Seismic Monitoring Advisory Committee Meeting

01 April 2017 to 30 September 2017 Reporting Period

Calpine Geothermal Visitors Center

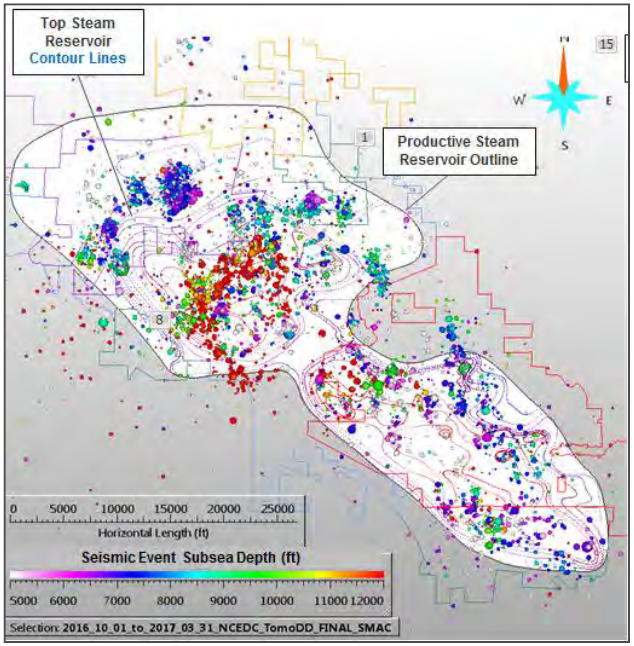
Middletown, California

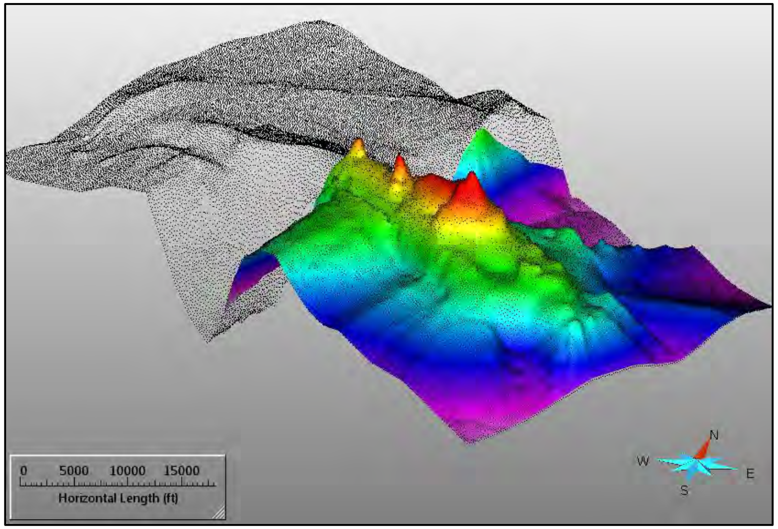
13 November2017

Craig Hartline Senior Geophysicist Calpine Corporation The Geysers

Seismic Monitoring Advisory Committee Meeting
Calpine Presentation Agenda
Reporting Period: 01 April 2017 to 30 September 2017

- Status of Seismic Monitoring Networks
  - LBNL Seismic Monitoring Network
  - USGS / Northern California Seismic Network
  - Strong Motion Stations
- Fieldwide Seismicity Analysis
- Synchronized Fieldwide Water Injection and Seismicity Analysis
- Community Hotline
- Strong Motion Analysis
- Regional Seismicity Analysis
- Water Injection Goals and Modifications
- 3D Structural Model Building
  - Fault/Fracture Analysis
- Additional Seismic Monitoring and Research





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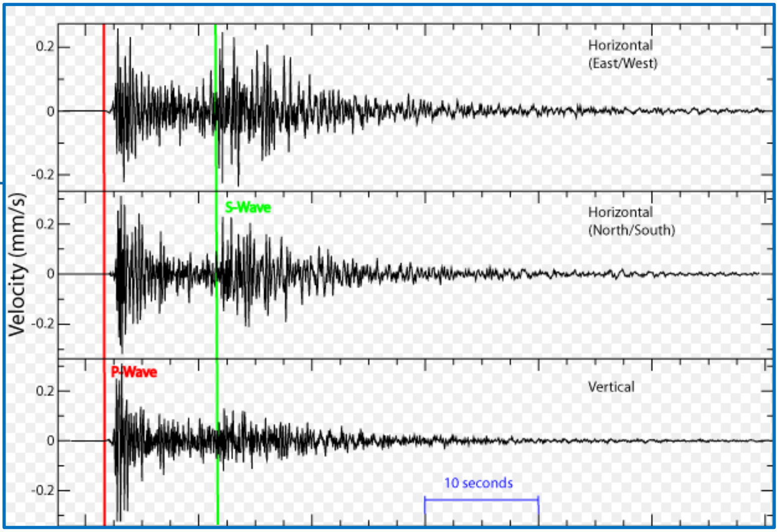
Status of Seismic Monitoring Networks



LBNL Seismic Monitoring Network
Fully Functional

USGS / Northern California Seismic Network
Fully Functional

Cobb Strong Motion
Multiple issues have delayed re-installation.
LBNL contractor Ramsey Haught intends to install a Nanometrics Titan three-component accelerometer by 31 December 2017 at Hess family property.

Anderson Springs Strong Motion ADS2
Fully functional. Database at: ftp://ehzftp.wr.usgs.gov/luetgert/calpine/sm_sum.txt

Anderson Springs Strong Motion (formerly ADSP)
Site determination required additional consideration in a community devastated by the Valley Fire.
Properties of McWilliams, Moulton and Engels were suggested by Jeff Gospe on 19 April 2017.

The property of Cheryl and John Engels best met the site criteria.
Nanometrics Titan three-component accelerometer installed by 20 September 2017.
New Name: Engels Strong Motion (ESM)

Solar power with battery back-up
Radio telemetry communication to LBNL seismic monitoring network

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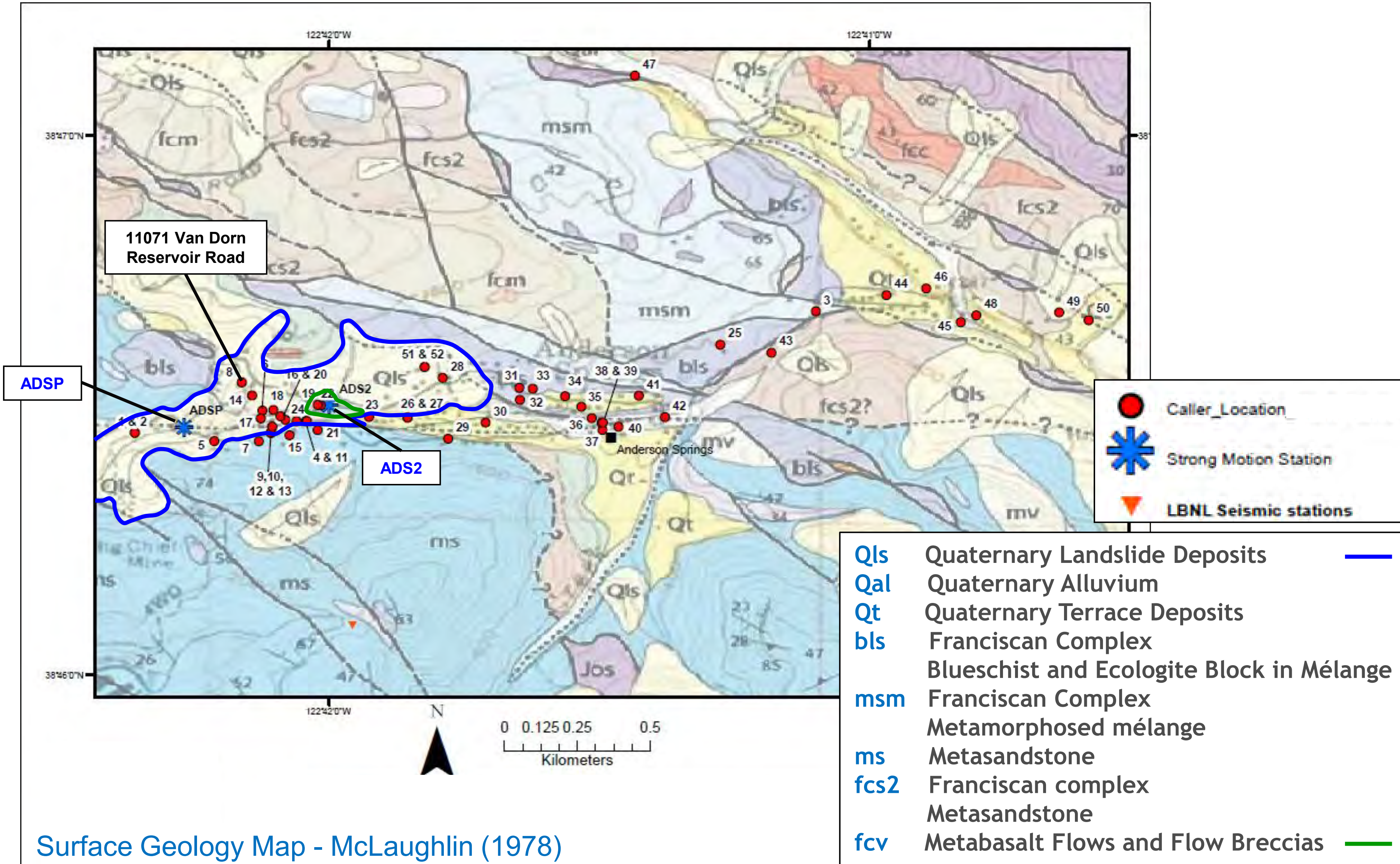
Status of Seismic Monitoring Networks

Anderson Springs Surface Geology and Hotline Caller Locations



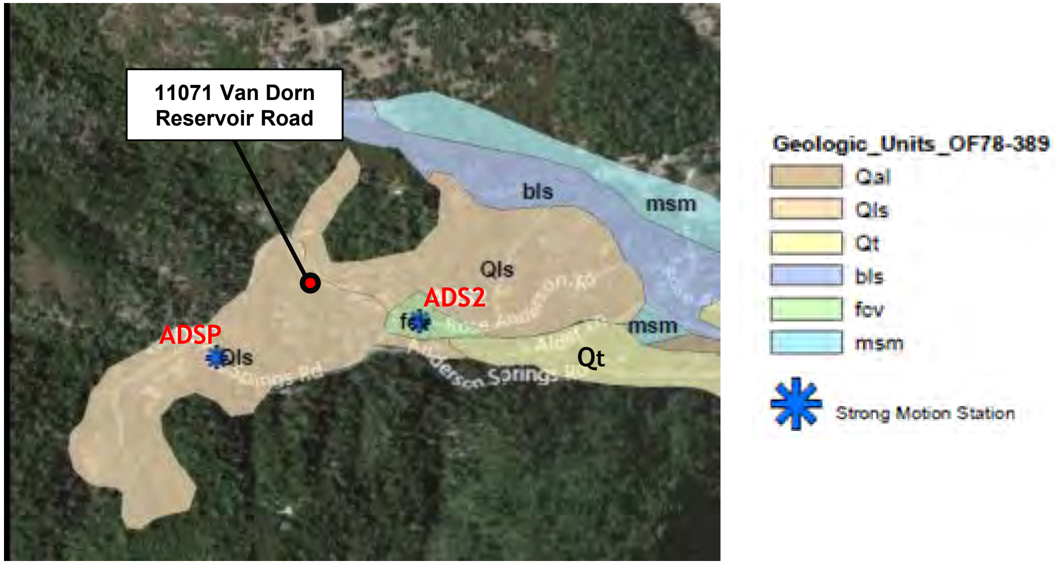
Surface Geology Map - McLaughlin (1978)

Status of Seismic Monitoring Networks
Anderson Springs Surface Geology and Hotline Caller Locations

The majority of the hotline callers have their residences on Qls landslide deposits* at the western end of the community.

ADSP site: Qls landslide deposits
- relatively thin soil overlying rock
- lower shear-wave velocities
- this leads to site amplification at short-to-moderate periods (moderate to high frequencies)
- this is consistent with relatively high peak ground acceleration values at ADSP

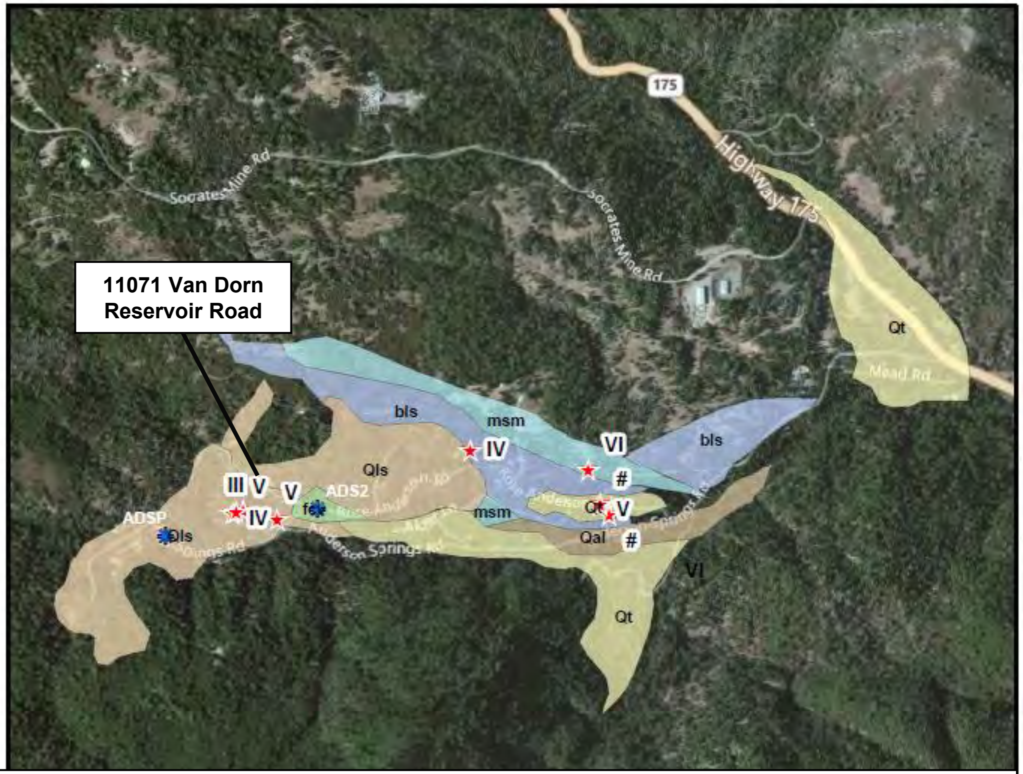
ADS2 site: fcv metabasalt
- ground motions recorded on ADS2 are generally lower than ADSP
- this is consistent with the observation of site amplification at ADSP due to Qls landslide deposits



** Qls = Quaternary landslide deposits*
The Quaternary period begins at the onset of Northern Hemisphere glaciation about 2.6 million years ago

Anderson Springs Surface Geology and Hotline Caller Locations

Magnitude 4.4 Seismic Event on 09 May 2005



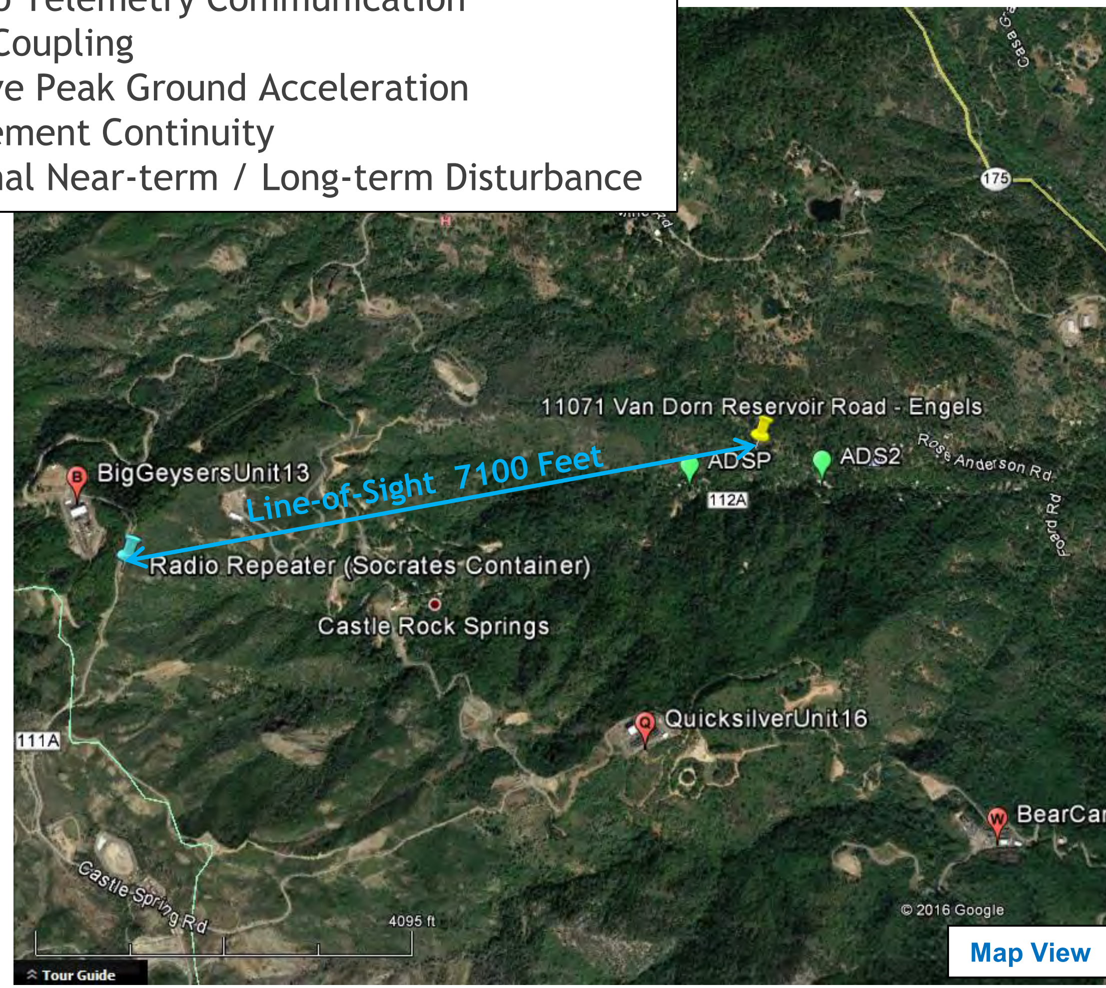
The observed shaking at the proposed site is:

- ***Consistently*** **equal to or greater than the neighboring observations as indicated by the determined Modified Mercalli Intensity.**
- **Representative of the western end of Anderson Springs and Qls surface geology.**

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

Status of Seismic Monitoring Networks
New Station - Engels Strong Motion (ESM)

Site Selection Criteria
- Landowner Approval
- Reliable Solar or AC Power Source / Battery Back-up
- Reliable Radio Telemetry Communication
- Good Sensor Coupling
- Representative Peak Ground Acceleration
- ADSP Measurement Continuity
- Area of Minimal Near-term / Long-term Disturbance



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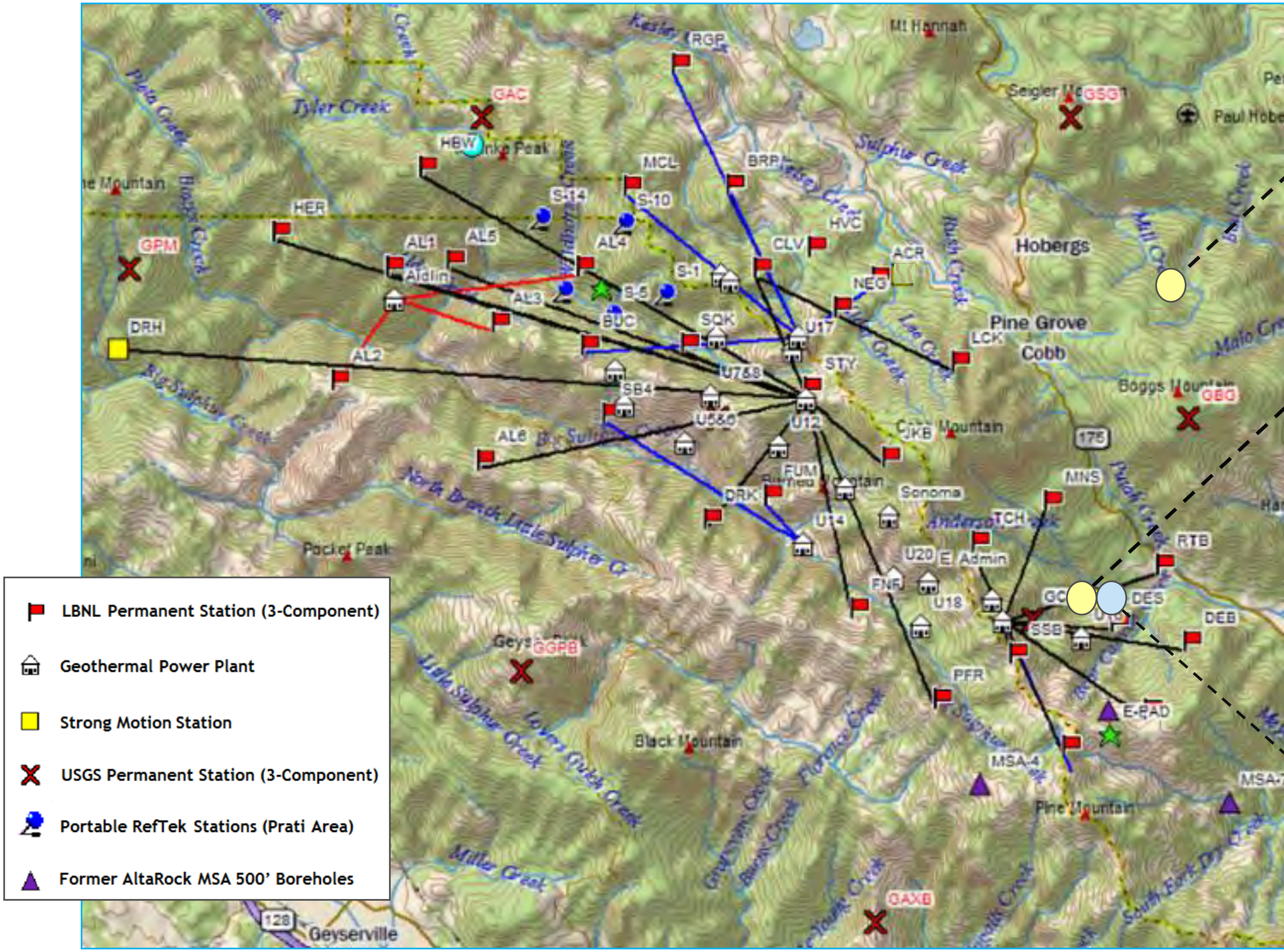
Status of Seismic Monitoring Networks

Integration of Nanometrics Titan Accelerometers into LBNL Network



Cobb
Strong Motion
Hess Property
HSM

LBNL

Nanometrics Titan
Solar Power
Radio Telemetry
To Be Installed
December 2017

Anderson Springs
Strong Motion
Engels Property
ESM

LBNL

Nanometrics Titan
Solar Power
Radio Telemetry
September 2017

Anderson Springs
Strong Motion
Community Center
ADS2

USGS

ETNA
Rural AC Power
Rural Communication
(phone line)
January 2016

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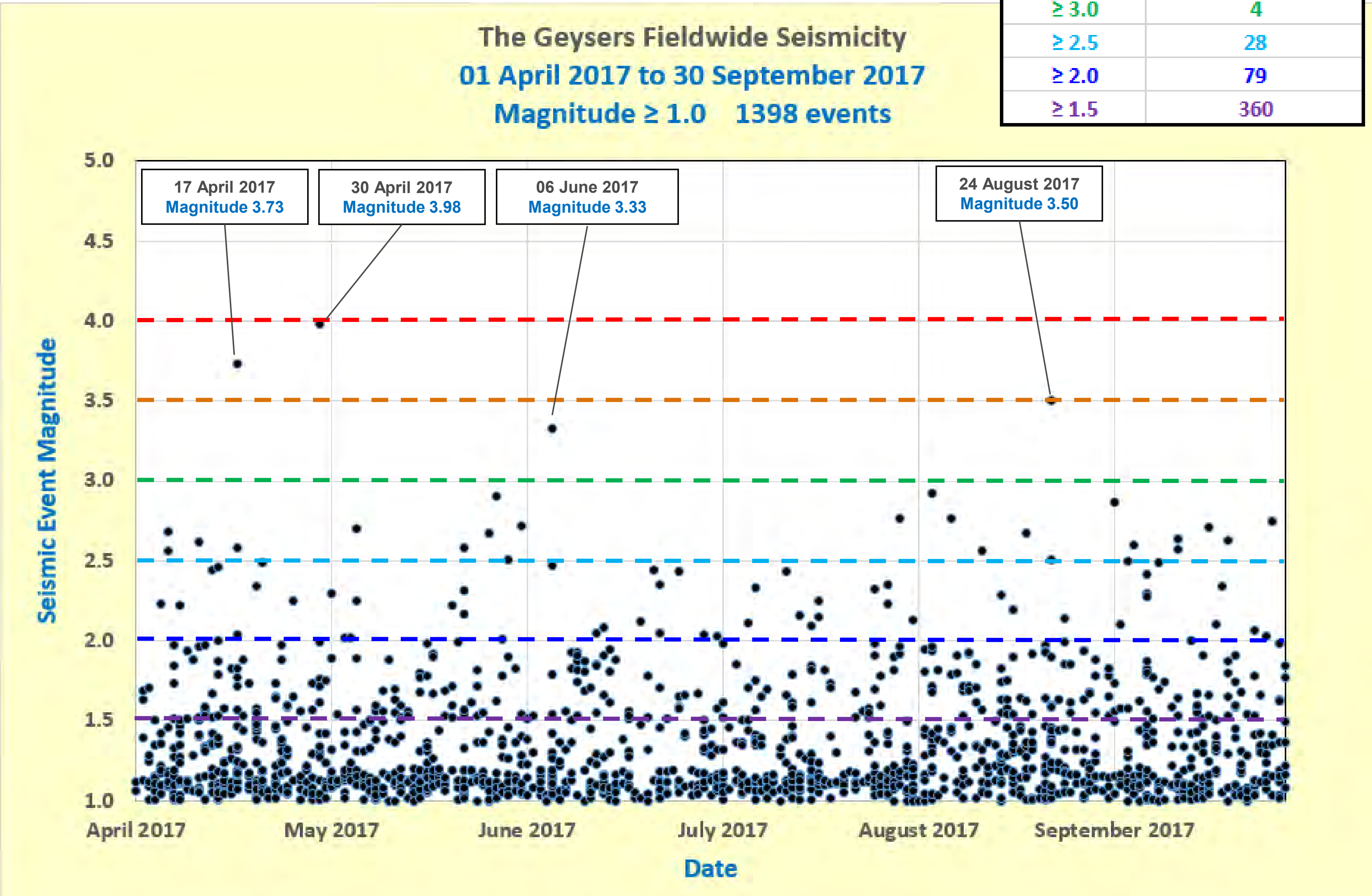
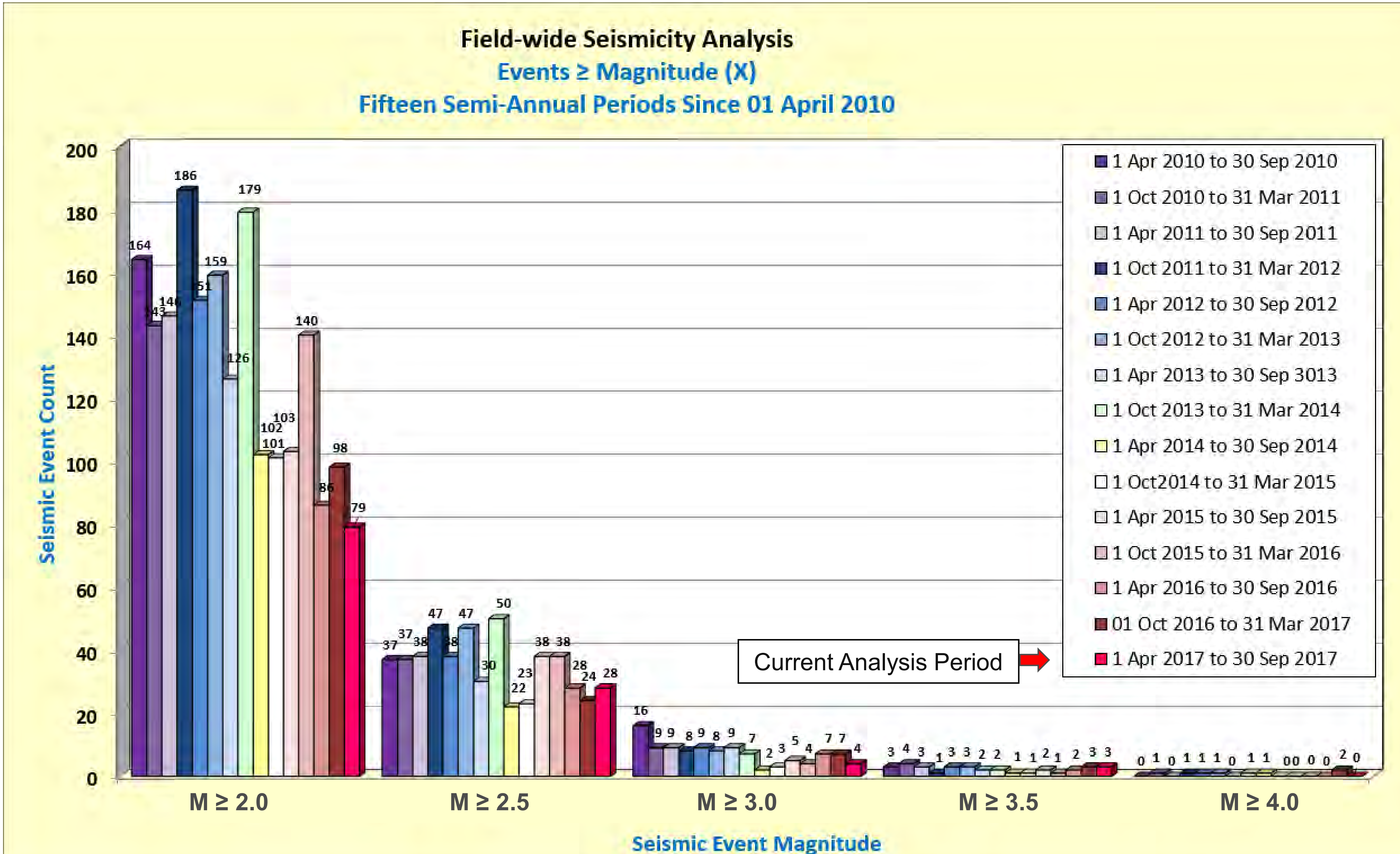
Field-wide Seismicity Analysis

01 April 2017 to 30 September 2017

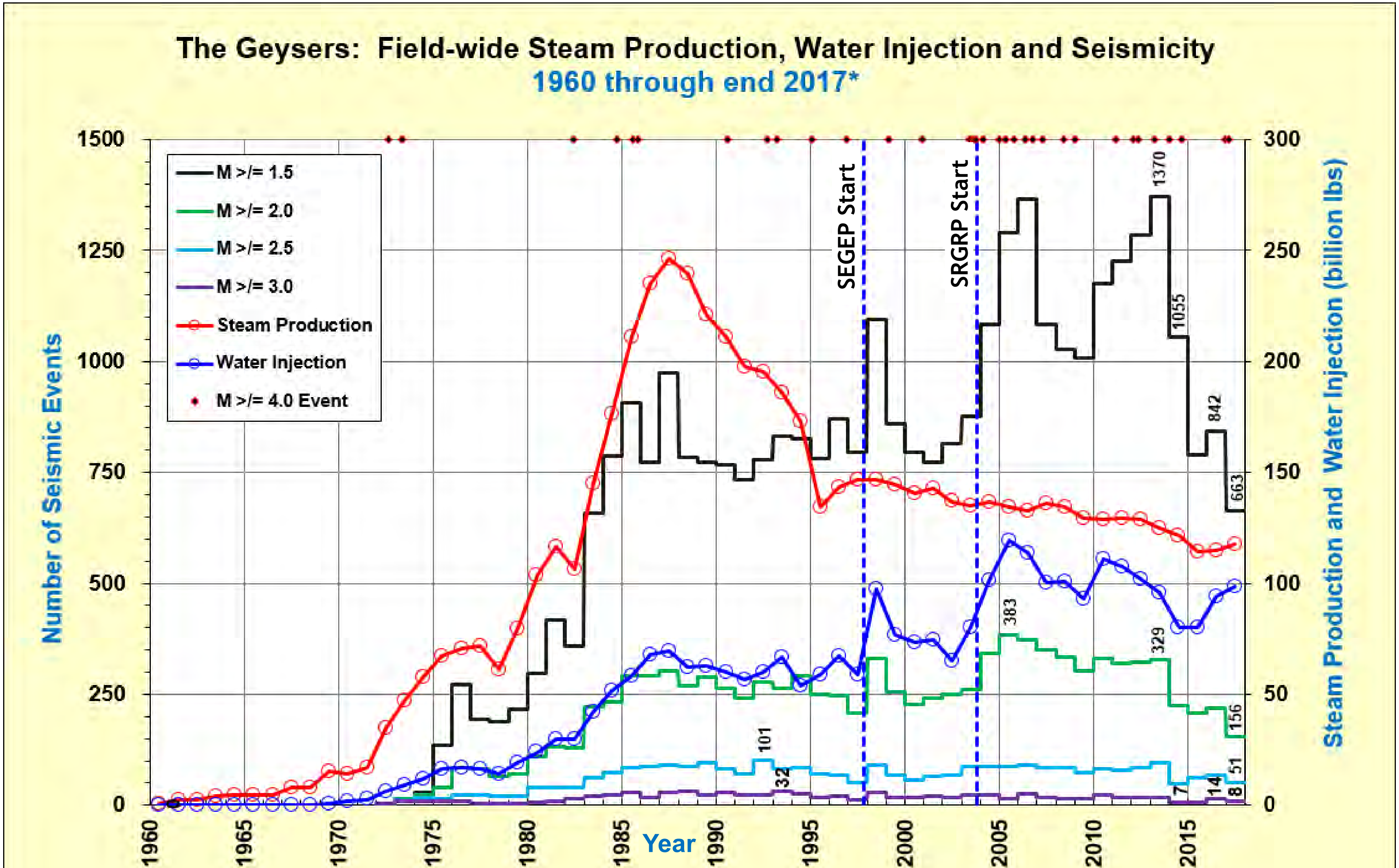
Magnitude	Number of Events
≥ 4.0	0
≥ 3.5	3
≥ 3.0	4
≥ 2.5	28
≥ 2.0	79
≥ 1.5	360



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

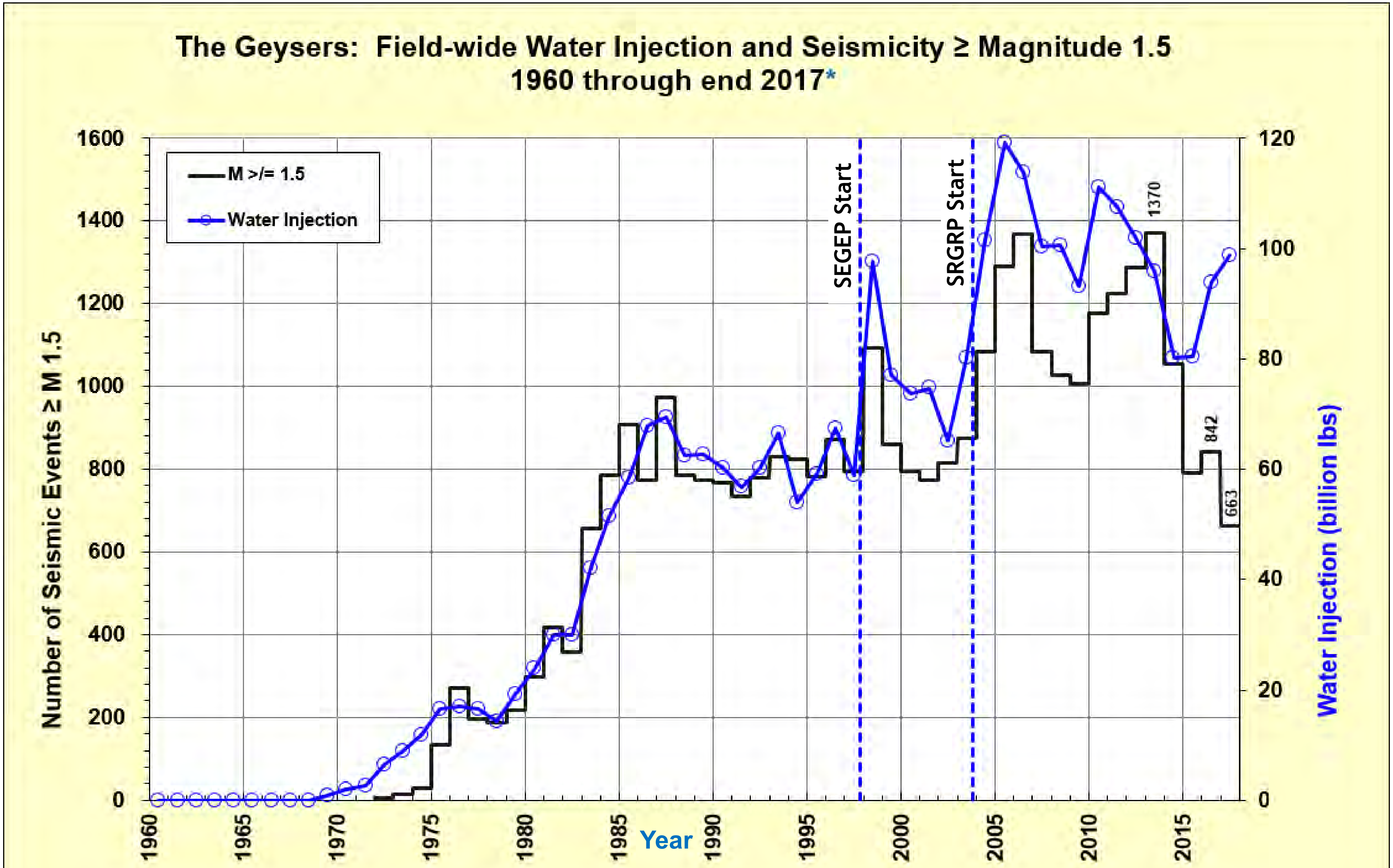


Yearly Field-wide Steam Production, Water Injection and Seismicity



* Seismicity Projected From 19 October 2017; Water Injection and Steam Production Projected From 01 September 2017
Database: Northern California Earthquake Data Center (NCEDC); UC Berkeley Seismological Laboratory

Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 1.5



* Seismicity Projected From 19 October 2017; Water Injection and Steam Production Projected From 01 September 2017
Database: Northern California Earthquake Data Center (NCEDC); UC Berkeley Seismological Laboratory

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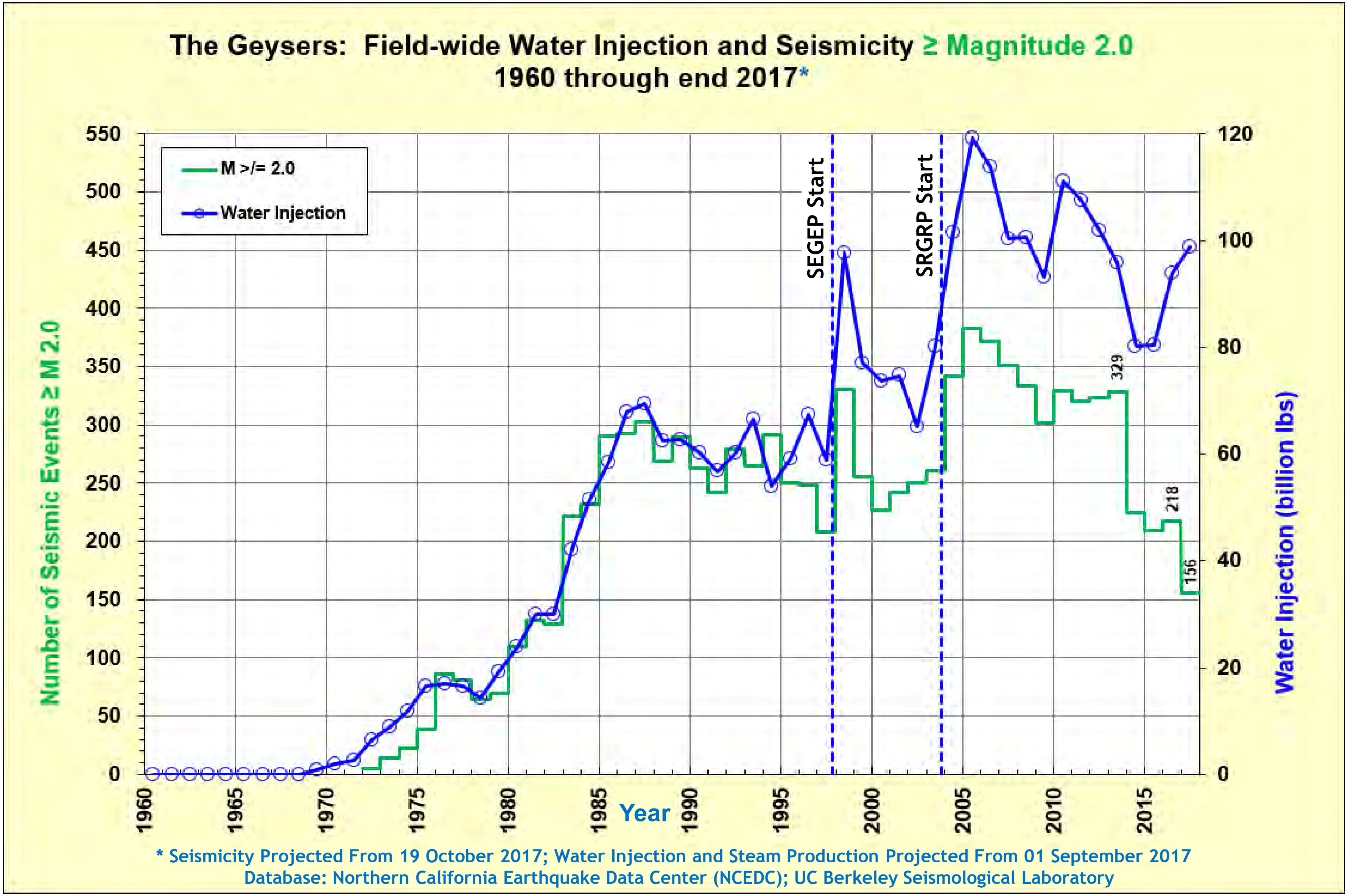
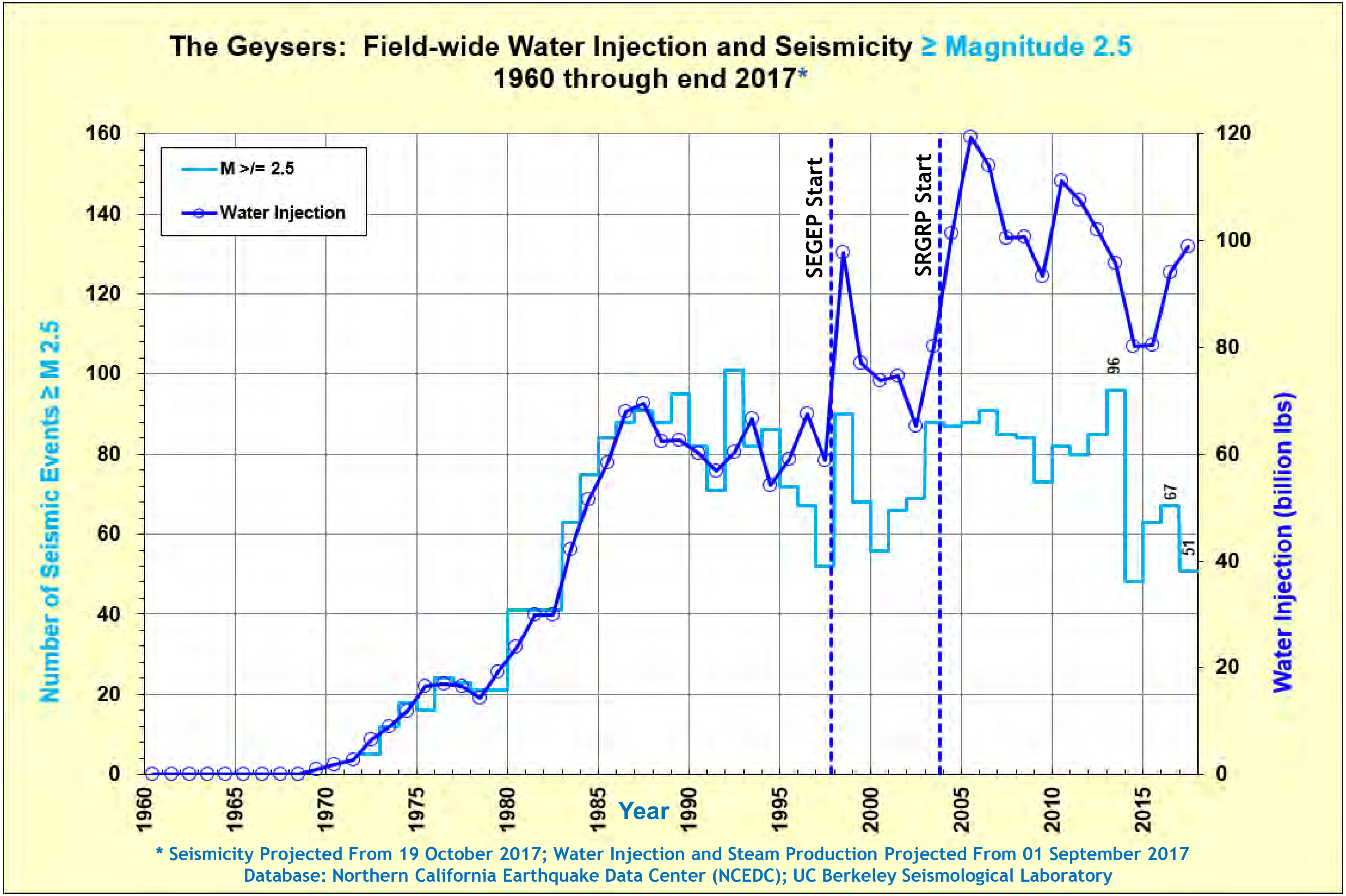
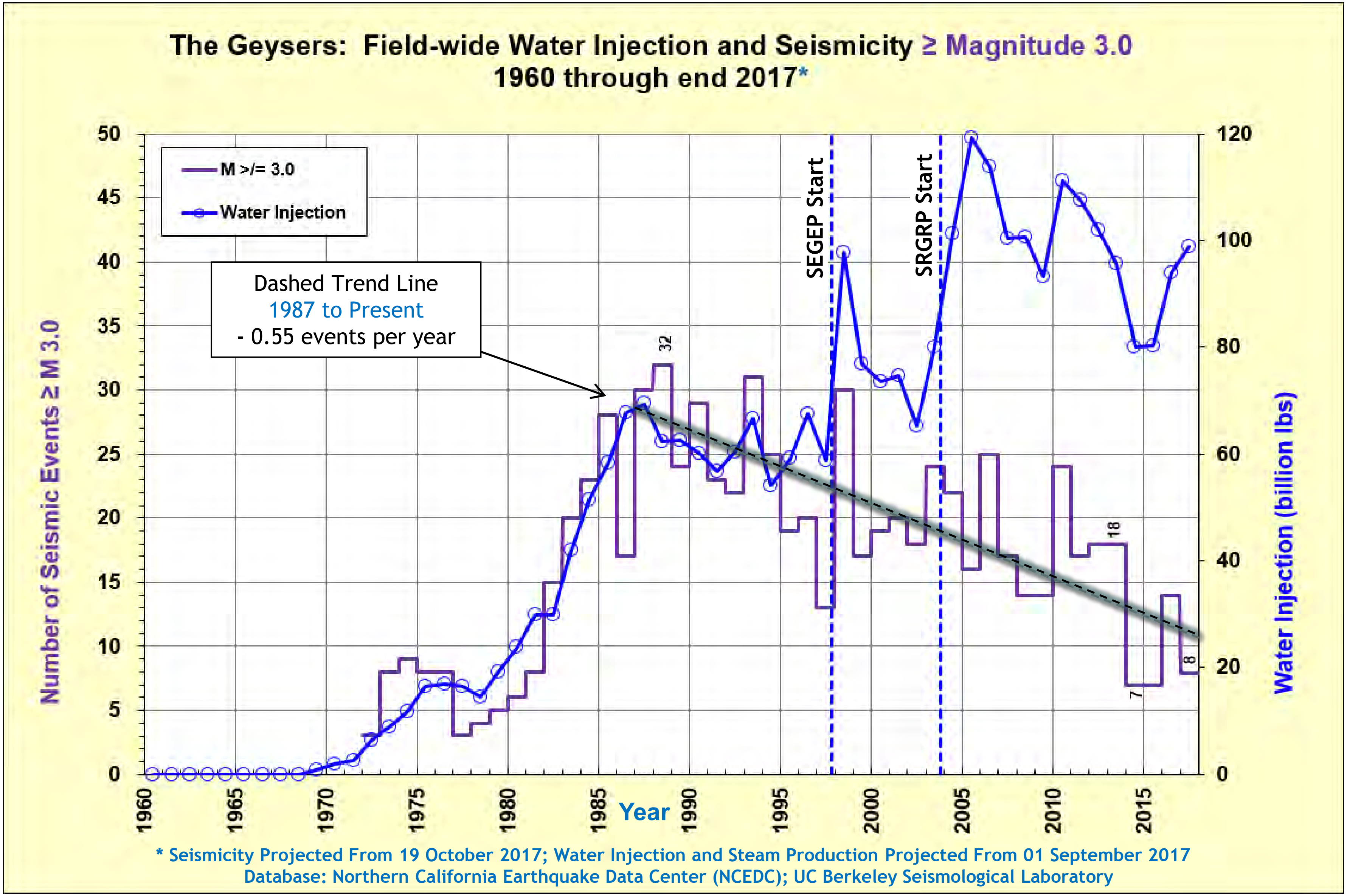
Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 2.0



Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 2.5



Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 3.0



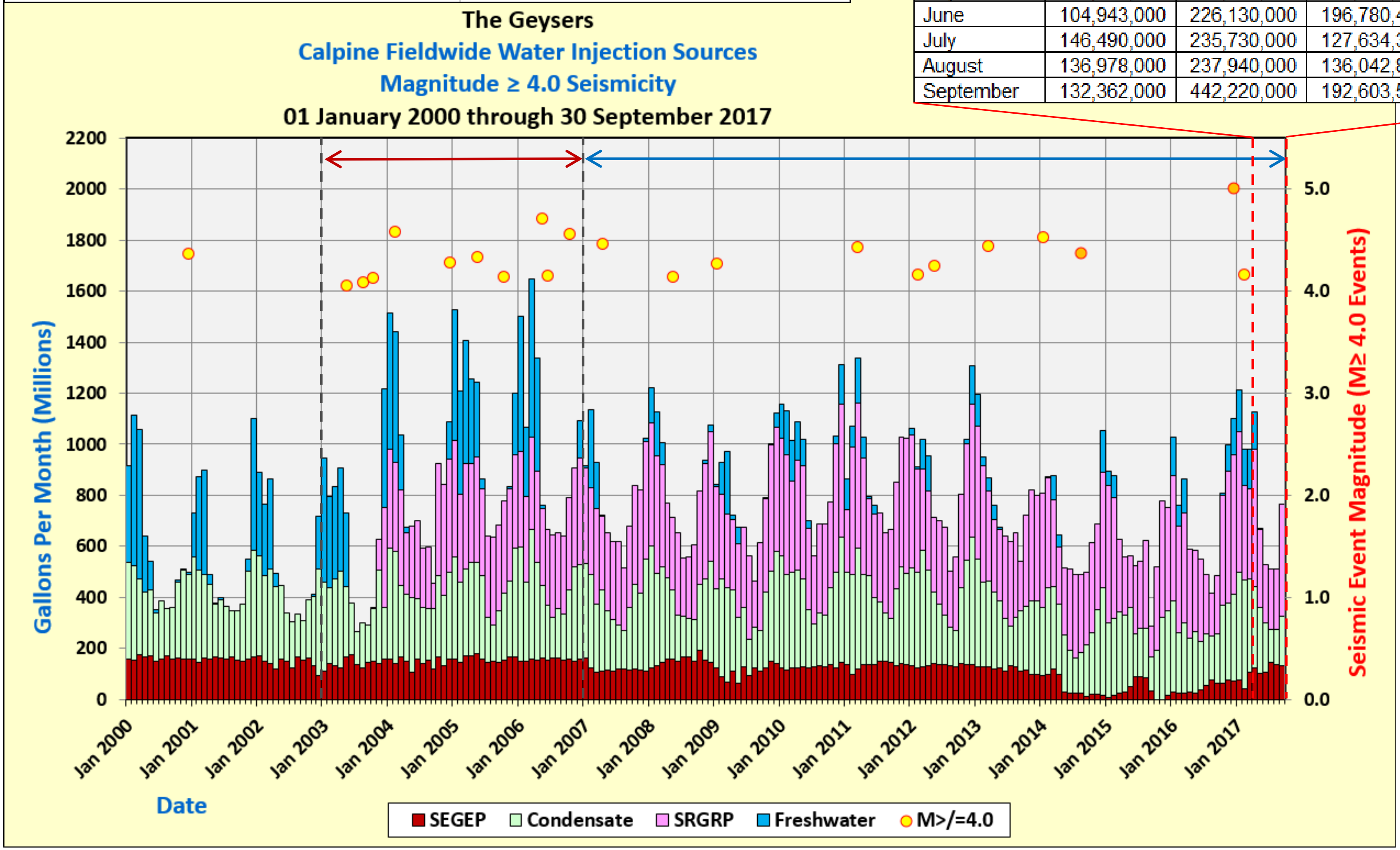
Monthly Field-wide Water Injection By Source vs. Magnitude ≥ 4.0 Seismicity

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

Time Period	Magnitude ≥ 4.0 Seismic Events
January 2003 through December 2006	2.50 per year
January 2007 through March 2017	0.94 per year

Water Supply for Reporting Period (Six Months)

Water Injection Sources (Gallons)				
Month	SEGEP	SRGRP	Condensate	Fresh Water
April	125,545,000	534,570,000	318,340,965	150,576,275
May	101,653,000	307,570,000	258,352,022	3,244,746
June	104,943,000	226,130,000	196,780,403	0
July	146,490,000	235,730,000	127,634,358	0
August	136,978,000	237,940,000	136,042,883	0
September	132,362,000	442,220,000	192,603,510	0



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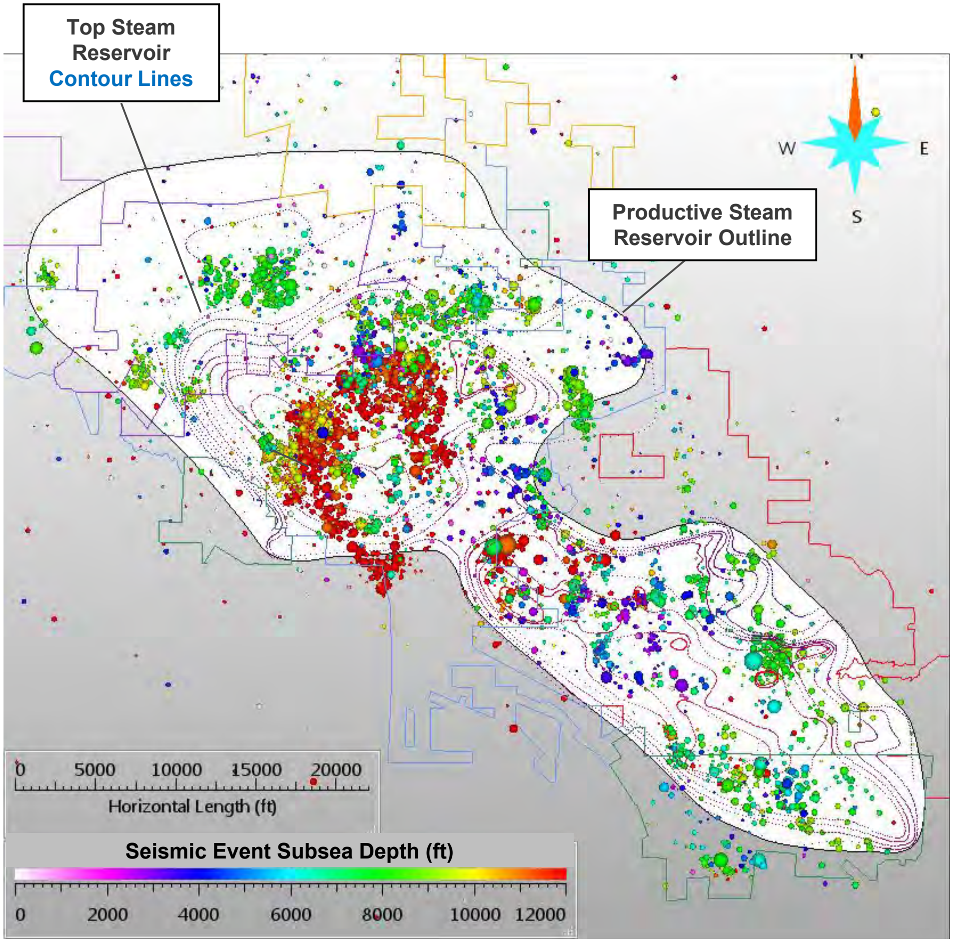
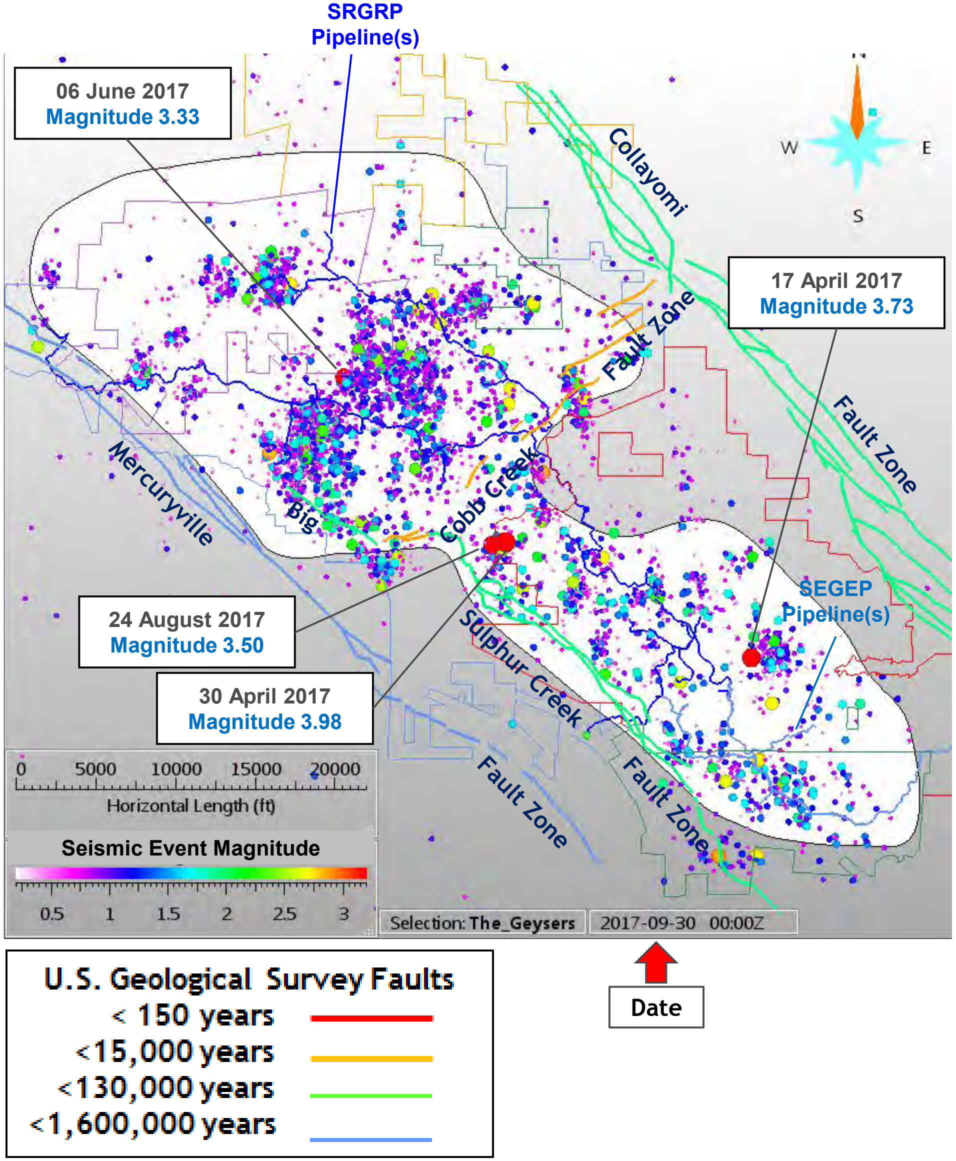
Fieldwide Induced Seismicity Animation

01 April 2017 to 30 September 2017





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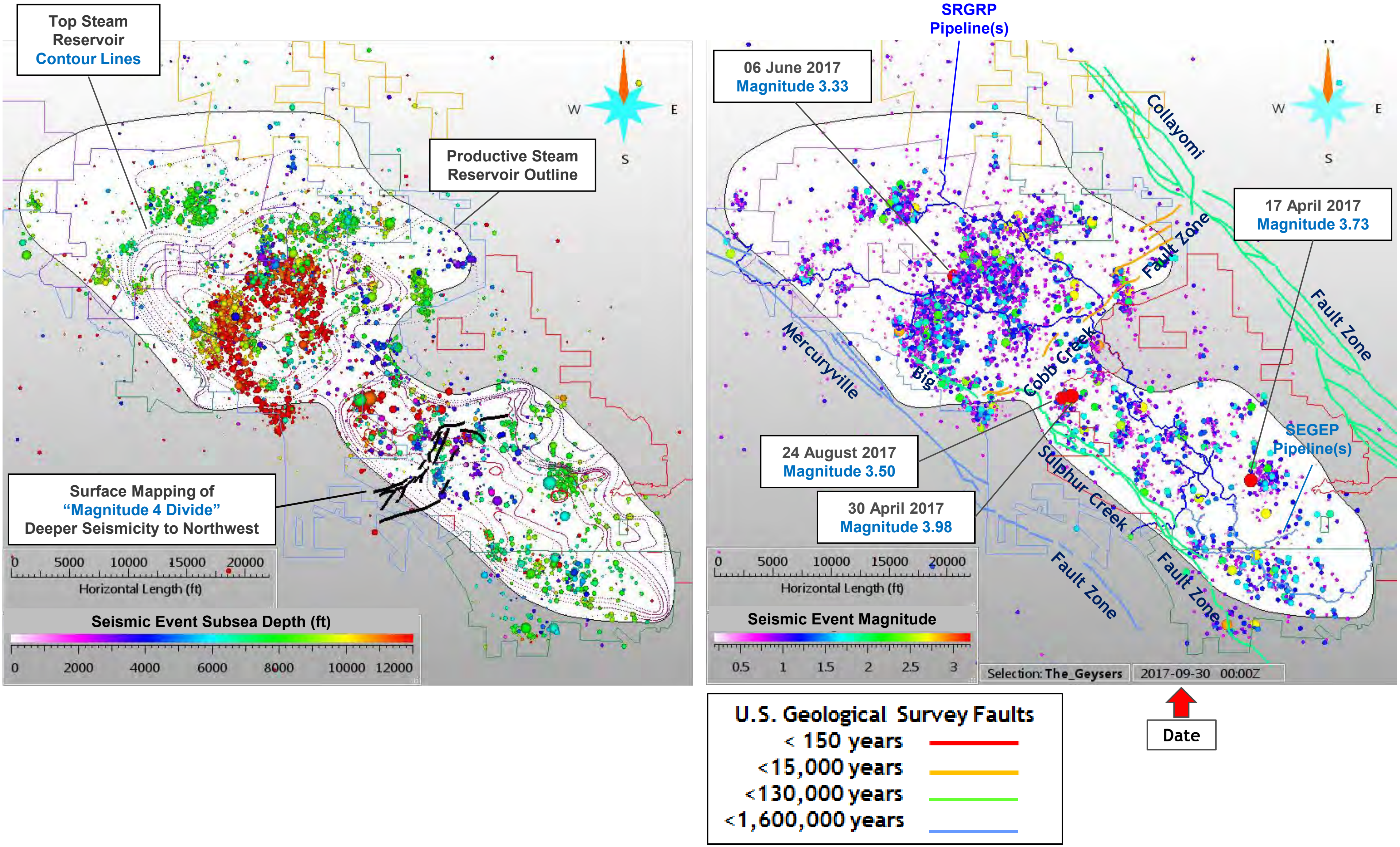

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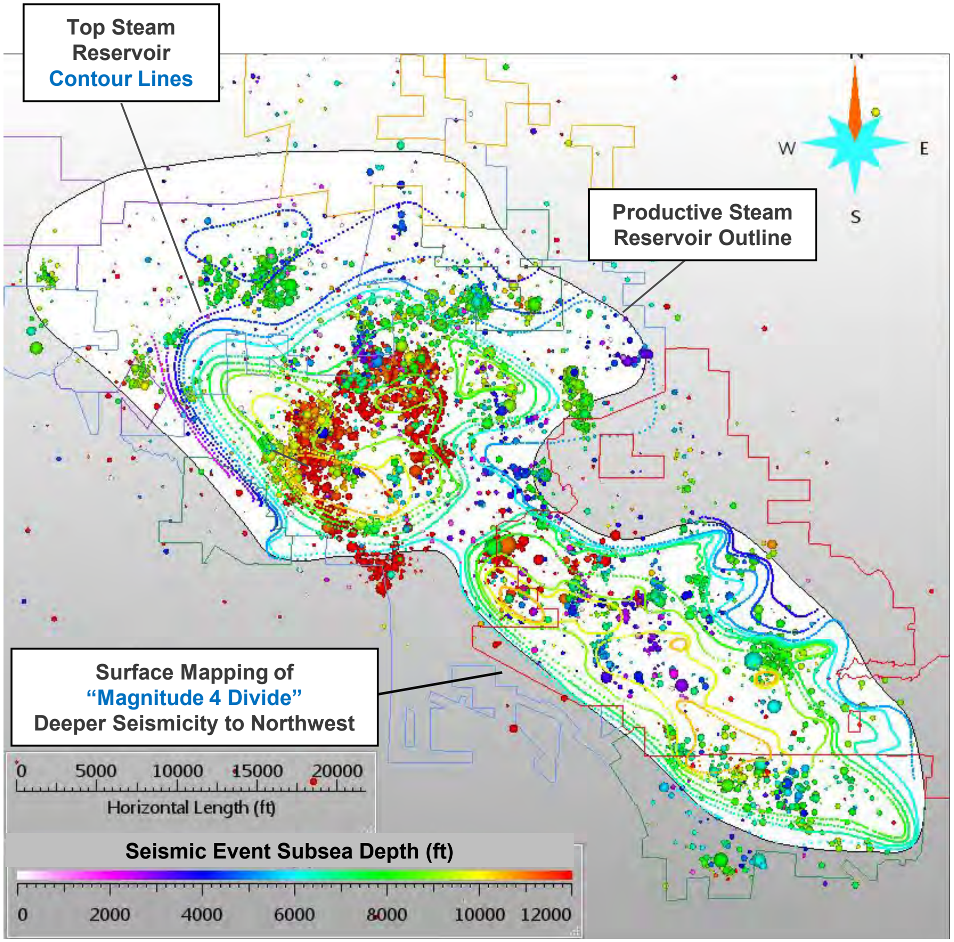
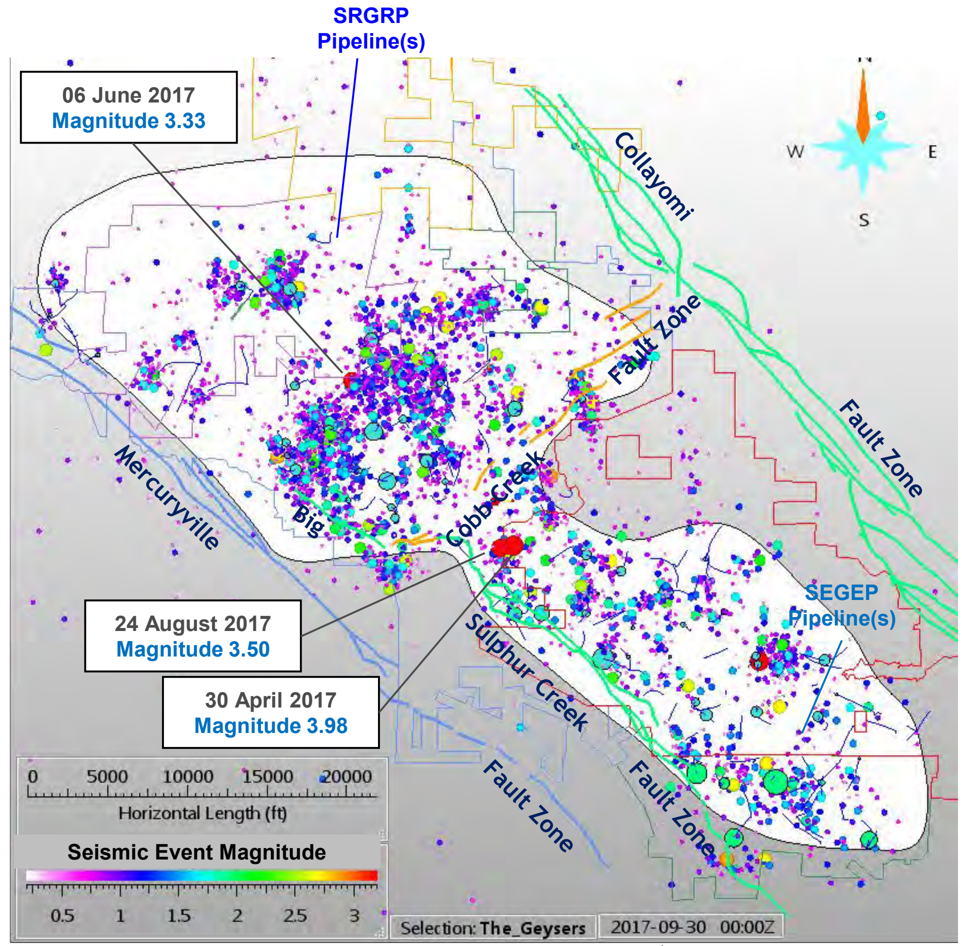
Fieldwide Induced Seismicity Animation

01 April 2017 to 30 September 2017 (WITH WATER INJECTION VOLUMES)





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

Date

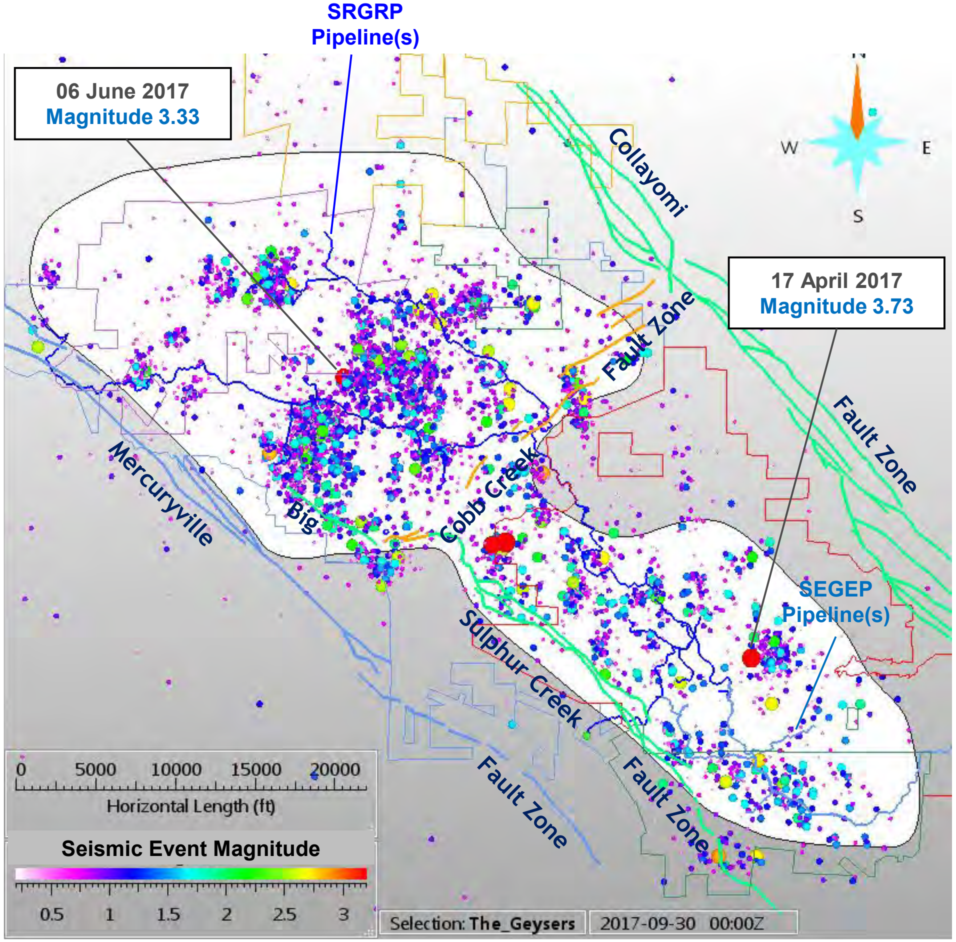
Calpine Seismicity Hotline

The communities are understandably focused on efforts to recover from the Valley Fire, resulting in only a total of two calls from Anderson Springs to the Calpine Community Hotline during the current reporting period of 01 April 2017 to 30 September 2017. The events responsible for calls were:

Magnitude 3.73 Seismic Event (one call)
Date and Time: 17 April 2017 at 20:31:45 UTC
Latitude: North 38.77400
Longitude: West 122.72234
Depth: 4430 feet (1.35 km) Below Sea Level

Magnitude 3.33 Seismic Event (one call)
Date and Time: 06 June 2017 at 01:49:39 UTC
Latitude: North 38.82250
Longitude: West 122.81150
Depth: 9940 feet (3.03 km) Below Sea Level

There was also a call describing a sharp pre-dawn jolt followed by a partial power outage. Nor surprisingly, it was thought that this may be a seismic event. However, an immediate investigation identified no correlated seismic event.
A subsequent daylight investigations indicated a very large tree fell close to the caller's home.



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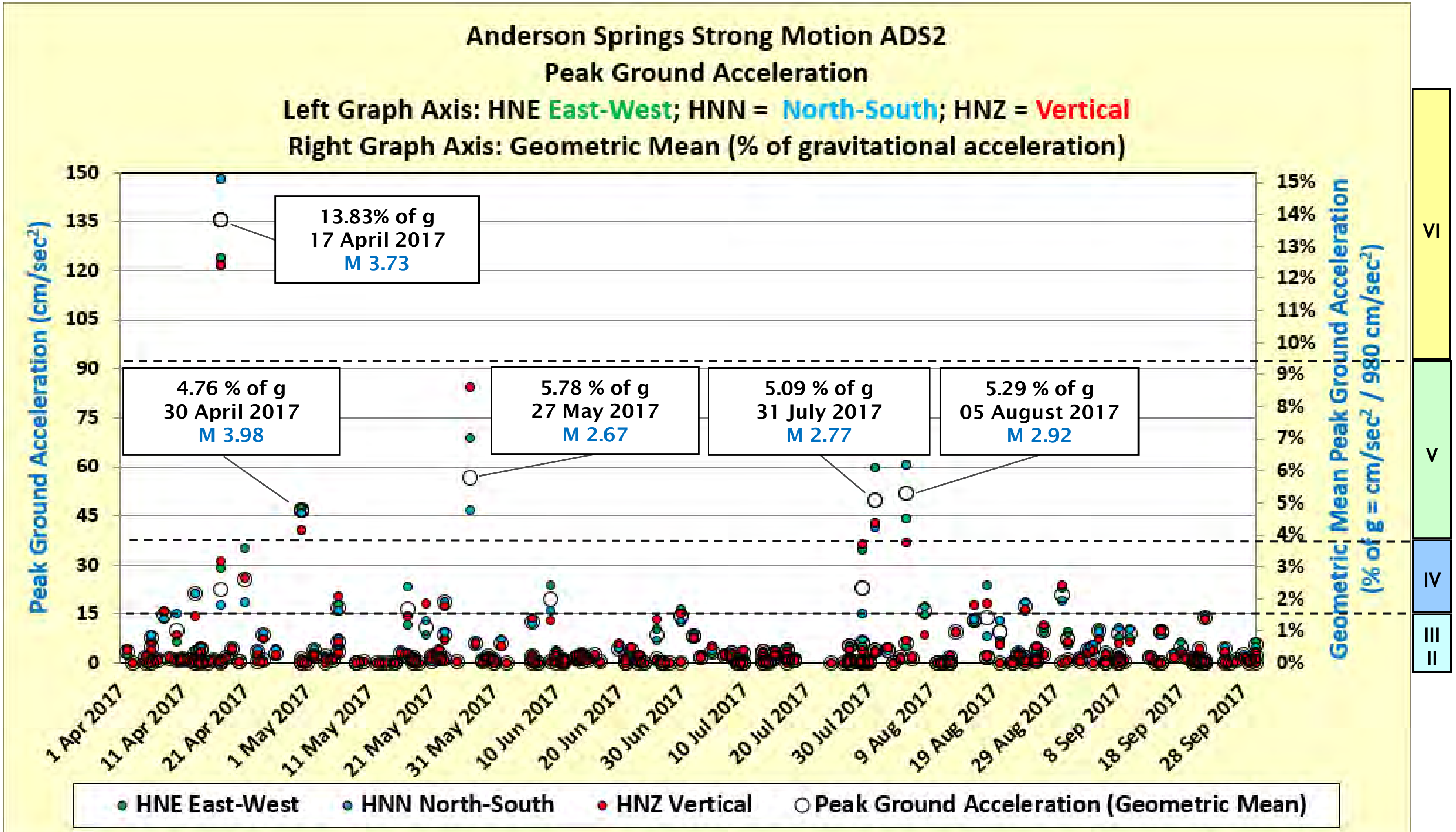
Anderson Springs Strong Motion Station ADS2



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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

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Calpine Geysers Water Injection Goals

Improve Injection Distribution

- Expansion to northwest and away from communities
- Additional injection wells
- Shallow low-rate injectors (~150 gallons/minute)

Minimize Injection Rate Variations

- Individual wells and field-wide
- Emphasis on limited variation for wells nearest communities
- Suitable injection rates per well continually evaluated (dependent on local geology)
- Designed any tests concerning injection rate variability far from communities
- More gradual transition of SRGRP water for injection

06 November 2017 email from SRGRP Representative to Central Operations Manager Kevin Petersen:

Here are the discussed flow rate modifications. Please let me know if this is acceptable to Calpine.

Reduce flow from 11.5 mgd * *to 9.5 mgd on November 9th at 8:00 am*
Reduce flow from 9.5 mgd to 7.7 mgd on November 10th at 8:00 am
Reduce flow from 7.7 mgd to 0 mgd on November 11th at 4:00 am

Increase flow to 7.7 mgd on November 12th at 8:00 am

We may be able to increase flow on November 11th if repairs are completed

* mgd = million gallons per day

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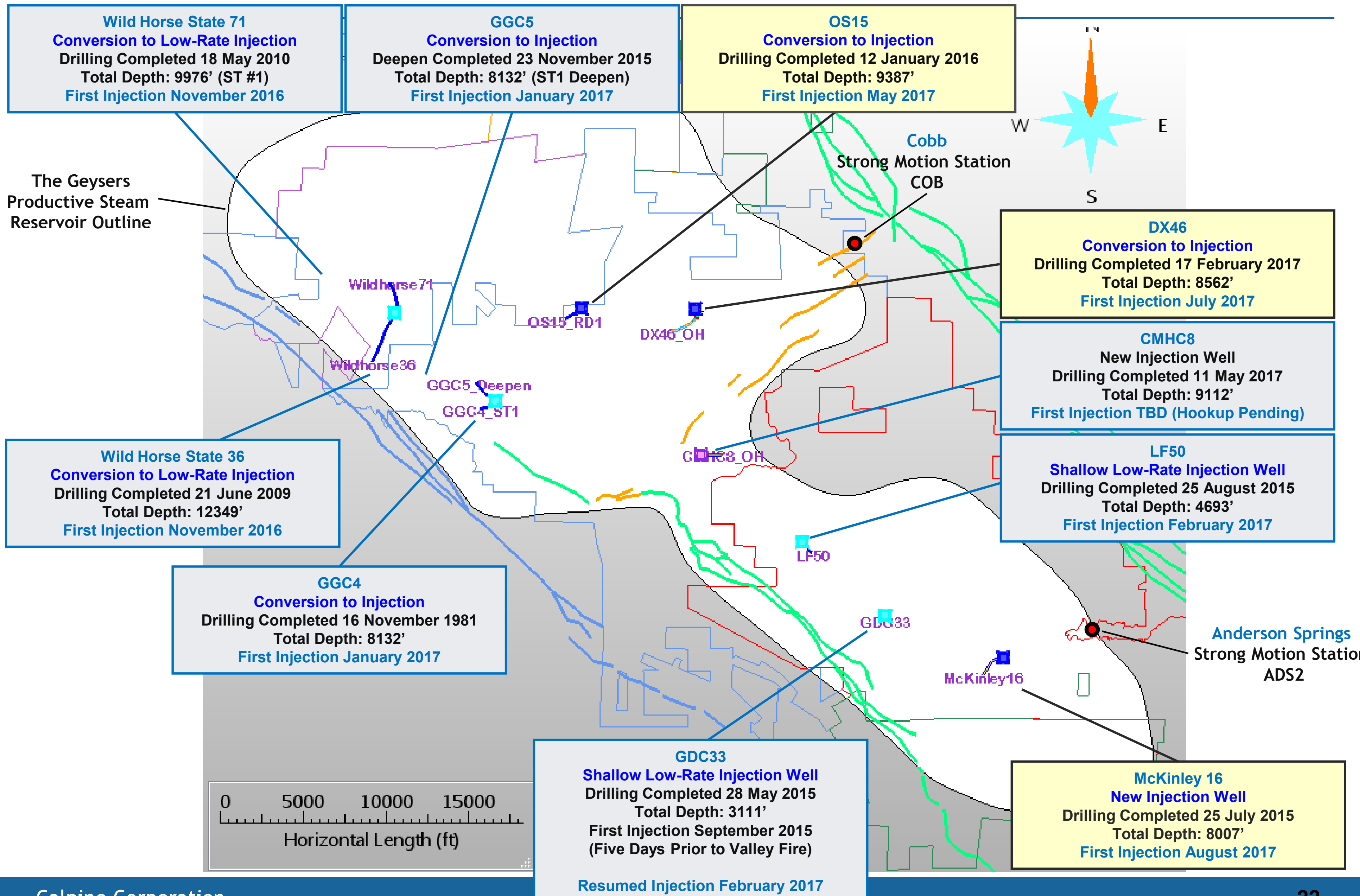
Additional Water Injection Wells to Improve Injection Distribution



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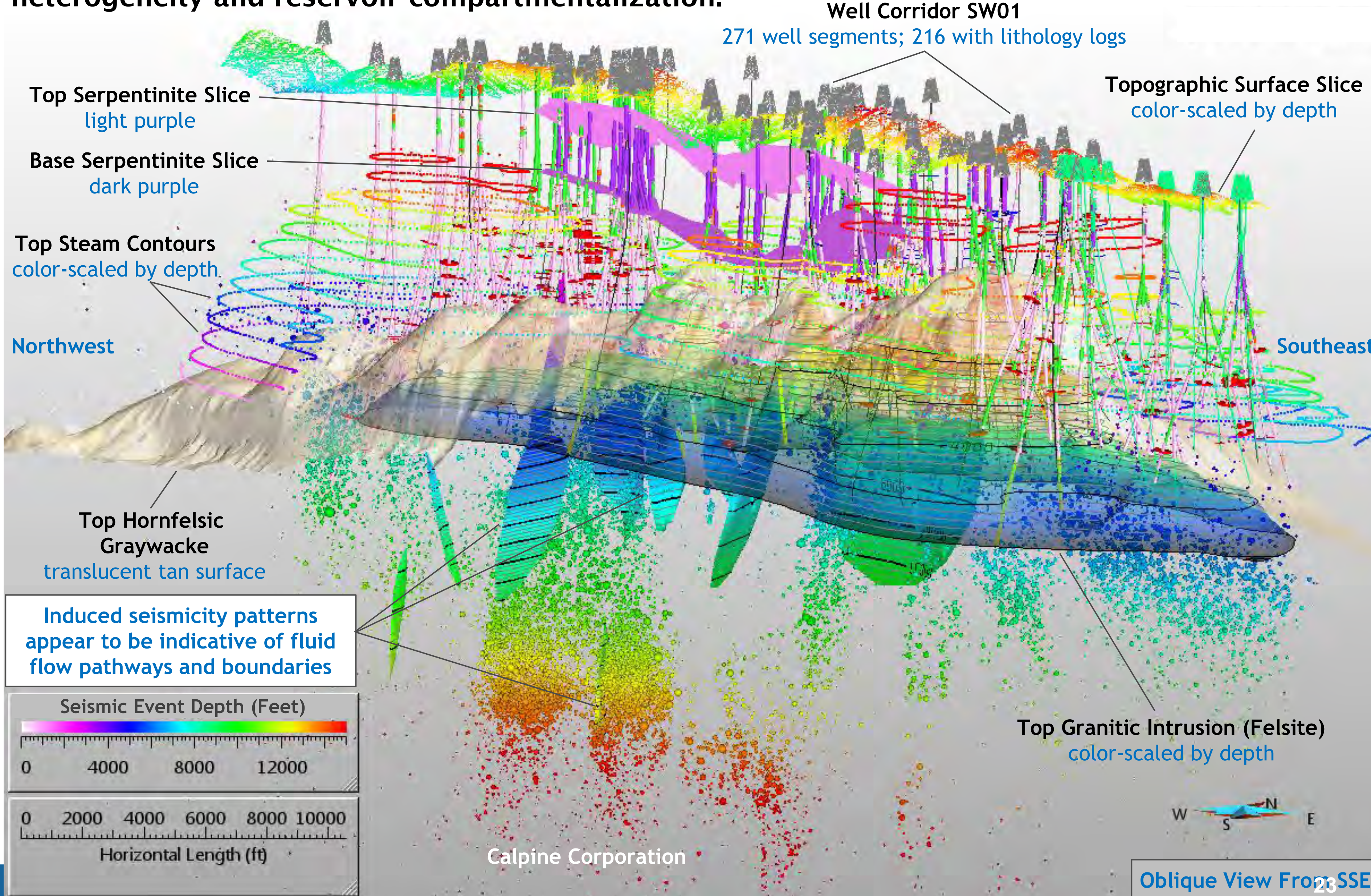
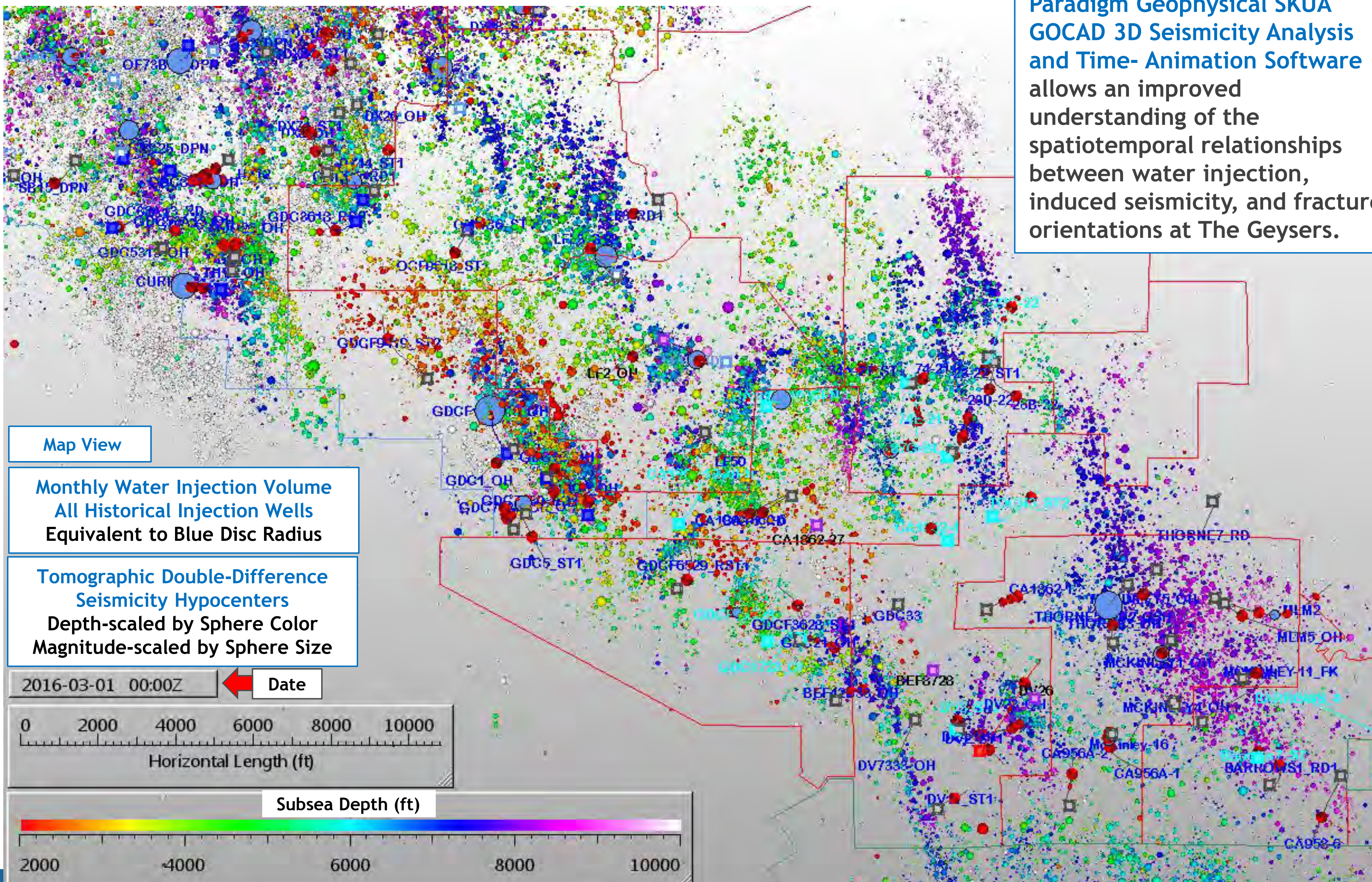
3D Structural Model Building Goal: Improved reservoir management and induced seismicity mitigation through a refined understanding of fluid flow paths, fluid boundaries, reservoir heterogeneity and reservoir compartmentalization.



The Geysers

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

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.

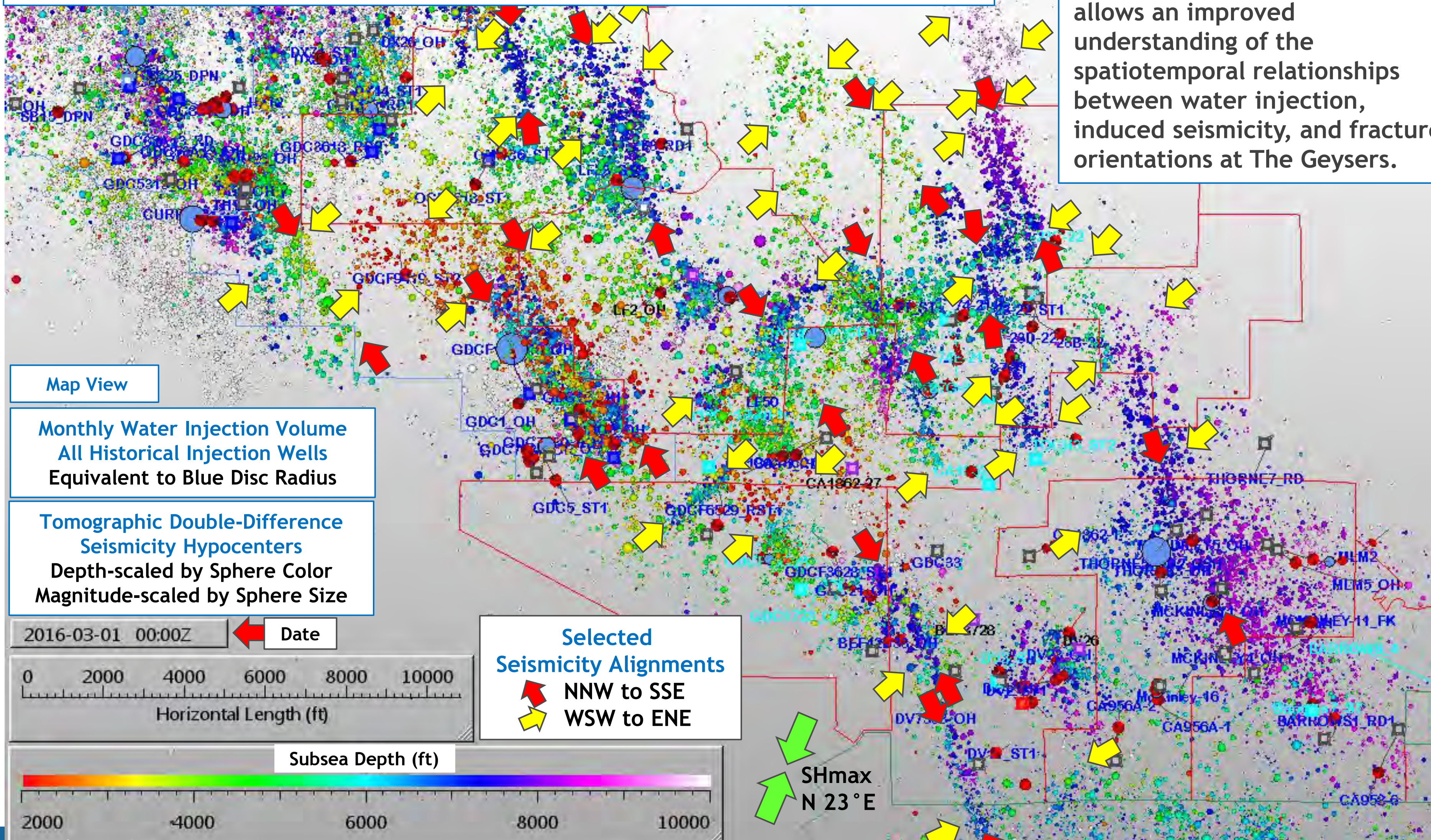


The Geysers

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

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.

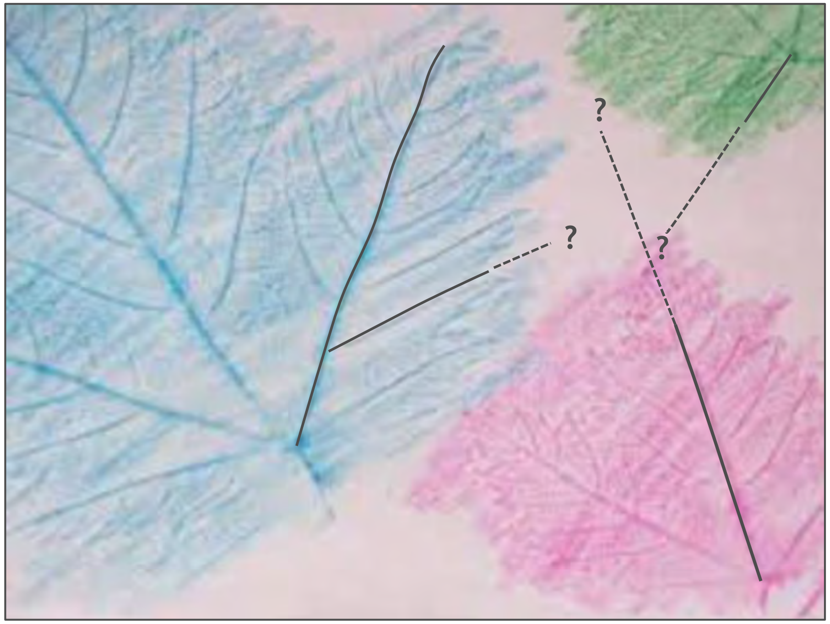
Paradigm Geophysical SKUA GOCAD 3D Seismicity Analysis and Time- Animation Software allows an improved understanding of the spatiotemporal relationships between water injection, induced seismicity, and fracture orientations at The Geysers.



3D Fault Interpretation Technique With Paradigm Geophysical SKUA GOCAD Software

Water Injection Wells illuminate the subsurface similar to the colored pencil showing the patterns in the underlying leaves.

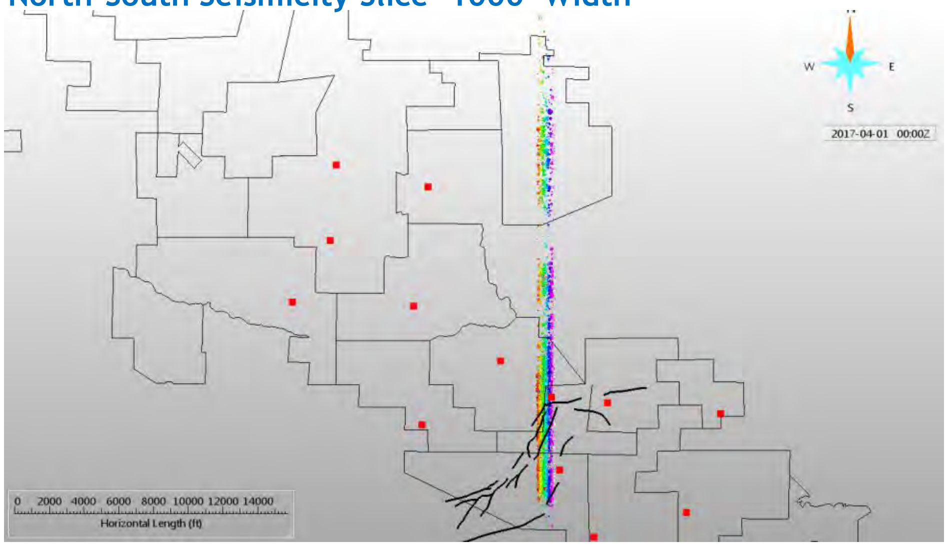
Significant gaps exist where injection well has not illuminated the subsurface.



The Geysers
3D Fault Interpretation Using Oriented Seismicity Slices
Paradigm Geophysical SKUA GOCAD Software

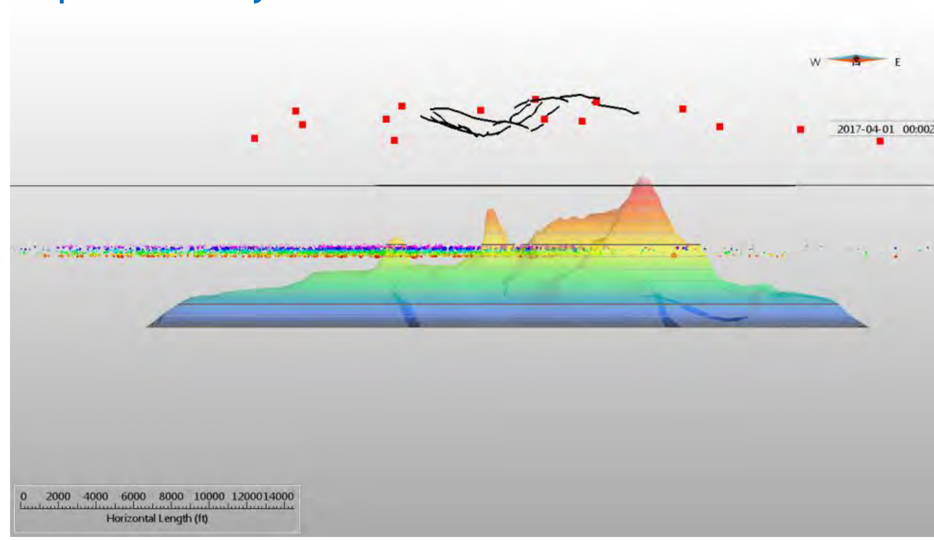
Map View Example

North-South Seismicity Slice 1000' Width



Cross-Sectional View Example

Depth Seismicity Slice 2500' to 3000' Subsea



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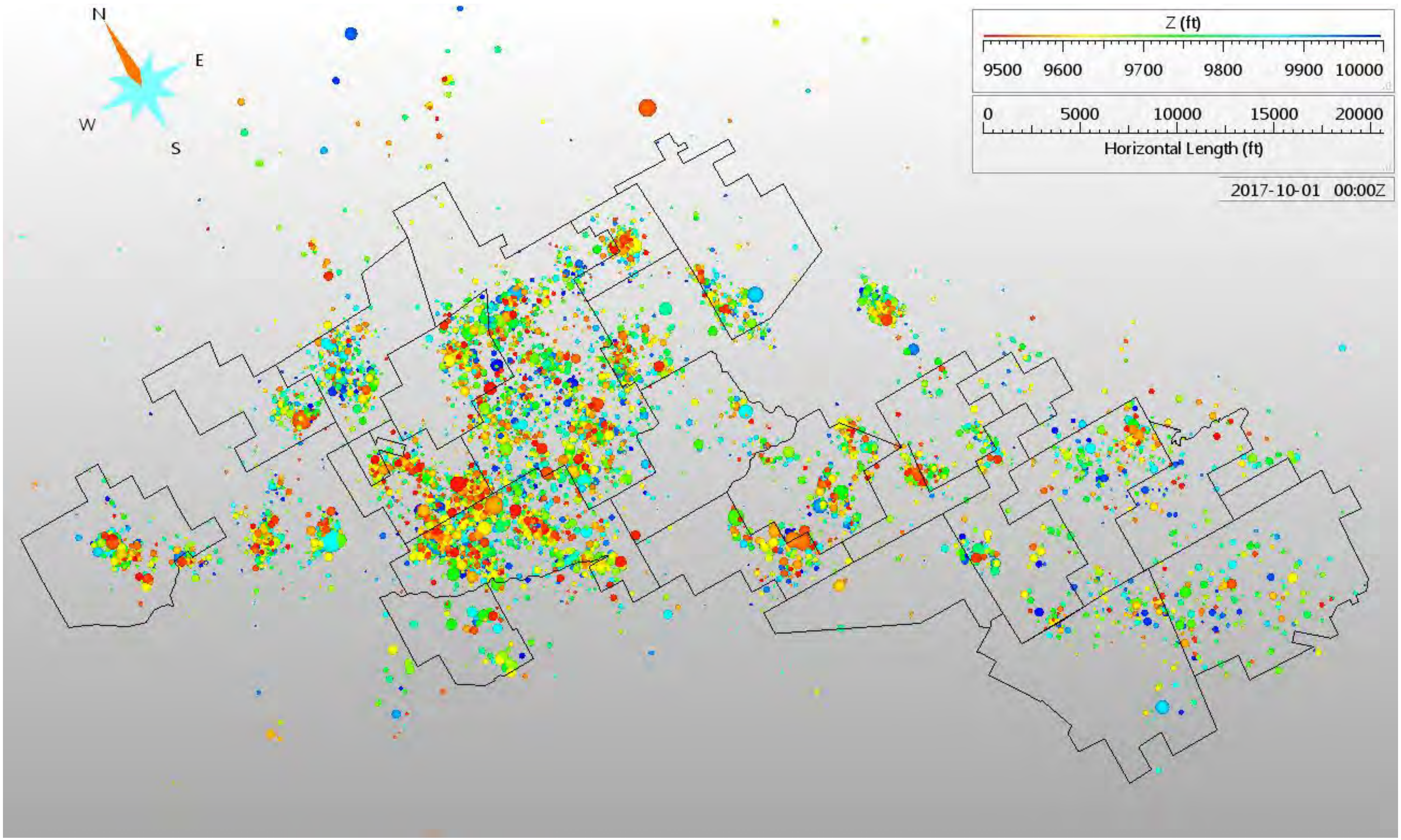
Fault/Fracture Analysis and Interpretation
Depth Slice 9500 to 10000 Feet Subsea



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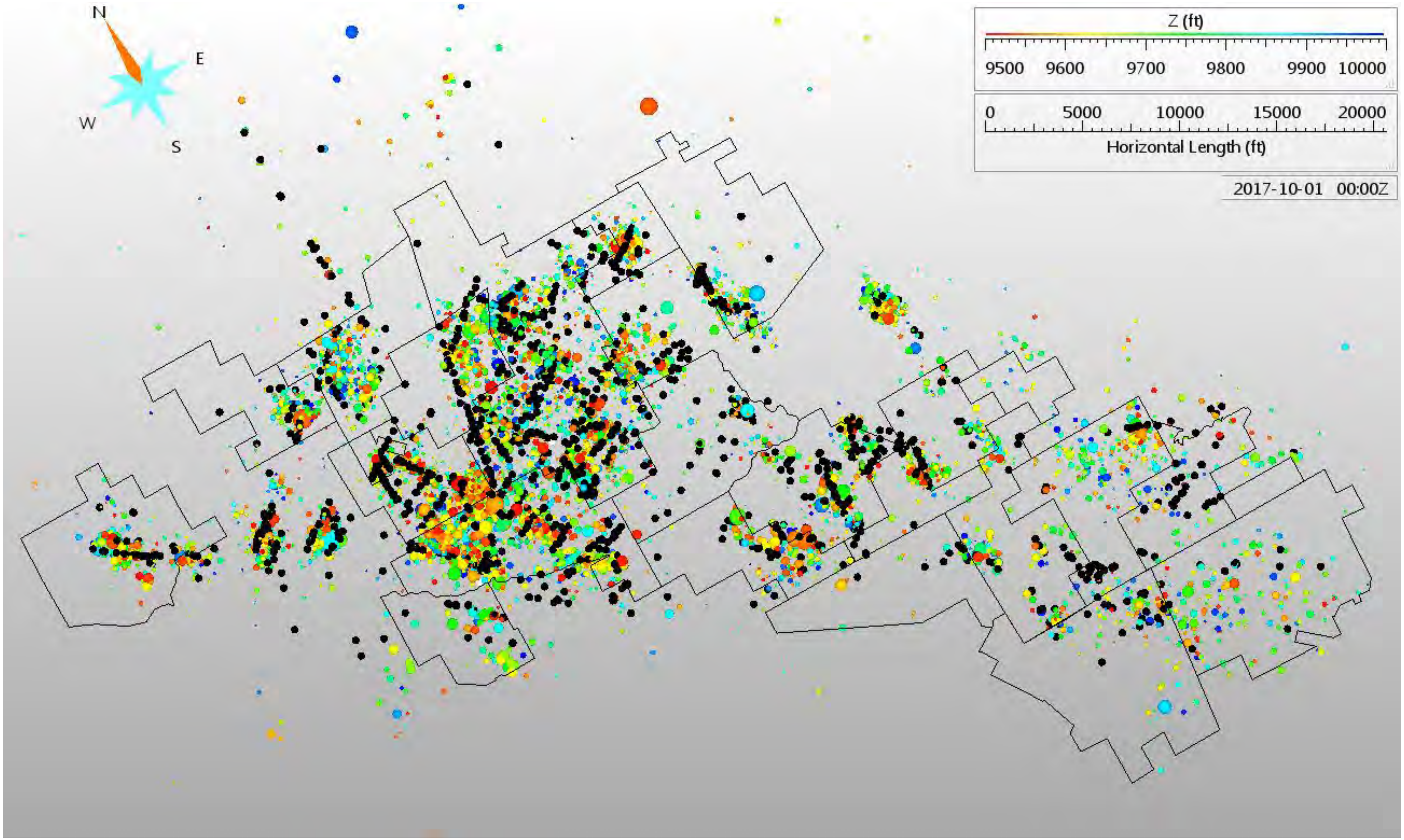

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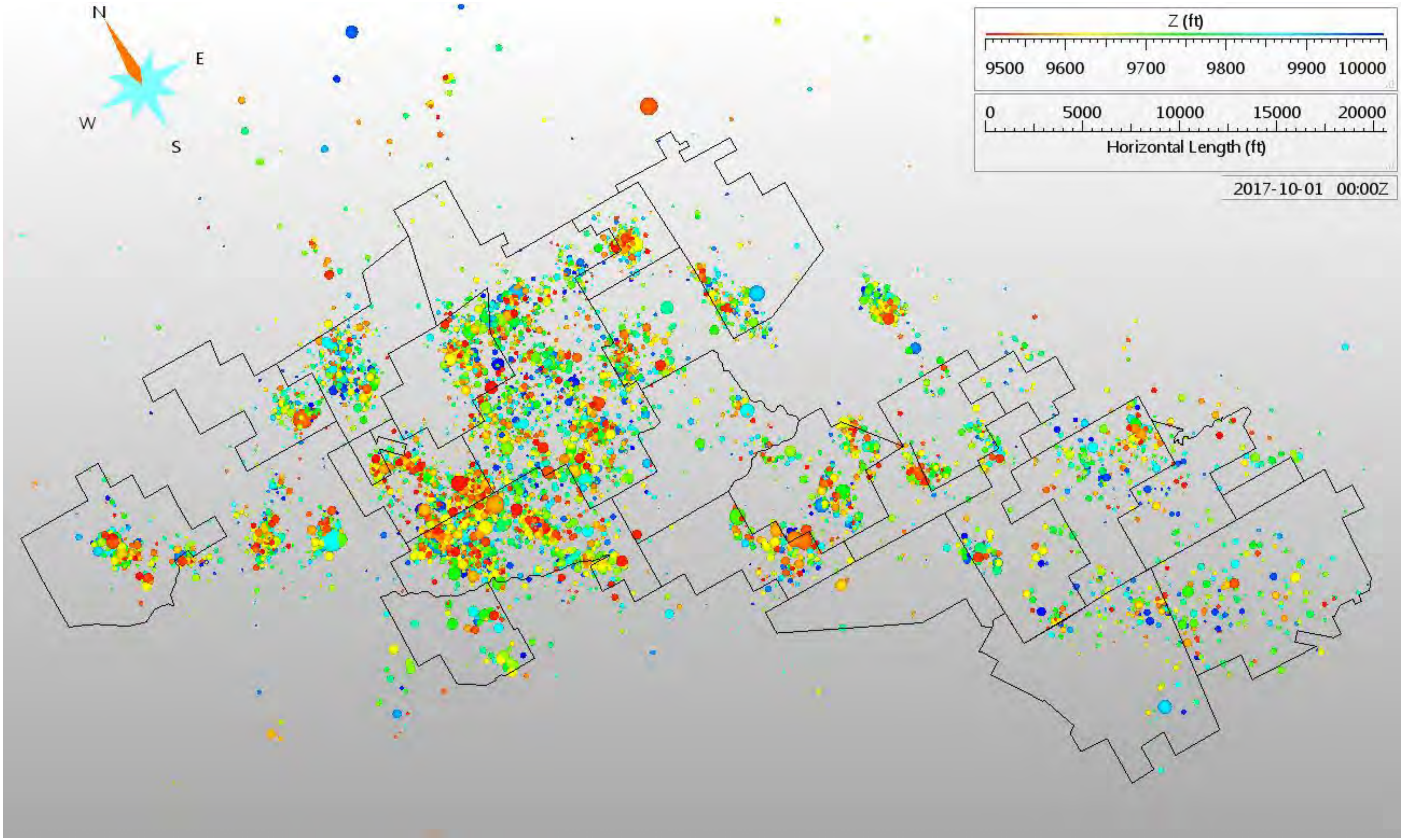
Depth Slice 9500 to 10000 Feet Subsea



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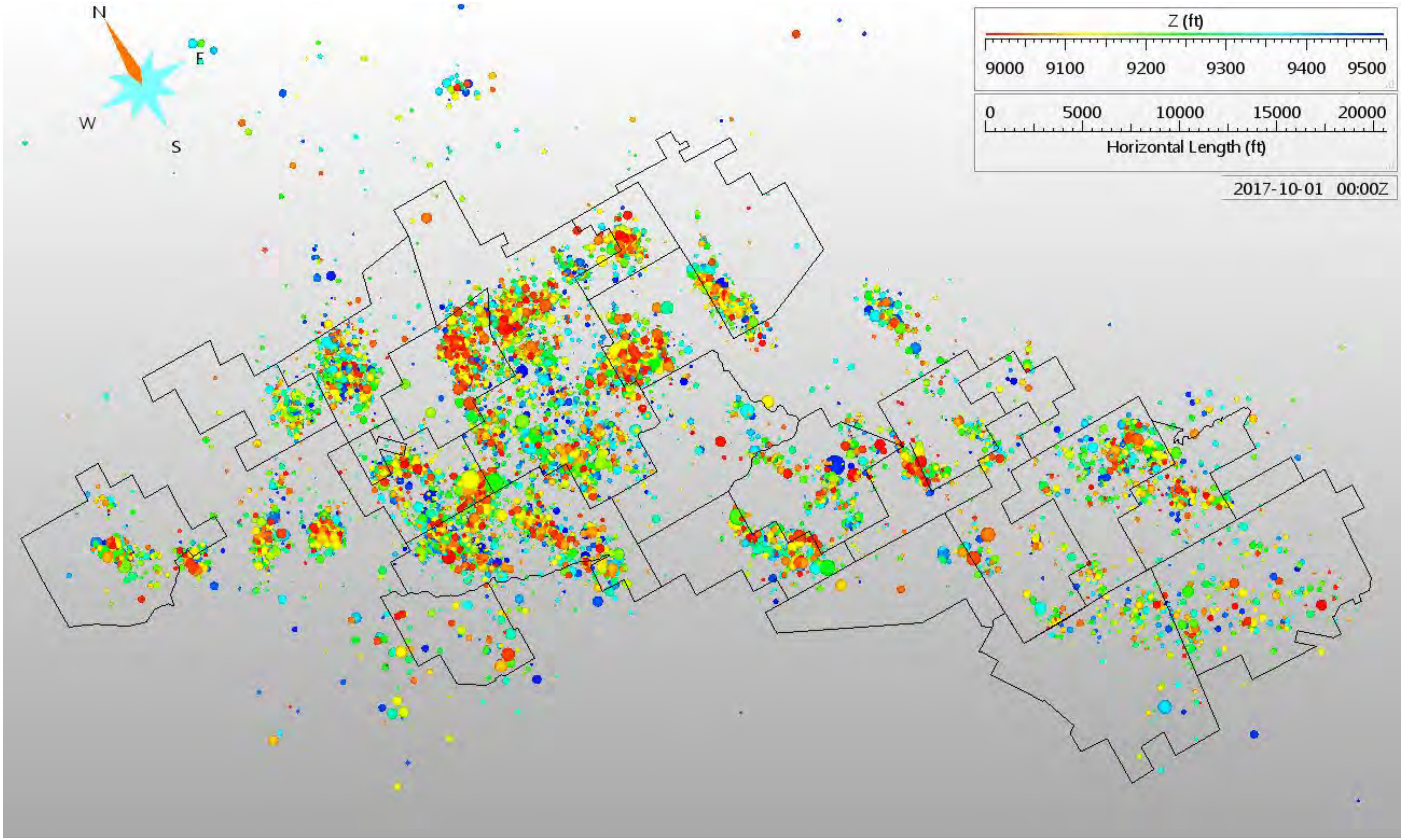
Fault/Fracture Analysis and Interpretation
Depth Slice 9000 to 9500 Feet Subsea



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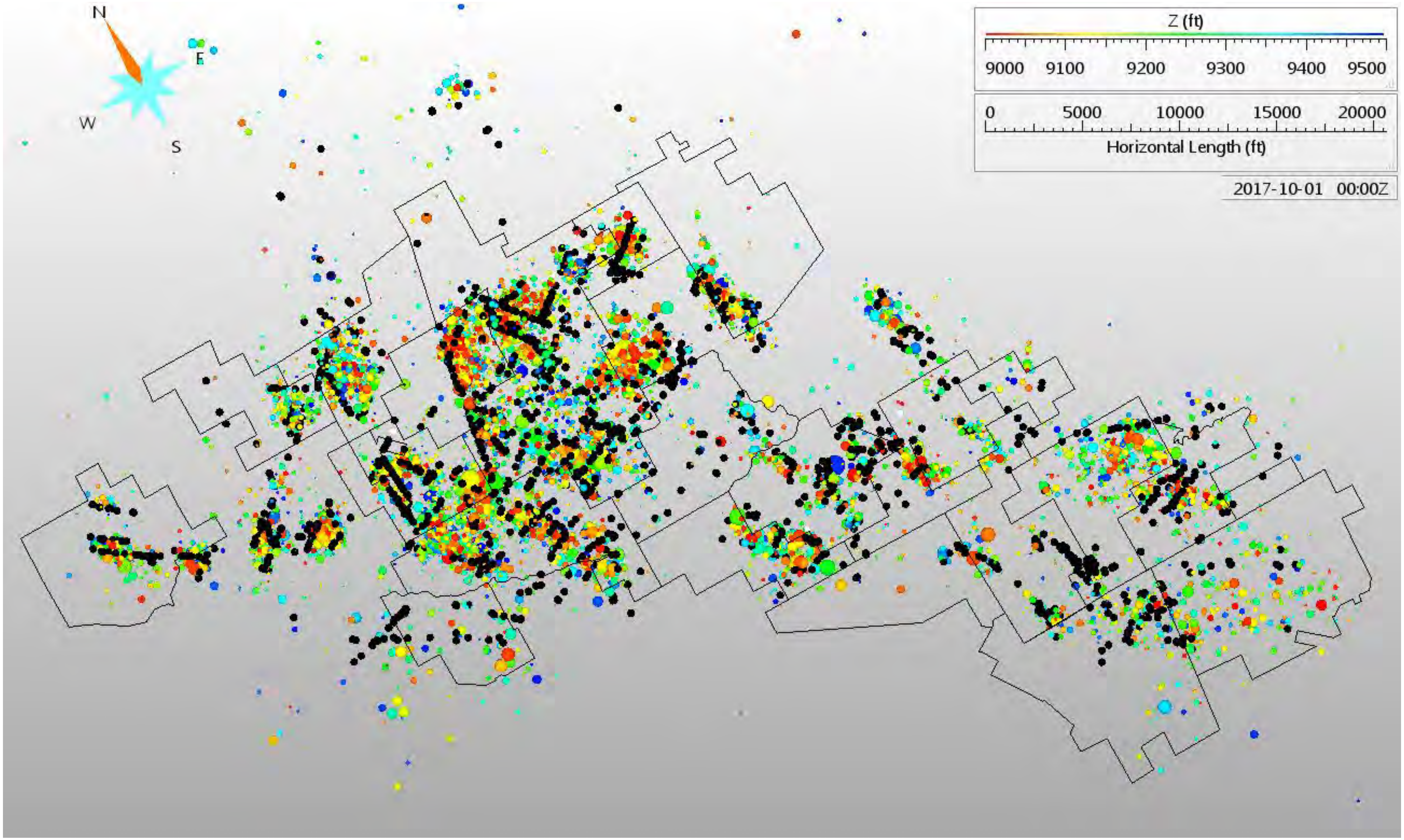
Fault/Fracture Analysis and Interpretation
Depth Slice 9000 to 9500 Feet Subsea



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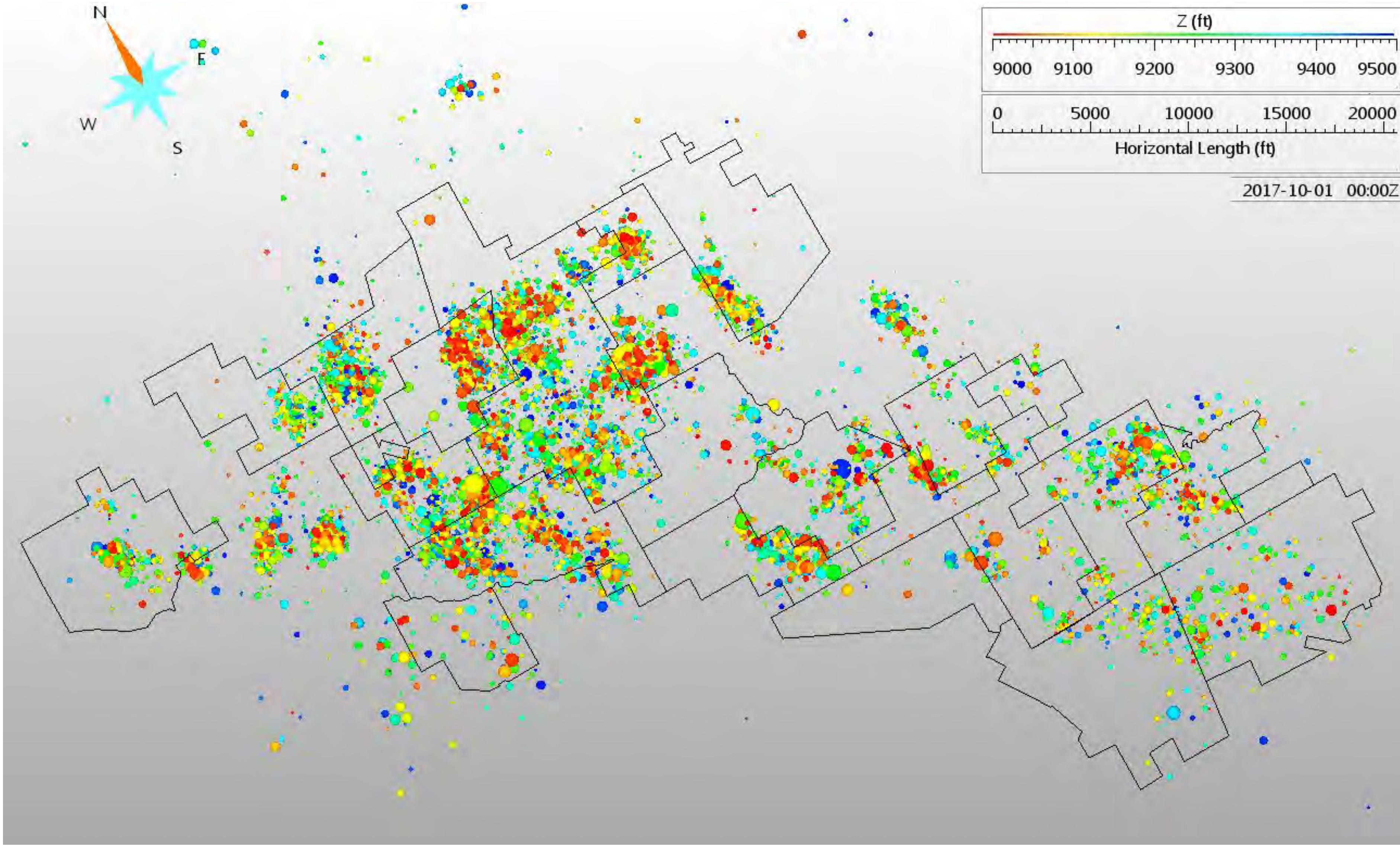
Fault/Fracture Analysis and Interpretation
Depth Slice 9000 to 9500 Feet Subsea



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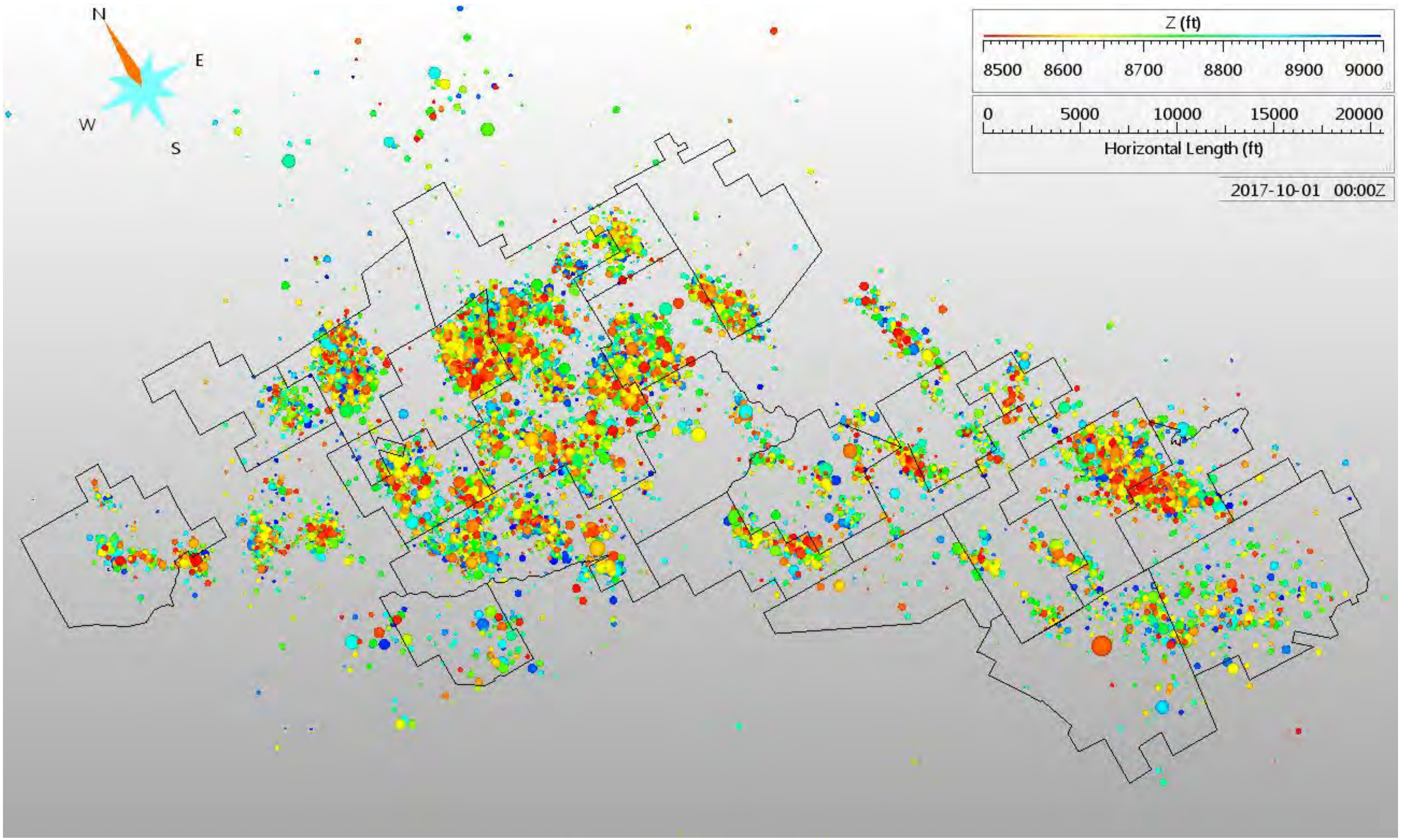
Fault/Fracture Analysis and Interpretation
Depth Slice 8500 to 9000 Feet Subsea



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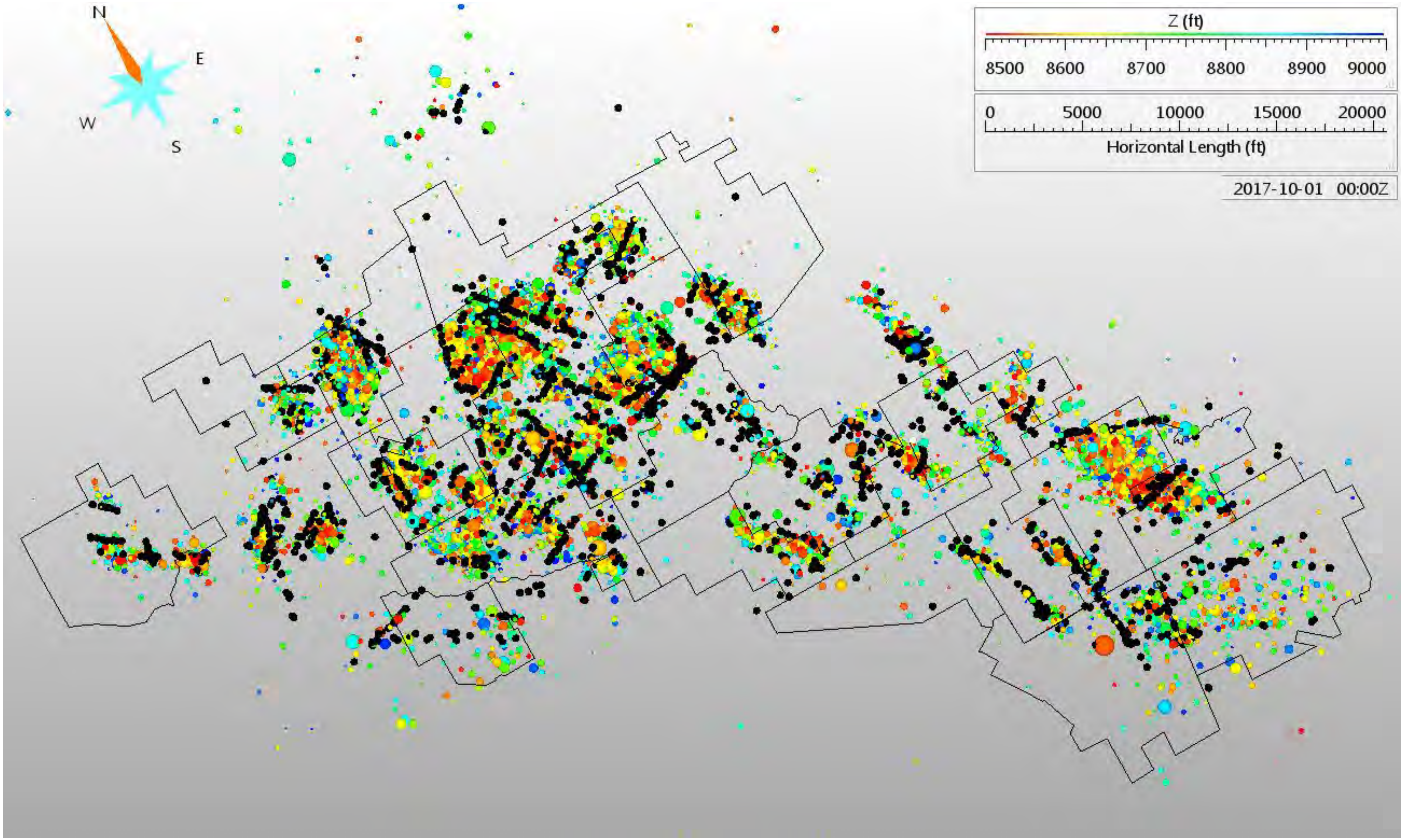
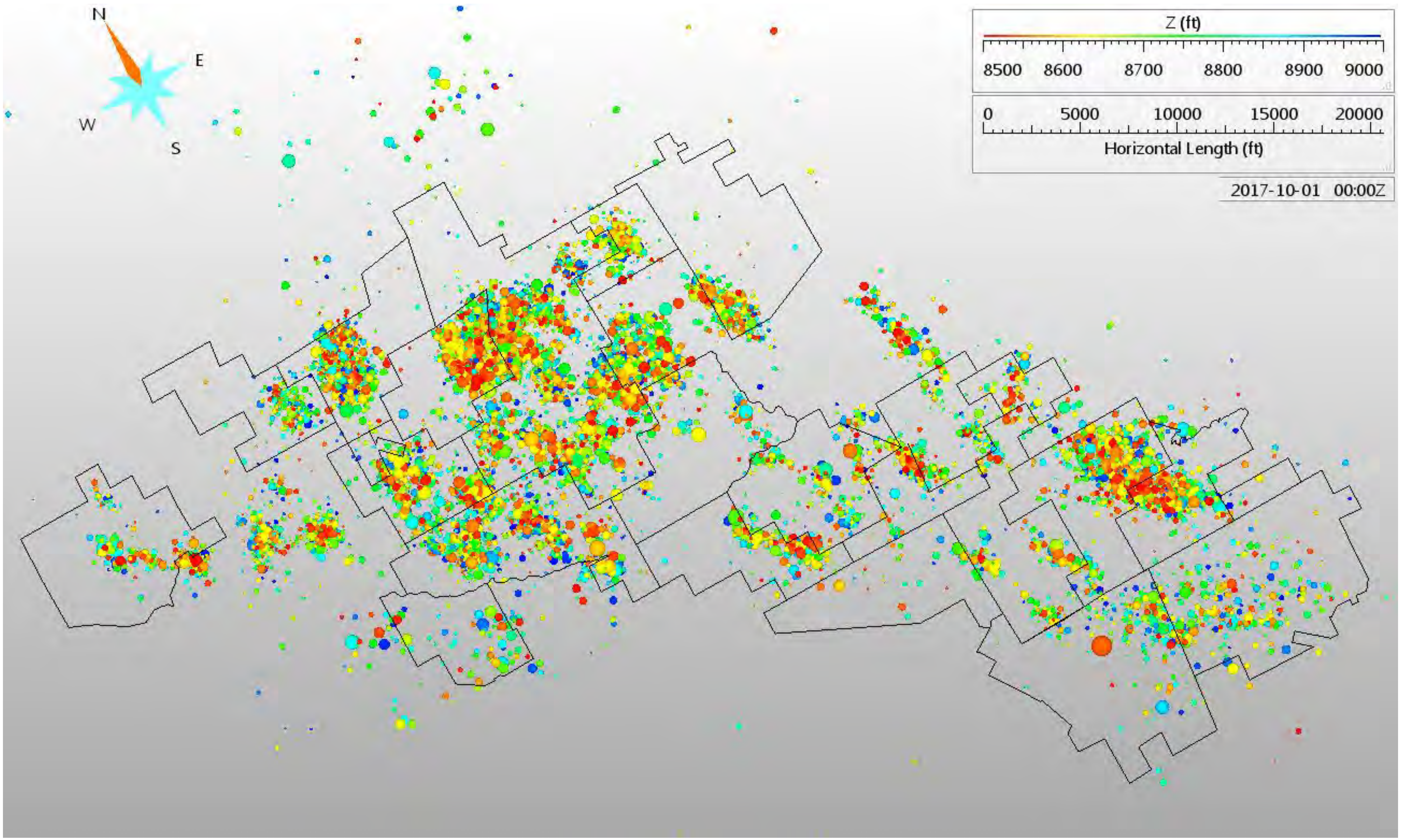
Fault/Fracture Analysis and Interpretation
Depth Slice 8500 to 9000 Feet Subsea



Seismic Monitoring Advisory Committee Meeting
Fault/Fracture Analysis and Interpretation
Depth Slice 8500 to 9000 Feet Subsea



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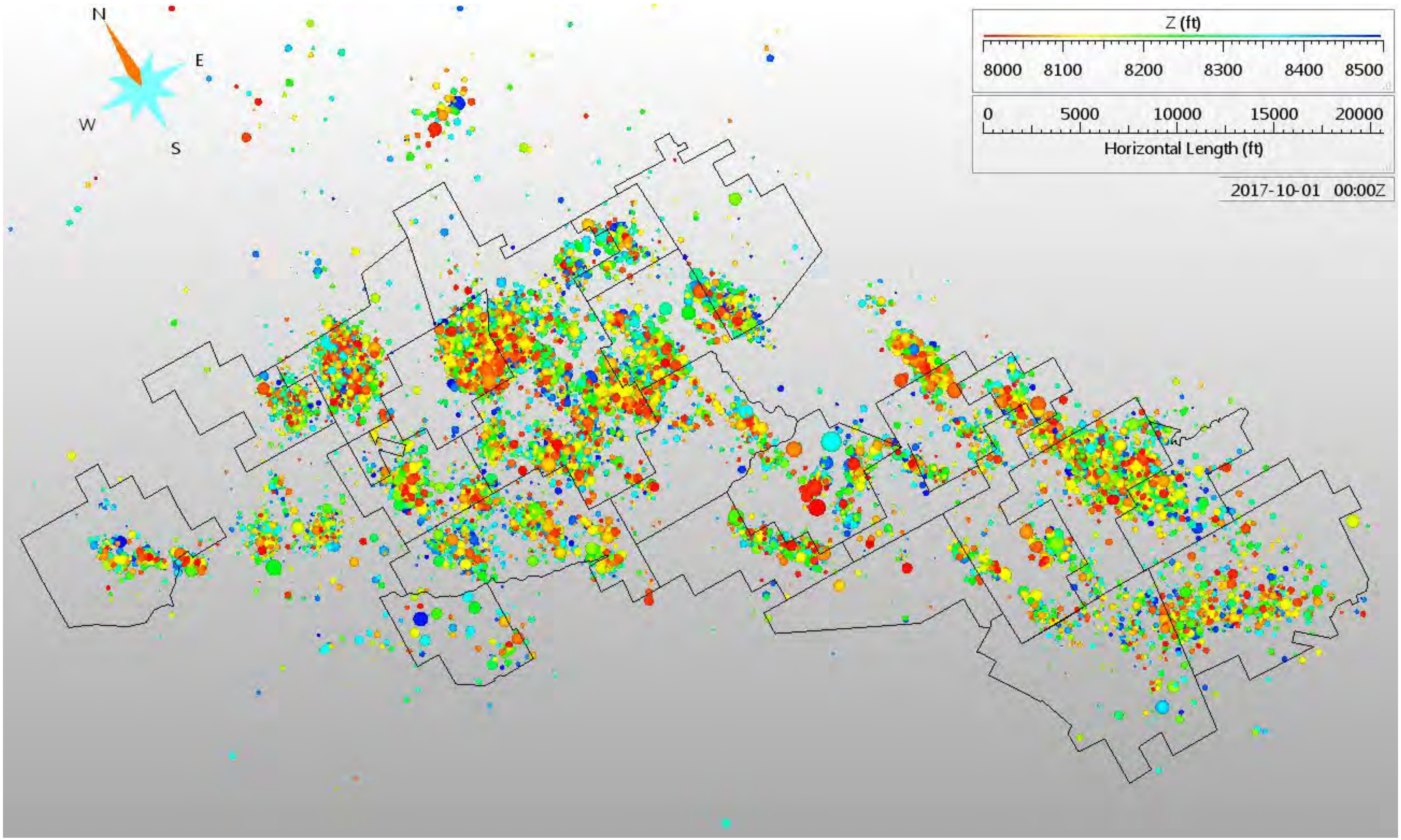
Fault/Fracture Analysis and Interpretation
Depth Slice 8000 to 8500 Feet Subsea



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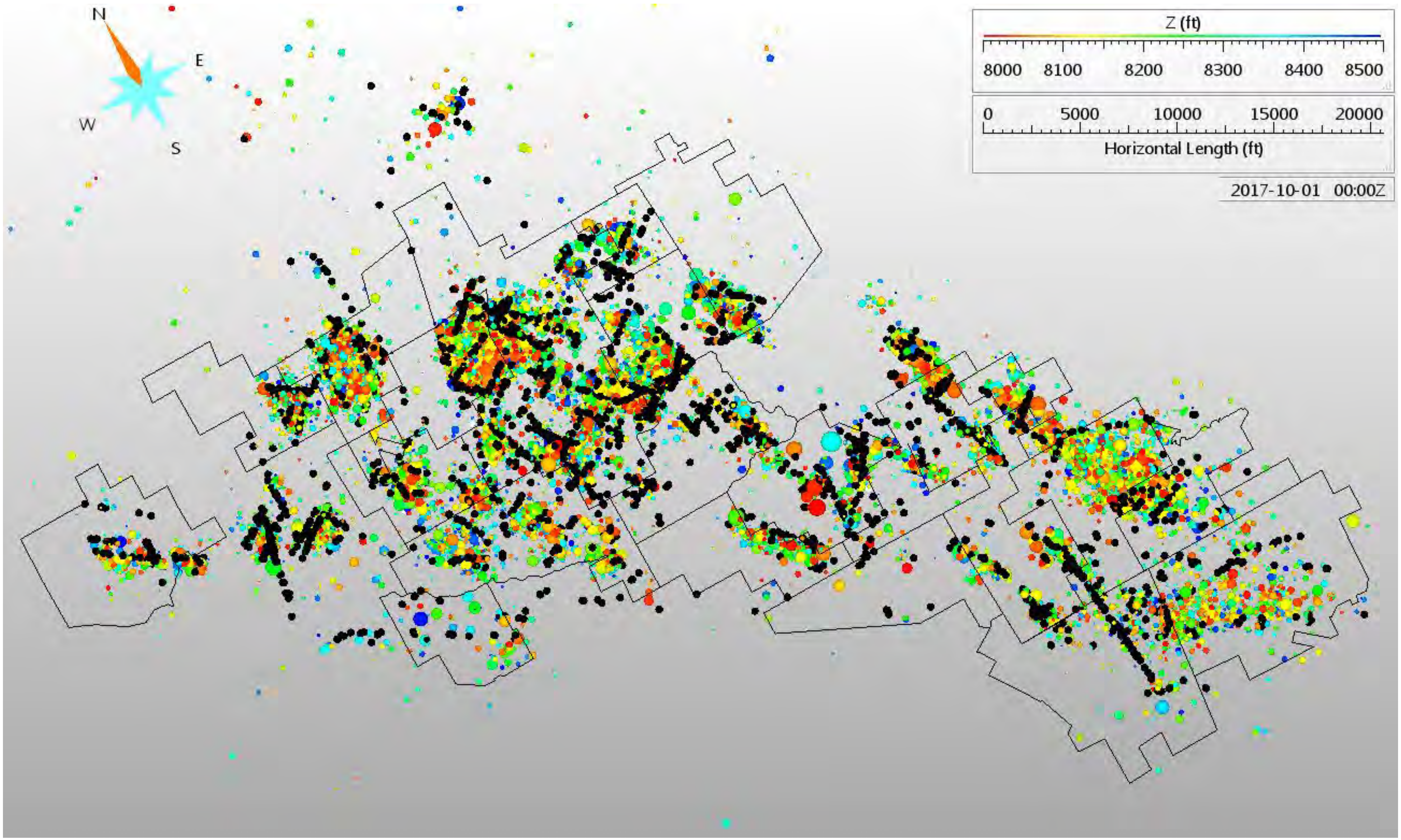
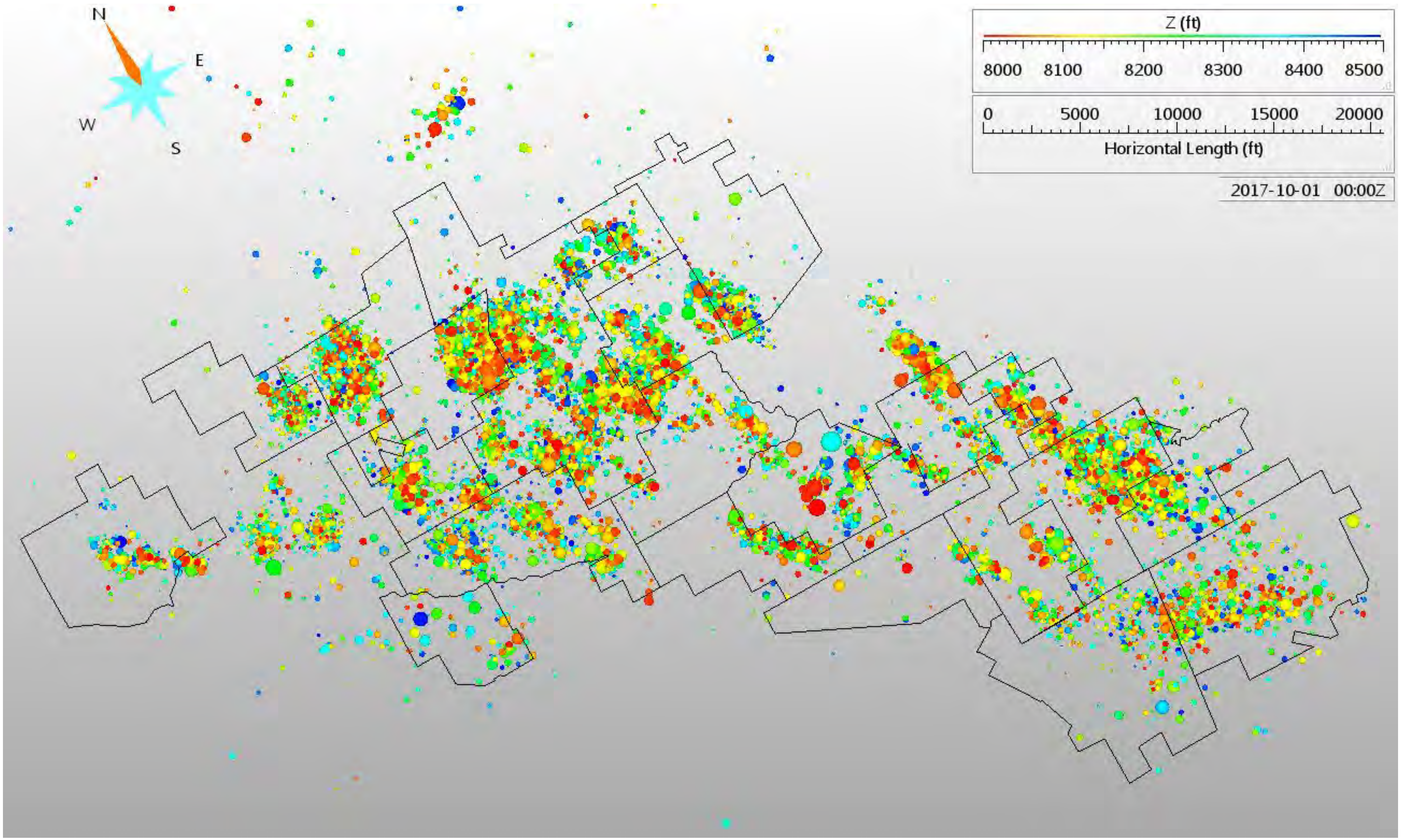
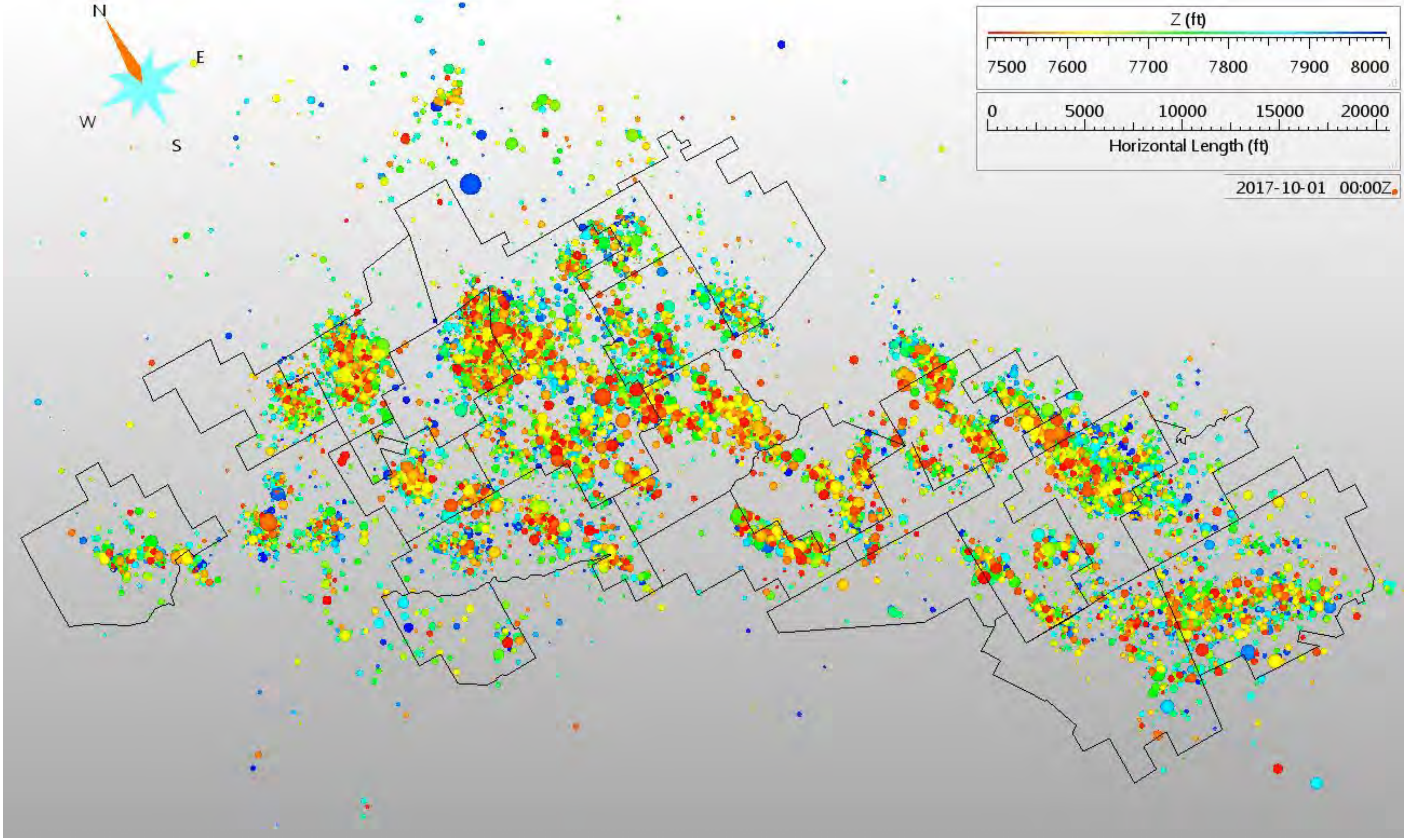
Fault/Fracture Analysis and Interpretation
Depth Slice 8000 to 8500 Feet Subsea



Seismic Monitoring Advisory Committee Meeting
Fault/Fracture Analysis and Interpretation
Depth Slice 8000 to 8500 Feet Subsea

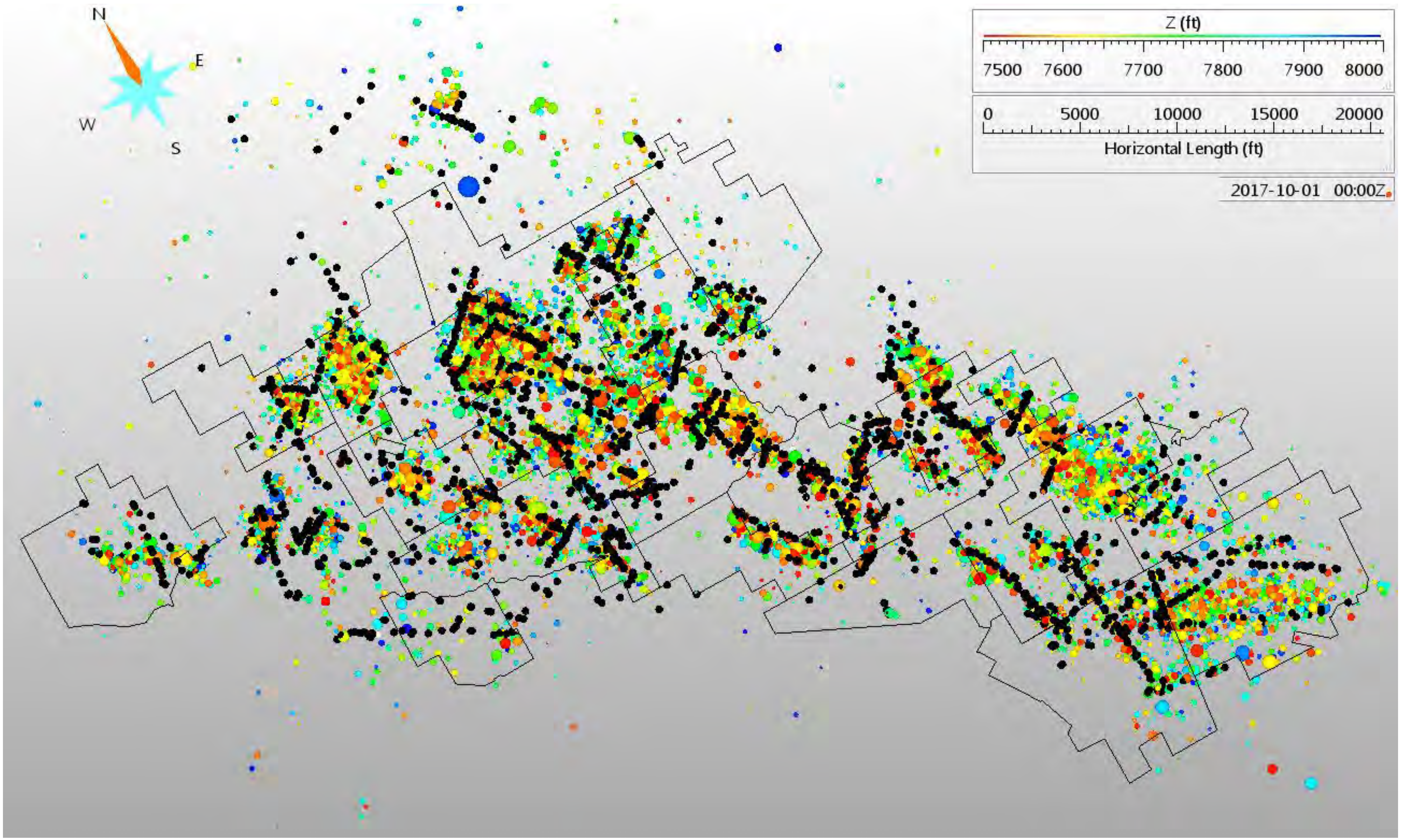


Seismic Monitoring Advisory Committee Meeting
Fault/Fracture Analysis and Interpretation
Depth Slice 7500 to 8000 Feet Subsea



Seismic Monitoring Advisory Committee Meeting

Fault/Fracture Analysis and Interpretation
Depth Slice 7500 to 8000 Feet Subsea



Seismic Monitoring Advisory Committee Meeting

Fault/Fracture Analysis and Interpretation
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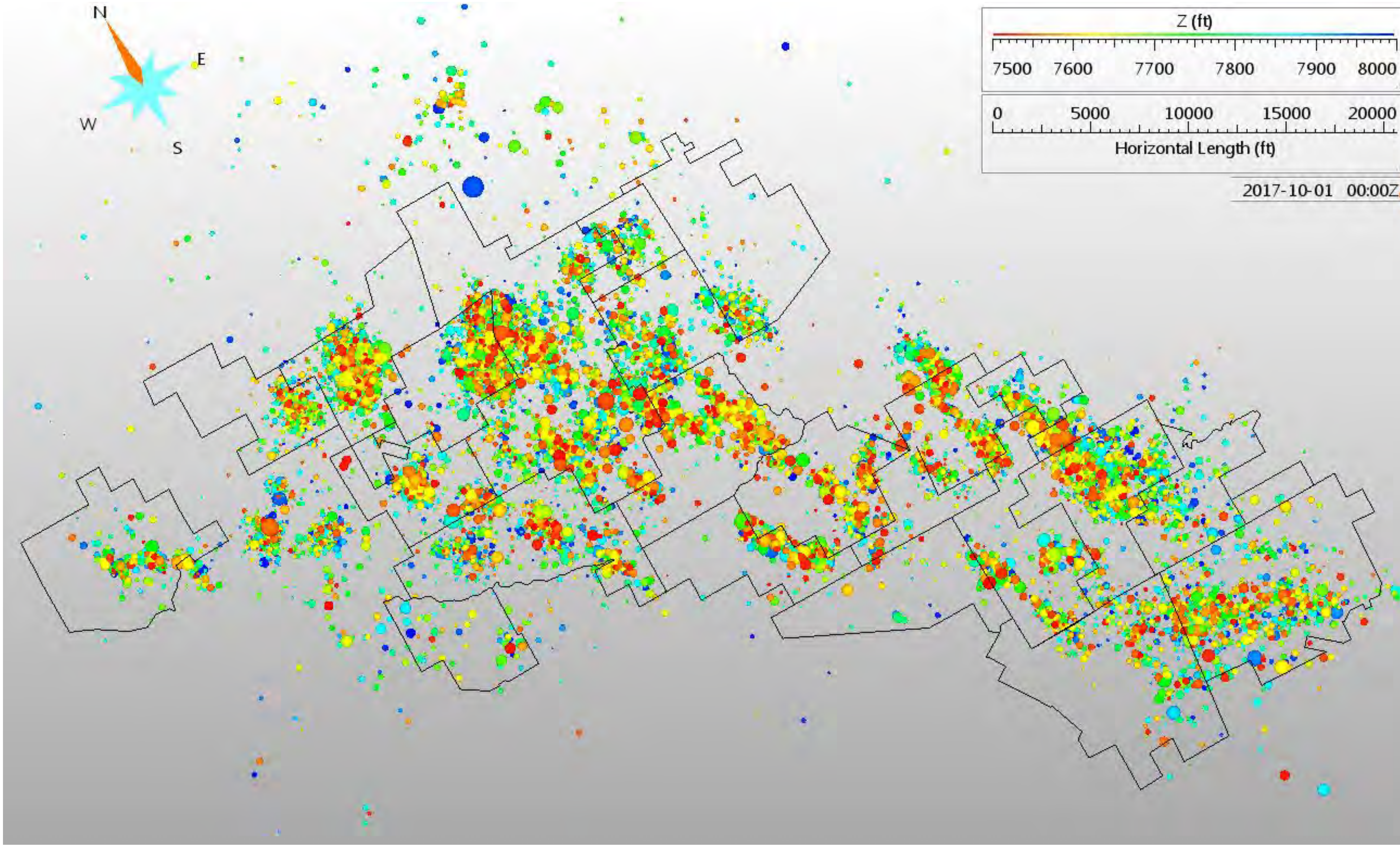
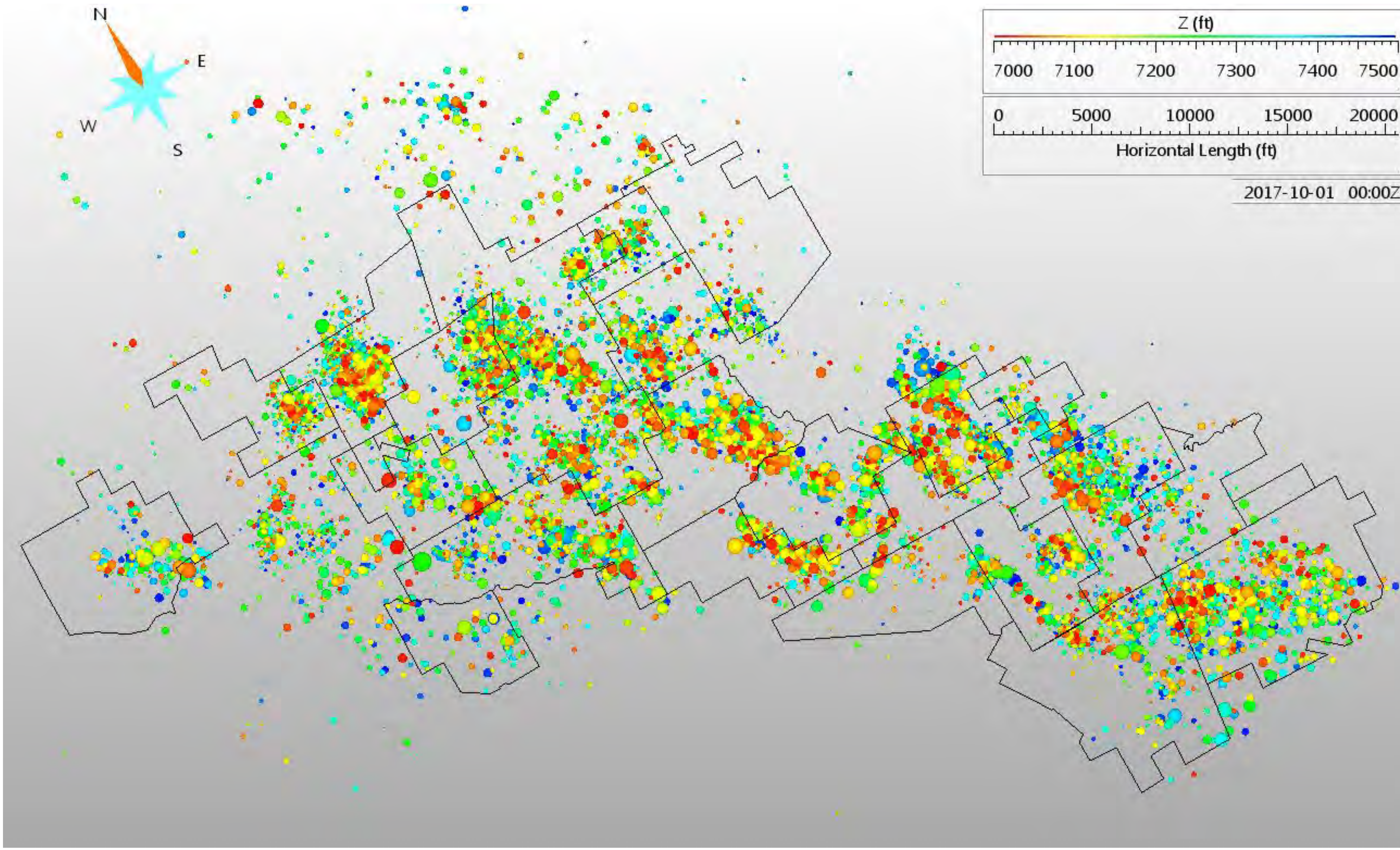
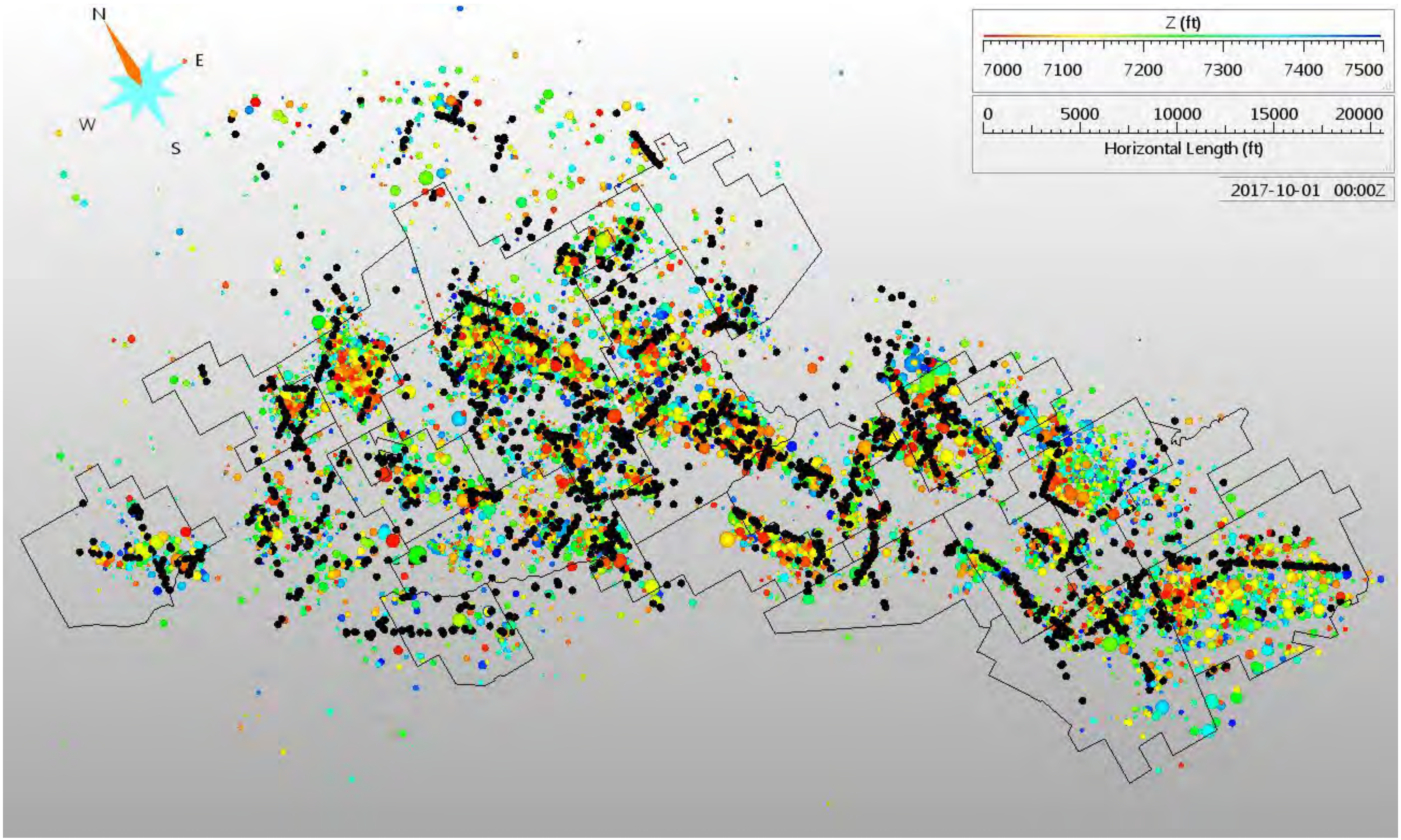


Seismic Monitoring Advisory Committee Meeting
Fault/Fracture Analysis and Interpretation
Depth Slice 7000 to 7500 Feet Subsea

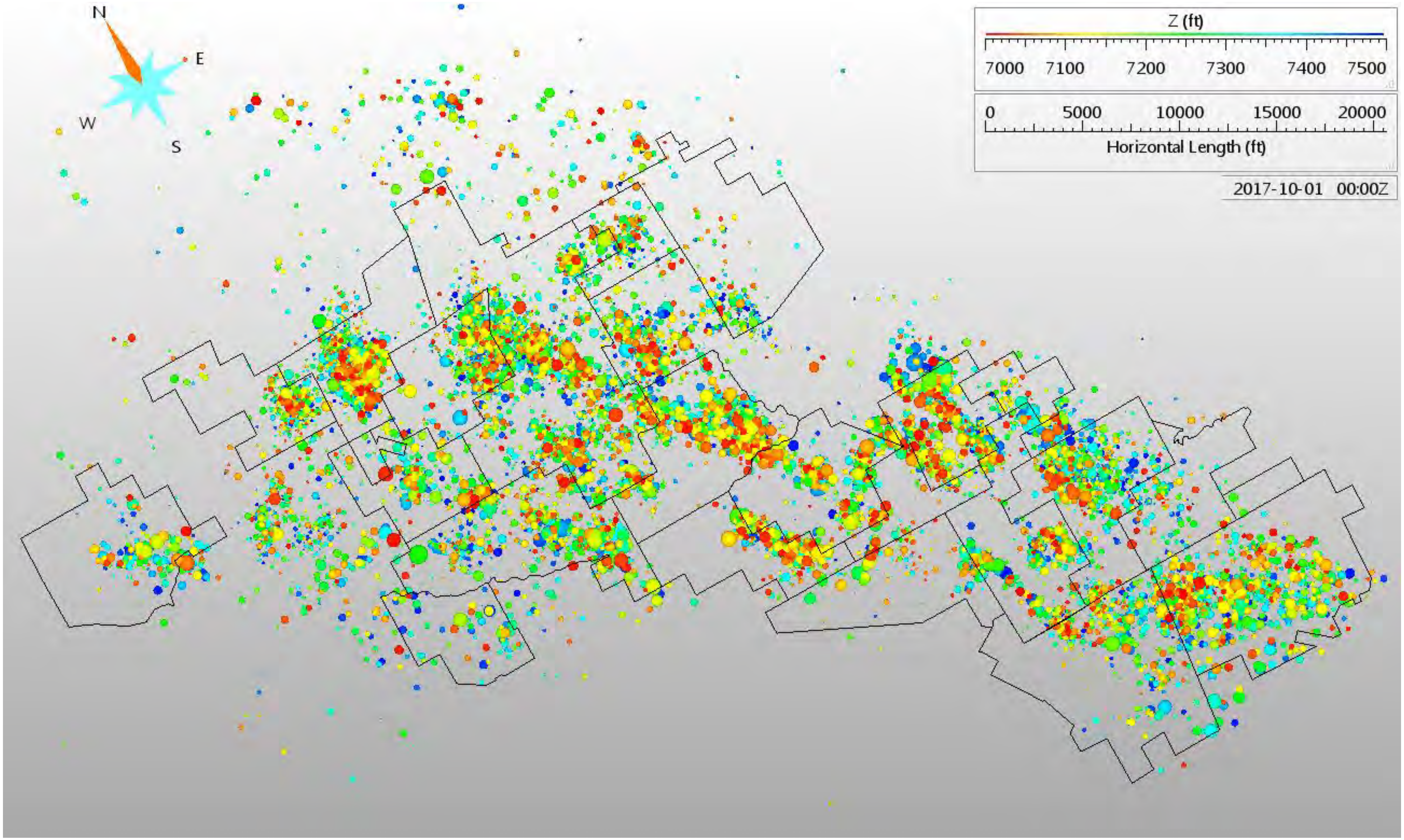


Seismic Monitoring Advisory Committee Meeting

Fault/Fracture Analysis and Interpretation
Depth Slice 7000 to 7500 Feet Subsea

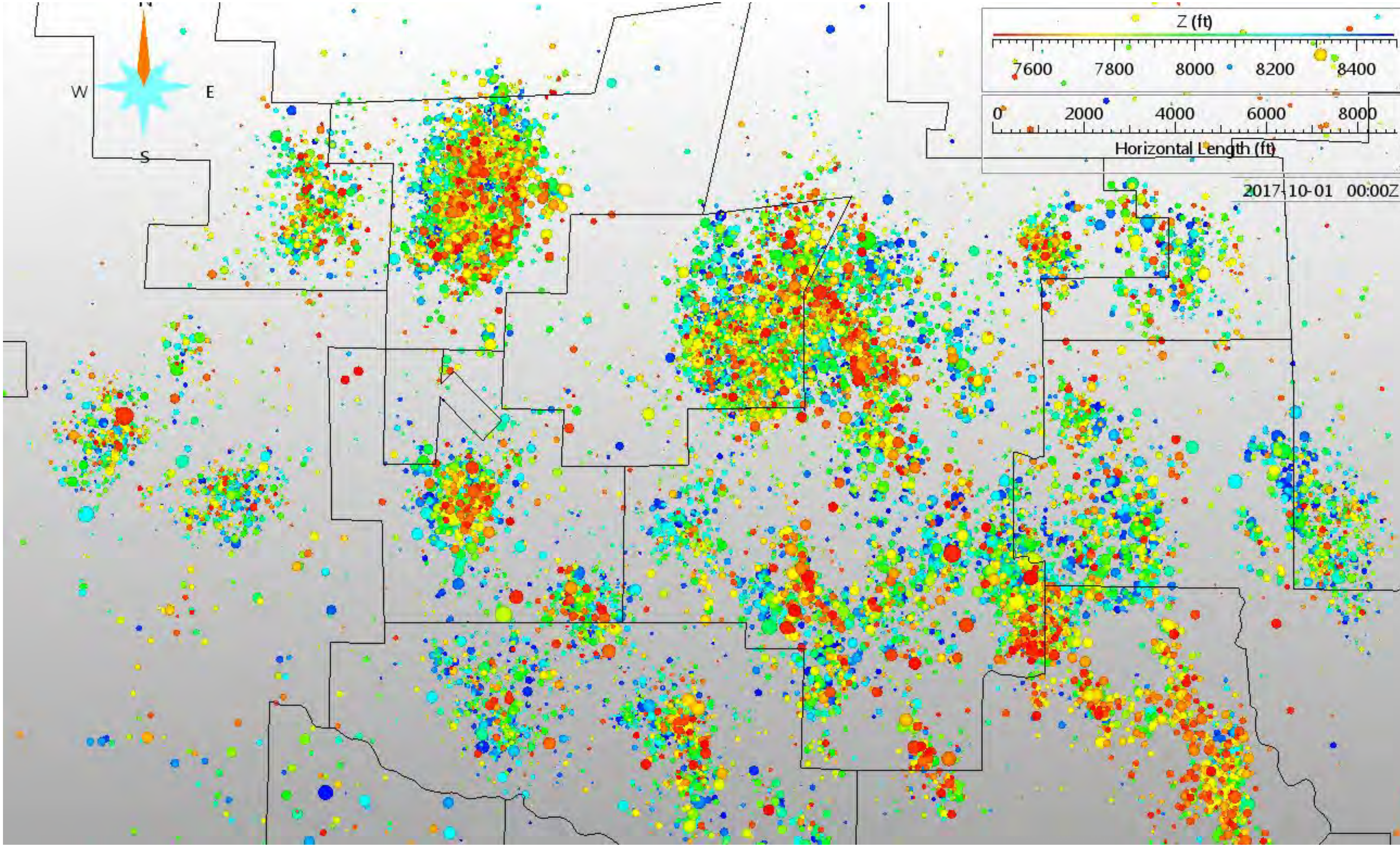


Fault/Fracture Analysis and Interpretation
Depth Slice 7000 to 7500 Feet Subsea



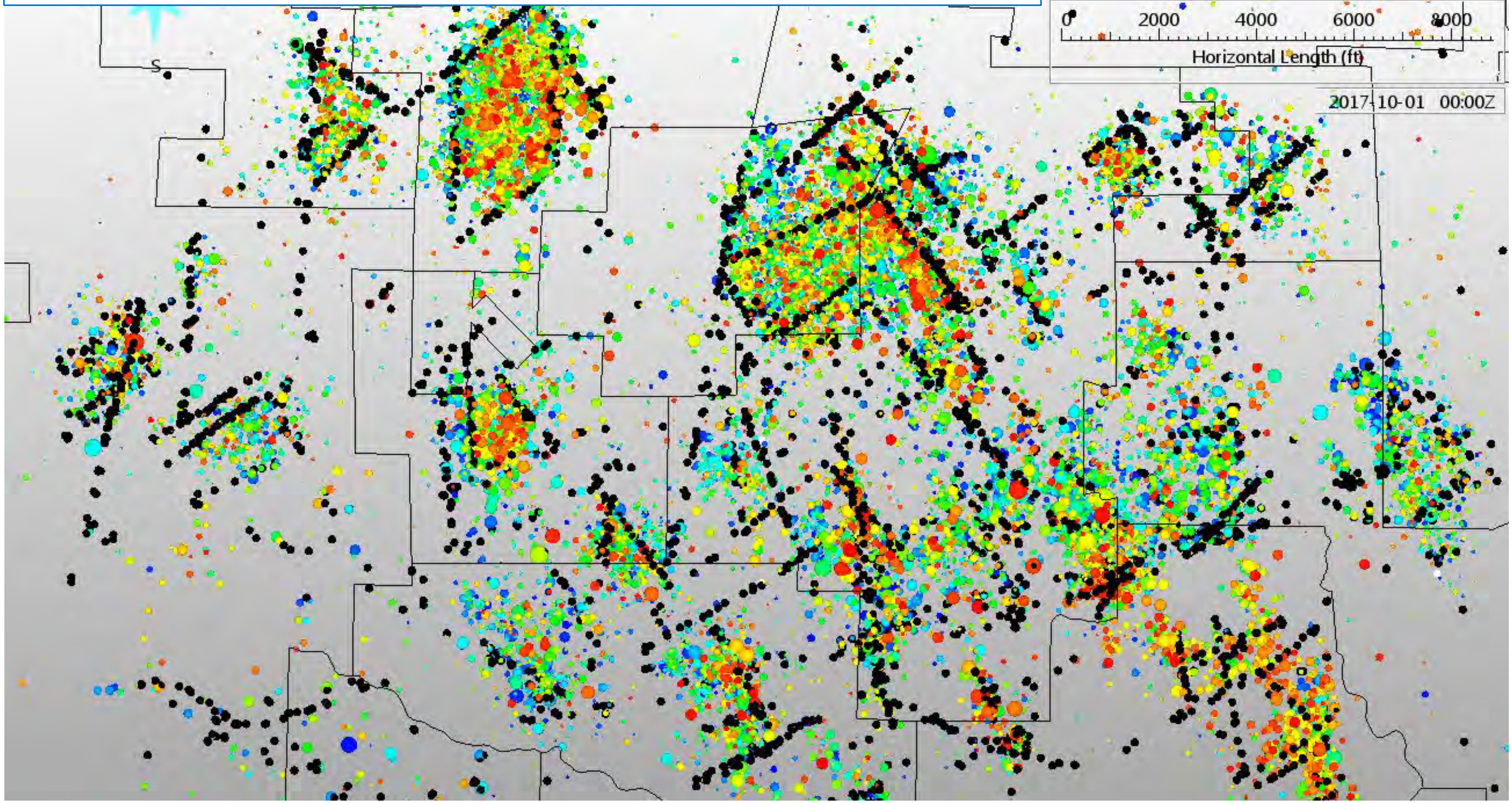
Seismic Monitoring Advisory Committee Meeting

Fault/Fracture Analysis and Interpretation
Depth Slice 7500 to 8500 Feet Subsea



Fault/Fracture Analysis and Interpretation
Depth Slice 7500 to 8500 Feet Subsea – North Geysers

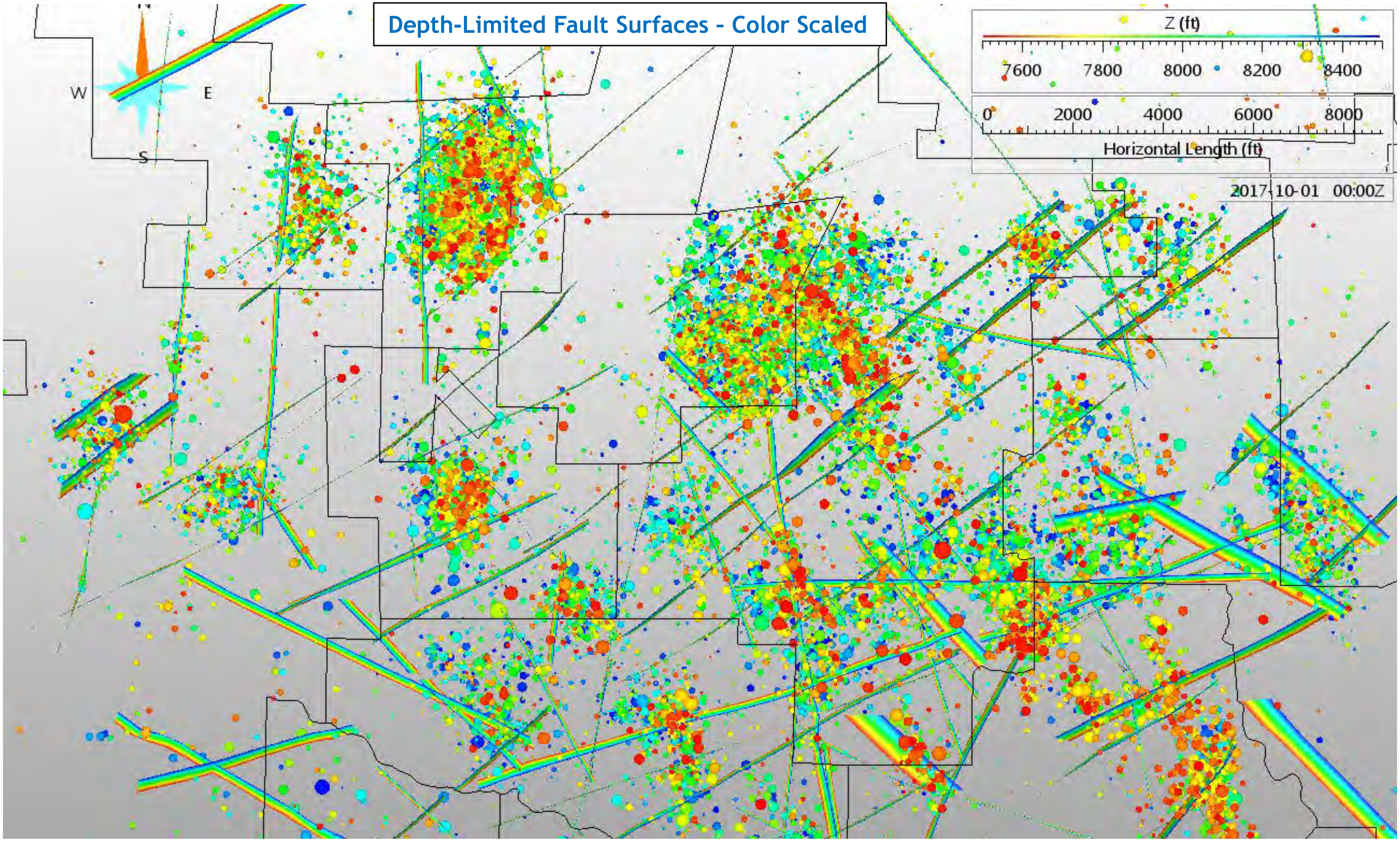
The induced seismicity patterns are indicative of fluid flow pathways and fluid flow boundaries (permeability variations). The steam reservoir appears to be subdivided by intersecting zones of faulting and fracturing, resulting in some degree of compartmentalization of the steam reservoir.



Seismic Monitoring Advisory Committee Meeting

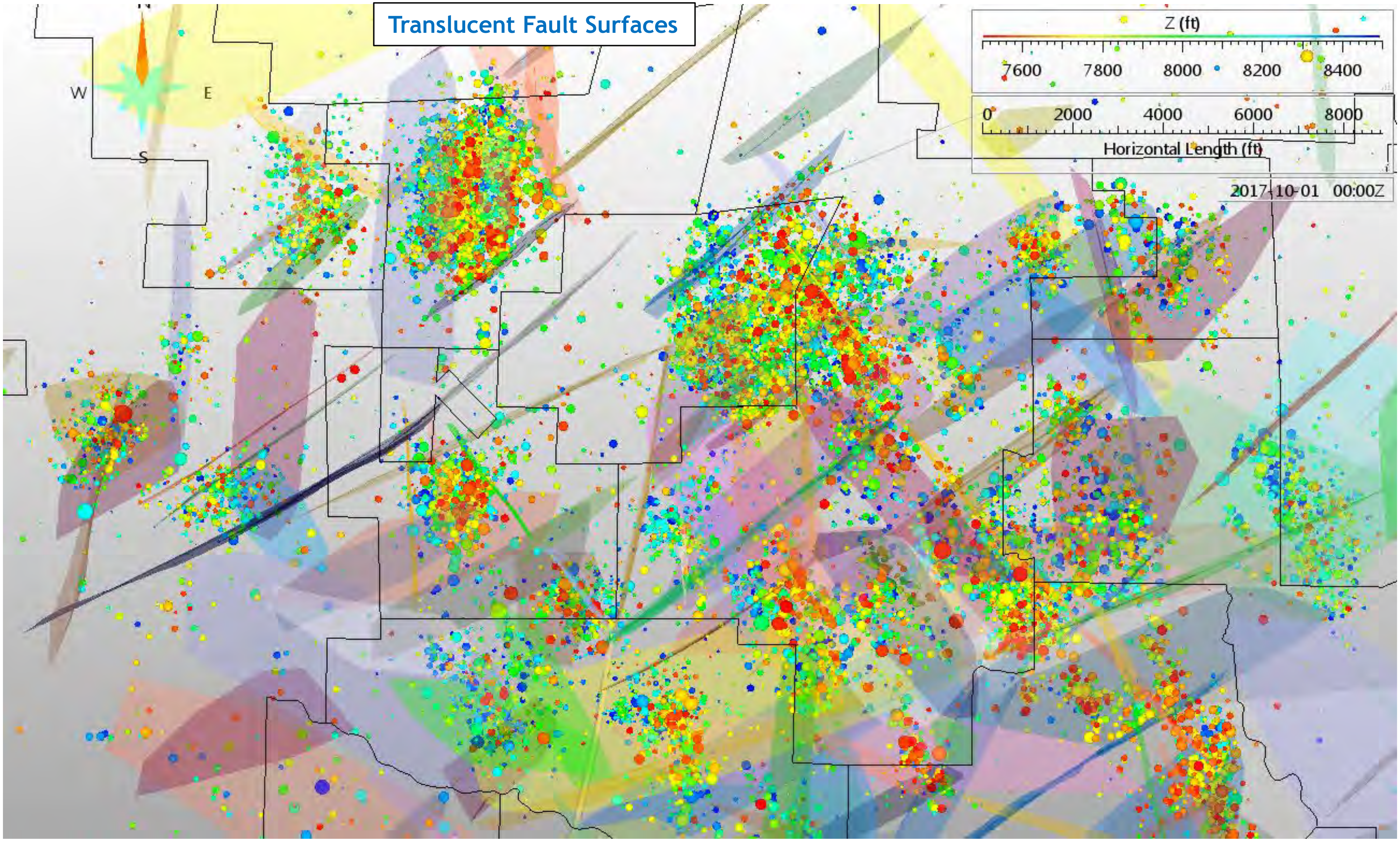
Fault/Fracture Analysis and Interpretation

Depth Slice 7500 to 8500 Feet Subsea – North Geysers



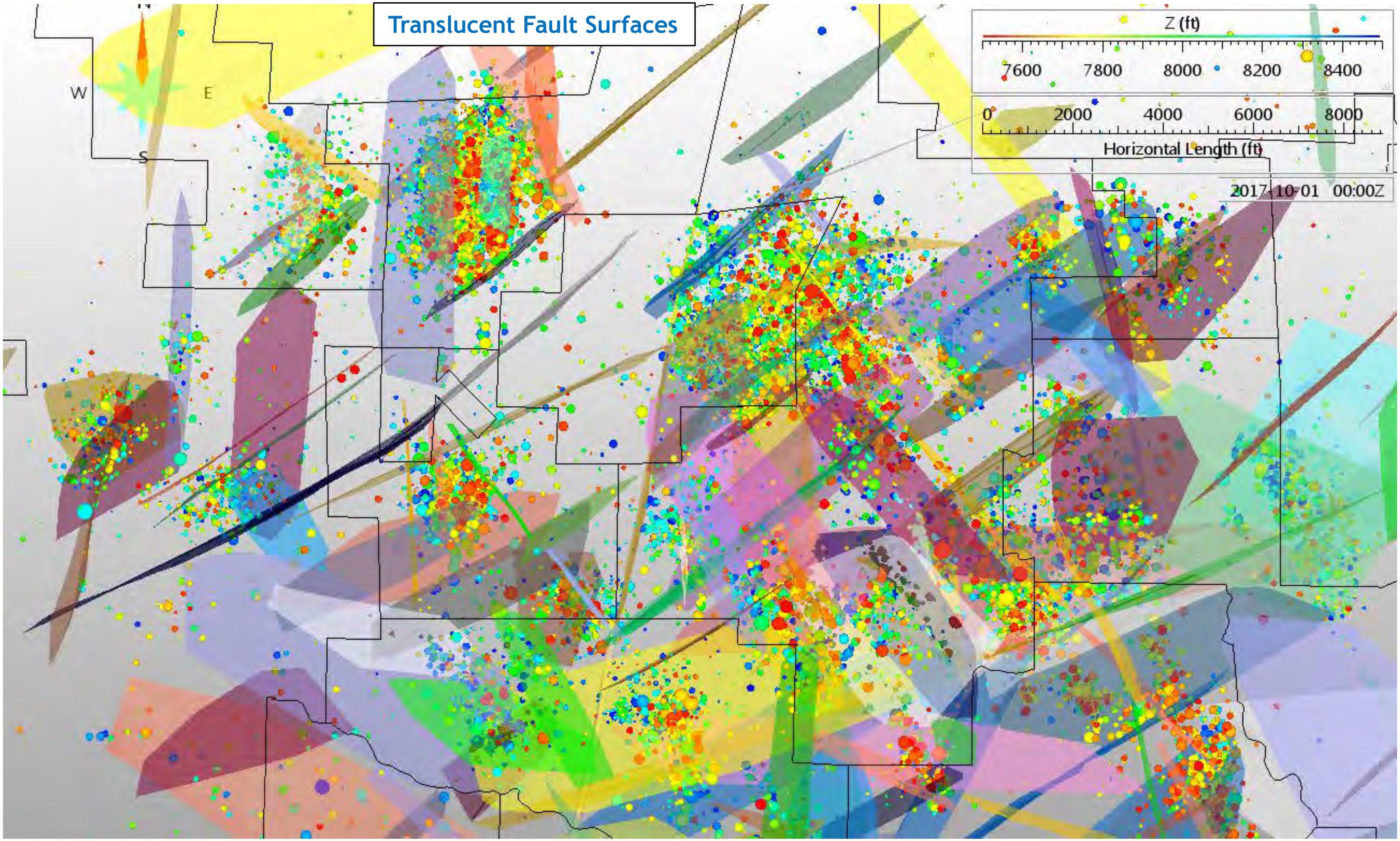
Seismic Monitoring Advisory Committee Meeting

Fault/Fracture Analysis and Interpretation
Depth Slice 7500 to 8500 Feet Subsea - North Geysers

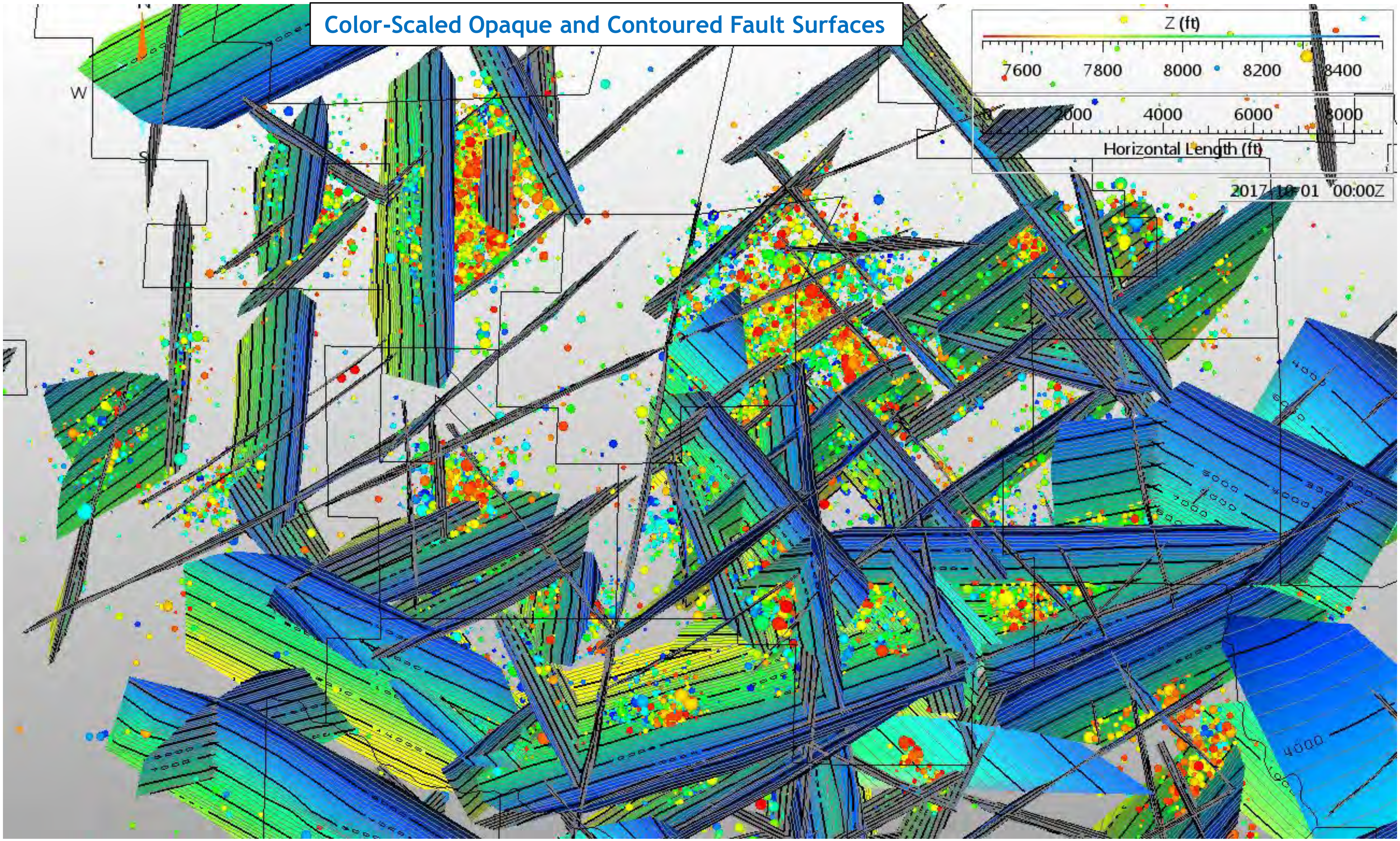


Seismic Monitoring Advisory Committee Meeting

Fault/Fracture Analysis and Interpretation
Depth Slice 7500 to 8500 Feet Subsea - North Geysers



Seismic Monitoring Advisory Committee Meeting
Fault/Fracture Analysis and Interpretation
Depth Slice 7500 to 8500 Feet Subsea

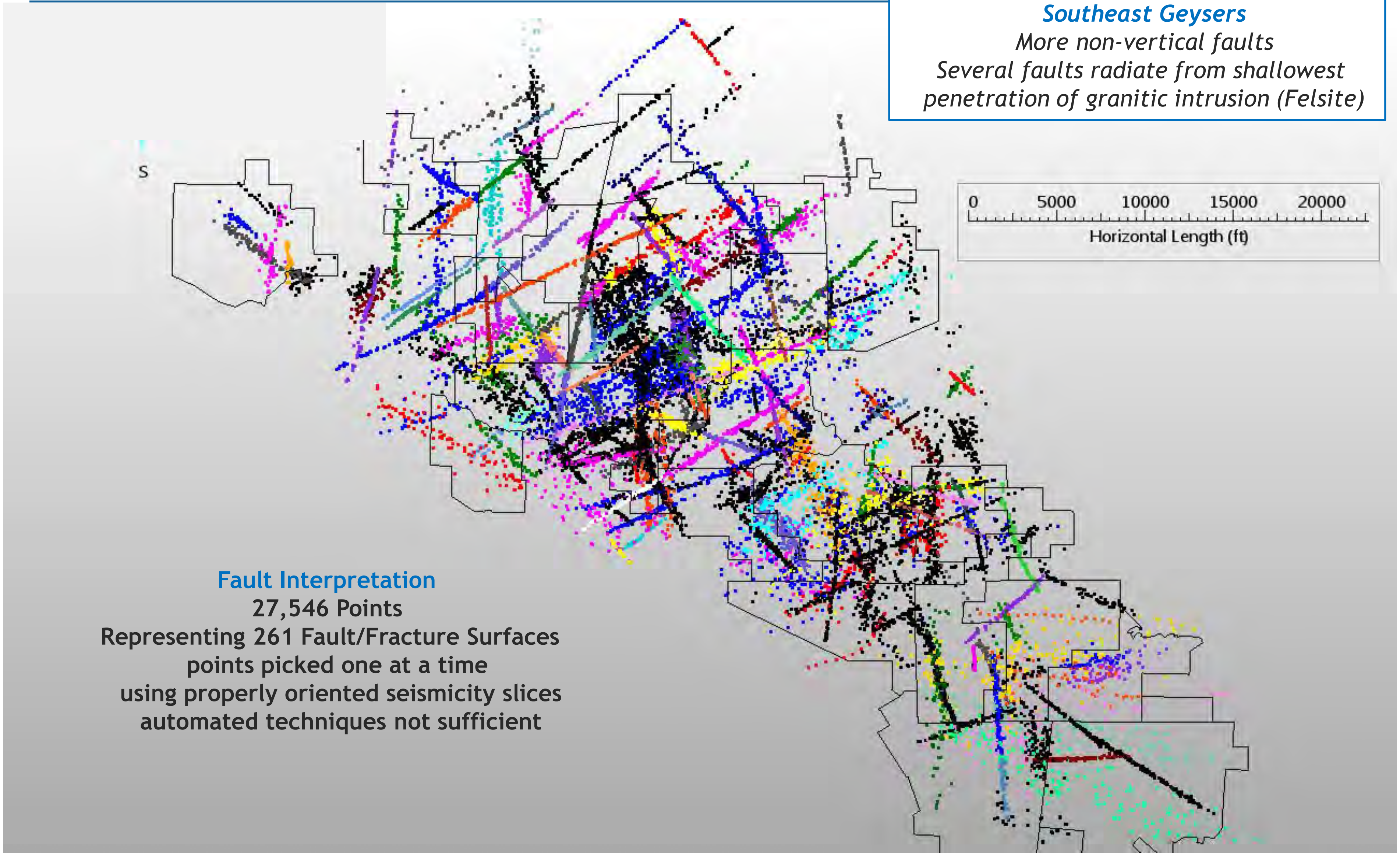


The Geysers

3D Structural and Stratigraphic Model Workflow
Fault/Fracture Interpretation With Seismicity Slices

Northwest Geysers
Primarily near vertical faults
Orientation consistent with regional stress

Southeast Geysers
More non-vertical faults
Several faults radiate from shallowest penetration of granitic intrusion (Felsite)



Fault Interpretation
27,546 Points
Representing 261 Fault/Fracture Surfaces
points picked one at a time
using properly oriented seismicity slices
automated techniques not sufficient

The Geysers

3D Structural and Stratigraphic Model Workflow
Fault/Fracture Interpretation With Seismicity Slices

Northwest Geysers

Primarily near vertical faults
Orientation consistent with regional stress

Southeast Geysers

More non-vertical faults
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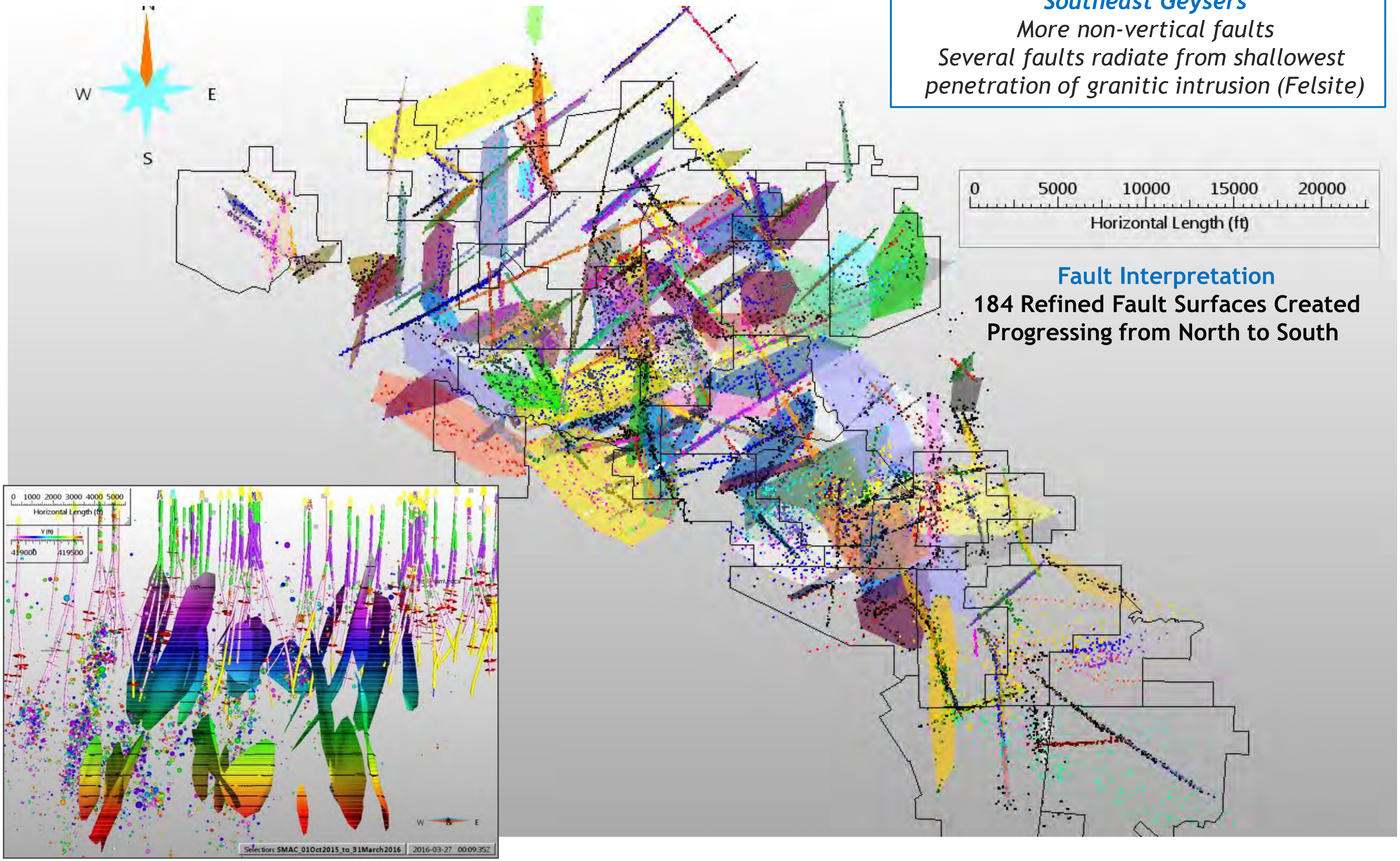
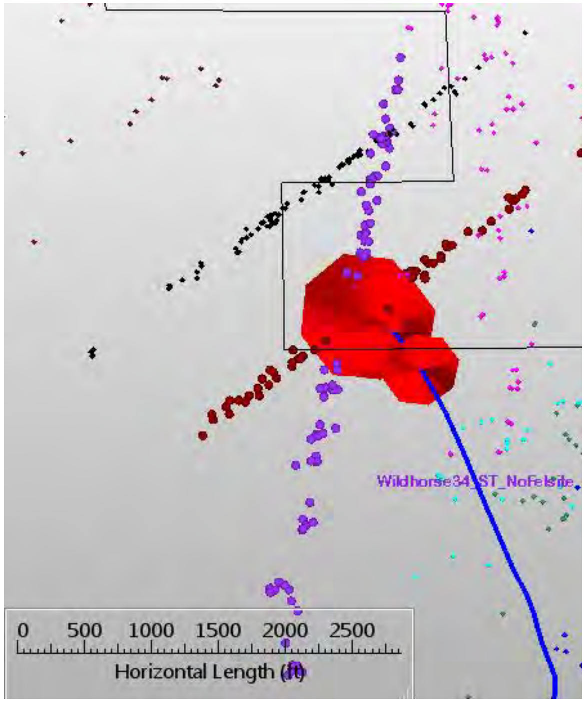


Fault Interpretation

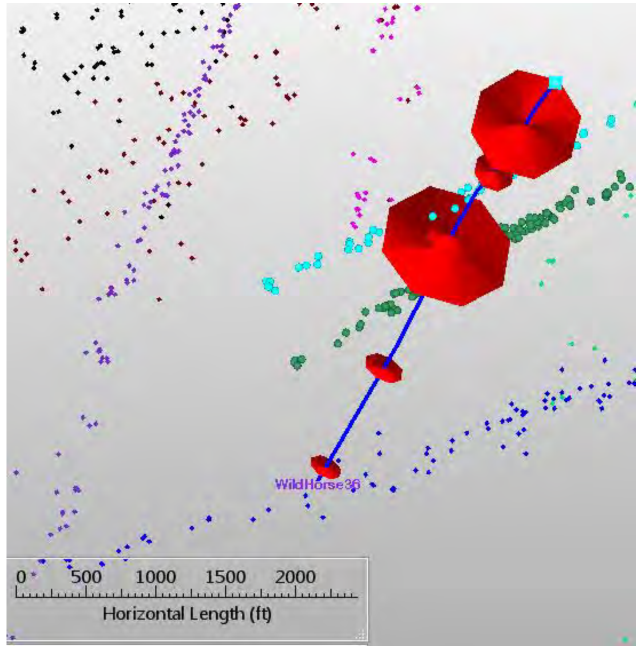
184 Refined Fault Surfaces Created Progressing from North to South

The Geysers

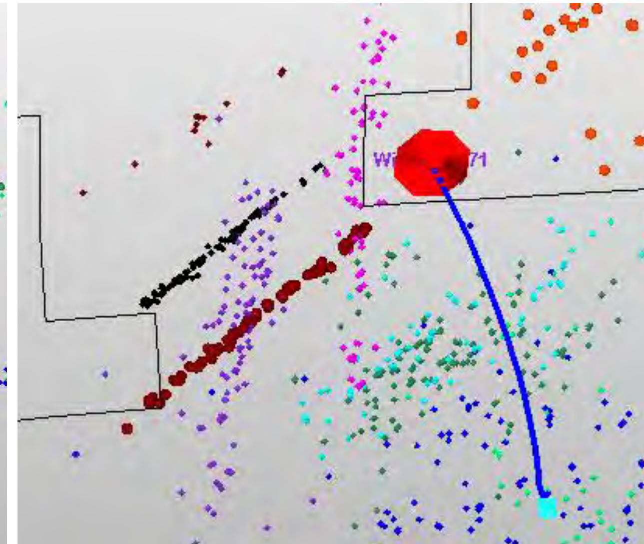
3D Fault Interpretation Technique with Paradigm Geophysical SKUA GOCAD Software
Wildhorse Wells – Steam Entries vs. Interpreted Fracture Surfaces (Unbiased)



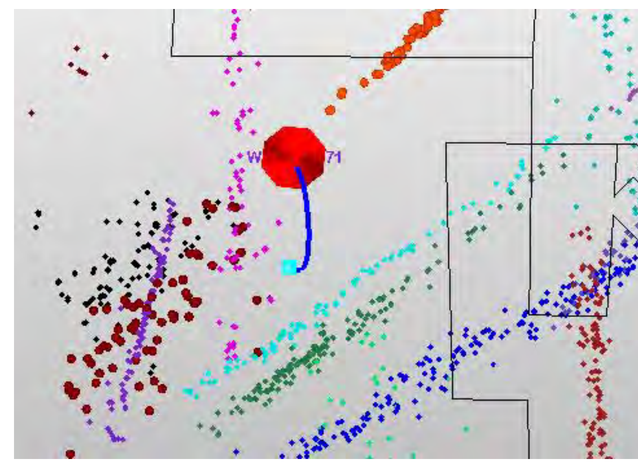
Wildhorse State 34



Wildhorse State 36



Wildhorse State 71



The most significant steam entries are shown as red disks on the well tracks, These occur at/near the intersection of the recently interpreted fault/fracture Surfaces for the Wildhorse State wells.

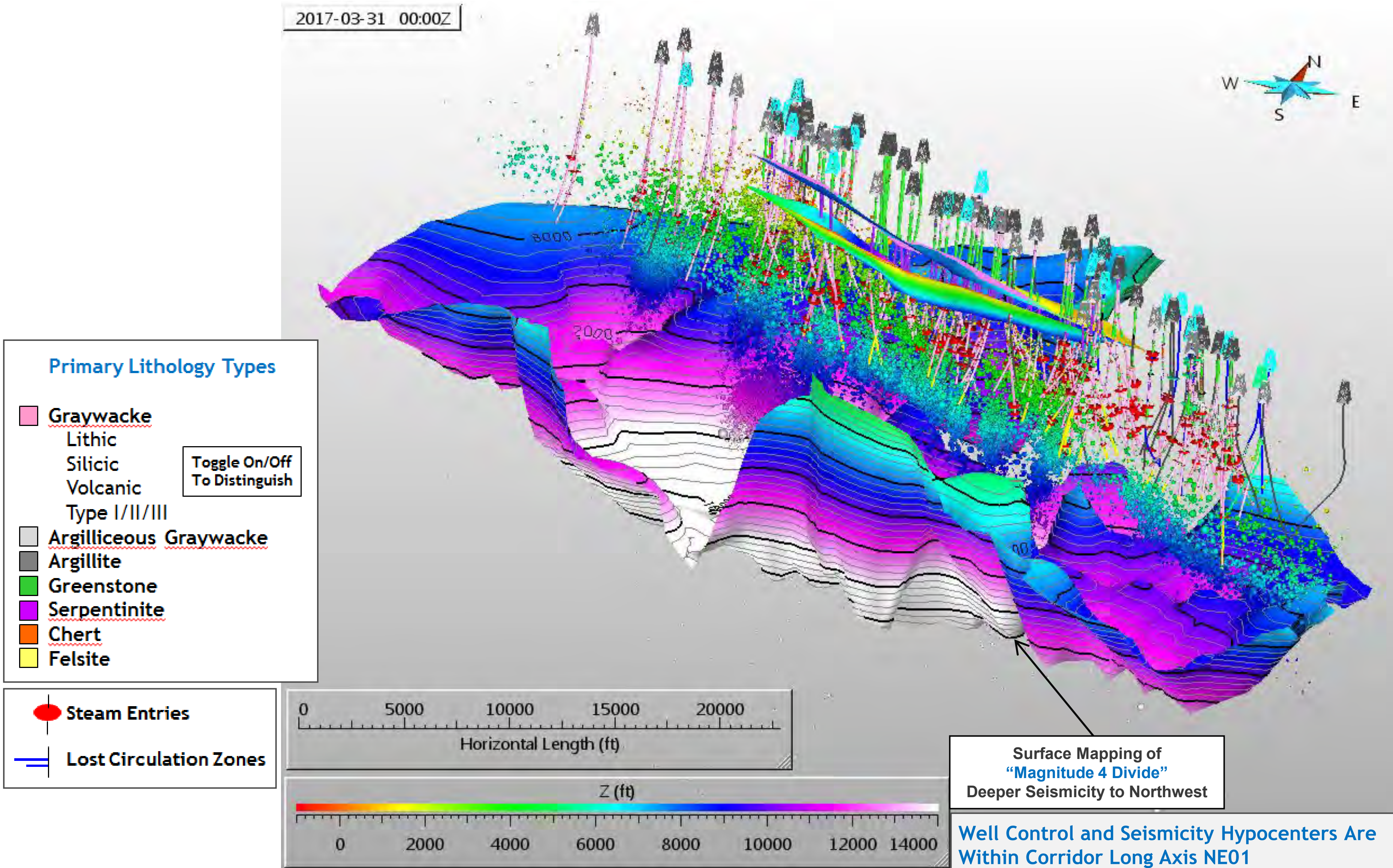
The interpreted points defining nearly vertical fracture surfaces are seen as aligned points in these views from directly above or a slight angle from vertical. .

This provides confidence that the fault/fracture interpretation is consistent with drilling results.

The Geysers

3D Structural and Stratigraphic Model Workflow

Interpreted Faults Will Be Included in the *Developing* 3D Structural Model

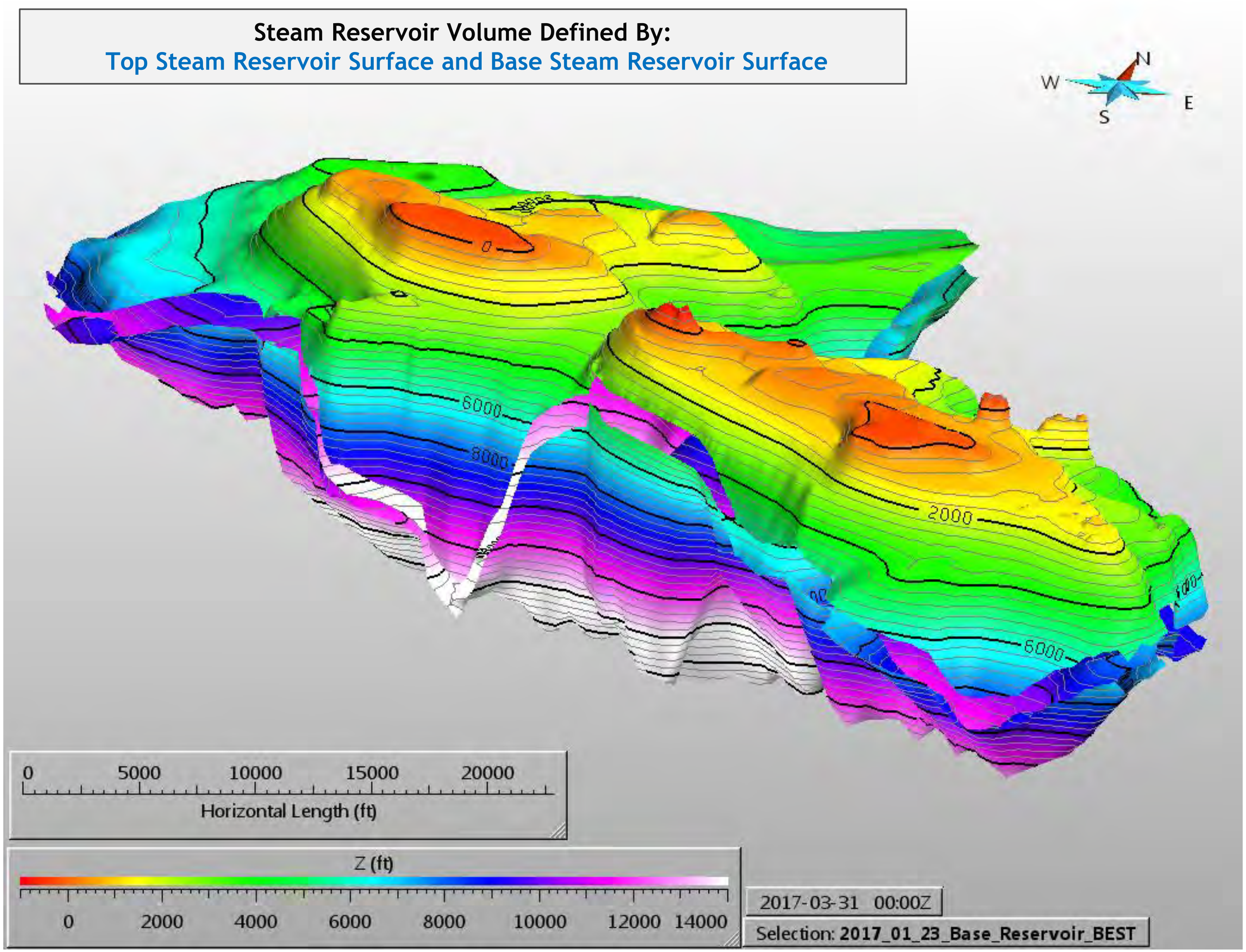


Well Control and Seismicity Hypocenters Are Within Corridor Long Axis NE01

The Geysers

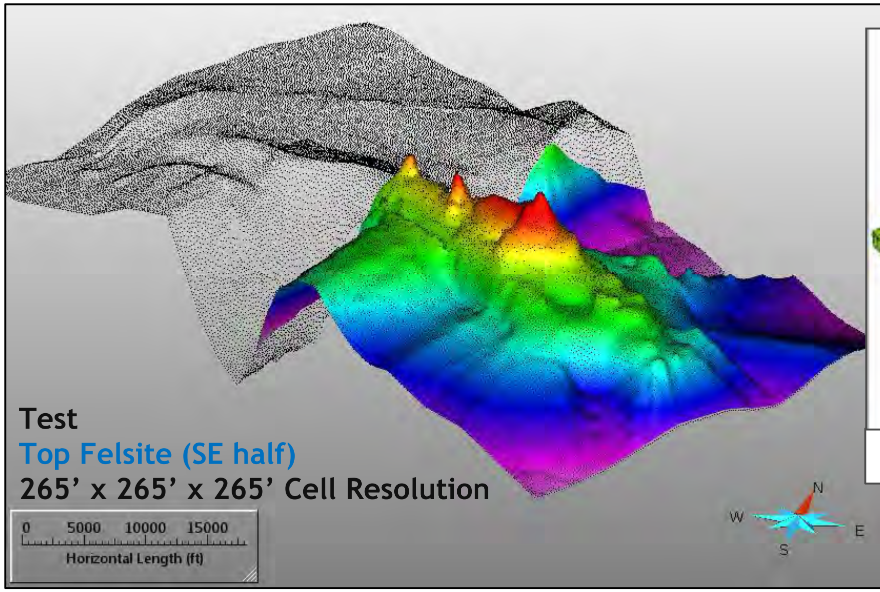
3D Structural and Stratigraphic Model Workflow

Interpreted Faults Will Be Included in the *Developing* 3D Structural Model

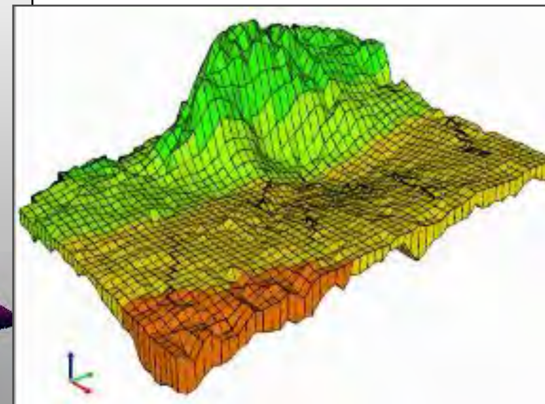


The Geysers

3D Structural and Stratigraphic Model Workflow
In Progress: Fieldwide Cell-Based Geological and Reservoir Model Development

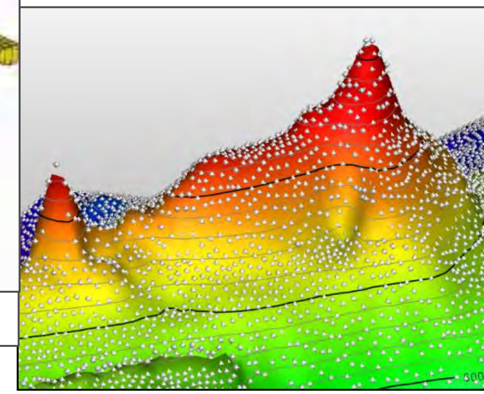


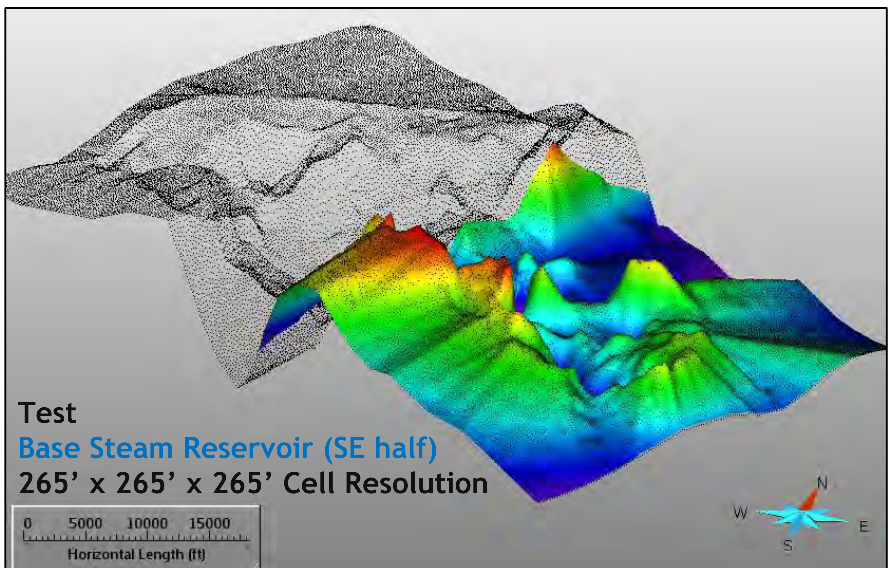
Test
Top Felsite (SE half)
265’ x 265’ x 265’ Cell Resolution



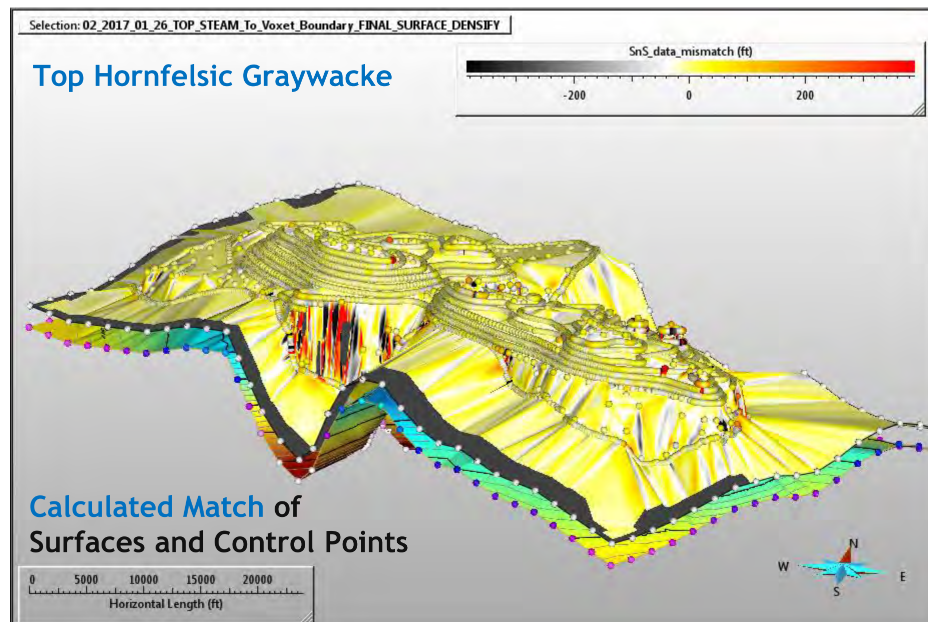
Limited Volume of Cell-Based Model

Visual Match of
Surface and Control Points





Test
Base Steam Reservoir (SE half)
265’ x 265’ x 265’ Cell Resolution



Top Hornfelsic Graywacke

Calculated Match of
Surfaces and Control Points

Additional Seismic Monitoring and Research

California Energy Commission Electric Program Investment Charge (EPIC) Program EPC-16-021

Accepted Proposal

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

Program Goal

Development of advanced, low-cost, microseismic imaging for high-resolution spatial and temporal images of subsurface fluid flow, flow barriers and heterogeneity in producing geothermal fields. The project will focus on microseismicity imaging challenges that are unique to geothermal reservoirs.

Improved 3D and time-lapse subsurface resolution is anticipated to assist with seismicity mitigation efforts at The Geysers.

Applicant

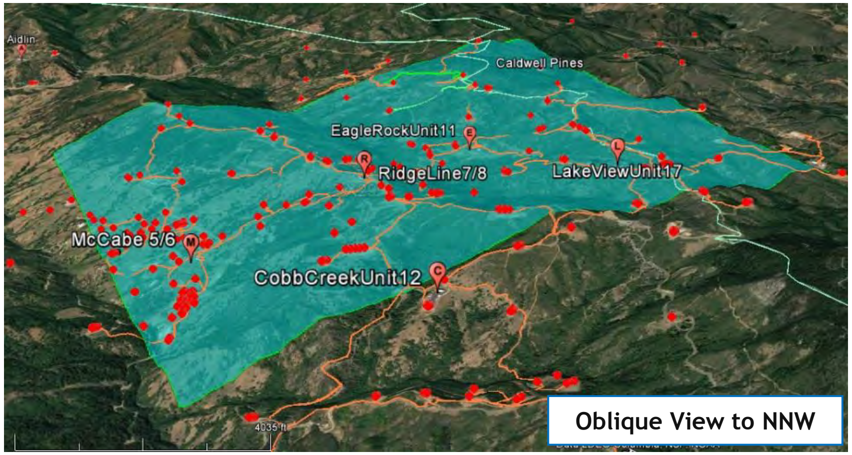
Lawrence Berkeley National Laboratory

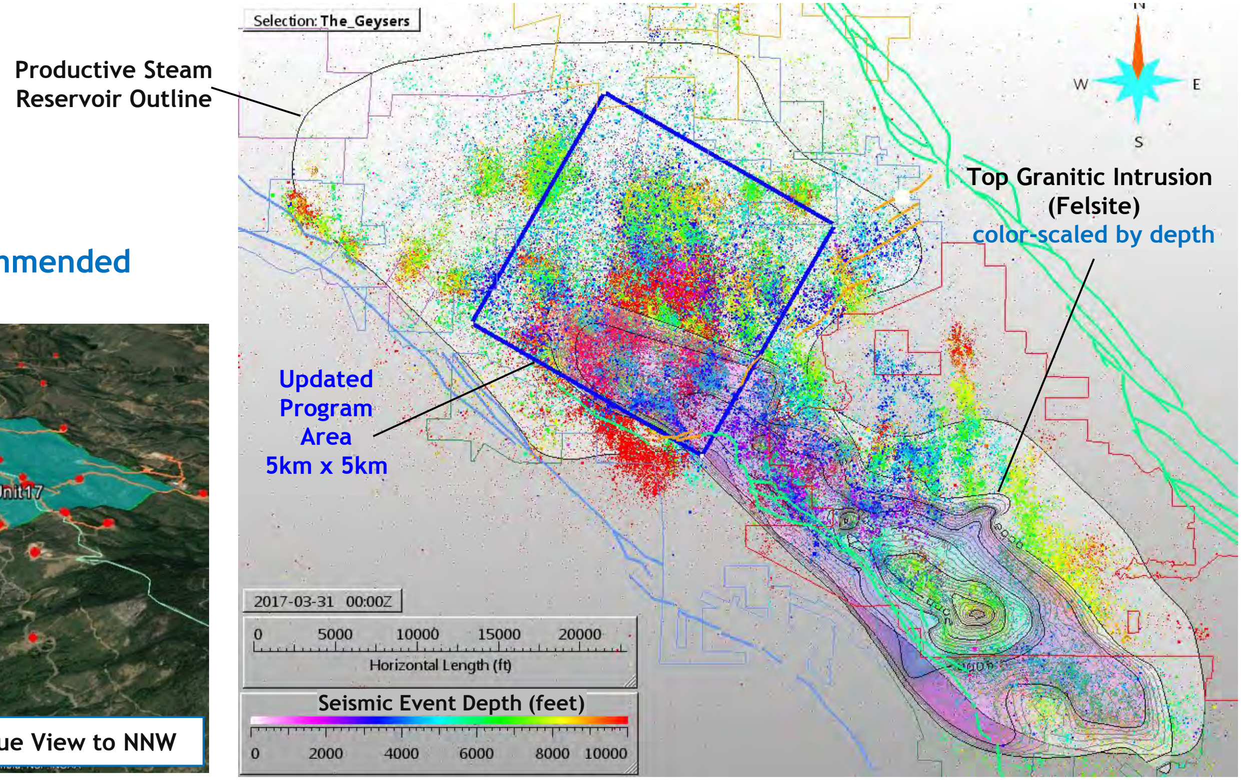
Project Partners

Calpine Corporation
Array Information Technology

California Energy Commission Funds Recommended

$1,672,639





Seismic Monitoring Advisory Committee Meeting

Additional Seismic Monitoring and Research

California Energy Commission Electric Program Investment Charge (EPIC) Program

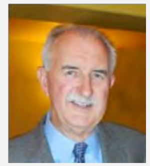
Approval of Grant Funding Opportunity 16-301

Project Team

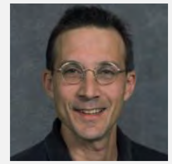
Kurt Nihei
Principal Investigator
Geomechanics
LBNL

Roland Gritto
(Co-PI)
Geophysics
Array Info Tech

Larry Hutchings
Geophysics
Jarpe Data Solution

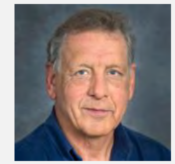


Don Vasco
Hydrogeophysics
LBNL



Katie Freeman
Geophysics
LBNL

Bill Foxall
Geophysics
LBNL



Seiji Nakagawa
Rock Physics
LBNL

Yves Guglielmi
Geomechanics
LBNL

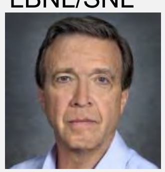
Pierre Jeane
Geomechanics
LBNL

Steve Jarpe
Geophysics
Jarpe Data Solution

Michelle Robertson, Geophysicist, LBNL
Ramsey Haught, Geophysicist, Consultant

Proposed Technical Advisory Committee

Ernie Majer
Induced Seismicity
LBNL/SNL



Craig Hartline
Induced Seismicity
Calpine Corporation

Brian Bonner
Rock Physics
LBNL (LLNL)

Lane Johnson
Earthquake Seismology
LBNL (UC Berkeley)

Schedule

2017				2018				2019				2020
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
Task 1 - Project Management												
	Task 2 - Dense Network Design											
		Task 3 - Fast-Turnaround, High-Resolution Imaging										
				Task 4 - Field Demo								
					Task 5 - Rock Physics Transforms							

Seismic Monitoring Advisory Committee Meeting

Additional Subsurface Research

US Geological Survey Magnetotelluric (MT) Data Acquisition at The Geysers

US Geological Survey

Margaret Mangan, Ph. D. - Scientist-in-Charge

Jared Peacock - Mendenhall Post Doctoral Student

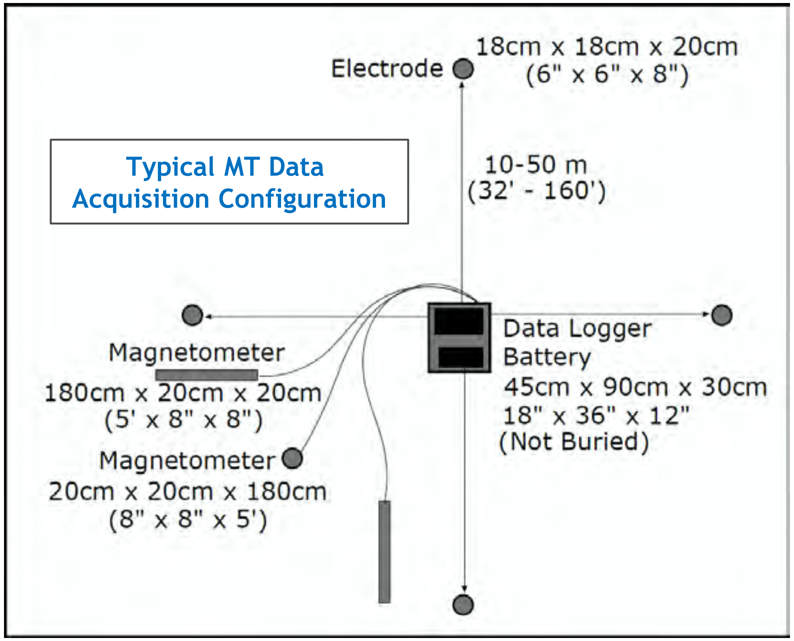
Calpine Corporation The Geysers

Mark Walters - Senior Geologist

Craig Hartline - Senior Geophysicist

Background

- Solar energy and lightning cause natural variations in the earth's magnetic field and produce electrical currents.
- Different rocks, sediments and geological structures respond differently to these electrical currents.
- Magnetotelluric surveys *passively* measure the variations in electrical current response.
- Magnetotelluric surveys are very important tool in deep earth research.



Additional Subsurface Research

US Geological Survey Magnetotelluric (MT) Data Acquisition at The Geysers

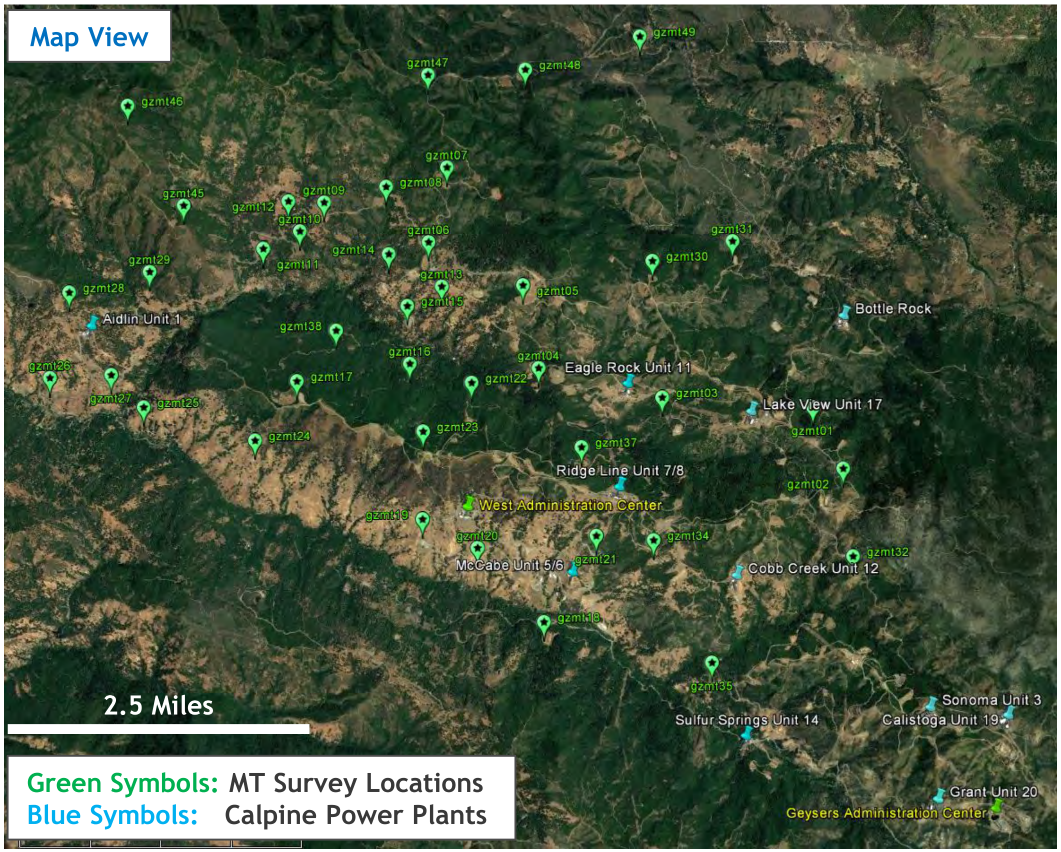
Program

- Summer 2017 magnetotelluric data acquisition of 41 survey locations in the central and north Geysers

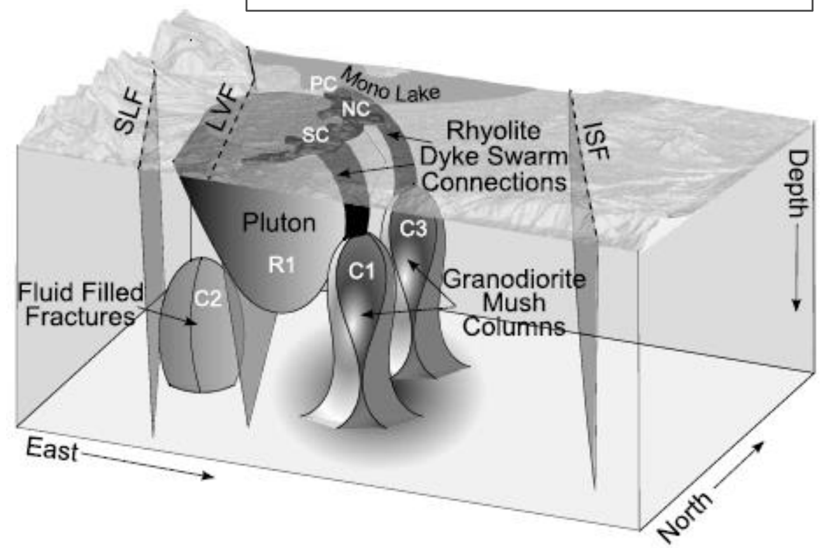
Goal

- Create a three-dimensional subsurface electrical resistivity model.
- Better understand the development of The Geysers geothermal resource in relation to a series of magmatic intrusions.
- Create a conceptual geological model of very complex deep subsurface at The Geysers.

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



Conceptual Geological Model of the Mono Basin in the Long Valley Volcanic Region. Peacock et al., 2015



Seismic Research Collaboration with Seismic Warning Systems

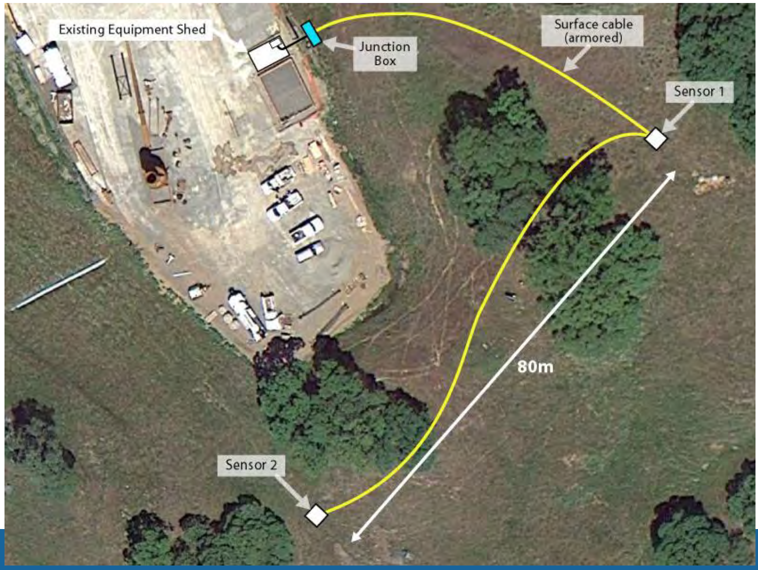
Early Detection and Warning System for Natural Earthquakes

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.
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 Seismic Warning Systems

Press Release

September 28, 2017 02:00 PM Eastern Daylight Time

SAN FRANCISCO--(BUSINESS WIRE)- Pacific Gas and Electric Company (PG&E) today announced that it has successfully deployed a commercial-grade earthquake early warning (EEW) system on a bank of four elevators at its downtown San Francisco headquarters.

The 34-story office building located at 77 Beale St. in the heart of San Francisco's Financial District is now the first high-rise building on the West Coast to have elevators equipped with immediate, automated recall.

In the event of a strong earthquake, the four elevator cars connected to the EEW system will receive a warning signal up to one minute before shaking begins and automatically stop at the closest floor and open the doors, enabling passengers to safely exit the elevator before shaking occurs.

Earthquake early warning is intended to identify and characterize an earthquake a few seconds after it begins, calculate the likely intensity of ground shaking that will result, and deliver warnings to people and infrastructure in harm's way via PA system, computer, smartphone, and eventually, via television and radio. The amount of warning time at a particular location depends on its distance from the earthquake epicenter.

Over the past year, PG&E worked closely with Seismic Warning Systems (SWS) – a privately held earthquake warning developer and integrator – to install sensors, equipment and communications capabilities at its headquarters.

The deployment of this system is a pilot project which PG&E hopes to extend to additional elevators at its headquarters and at other offices and facilities. PG&E is also working with SWS to deploy earthquake warning system sensors at both a substation and a service center located on the San Francisco Peninsula.

In addition to working with SWS, PG&E is actively piloting other EEW solutions to test which ones will allow both automated and human actions in the seconds before an earthquake to protect lives, lessen property damage and ensure rapid service restoration.

In particular, PG&E is participating in the ShakeAlert project, an experimental EEW system for the west coast of the United States developed by the United States Geological Survey (USGS) along with a coalition of State and university partners including the Berkeley Seismological Laboratory at the University of California, Berkeley.

Research Collaborations

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