



America's Premier Competitive Power Company
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Seismic Monitoring Advisory Committee Meeting

01 October 2017 to 31 March 2018 Reporting Period

Calpine Geothermal Visitors Center

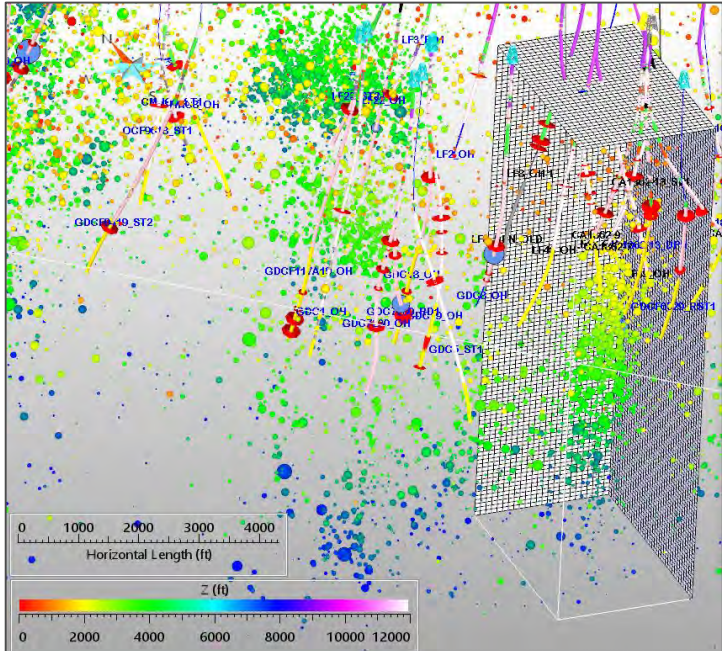
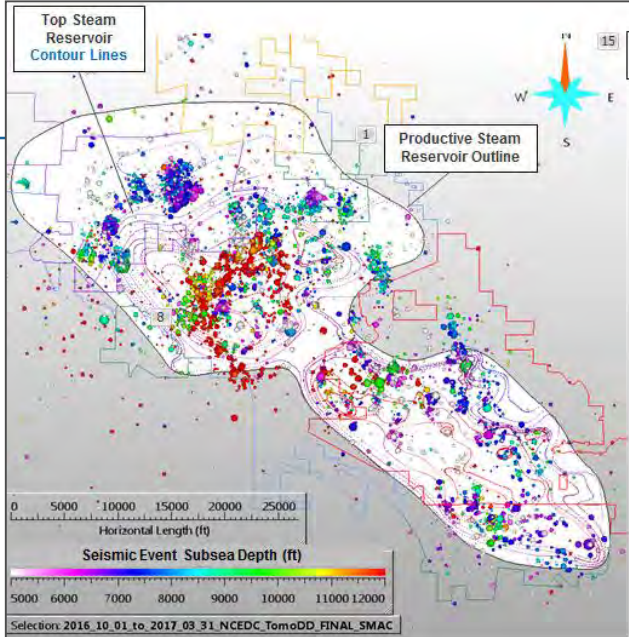
Middletown, California

14 May 2018

Craig Hartline Senior Geophysicist Calpine Corporation The Geysers

Reporting Period: 01 October 2017 to 31 March 2018

- **Status of Seismic Monitoring Networks**
 - **LBNL Seismic Monitoring Network**
 - **USGS / Northern California Seismic Network**
 - **Strong Motion Stations**
 - **Fieldwide Seismicity Analysis**
 - **Yearly Field-wide Water Injection and Seismicity**
 - **Synchronized Fieldwide Water Injection and Seismicity Analysis**
 - **Community Hotline**
 - **Strong Motion Analysis**
 - **3D Structural Model Building**
 - **Fault/Fracture Analysis**
 - **Compartmentalization**
 - **Additional Seismic Monitoring and Research**
- 
- A vertical decorative graphic on the right side of the slide, consisting of a dense cluster of small, multi-colored dots in shades of green, blue, red, and yellow, resembling a seismicity map or a data visualization.



Seismic Monitoring Advisory Committee Meeting

Status of Seismic Monitoring Networks

LBLN Seismic Monitoring Network

- Fully Functional

USGS / Northern California Seismic Network

- Fully Functional

Strong Motion Stations

- Anderson Springs

Community Center Strong Motion ADS2

Communications / SIM* card failure in early February.

Reported by Calpine and repaired by USGS (John Hamilton).

Now fully functional with data gap from 03 February 2018 to 03 May 2018.

Database at: ftp://ehzftp.wr.usgs.gov/luetgert/calpine/sm_sum.txt

- Anderson Springs

Engels Strong Motion ESM

Nanometrics Titan three-component accelerometer installed September 2017.

Solar power with batteries; radio telemetry communication to LBNL seismic monitoring network.

- Cobb

Alder Creek Strong Motion ASM

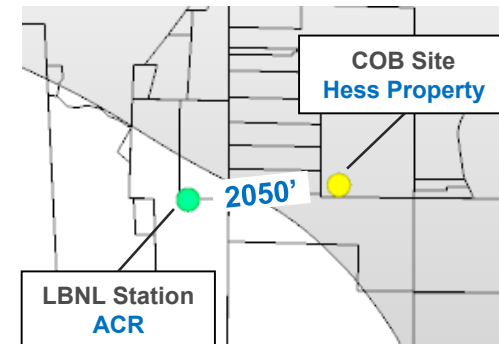
Nanometrics Titan three-component accelerometer installed May 2018 by Ramsey Haught.

Location ACR is ~2050' west-southwest of COB station on Hess property.

Solar power with batteries; radio telemetry communication to LBNL seismic monitoring network.



Alder Creek Strong Motion ASM

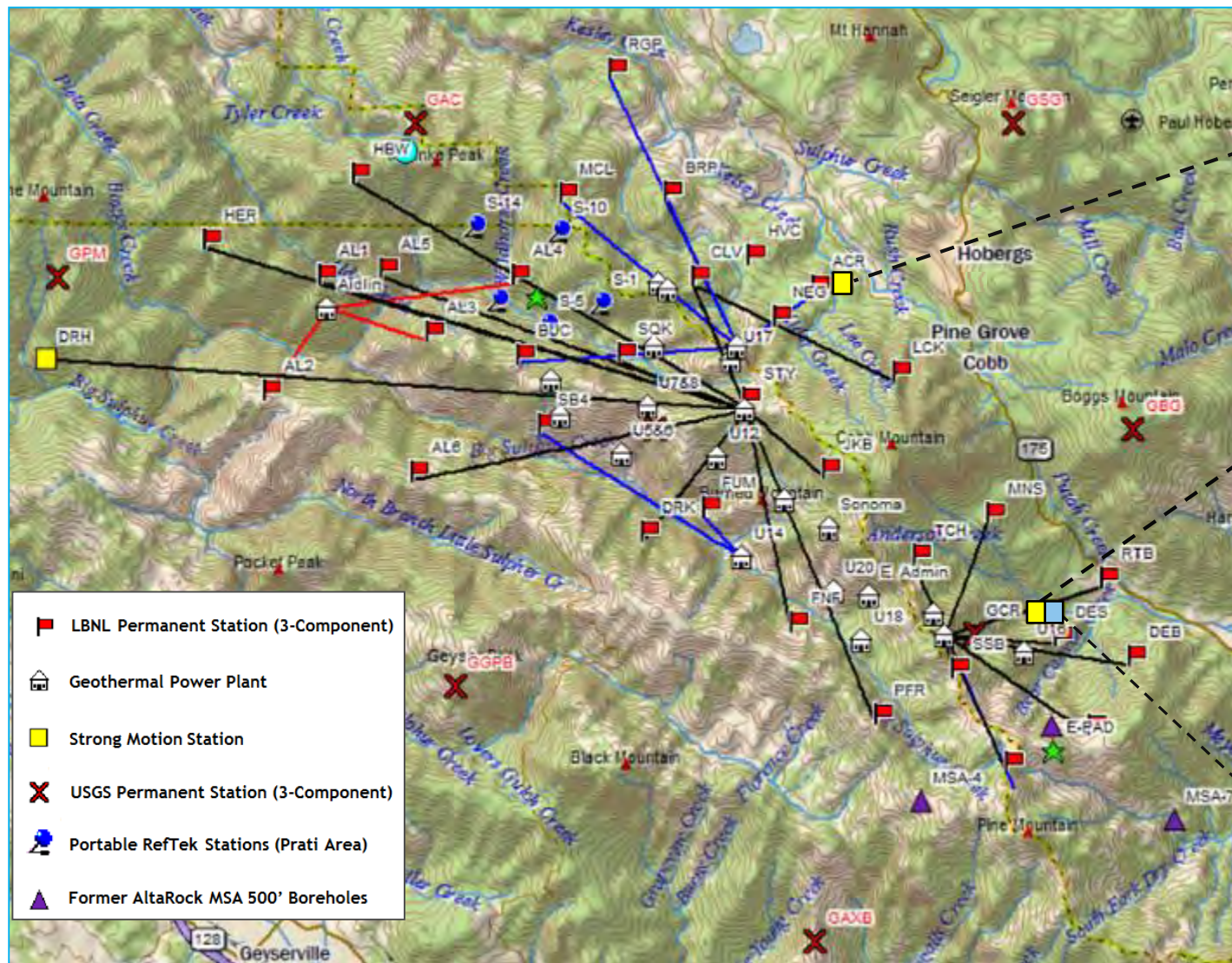


*Subscriber Identification Module

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Status of Seismic Monitoring Networks

Integration of Nanometrics Titan Accelerometers into LBNL Network



Cobb
ASM
Strong Motion
At LBNL ACR Site
~2050' WSW of Hess COB Site

LBNL

Nanometrics Titan
Solar Power and Radio Telemetry
May 2018

Anderson Springs
ESM

Strong Motion
Engels Property

LBNL

Nanometrics Titan
Solar Power and Radio Telemetry
September 2017

Anderson Springs
ADS2
Strong Motion
Community Center

USGS

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

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Field-wide Seismicity Analysis

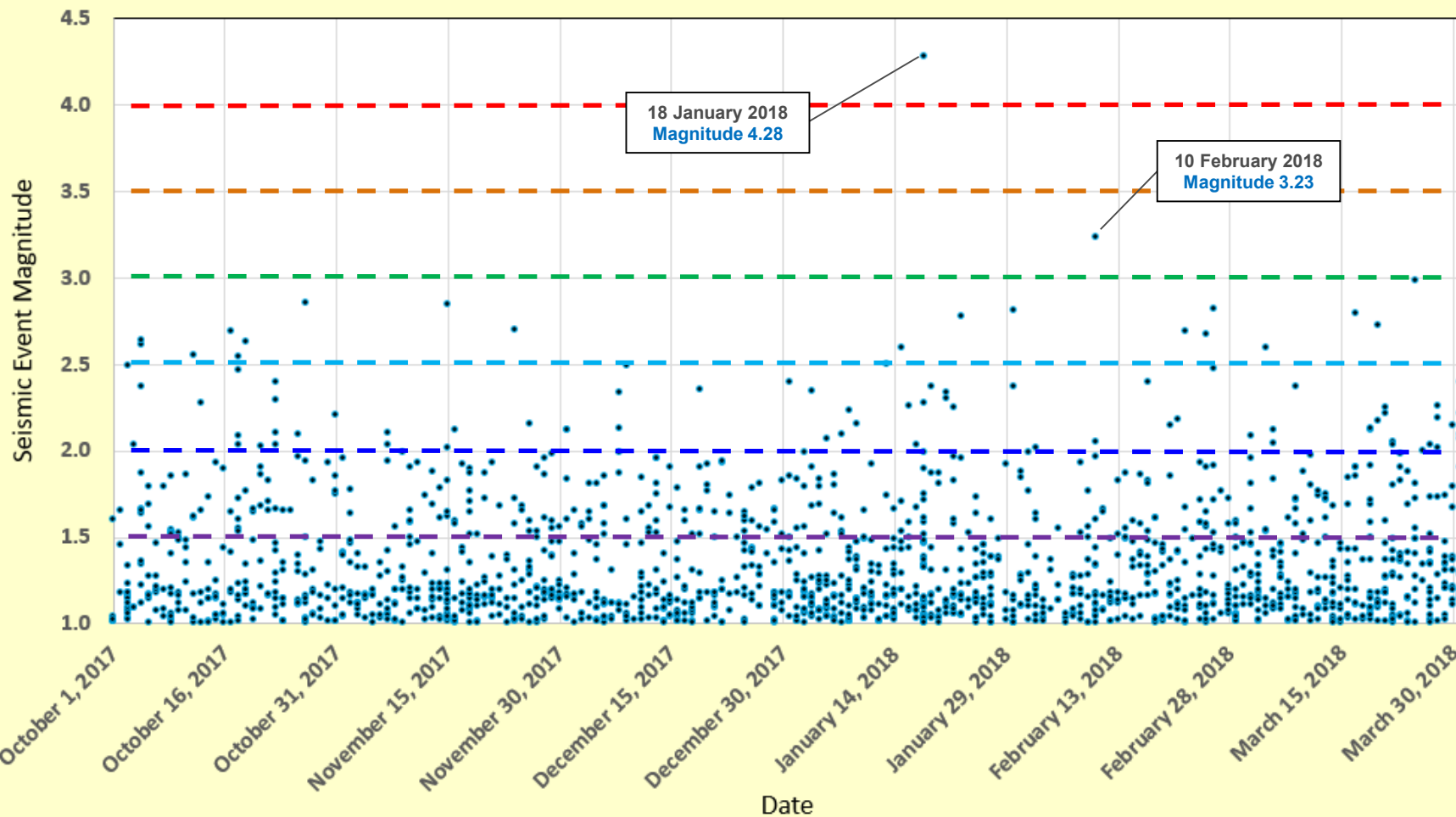
01 October 2017 to 31 March 2018

Magnitude	Number of Events
≥ 4.0	1
≥ 3.5	1
≥ 3.0	2
≥ 2.5	20
≥ 2.0	66
≥ 1.5	400

The Geysers Fieldwide Seismicity

01 October 2017 to 31 March 2018

Magnitude ≥ 1.0

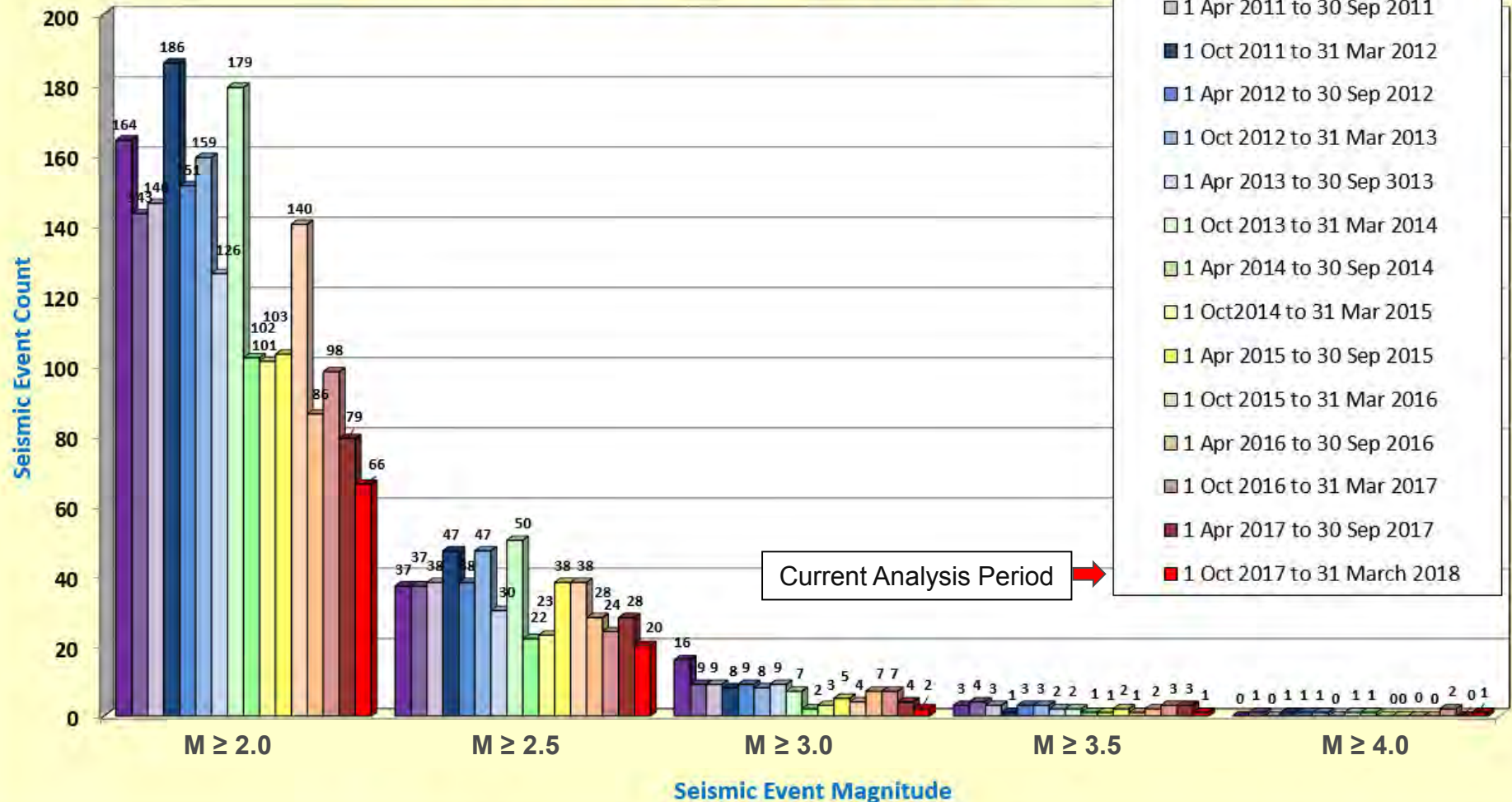


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Field-wide Seismicity Analysis

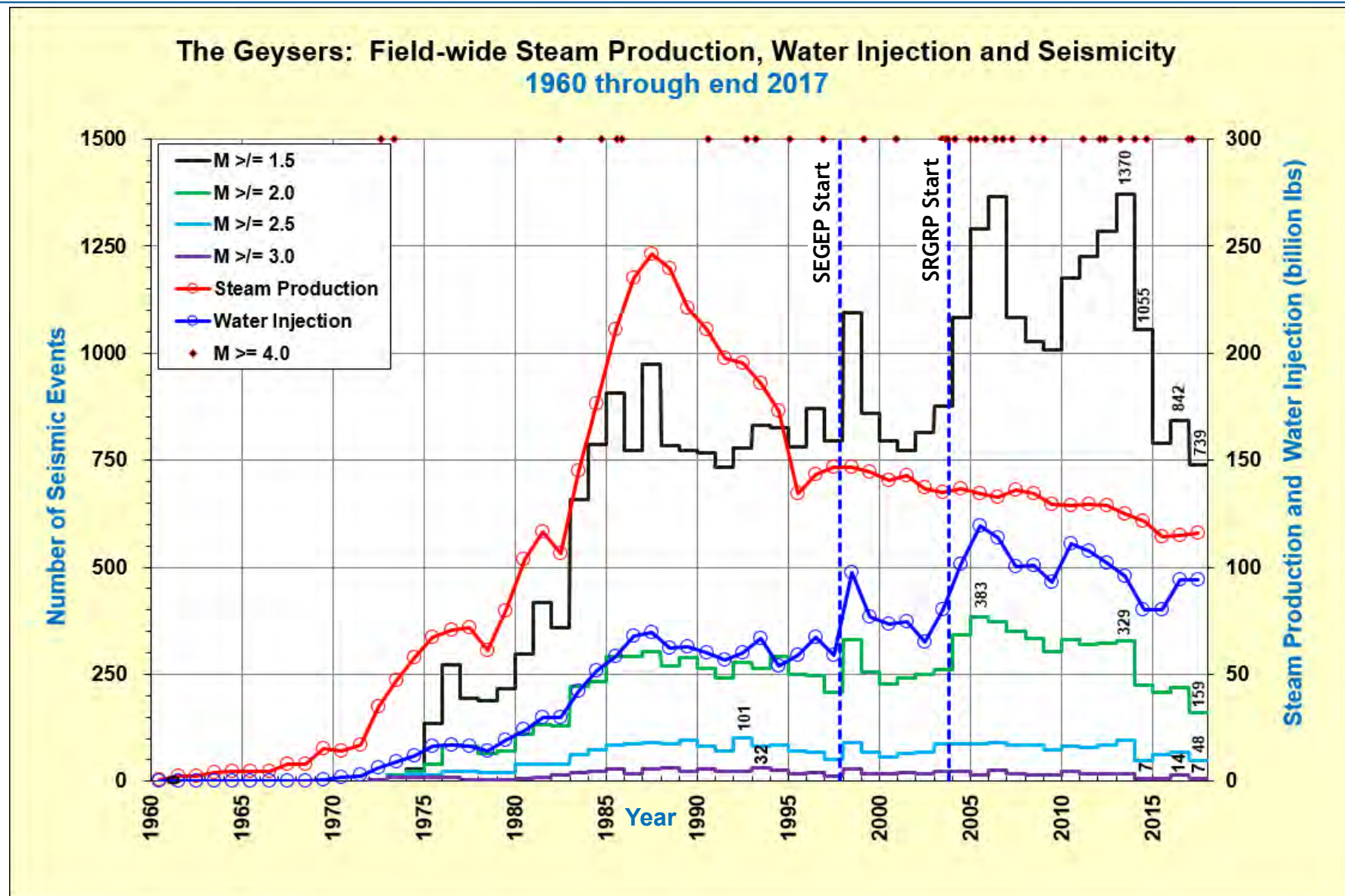
Comparison of Sixteen Semi-annual Reporting Periods

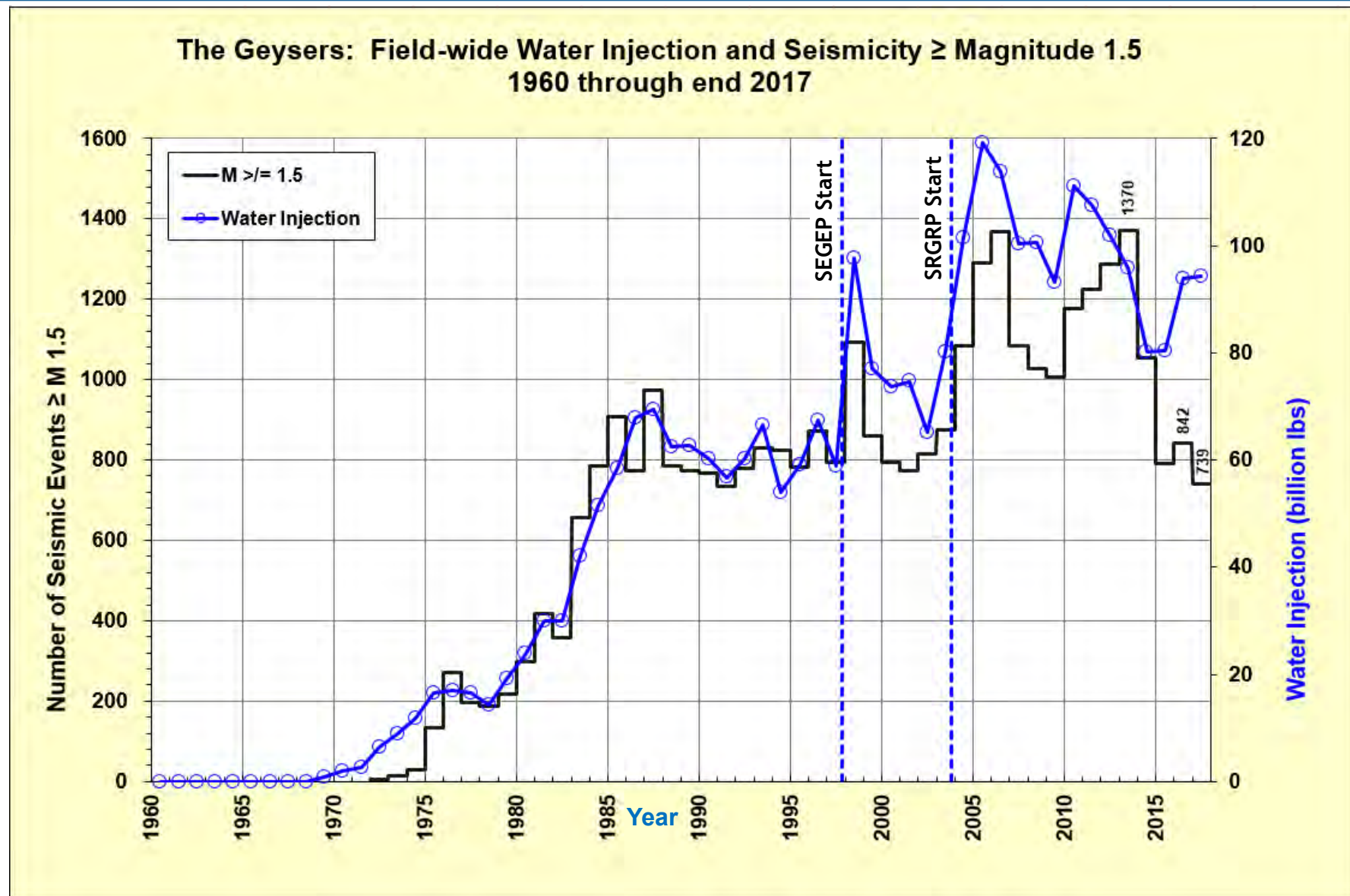
Field-wide Seismicity Analysis
Events \geq Specified Magnitude
Sixteen Semi-Annual Periods Since 01 April 2010



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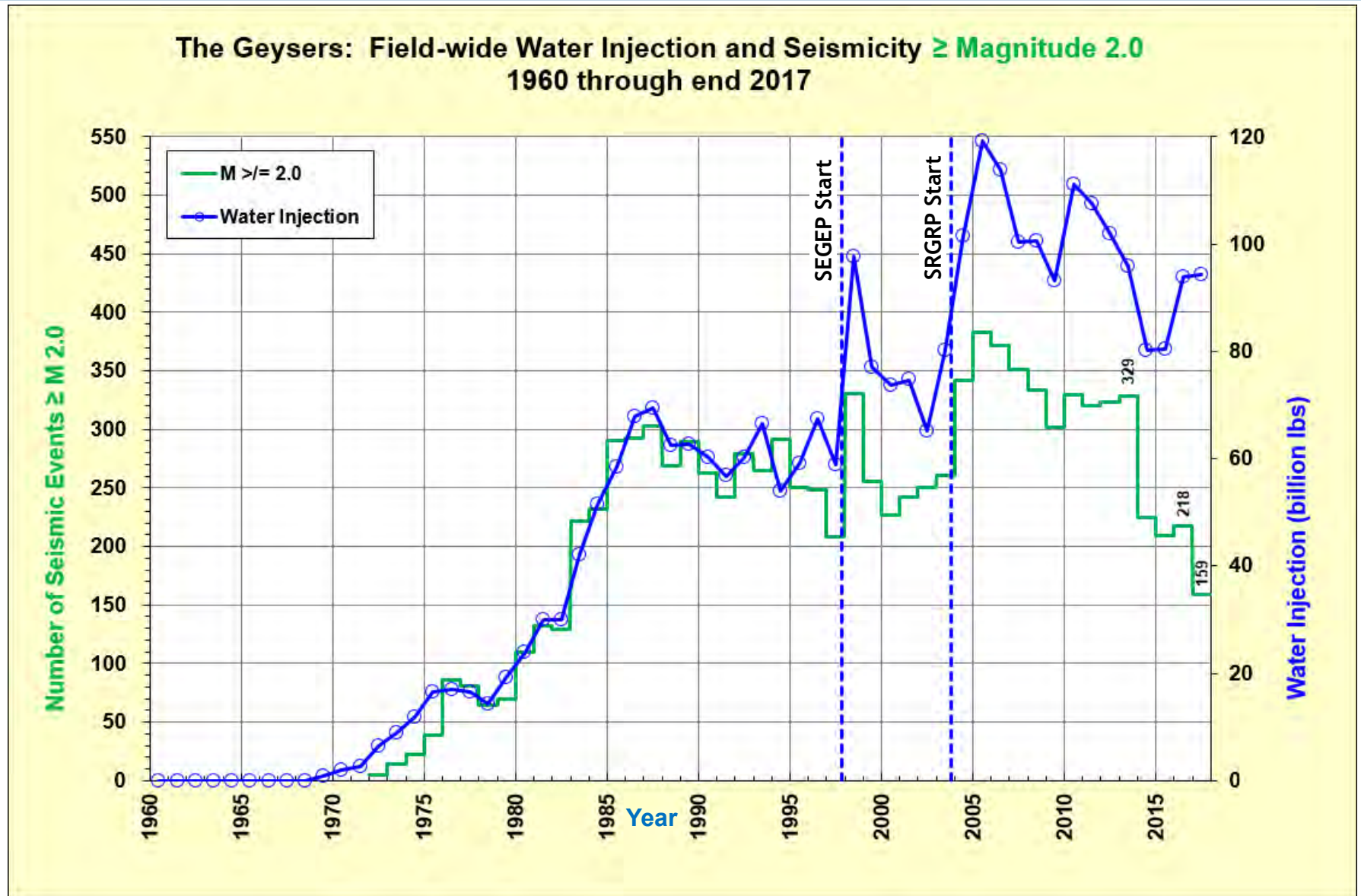
Yearly Field-wide Steam Production, Water Injection and Seismicity





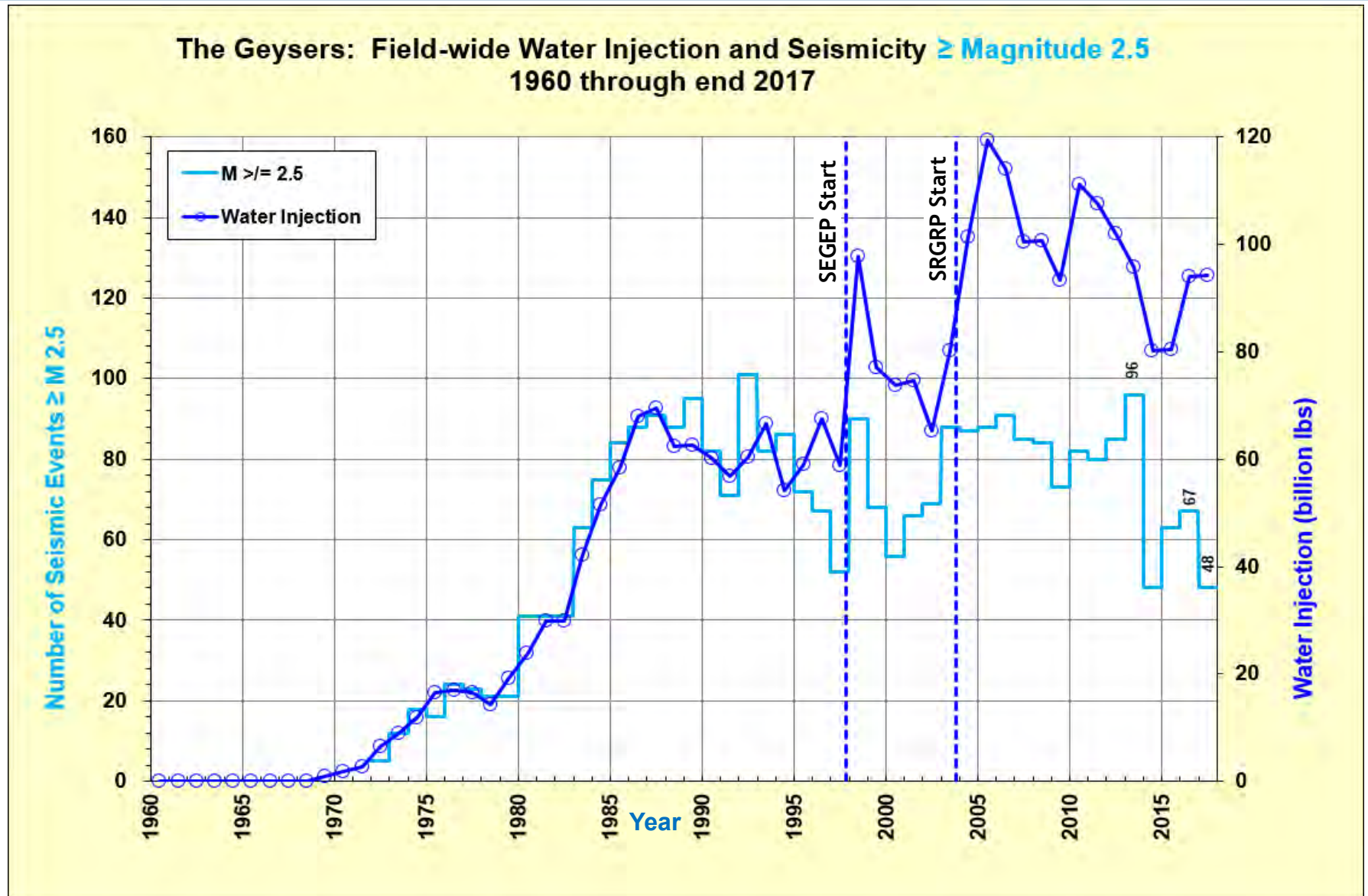
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Yearly Field-wide Water Injection and Seismicity \geq Magnitude 2.0



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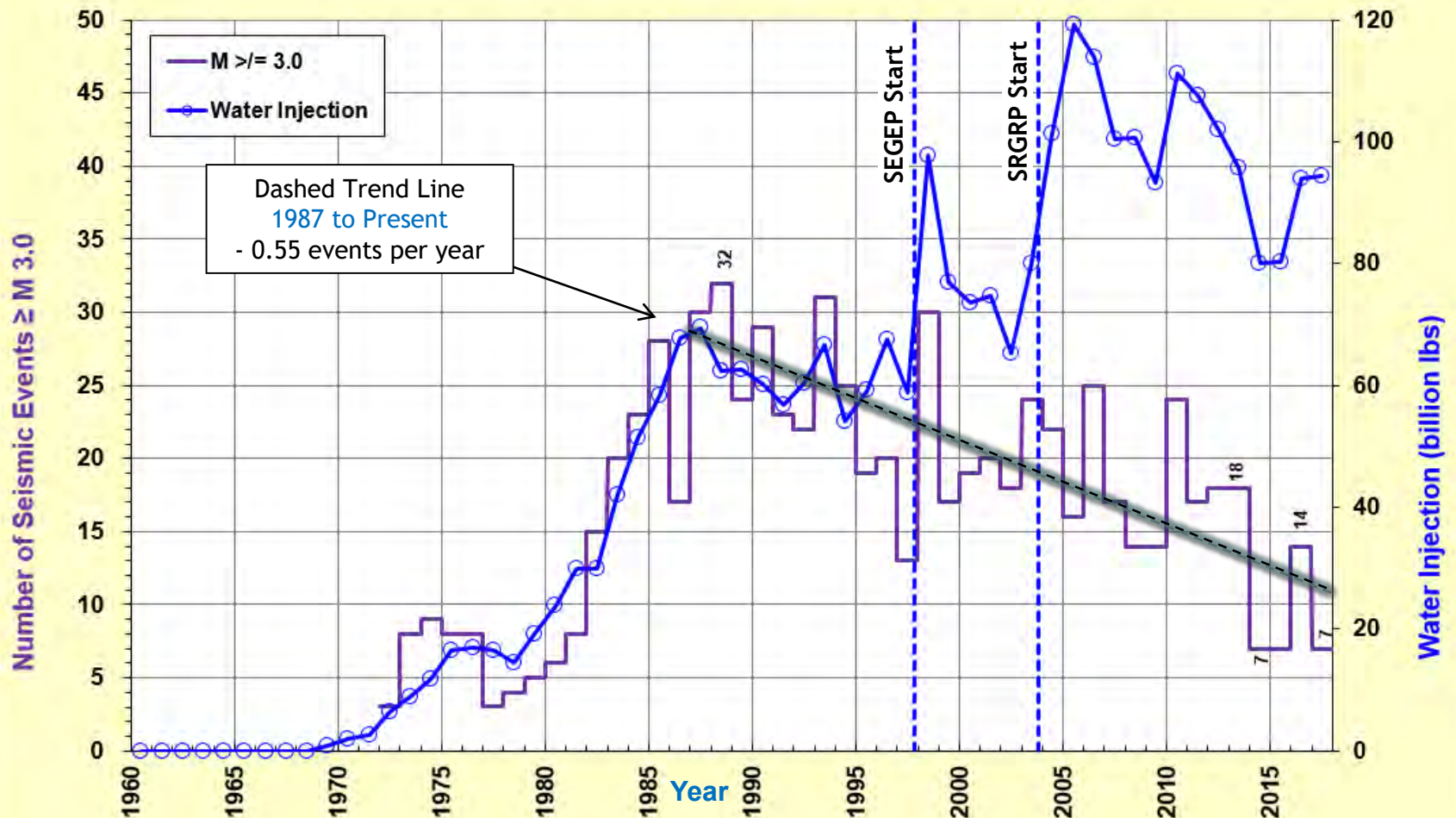
Yearly Field-wide Water Injection and Seismicity \geq Magnitude 2.5



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Yearly Field-wide Water Injection and Seismicity \geq Magnitude 3.0

The Geysers: Field-wide Water Injection and Seismicity \geq Magnitude 3.0
1960 through end 2017



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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

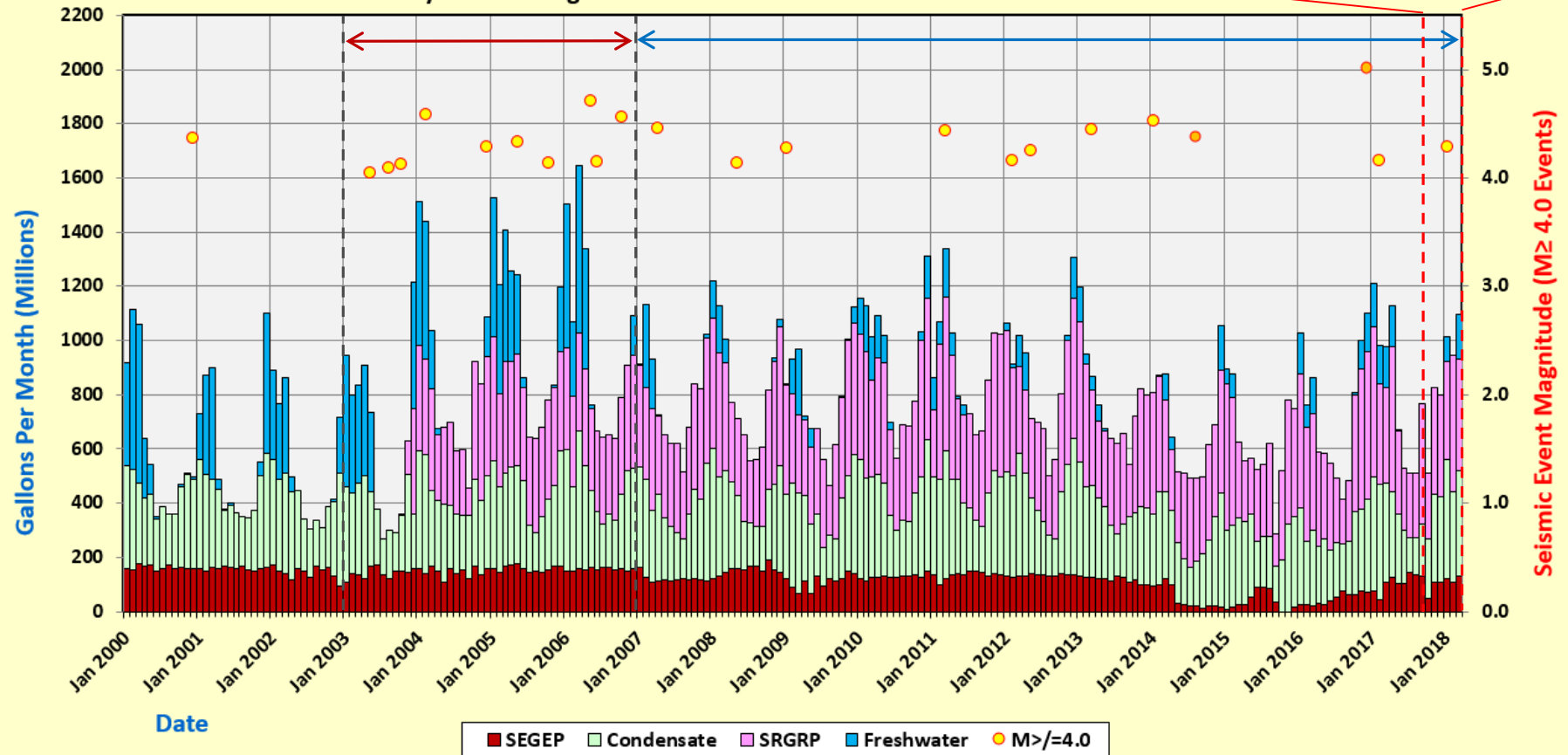
Water Supply for Reporting Period (Six Months)

Water Injection Sources (Gallons)				
Month	SEGEF	SRGRP	Condensate	Fresh Water
October	49,843,000	241,550,000	218,251,010	0
November	108,488,000	394,690,000	324,215,571	0
December	107,527,000	375,250,000	314,305,742	0
January	122,434,000	364,560,000	436,268,490	91,264,006
February	108,737,000	502,040,000	333,067,652	0
March	128,632,000	414,740,000	389,579,727	162,528,067

Time Period Magnitude ≥ 4.0 Seismic Events

January 2003 through December 2006	2.50 per year
January 2007 through March 2018	1.06 per year

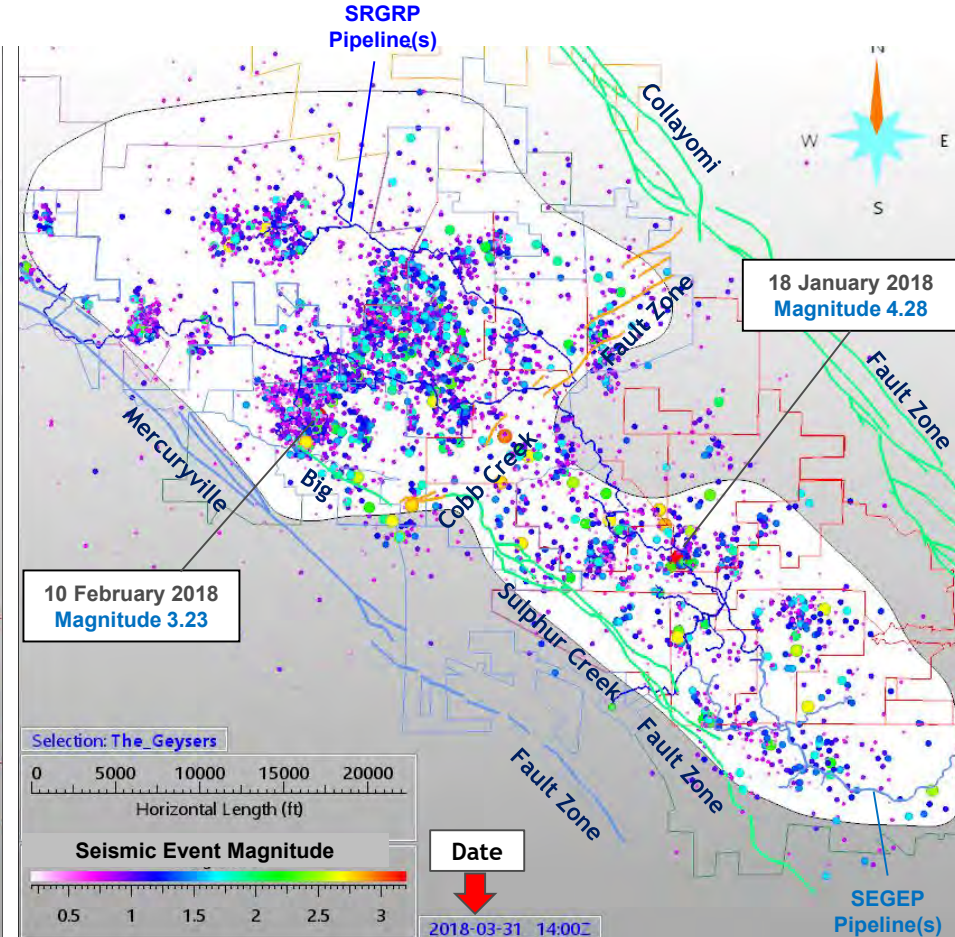
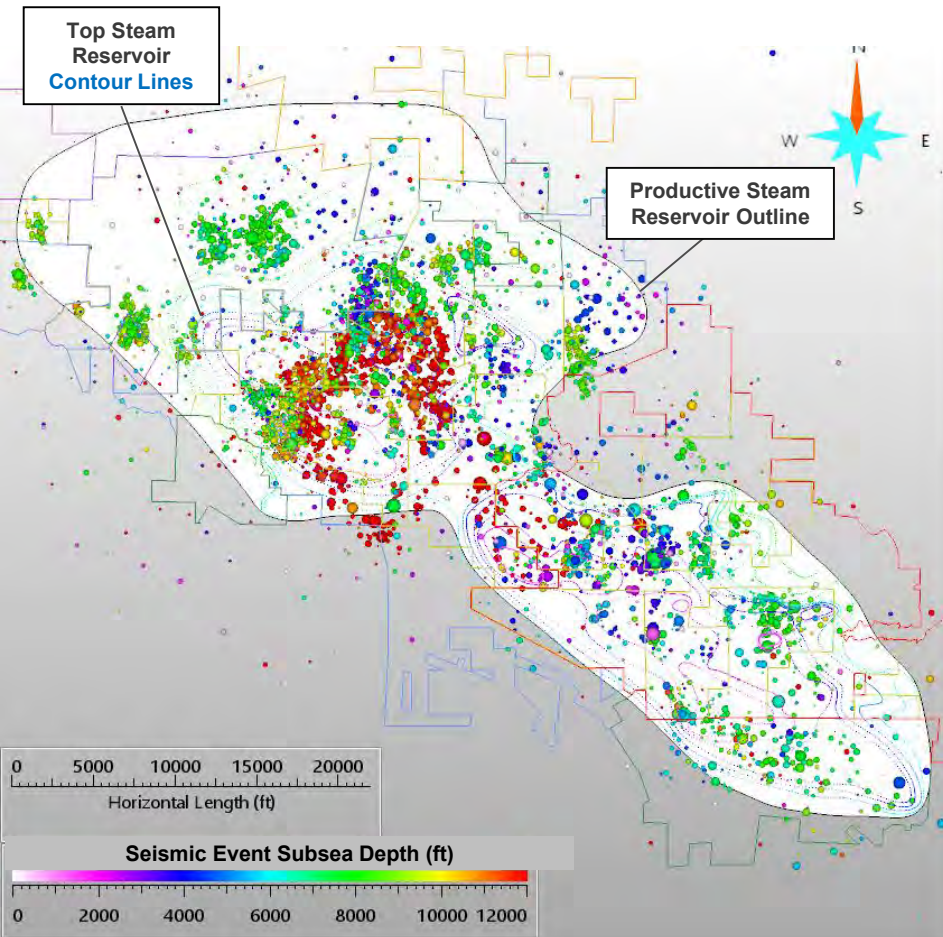
The Geysers
Calpine Fieldwide Water Injection Sources
Magnitude ≥ 4.0 Seismicity
01 January 2000 through 31 March 2018



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Fieldwide Induced Seismicity Animation

01 October 2017 to 31 March 2018



U.S. Geological Survey Faults	
< 150 years	Red line
< 15,000 years	Orange line
< 130,000 years	Green line
< 1,600,000 years	Blue line

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Calpine Community Hotline

The communities continue to focus on efforts to recover from the Valley Fire, resulting in only **two calls** to the Calpine Community Hotline during the current reporting period of **01 October 2017 to 31 March 2018**. The seismic event responsible for both calls:

Magnitude 4.28 Seismic Event

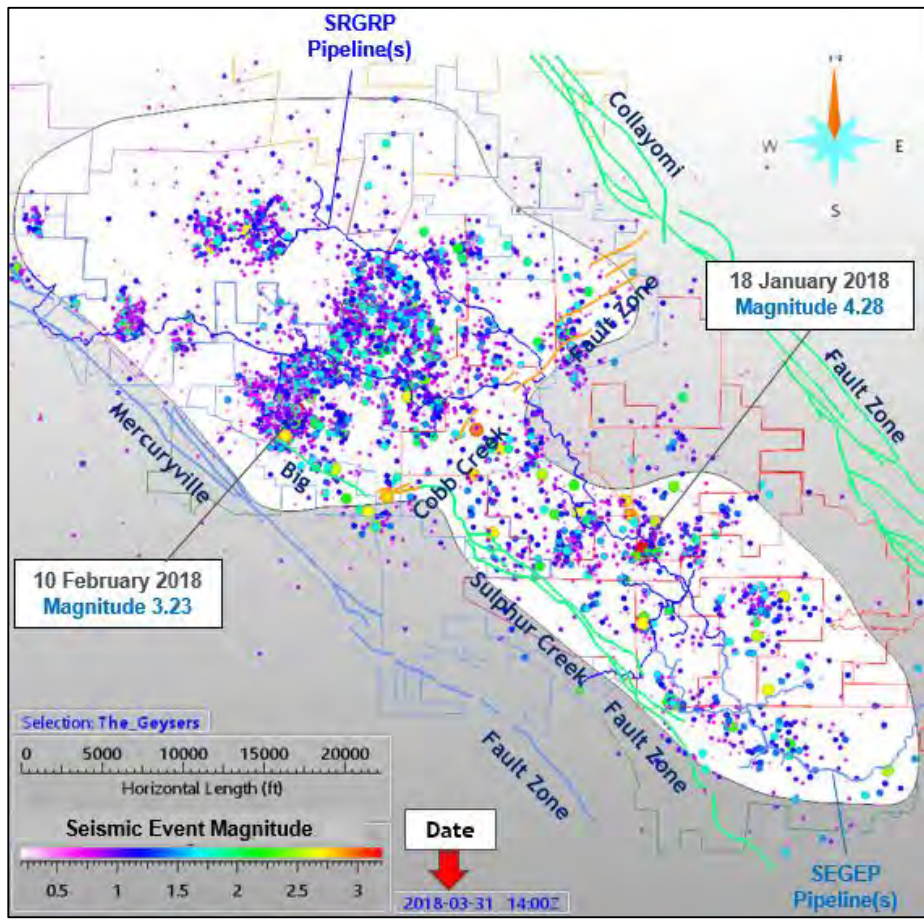
Date and Time: 17 January 2018 at 21:55:12 Pacific Time
18 January 2018 at 05:55:12 UTC
Latitude: North 38.78500
Longitude: West 122.74333
Depth: 5940 Feet (1.81 km) Below Sea Level

Anderson Springs

Call on 18 January 2018 at 11:24 am
“One of the stronger events experienced. It definitely got our attention and shook the house for a bit longer than usual.”
No call back requested.

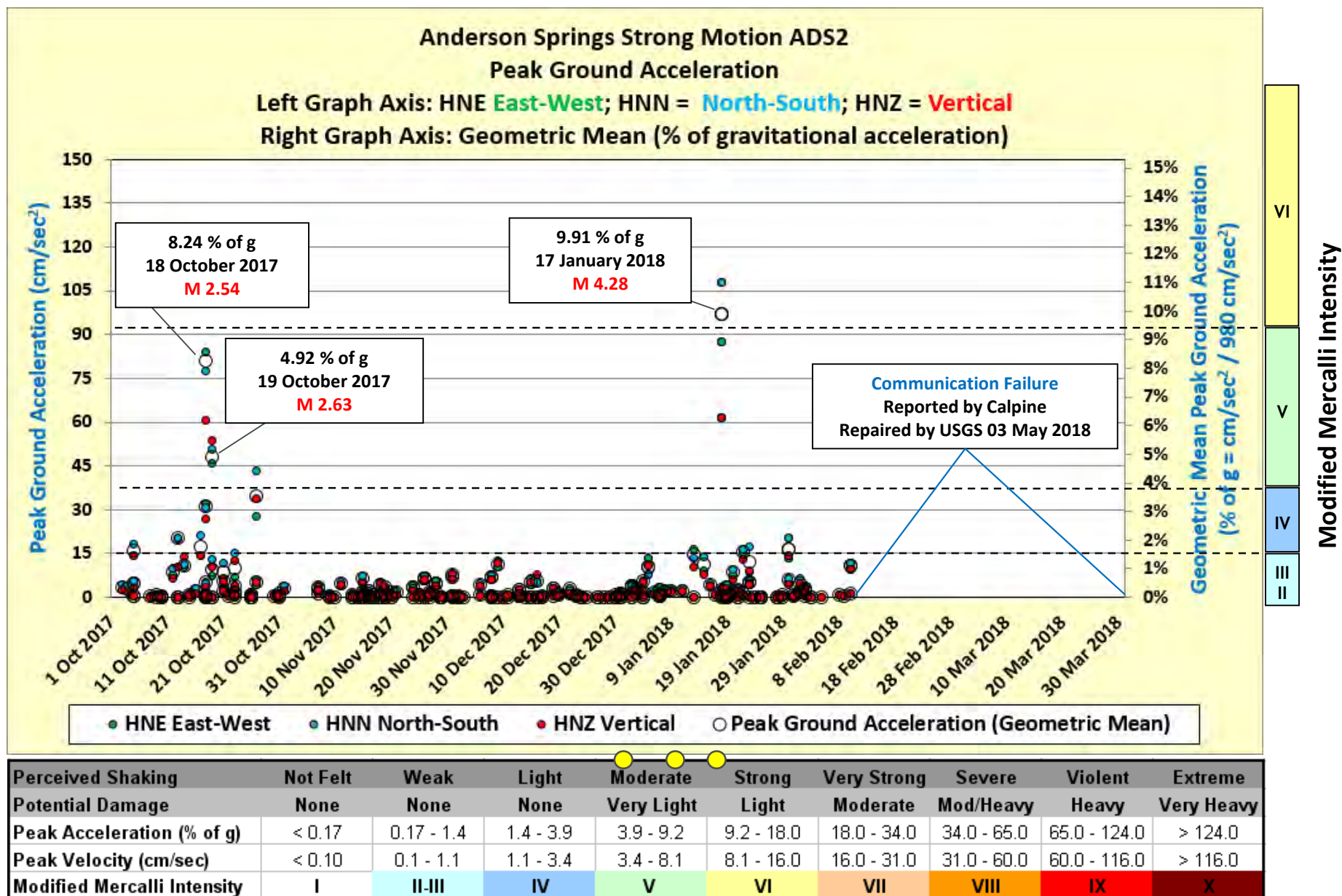
Cobb

Call on 22 January 2018 at 11:49 am
“I have some questions about the recent earthquake on Wednesday at about 9:50 pm”
Call back requested.
Danielle Mathews Seperas and Craig Hartline provided the caller with scientific information concerning the 4.28 seismic event and Calpine’s community relations program, including the semi-annual Seismic Monitoring Advisory Committee meetings.



Seismic Monitoring Advisory Committee Meeting

Anderson Springs Strong Motion Station ADS2



Seismic Monitoring Advisory Committee Meeting

Center for Engineering Strong Motion Data

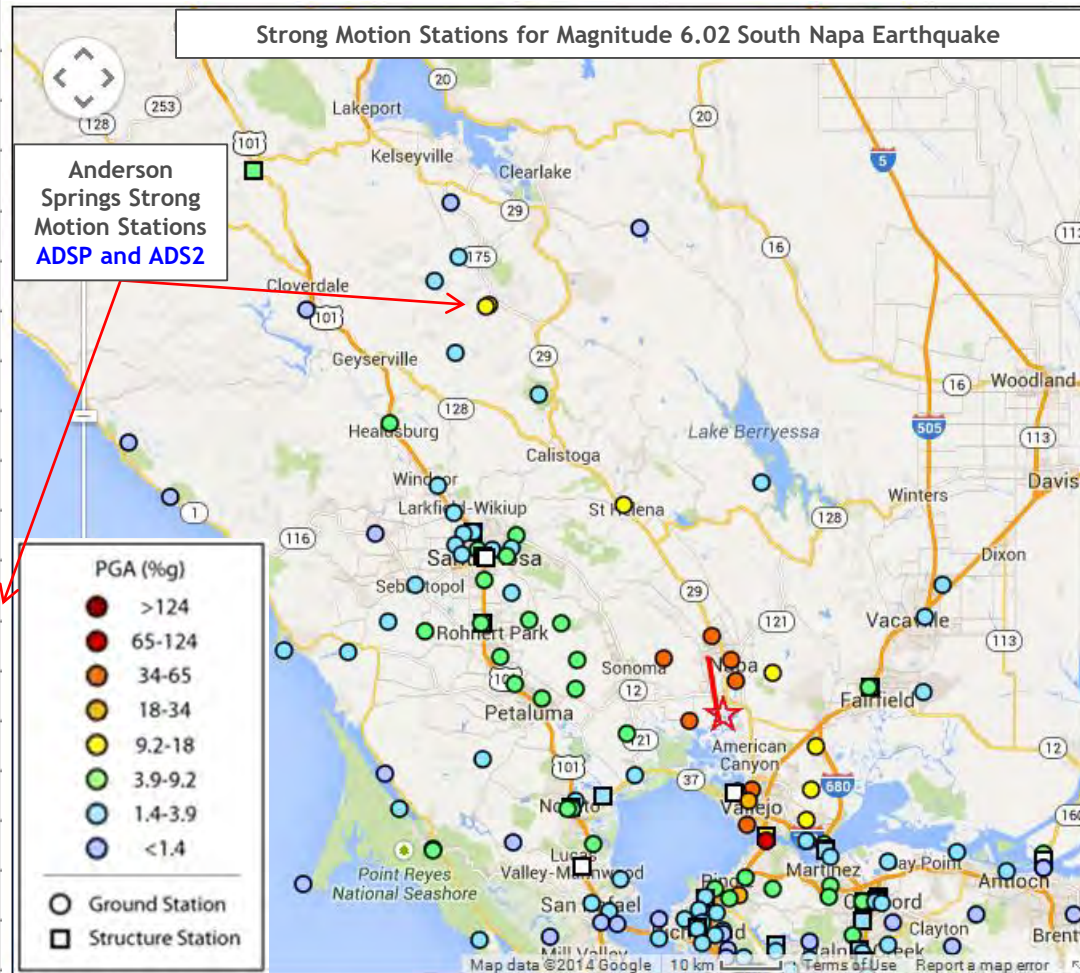
Magnitude 6.02 South Napa Earthquake

16 October 2014

USGS submitted strong motion records to the Center for Engineering Strong Motion Data
ADSP and ADS2 not consistent with regional patterns for peak ground acceleration

event link: http://strongmotioncenter.org/cgi-bin/CESMD/iqr_dist_DM2.pl?iqrID=SouthNapa_24Aug2014_72282711&SFlag=0&Flag=2

Station	Code /ID	Network	Distance (km)		Peak Ground Acceleration relative to g
			Epic.	Fault	
Crockett - Carquinez Br Geotech Array #1	68206	CGS	19.6	--	0.995
Main St, Napa, CA	N016	NCSN	9.1	4.4	0.611
Vallejo - Broadway & Sereno	68294	CGS	11.7	12.1	0.469
Crockett - Carquinez Br Geotech Array #2	68259	CGS	19.5	--	0.436
Napa: Fire Station No. 3	1765	USGS	12.3	3.3	0.427
Huichica Creek	NHC	NCSN	3.5	4.4	0.403
Napa - Napa College	68150	CGS	7.1	4.5	0.375
Mare Island	NMI	NCSN	16.7	16.8	0.369
Lovall Valley Loop Rd	N019B	NCSN	12.0	6.4	0.342
Vallejo: Fire Station	1759	USGS	13.4	13.6	0.329
Pinole - Adobe & Pinole Valley Rd	58368	CGS	26.3	26.9	0.203
Vallejo - Hwy 37/Napa River E Geo. Array	68310	CGS	11.0	--	0.198
Anderson Springs	ADSP	USGS	70.4	--	0.174
CA: Anderson Springs; Town Pool	ADS2	USGS	70.2	--	0.159
Vallejo - Carquinez/180 East Bridge	68184	CGS	18.9	19.4	0.149
McCall Drive, Benicia, CA	C032	NCSN	20.3	20.6	0.140
Green Valley Road	NGVB	NCSN	11.5	9.7	0.110
St. Helena: Fire Station No. 17	1764	USGS	34.7	25.0	0.104
Lake Herman	NLH	NCSN	18.0	18.1	0.094




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Center for Engineering Strong Motion Data



Engels Strong Motion ESM

The Engels Strong Motion station data is transferred by radio telemetry to the LBNL seismic monitoring network and accessible at the [Center for Engineering Strong Motion Data*](https://www.strongmotioncenter.org/), a cooperative effort of the [United States Geological Survey](#), [California Geological Survey](#) and the [Advanced National Seismic System](#).




CESMD Strong-Motion Data Set

[Home](#)
[Archives](#)
[Search !\[\]\(15a01675795da3c0924461c44b8bf202_img.jpg\)](#)
[Earthquake/Station Maps](#)
[About](#)

[Internet Data Report](#)

The Geysers Earthquake of 17 Jan 2018
 4.2MW, 21:55:11 PST, 38.7850N 122.7433W Depth 1.8 km

[Download Table](#)
Last Update

Station	Code /ID	Network	Distance (km)		Horiz. Apk (g)	
			Epic.	Fault	Ground	Struct.
Engels Strong Motion	ESM	BGSN	3.6	--	0.166	--
CA: Anderson Springs; Town Pool	ADS2	NSMP	4.0	--	0.112	--
Geysers	GDXB	NCSN	5.2	--	0.079	--
Hale Ranch	DRH	BGSN	18.7	--	0.006	--

Channel 90 Degree (East-West)

Peak acceleration = -133.428 cm/sec/sec
 Peak velocity = 2.285 cm/sec
 Peak displacement = -.062 cm

Channel 360 Degree (North-South)

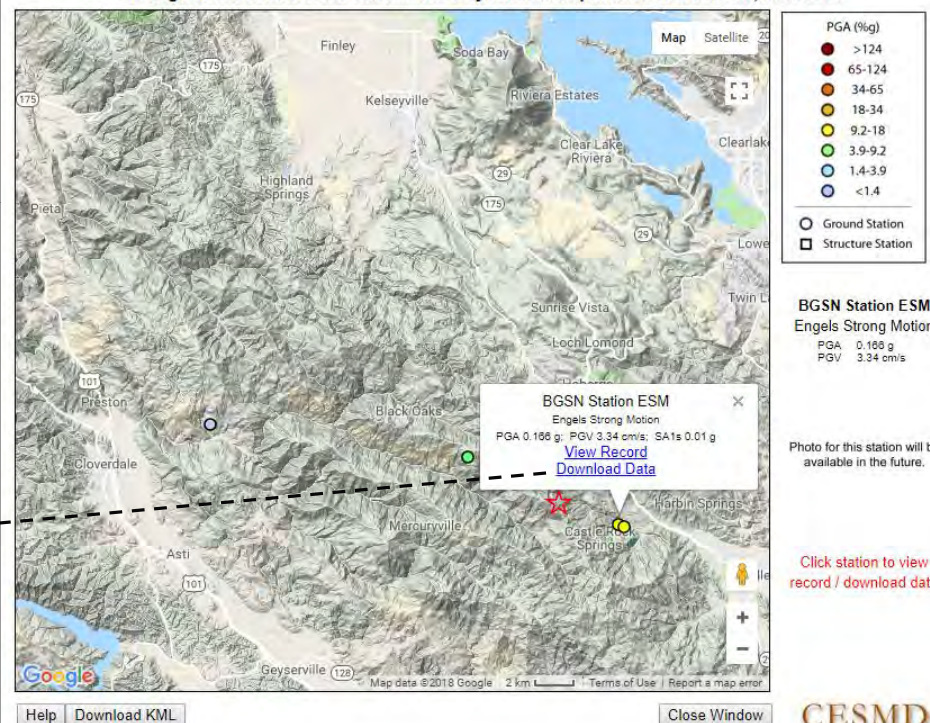
Peak acceleration = -157.753 cm/sec/sec
 Peak velocity = 3.339 cm/sec
 Peak displacement = -.181 cm

Center for Engineering Strong Motion Data

CESMD - A Cooperative Effort



Strong Motion Stations for 4.2MW The Geysers Earthquake of 17 Jan 2018, 2155 PST



* <https://www.strongmotioncenter.org/>

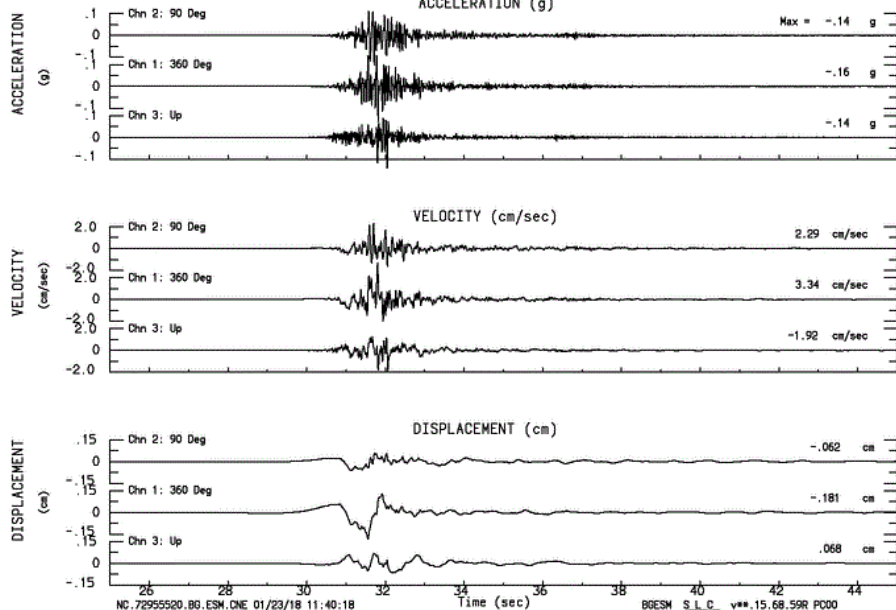
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Center for Engineering Strong Motion Data

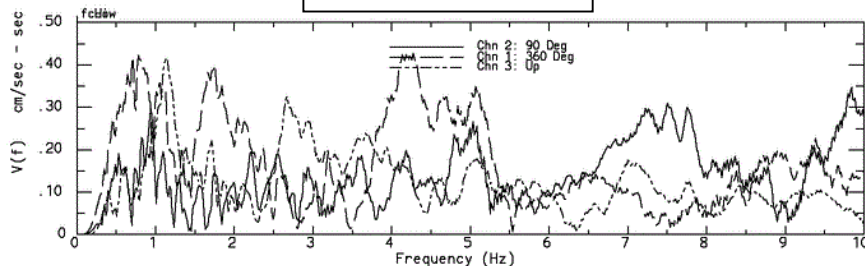
Engels Strong Motion ESM

Acceleration, Velocity and Surface Displacement

Engels Strong Motion BGSN Sta ESM
Rcd of Wed Jan 17, 2018 21:54:42.8 PST
Frequency Band Processed: 3.3 secs to 40.0 Hz
CISM/CSMP Preliminary Strong Motion Processing - Subject to Revision



Spectral Analysis

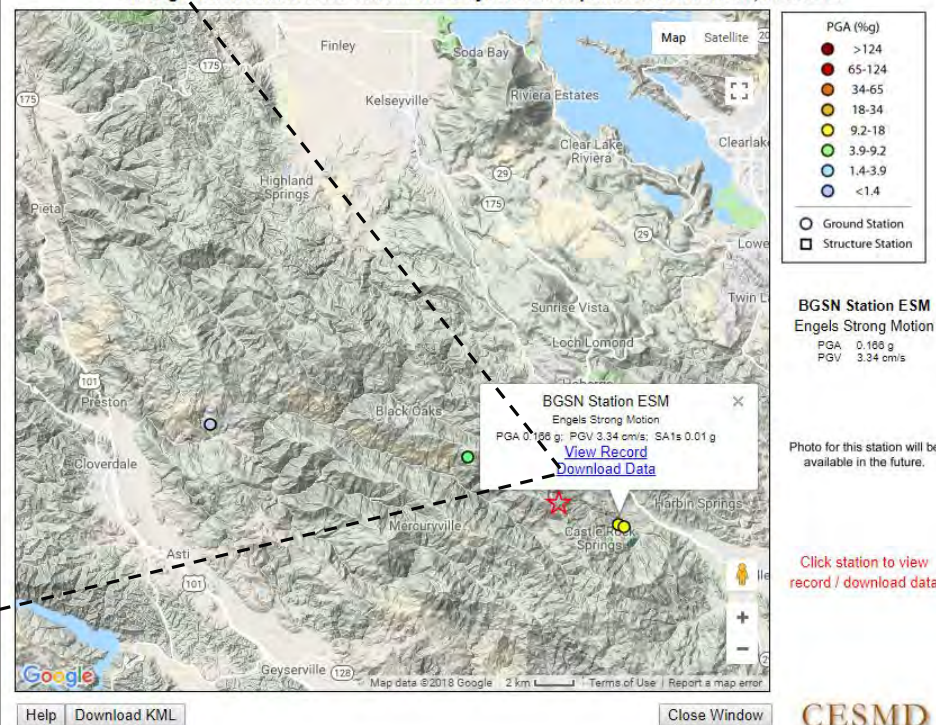


Center for Engineering Strong Motion Data

CESMD - A Cooperative Effort



Strong Motion Stations for 4.2MW The Geysers Earthquake of 17 Jan 2018, 2155 PST



Seismic Monitoring Advisory Committee Meeting

Anderson Springs Strong Motion Station

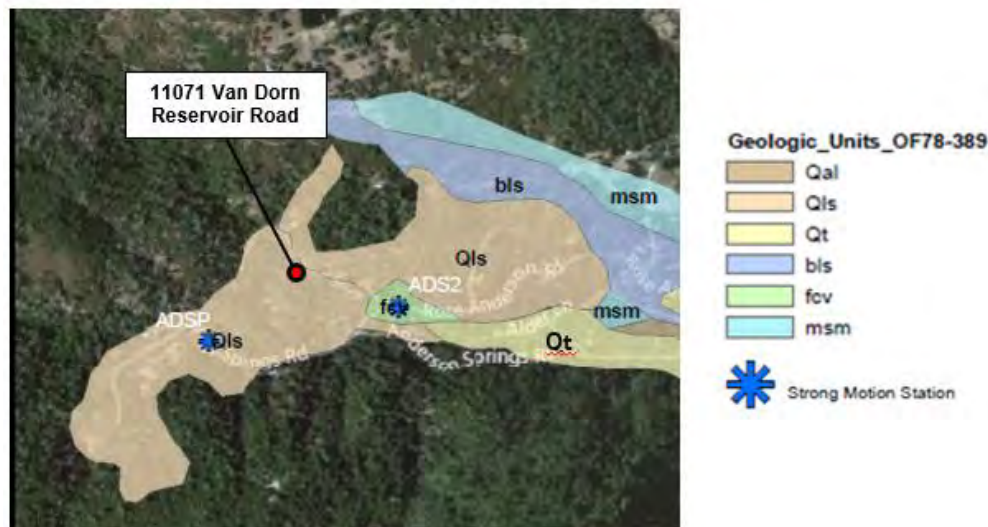
Engels Strong Motion ESM vs Fire-Damaged ADSP Strong Motion

Site Selection Criteria to Replace ADSP

- 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

ADSP and Engels Strong Motion (ESM) Stations

- 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)
- ESM measurements very consistent with relatively high peak ground acceleration values at ADSP
- consistently higher measurements than ADS2



M 4.2 2018-01-17 21:55:11 Pacific Time

Engels Strong Motion (ESM)

HNE cm/sec ²	HNN cm/sec ²	HNZ cm/sec ²	Geometric Mean	g	% of g
133.42800	157.75300	76.49680	145.08	0.15	14.8

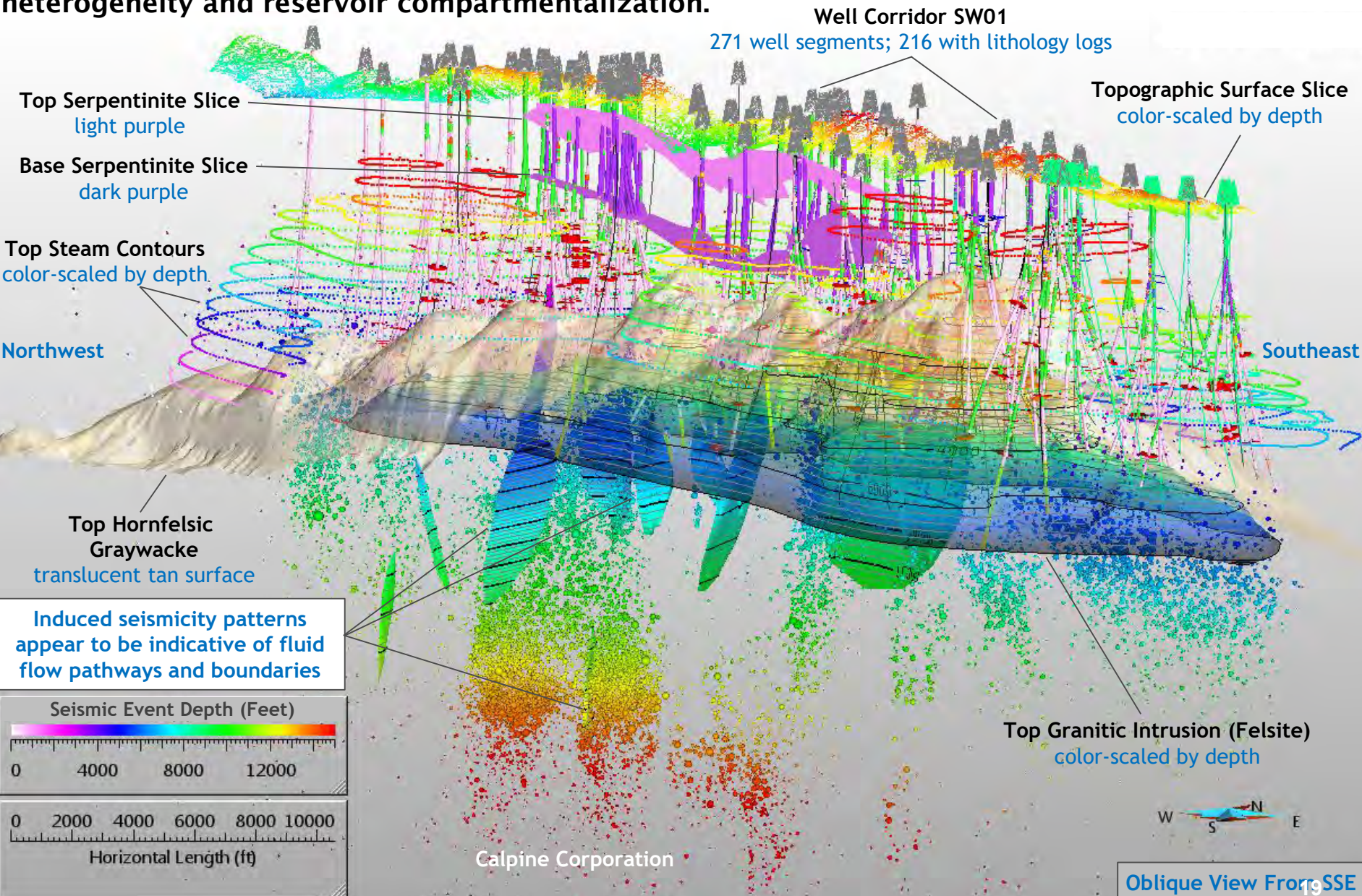
ADSP 9.9%

ESM 14.8%

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 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

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)

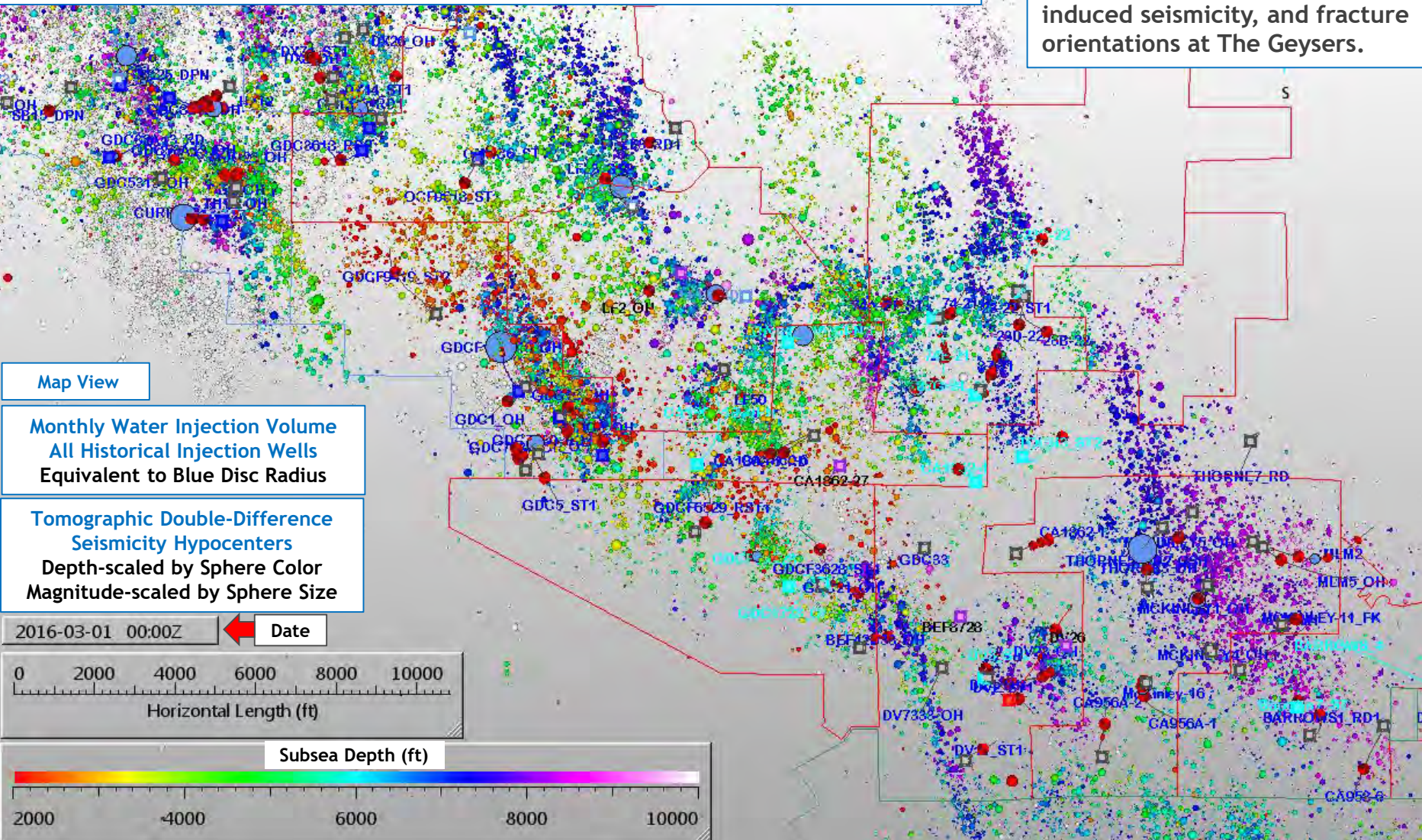
Minimize Injection Rate Variations

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

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.



Map View

Monthly Water Injection Volume All Historical Injection Wells Equivalent to Blue Disc Radius

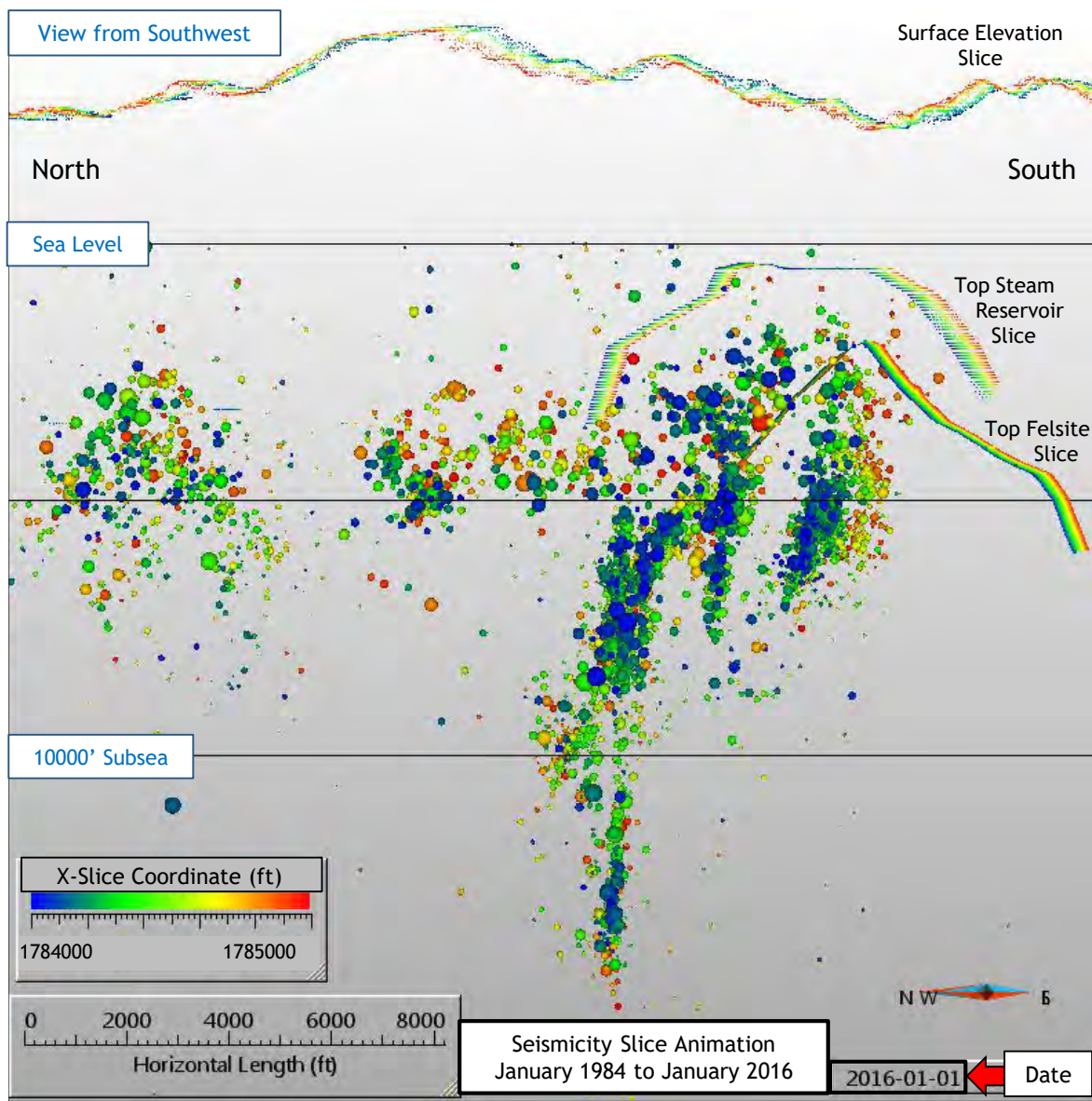
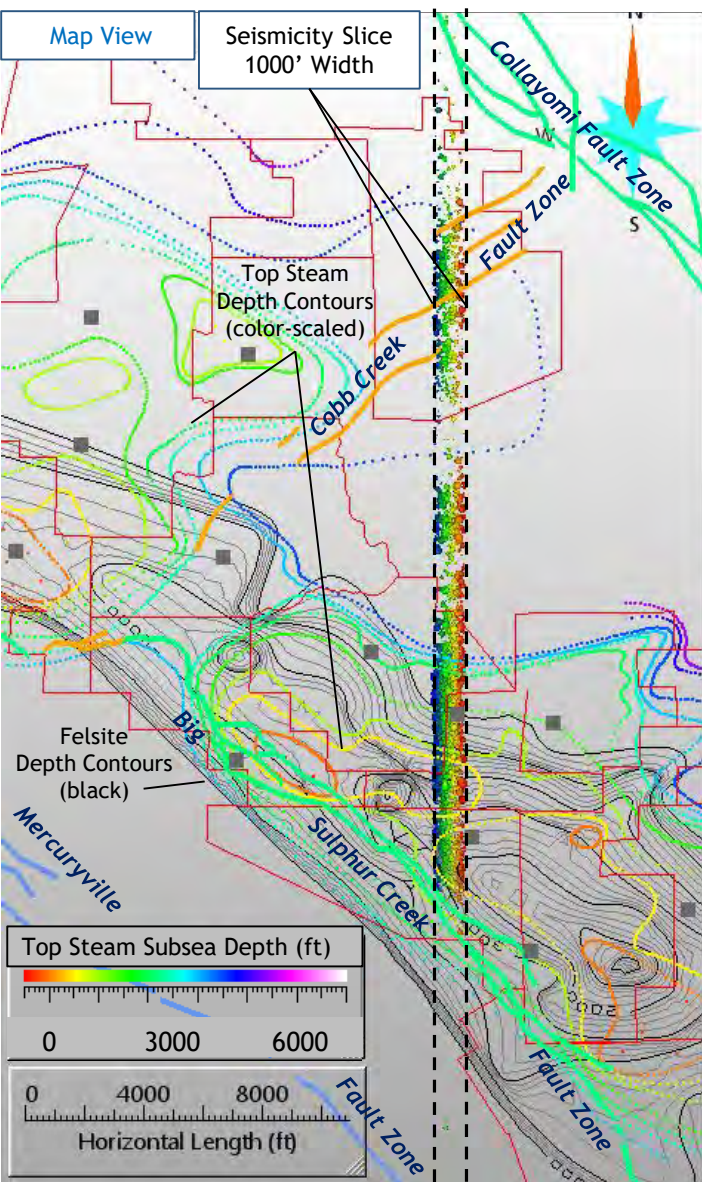
Tomographic Double-Difference
Seismicity Hypocenters
Depth-scaled by Sphere Color
Magnitude-scaled by Sphere Size

2016-03-01 00:00Z  Date

A horizontal axis scale labeled "Horizontal Length (ft)" with major tick marks at 0, 2000, 4000, 6000, 8000, and 10000. Minor tick marks are present every 1000 units.

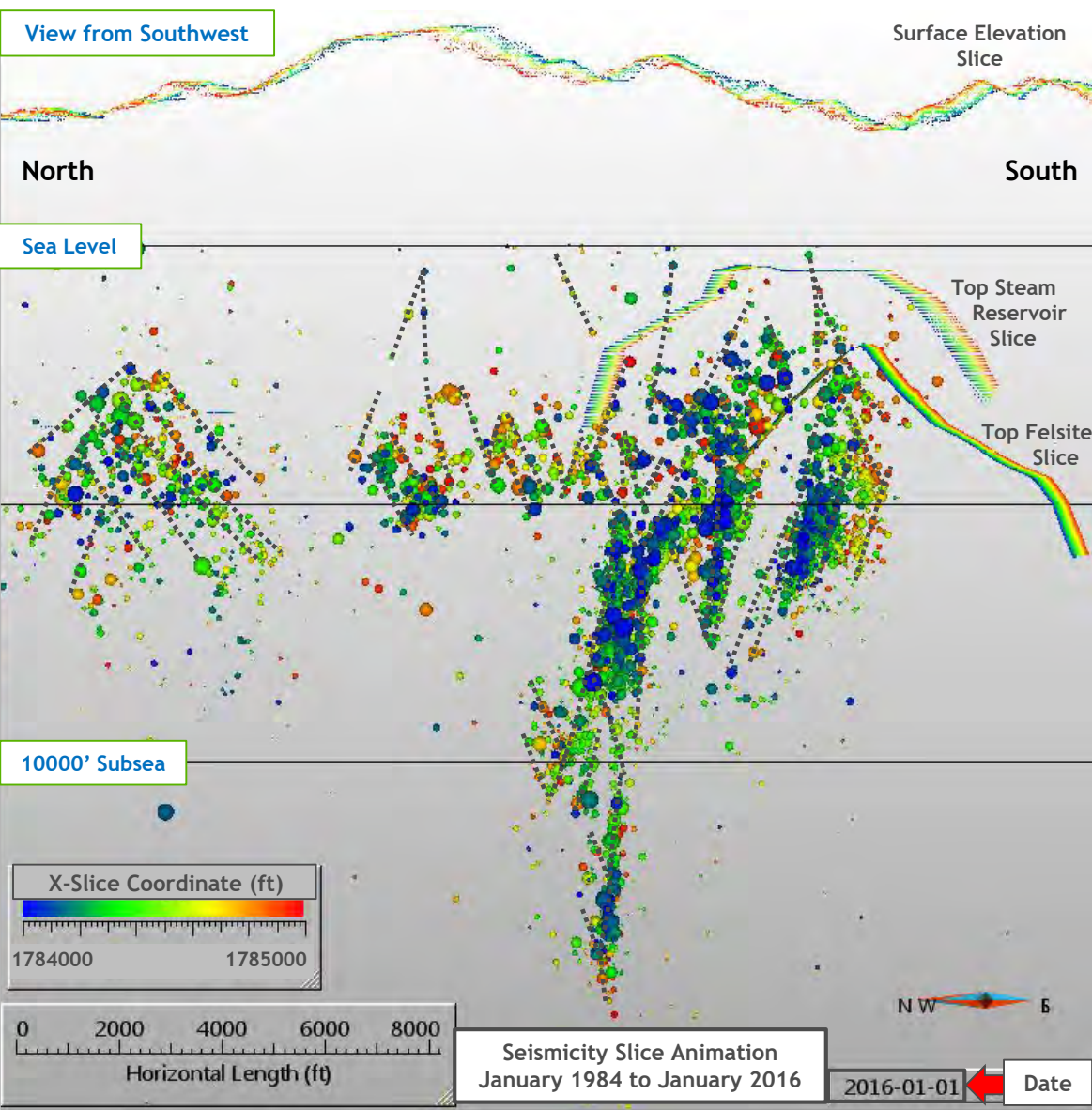
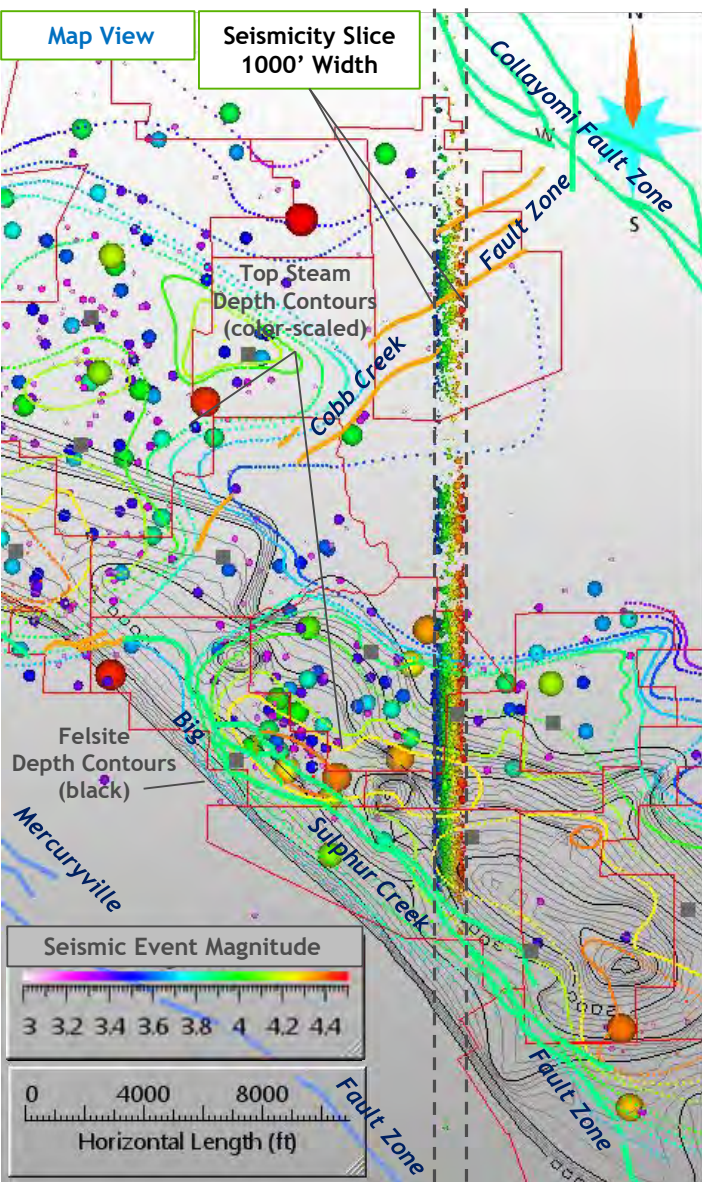
Seismic Monitoring Advisory Committee Meeting

Seismicity Slice Analysis and Fracture Zone Interpretation



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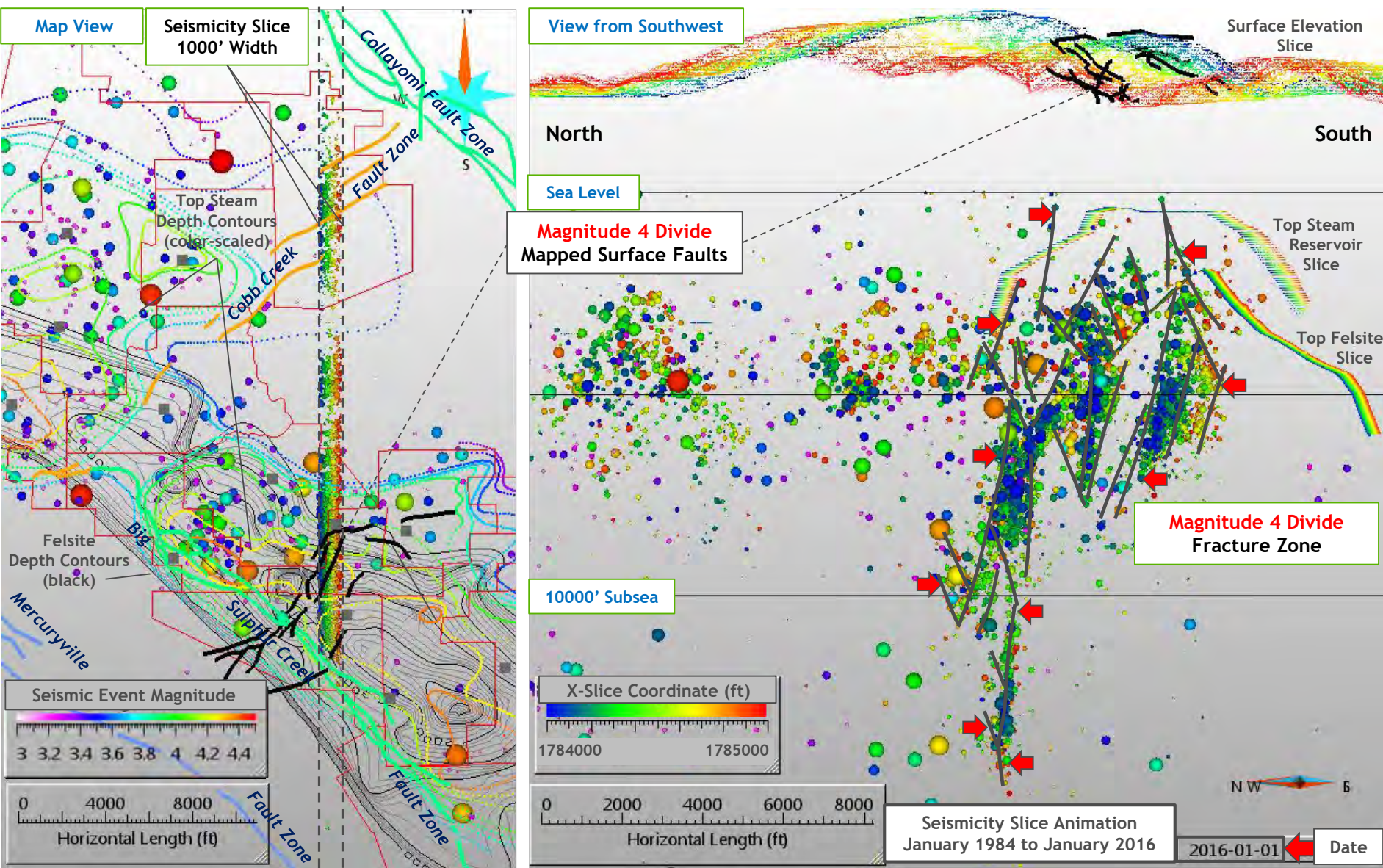
Seismicity Slice Analysis and Fracture Zone Interpretation



Seismic Monitoring Advisory Committee Meeting

Seismicity Slice Analysis and Fracture Zone Interpretation

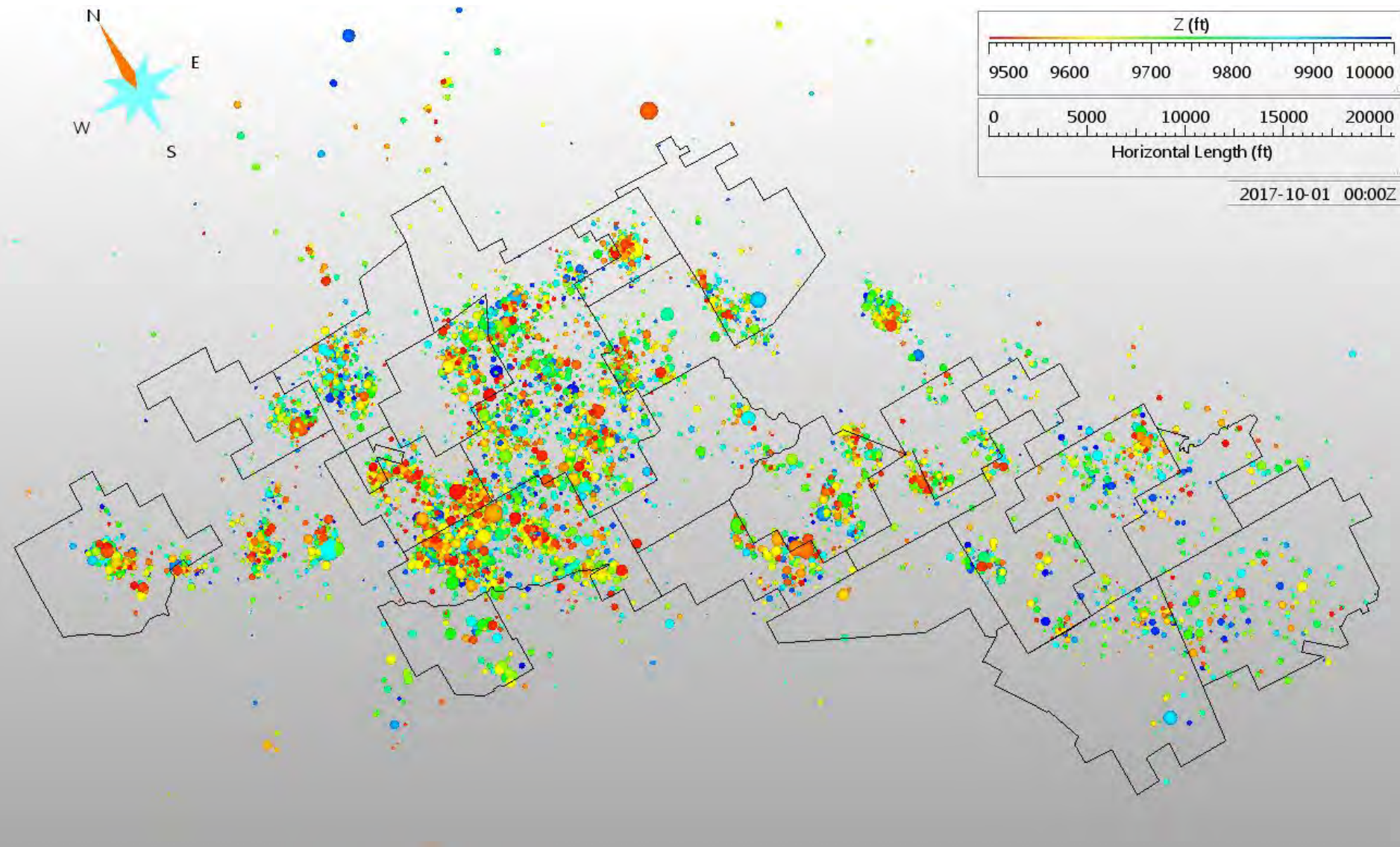
“Magnitude 4 Divide”



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Fault/Fracture Analysis and Interpretation

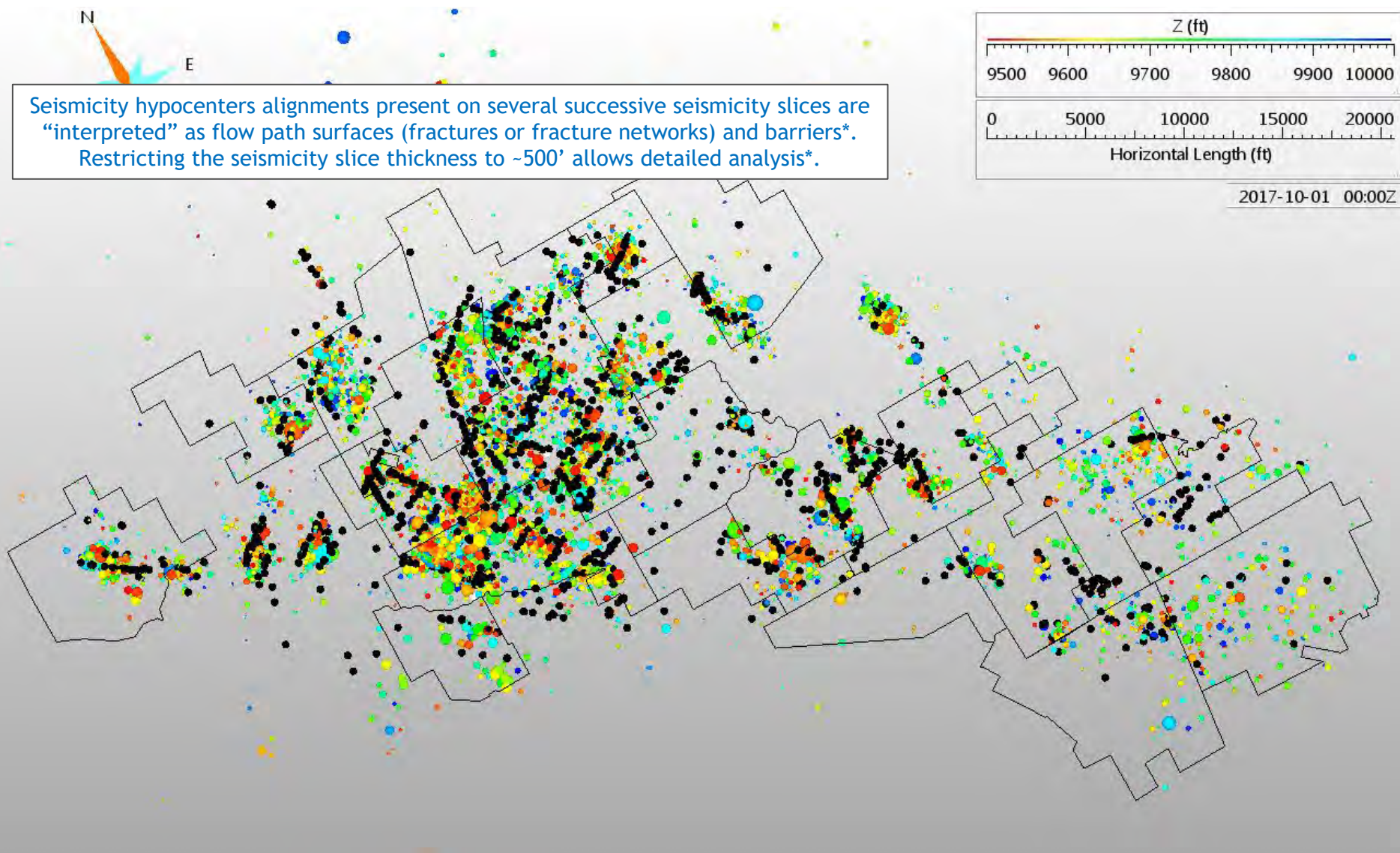
Depth Slice 9500 to 10000 Feet Subsea



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Fault/Fracture Analysis and Interpretation

Depth Slice 9500 to 10000 Feet Subsea

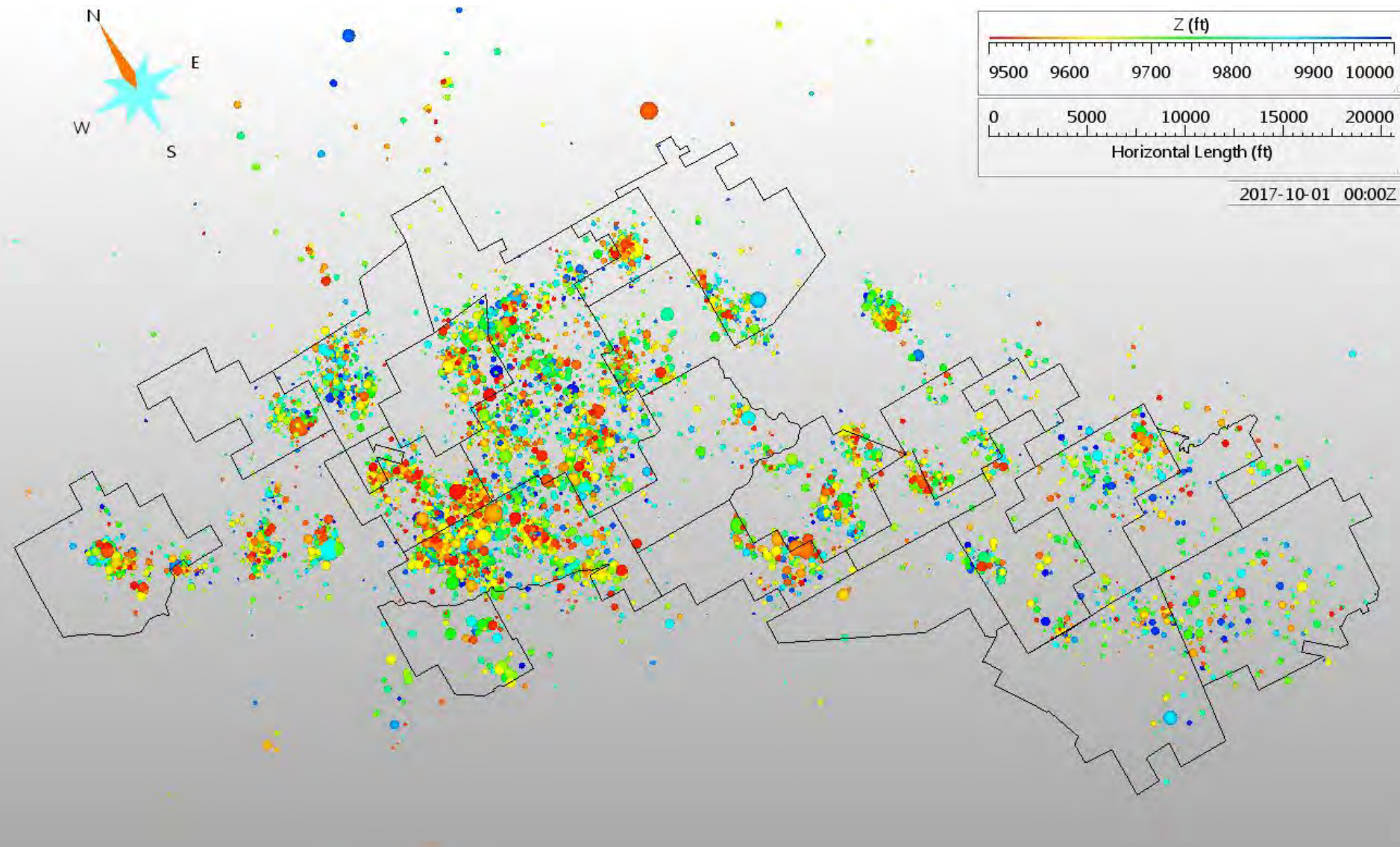


* Barrier: A physical feature that tends to limit or prevent the free movement and mixing of populations or individuals.

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Fault/Fracture Analysis and Interpretation

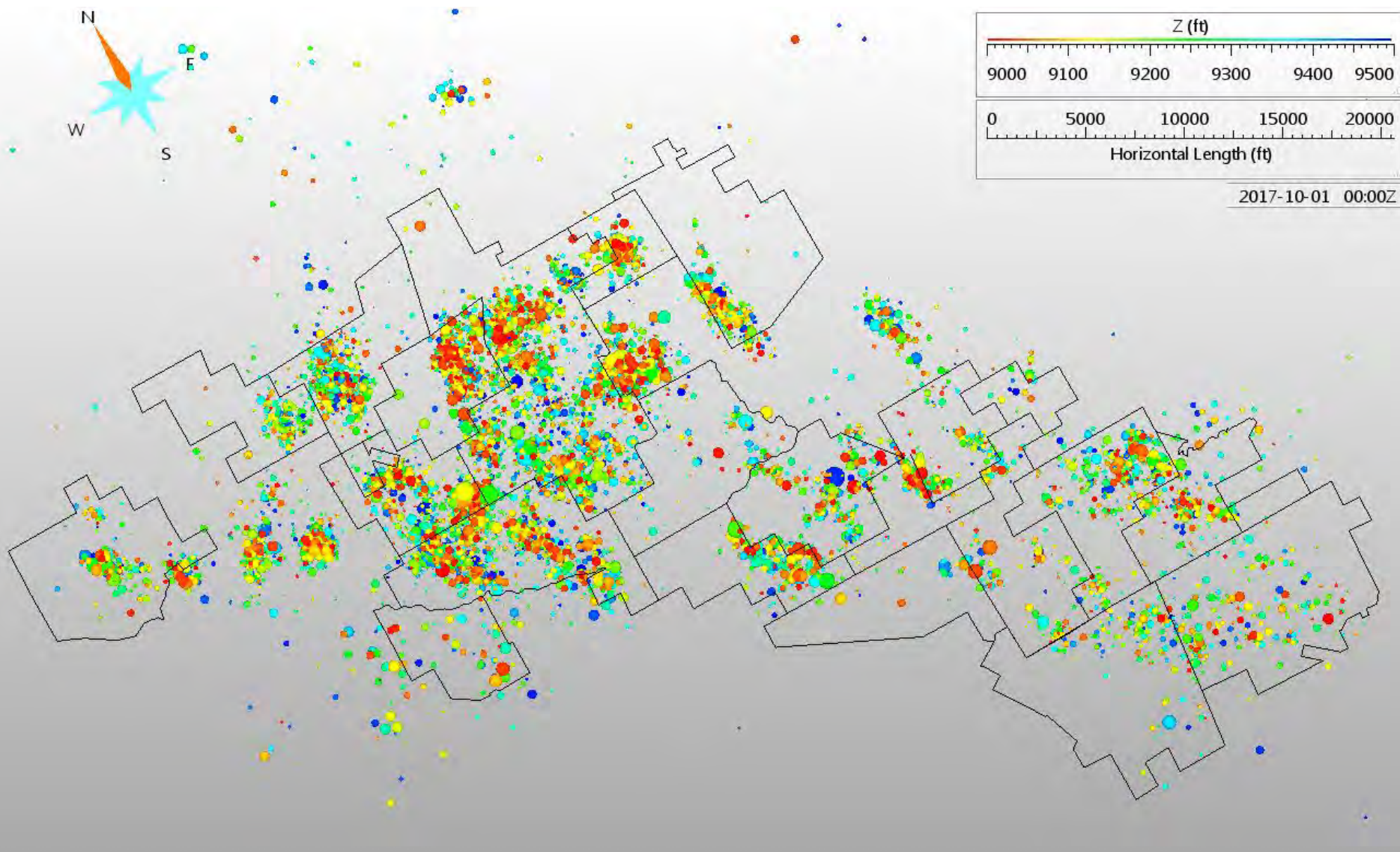
Depth Slice 9500 to 10000 Feet Subsea



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Fault/Fracture Analysis and Interpretation

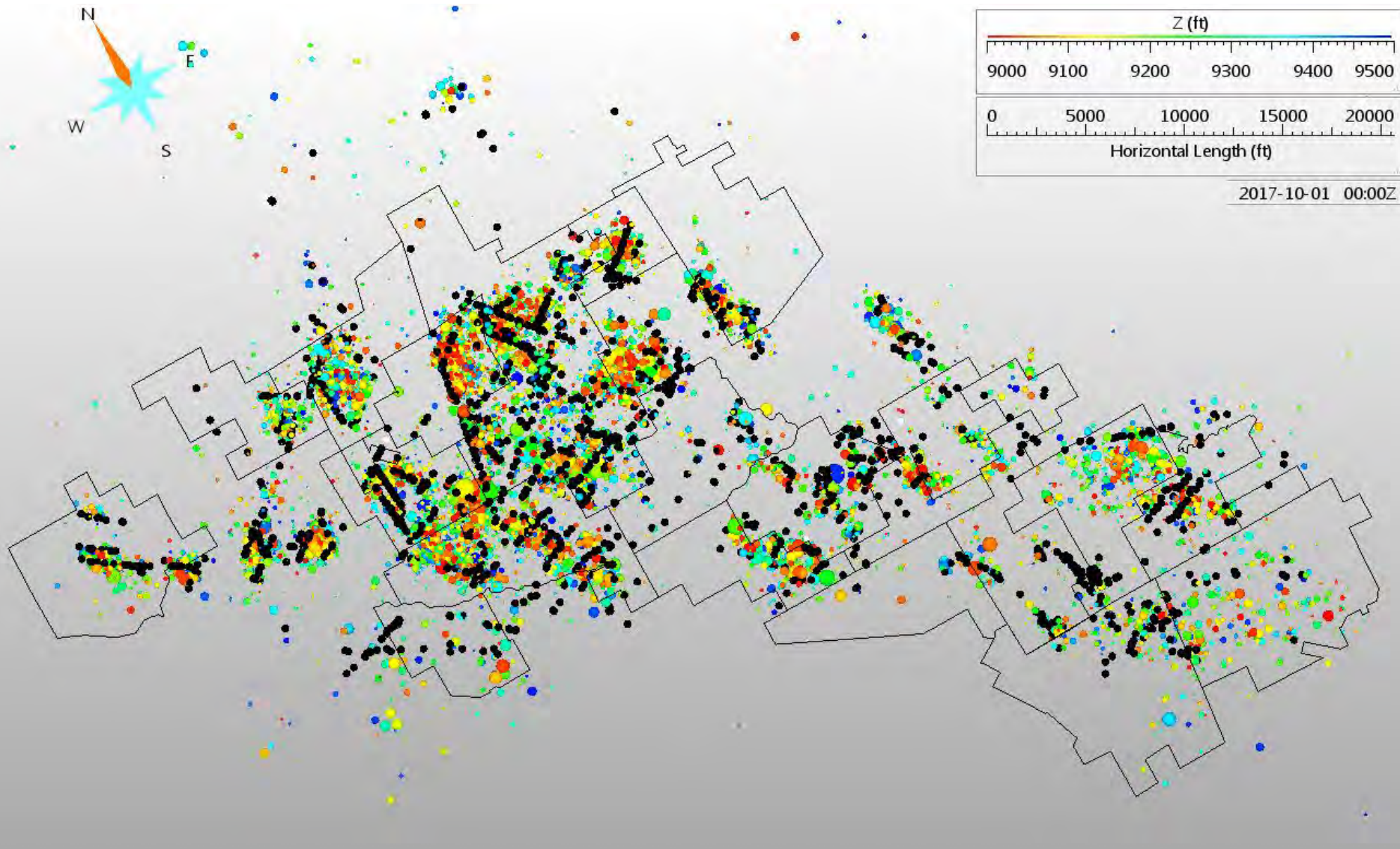
Depth Slice 9000 to 9500 Feet Subsea



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Fault/Fracture Analysis and Interpretation

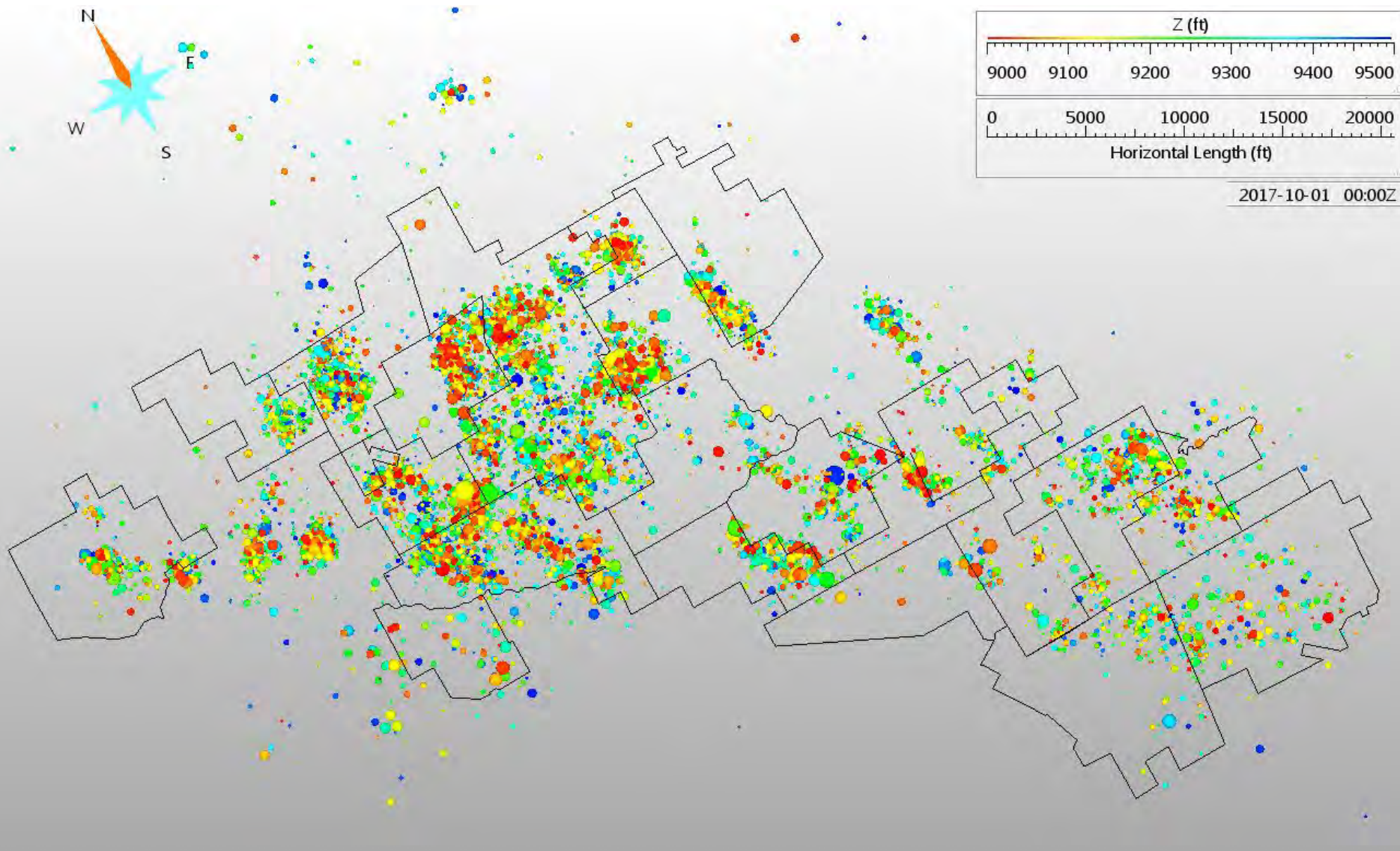
Depth Slice 9000 to 9500 Feet Subsea



Seismic Monitoring Advisory Committee Meeting

Fault/Fracture Analysis and Interpretation

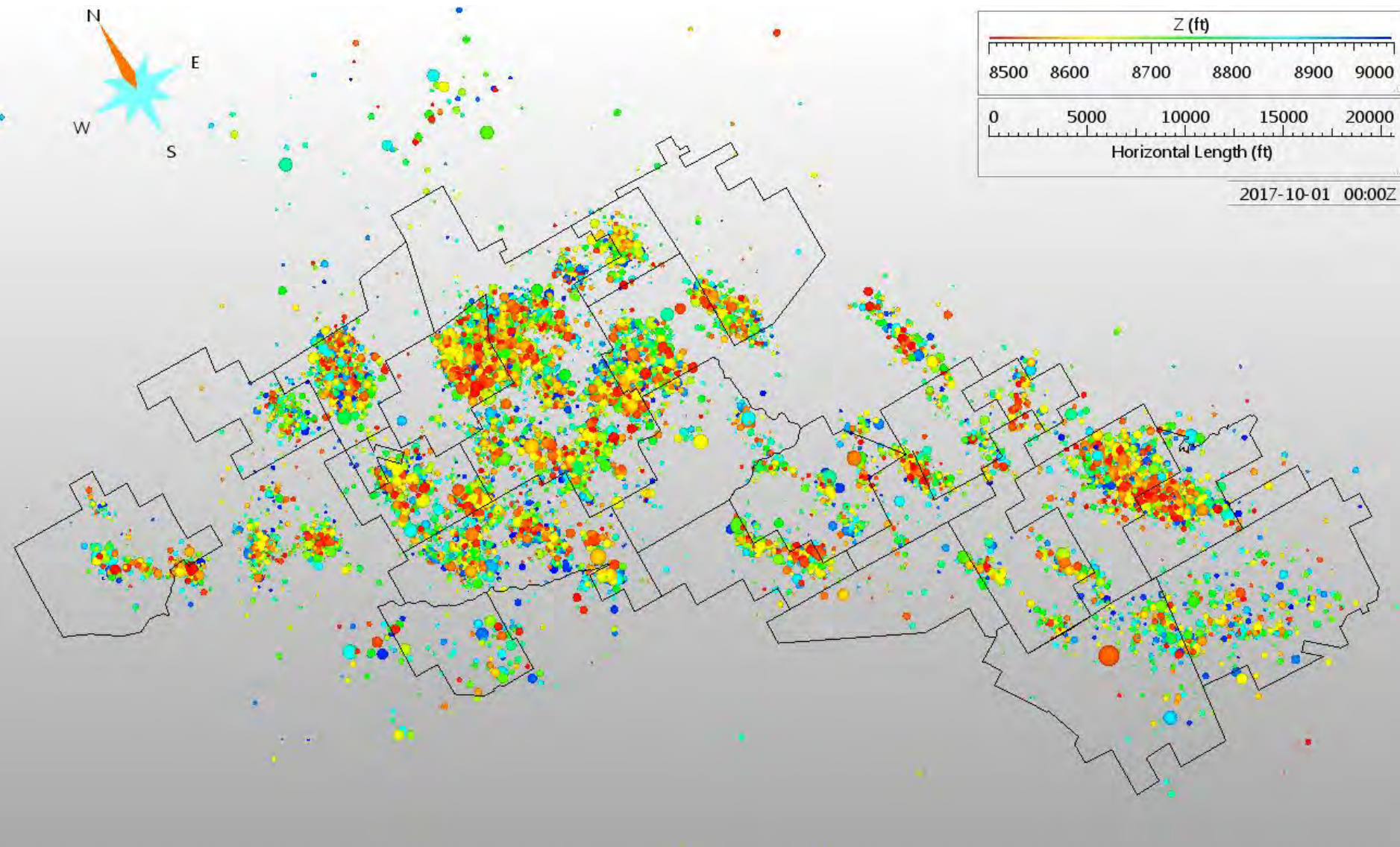
Depth Slice 9000 to 9500 Feet Subsea



Seismic Monitoring Advisory Committee Meeting

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

