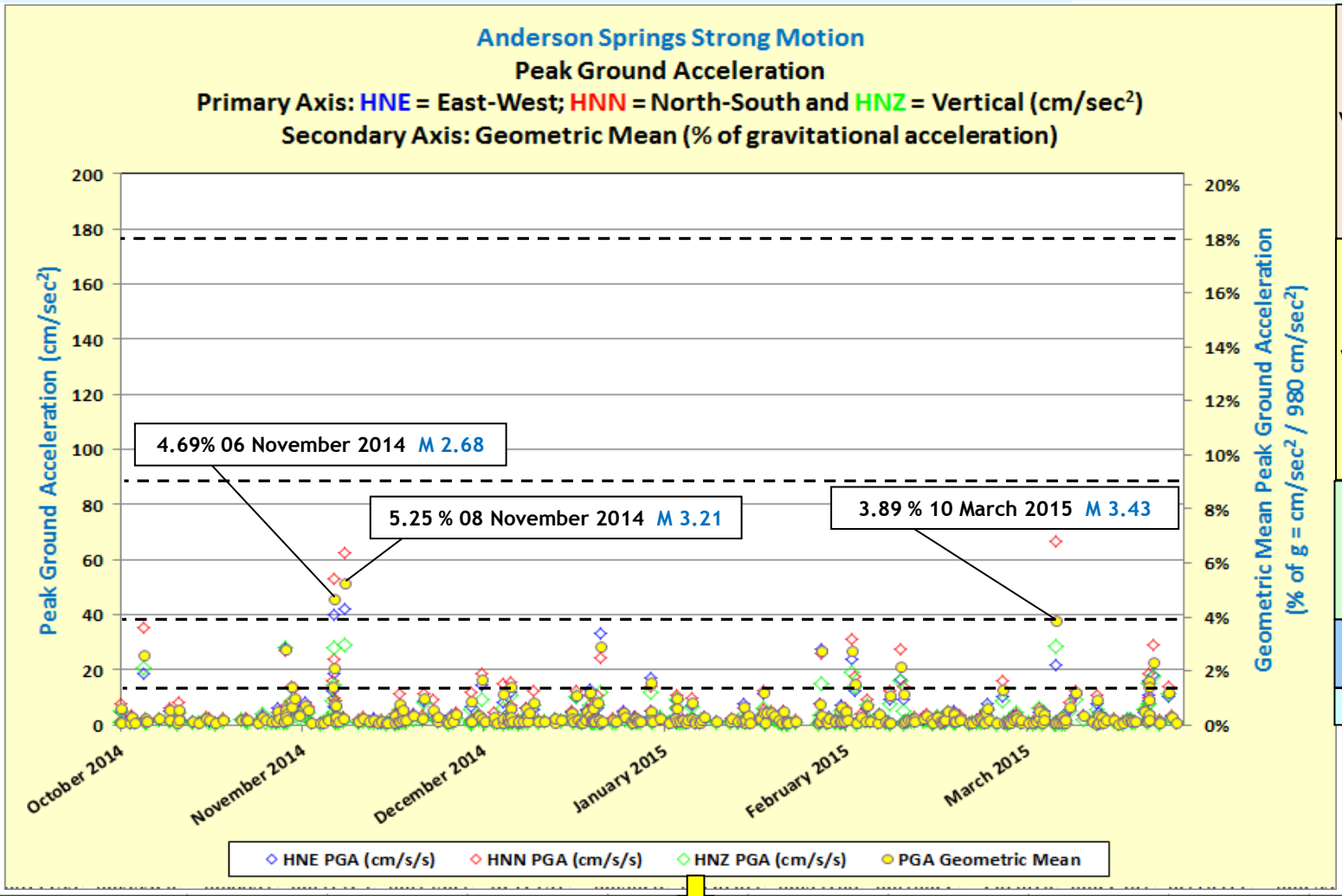


Perceived Shaking	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	None	None	None	Very Light	Light	Moderate	Mod/Heavy	Heavy	Very Heavy
Peak Acceleration (% of g)	< 0.17	0.17 - 1.4	1.4 - 3.9	3.9 - 9.2	9.2 - 18.0	18.0 - 34.0	34.0 - 65.0	65.0 - 124.0	> 124.0
Peak Velocity (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

Anderson Springs Peak Ground Acceleration
01 October 2014 to 31 March 2015



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

Seismic event magnitude is dependent on:

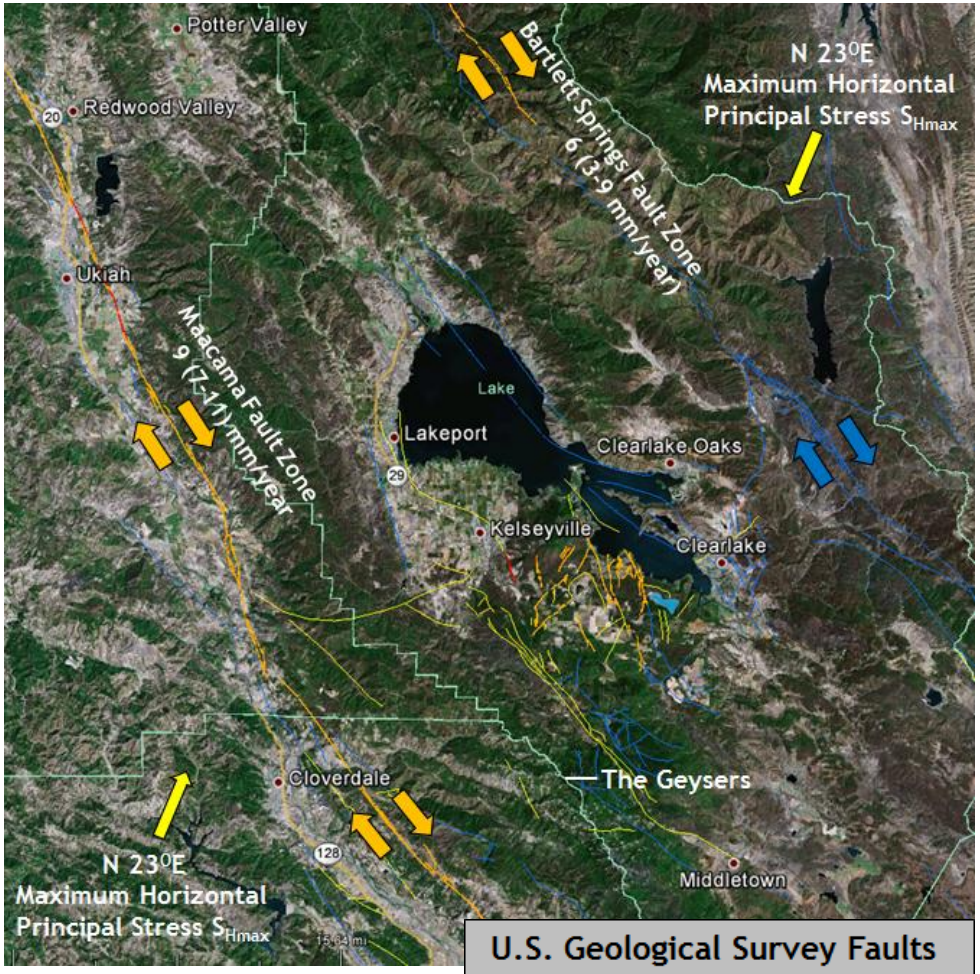
- Fault Area
- Average Slip
- Rock Rigidity

The Earth's crust is crossed by a network of pre-existing faults and fractures of various sizes.

Within The Geysers, CGS/USGS* mapped faults are inactive and restricted in area. This fact, along with highly-fractured steam reservoir (as defined by extensive drilling activities) provides confidence that there is not sufficient fault area to support a large earthquake (Majer et al, 2007).

A three-dimensional structural model is currently under development for The Geysers geothermal field.

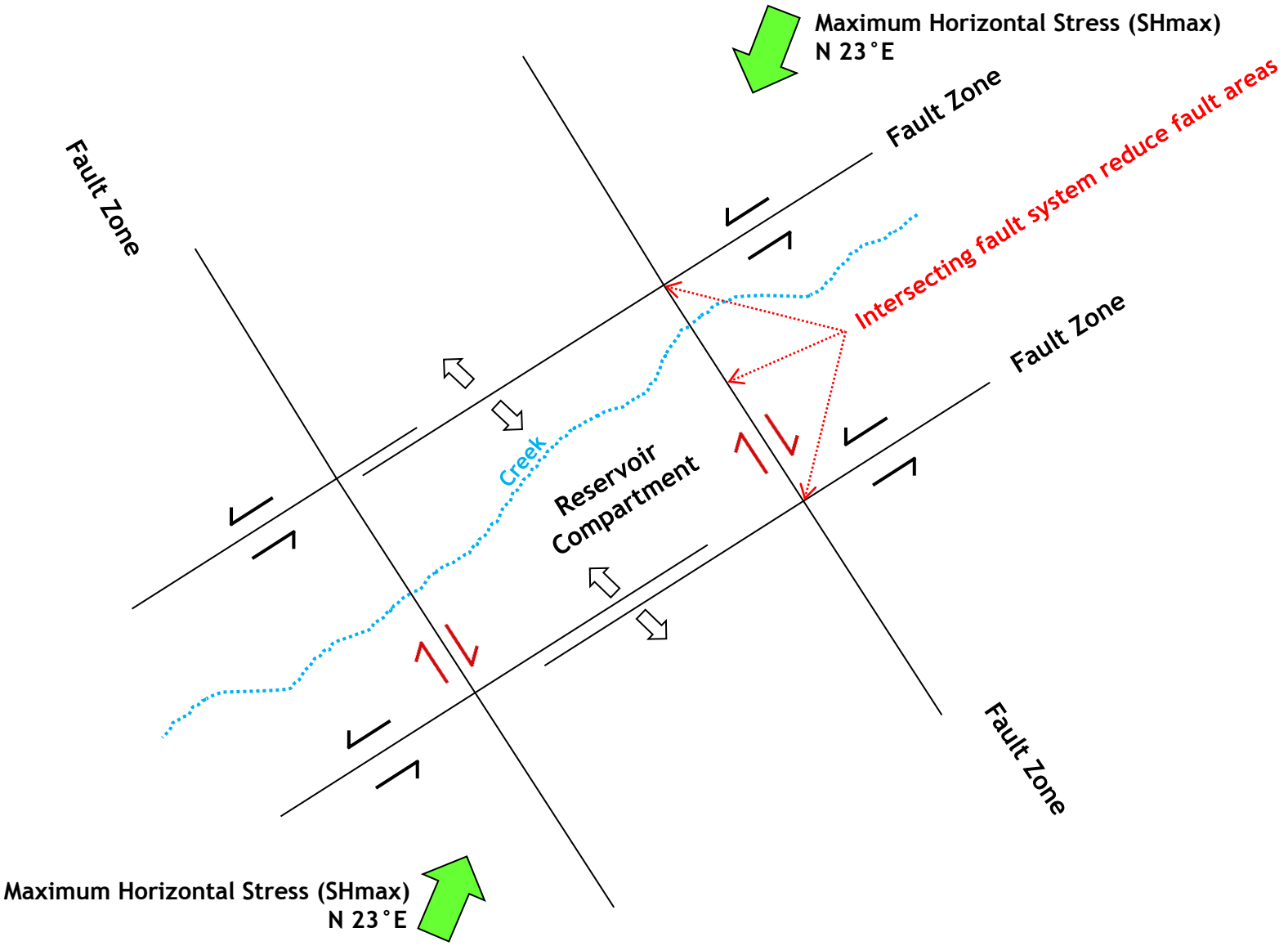
This 3D structural model (including pre-existing fault zones and fractures) will assist in understanding induced seismicity at The Geysers.



2012 Google Earth

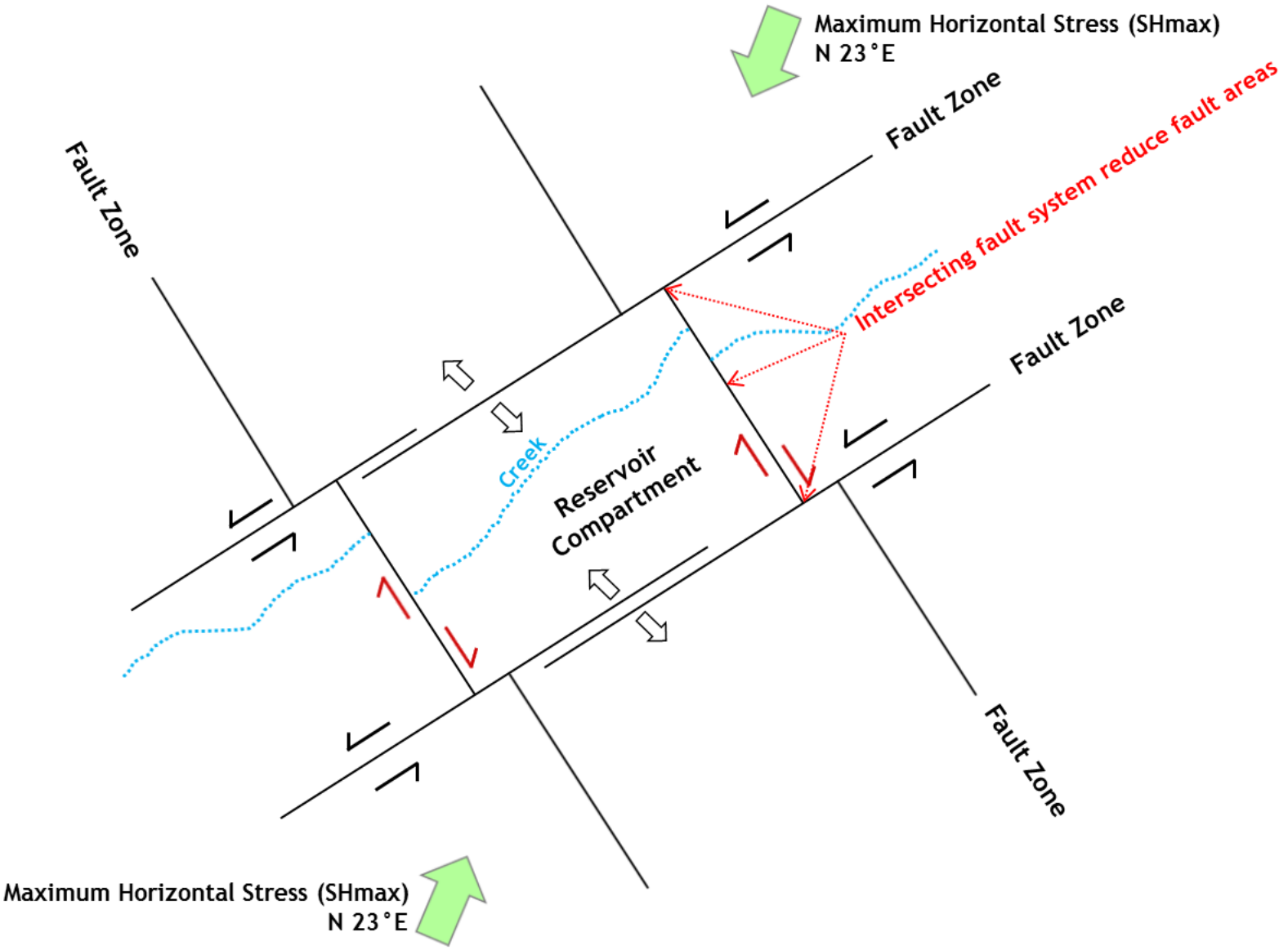
* California Geological Survey, United States Geological Survey

Fault Zones and Reservoir Compartmentalization Idealized Diagram *



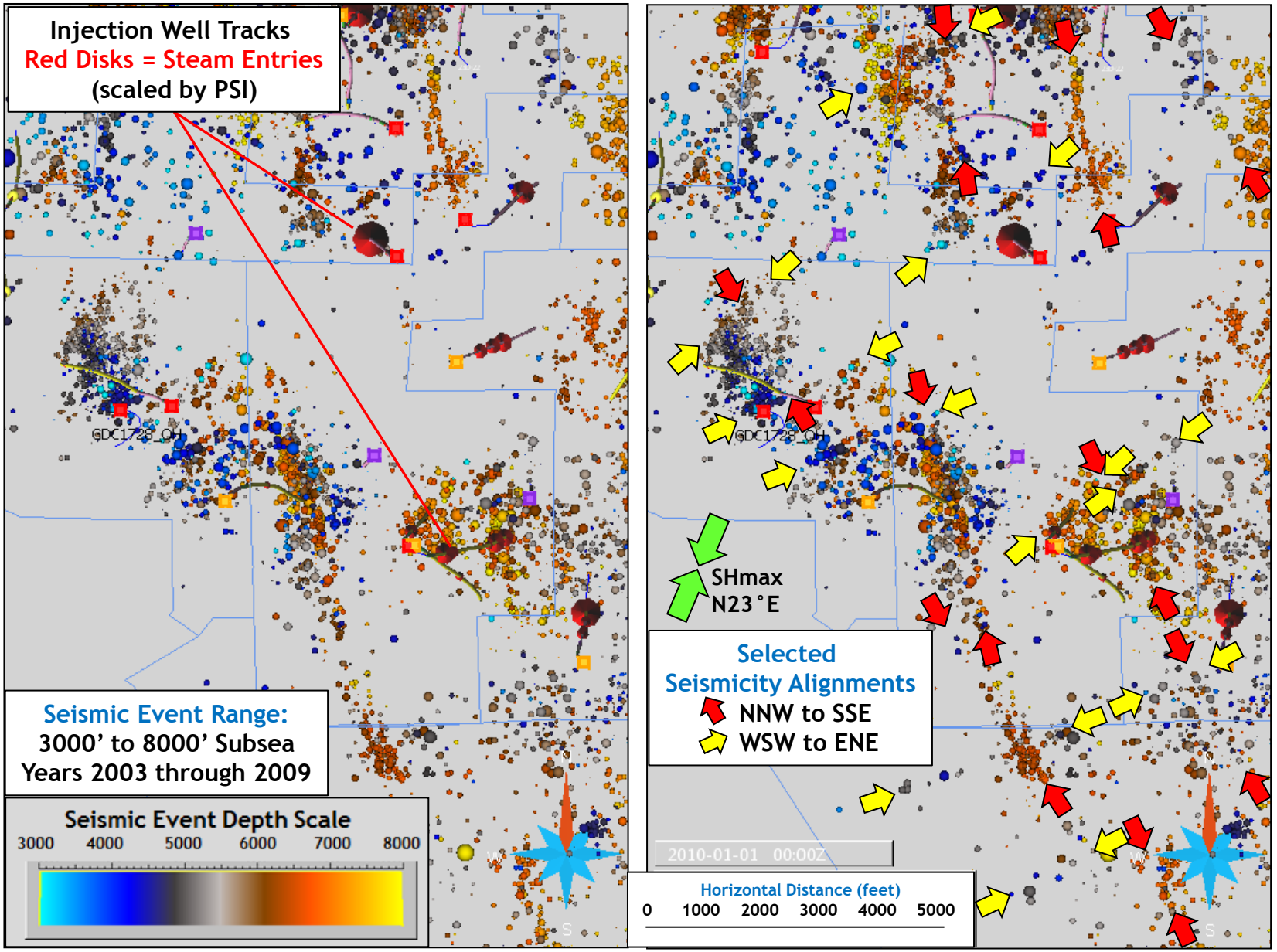
* The Geysers fault patterns are much more complicated.

Fault Zones and Reservoir Compartmentalization Idealized Diagram *



Induced Seismicity Patterns

Goal: Seismicity mitigation through a refined understanding of fluid flow paths, fluid boundaries, reservoir heterogeneity and reservoir compartmentalization at The Geysers.



Seismic Monitoring Advisory Committee Meeting

3D Analysis in Vicinity of Wells GGC4-ST1 and GGC5-OH

Seismicity Time Animation

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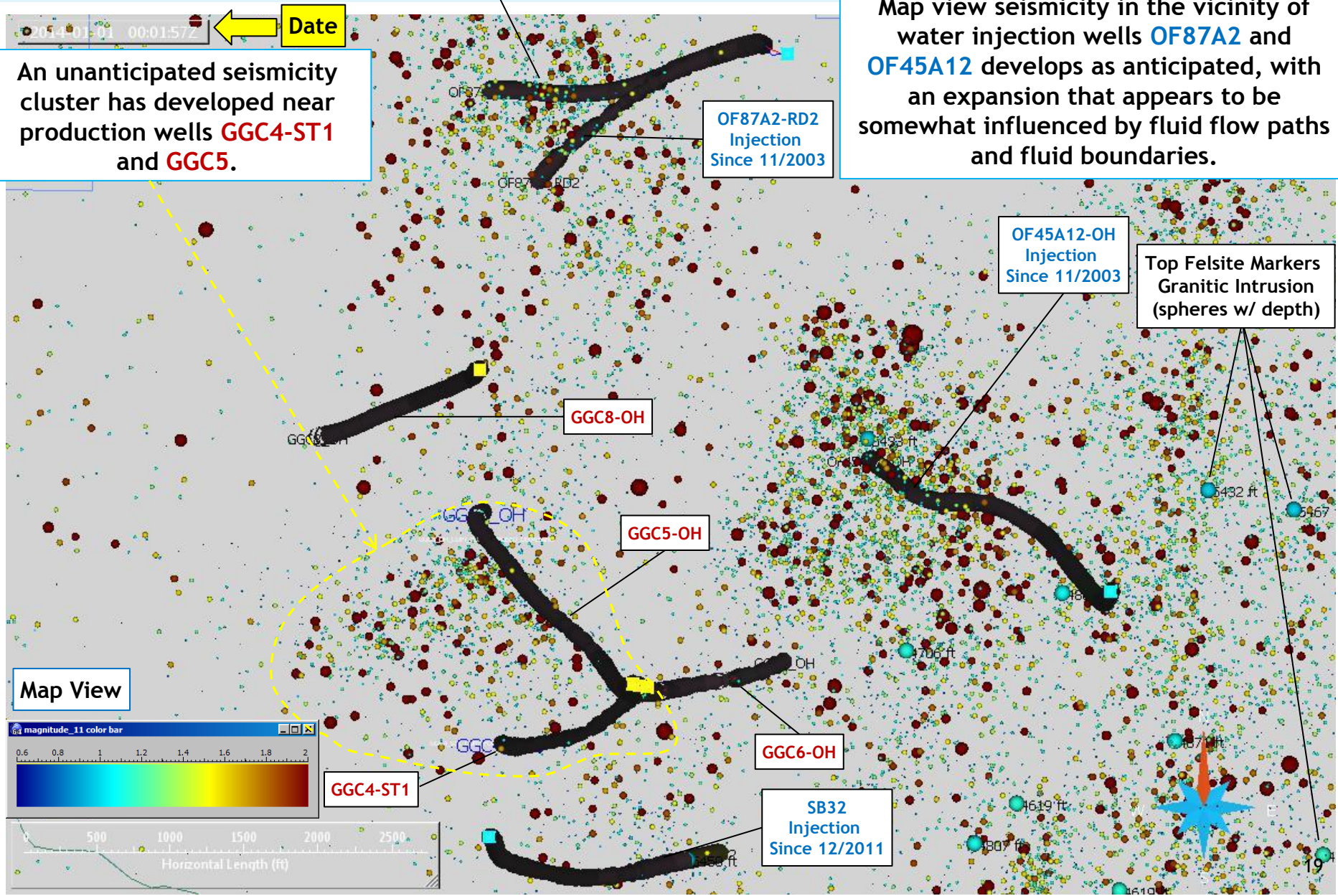

3D Analysis in Vicinity of Wells GGC4-ST1 and GGC5-OH

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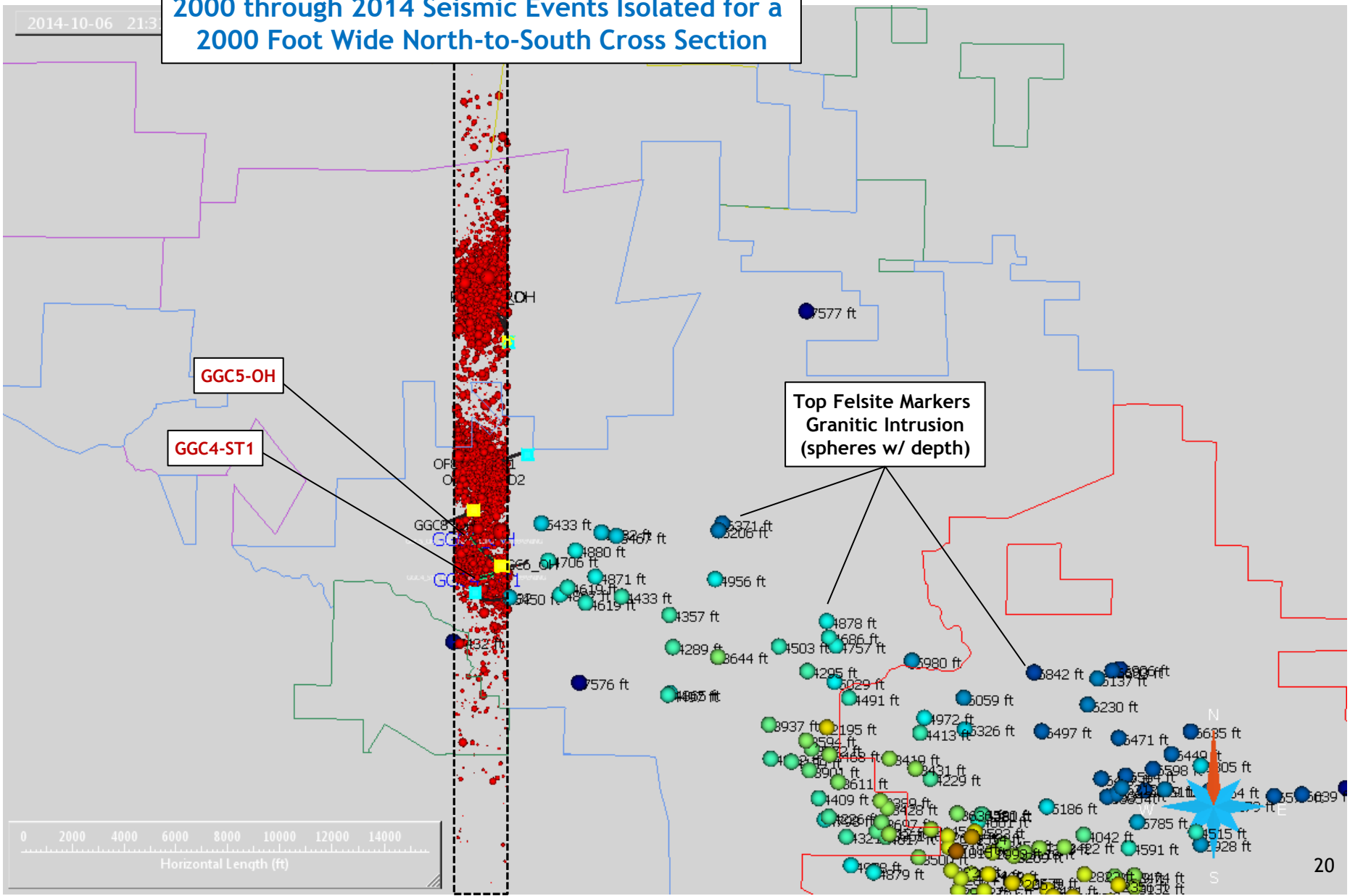
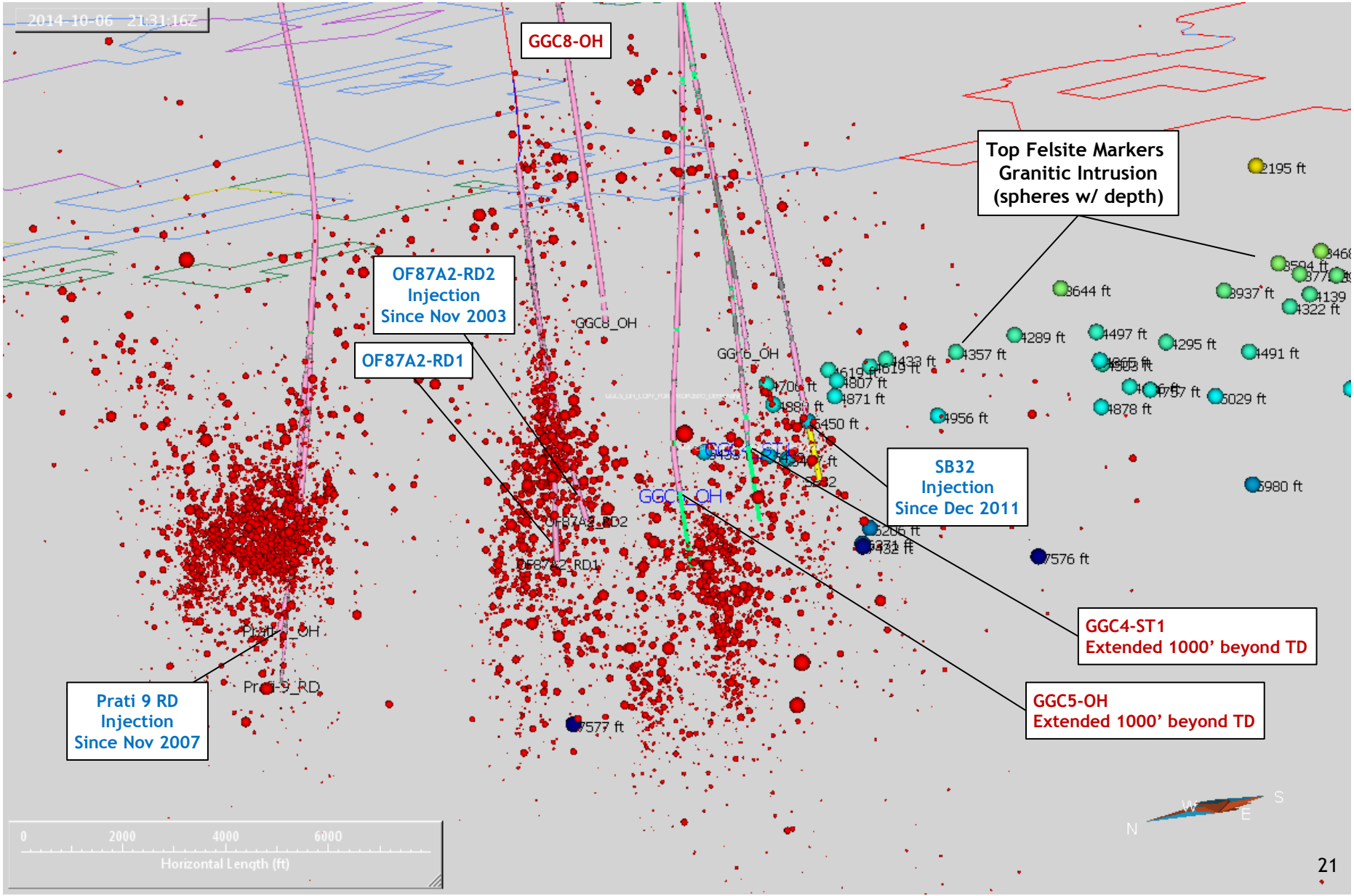


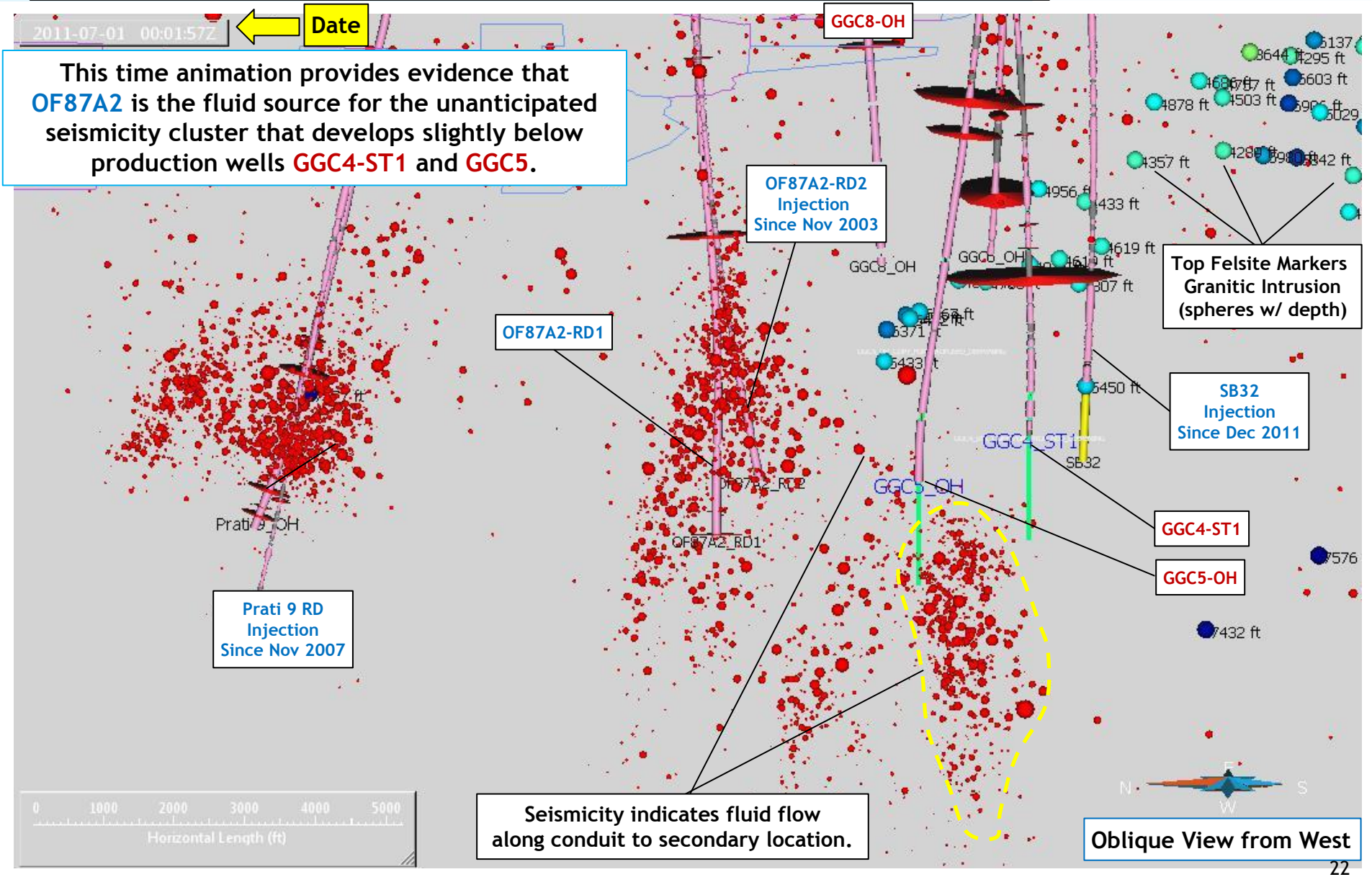
3D Analysis in Vicinity of Wells GGC4-ST1 and GGC5-OH

2000 through 2014 Seismic Events for a 2000' Wide North-to-South Cross Section



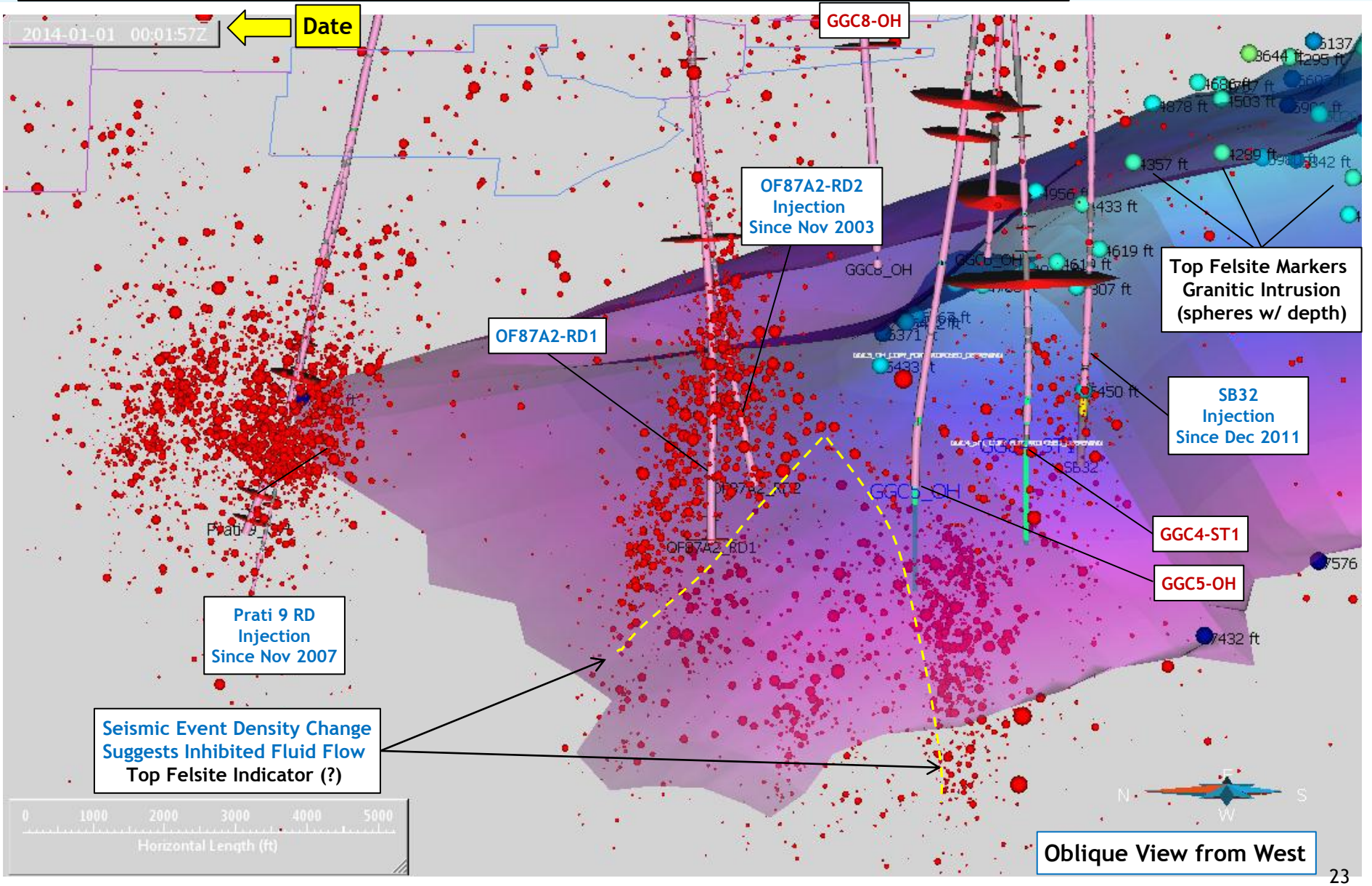
3D Analysis in Vicinity of Wells of GGC4-ST1 and GGC5-OH

2003 to 2011 Seismicity Animation of 2000' Wide North-to-South Cross Section



3D Analysis in Vicinity of Wells GGC4-ST1 and GGC5-OH

2000 through 2014 Seismic Events for a 2000' Wide North-to-South Cross Section

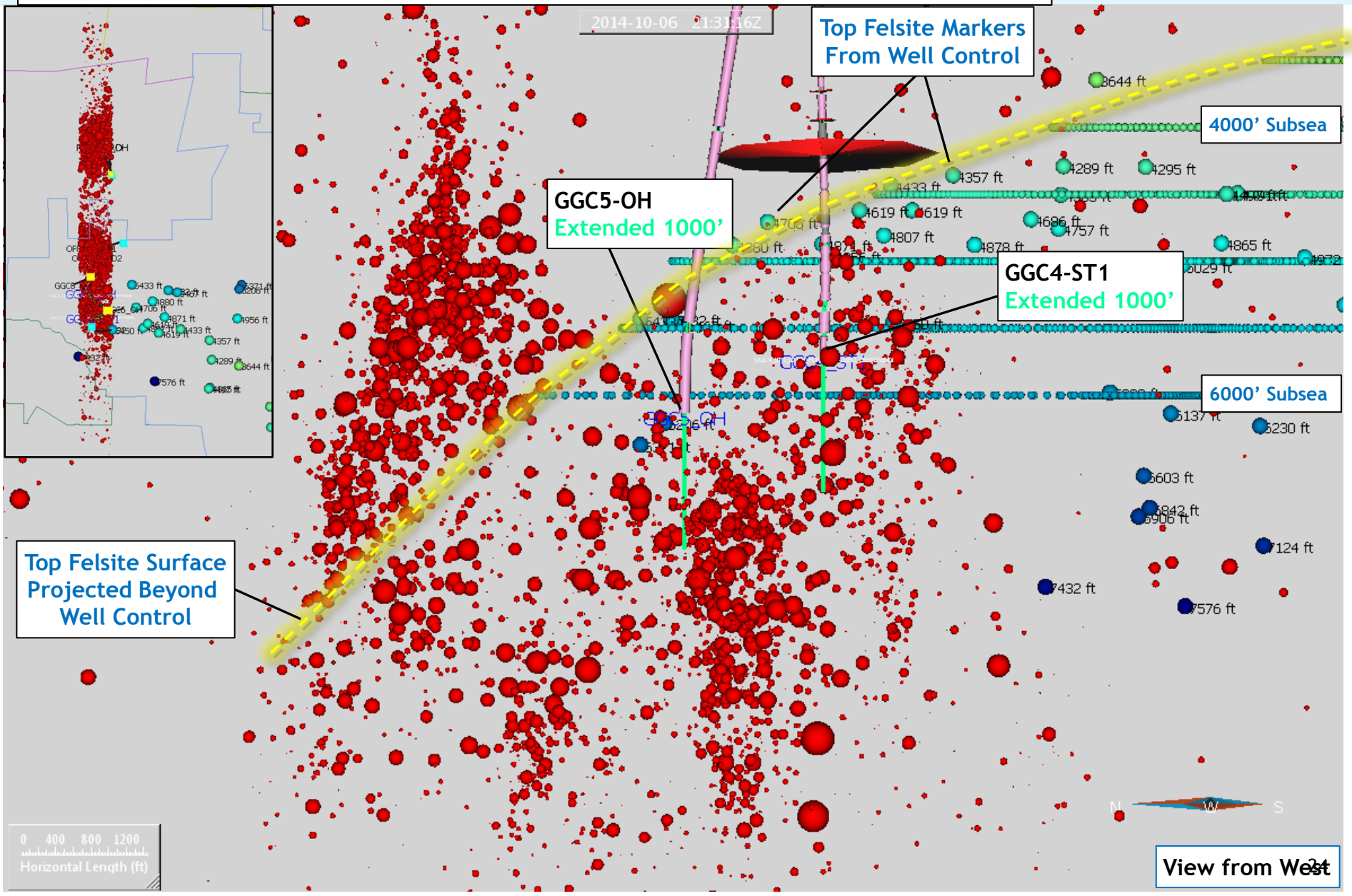


Seismic Monitoring Advisory Committee Meeting

3D Analysis in Vicinity of Wells GGC4-ST1 and GGC5-OH

CALPINE NYSE CPN

2000 through 2014 Seismic Events for a 2000' Wide North-to-South Cross Section



3D Analysis in Vicinity of LF9 Well Pad

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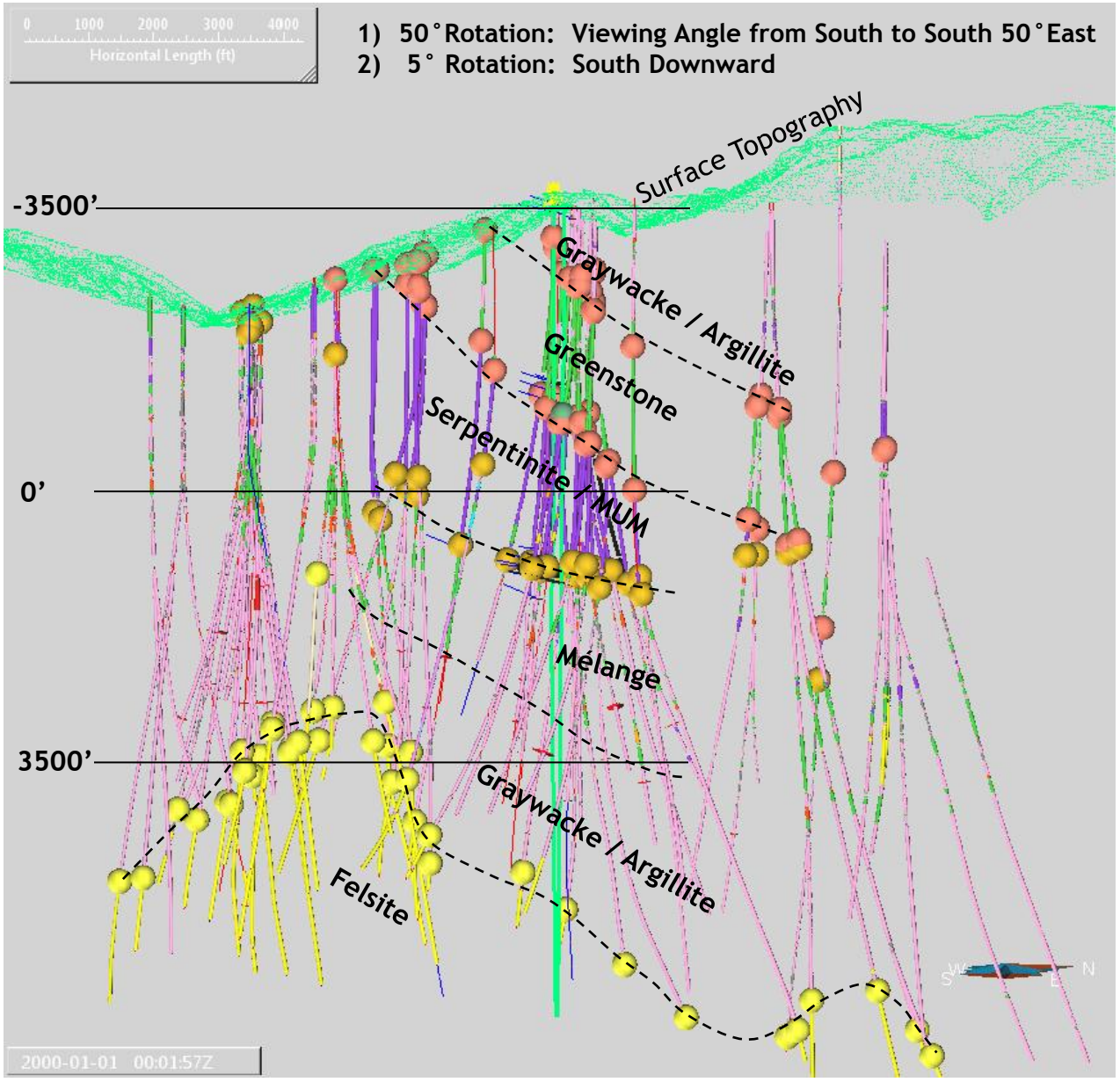
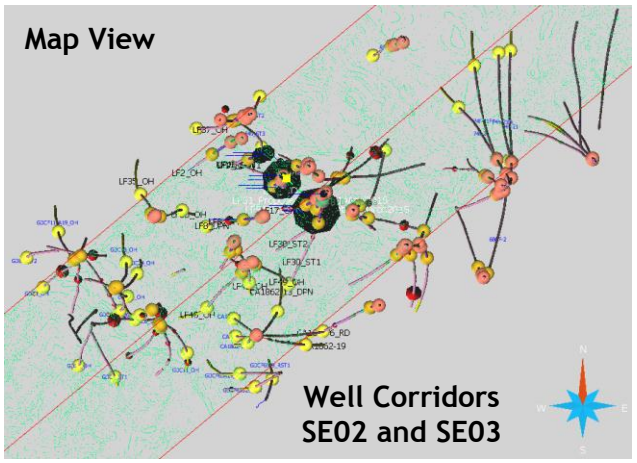




Lithology in the vicinity LF9 consists the following east/northeast dipping units:

Graywacke/Argillite

Greenstone

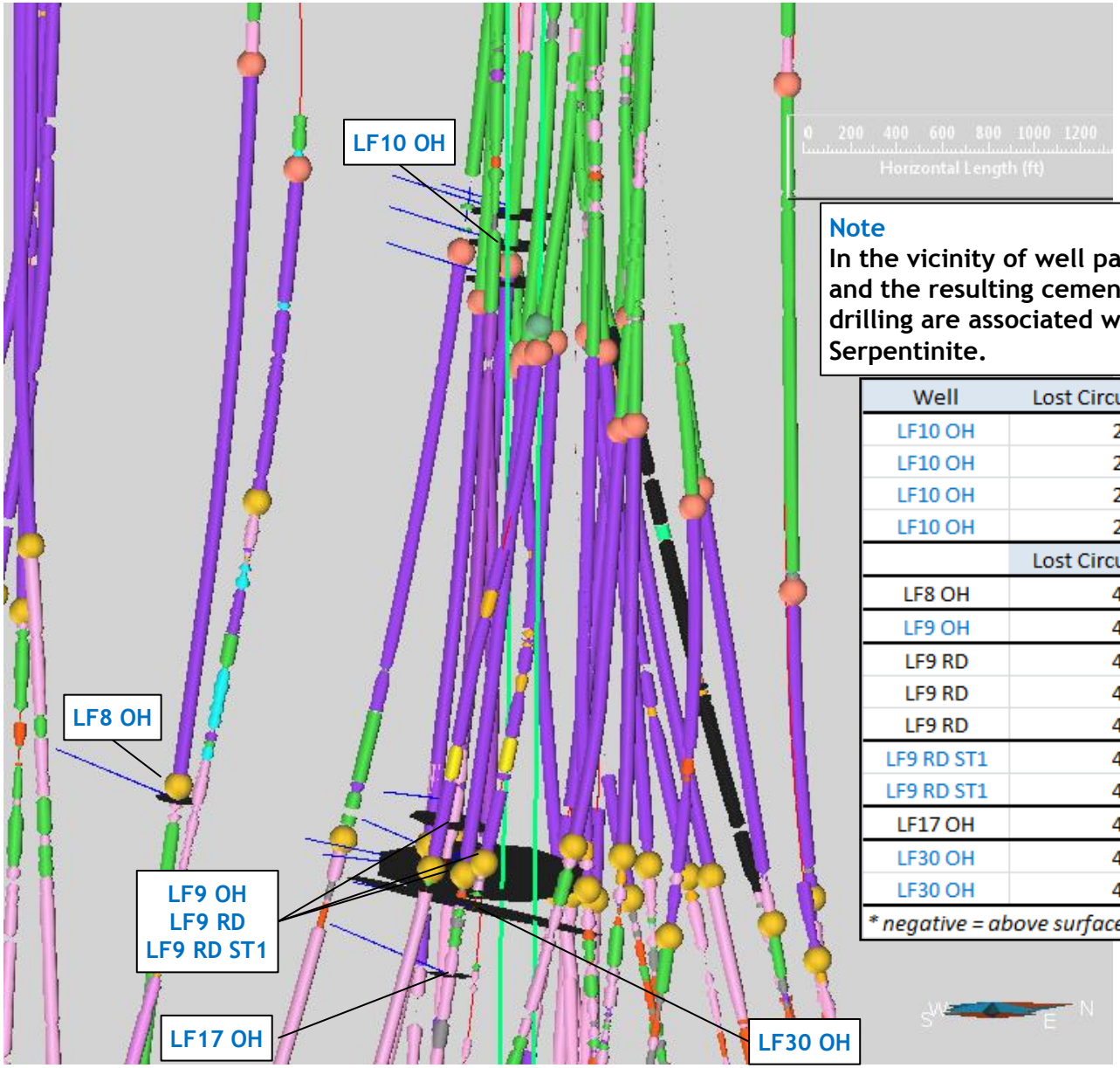
Serpentinite/Meta-ultramafic (MUM)

Mélange
Graywacke/Chert/
Greenstone/Serpentinite

Graywacke / Argillite

Felsite (possible)

3D Analysis in the Vicinity of LF9 Well Pad



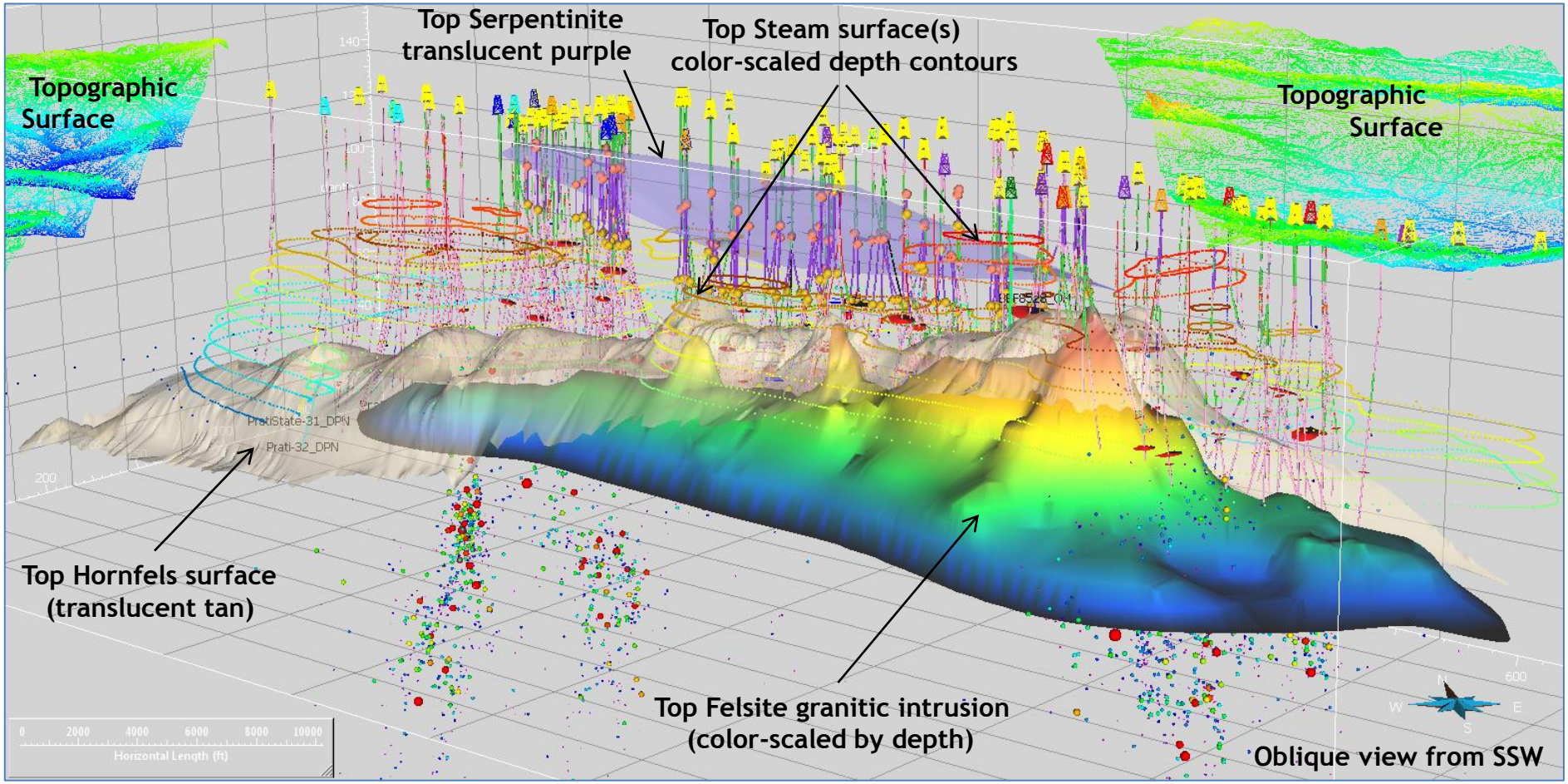
Note

In the vicinity of well pad LF9, lost circulation zones (blue lines) and the resulting cement plugs (black discs) encountered during drilling are associated with the Top Serpentinite and Base Serpentinite.

Well	Lost Circulation Zone	Top Serpentinite	Separation*
LF10 OH	2194	2399	-205
LF10 OH	2218	2399	-181
LF10 OH	2328	2399	-71
LF10 OH	2455	2399	56
	Lost Circulation Zone	Base Serpentinite	Separation*
LF8 OH	4116	4065	51
LF9 OH	4433	4063	370
LF9 RD	4194	4064	130
LF9 RD	4270	4064	206
LF9 RD	4442	4064	378
LF9 RD ST1	4430	4331	99
LF9 RD ST1	4450	4331	119
LF17 OH	4860	4501	359
LF30 OH	4608	4460	148
LF30 OH	4618	4460	158

** negative = above surface; positive = below surface*

3D Visualization and Model Building
01 May 2015 Example



Two selected northwest-to-southeast well track "corridors" are displayed with assigned lithology (rock type).
Steam entries displayed as red disks (scaled by stream pressure increase).
Seismicity is displayed for 2500' wide southwest-to-northeast oriented corridors in the:
(1) Northwest Geysers NW04
(2) Southeast Geysers SE09

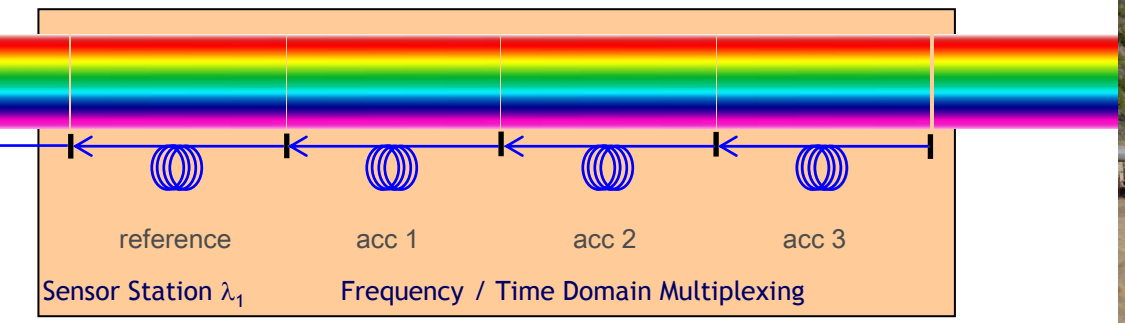
Vertical exaggeration of 1.25 x

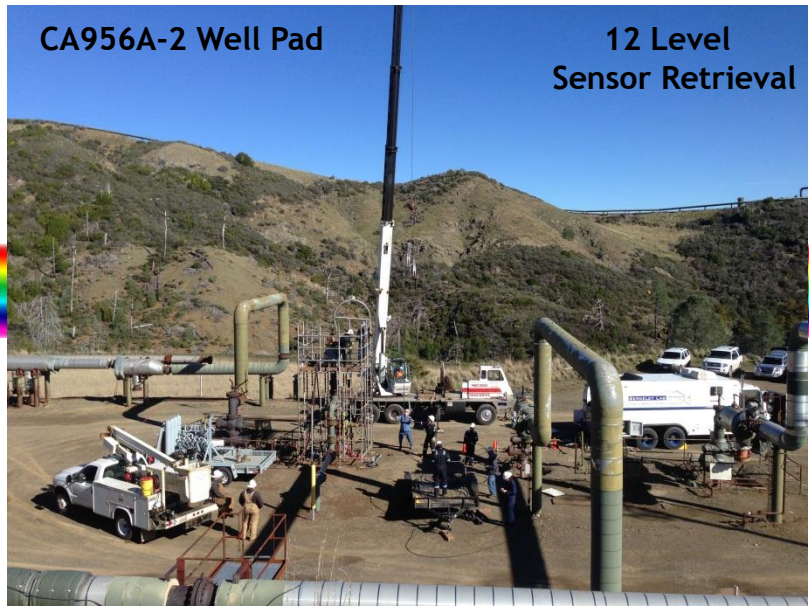
Seismicity Monitoring Research
Borehole Fiber Optic Seismic Sensor Tests

Calpine Corporation is promoting the development of "next-generation" three-component fiber optic seismic sensor technologies suitable for high-temperature boreholes and providing improved seismic data resolution.

Fiber Bragg Gratings

The fiber *is* the sensor - no electronics below ground surface!
Partially reflects light of a specific wavelength
(other wavelengths transmitted)





1) United States Seismic Systems / Calpine / LBNL*

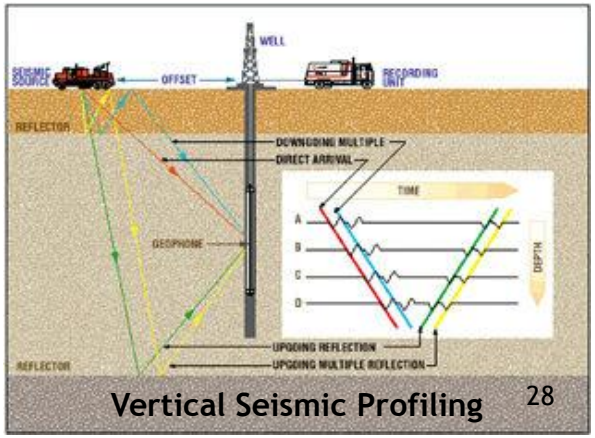
12 level / 36 sensor high-temperature (215°C / 415°F) test completed 20 January 2015 at well CA956A-2.

2) Paulsson Incorporated / Calpine / LBNL*

Submitted research proposal to California Energy Commission
Nearly $900,000 in research funding approved for a two-well program:

- Passive induced seismicity monitoring
- Active vertical seismic profile (VSP) imaging (with a"Vibroseis" energy source)
- Summer 2015 target

Sensor Pods



Vertical Seismic Profiling

* Lawrence Berkeley National Laboratory

Additional Seismic Monitoring and Research

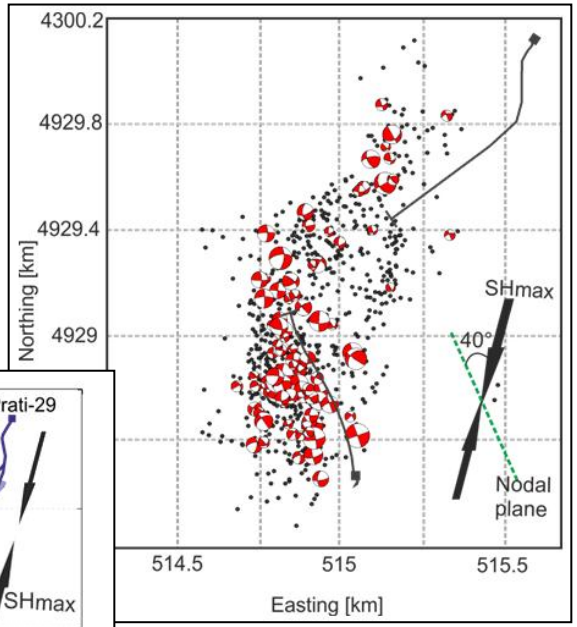
This Collaboration is Being Expanded Beyond the Recent Prati 9 Injection Well Analysis.
Calpine is currently providing data for additional NW Geysers wells.

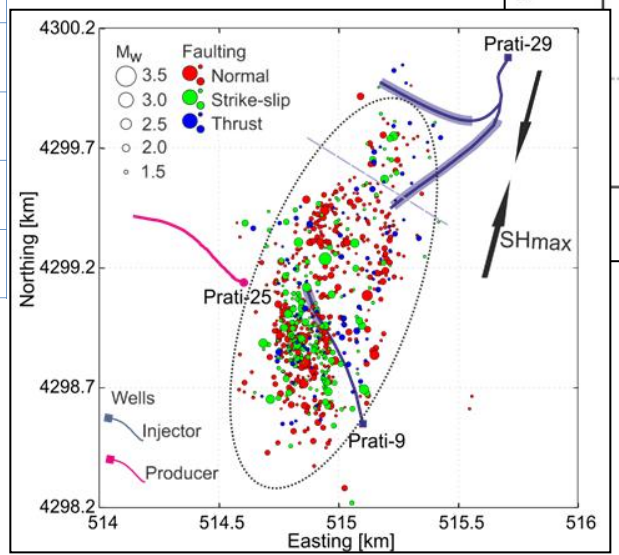
Helmholtz-Centre Potsdam GFZ German Research Centre for Geosciences, Potsdam, Germany (1)
Free University Berlin, Institute of Geological Sciences, Berlin, Germany (2)
Calpine Corporation, The Geysers, Middletown, California, USA (3)

"*Spatiotemporal changes, faulting regimes and source-parameters of induced seismicity: A case study from The Geysers geothermal field*"
Patricia Martínez-Garzón[1], Grzegorz Kwiatek[1], Marco Bohnhoff[1,2], Georg Dresen[1], Hiroki Sone[1], Craig Hartline[3]

Detailed analysis of Prati 9 water injection and associated induced seismicity.

	During peak injection	Potential implications
Number of strike-slip and thrust faulting events	⇧	Temporal change in faulting
Hypo-/epicentral distance	⇧	Temporal change in spatial scale
Relative stress magnitude	⇧	Pore pressure increase
(b-value)	⇩	Correlation with mean stress level
(stress drop thrust faulting)	⇧	Observation
Alignment with S_{HMax}	⇧	Change in reservoir stresses





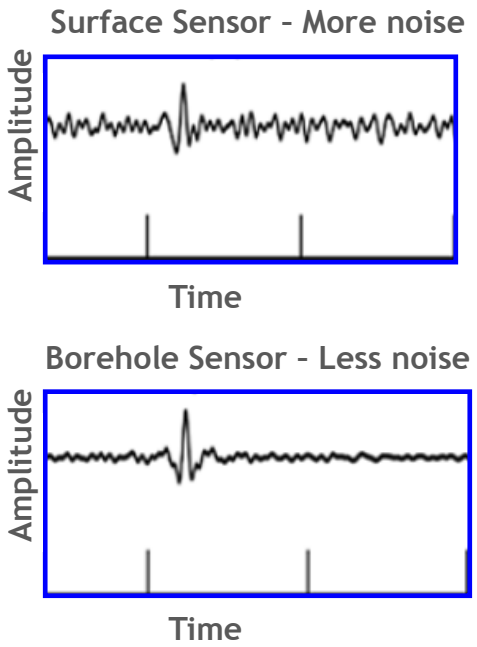
Additional Seismic Monitoring and Research

Seven AltaRock Microseismic Array (MSA) Boreholes Transferred to Calpine Corporation

Collaboration with Lawrence Berkeley National Laboratory.

Three-component borehole seismic monitoring stations installed by LBNL contractor Ramsey Haught at:

- (PSB P-Site Borehole) MSA-2 ..... 475' depth
- (SRB Sheepskin Ridge Borehole) MSA-3 ..... 457' depth
- (SSB Super Sump Borehole) MSA-5 ..... next installation
- (RTB Reynolds Trucking Borehole) MSA-6 ..... 454' depth
- (DEB Davies Estate Borehole) MSA-8 ..... 490' depth



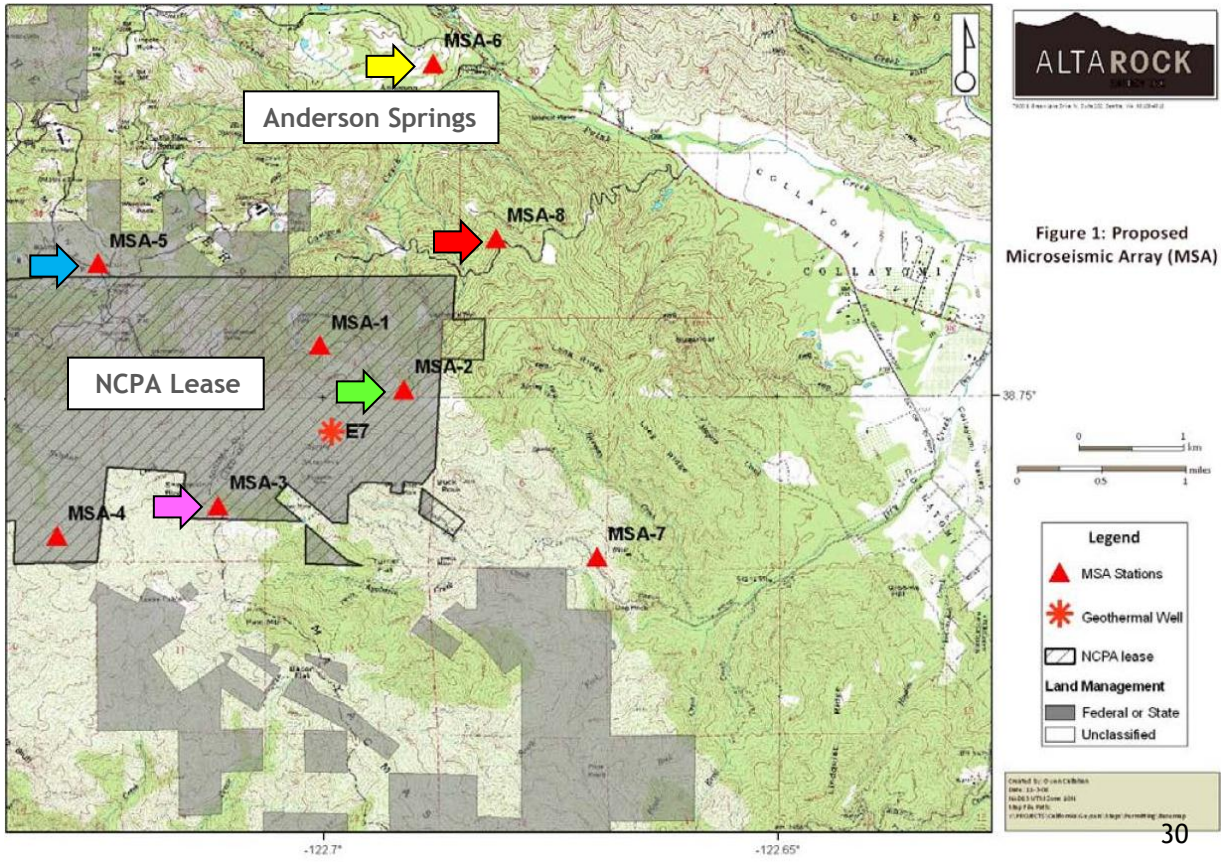


Figure 1: Proposed Microseismic Array (MSA)

Additional Seismic Monitoring and Research

System Installed 15 September 2014 – Fully Functional

CALPINE NYSE CPN

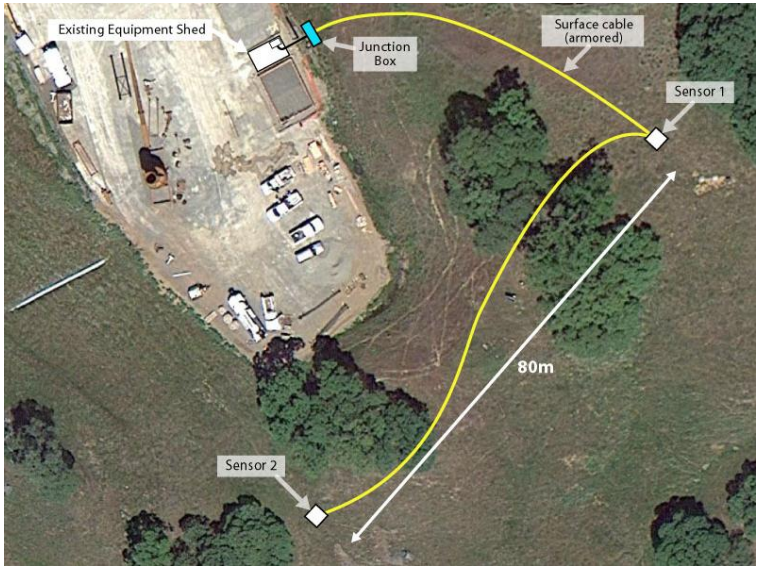
Research Collaboration with Seismic Warning Systems
Early Detection and Warning System for Natural Earthquakes

SEISMIC WARNING SYSTEMS

Primary Goal

Automated control (and shutdown) of natural gas, electricity and water supply for refineries, chemical plants, public schools, medical facilities, …

Two test sensors at The Geysers Prati 32 well pad.
Tied in to Calpine power and communications.



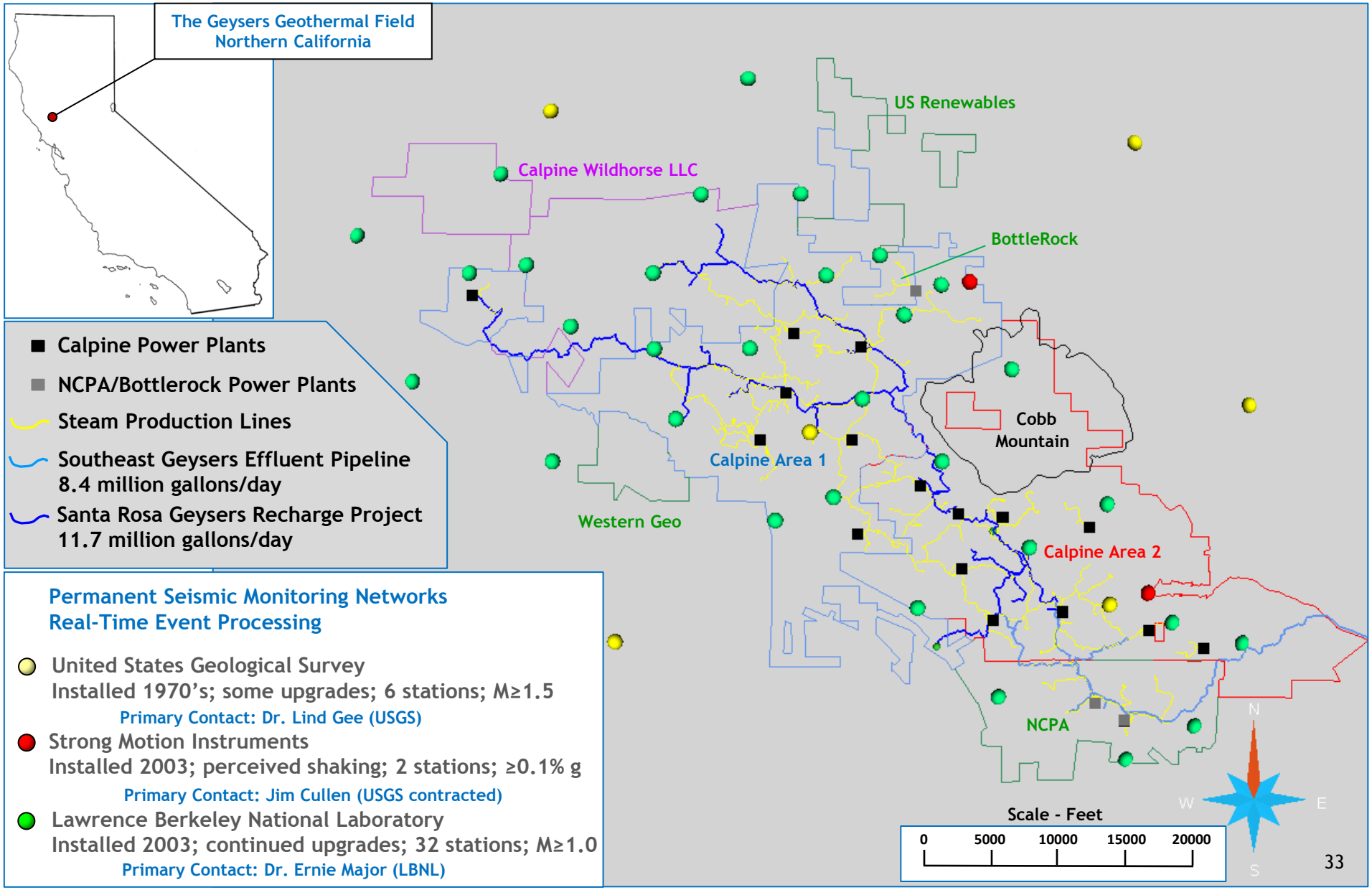
Geysers Project Goal

Refinement of event detection software to:

- Avoid false positives (caused by human activity)
- Distinguish between:
  - smaller seismic events typical of The Geysers these should be ignored
  - large seismic events (earthquakes) triggering automated warnings and shutdowns


CALPINE®
NYSE CPN

Reference
Permanent Seismic Monitoring Networks



2014 Calpine Geysers Field Facts

- 75 miles north of San Francisco, California
- 10 power plants in Sonoma County: Aidlin, Sonoma, McCabe, Ridgeline, Eagle Rock, Cobb Creek, Sulphur Springs, Lake View, Socrates and Grant.
- 5 power plants in Lake County: Bear Canyon, West Ford Flat, Big Geysers, Quicksilver and Calistoga.
- 29,000 acres (45 square miles)

- 333 steam wells
- 60 injection wells
- Deepest well: 12,900 feet, or over two miles
- Average well depth: 8,500 feet
- Total Calpine Geysers wells drilled to date: 587
- Today's Average Grassroots Drilling Time: 85 days (75 days drilling + 10 rig up/down)
- 2013 Average Steam Production per well: 36,690 pounds per hour
- Average Reservoir Steam Temperature: 359 degrees Fahrenheit
- Average Flowing Steam Pressure: 76.6 PSIG
- Most recent steam well drilled: Aidlin-10, January 13, 2014
- Most recent injection well drilled: LF-22 , August 27, 2013

- 15 operating geothermal plants
- Steam pipelines: 80 miles
- Injection water lines: 69 miles
- 21kV power lines: 70 miles
- Project roads: over 167 miles

World's largest geothermal power producer

18% of California's renewable electricity generation
39% of USA geothermal electricity generation

- Two large-scale wastewater injection projects
  - Santa Rosa Geysers Recharge Project Average: 11.73 MGD
  - Calpine Southeast Geysers Effluent Pipeline Average: 3.88 MGD
  - Calpine + Northern California Power Agency Average: 8.39 MGD

- 2013 Average Load: 685.2 net megawatts
- 2013 Generation: 6,002,660 net megawatt hours
- 2013 Average Unit Availability: 96.0%