CALPINE® NYSE CPN

A GENERATION AHEAD, *today*

Seismic Monitoring Advisory Committee Meeting
14 November 2016

Calpine Geothermal Visitors Center
Middletown, California

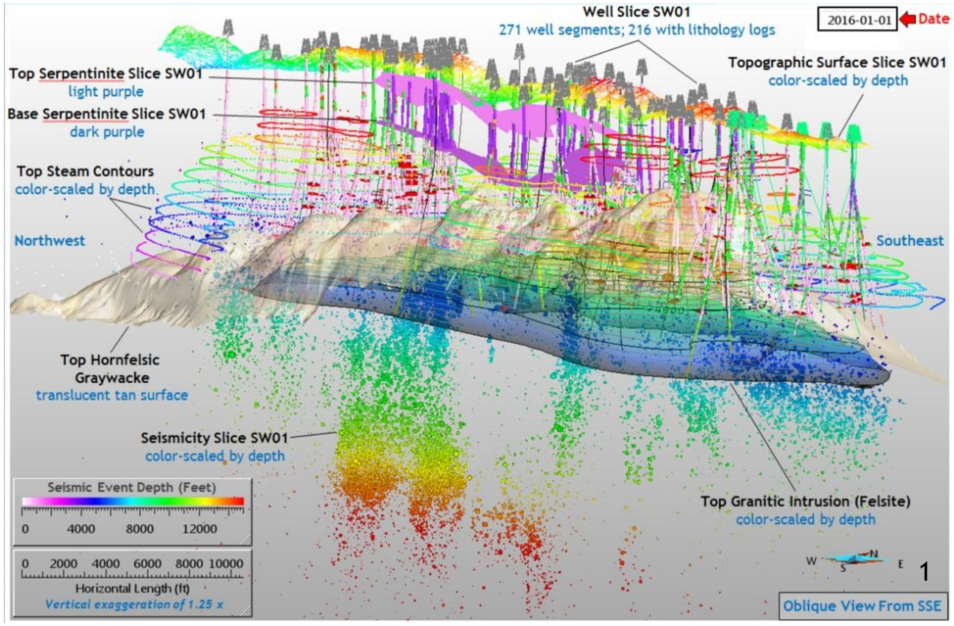
Reporting Period:
01 April 2016 to 30 September 2016

Craig Hartline
Senior Geophysicist
Calpine Corporation
The Geysers

CLEAN MODERN EFFICIENT FLEXIBLE POWER GENERATION

Seismic Monitoring Advisory Committee Meeting
Calpine Presentation Agenda
Reporting Period: 01 April 2016 to 30 September 2016

- Status of Seismic Monitoring Networks
  - LBNL Seismic Monitoring Network
  - USGS / Northern California Seismic Network
  - Strong Motion Stations
- Seismicity Hotline
- Field-wide Seismicity Analysis
- Synchronized Field-Wide Water Injection and Seismicity Analysis
- Induced Seismicity, Fracture Zones and Reservoir Compartmentalization
- 3D Visualization and Structural Model Building
- Additional Seismic Monitoring and Research



Status of Seismic Monitoring Networks

LBNL Seismic Monitoring Network - Fully Functional
USGS / Northern California Seismic Network - Fully Functional

Strong Motion Stations

- Station ADS2
  This sensor was determined to be fully functional by the U.S. Geological Survey and returned to service at the intact community center snack bar. The database is online at: ftp://ehzftp.wr.usgs.gov/luetgert/calpine/sm_sum.txt

- Stations ADSP and COB assessed by United States Geological Survey; both require replacement due to fire-damage.

  Replacement with state-of-the-art Titan Nanometrics Accelerometers providing:
  - Strong motion monitoring — three-component peak ground acceleration* values
  - Conventional seismic monitoring — three-component velocity* values

  Integration into the existing LBNL seismic monitoring network:
  - Solar power
  - Radio telemetry
  - More reliable service - ETNA stations at ADSP and COB utilized rural power and communication.

  - Titan Nanometrics Accelerometers purchased by Calpine and bench-tested by LBNL contractor Ramsey Haught

  - To be installed by Ramsey Haught (under the guidance of Dr. Ernie Majer)
    - Cobb Station
      to be installed at existing site (Hamilton Hess property)
    - Anderson Springs Station
      received landowner approval for site southwest of Anderson Springs water tanks
      proximity to east-west property line - survey markers located and east-west boundary determined
      very recent issues with easements for Mira Vista Road
      discussions ongoing with Calpine Land Manager Kevin Talkington, property owners and LBNL

* There is a mathematical relationship between acceleration and velocity that can be calculated.
The measured acceleration can be *integrated* to determine the velocity (acceleration is the *derivative* of the velocity).

Titan Accelerometer

The Titan is a force balance triaxial accelerometer that provides exceptional performance over a wide frequency range from DC to 430 Hz. The Titan features industry leading dynamic range and ultra-low self-noise performance that is comparable to that of some broadband seismometers. Combine the Titan with the Centaur digitizer to achieve a complete data acquisition and recording system that is suitable for deployment in both remote and networked locations.

The Titan is the first accelerometer to incorporate digitally selectable full scale range and offset zeroing capabilities; features that are ideal for difficult to access or remote deployments, where site visits should be minimized.

The triaxial sensor and electronics are housed in a rugged, compact aluminum enclosure featuring a single bolt anchoring slot, adjustable leveling screws and integrated bubble level.

The Titan Accelerometer has been designed to provide the highest performance available while ensuring efficient, low cost deployments and ease of use.

Industry Leading Performance Attributes:

- Industry leading 166 dB dynamic range
- Ultra-low self-noise comparable to some broadband seismometers
- Wide operational frequency range: DC to 430 Hz
- Best in class thermal stability and high accuracy provide increased data quality
- Full scale range of ±0.25 *g* to ±4 *g* with independent horizontal and vertical range selection

Ease of use advantages:

- Electronically selectable full scale range facilitates remote sensor control when deployments are distant or difficult to access
- Integrated web server provides efficient instrument management and control
- Installation features that include an integrated bubble level, adjustable leveling screws, single bolt keyhole mount, and a compact footprint ensure that deployments are completed efficiently and quickly

Titan accelerometer connected to and powered by a Centaur Digitizer

Specifications

Accelerometer Technology and Performance

Topology	Triaxial, horizontal-vertical
Feedback	Force balance with capacitive displacement transducer
Centring	Electronic offset zeroing via user interface or control line
Full-scale Range	Electronically selectable range: ±4 *g*, ±2 *g*, ±1 *g*, ±0.5 *g*, and ±0.25 *g* (peak)
Bandwidth	DC to 430 Hz (-3 dB point)
Dynamic Range (Integrated RMS)	166 dB @ 1 Hz over 1 Hz bandwidth 155 dB, 3 to 30 Hz
Offset	Electronically zeroed to within ±0.005 *g*
Non-linearity	< 0.015% total non-linearity
Hysteresis	< 0.005% of full scale
Cross-axis Sensitivity	< 0.5% total
Offset Temperature Coefficient	Horizontal sensor: 60 µg/°C, typical Vertical sensor: 320 µg/°C, typical

Digital Command and Control Interface

Digital Interface	Onboard web server standard HTTP RS-232 compatible Serial Line Internet Protocol (SLIP) RS-232 command-line interface
Commands	Gain range selection Auto-zero, or set to specific offset Self-test Calibration enable State of health request Firmware updates
Data Outputs	Sampled XYZ outputs (in volts and *g*) Instrument temperature Trimmer settings Instrument serial number Hardware assemblies and firmware revisions

Physical and Environmental

Housing	Aluminum, surface resistant to corrosion, scratches, and chips
Mounting	Single bolt keyhole mount
Leveling	Integrated bubble level Adjustable locking levelling screws
Size	Length: 14 cm (5.5") Width: 8.5 cm (3.3") Height: 5.8 cm (2.3")
Weight	960 g (2.1 lb)
Operating Temperature	-40°C to 60°C
Storage Temperature	-65°C to 75°C
Humidity	0 to 100%
Weather Resistance	Rated to IP-67

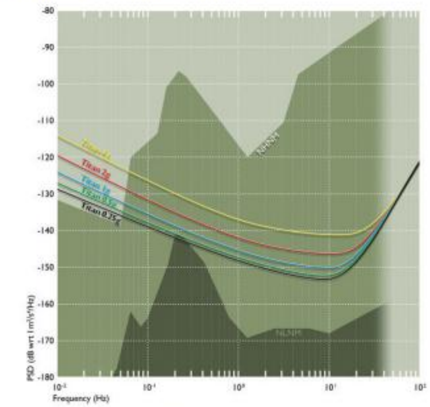
Hardware Interface

Connectors	MIL-C-26482G Series 1, 14-pin, shell size 12
Acceleration Output	40 Vpp differential
Output Impedance	2 x 100 Ω
Calibration Input	Single voltage input, all channels enabled together
Control Input	Single control signal can be configured to initiate auto-zero, initiate self-test, or enable calibration
Status Output	Asserted: Unit OK, output signal valid Deasserted: Self-test in progress or failed, auto-zeroing in progress, calibration enabled, or starting up
Serial Port	9600 Baud RS-232 compatible

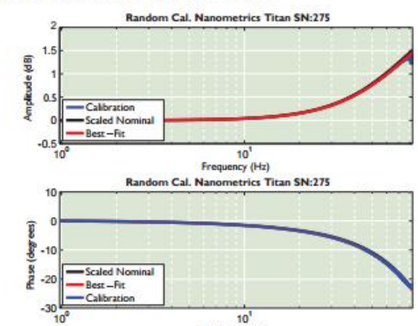
Power

Supply Voltage	9 to 36 V DC isolated input
Power Consumption	1.1 W typical quiescent
Protection	Reverse-voltage and over-/under-voltage protected Self-resetting over-current protection
Isolation	Supply power is isolated from signal ground
Grounding	Predrilled holes (4) for M4 x 5 grounding lug screw
Voltage Disconnect	Software configurable (low/high)

Titan Accelerometer Self-Noise



Sensor Performance: Flat Response



Test results courtesy of USGS

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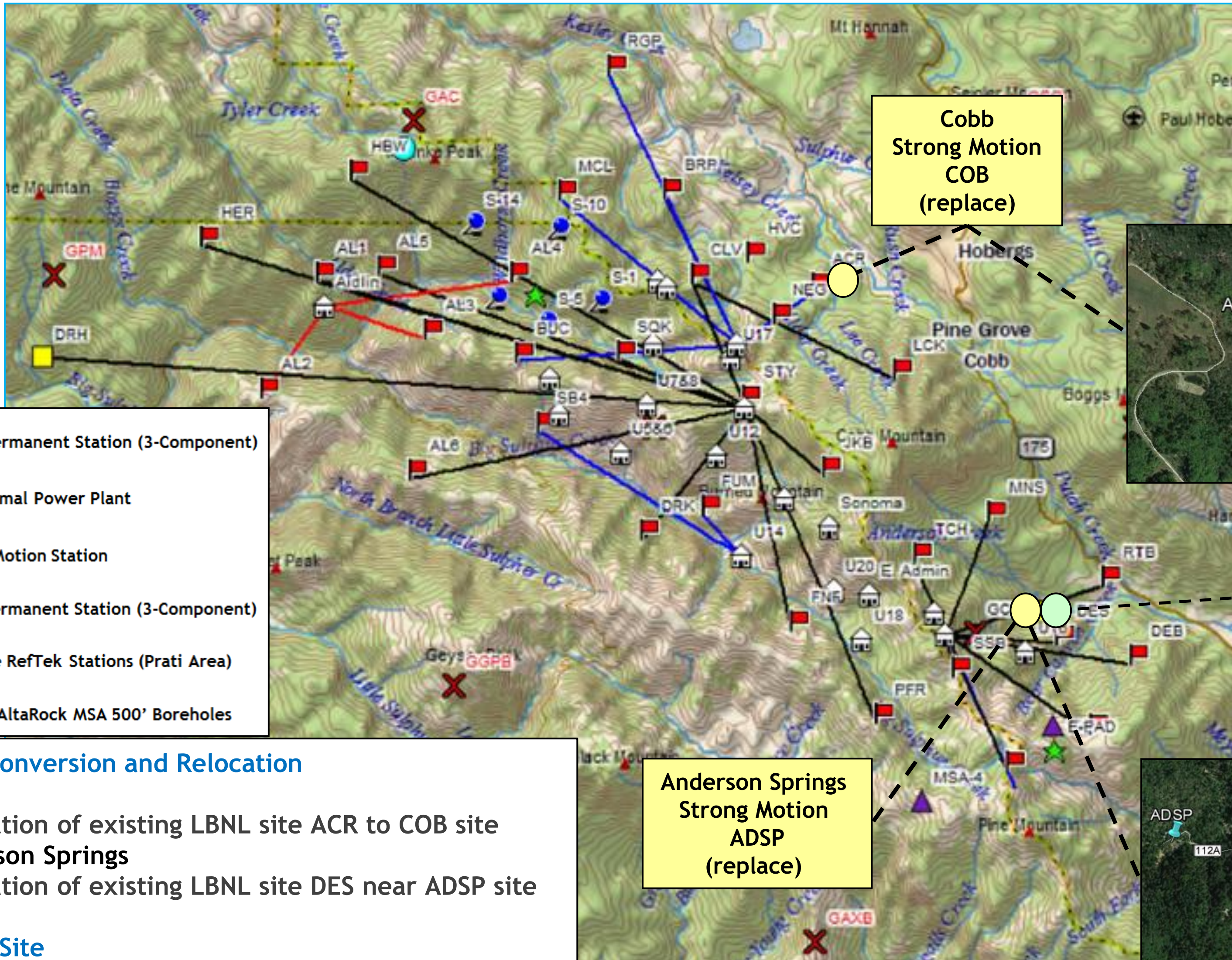
Document #: 1002.15.01 Printed in Canada

Integration of Nanometrics Titan Accelerometer into LBNL Network



- LBNL Permanent Station (3-Component)
- Geothermal Power Plant
- Strong Motion Station
- USGS Permanent Station (3-Component)
- Portable RefTek Stations (Prati Area)
- Former AltaRock MSA 500' Boreholes

System Conversion and Relocation

- ❑ Cobb
  Relocation of existing LBNL site ACR to COB site
- ❑ Anderson Springs
  Relocation of existing LBNL site DES near ADSP site

Cost Per Site

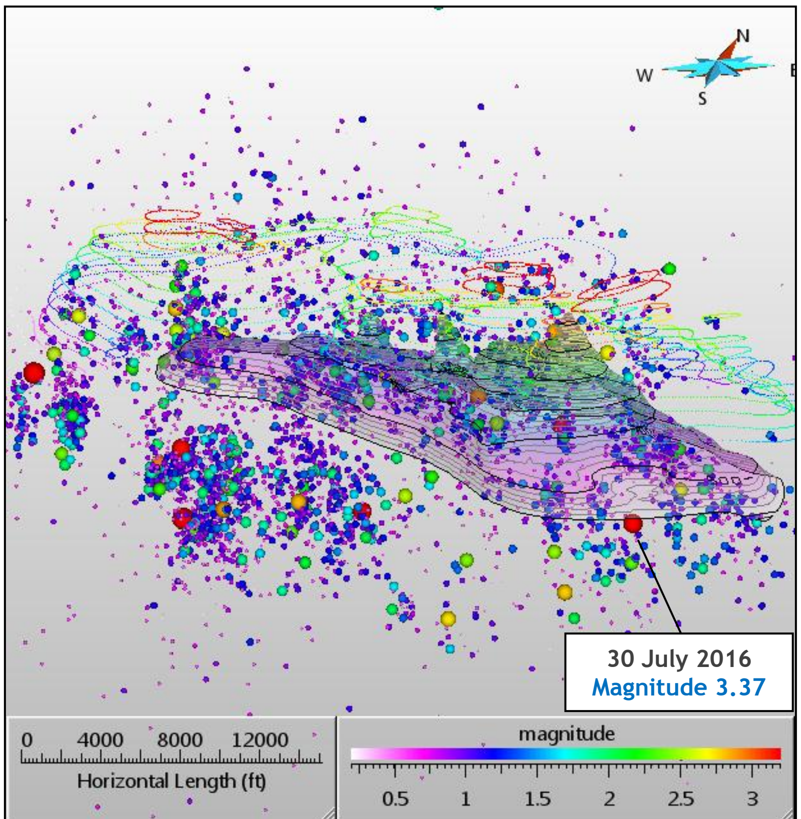
- $4800 for Accelerometer and Cable
- $2500 for Labor
- $7300 Total

Calpine Seismicity Hotline

The communities are understandably focused on efforts to recover from the Valley Fire, resulting in only two calls on 30 July 2016 to the Calpine Seismicity Hotline during the current reporting period of 01 April 2016 to 30 September 2016.

Magnitude 3.37 Seismic Event

Date and Time: 30 July 2016 at 10:11:23 am Pacific Time
Latitude: North 38.74647
Longitude: West 122.72014
Depth: 6496 feet (1.98 km) Below Sea Level



325 Active Steam Production Wells

725 MW of electrical energy production – equivalent to the energy requirements of San Francisco

18% of California's renewable energy

75% of the produced steam mass exits the cooling towers (yearly average), so:

52 Active Water Injection Wells

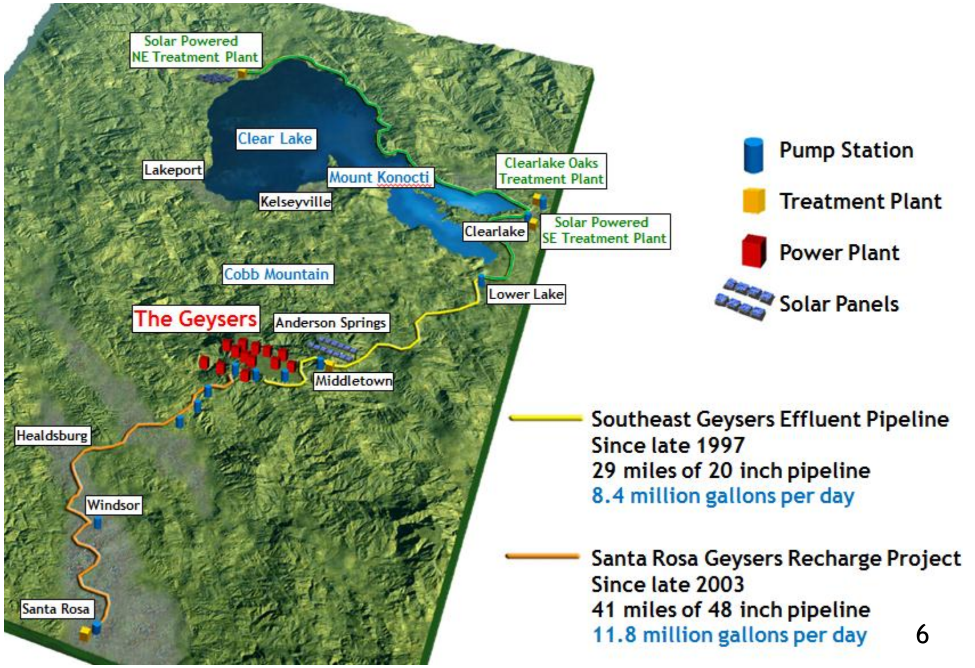
Water injection is required to replace the unrecovered mass and sustain The Geysers' steam reservoir

Water Sources

Power plant condensate (remaining 25% of the produced steam mass)

Fresh water during peak precipitation

Treated waste water from surrounding communities (an environmentally friendly "win-win" solution)



Induced Seismicity

Cool water "free falls" into hot rock and reactivates fractures (thermal contraction)

Modest pressure increases also reactivate fractures

Calpine Corporation has well-developed community relations programs and worldwide seismicity research collaborations to address induced seismicity at The Geysers.

Mechanism	Nodal Plan 1 Strike, Dip, Rake	Nodal Plan 1 Strike, Dip, Rake
	(339°, 80°, 175°)	(70°, 85°, 10°)

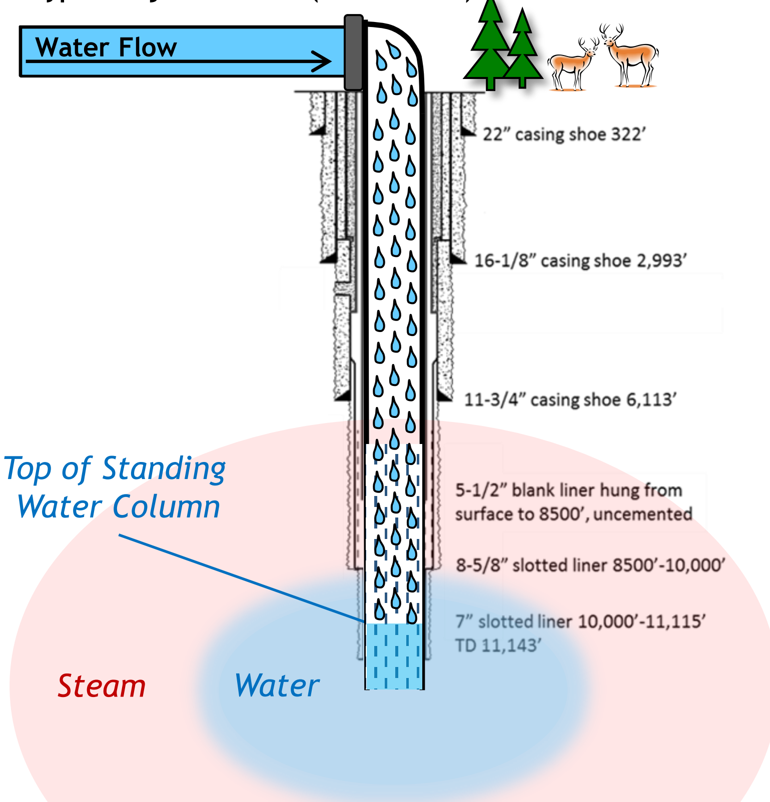
Cobb, California
8.0 km (5.0 mi) W

Anderson Springs, California
11.0 km (6.8 mi) WNW

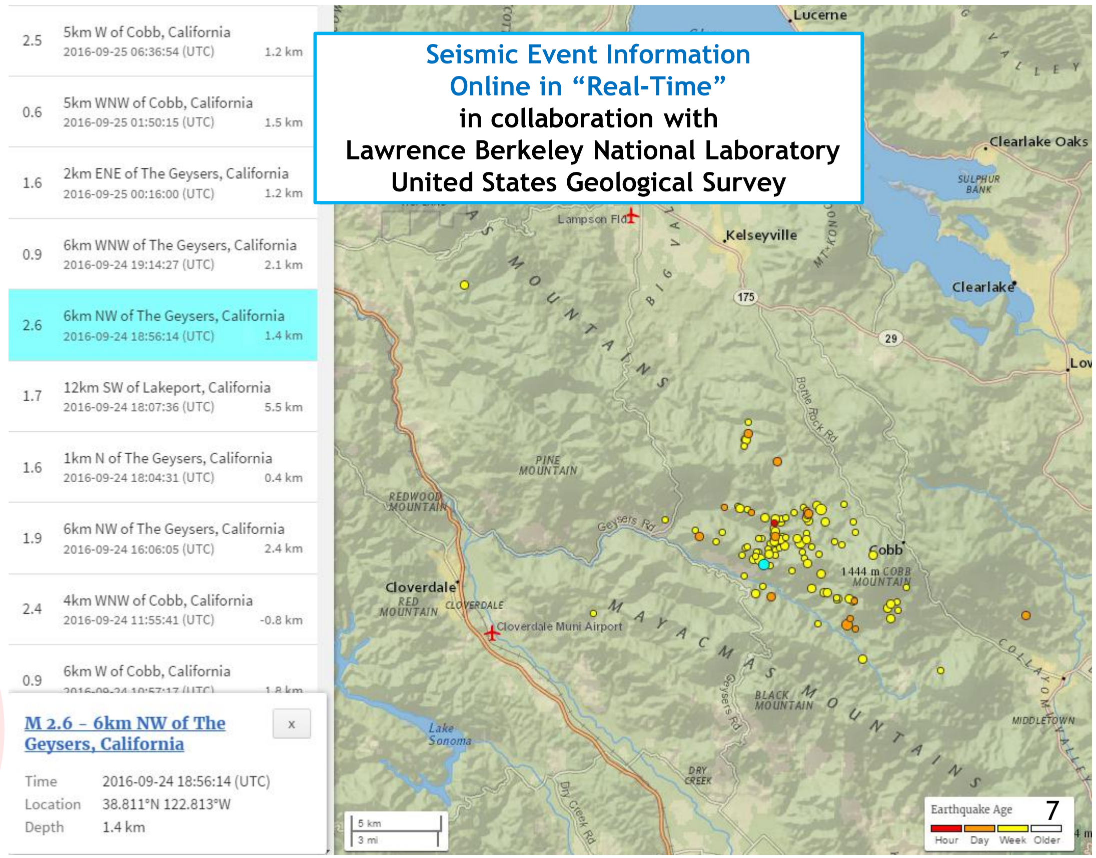
Cloverdale, California
18.0 km (11.2 mi) E

Santa Rosa, California
41.0 km (25.5 mi) NNW

Typical Injection Well (not to scale)



Seismic Event Information Online in "Real-Time" in collaboration with Lawrence Berkeley National Laboratory United States Geological Survey



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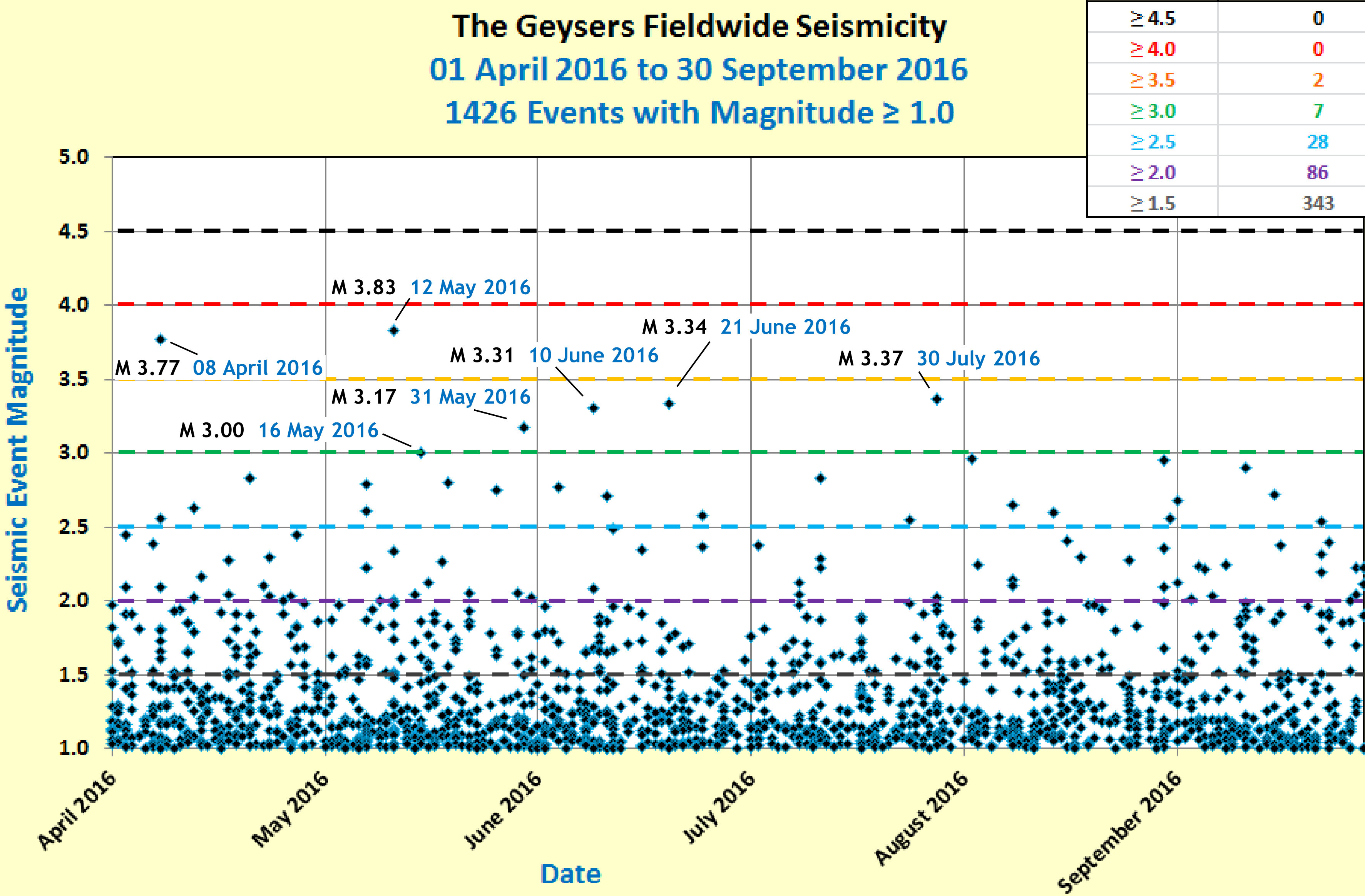
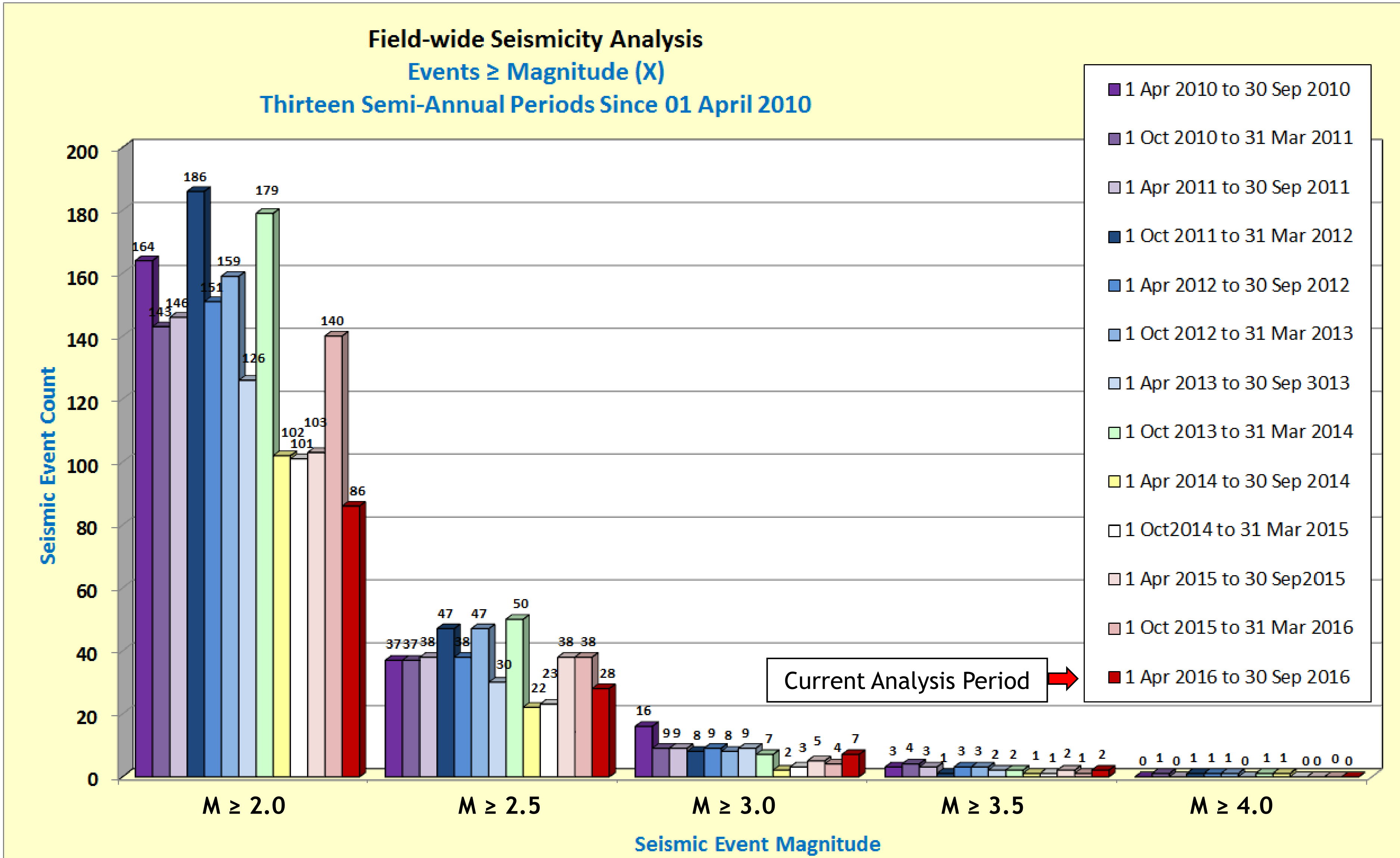
Field-wide Seismicity Analysis
01 April 2016 to 30 September 2016

Magnitude	Number of Events
≥ 4.5	0
≥ 4.0	0
≥ 3.5	2
≥ 3.0	7
≥ 2.5	28
≥ 2.0	86
≥ 1.5	343

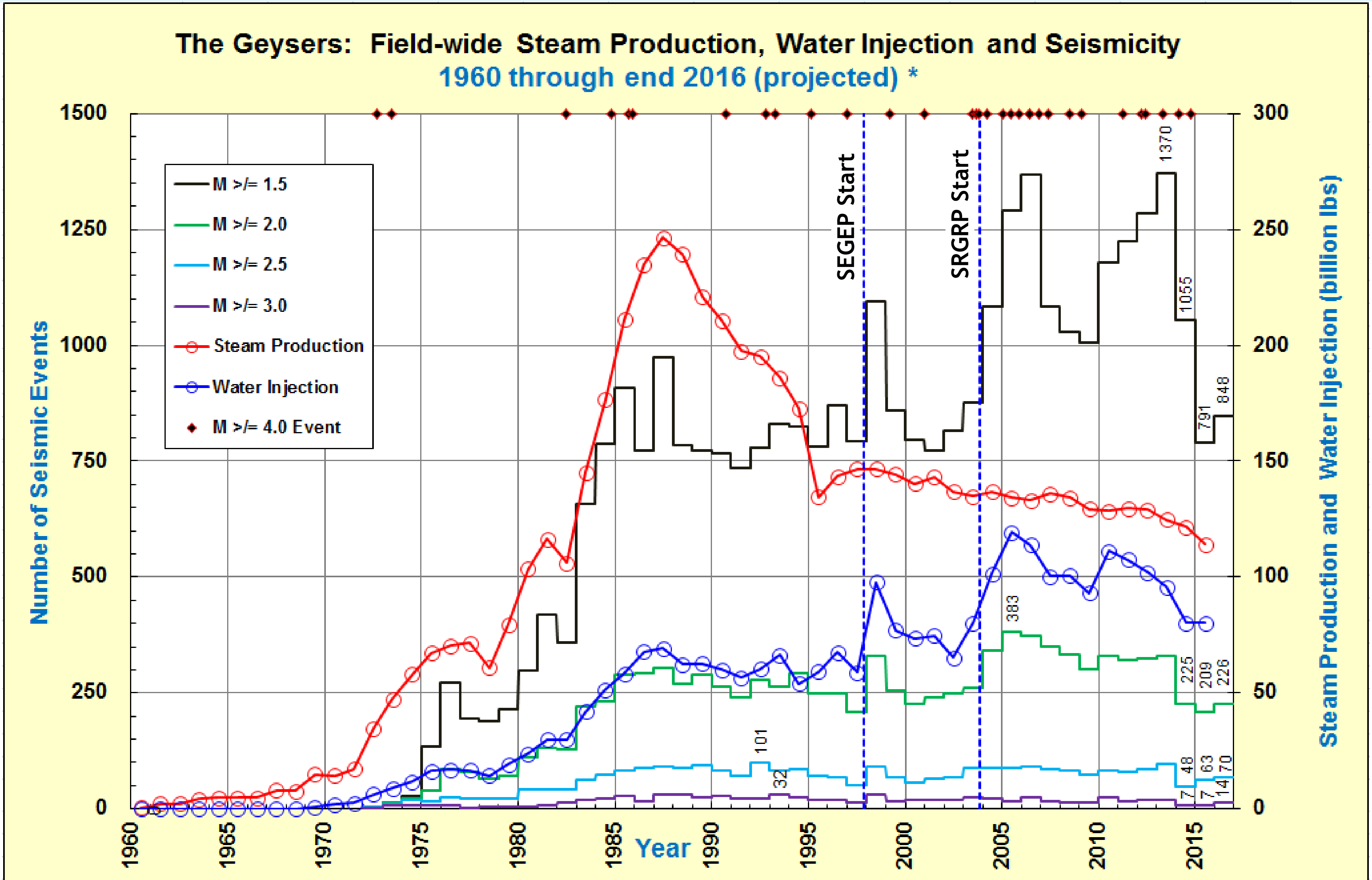


Field-wide Seismicity Analysis
Comparison of Eleven Semi-annual Reporting Periods



Yearly Field-wide Steam Production, Water Injection and Seismicity

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



The seismic event counts decreased for approximately one month following the September 12, 2015 Valley Fire due to power and communication outages.
This was more pronounced for low magnitude seismic events due to decreased station density.
2016 seismic event counts projected from Day 315 (11 November 11 2016)
2016 steam production and water injection values not estimated as available only through end September 2016

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Yearly Field-wide Water Injection and Magnitude ≥ 1.5 Seismicity

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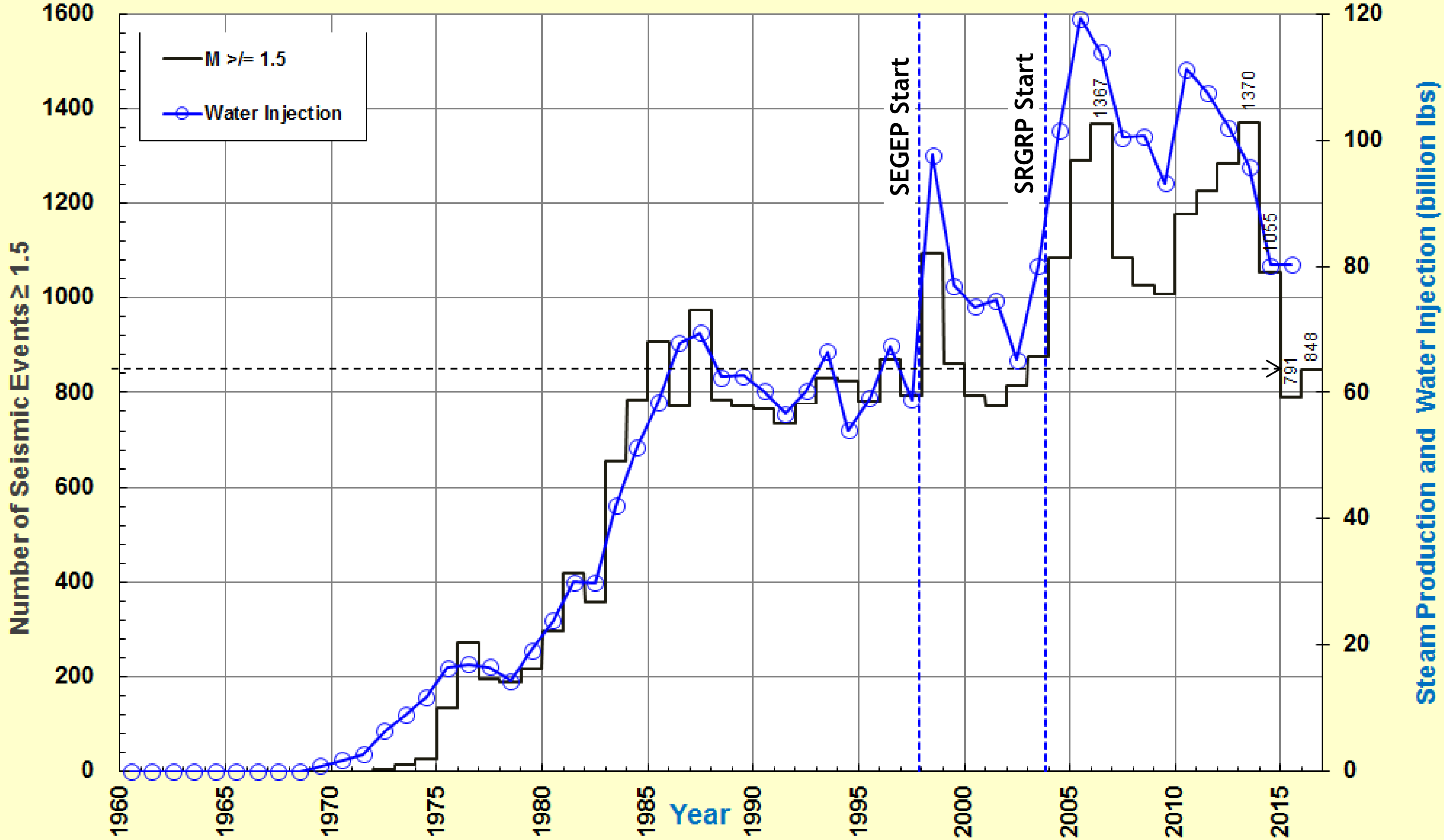
Database: Northern California Earthquake Data Center (NCEDC); UC Berkeley Seismological Laboratory

The Geysers: Field-wide Water Injection and M ≥ 1.5 Seismicity

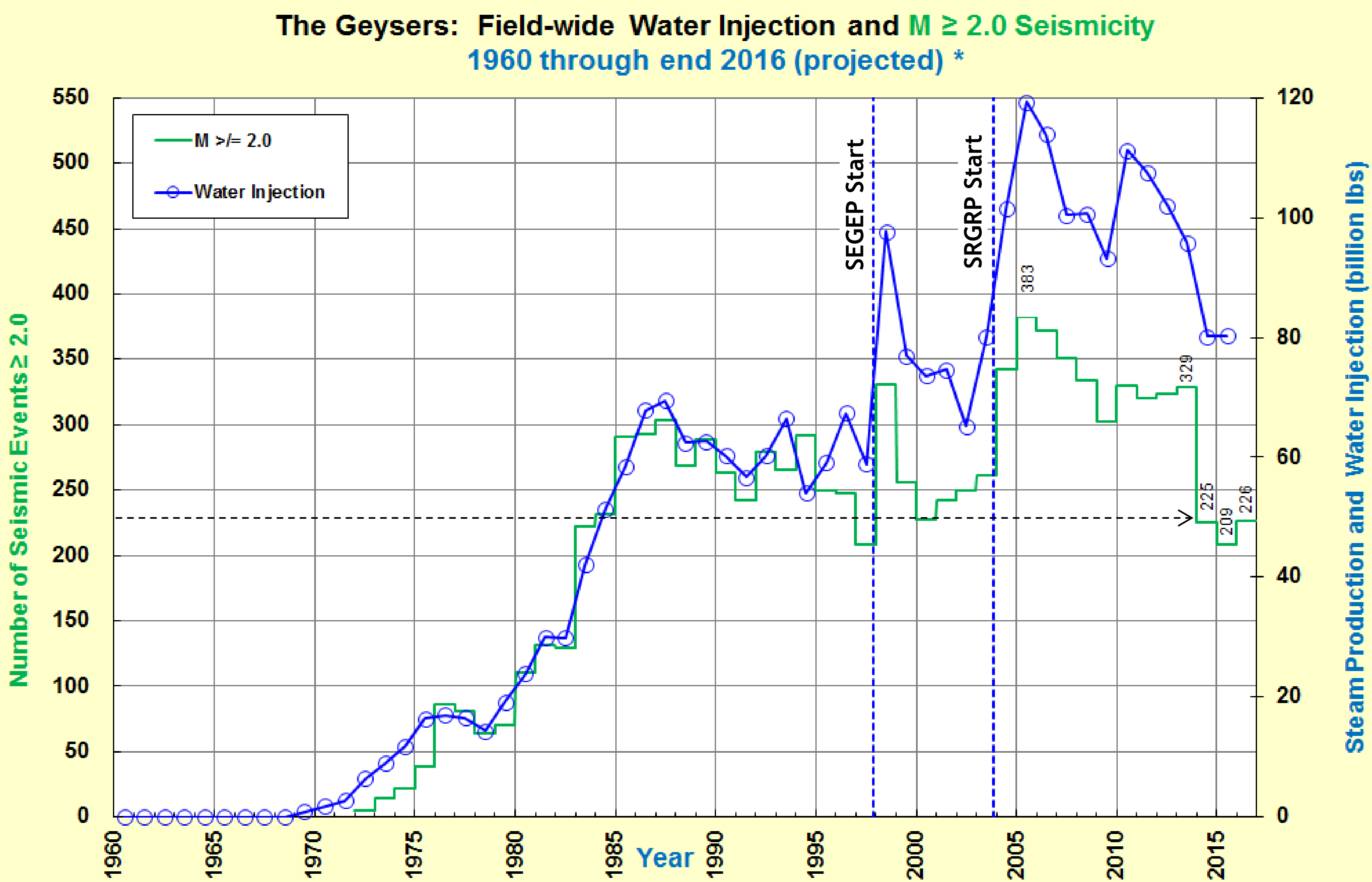
1960 through end 2016 (projected) *



** The seismic event counts decreased for approximately one month following the September 12, 2015 Valley Fire due to power and communication outages. This was more pronounced for low magnitude seismic events due to decreased station density.*
2016 seismic event counts projected from Day 315 (11 November 11 2016)
2016 steam production and water injection values not estimated as available only through end September 2016

Yearly Field-wide Water Injection and Magnitude ≥ 2.0 Seismicity

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



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Yearly Field-wide Water Injection and Magnitude ≥ 2.5 Seismicity

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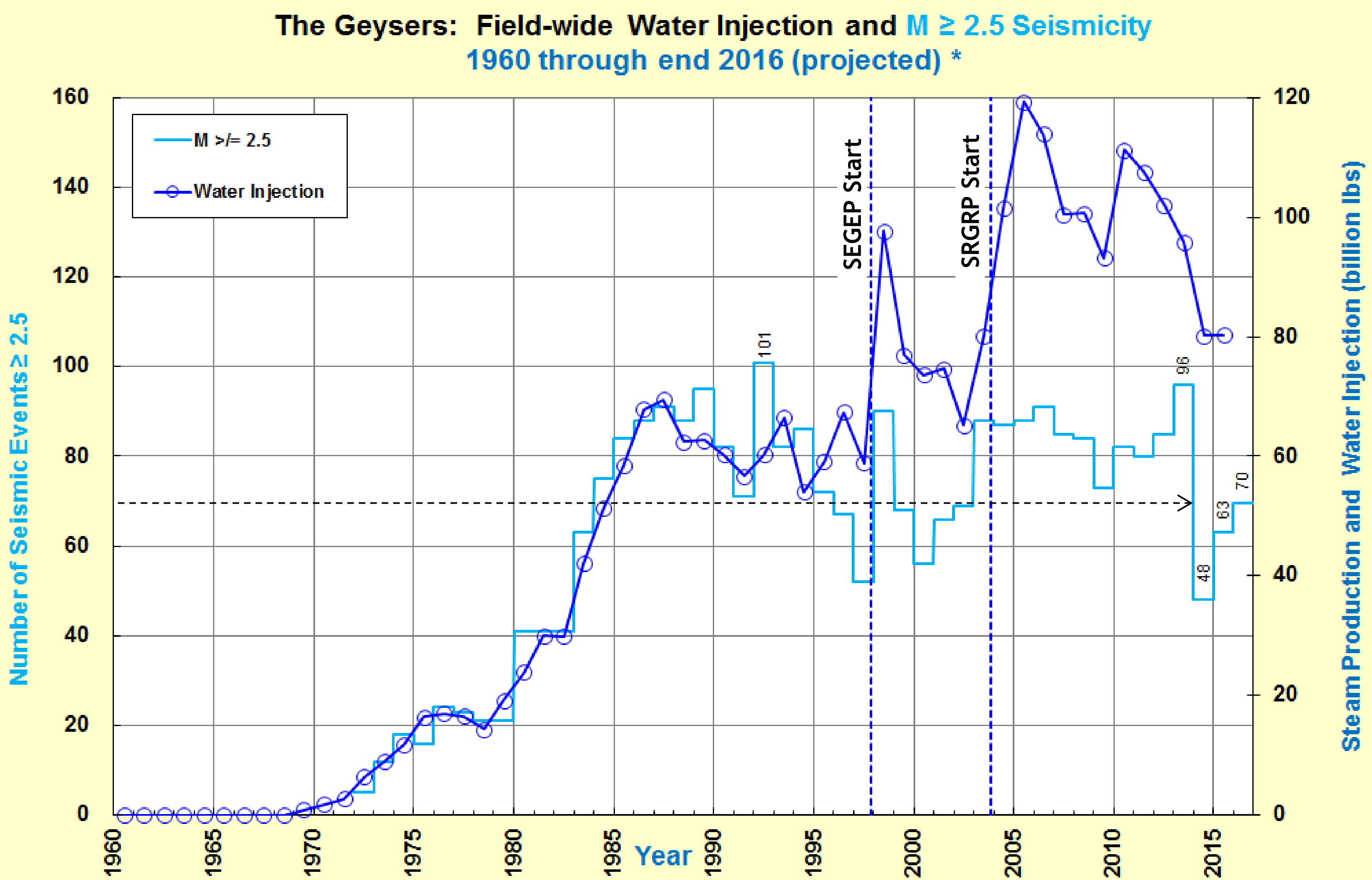
Database: Northern California Earthquake Data Center (NCEDC); UC Berkeley Seismological Laboratory



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2016 seismic event counts projected from Day 315 (11 November 11 2016)
2016 steam production and water injection values not estimated as available only through end September 2016

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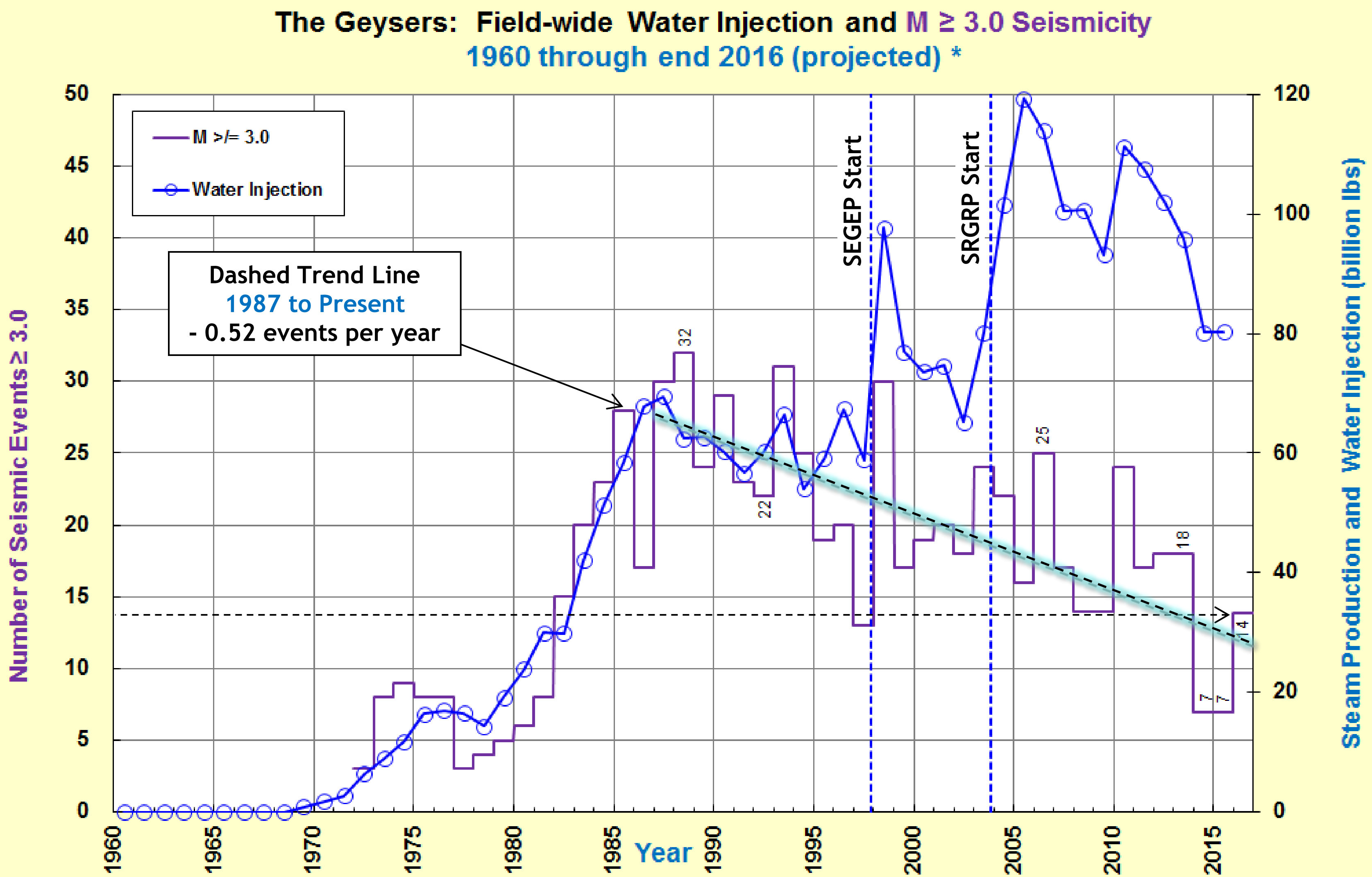
Yearly Field-wide Water Injection and Magnitude ≥ 3.0 Seismicity 1960 Through End 2015*

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



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2016 seismic event counts projected from Day 315 (11 November 11 2016)

2016 steam production and water injection values not estimated as available only through end September 2016

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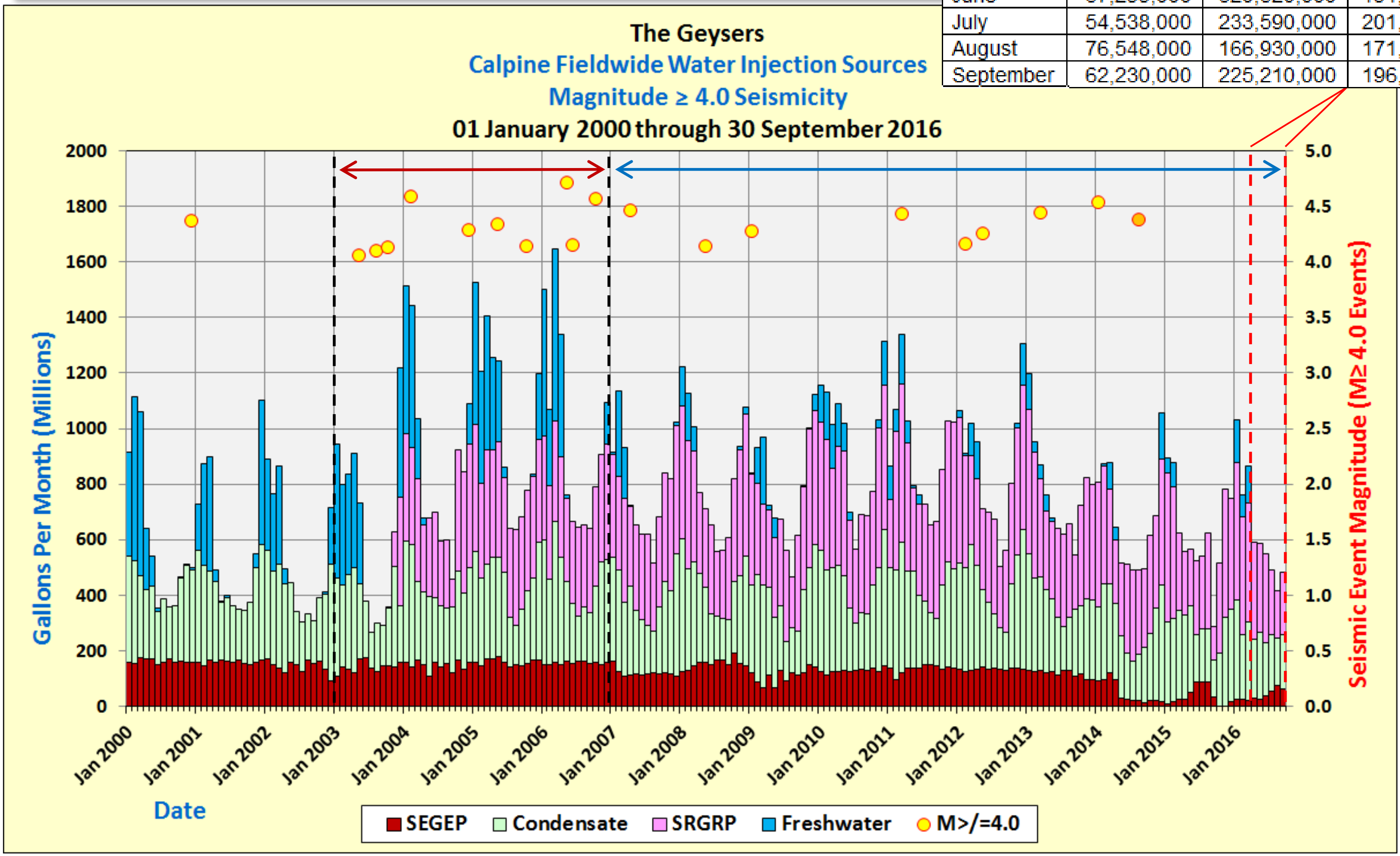
Field-wide Water Injection Sources and Magnitude ≥ 4.0 Seismicity
Monthly Values from 01 January 2000 to 30 September 2016

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

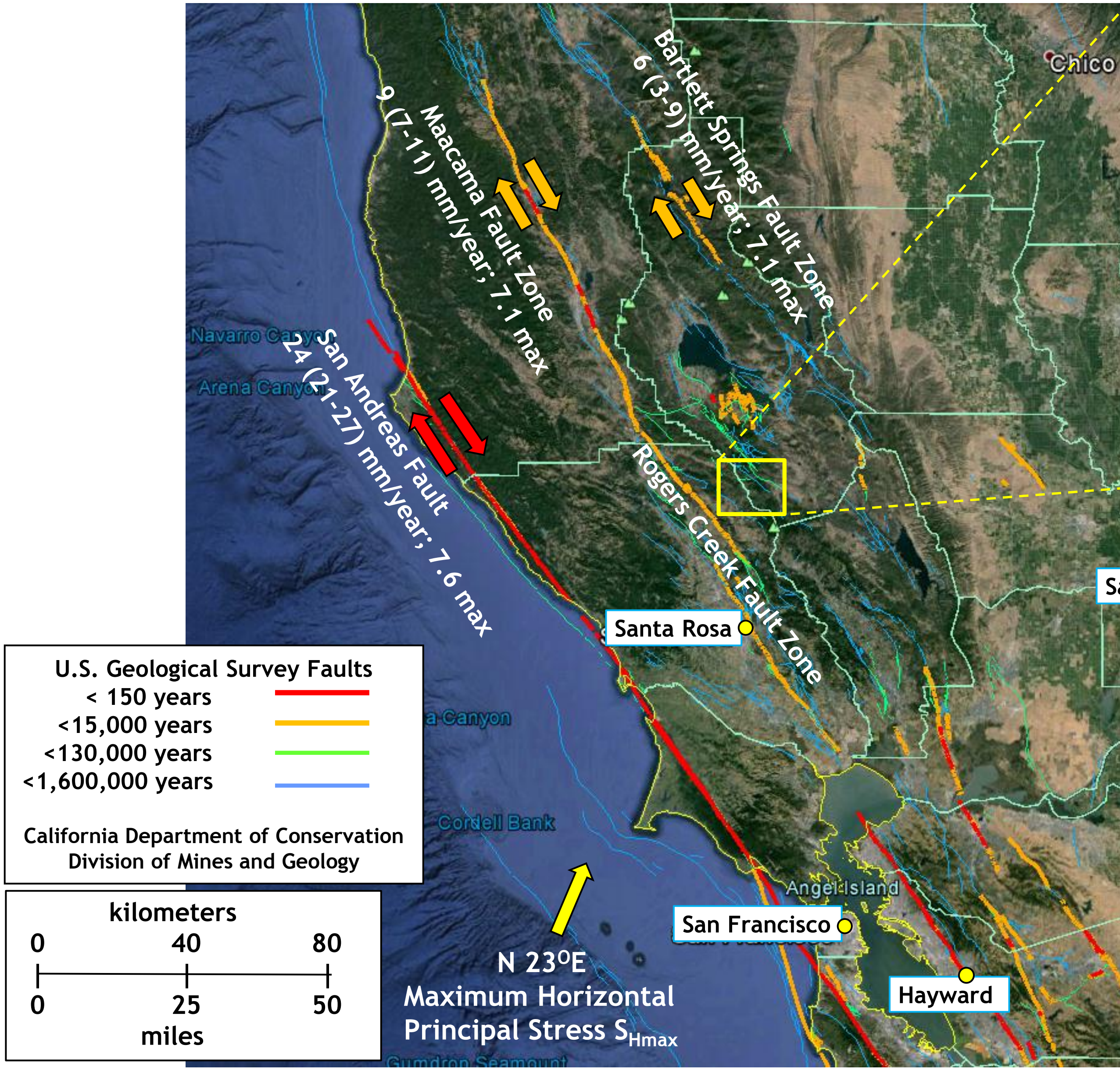
Time Period	M ≥ 4.0 Seismic Events	
January 2003 through December 2006	2.50 events per year	10.0 / 4.0
January 2007 through September 2016	0.92 events per year	9.0 / 9.75

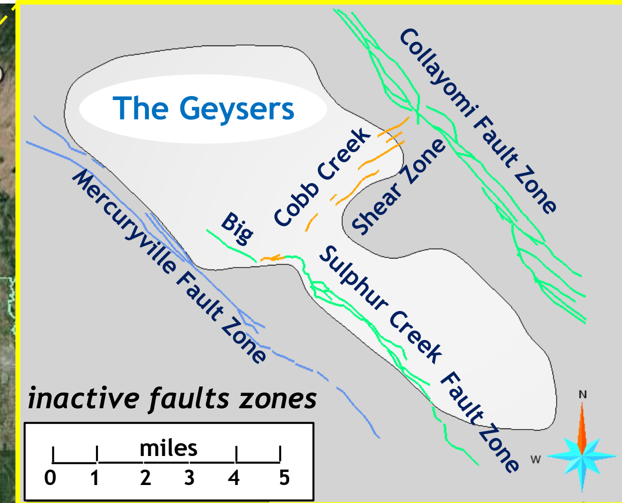
Water Supply for Reporting Period (Six Months)

Water Injection Sources (Gallons)				
Month	SEGEP	SRGRP	Condensate	Fresh Water
April	29,415,000	348,300,000	212,602,303	-
May	24,804,000	317,540,000	243,046,445	-
June	37,299,000	320,520,000	191,662,284	-
July	54,538,000	233,590,000	201,888,001	-
August	76,548,000	166,930,000	171,048,629	-
September	62,230,000	225,210,000	196,066,291	-



Regional Geology and Limitations on Seismic Event Magnitude





Seismic event magnitude depends on:

- fault area
- rock rigidity
- slip rate

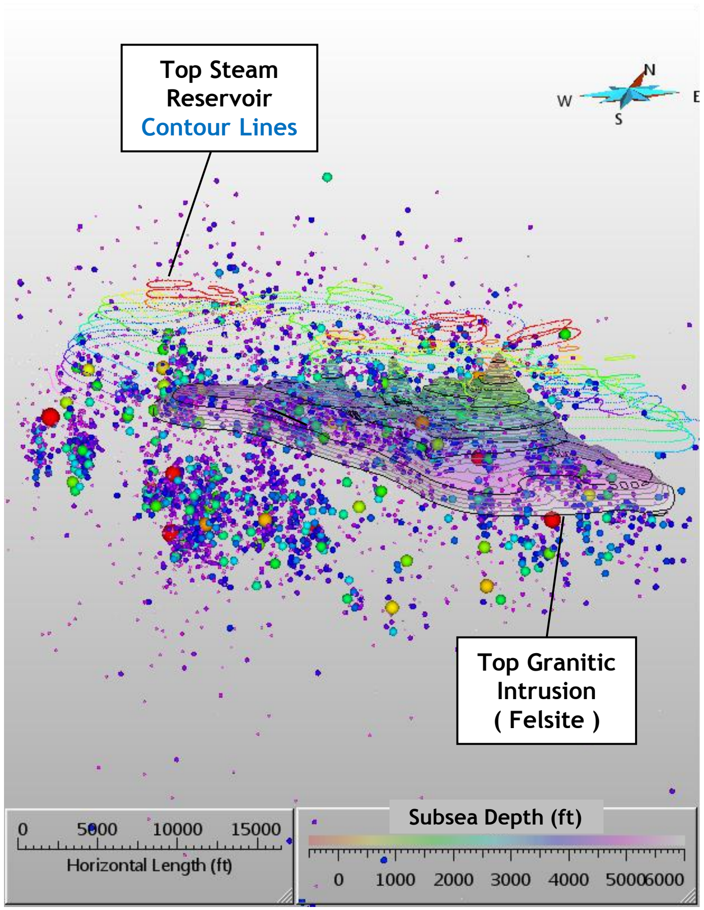
Within The Geysers, mapped faults are inactive and restricted in area, limiting the maximum possible seismic event magnitude and duration.

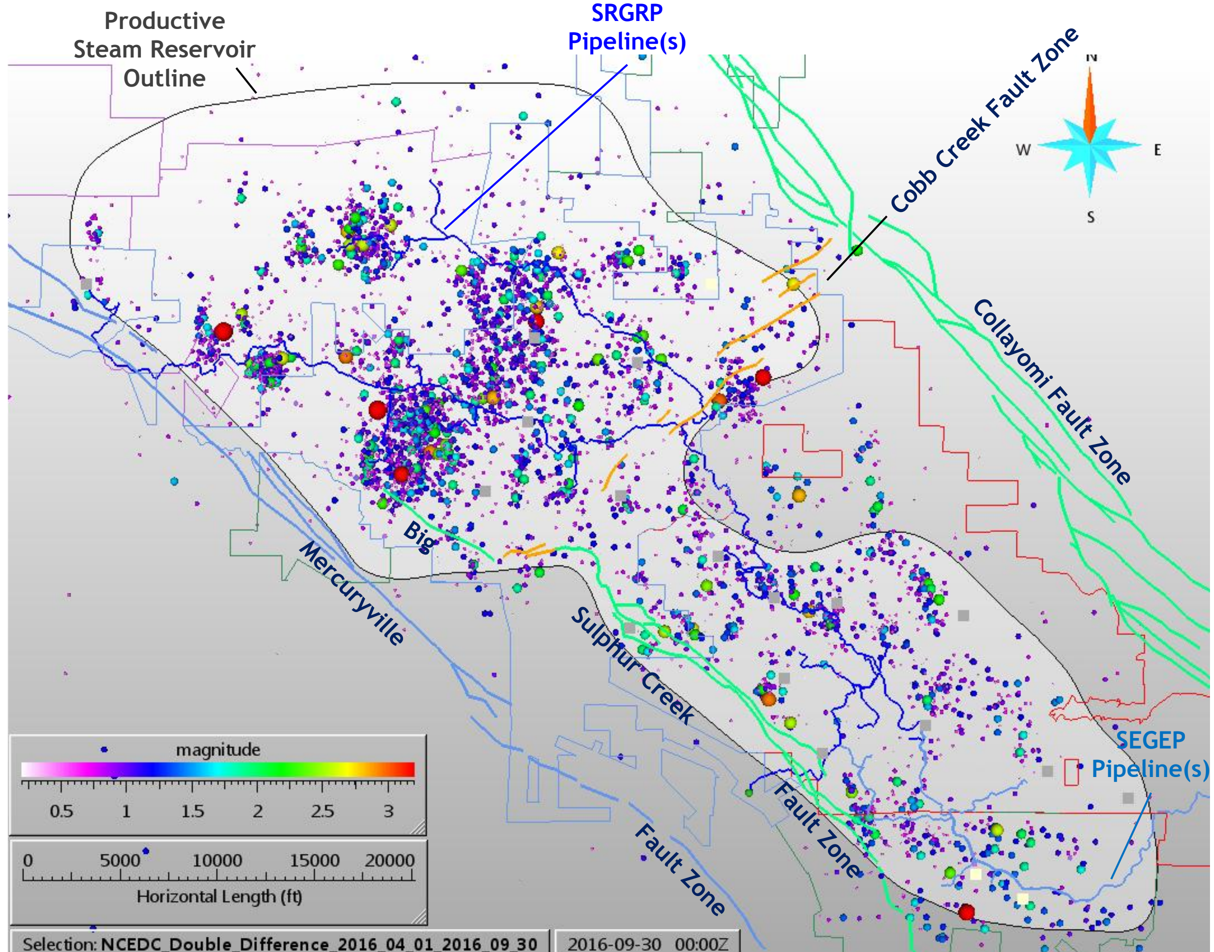
High heat content also limits the depth of faulting and fracturing at The Geysers.

Rocks deeper than the brittle/ductile transition depth behave ***plastically***

Field-wide Seismicity Analysis

01 April 2016 to 30 September 2016 - Bi-weekly Animation





U.S. Geological Survey Faults	
< 150 years	red
<15,000 years	orange
<130,000 years	green
<1,600,000 years	blue

Date

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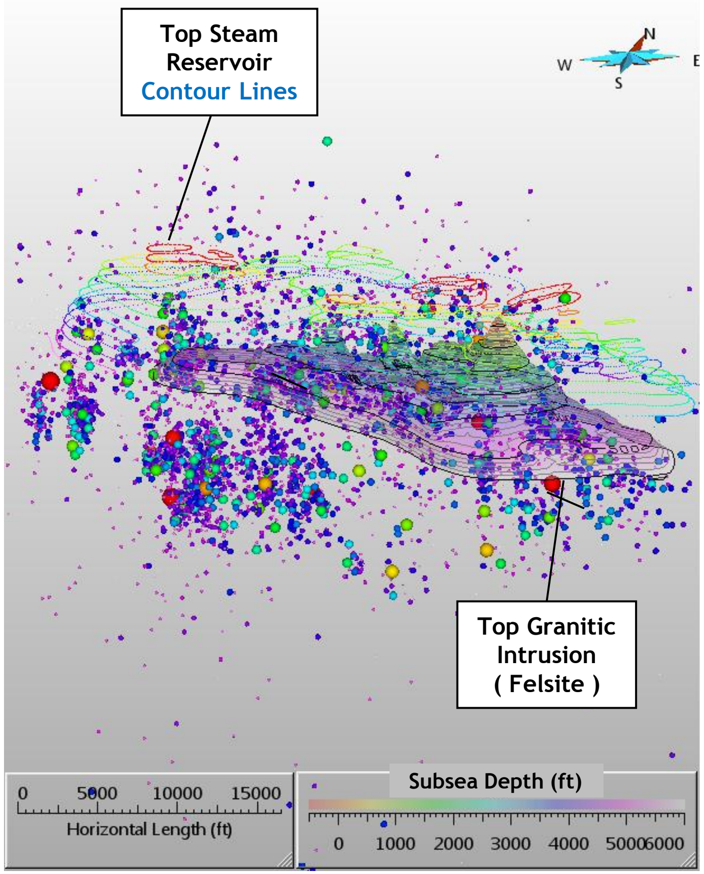
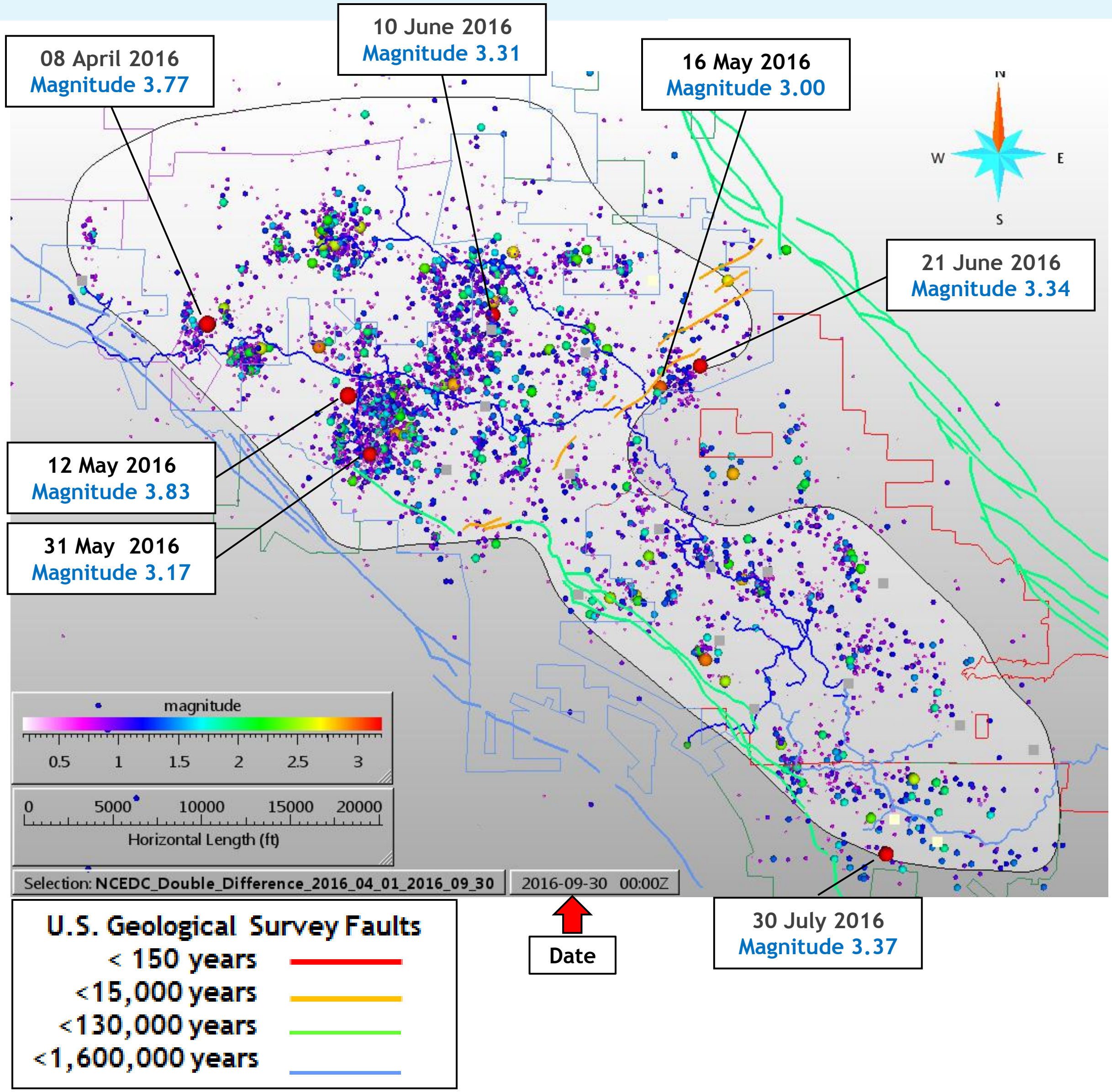
Fieldwide Seismicity Analysis
01 April 2016 to 30 September 2016 - Bi-weekly Animation





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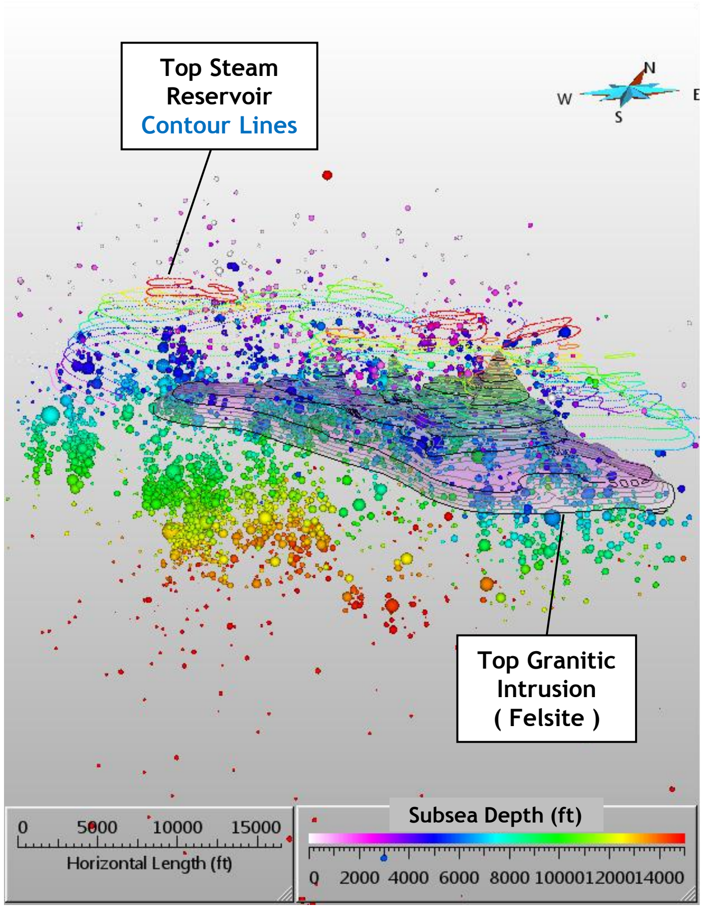
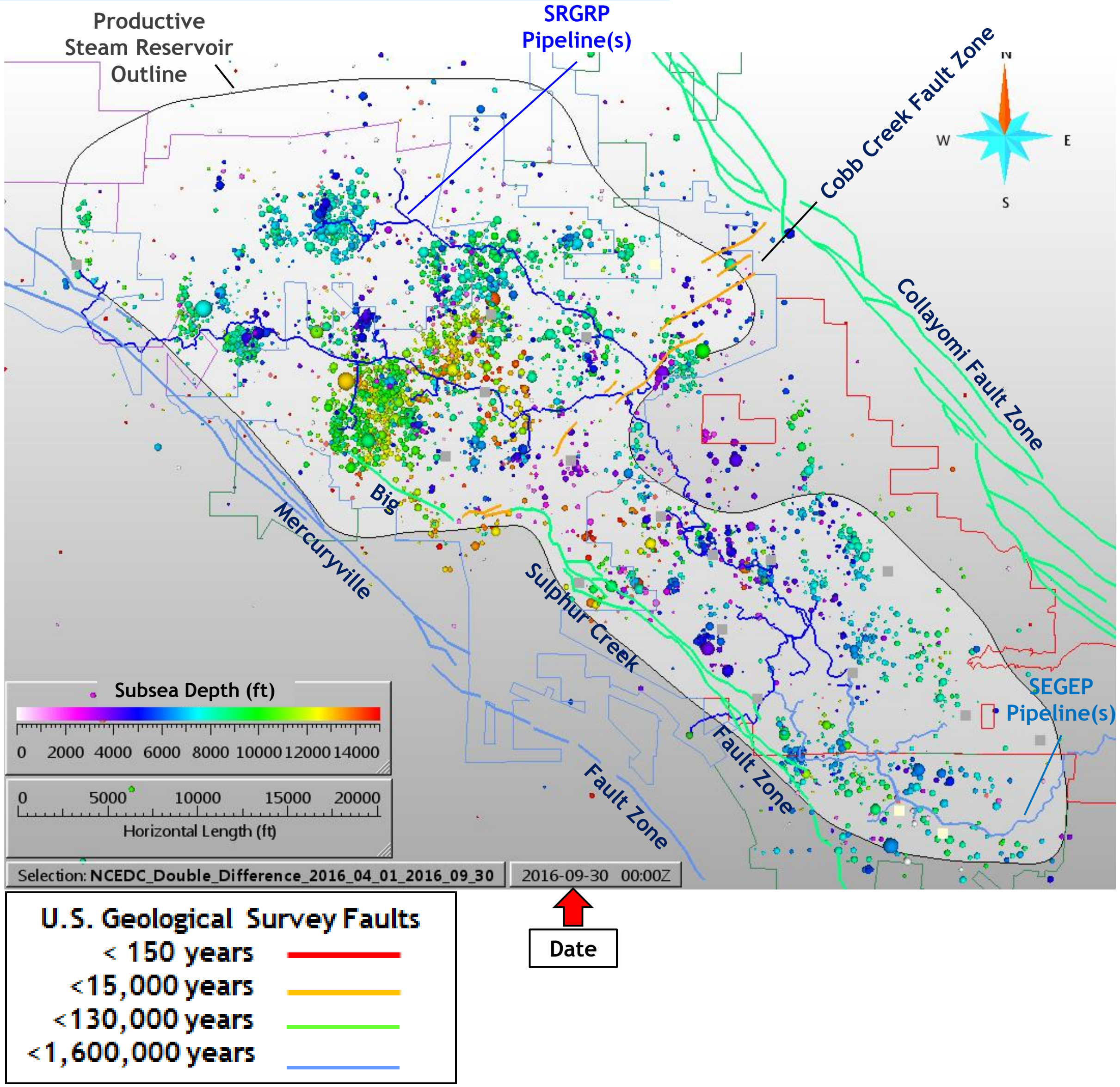
Fieldwide Seismicity Analysis
01 April 2016 to 30 September 2016 - Bi-weekly Animation





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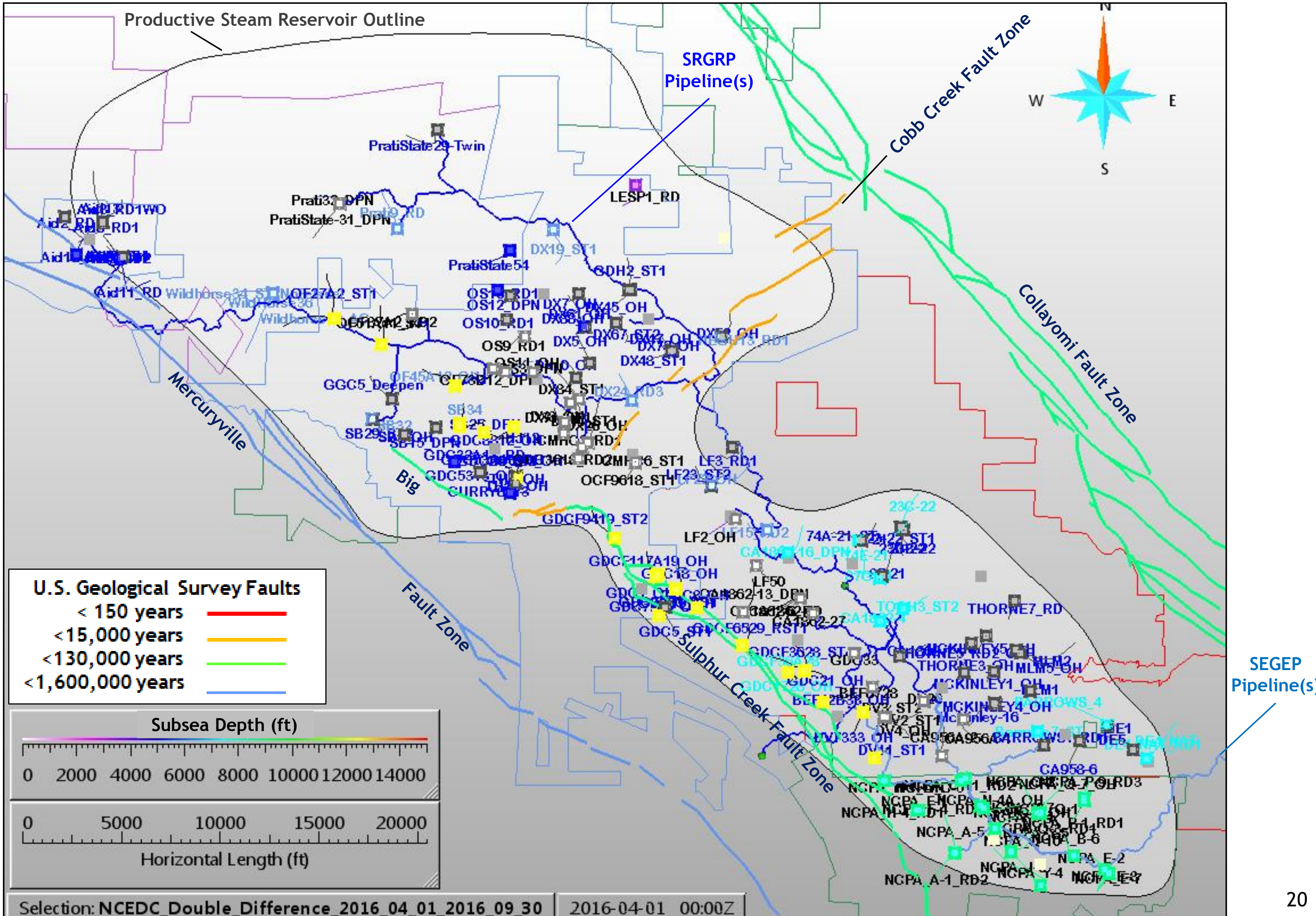
Fieldwide Synchronized Water Injection and Seismicity Analysis

01 April 2016 to 30 September 2016



Fieldwide Synchronized Water Injection and Seismicity Analysis
01 April 2016 to 30 September 2016

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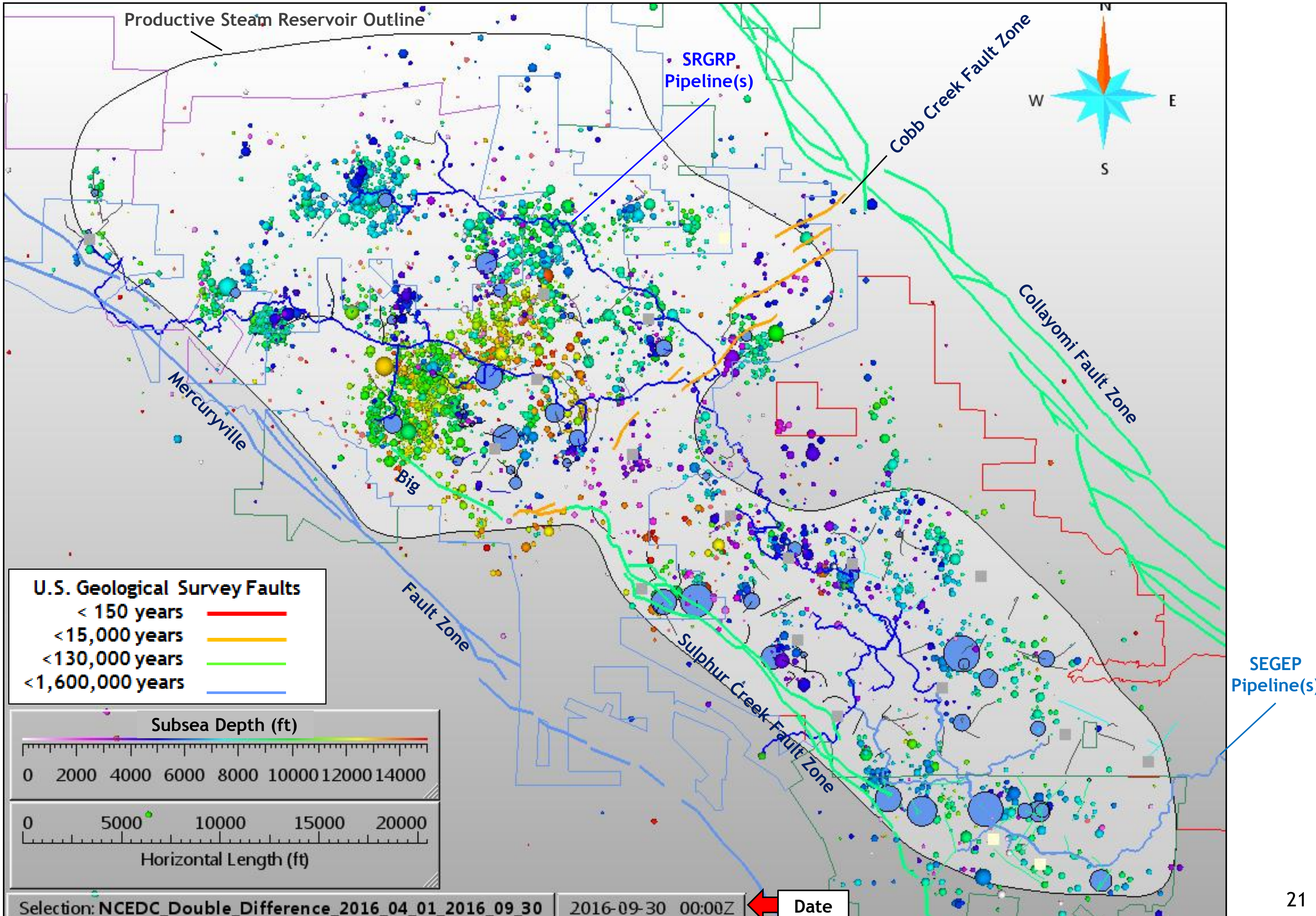

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1984 through 2016 Time-Synchronized Animation
Monthly Water Injection and Induced Seismicity Hypocenters

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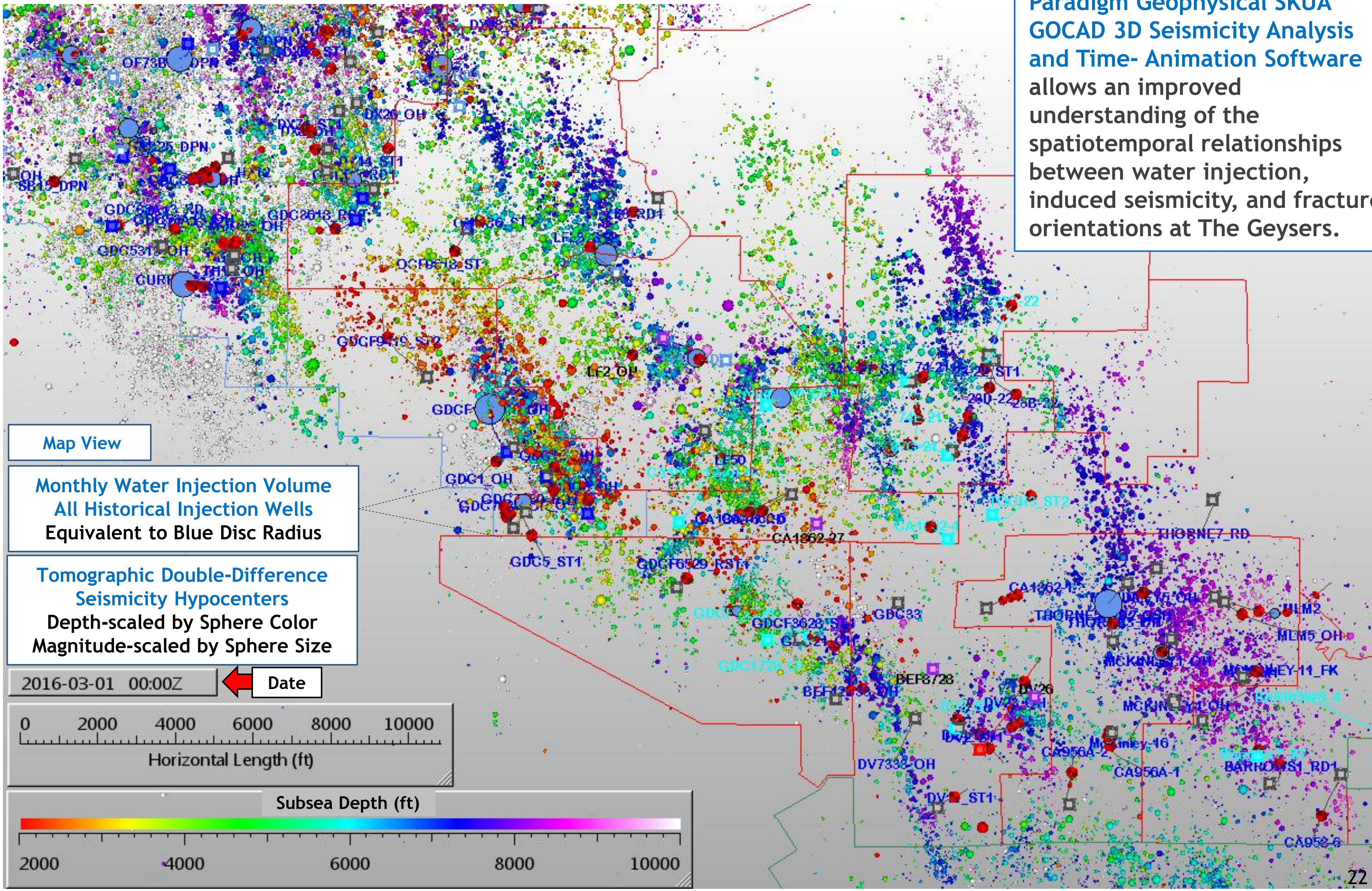
Paradigm Geophysical SKUA GOCAD 3D Seismicity Analysis and Time- Animation Software allows an improved understanding of the spatiotemporal relationships between water injection, induced seismicity, and fracture orientations at The Geysers.



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1984 through 2016 Time-Synchronized Animation
Monthly Water Injection and Induced Seismicity Hypocenters

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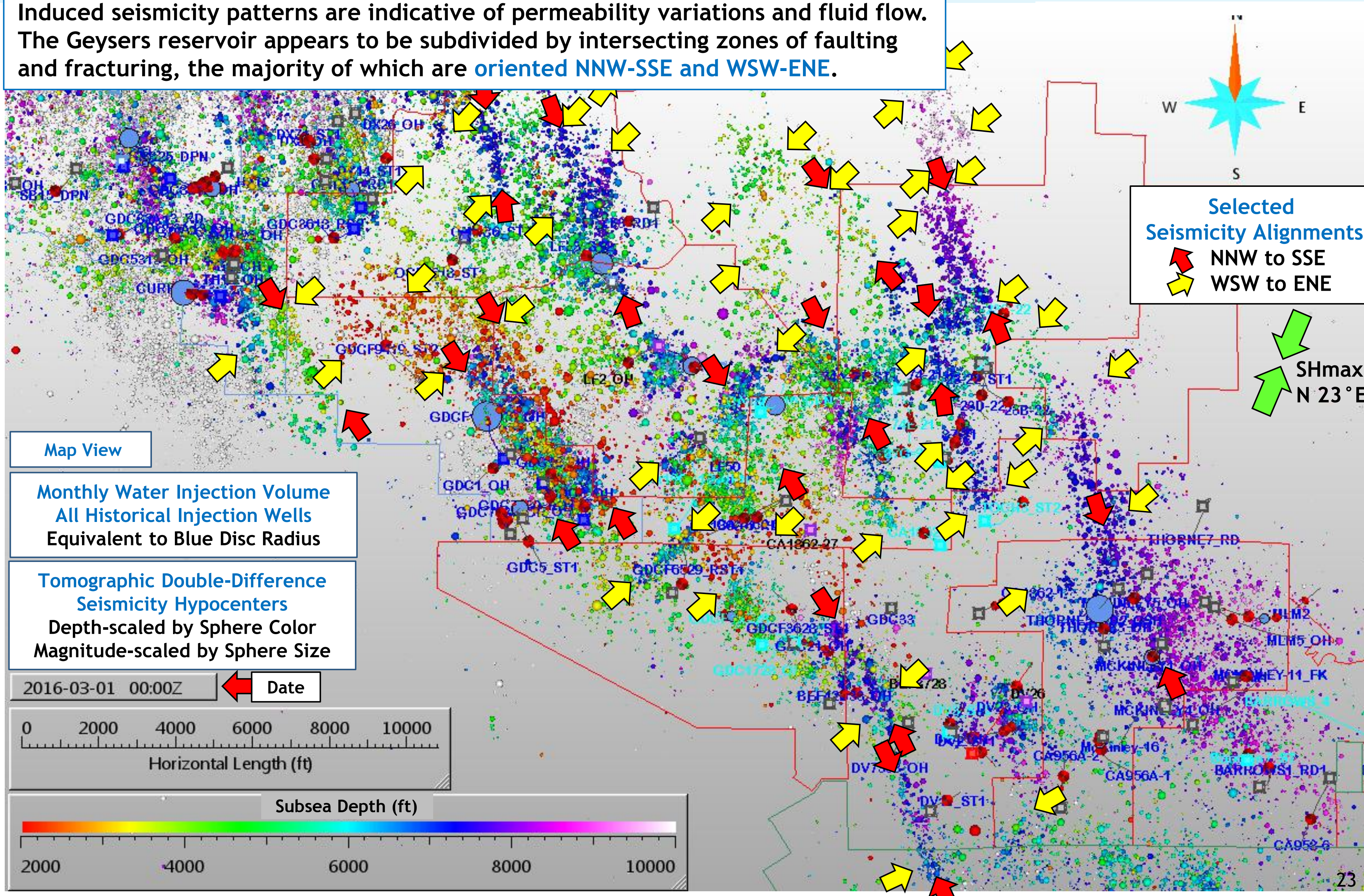
Induced seismicity patterns are indicative of permeability variations and fluid flow. The Geysers reservoir appears to be subdivided by intersecting zones of faulting and fracturing, the majority of which are oriented NNW-SSE and WSW-ENE.



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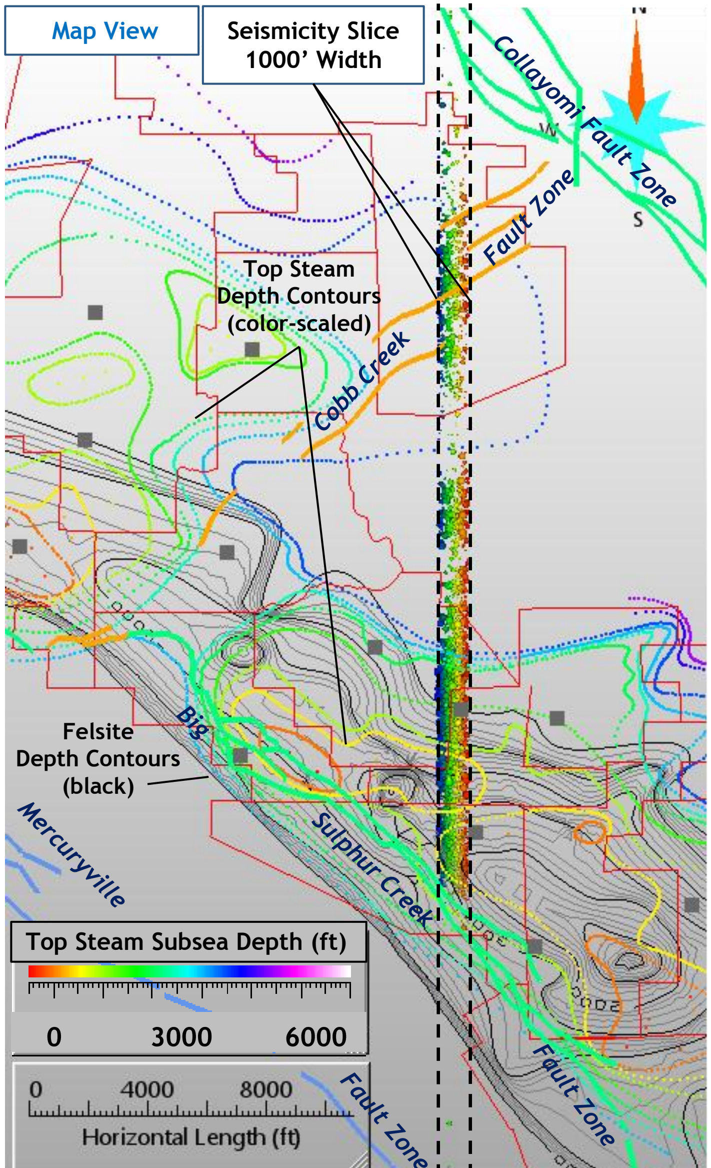
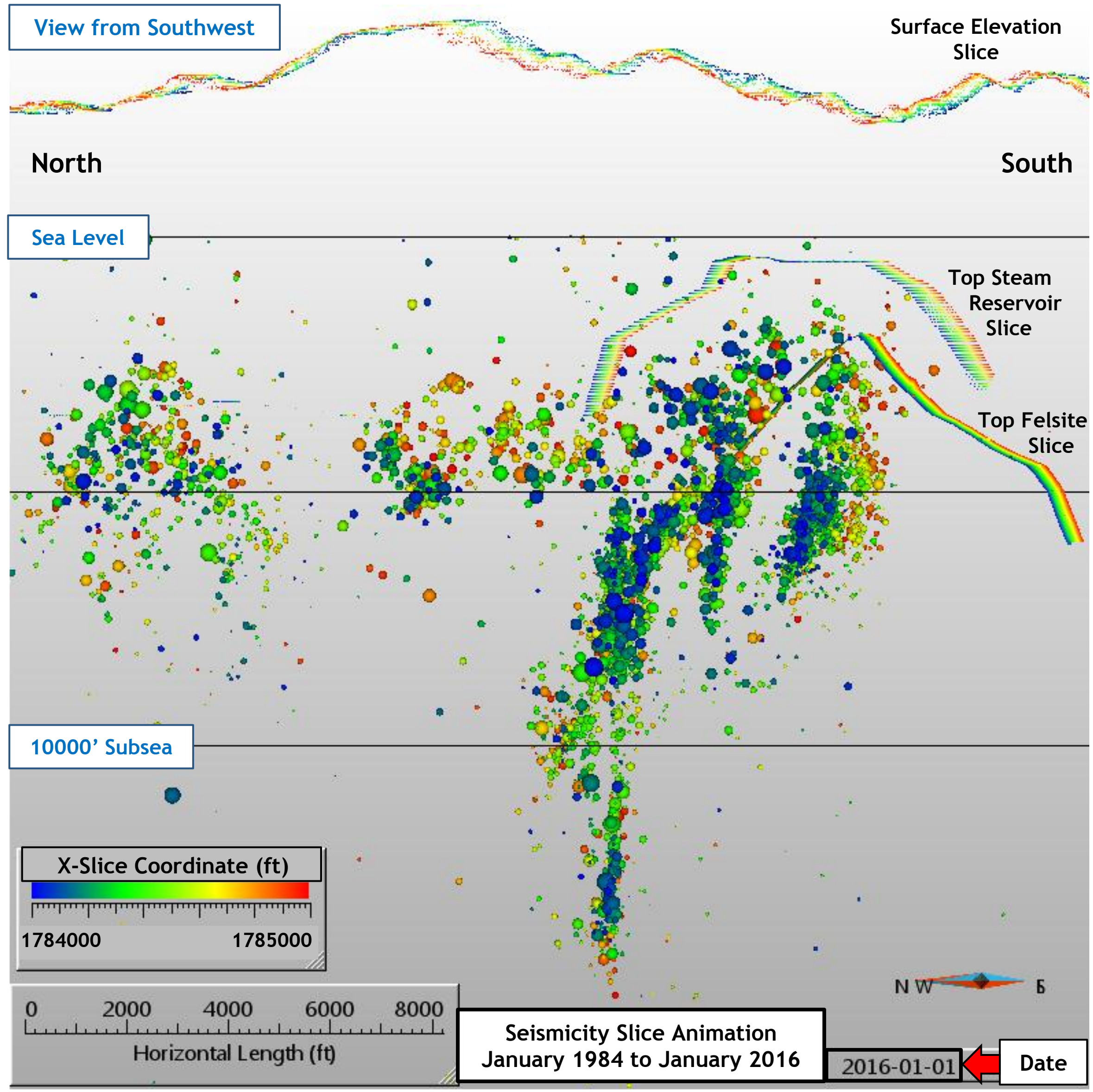
Seismicity Slice Analysis and Fracture Zone Interpretation





Vertical exaggeration of 1.25 x

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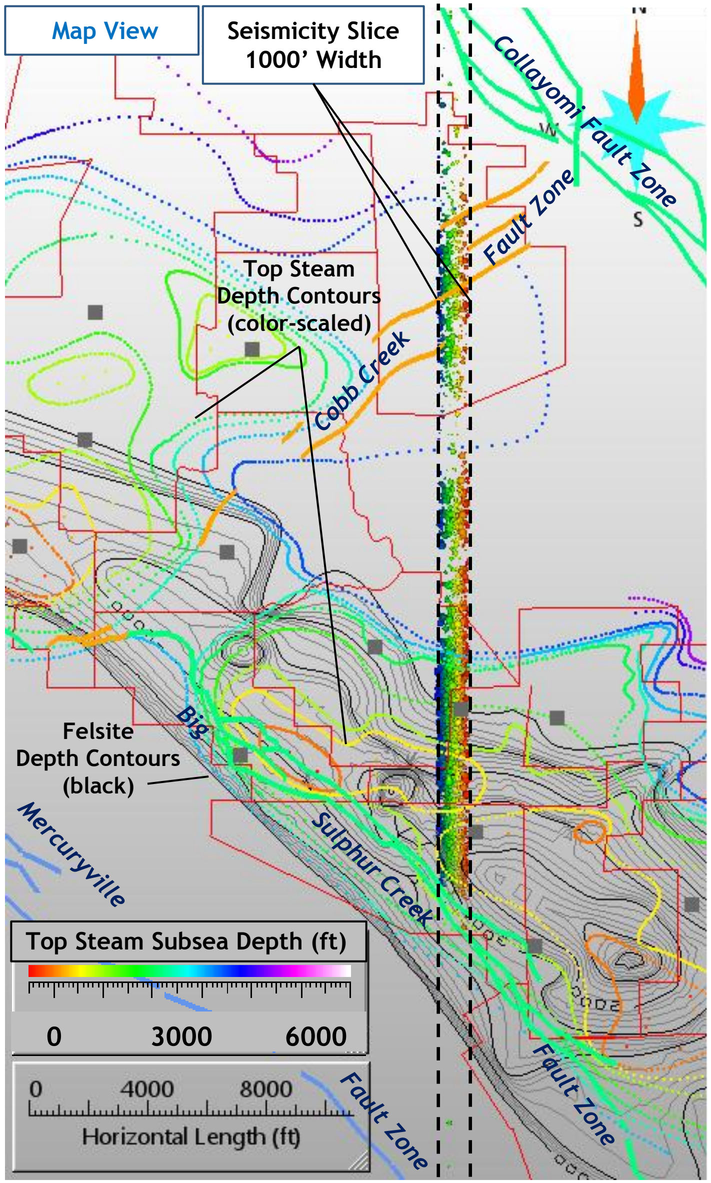
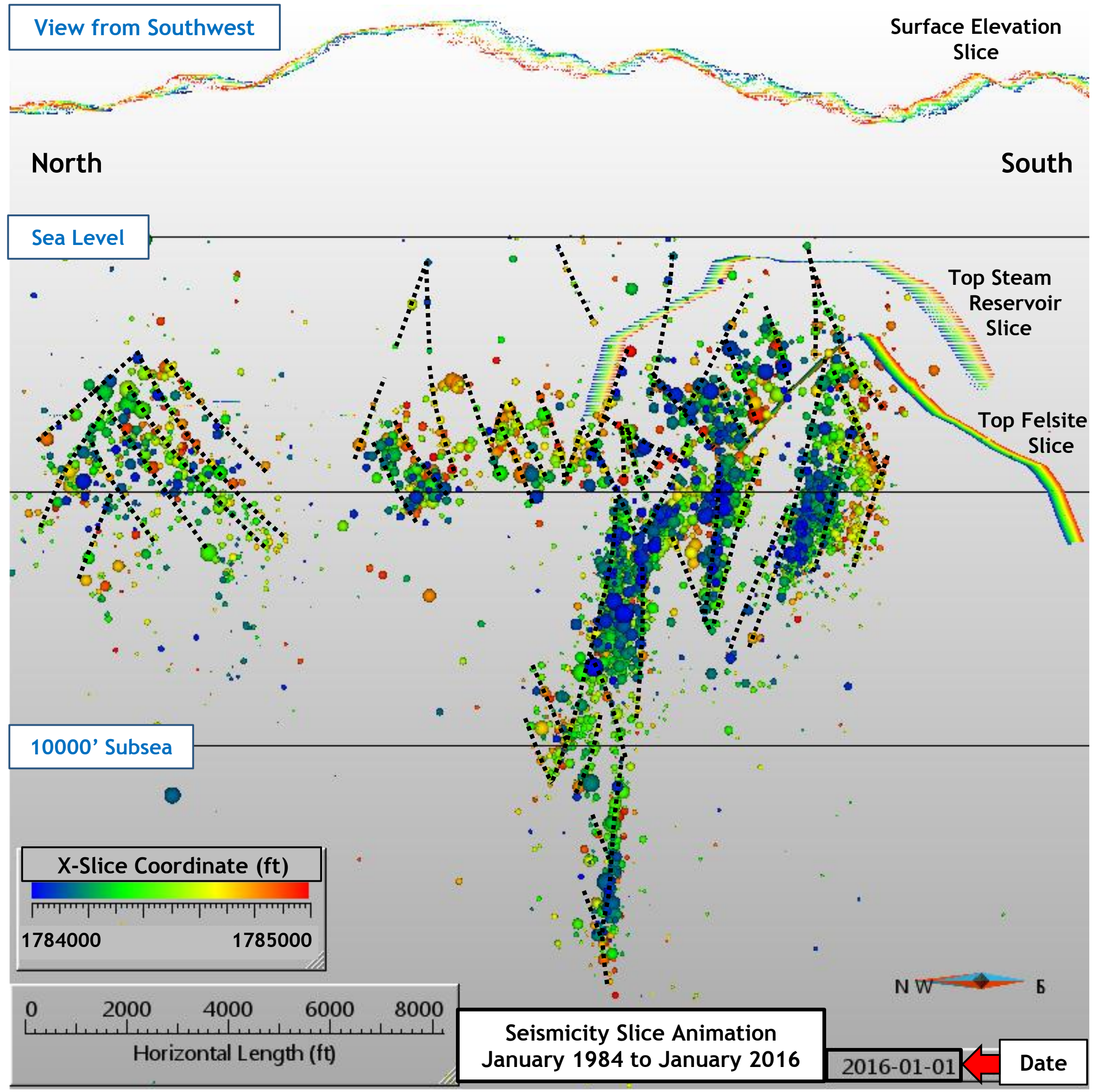
Seismicity Slice Analysis and Fracture Zone Interpretation





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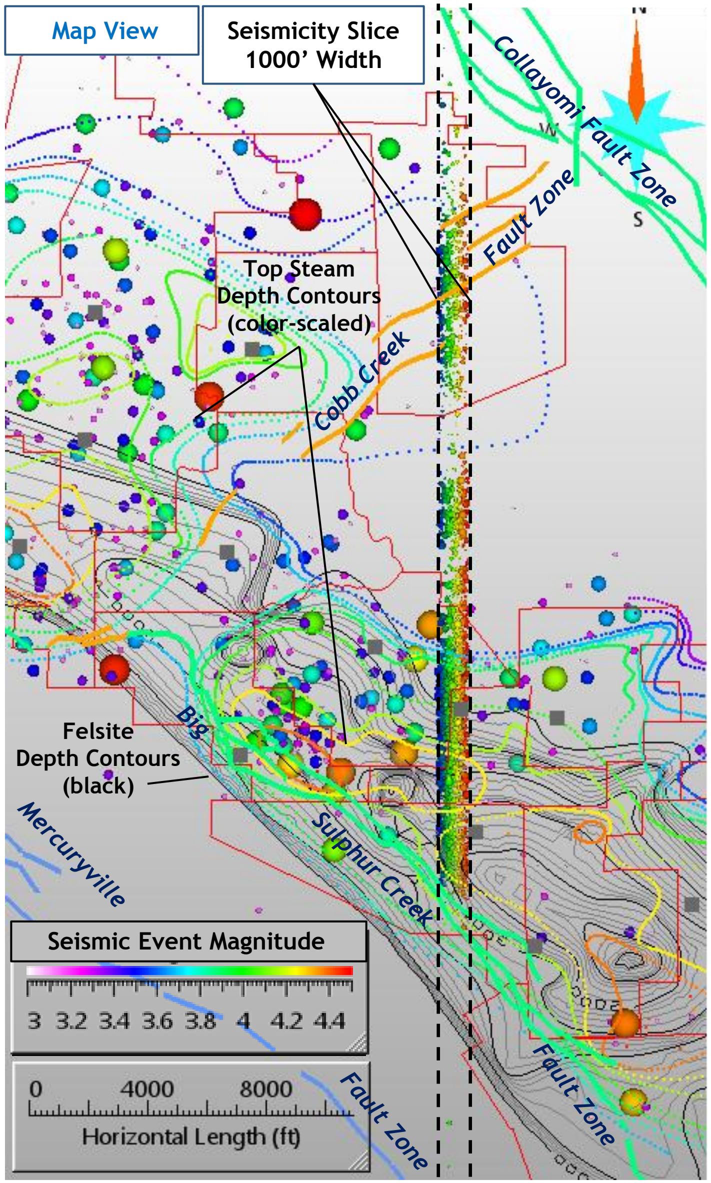
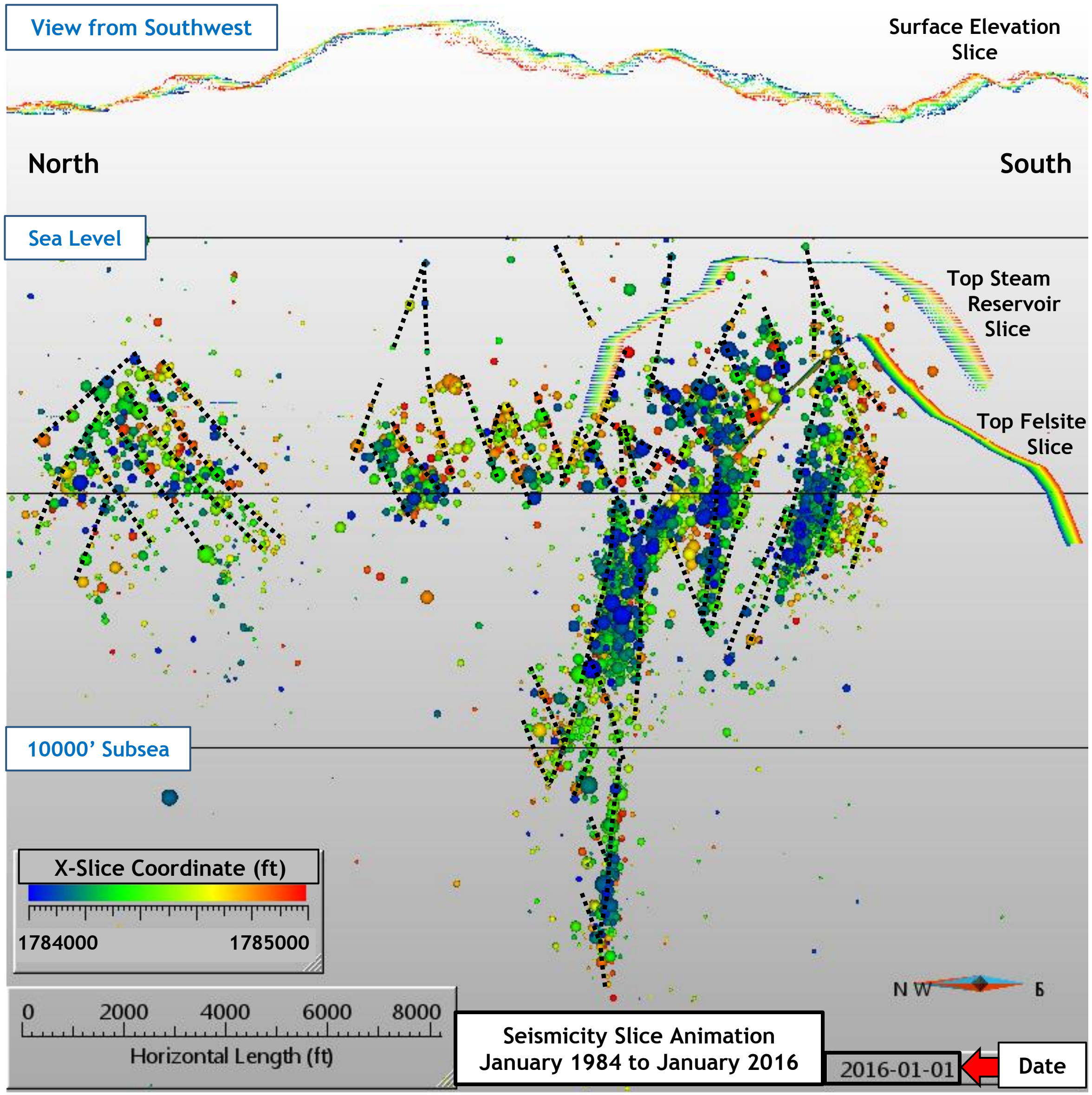
Seismicity Slice Analysis and Fracture Zone Interpretation





Vertical exaggeration of 1.25 x

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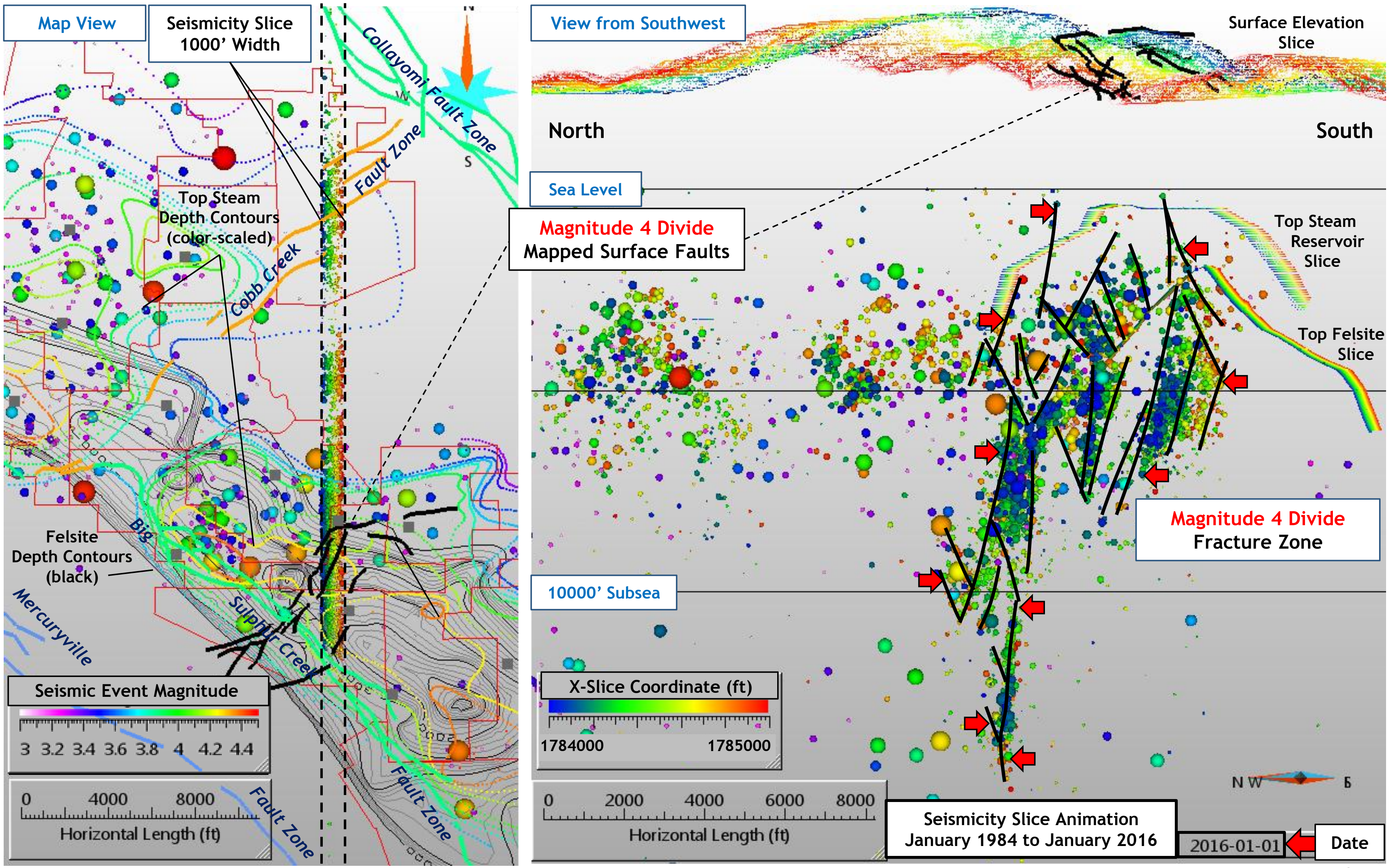
Seismicity Slice Analysis and Fracture Zone Interpretation
"Magnitude 4 Divide"

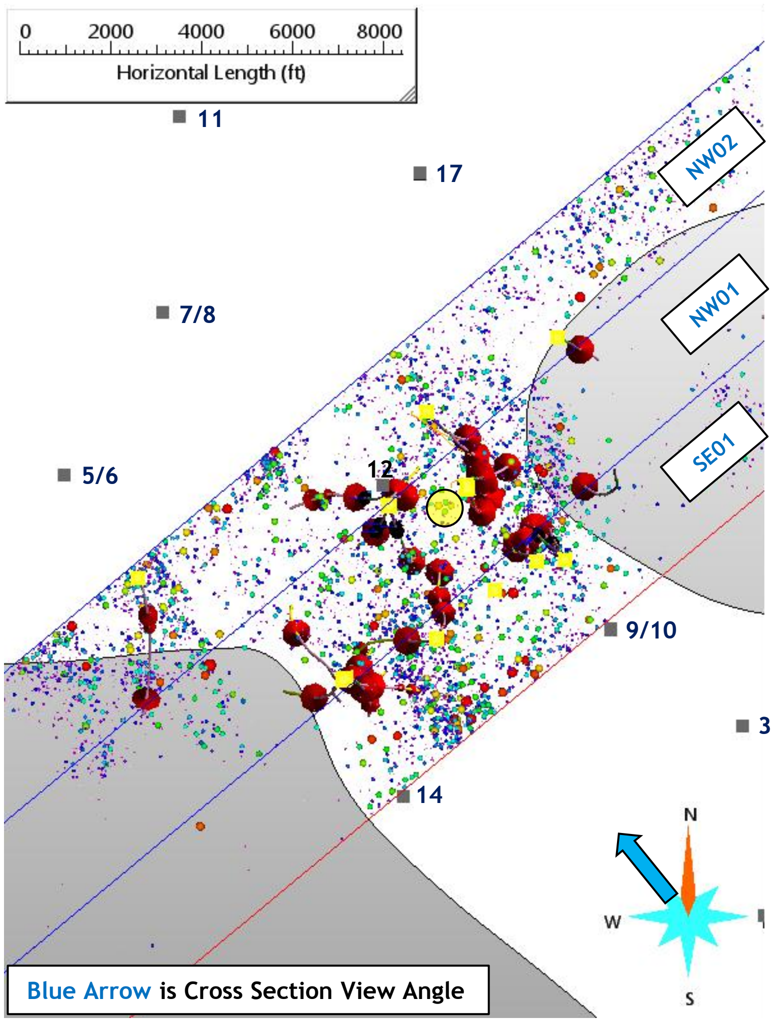
CALPINE NYSE CPN



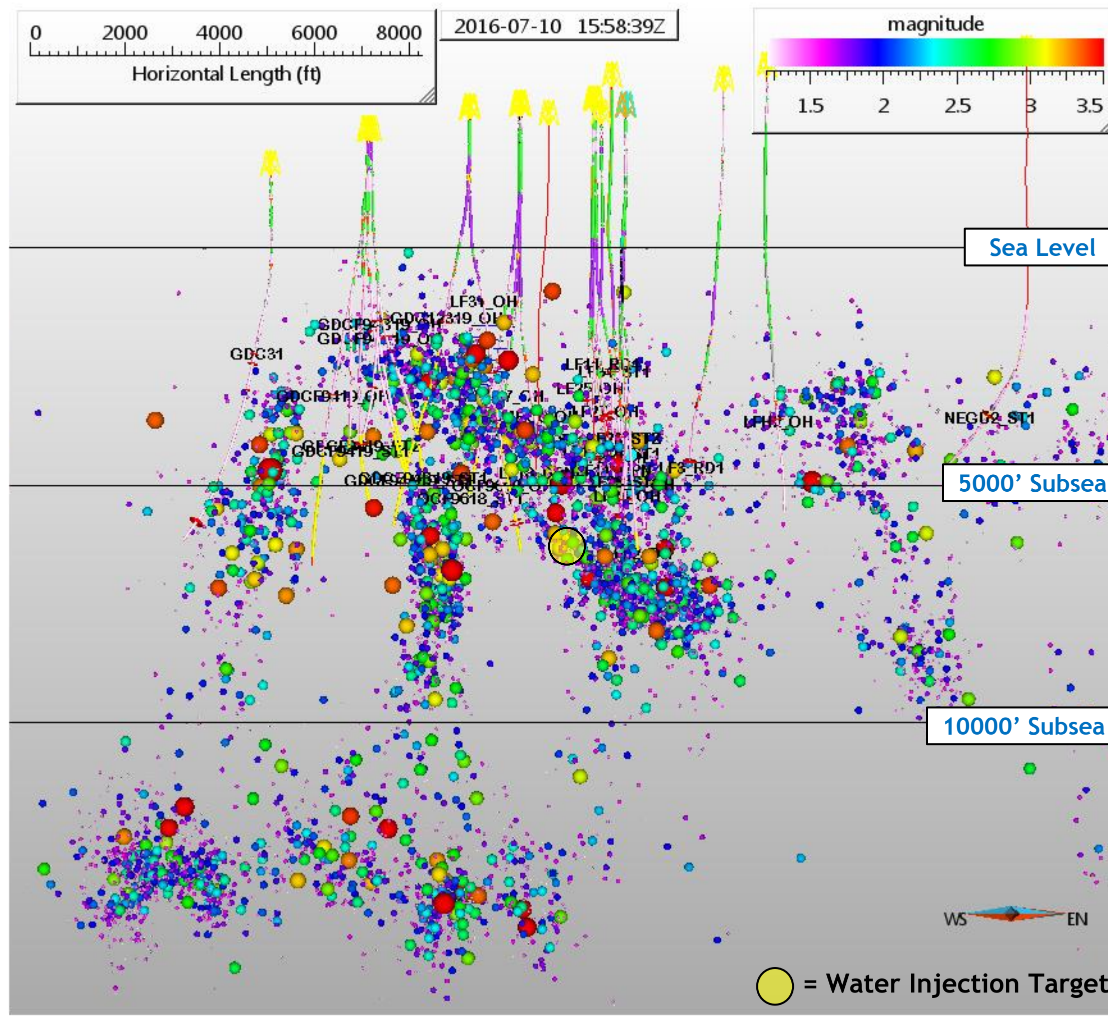
Vertical exaggeration of 1.25 x

Seismic Monitoring Advisory Committee Meeting
3D Analysis of Injection Well Options
Induced Seismicity Relationships

Map View



View From Southeast (Along Azimuth 320°)



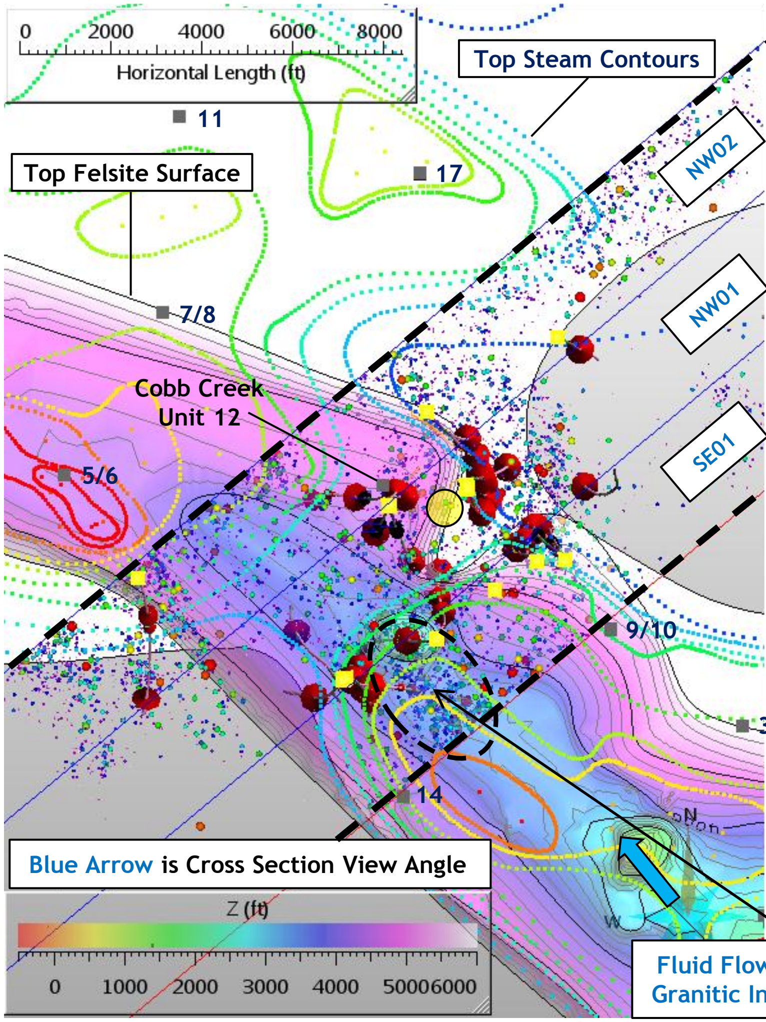
January 1984 through July 2016 seismic events* within slices SE01, NW01 and NW02 are shown in both views

The wells within slice NW01 are shown in both views
(a portion of the well is within corridor)

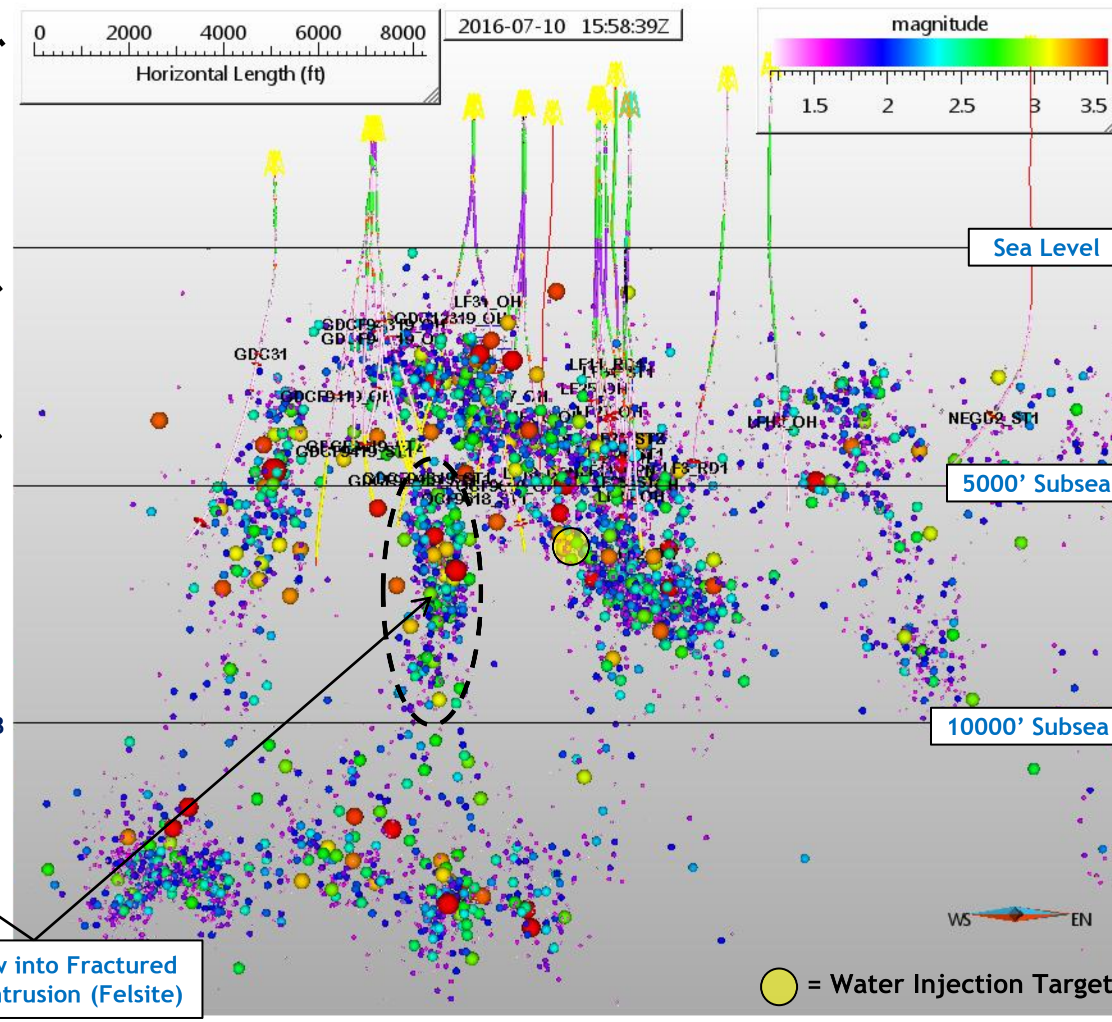
** USGS Tomographic Double Difference Refined Hypocenters*

Seismic Monitoring Advisory Committee Meeting
3D Analysis of Injection Well Options
Induced Seismicity Relationships

Map View



View From Southeast (Along Azimuth 320°)



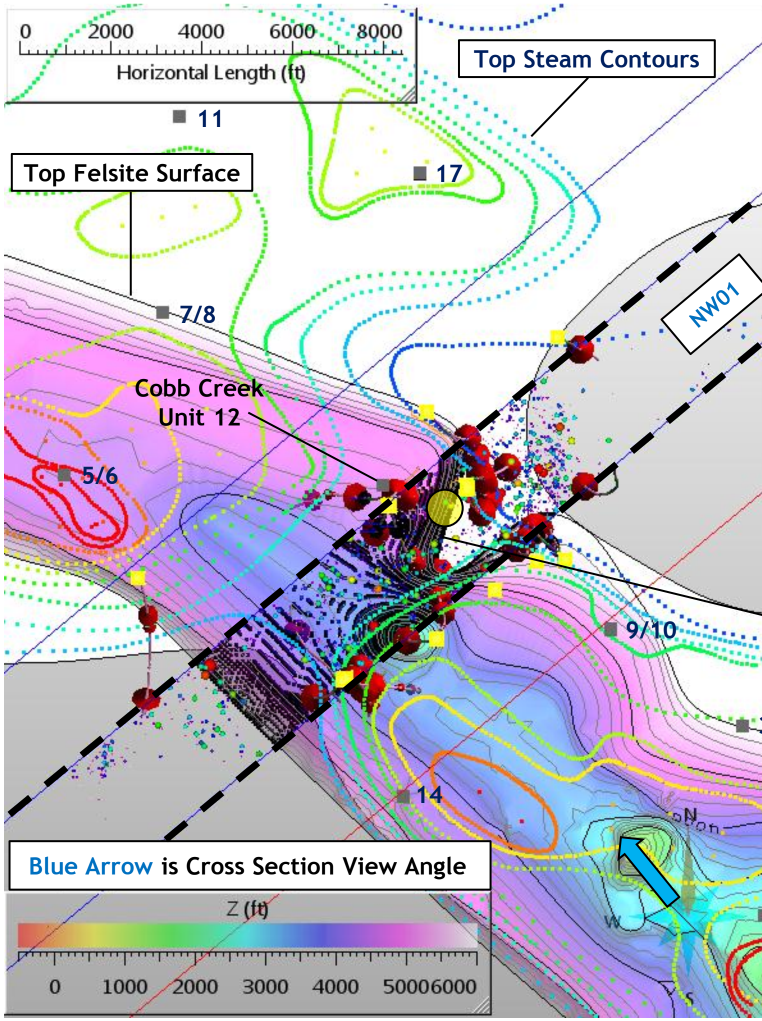
January 1984 through July 2016 seismic events* within slices SE01, NW01 and NW02 are shown in both views

The wells within slice NW01 are shown in both views
(a portion of the well is within corridor)

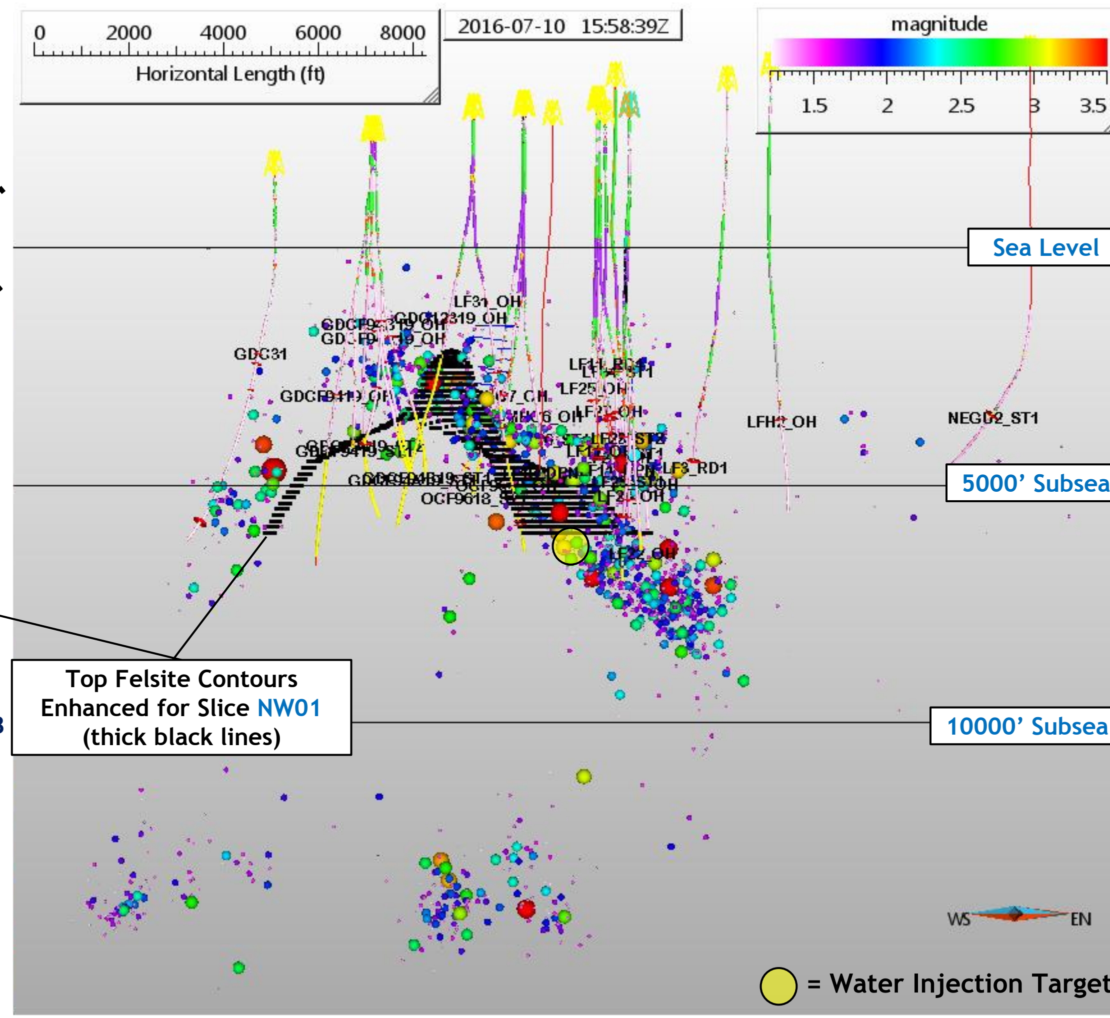
** USGS Tomographic Double Difference Refined Hypocenters*

3D Analysis of Injection Well Options
Induced Seismicity Relationships

Map View



View From Southeast (Along Azimuth 320°)



Top Felsite Contours Enhanced for Slice NW01 (thick black lines)

January 1984 through July 2016 seismic events* within polygon NW01 are shown in both views

The wells within polygon NW01 are shown in both views (a portion of the well is within corridor)

** USGS Tomographic Double Difference Refined Hypocenters*

Seismic Monitoring Advisory Committee Meeting

3D Analysis of Injection Well Options
Induced Seismicity Relationships

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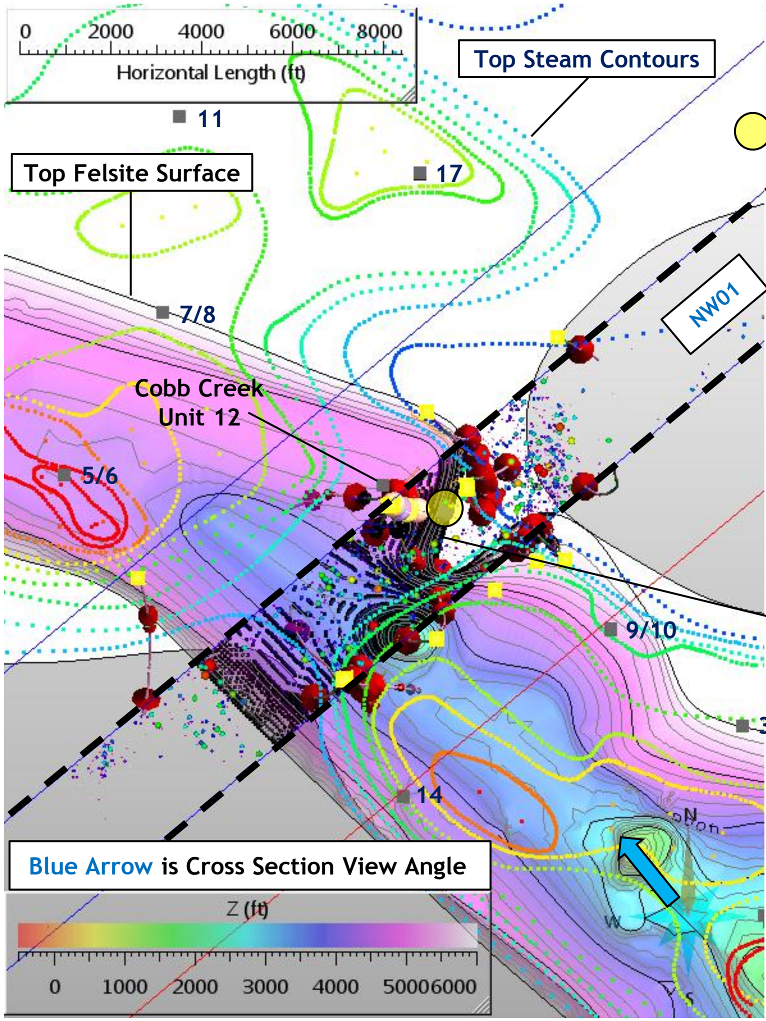
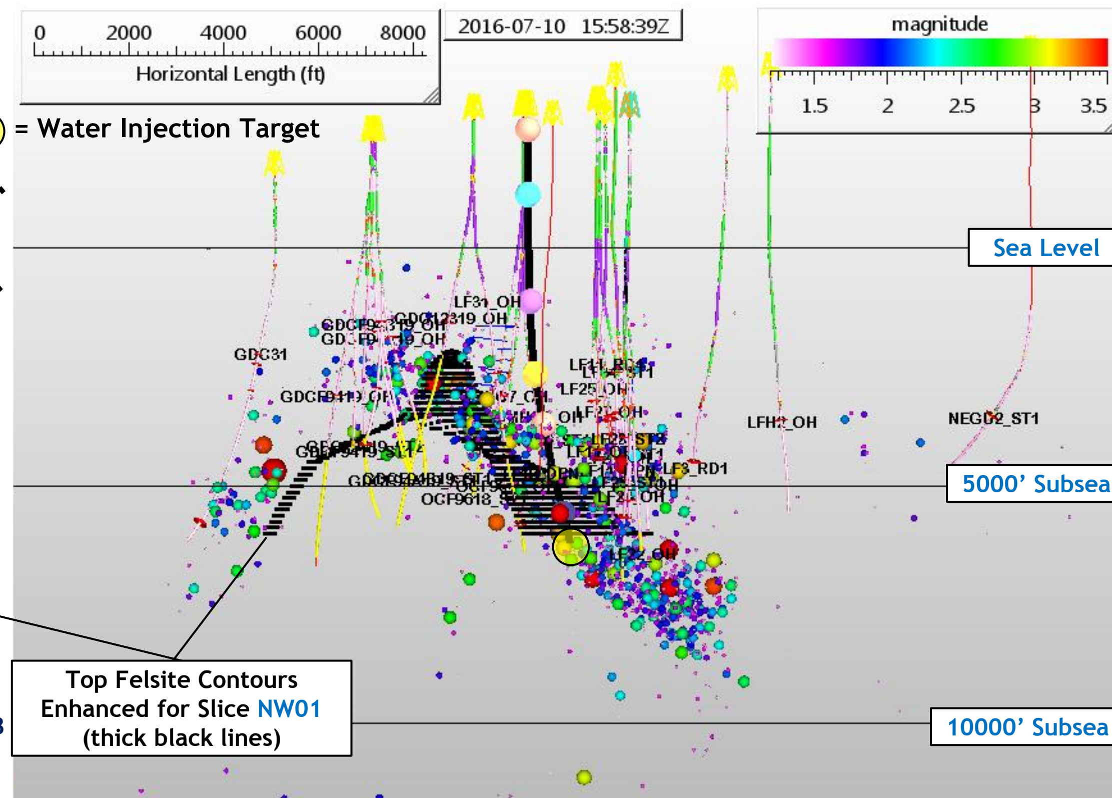
Map View



View From Southeast (Along Azimuth 320°)



1984-2016 seismic events within polygon NW01 are shown in both views

The wells within polygon NW01 are shown in both views (a portion of the well is within corridor)

Unit 12 Water Injection Target:

Induced seismicity animations suggest that fluid flow has primarily descended northeastward within the permeable Graywacke interval overlying less permeable Felsite.

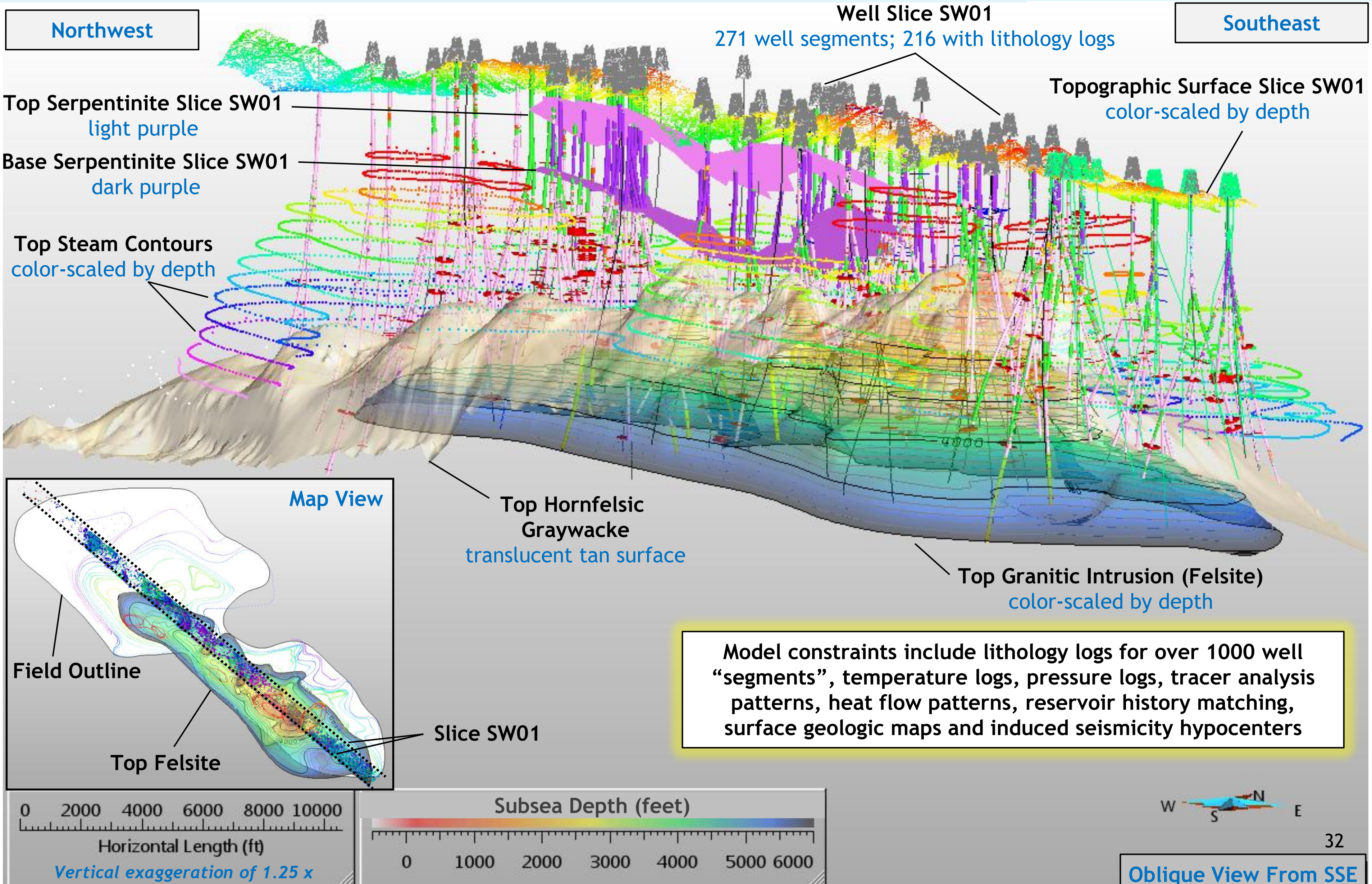
Propose a well track encountering a substantial portion of the permeable (brittle and fractured) Graywacke interval directly above the Felsite.

Fluid flow *does* penetrate Felsite fracture systems in other areas, including the Unit 14 area to the southwest.

Seismic Monitoring Advisory Committee Meeting

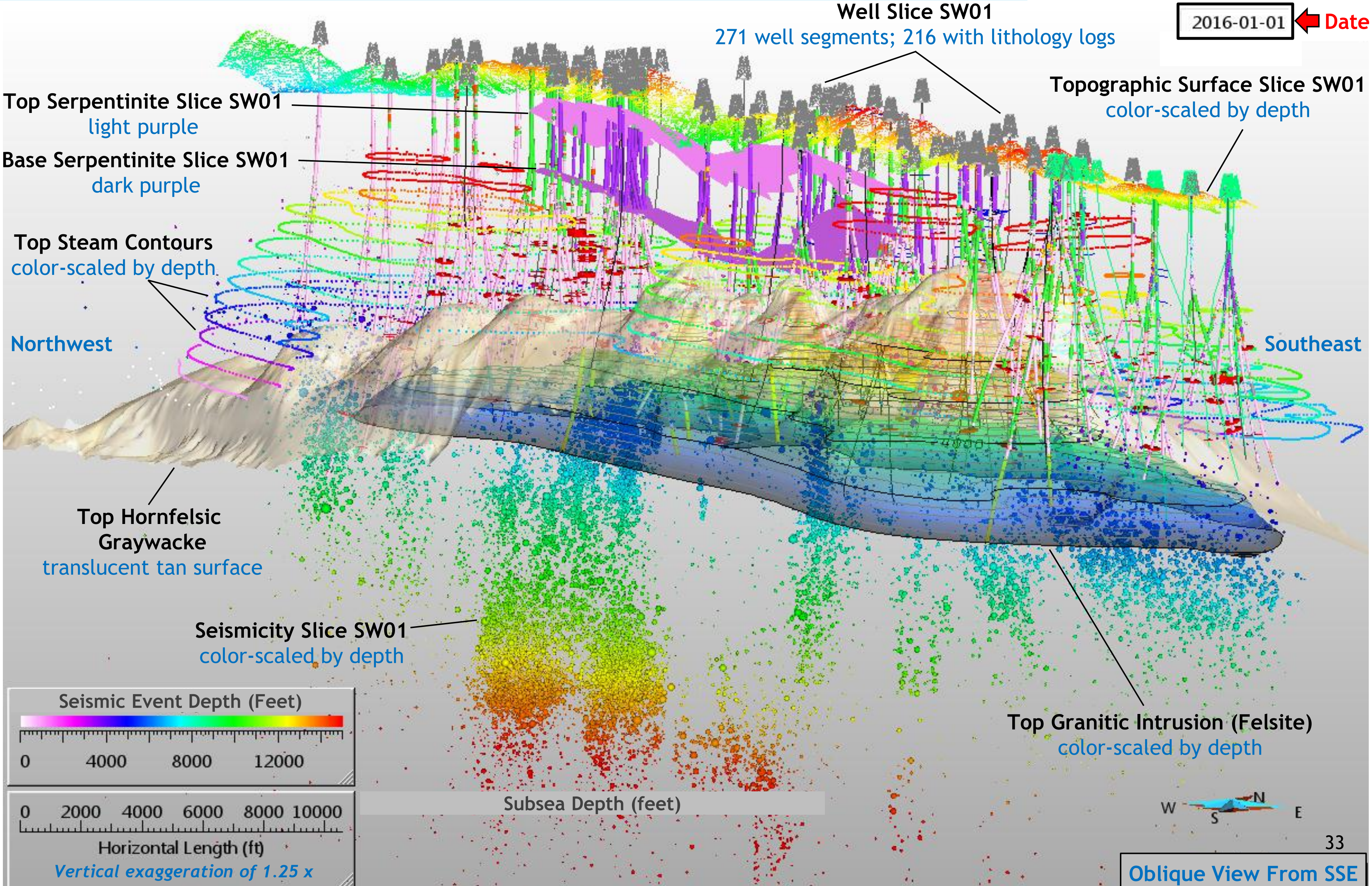
3D Structural Model Building with Paradigm Geophysical SKUA GOCAD Software

CALPINE NYSE CPN



Seismic Monitoring Advisory Committee Meeting

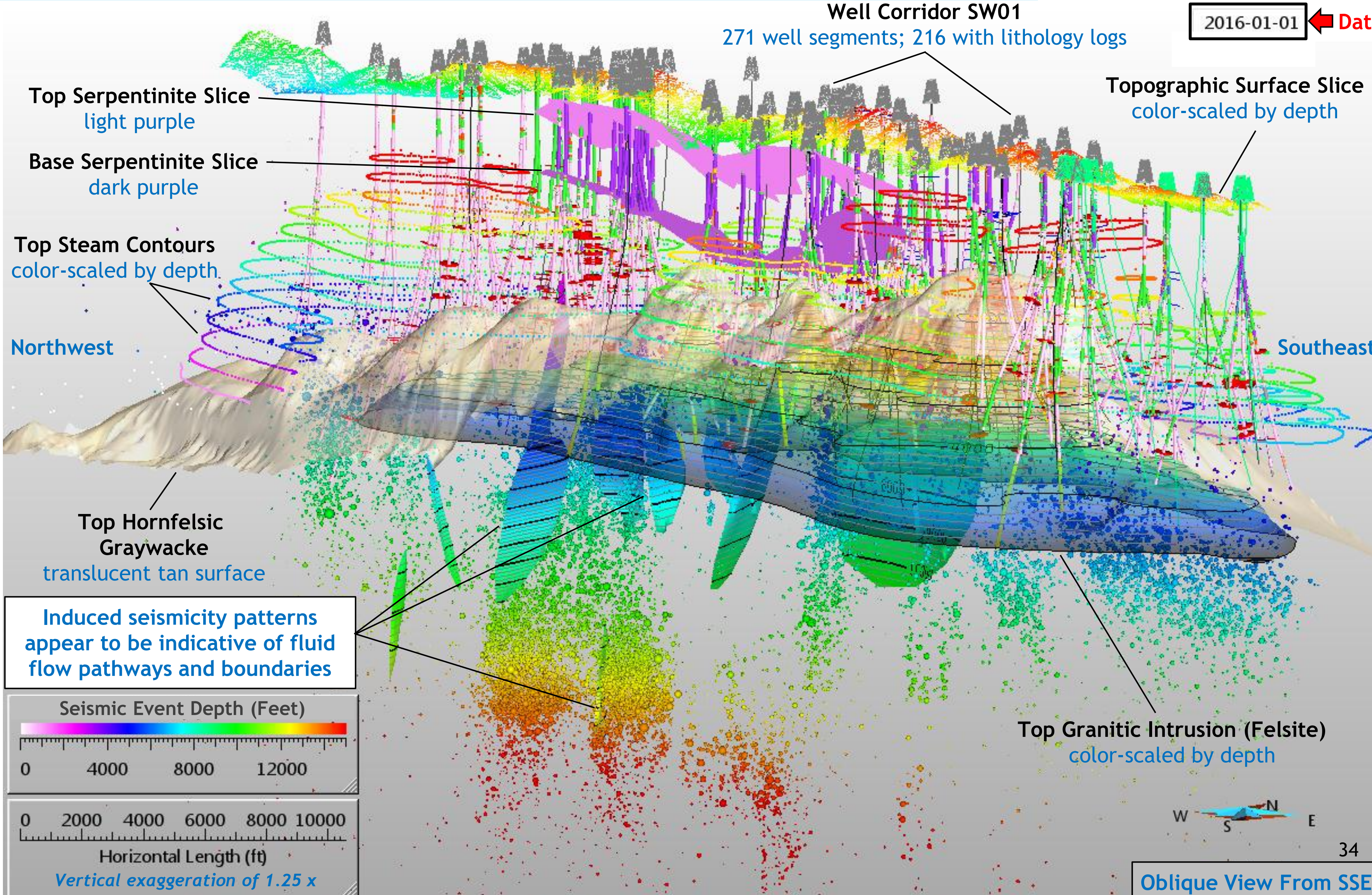
3D Structural Model Building with Paradigm Geophysical SKUA GOCAD Software
2003 to 2016 Induced Seismicity Animation; Slice SW01



Seismic Monitoring Advisory Committee Meeting

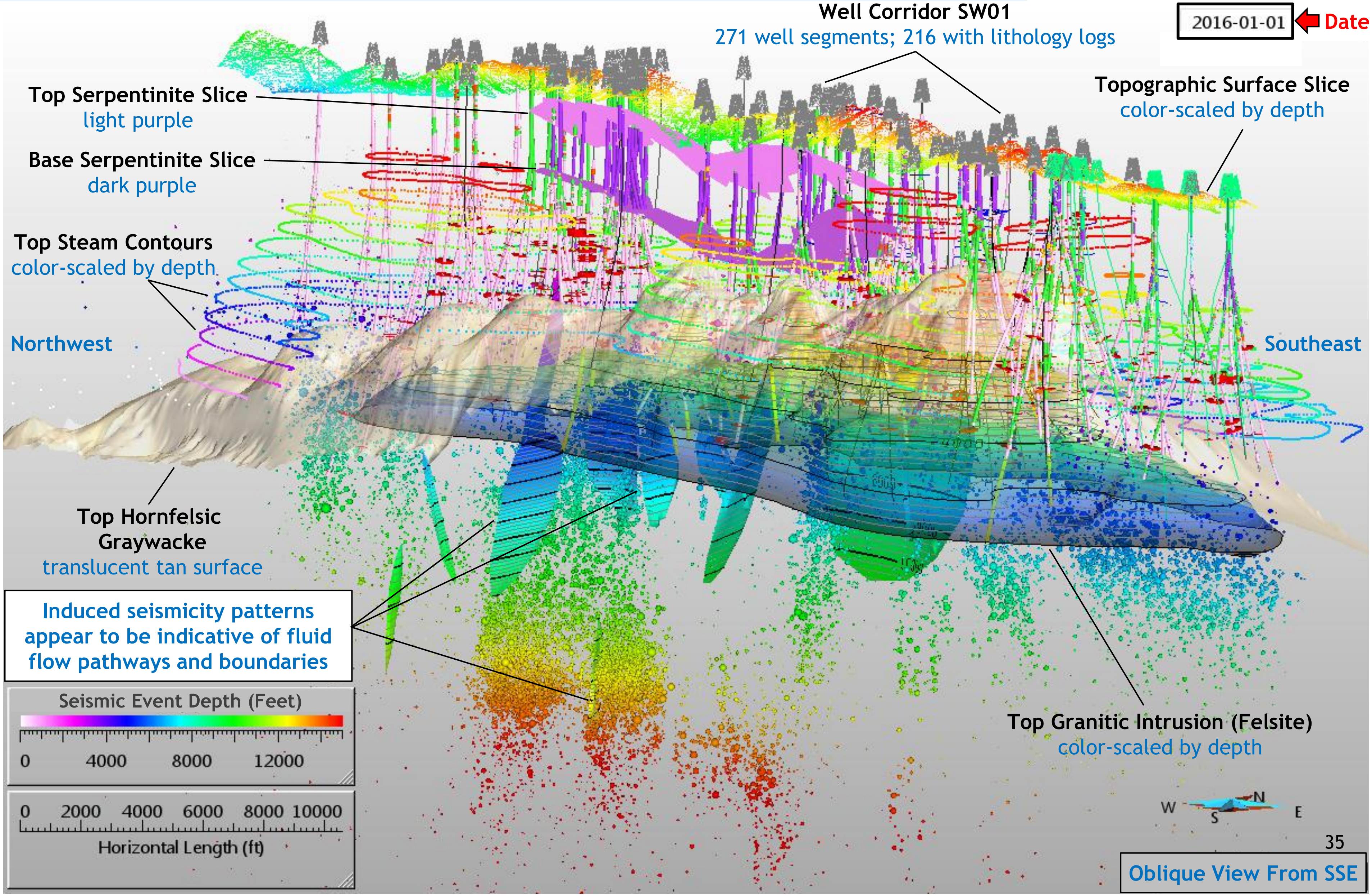
3D Structural Model Building with Paradigm Geophysical SKUA GOCAD Software
Fracture Network Interpretation (in progress)

CALPINE NYSE CPN



Seismic Monitoring Advisory Committee Meeting

3D Structural Model Building Goal: **Improved reservoir management and induced seismicity mitigation through a refined understanding of fluid flow paths, fluid boundaries, reservoir heterogeneity and reservoir compartmentalization.**



Seismic Monitoring Advisory Committee Meeting

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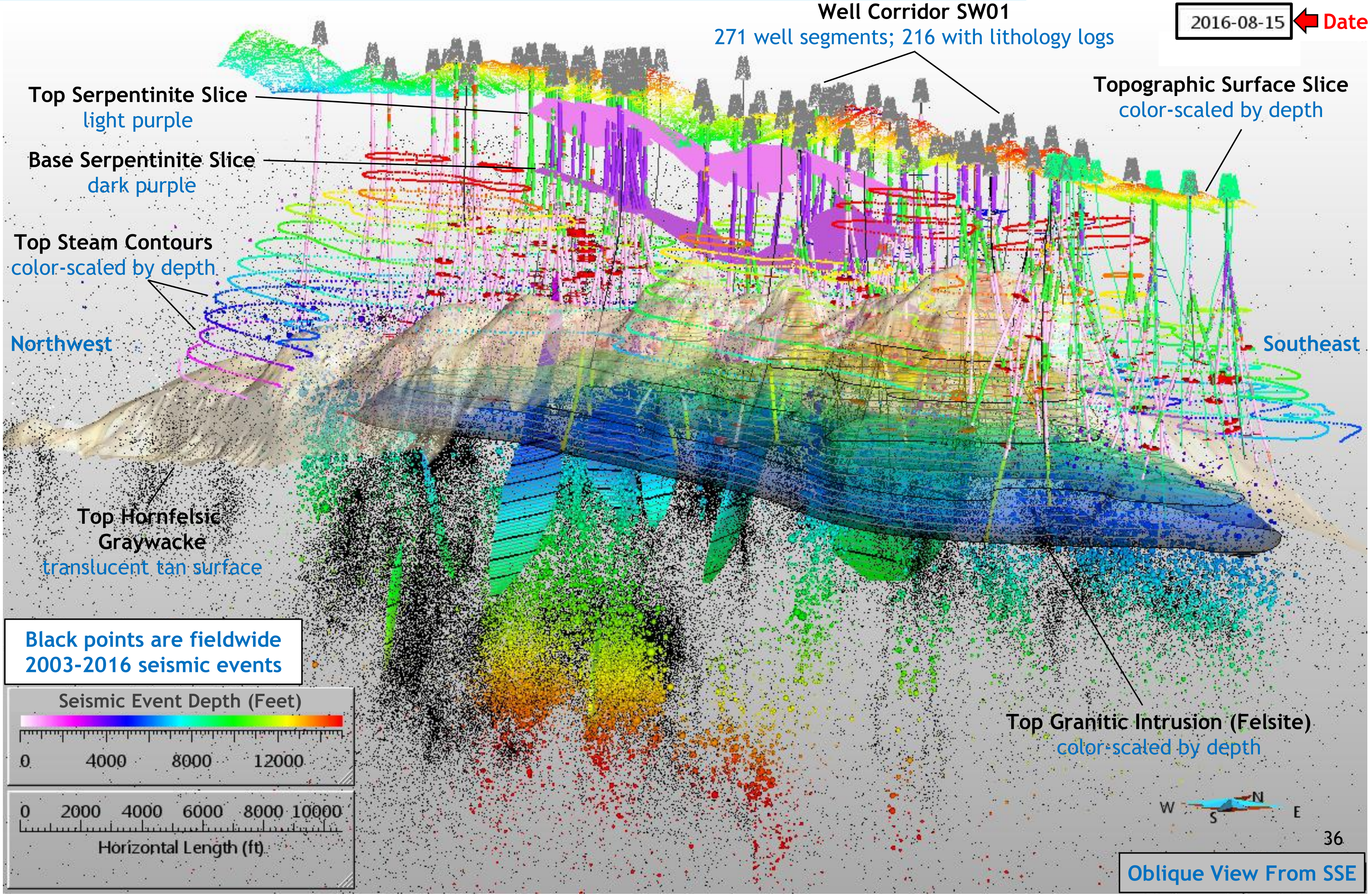


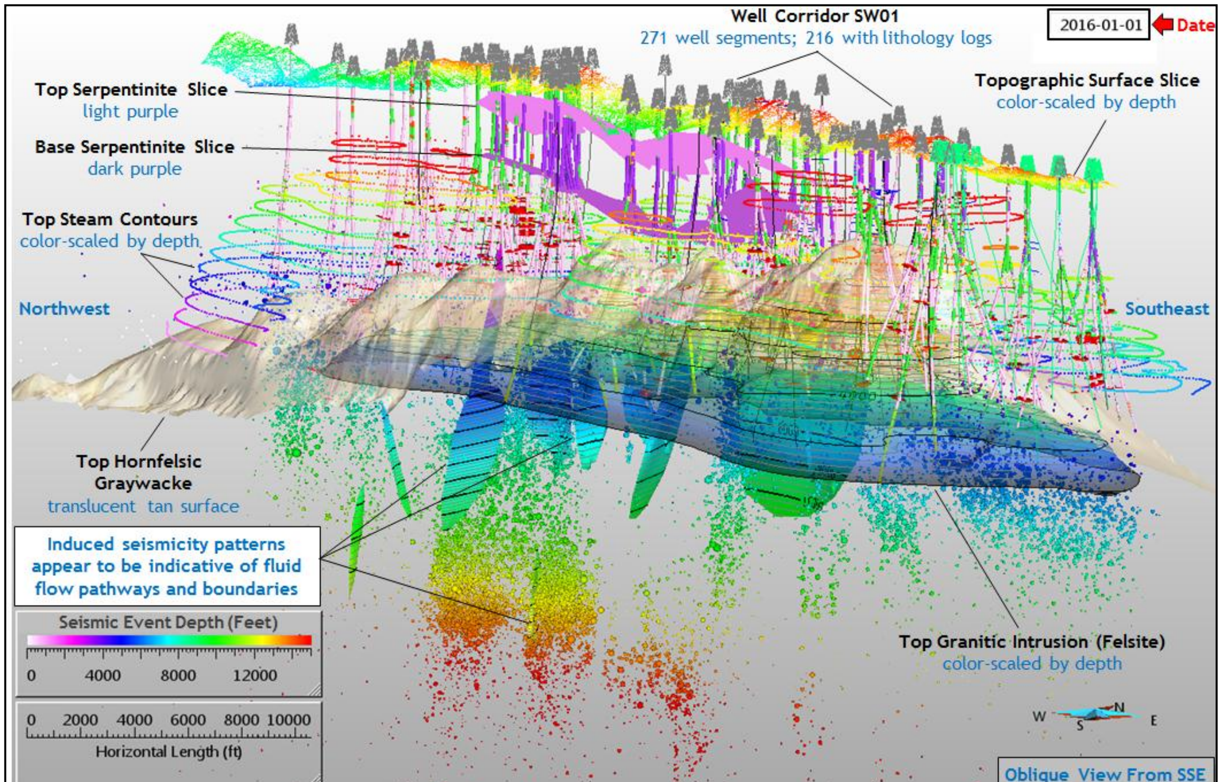
Induced Seismicity Analysis and 3D Structural Model Building Summary

Present Capabilities

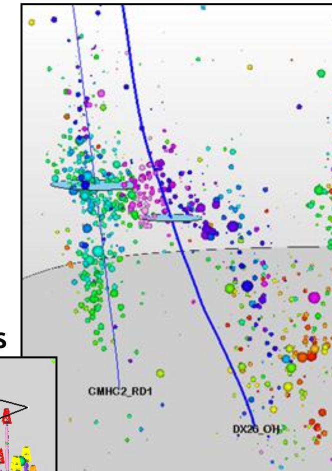
Synchronized Water Injection / Induced Seismicity Analysis
3D Well Planning
3D Real-Time Drilling Analysis

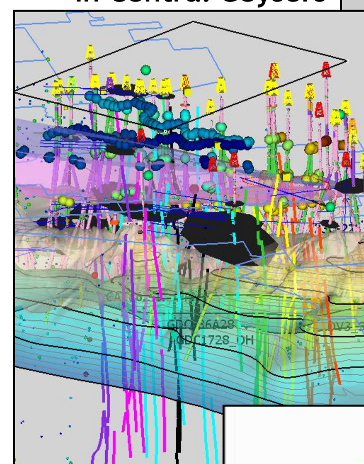
In Progress

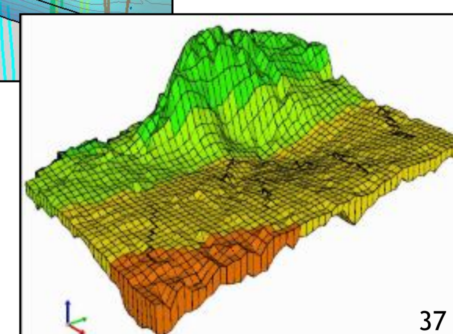
Seismicity Mitigation
Refinement 3D Reservoir Model / Flow Simulation
Reservoir Management



3D Cell-Based Structural Model Test Volume in Central Geysers







Seismic Monitoring Advisory Committee Meeting
Geothermal Industry Outreach

Geothermal Resource Council Annual Meeting
Sacramento, California, USA
23-26 October 2016

Geysers Update Session
Tuesday, 25 October 2016; 1:30 pm to 3:40 pm

Overview and Valley Fire Update
Jim Kluesener
Vice President Regional Operations; Geysers

Geology Introduction
Mark Walters
Senior Geologist

Induced Seismicity Analysis and 3D Structural Model Building
Craig Hartline
Senior Geophysicist

Geochemical Monitoring
Melinda Wright
Senior Geologist

Steamfield and Wells
John Farison
Senior Engineering Project Manager

Power Plants
Tim Conant
Director of Geothermal Engineering


Sonoma Unit 3 Power Plant


SR-1 Pump Station


High Efficiency “Super Rotor”

Quicksilver Unit 16 Cooling Tower Rebuild


Additional Seismic Monitoring and Research

CALPINE
NYSE CPN

PROCEEDINGS, 41st Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 22-24, 2016
SGP-TR-209

Three-Dimensional Structural Model Building, Induced Seismicity Analysis, Drilling Analysis and Reservoir Management at The Geysers Geothermal Field, Northern California

Craig S. Hartline[1], Mark A. Walters[1], Melinda C. Wright[1], Corina K. Forson[2] and Andrew J. Sadowski[3]

1 Calpine Corporation, 10350 Socrates Mine Road, Middletown, CA 95461

2 Washington State Department of Natural Resources, 1111 Washington St. SE, Olympia, WA 98504

3 Nevada Bureau of Mines and Geology, University of Nevada, Reno, NV

Craig.Hartline@calpine.com, Mark.Walters@calpine.com, Melinda.Wright@calpine.com, corinaforson@gmail.com, andrew.j.sadowski@gmail.com

Keywords: Three-dimensional, Visualization, Structural Model, Induced Seismicity, Reservoir Management, The Geysers

ABSTRACT

A three-dimensional structural model of The Geysers geothermal field is being developed by Calpine Corporation using Paradigm Geophysical SKUA GOCAD software originally designed for the oil and gas industry. Structural model building constraints include lithology logs, surface geologic maps and seismicity hypocenters available from the Northern California Earthquake Data Center (NCEDC) and Lawrence Berkeley National Laboratory (LBNL), as well as temperature logs, pressure logs, tracer analysis patterns, heat flow patterns, and reservoir history matching. A field-wide ArcGIS digital surface map compiled in 2014 from existing hard copy surface geology maps and refined in 2015 now provides improved constraint on the surface-to-subsurface structural relationships. Recent advances to the SKUA GOCAD 3D seismicity analysis software include the ability to perform synchronized time animation of water injection volumes and induced seismicity hypocenters at any time interval. This provide an additional and substantial constraint on structural model building through enhanced visualization of the spatiotemporal relationships between water injection, induced seismicity and fracture orientations at The Geysers. The result is a refined understanding of structural relationships, fluid flow paths, fluid boundaries, reservoir heterogeneity and compartmentalization at The Geysers. We can now demonstrate that The Geysers reservoir is subdivided by intersecting zones of faulting and fracturing, the majority of which are oriented NNW-SSE and ENE-WSW and sometimes expressed in the surface geology. The 3D structural model development is part of a program to honor a vast collection of field data and more closely link geoscience, reservoir engineering and drilling. This is anticipated to contribute to reservoir management and induced seismicity mitigation efforts at The Geysers.

1. INTRODUCTION

The Geysers, located in Northern California and approximately 75 miles north of San Francisco, is the largest producing geothermal field in the world. Calpine Corporation operations at The Geysers include 14 geothermal plants, approximately 330 active steam production wells, and 60 active water injection wells producing about 720 million watts of electricity (and approximately 18% of California's renewable power).

1.1 Regional Geology

This geothermal resource exists within a complex assemblage of Franciscan rocks (200 to 80 Ma in age) representing the ancient Farallon plate subduction complex. Approximately 30 Ma ago a transition from eastward-directed subduction to right-lateral strike-slip faulting occurred as the spreading center between the Pacific Plate and the Farallon Plate descended beneath the western edge of the North American Plate. Since this transition, the relative motion between the Pacific Plate and North American Plate has been accommodated by right-lateral strike-slip motion along the San Andreas Fault Zone (DeCourten, 2008). This zone of subparallel right-lateral strike-slip faults move at progressively slower slip rates eastward and initiated a transtensional tectonic environment between the active Maacama fault and the active Bartlett Springs Fault Zone (Figure 1).

The modern-day Geysers geothermal field is bounded to the southwest by the inactive Mercuryville and Big Sulphur Creek fault zones and to the northeast by the inactive Collayomi fault zone (see inset within Figure 1). There are no faults in or adjacent to The Geysers which are known to be active within the last 15,000 years. Beginning about 1.1 Ma ago, a 1400 °F (760 °C) multiphase granitic pluton locally known as "Felsite" began intruding the brittle Franciscan graywacke found throughout the subsurface of The Geysers region. Extensive fracture enhancement by the mechanical and hydraulic forces associated with intrusion as well as the thermal metamorphism of the graywacke to a biotite hornfels occurred above the granitic pluton. Heating of the formation water within this fracture system created a liquid-dominated hydrothermal reservoir in the Franciscan graywacke and the upper portion of the granitic pluton.

Containment of The Geysers initial hydrothermal reservoir was primarily dependent on the transition from abundant open fractures to very limited open fractures with decreasing depth. This is well illustrated in the present-day northwest Geysers, where an open fracture network in the silicified graywacke reservoir rock transitions to very limited open fractures within the overlying graywacke caprock. Caprock development throughout The Geysers was aided by the acid alteration of rock to clay minerals and the shallow precipitation of dissolved silica derived from deeply circulating ground water (that reacted with magmatic and hydrothermal gases). The present maximum enthalpy 465 °F (240 °C) vapor-dominated Geysers geothermal reservoir exists due to a phreatic eruption approximately 0.25

1

41st Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California February 22-24, 2016, SGP-TR-209

Three-Dimensional Structural Model Building, Induced Seismicity Analysis, Drilling Analysis and Reservoir Management at The Geysers Geothermal Field, Northern California

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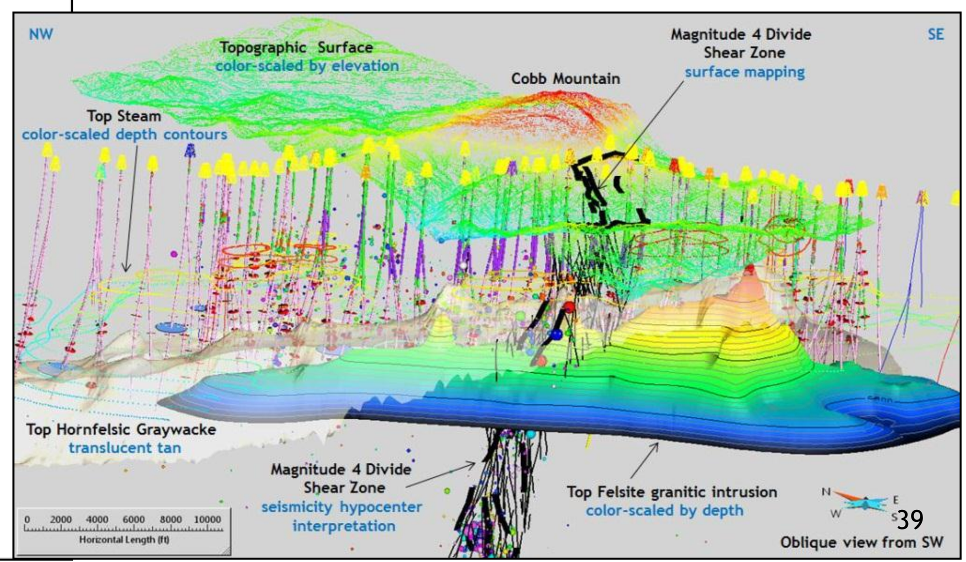
"This is anticipated to contribute to reservoir management and induced seismicity mitigation efforts at The Geysers."



Seismic Monitoring Advisory Committee Meeting

Additional Seismic Monitoring and Research

California Energy Commission Electric Program Investment Charge (EPIC) Program

Approval of Grant Funding Opportunity 16-301

CALPINE NYSE CPN

Accepted Proposal:

High-Resolution Micro-Earthquake Imaging of Flow Paths Using a Dense Seismic Network and Fast-Turnaround, Automated Processing

Applicant

Lawrence Berkeley National Laboratory

Project Partners

Array Information Technology
Calpine Corporation

Project goals include the development of an advanced, low-cost, automated tomographic imaging system that uses micro-earthquakes to form high-resolution spatial and temporal images of subsurface fluid flow, flow barriers and heterogeneity in producing geothermal fields. The project will focus on micro-earthquake imaging challenges that are unique to geothermal reservoirs, which can include complex fracturing and faulting, heterogeneous overburden and limited seismic velocity control.

Better 3D (and 4D) subsurface resolution is anticipated to assist with seismicity mitigation efforts at The Geysers.

California Energy Commission

GFO-16-301

Improving Performance and Cost Effectiveness of Small Hydro, Geothermal and Wind Energy Technologies

Notice of Proposed Awards

Group 2: Improving the Cost-Effectiveness and Operational Flexibility of Geothermal Energy Production

October 3, 2016

Rank Number	Project Applicant	Title	Energy Commission Funds Requested	Energy Commission Funds Recommended	Match Funds	Score	Award Status
Proposed Awards							
1	Lawrence Berkeley National Laboratory	High-Resolution Micro-Earthquake Imaging of Flow Paths Using a Dense Seismic Network and Fast-Turnaround, Automated Processing	$1,672,639	$1,672,639	$50,000	77.30	Awardee
2	SRI International	Recovery of Lithium from Geothermal Brines	$873,387	$873,387	$0	76.20	Awardee
3	Lawrence Berkeley National Laboratory	Coupled Reservoir-Wellbore Thermal-Hydrological-Mechanical-Chemical Modeling	$999,032	$999,032	$0	75.80	Awardee

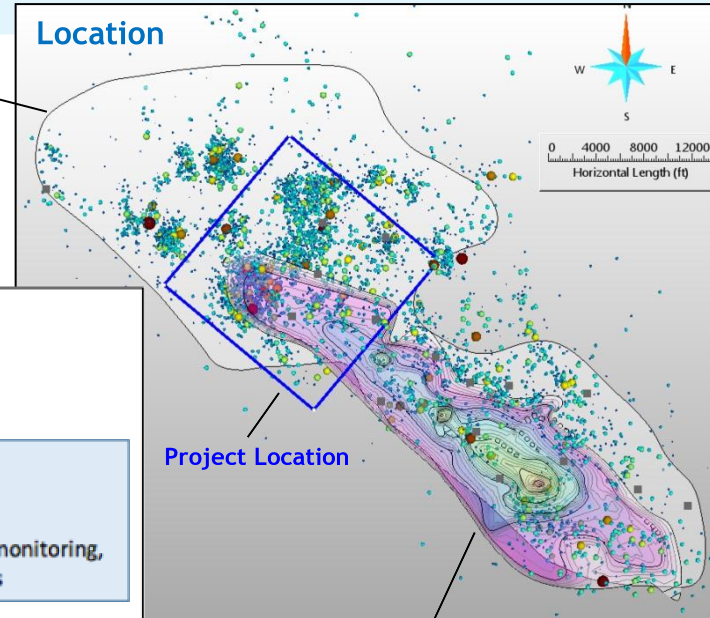
Seismic Monitoring Advisory Committee Meeting

Additional Seismic Monitoring and Research

California Energy Commission Electric Program Investment Charge (EPIC) Program

Approval of Grant Funding Opportunity 16-301

Location



Productive Steam Reservoir Outline

Project Location

Top Granitic Intrusion (Felsite)
color-scaled by depth

Project Team and Tasks

Principal Investigator & Project Manager
Kurt Nihei

Co-PI
Roland Gritto

Technical Advisors
Ernie Maier (LBNL) - Microseismic monitoring
Brian Bonner (LBNL) - Rock physics
Craig Hartline (Calpine) – Earth modeling, microseismic monitoring, geothermal operations, field logistics at The Geysers

Project Tasks

Task 1 General Project Administration
Kurt Nihei, Lead

Task 6 Evaluation of Project Benefits
Roland Gritto, Lead

Kurt Nihei
Larry Hutchings

Task 7 Technology/Knowledge Transfer Activities
Kurt Nihei, Lead

Roland Gritto
Larry Hutchings

Technical Tasks

Task 2 Dense Network Design
Roland Gritto, Lead

Kurt Nihei
Larry Hutchings
Don Vasco
Bill Foxall
Katie Freeman

Task 3 Fast-Turnaround, High-Resolution Imaging
Kurt Nihei, Lead

Roland Gritto
Steve Jarpe
Larry Hutchings
Bill Foxall
Katie Freeman

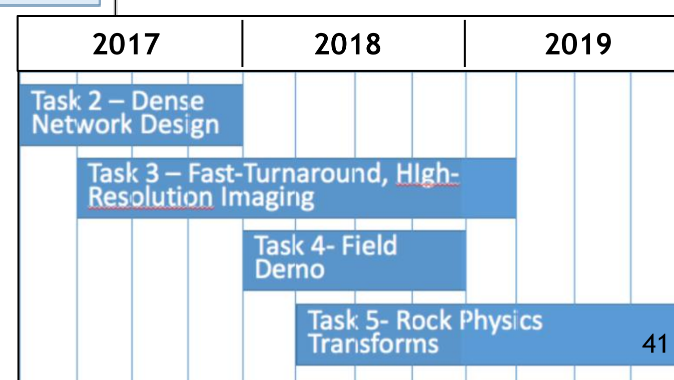
Task 4 Field Demonstration at The Geysers
Roland Gritto, Lead

Kurt Nihei
Steve Jarpe
Larry Hutchings
Katie Freeman
Ramsey Haught
Michelle Robertson

Task 5 Rock Physics Transforms
Seiji Nakagawa, Lead

Kurt Nihei
Roland Gritto
Don Vasco
Bill Foxall
Yves Guglielmi
Pierre Jeanne

Schedule



Seismic Research Collaboration with Seismic Warning Systems

CALPINE NYSE CPN

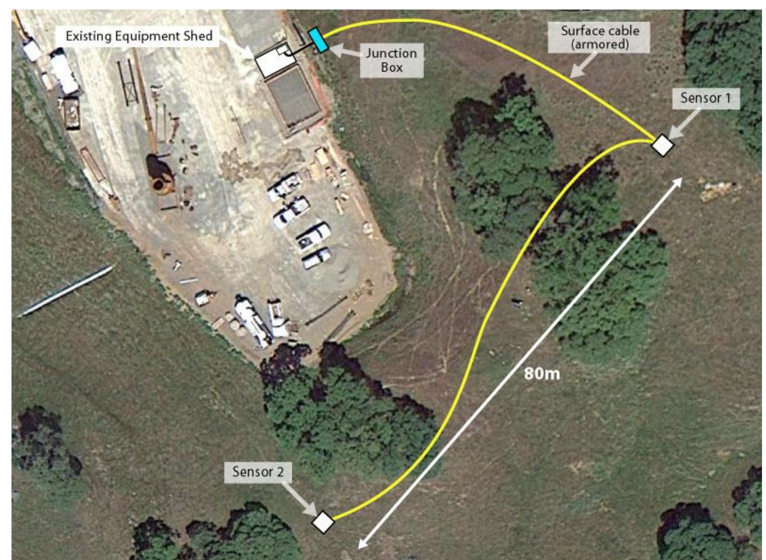
SEISMIC WARNING SYSTEMS

Early Detection and Warning System for Natural Earthquakes

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.
Installation date 15 September 2014.
Tied in to Calpine power and communications.



Geysers Project Goals

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

Seismic Research Collaboration with Zizmos

Early Detection and Warning System for Natural Earthquakes

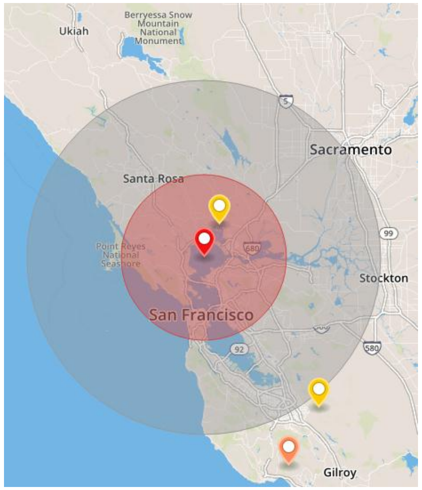
Primary Goal

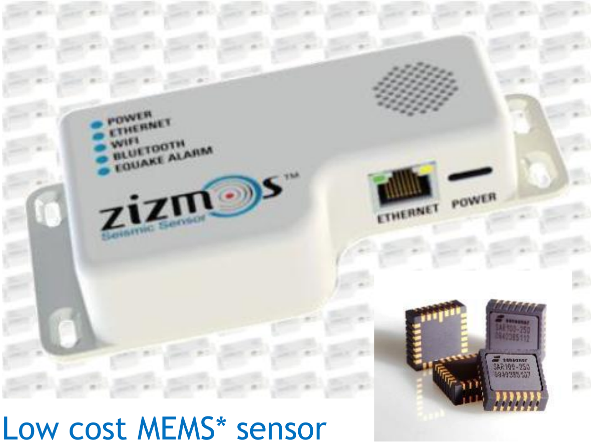
Cost-effective cloud-connected seismic network that provides earthquake early-warning and high-resolution shake maps. Designed to complement existing scientific solutions with the addition of low-cost mobile and wireless sensors.

Hybrid approach to reduce casualties and provide structural engineers, utilities, transportation officials, and property owners with unprecedented near real-time information about the shake hazards. Backed by the National Science Foundation ($250,000) and Verizon ($1,000,000).

Geysers Project Goals

Initial sensor placement at the Calpine Geothermal Visitor Center for testing of network and firewall issues. Future expansion into The Geysers geothermal field for refinement of automated event detection and warning.





Low cost MEMS* sensor
Available Networking and Cloud Computing

* Micro Electro-Mechanical Systems

Research Collaborations

CALPINE NYSE CPN

Lawrence Berkeley National Laboratory

36 station three-component permanent seismic monitoring network

Collaboration on successful DOE co-funded EGS Demonstration Project, including two temporary seismic monitoring networks

Collaboration on high-temperature tolerant borehole fiber optical seismic sensor testing

Borehole seismic sensor installation and testing in the southeast Geysers

Initiating collaboration for high-resolution imaging of fluid flow paths using a dense seismic network and automated processing

United States Geological Survey

Geysers' seismicity processing and real-time availability, detailed analysis of magnitude ≥ 3.5 events

Collaboration on full-waveform six-component (3 translational/3 rotational) seismic sensor testing

Collaboration on Silicon Audio high-sensitivity optical accelerometer testing

Massachusetts Institute of Technology

Collaboration on installation and operation of three continuous monitoring GPS instruments

Array Information Technology

Research Collaborations with European GEISER Project

Installation and recovery of 32 continuous broadband seismic recording instruments from GFZ Potsdam / GEISER Instrument Pool

GFZ Potsdam

Collaboration on studies of spatiotemporal induced seismicity changes associated with variable water injection in the northwest Geysers

United States Seismic Systems

High-temperature tolerant borehole fiber optical seismic sensor array test program

Seismic Warning Systems

Northwest Geysers test site for calibration of earthquake early warning systems

Zizmos

Geothermal Visitor Center test site for cloud-connected seismic network earthquake early warning systems