Seismic Monitoring Advisory Committee Meeting

01 October 2019 to 31 March 2020 Reporting Period

Calpine Geothermal Visitors Center

Middletown, California

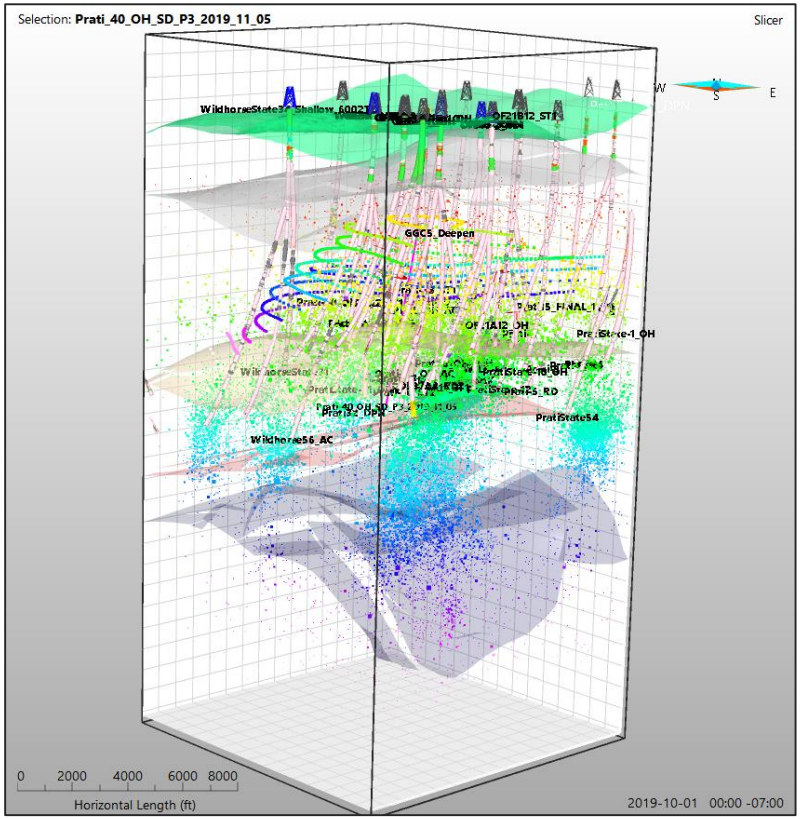
08 July 2020

Meeting Cancelled Due to COVID-19 Concerns

Craig Hartline *Senior Geophysicist* *Calpine Corporation* *The Geysers*

Seismic Monitoring Advisory Committee Meeting
Calpine Presentation Agenda
Reporting Period: 01 October 2019 to 31 March 2020

- Geysers Geothermal Field and Nearby Communities
- Status of Seismic Monitoring Networks
  - LBNL/Calpine Seismic Monitoring Network
  - LBNL/Calpine Strong Motion Network
  - USGS / Northern California Seismic Network
- Kincade Fire Summary
- Fieldwide Seismicity Analysis
- Field-wide Water Injection and Seismicity
- Water Injection and Induced Seismicity Animations
- Community Hotline
- 3D Structural Model Building
  - Fault/Fracture Analysis
  - Significant Steam Entry Alignments
- New Water Injection and Induced Seismicity Response
- Additional Seismic Monitoring and Research



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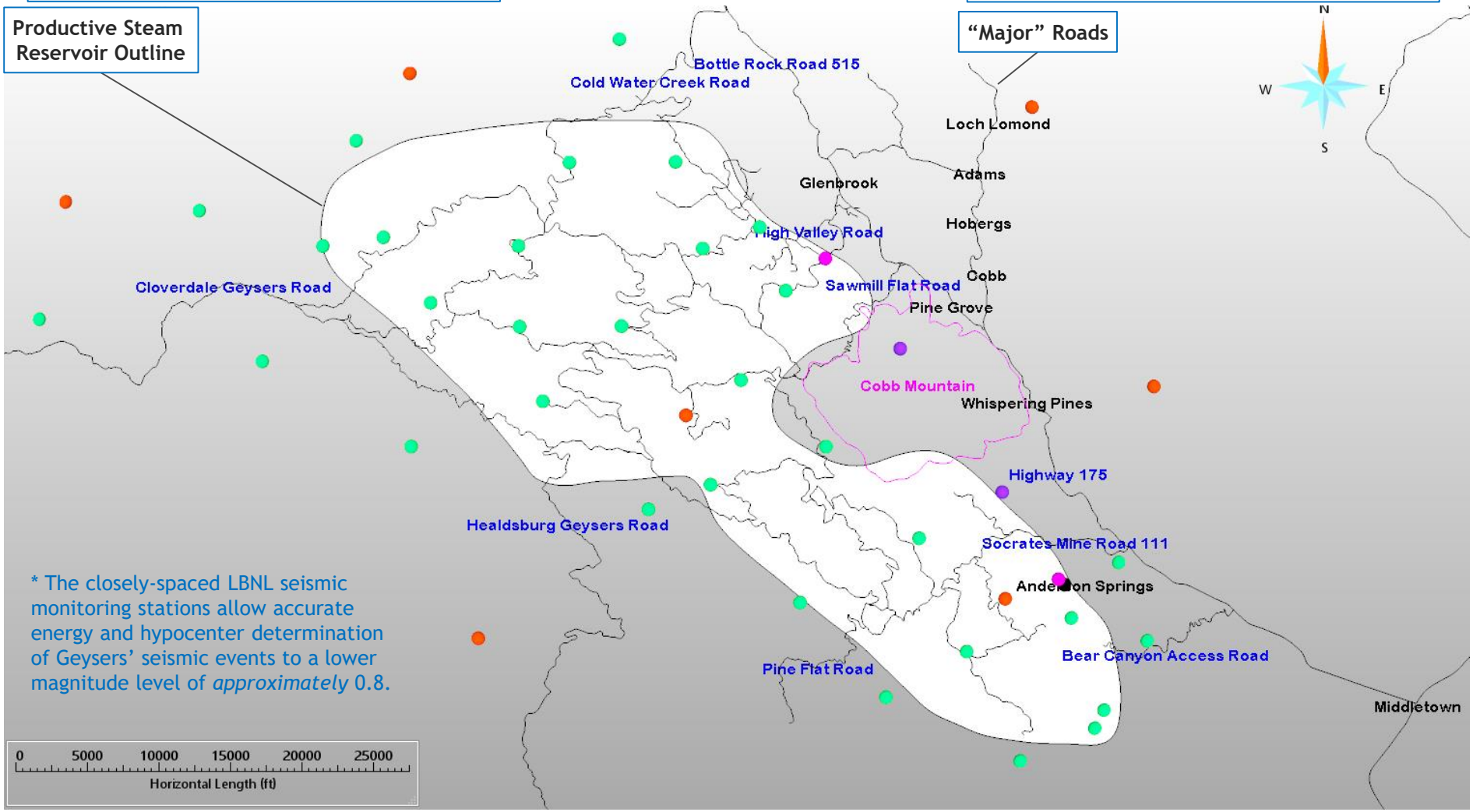
Geysers Geothermal Field, Nearby Communities and Seismic Monitoring Networks

Lawrence Berkeley National Laboratory
2003 installation; continuing upgrades
34 stations
Magnitude 0.8 Threshold *

Strong Motion Accelerometers
2017/18 Nanometrics installation (2)
2020 Q1 Nanometrics installation (2)
0.1% of Gravitational Acceleration Threshold

US Geological Survey Regional Network
1970's installation; several upgrades
7 contributing stations
Magnitude 1.5 Threshold *



* The closely-spaced LBNL seismic monitoring stations allow accurate energy and hypocenter determination of Geysers' seismic events to a lower magnitude level of *approximately* 0.8.

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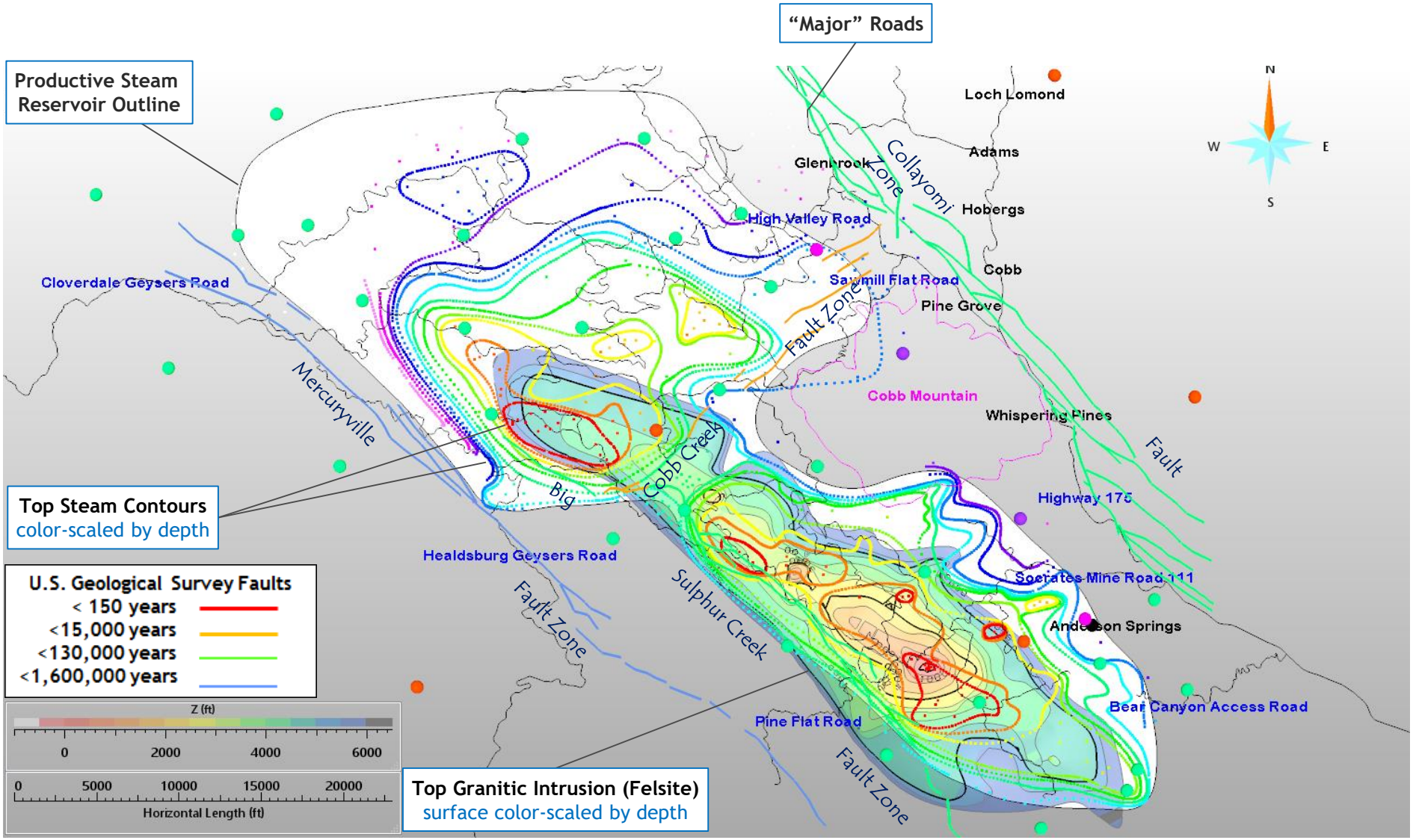
Geysers Geothermal Field, Top Granitic Intrusion and Top Steam Reservoir



Status of Seismic Monitoring Networks

LBNL Strong Motion USGS

LBNL Seismic Monitoring Network

Fully Functional

The Department of Energy's Geothermal Technologies Office shifted their research efforts to these programs:

FORGE

Frontier Observatory for Research in Geothermal Energy Milford, Utah

https://utahforge.com/

EGS Collab

Geothermal technology research by eight national laboratories, six universities, and industrial partners.

https://eesa.lbl.gov/projects/the-egs-collab-project/

Why is this important?

Department of Energy funding for The Geysers seismic monitoring network ended May 2019.

Calpine now contributes $110,000 for yearly maintenance and upgrades.

Ramsey Haught was previously contracted to LBNL for seismic monitoring network installation and maintenance.

This highly-experienced seismic specialist is now contracted directly by Calpine Corporation.

Jarpe Data Solutions* is also being contracted for data flow management tasks related to transition.

Calpine's Primary Seismic Monitoring Network Goal

Optimize LBNL network functionality, accuracy and reliability of prior to Ramsey's imminent retirement.

Optimize data flow from seismic data recovery, through data processing, and to efficient seismic data archival.

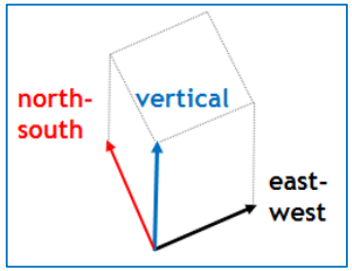
* Jarpe Data Solutions has long-term relationship with LBNL concerning seismic acquisition testing and seismic databases

LBNL Seismic Monitoring Network

Recent Improvements
- Calpine Purchased 24 Three-Component Geospace 2 Hz Sensors
- Completed Installation for 22 of 24 By May 2020

Geospace HS-1 3C arrays and cables
- Equipment: $2,400 per sensor station
- Installation: $ 500 per sensor station
- Total: $2,900 per sensor station

"ideally suited for seismological, engineering, and scientific applications where passive, low noise, short period, tri-axial sensors are required"



HS-1 3 Component Array

Status of Seismic Monitoring Networks

LBNL Strong Motion USGS

- **Geospace 2Hz Seismic Sensor Upgrades**
  - Completed: Upgrade of 22 seismic monitoring stations to Geospace 2Hz sensors
- **Strong Motion Station Installation**
  - Completed: Installation of two additional Nanometrics Titan accelerometer stations
    Total of four on eastern perimeter near communities
- **Borehole Seismic Sensor Installation**
  - In Progress: Determine optimal downhole seismic sensor for ~10 available shallow boreholes (≤ 500' depth)
- **Battery Replacement and Recycle**
  - Completed: Replacement Of 30 batteries At 15 LBNL seismic monitoring stations
    2 Sunlyte / MK deep cycle batteries per station (36 purchased)
  - In Progress: Additional battery replacements as required for remaining 23 stations
- **Hardware and Data Security**
  - Completed: Replacement of outdated Taurus/Janus digitizers
    Two LBNL servers now in Geysers Administration Center (one a back-up unit)
    Uninterrupted Power Source at Geysers Administration Center
    Uninterrupted Power Source at three radio repeater sites
    (DX Radio Repeater, Socrates Container, Microwave Tower)
  - In Progress: Power plant firewall / data security modifications
- **Software Upgrades**
  - Completed: Improvements to web-based strong motion data interface
    Improvements to strong motion waveform visualization software
  - In Progress: Arranging software trial for Itasca InSite Geo software for refined seismic waveform analysis
- **Data Quality and Continuity**
  - Completed: Transition to data transfer, processing and storage by Jarpe Data Solutions
    Eliminate noise spikes on 2 Hz sensor data (grounding issue)
    Replacement of cable for MIT-installed continuous GPS monitoring site TCH
  - In Progress: Additional "state of health" tracking for data servers and seismic monitoring stations

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Status of Seismic Monitoring Networks
LBNL Strong Motion USGS

ACCELEROMETER TECHNOLOGY AND PERFORMANCE

Topology: Triaxial, horizontal-vertical
Feedback: Force balance with capacitive displacement transducer
Centering: 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 μ*g*/°C, typical
- Vertical sensor: 320 μ*g*/°C, typical

Strong Motion Monitoring Network

Recent Improvements
- Calpine Purchased Four Nanometrics Titan Accelerometer Stations
- All Now Installed And Operational Along Eastern Perimeter Of Geysers Geothermal Field
- State-Of-The-Art Sensors Provide Improved Data Accuracy And Reliability

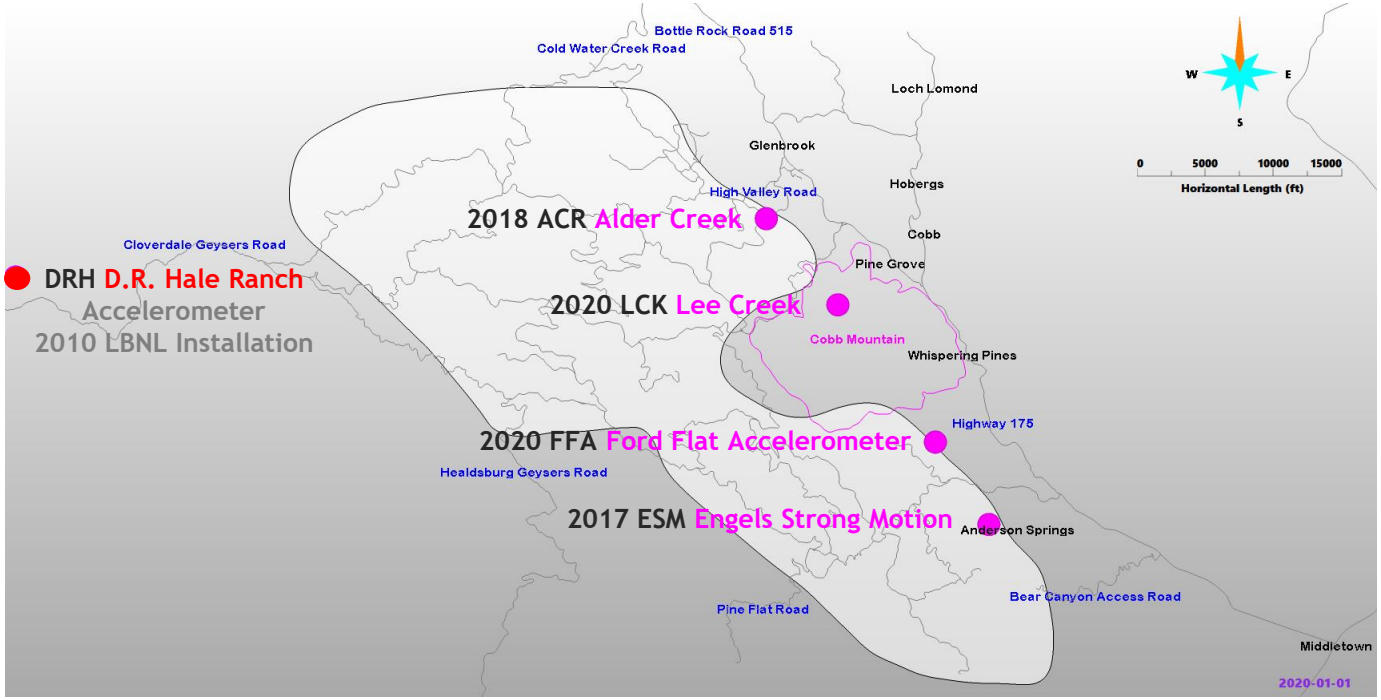
Nanometrics Titan Three- Component Accelerometer
Equipment: $4,800 per sensor station
Installation: $2,500 per sensor station
Total: $7,300 per sensor station

Power
- Solar Panels

Communications
- LBNL Radio Telemetry

Data Reliability Concerns
Related To Previous Generation
ETNA Strong Motion Stations
Greatly Reduced

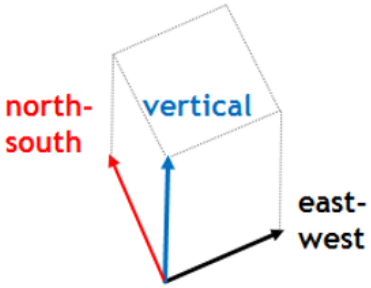
No Rural …
- AC Power
- Phone-Line Communication

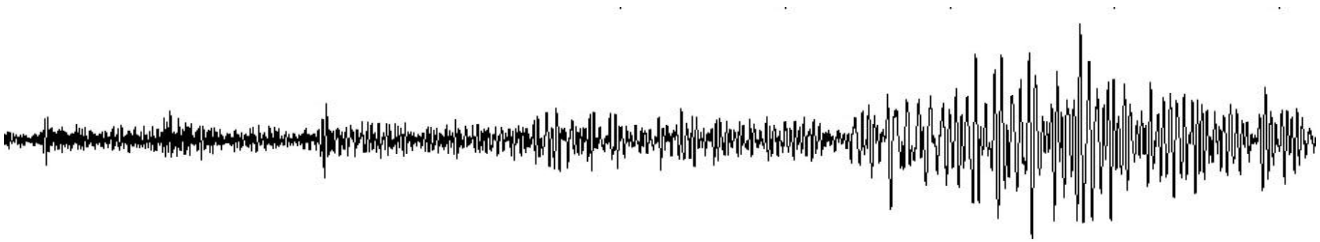


USGS*/ Northern California Seismic Network

The USGS and collaborating agencies provide services of significant value to The Geysers.
The USGS Regional Seismic Network is responsible for these fully functional items:

Seismic Data	
Acquisition	Six three-component USGS seismic stations contribute to seismicity determinations within The Geysers.
Processing	Seismic waveforms are intially compiled and p-wave arrival times calculated at the USGS "Waveserver"located within the Geysers Administration Center (and adjacent to the LBNL seismic data server).
Transfer	Merged LBNL/USGS station waveforms and arrival times are forwarded by a Northern California Seismic Network radio link to their Geysers Peak microwave hub, then transmitted to the USGS facility at Menlo Park.
Integration	LBNL/USGS P-wave arrival times are integrated with P-wave arrival times from other monitoring networks operated by the USGS, UC Berkeley, the California Geological Survey, and the California Department of Water Resources.
Analysis	Automatic determination of seismic event magnitude, hypocenter, first-motion mechanisms, and moment tensor solutions/shake maps (for seismic events with magnitude > 3.5). Seismologists complete reviews of more significant events.
Distribution	The USGS Eartquake Hazards Program website (https://earthquake.usgs.gov/) is the starting point for access to almost unlimited seismicty information, including nearly "real-time" availability of earthquake information (https://earthquake.usgs.gov/earthquakes/map/).
Archival	Waveforms and event determinations retrieved hourly for archival at the UC Berkeley Northern California Earthquake Data Catalog. Data derived from this catalog, including tomographic double-difference refined seismicty hypocenter determinations, contributes to Calpine/NCPA seismicity analysis, along with worldwide seismic research collaborations.





* United States Geological Survey

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Kincade Fire Perimeter

- Calpine Power Plants
- Calpine Facilities Of Interest
- Wellhead Locations
- LBNL Seismic Stations - Permanent
- CEC Research Seismic Stations - Temporary

The Kincade Fire began on 23 October 2019, resulting in limited seismic sensor station damage but significant central Geysers power and communications failures.

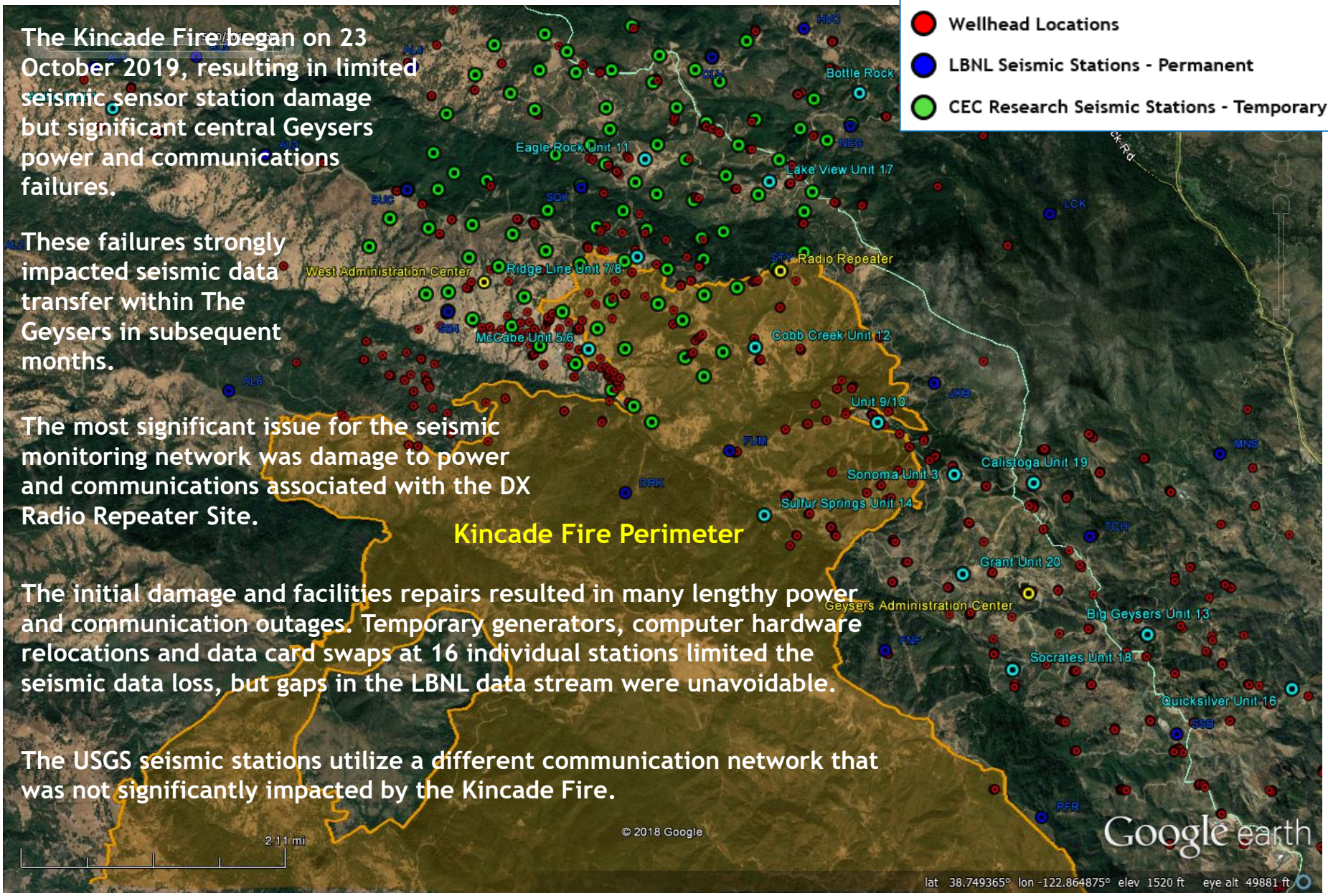
These failures strongly impacted seismic data transfer within The Geysers in subsequent months.

The most significant issue for the seismic monitoring network was damage to power and communications associated with the DX Radio Repeater Site.

Kincade Fire Perimeter

The initial damage and facilities repairs resulted in many lengthy power and communication outages. Temporary generators, computer hardware relocations and data card swaps at 16 individual stations limited the seismic data loss, but gaps in the LBNL data stream were unavoidable.

The USGS seismic stations utilize a different communication network that was not significantly impacted by the Kincade Fire.



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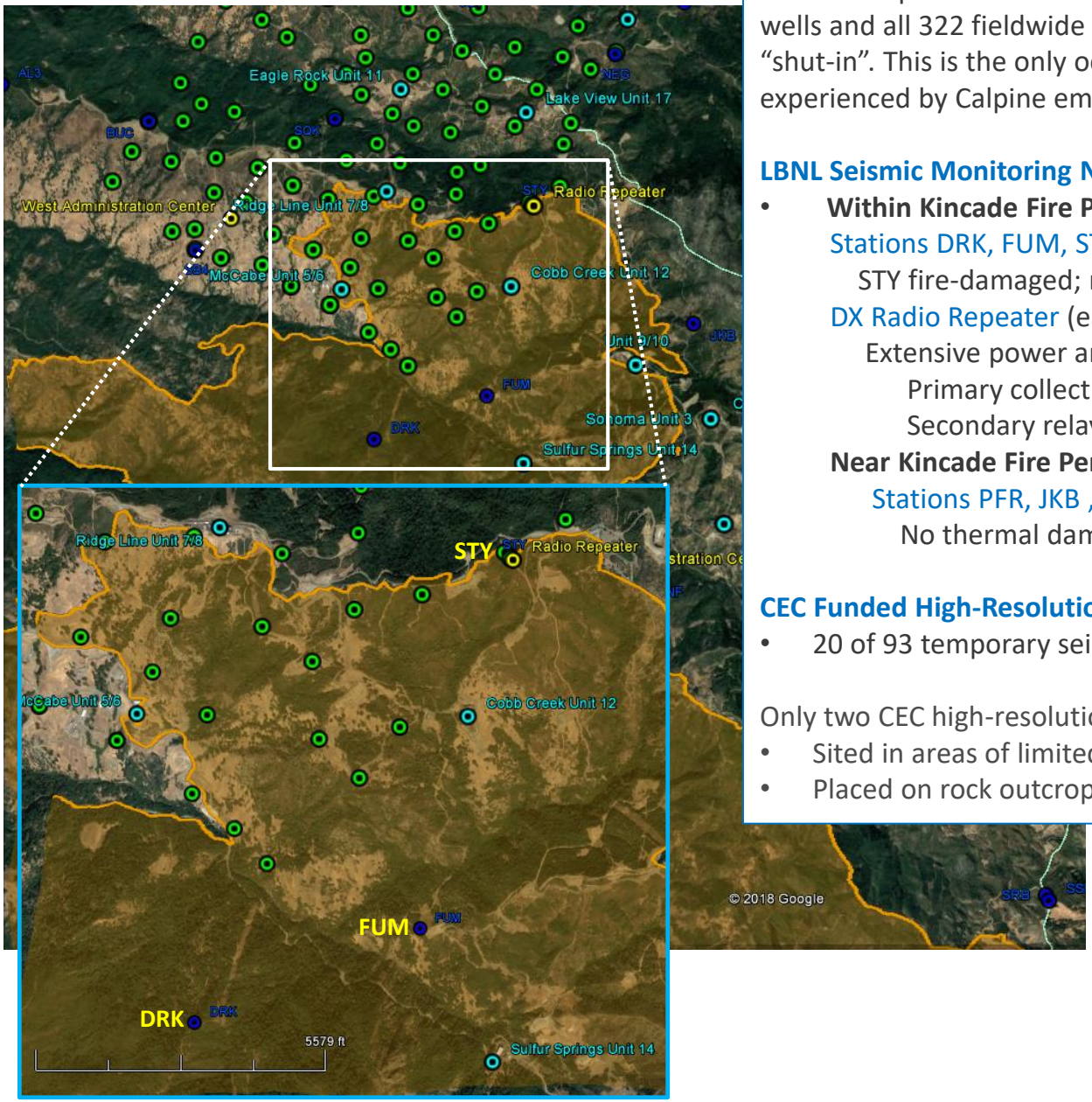
Kincade Fire



As a consequence of the Kincade Fire, all 54 fieldwide water injection wells and all 322 fieldwide steam production wells were initially "shut-in". This is the only occurrence of a fieldwide shut-in experienced by Calpine employees.

LBNL Seismic Monitoring Network

- **Within Kincade Fire Perimeter**
  - Stations DRK, FUM, STY
    - STY fire-damaged; repairs required
  - DX Radio Repeater (east of DX 24 well pad)
    - Extensive power and communication loss
      - Primary collection point for 16 seismic stations
      - Secondary relay point for an additional 4 stations
- **Near Kincade Fire Perimeter**
  - Stations PFR, JKB , FNF, SSR/SRB
    - No thermal damage detected

CEC Funded High-Resolution Seismic Network

- 20 of 93 temporary seismic stations within or *very* near perimeter

Only two CEC high-resolution stations damaged as they were:

- Sited in areas of limited vegetation for better solar exposure, and
- Placed on rock outcrops for better coupling

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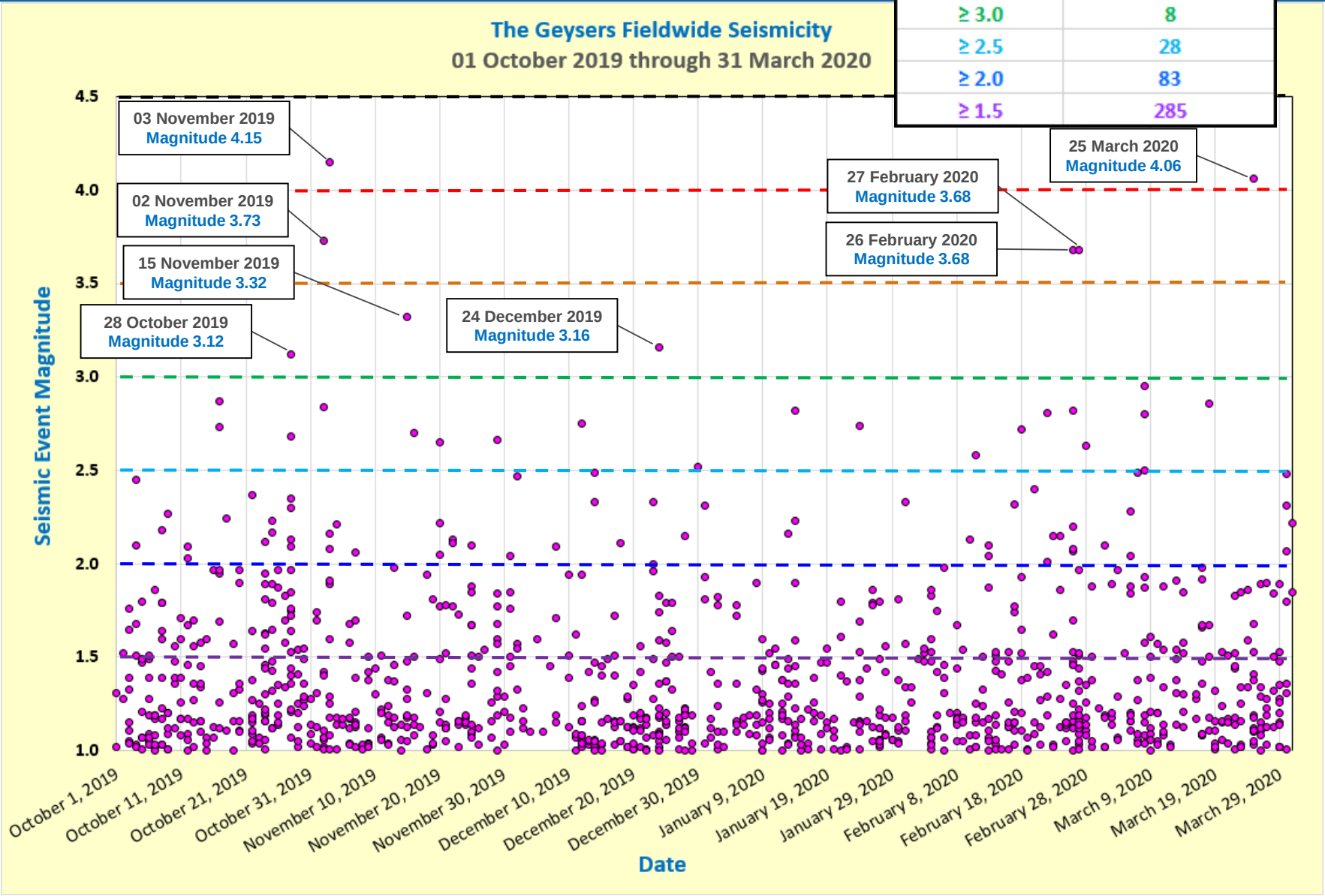
Field-wide Seismicity Analysis

01 October 2019 to 31 March 2020

Magnitude	Number of Events
≥ 4.5	0
≥ 4.0	2
≥ 3.5	5
≥ 3.0	8
≥ 2.5	28
≥ 2.0	83
≥ 1.5	285



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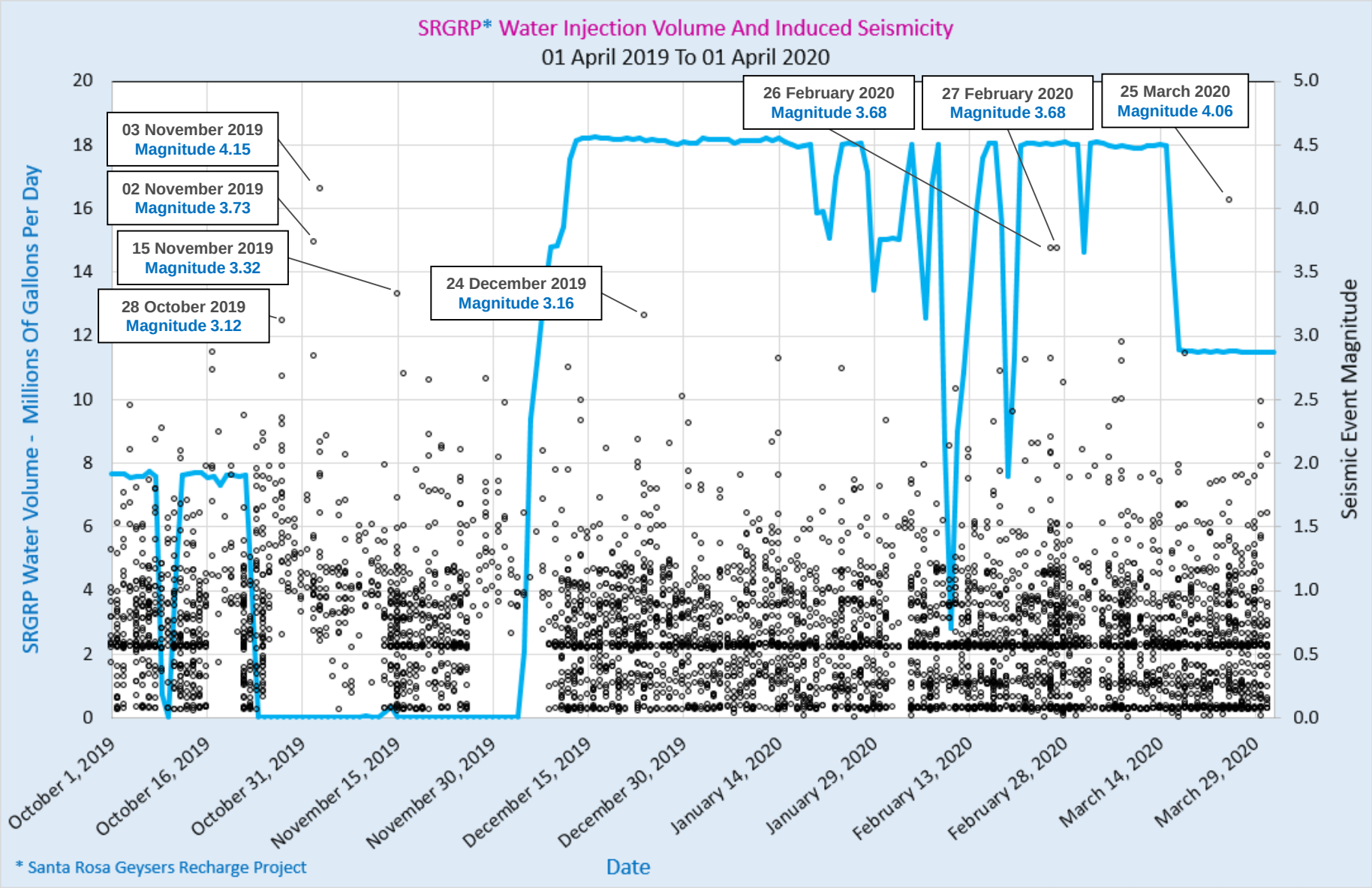
SRGRP Daily Water Injection Volume and Fieldwide Seismicity
01 October 2019 to 31 March 2020



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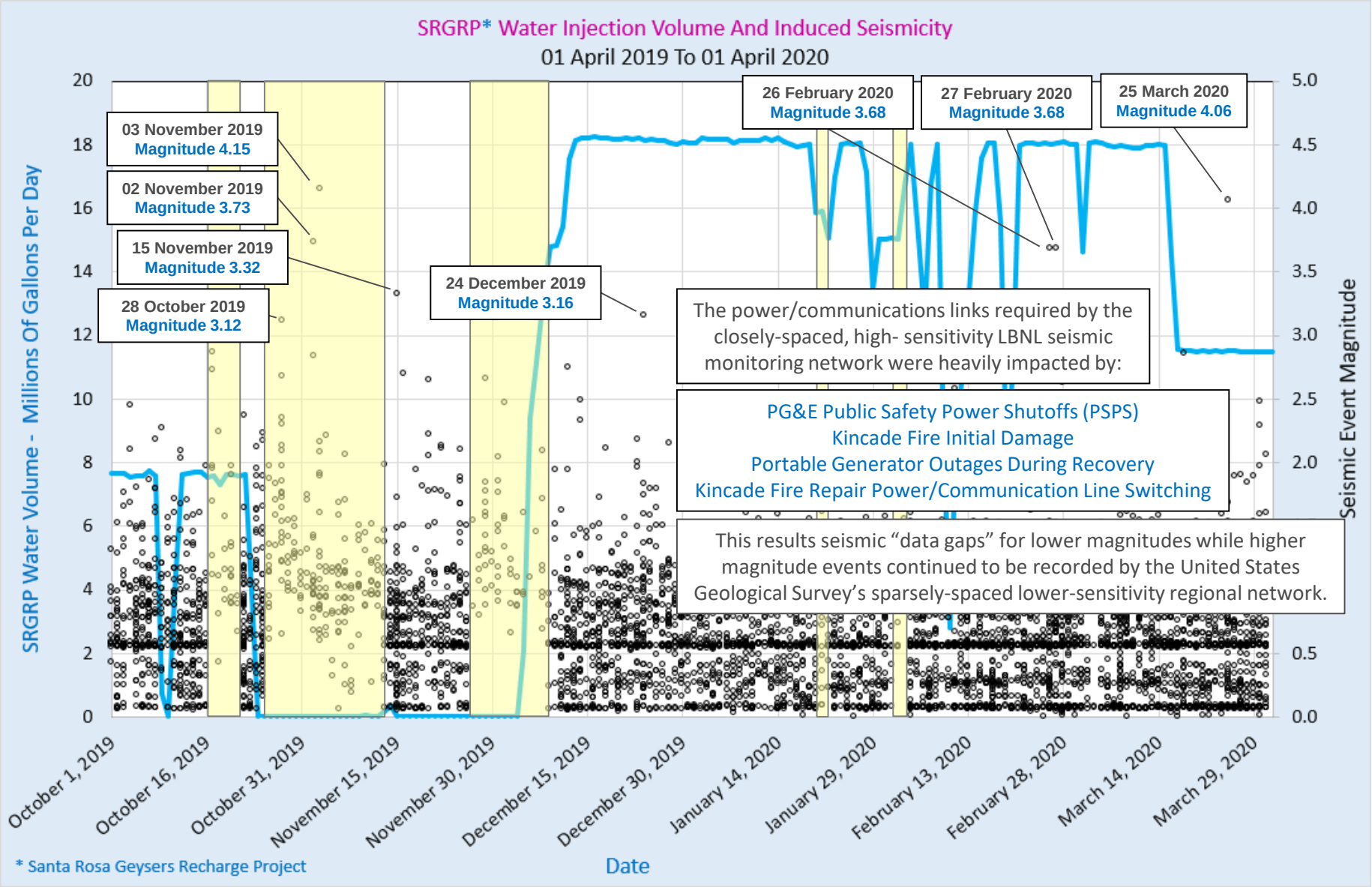
SRGRP Daily Water Injection Volume, Fieldwide Seismicity, Power/Communication Issues 01 October 2019 to 31 March 2020



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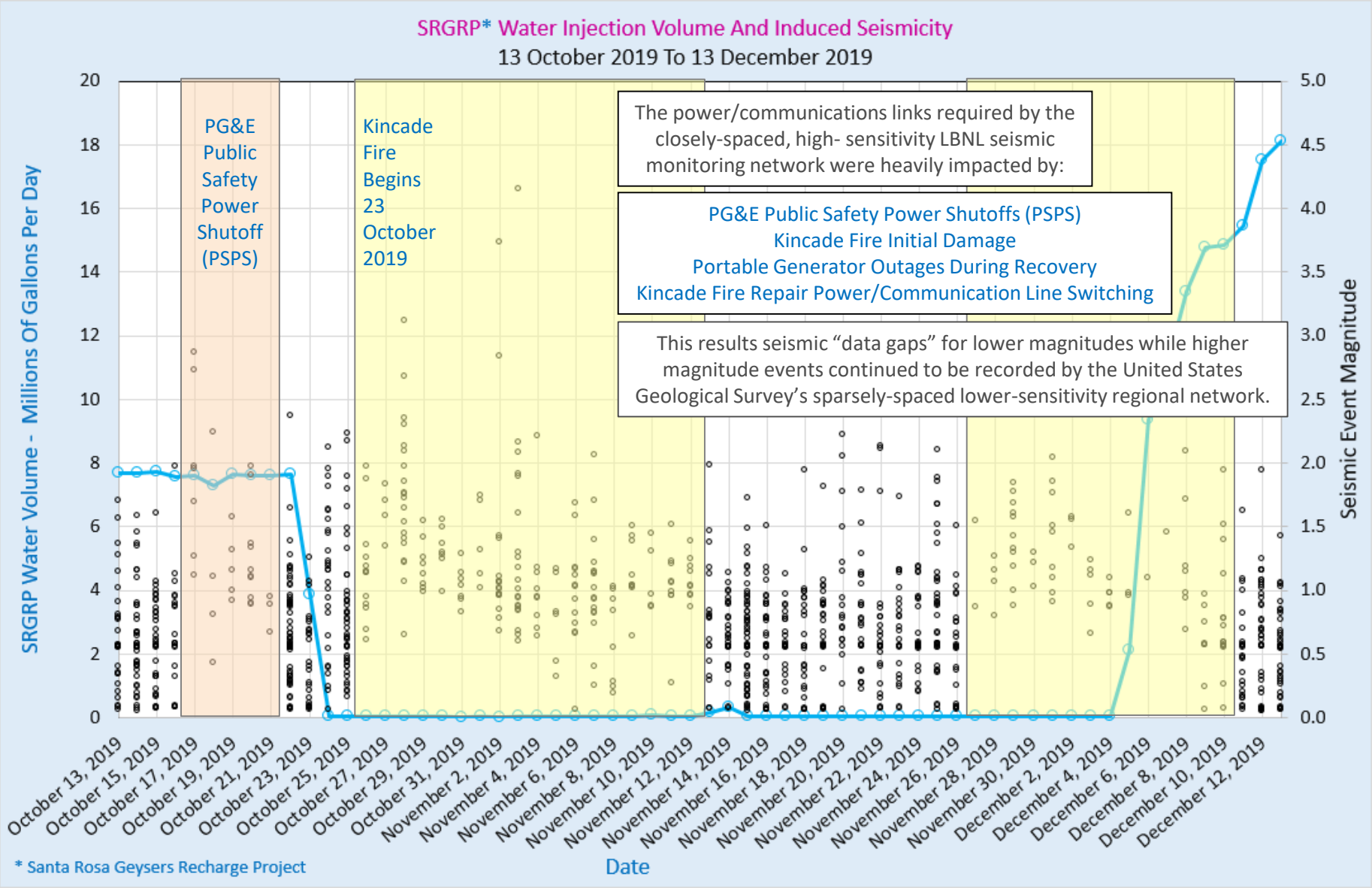
SRGRP Daily Water Injection Volume, Fieldwide Seismicity, Power/Communication Issues Detailed View of 13 October 2019 to 12 December 2019



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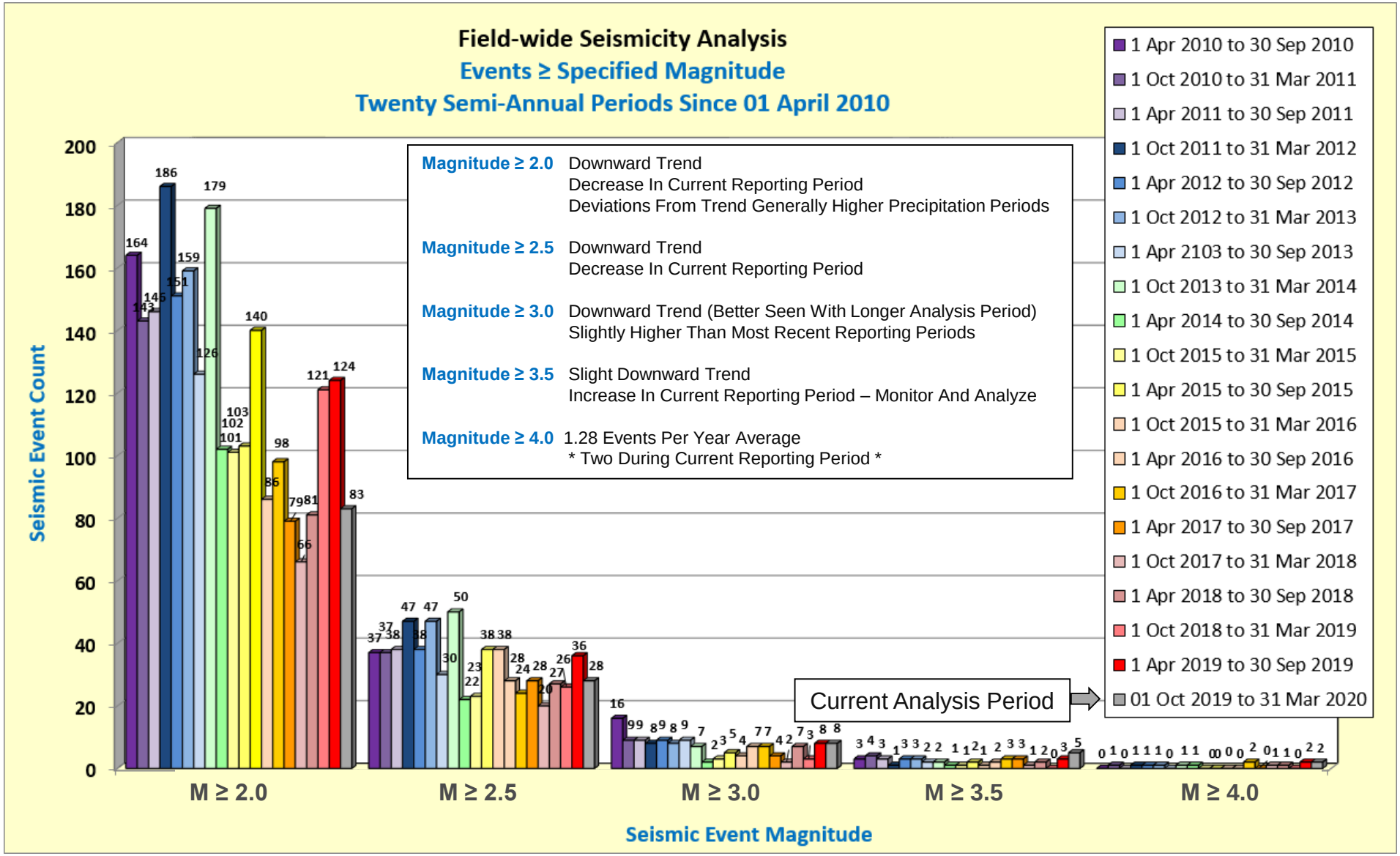
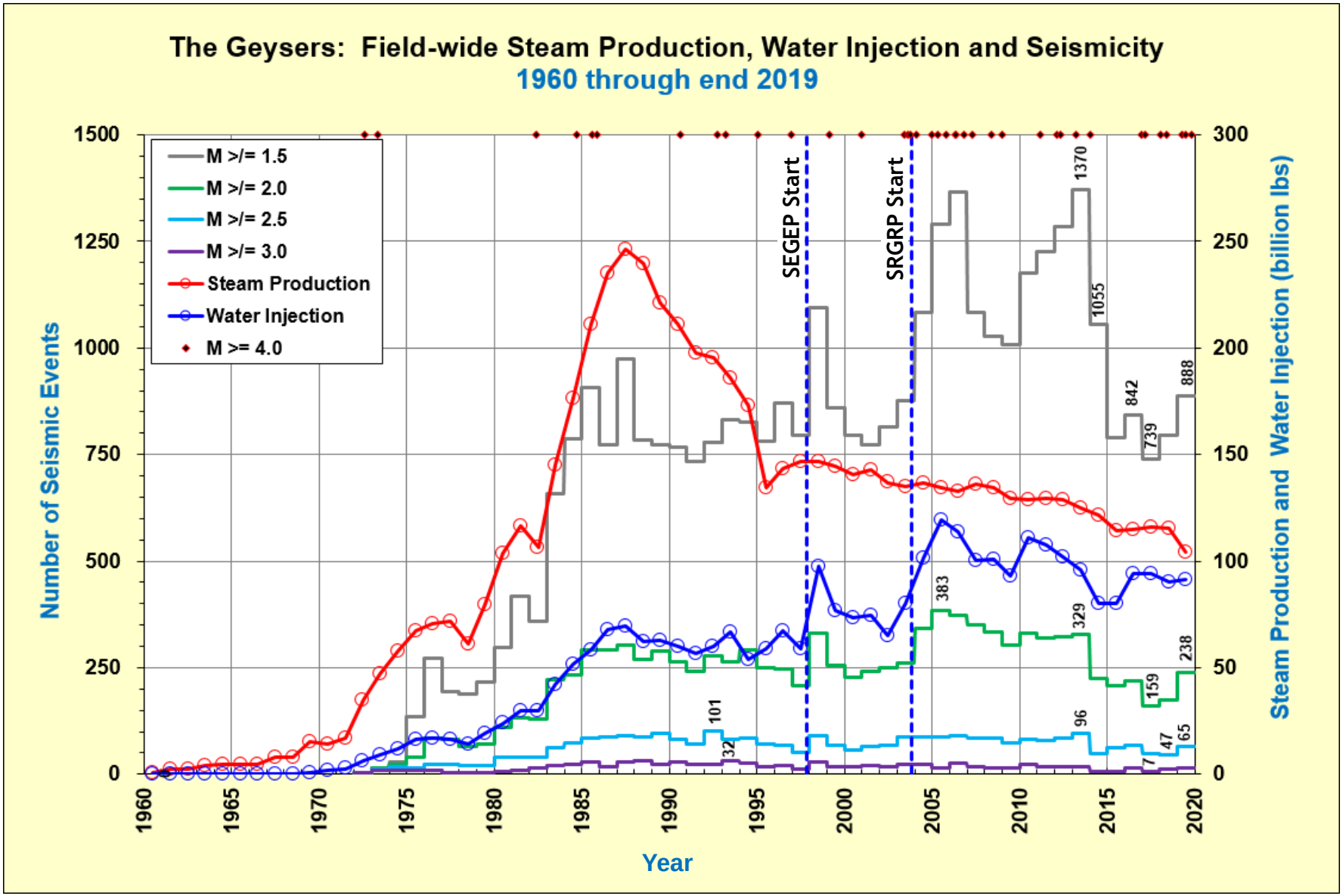
Field-wide Seismicity Analysis

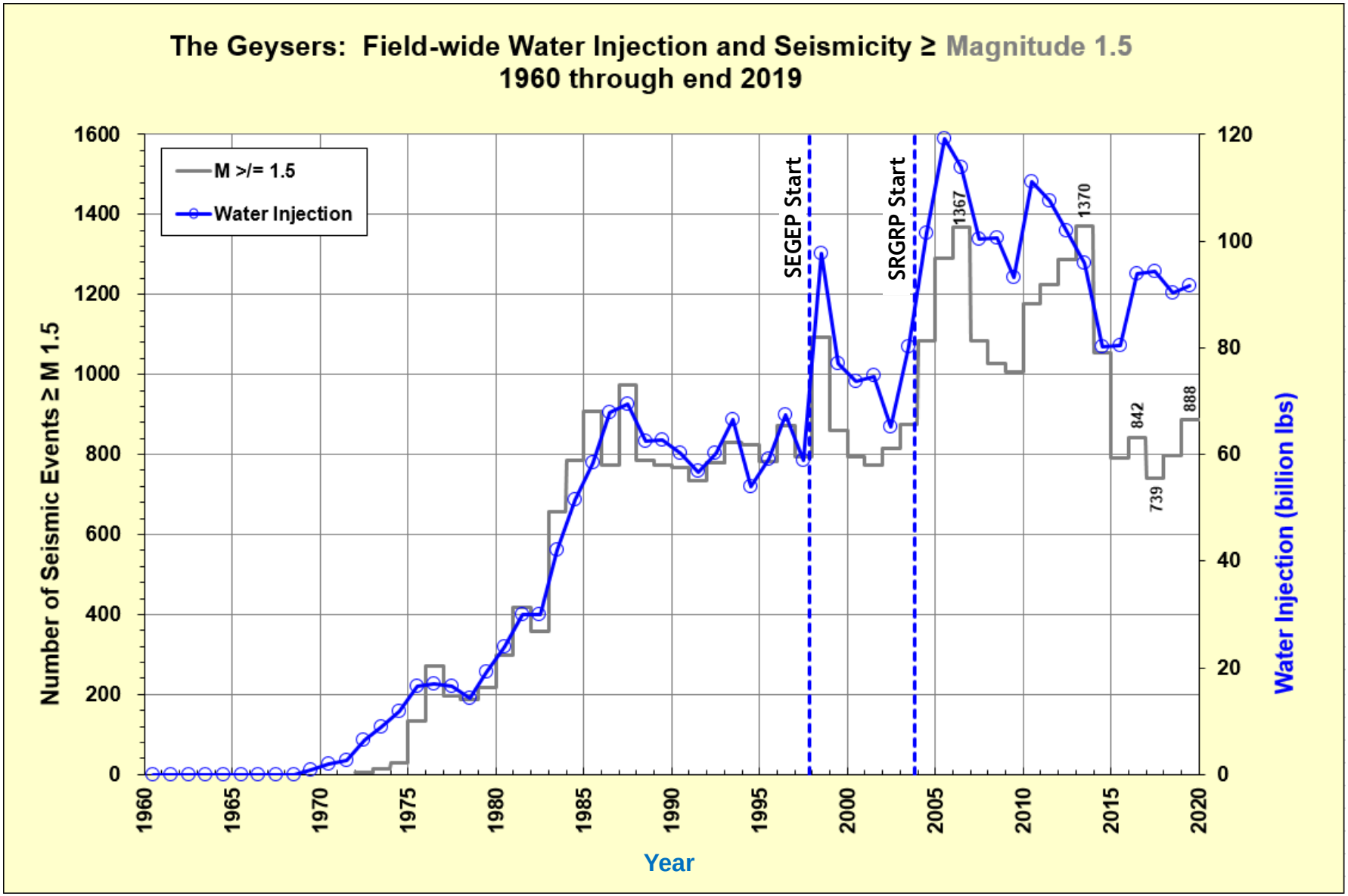
Comparison of Twenty Semi-annual Reporting Periods Since 01 April 2010



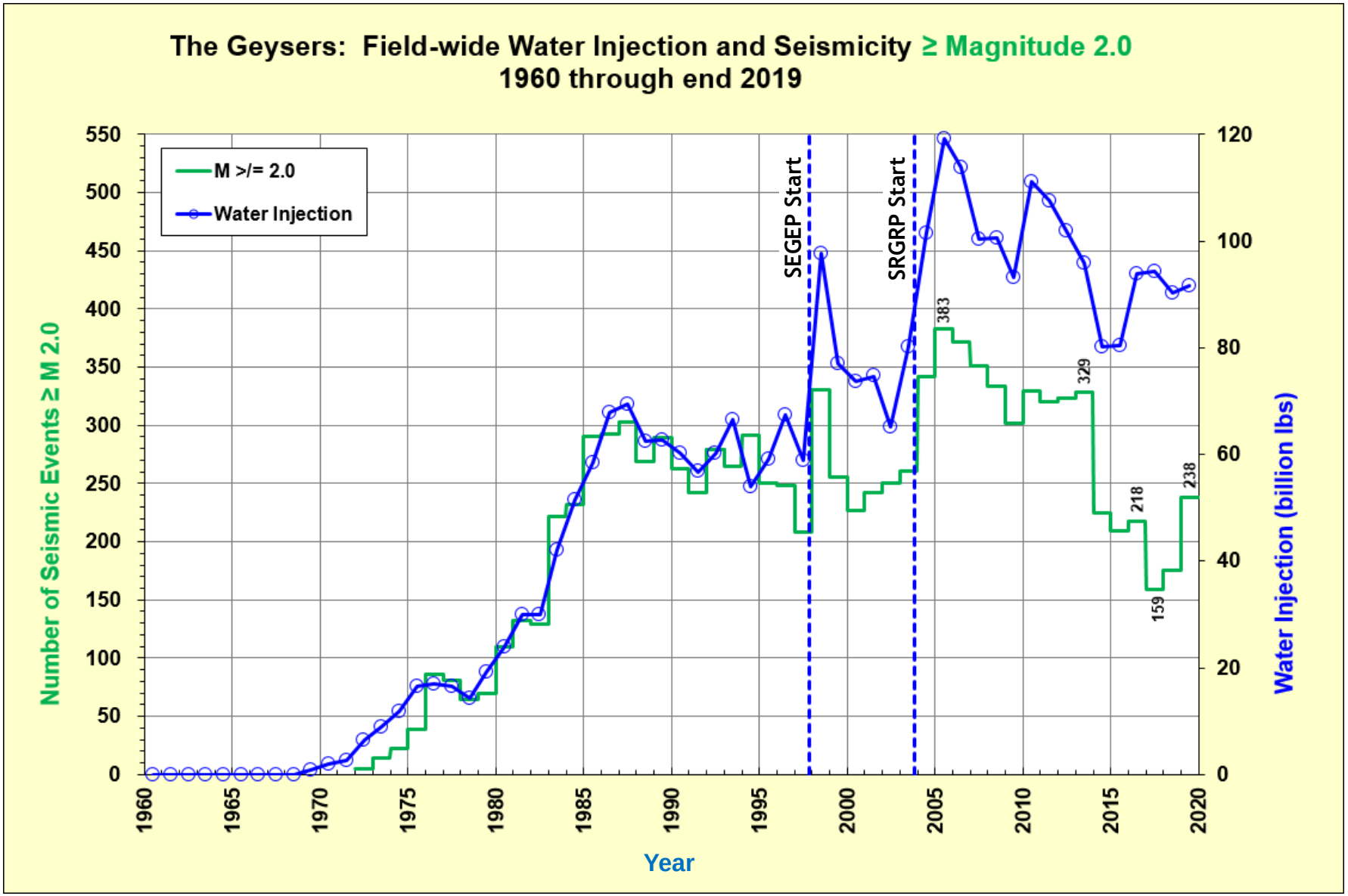
Yearly Field-wide Steam Production, Water Injection and Seismicity



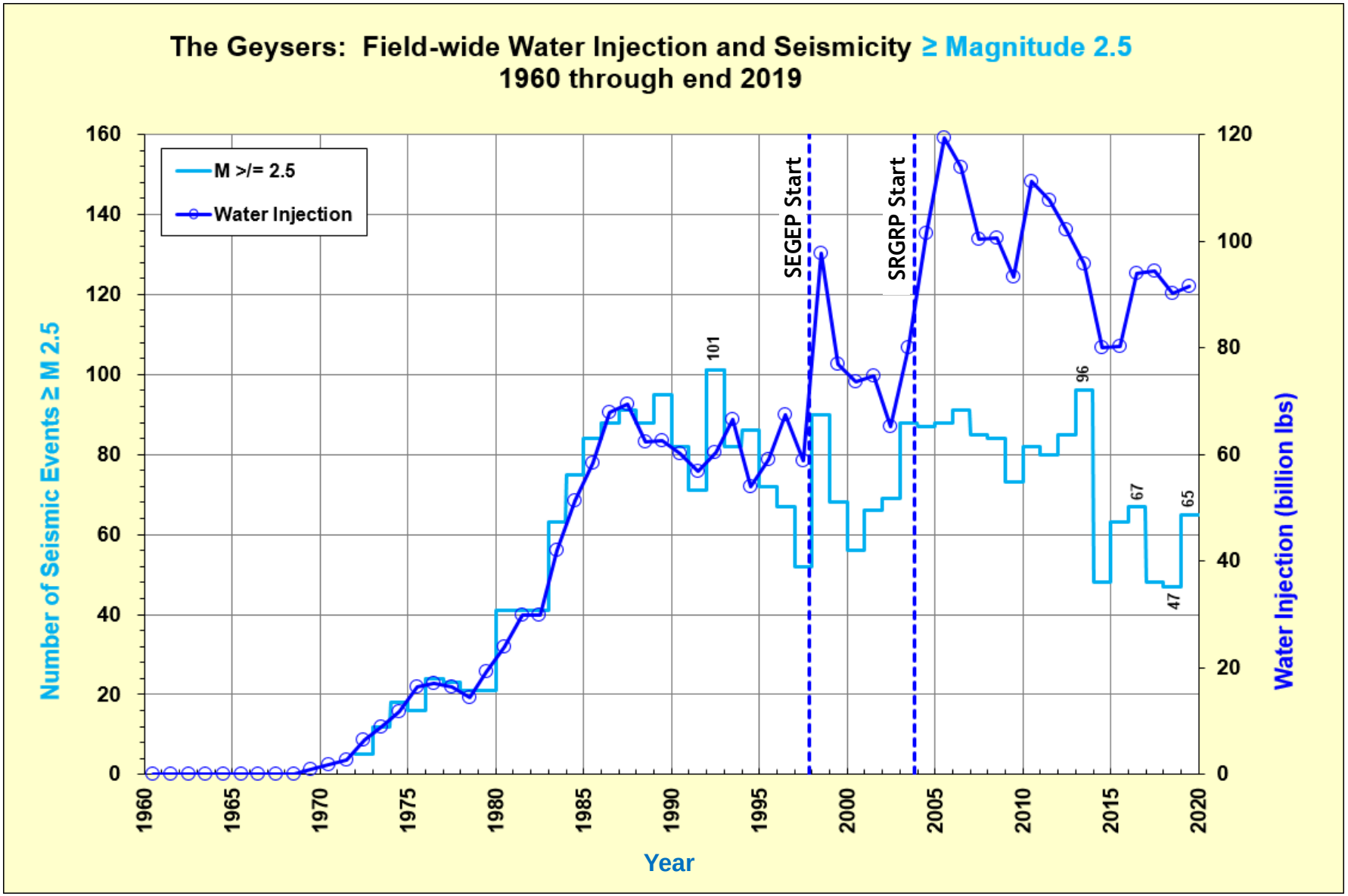
Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 1.5



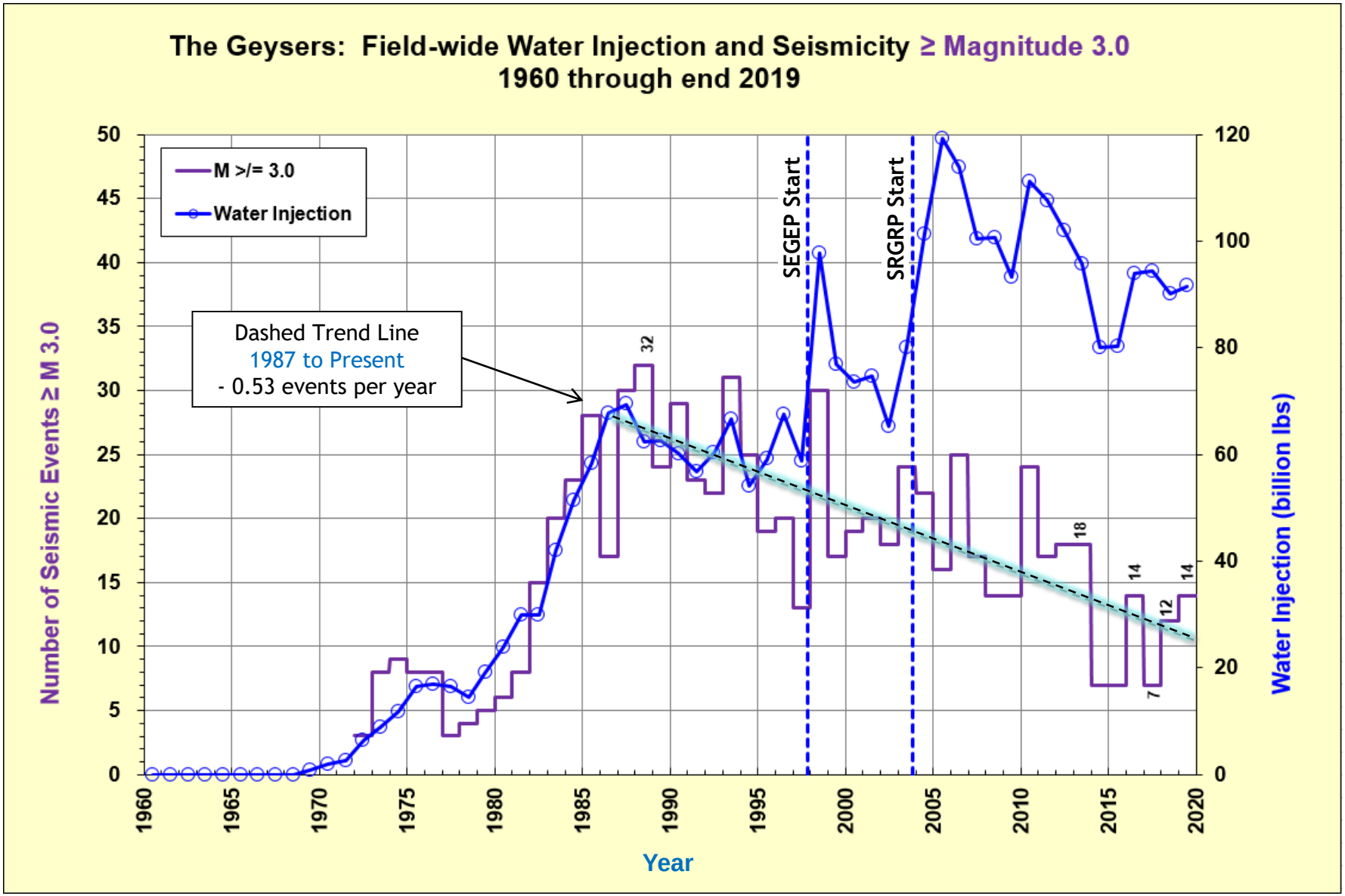
Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 2.0



Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 2.5



Yearly Field-wide Water Injection and Seismicity ≥ Magnitude 3.0



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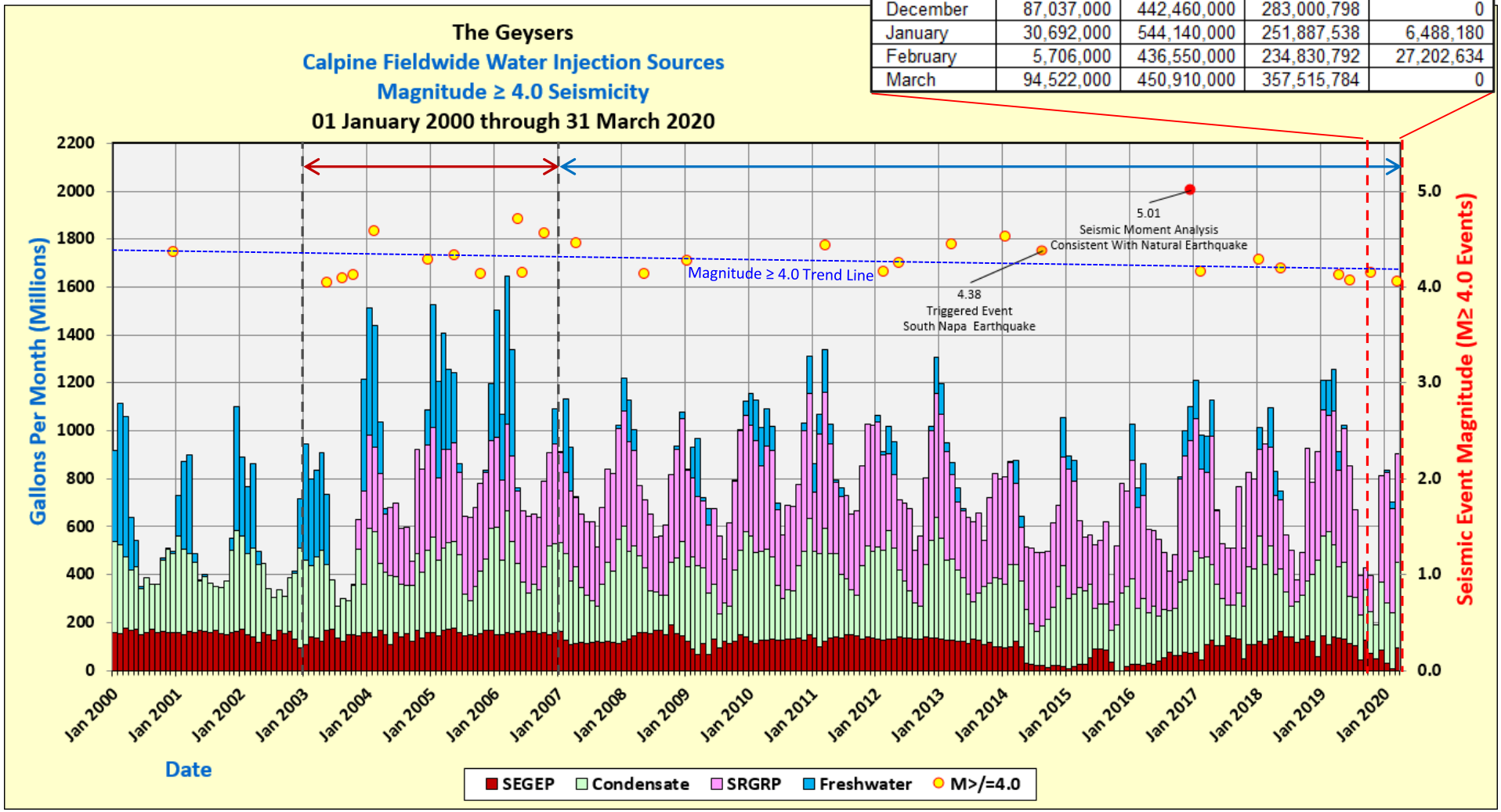
Monthly Field-wide Water Injection By Source vs. Magnitude ≥ 4.0 Seismicity

Average Number of Magnitude ≥ 4.0 Events Since January 2007 is 1.28 Per Year

Time Period	Magnitude ≥ 4.0 Seismic Events
January 2003 through December 2006	2.50 per year
January 2007 through March 2020	1.28 per year

Water Supply for Reporting Period (Six Months)

Water Injection Sources (Gallons)				
Month	SEGEP	SRGRP	Condensate	Fresh Water
October	72,216,000	153,050,000	171,568,358	0
November	49,551,000	0	140,045,165	0
December	87,037,000	442,460,000	283,000,798	0
January	30,692,000	544,140,000	251,887,538	6,488,180
February	5,706,000	436,550,000	234,830,792	27,202,634
March	94,522,000	450,910,000	357,515,784	0



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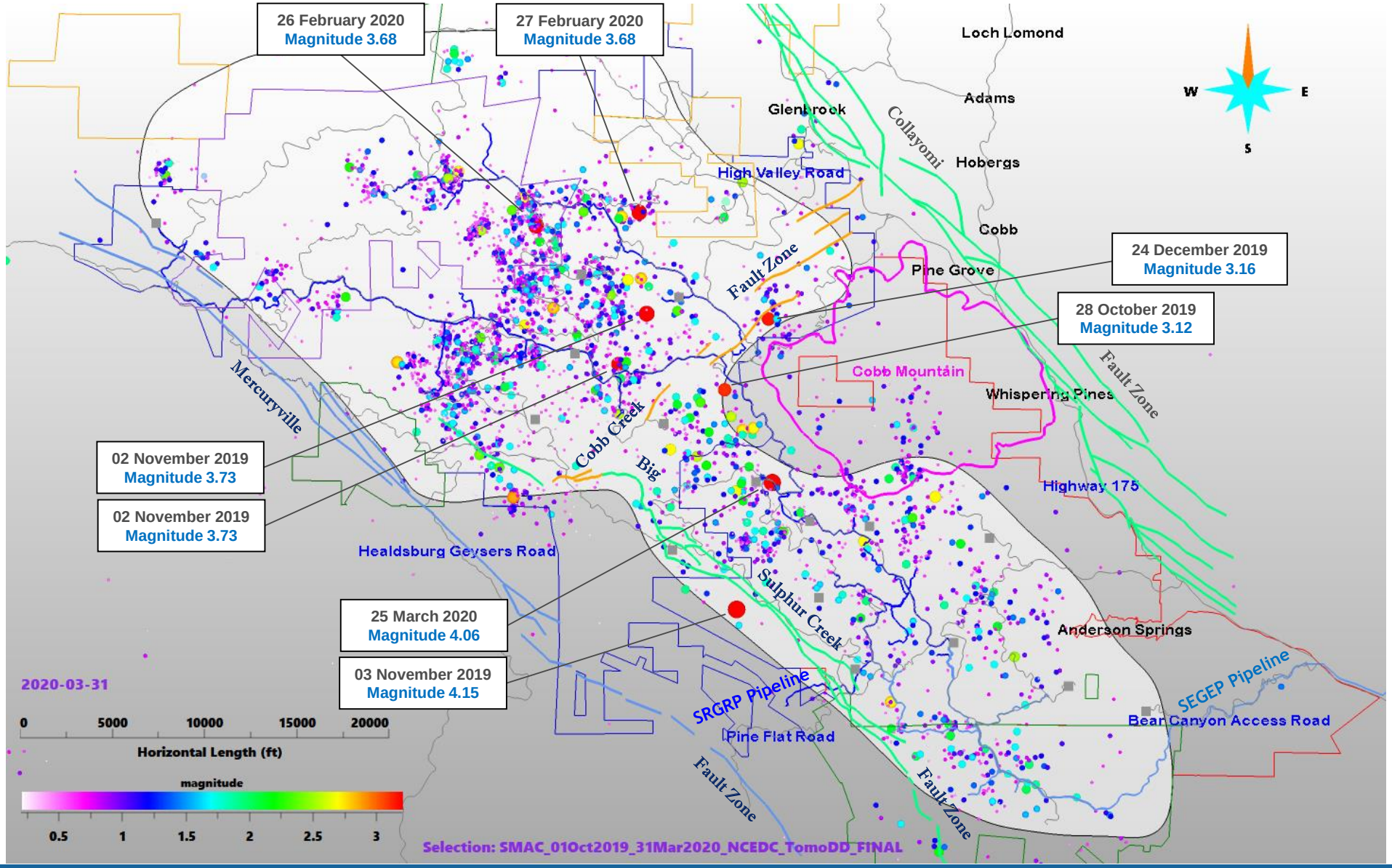
Field-wide Seismicity Animation

Seismic Events Color Scaled By Magnitude



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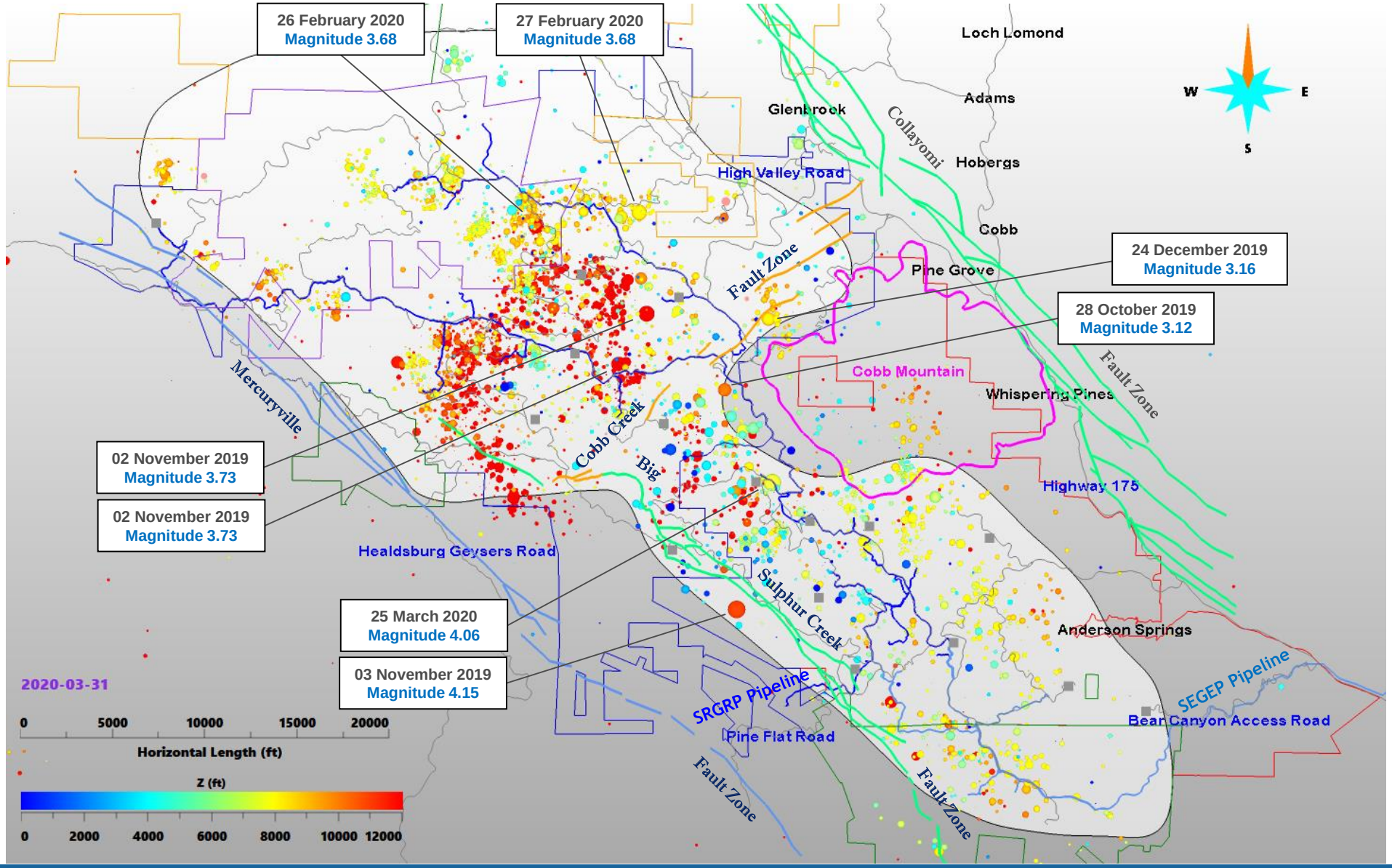
Field-wide Seismicity Animation

Seismic Events Color Scaled By Depth



Seismic Monitoring Advisory Committee Meeting
Calpine Community Hotline

A relatively active six-month interval for seismicity, plus encouragement from Calpine to utilize the community hotline, resulted in a total of 18 calls to the Calpine Community Hotline during the current reporting period of 01 October 2019 to 31 March 2020.

The five seismic events of primary concern were:

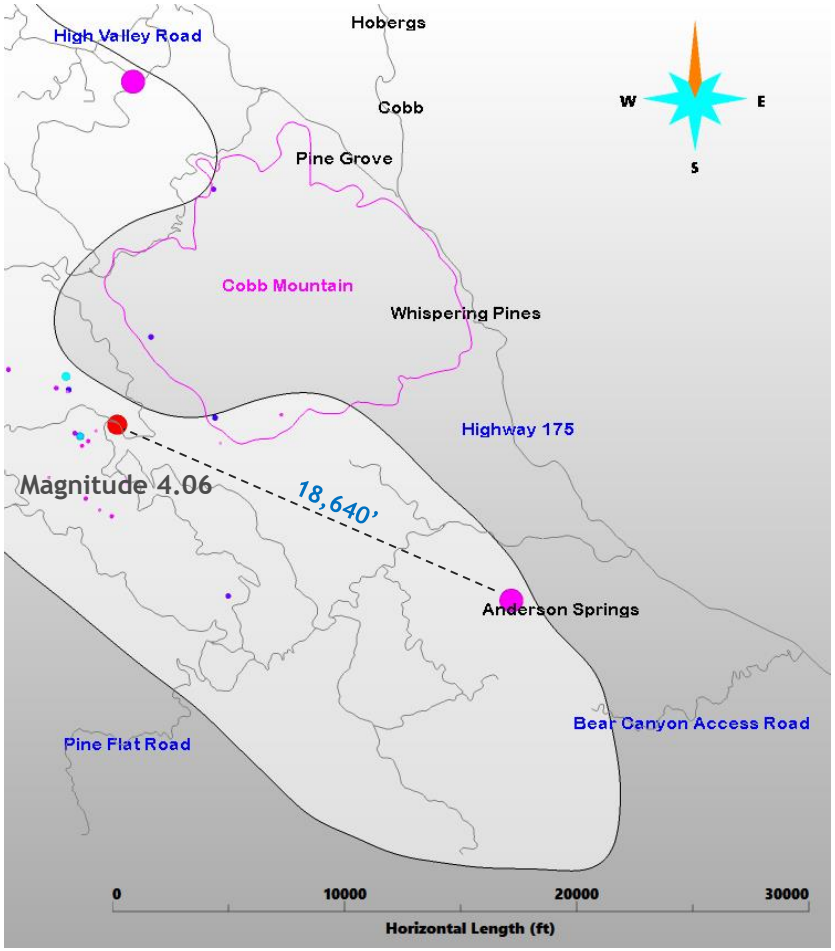
03 November 2019 Magnitude 4.15 at 20:34:57 UTC
18,950' West-Northwest of Anderson Springs 2 calls
45,000' West-Northwest of Middletown 1 call

21 February 2020 Magnitude 2.81 at 02:33:21 UTC
11,410' West-Southwest of Anderson Springs 2 calls

08 March 2020 Magnitude 2.95 at 06:16:00 UTC
31,650' West-Northwest of Anderson Springs 3 calls

25 March 2020 Magnitude 4.06 at 11:57:38 UTC
18,640' Northwest of Anderson Springs 4 calls

The 25 March 2020 seismic event was of greatest concern to the community, due to a magnitude of 4.06 and a relatively limited epicentral distance.
(energy *and* distance are important criteria)



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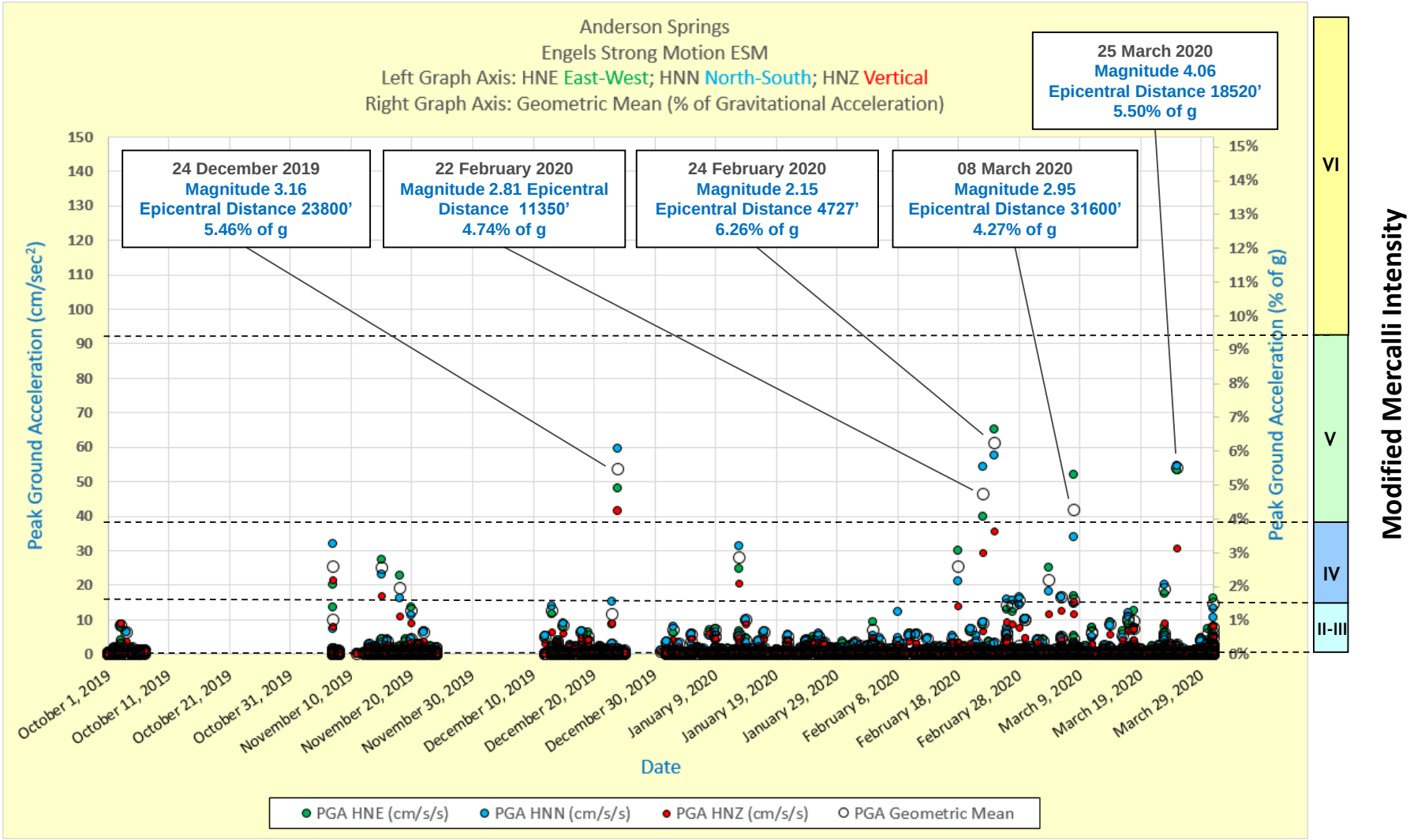
Anderson Springs Engels Strong Motion ESM



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

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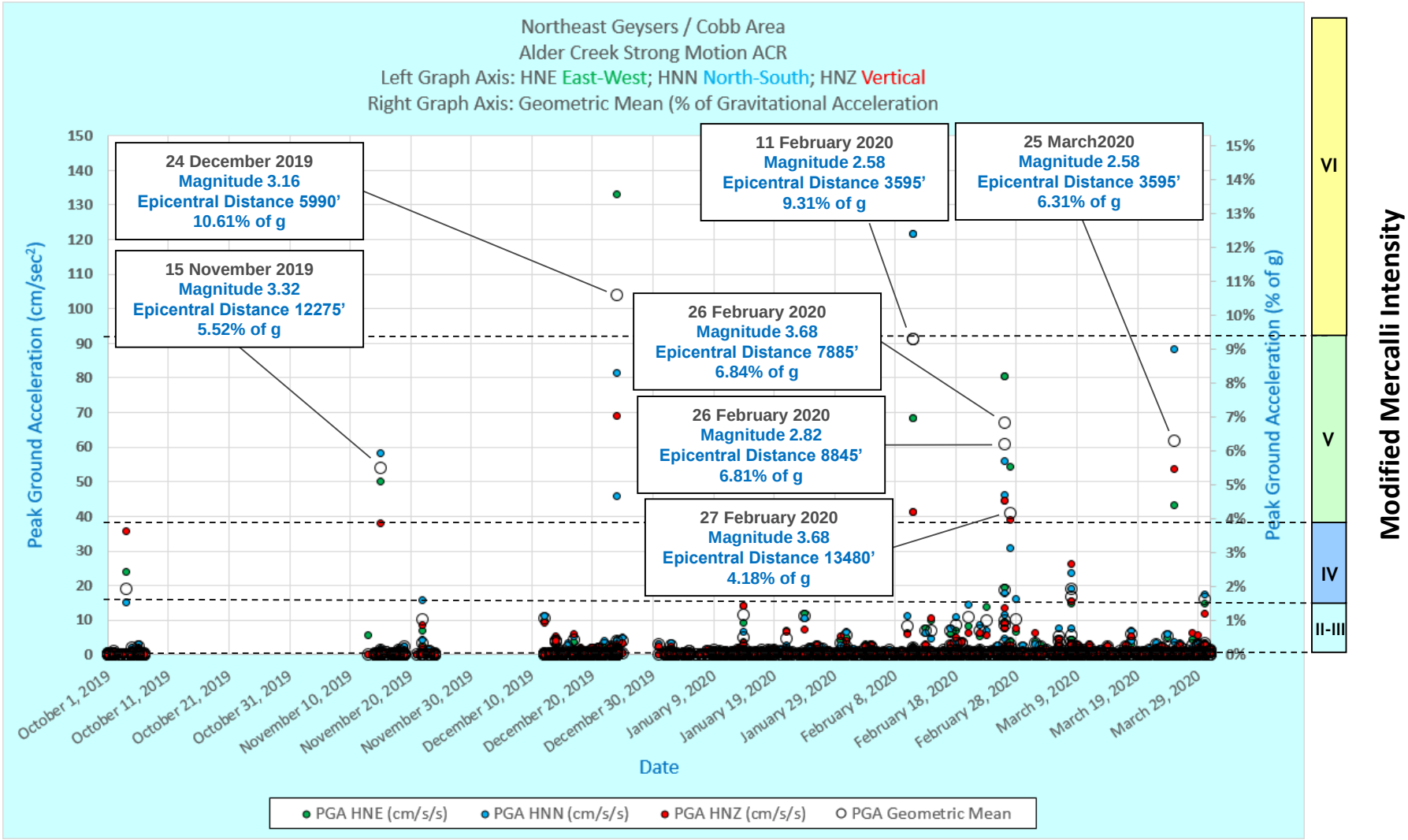
Cobb Area Alder Creek Strong Motion ACR



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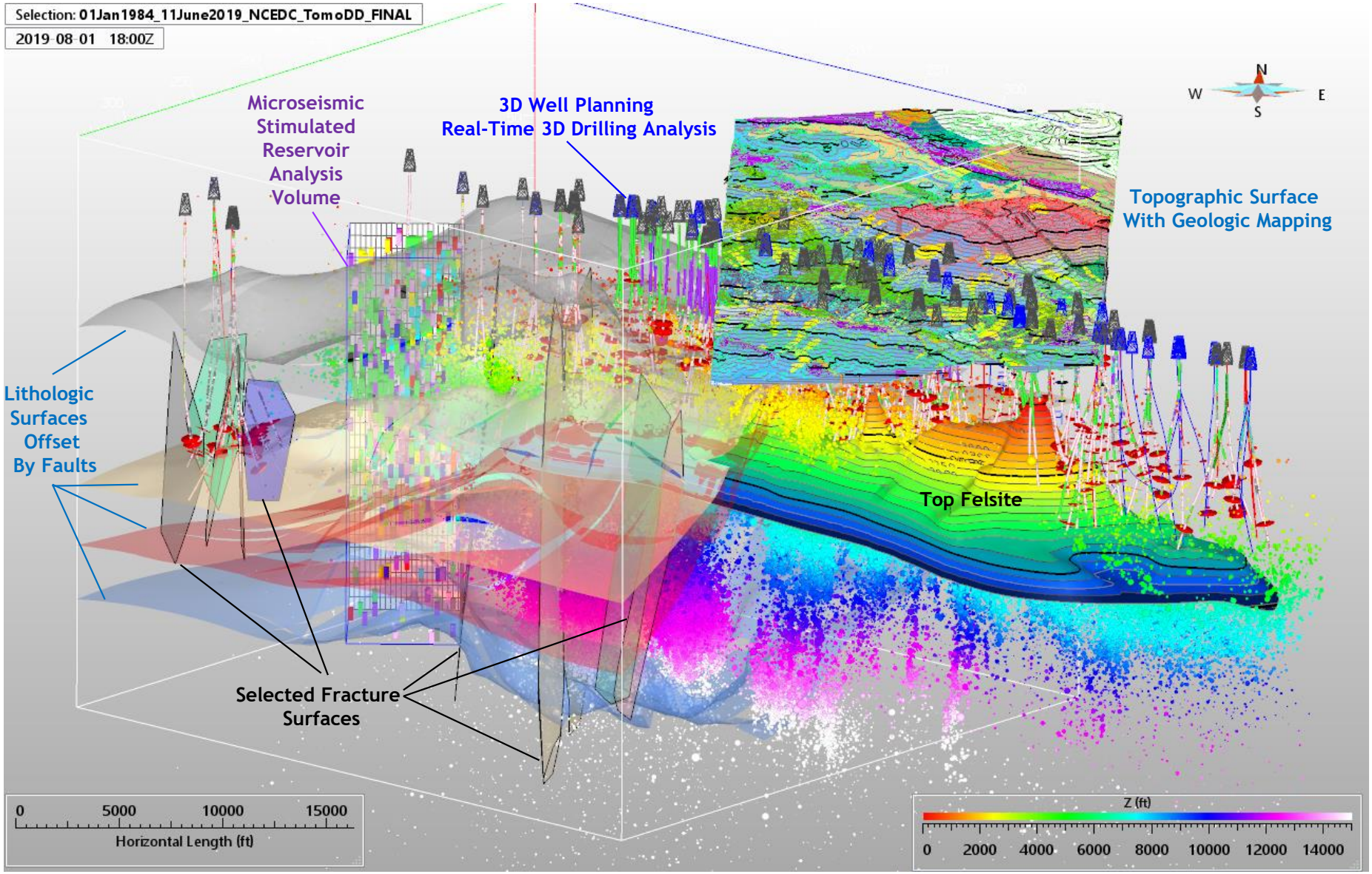
Peak Velocity (cm/sec)	< 0.10	0.1 - 1.1	1.1 - 3.4	3.4 - 8.1	8.1 - 16.0	16.0 - 31.0	31.0 - 60.0	60.0 - 116.0	> 116.0
Modified Mercalli Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X

Seismic Monitoring Advisory Committee Meeting

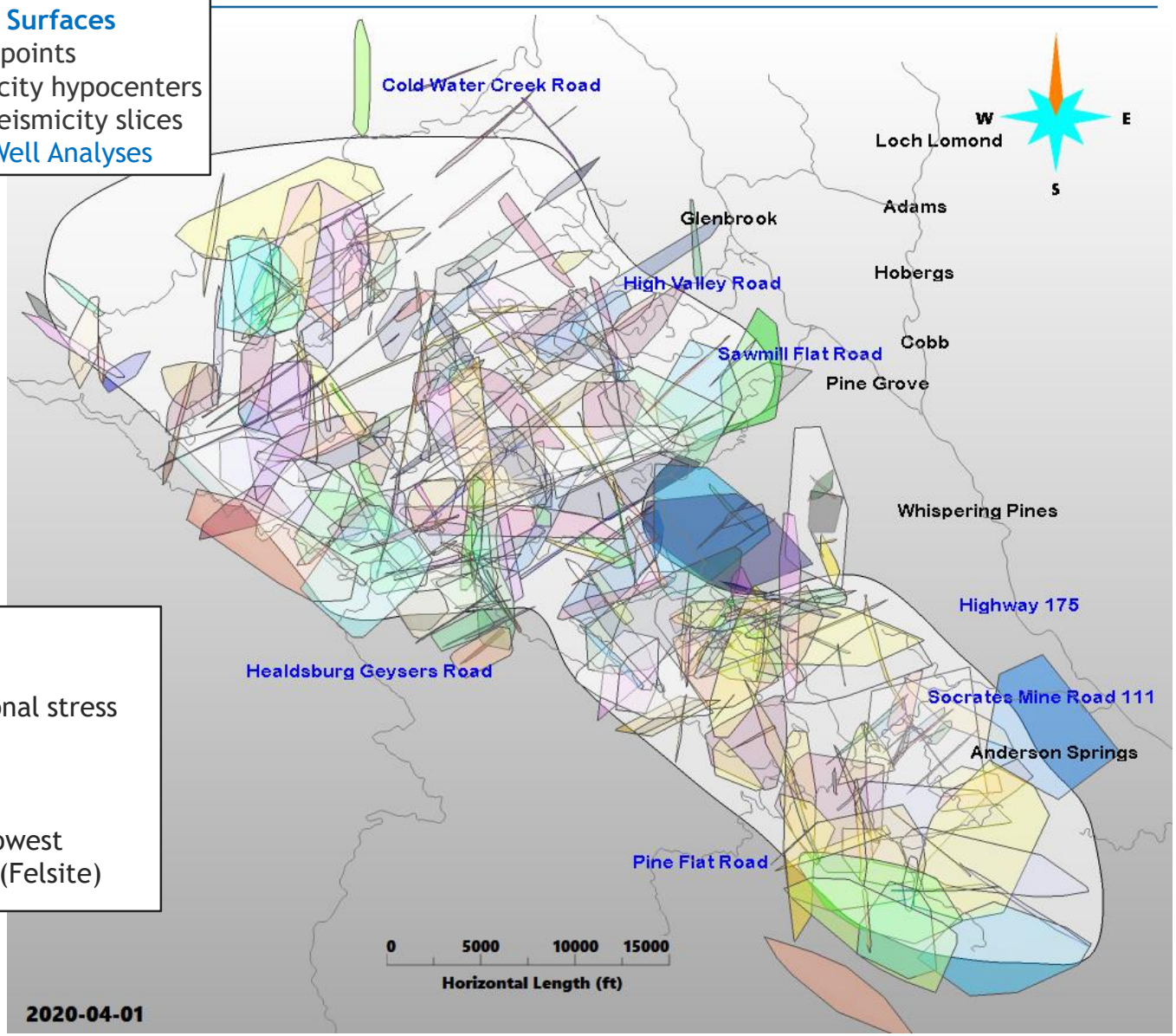
Current Status Of 3D Structural Model Development



Seismic Monitoring Advisory Committee Meeting

Fault/Fracture Interpretation Surfaces Based on Seismicity Alignments

April 2020: **327 Fault/Fracture Surfaces**
- Greater than 40,000 interpreted points
- Picked directly on aligned seismicity hypocenters
- Picked using variously-oriented seismicity slices
- Refinements during Pre-Drilling Well Analyses

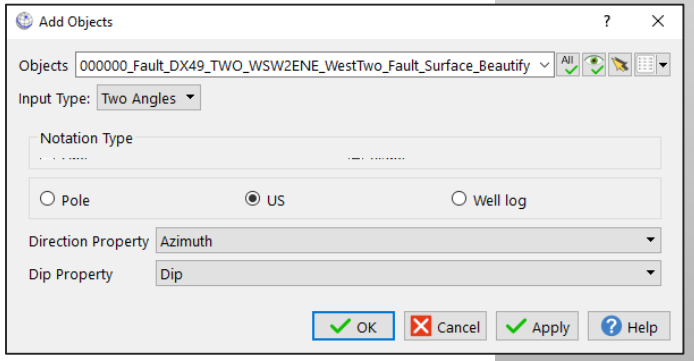


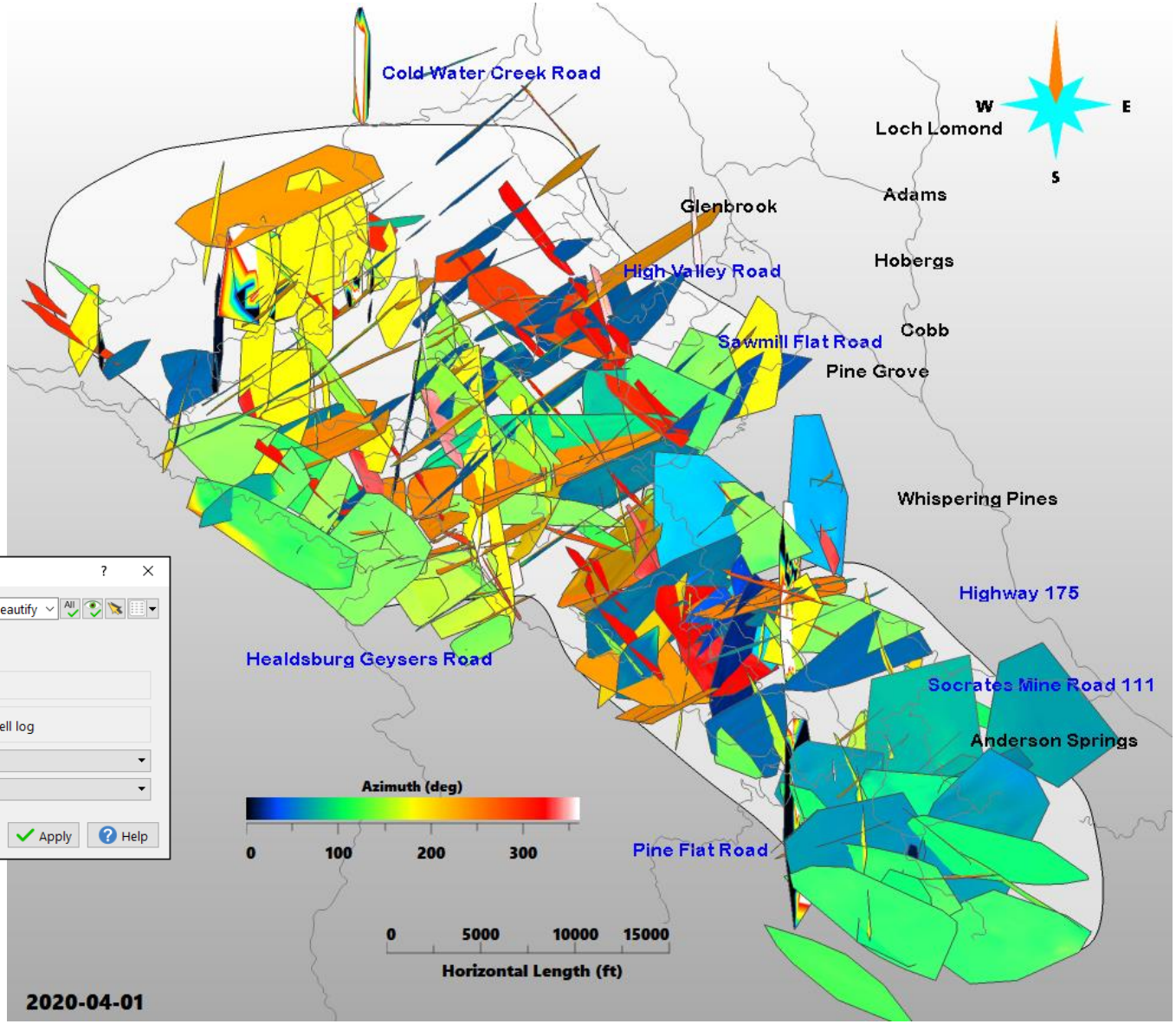
Northwest Geysers
- Primarily near vertical faults
- Orientation consistent with regional stress

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

Fault/Fracture Interpretation Surfaces Based on Seismicity Alignments

Azimuth Angle Visualized





Interpretation of Significant Steam Entry 3D Alignments
Summary From Interpretation And Analysis

30 distinct significant (high pressure) steam entry 3D alignments identified and interpreted within SKUA GOCAD 3D project.

This analysis suggests primarily near-vertical SW-NE to W-E alignment orientations and secondarily near-vertical NW-SE alignment orientations for significant (high PSI) Geysers steam entries.
(representing open steam-filled fracture zones)

Steam production well drilling programs targeted to intersect the existing (interpreted) steam entry alignments may have a higher success rate – if sufficient separation exists to allow access to untapped productive steam reservoir.

Wells intersecting near-vertical SW-NE to W-E oriented fractures appear most likely to encounter high pressure steam.

This makes sense, as the regional stress field at The Geysers (N 23°E Maximum Horizontal Principal Stress) results in:
(1) northwest-to-southeast oriented faults/fractures consistent with the San Andreas Fault System, and
(2) southwest-to-northeast oriented potentially open faults/fractures due to transtensional forces

This analysis/interpretation may also assist in better understanding potential (or existing) water breakthrough from water injection wells to steam production wells along high permeability open fracture systems.

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Interpretation of Significant Steam Entry 3D Alignments
Additional Constraint For Well Planning And Seismicity Mitigation (?)

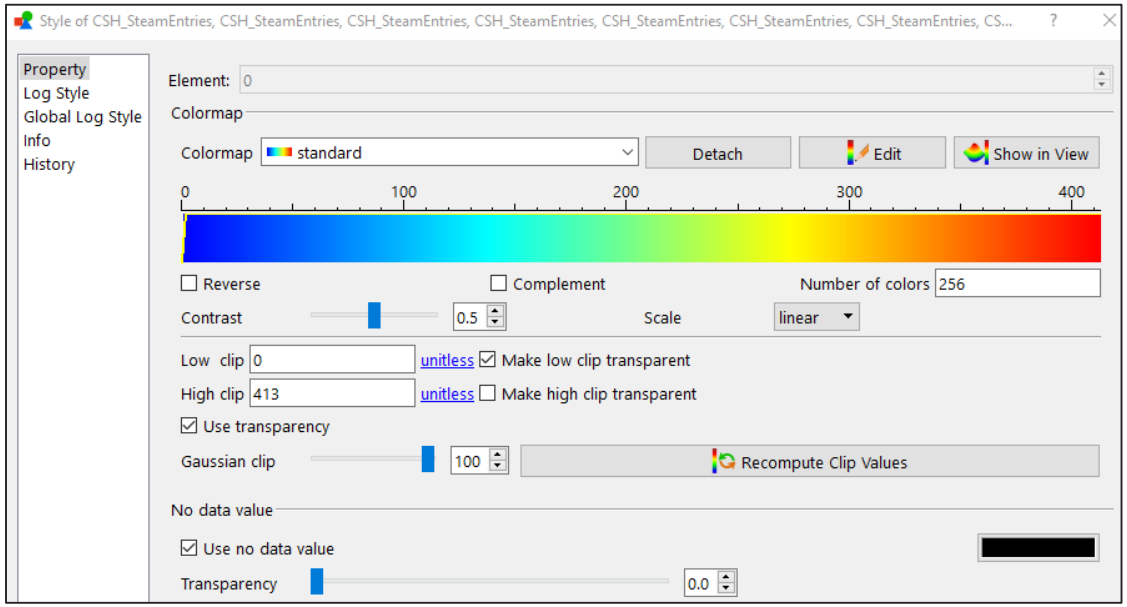
During several detailed pre-drilling project analyses (McKinley 17, LF51, GDC53B13, Prati 27) the following SKUA GOCAD 3D display changes were completed and noted to enhance significant steam entry alignments:

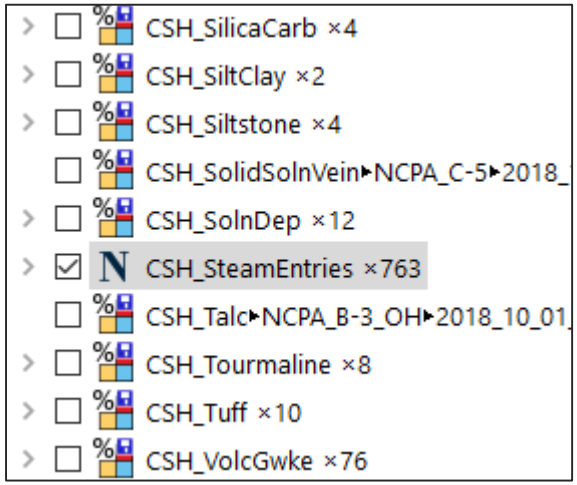
- 763 well segments displayed with ONLY steam entries (no wellhead symbol, well trajectory, other logs, markers, …)
- Fieldwide relative scaling parameters for steam entries set with "no clip values"
  (Range set as 0-431 psi; rather than 0-250 psi generally used to allow better distinction of lower psi steam entries)

These combined display parameters highlighted interesting alignments of the more significant steam entries in:

- Map view
- Various orientations highlighting stream entry dip angles of up to approximately 30° from vertical

The potential to use these interesting alignments in well planning and water breakthrough analyses is investigated.





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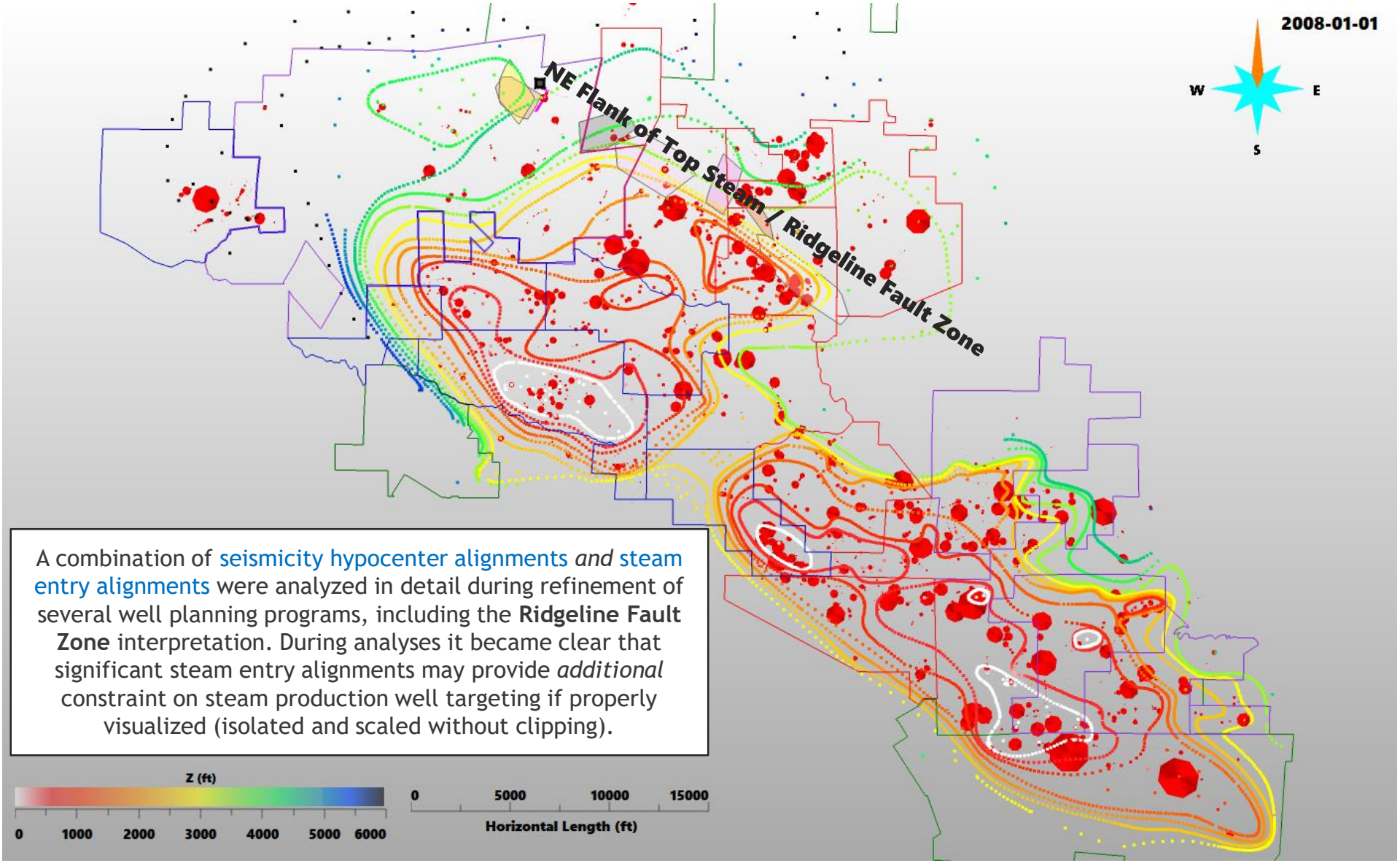
Interpretation of Significant Steam Entry 3D Alignments
Fieldwide Areas , Scaled Steam Entries and Colored-Scaled Top Steam Contours



A combination of seismicity hypocenter alignments *and* steam entry alignments were analyzed in detail during refinement of several well planning programs, including the **Ridgeline Fault Zone** interpretation. During analyses it became clear that significant steam entry alignments may provide *additional* constraint on steam production well targeting if properly visualized (isolated and scaled without clipping).

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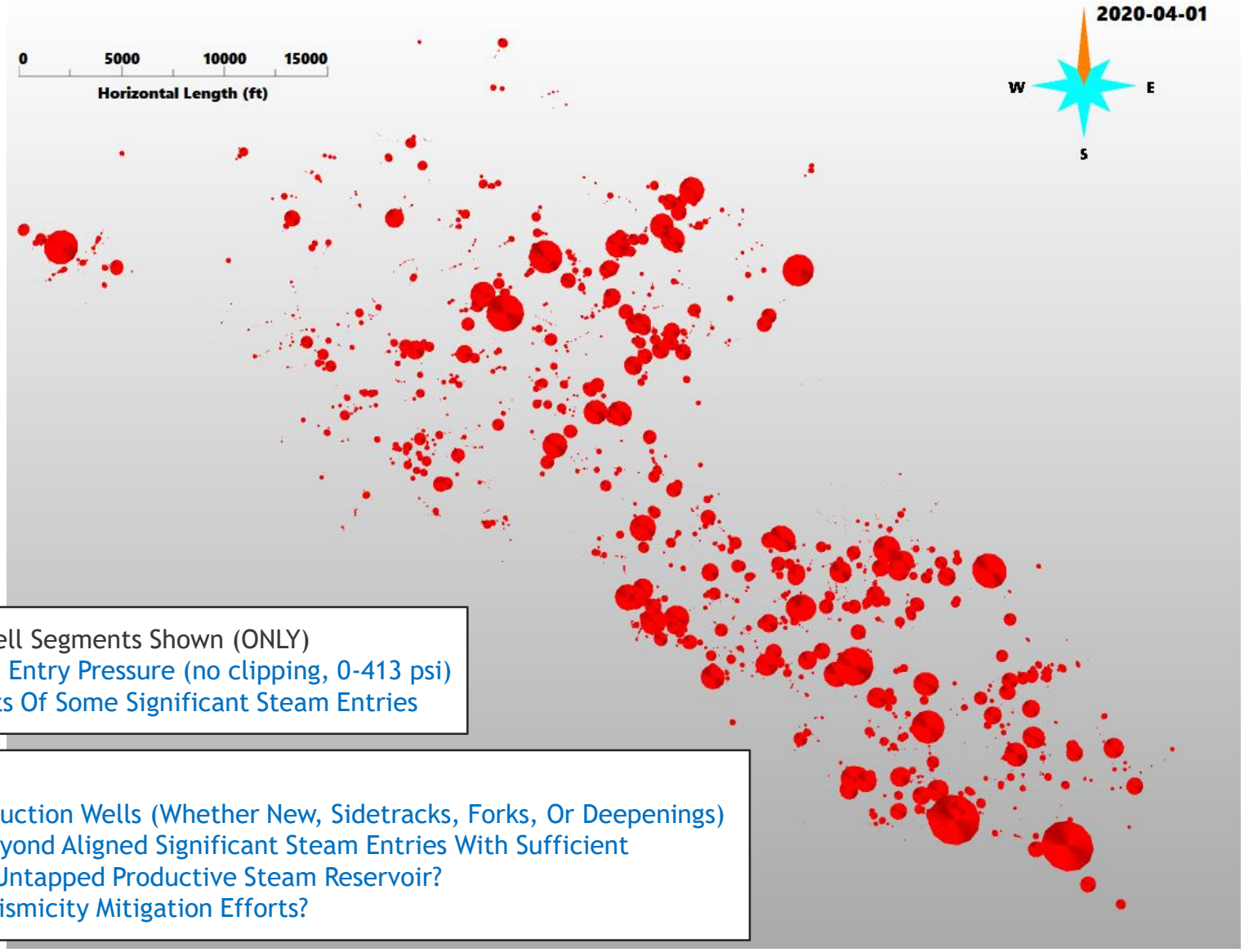
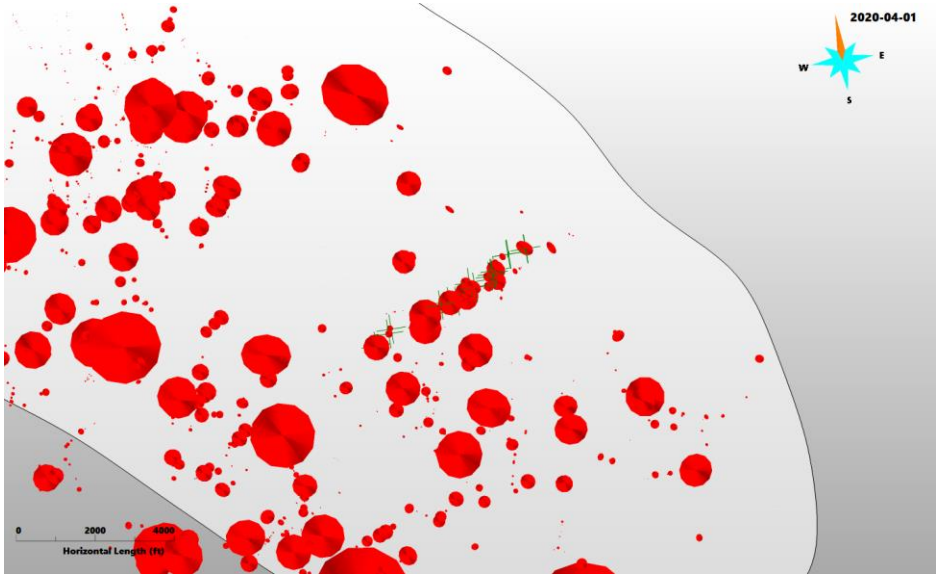
Interpretation of Significant Steam Entry 3D Alignments
Fieldwide Scaled Steam Entries Only

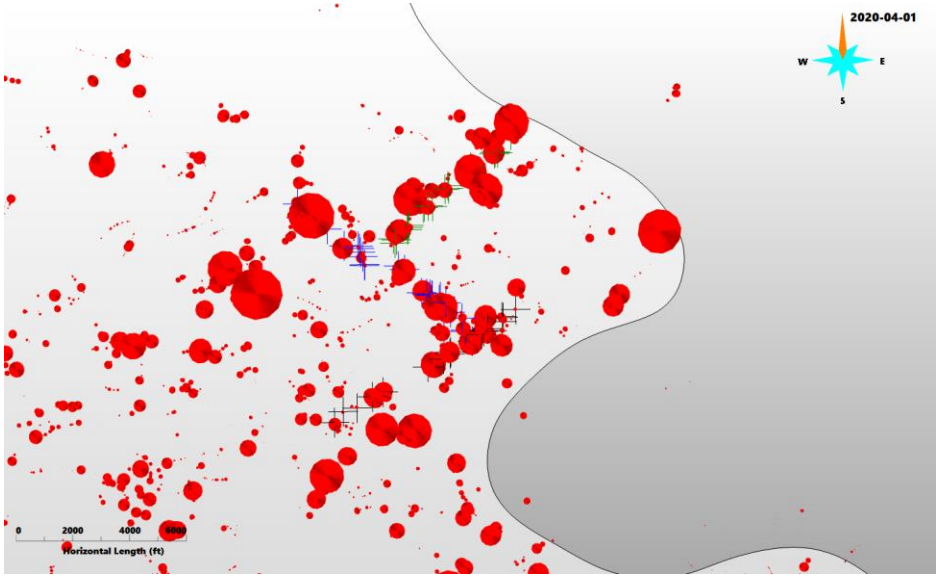


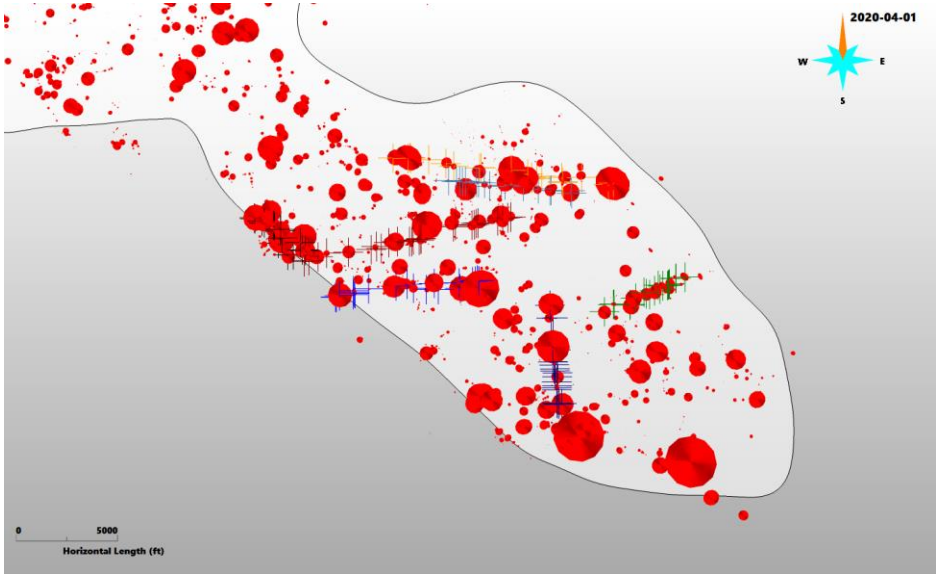
Steam Entries For 763 Well Segments Shown (ONLY)
Scaled Relative To Steam Entry Pressure (no clipping, 0-413 psi)
Note Potential Alignments Of Some Significant Steam Entries

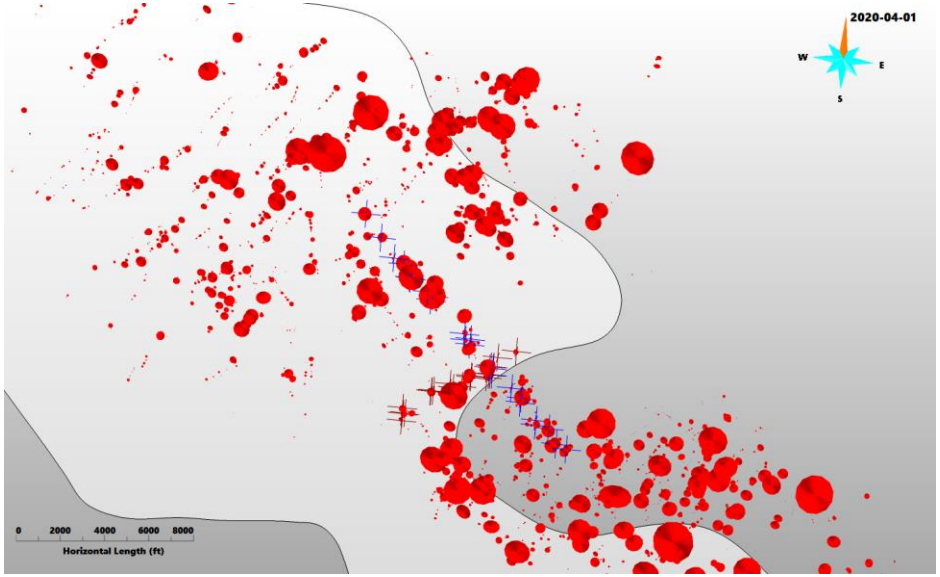
Question:
Could Future Steam Production Wells (Whether New, Sidetracks, Forks, Or Deepenings) Be Targeted Within or Beyond Aligned Significant Steam Entries With Sufficient Separation To Access To Untapped Productive Steam Reservoir?
Could This Assist With Seismicity Mitigation Efforts?

Interpretation of Significant Steam Entry 3D Alignments
Developing Fracture Surfaces From Aligned Steam Entries

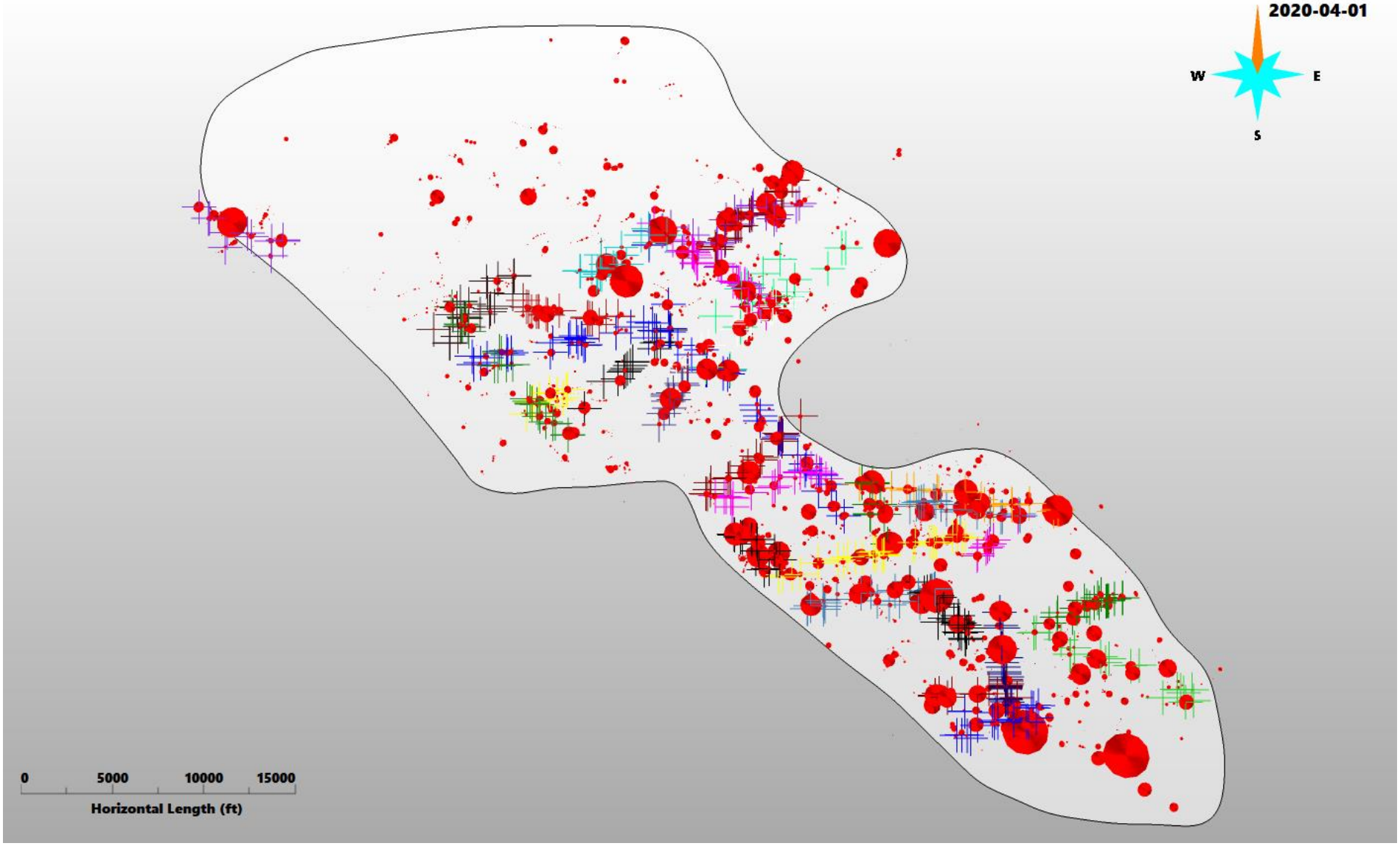








Interpretation of Significant Steam Entry 3D Alignments
Fieldwide Scaled Steam Entries And 30 Significant Steam Entry Alignment Picks



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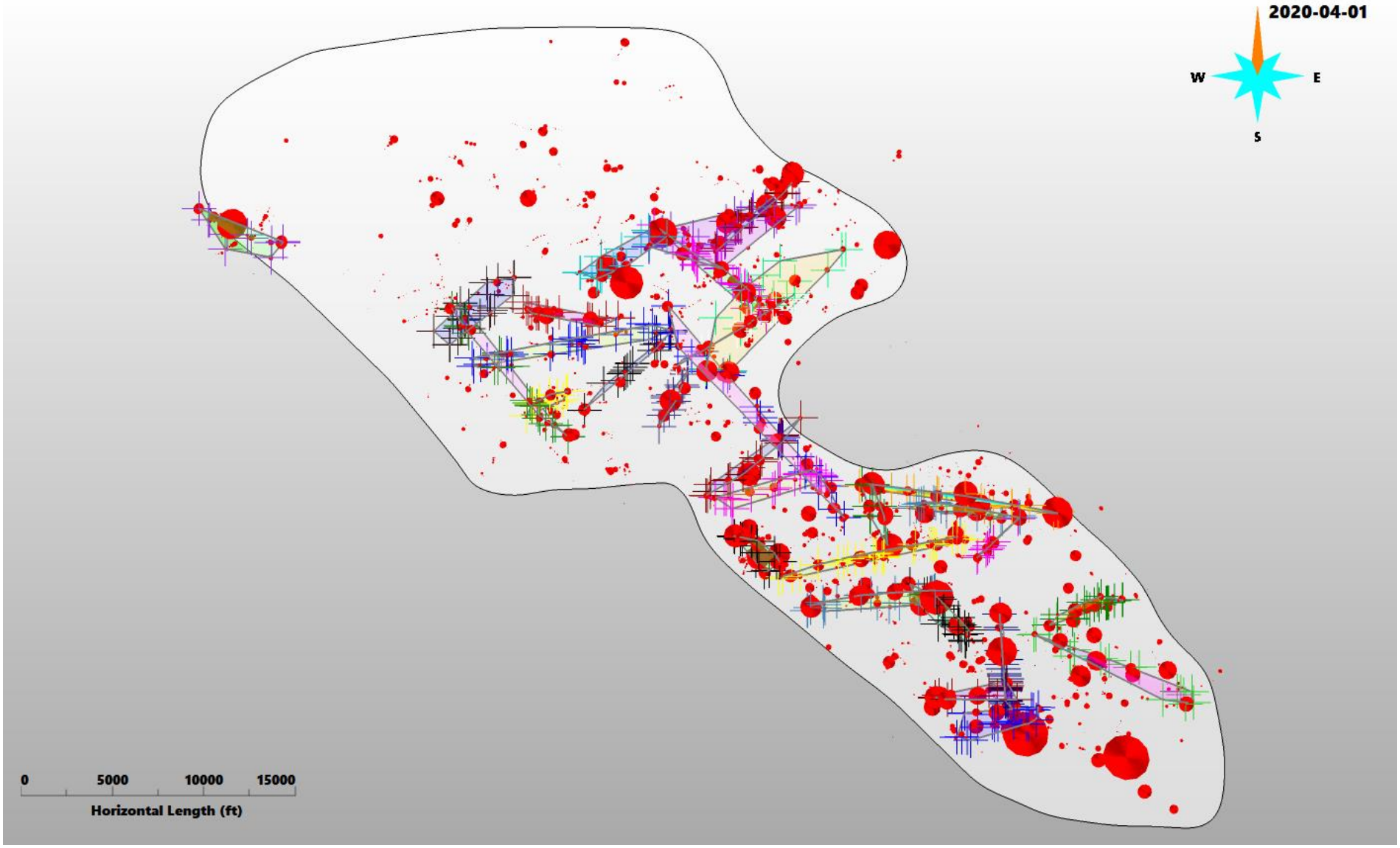
Interpretation of Significant Steam Entry 3D Alignments
Fieldwide Scaled Steam Entries And 30 Significant Steam Entry Alignment Fracture Surfaces



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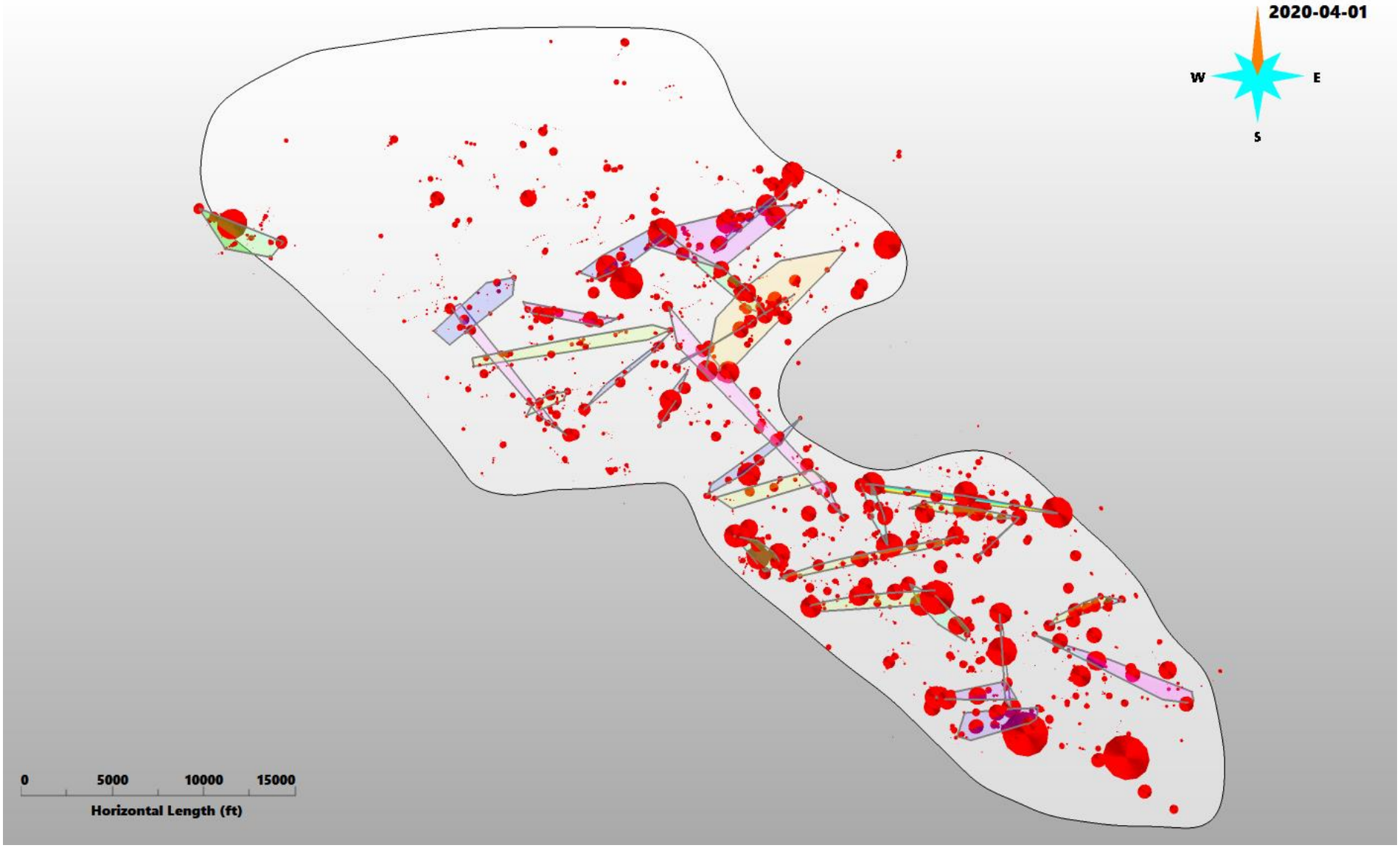
Interpretation of Significant Steam Entry 3D Alignments
Fieldwide Scaled Steam Entries And 30 Significant Steam Entry Alignment Fracture Surfaces



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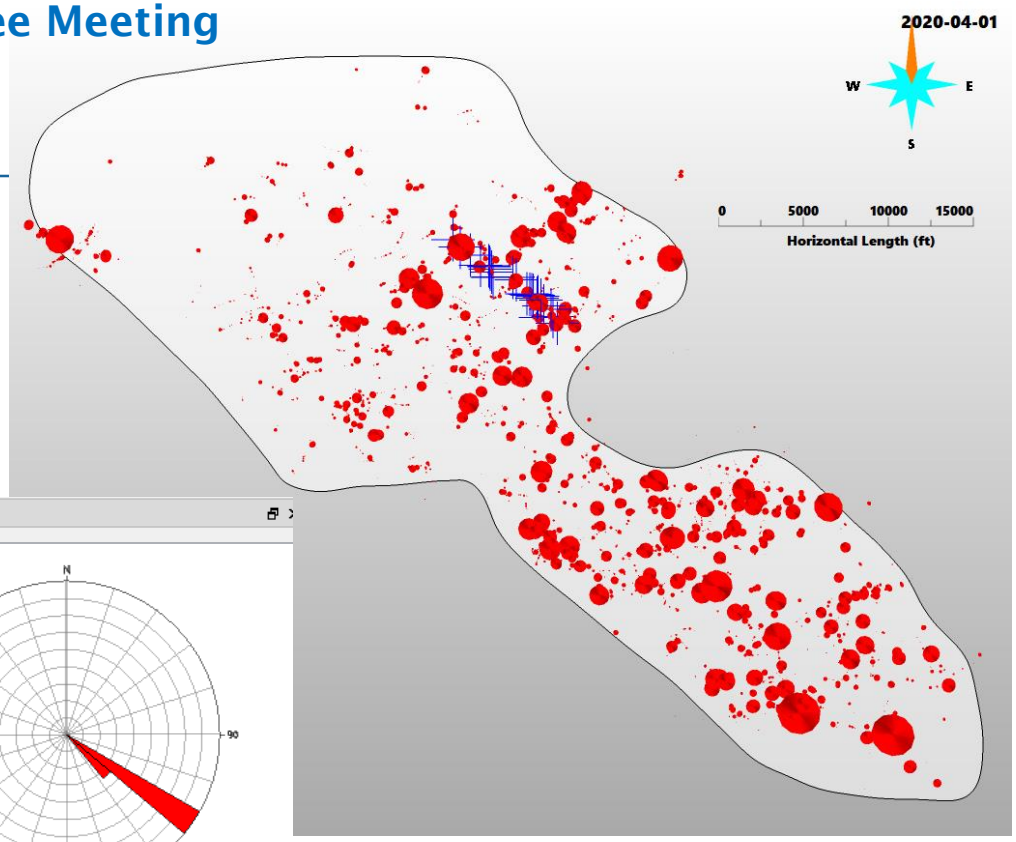
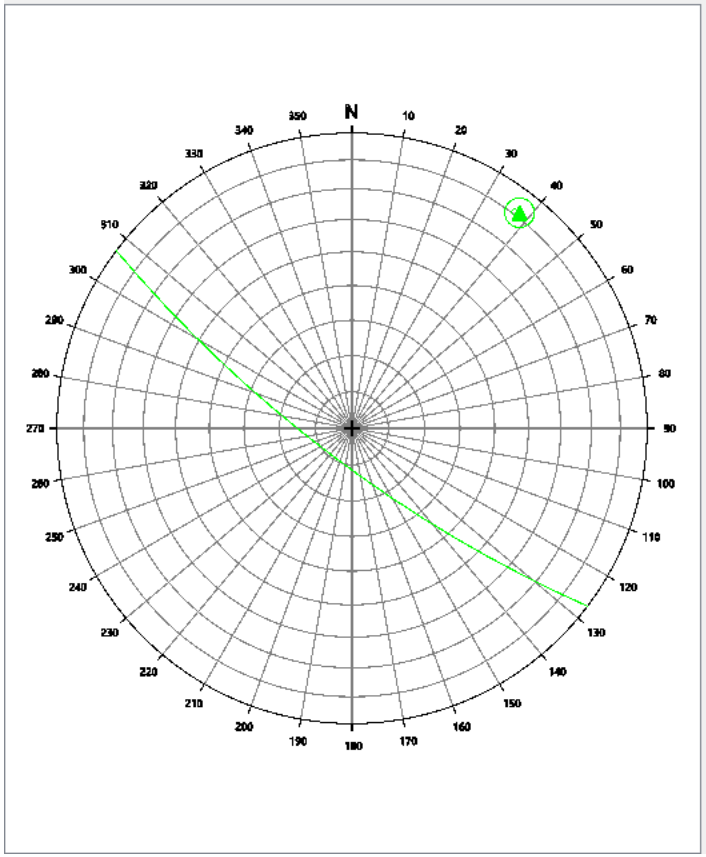
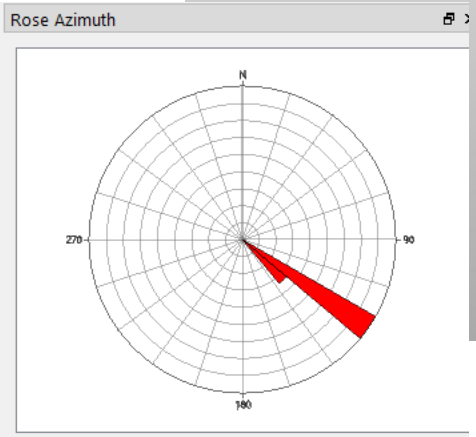
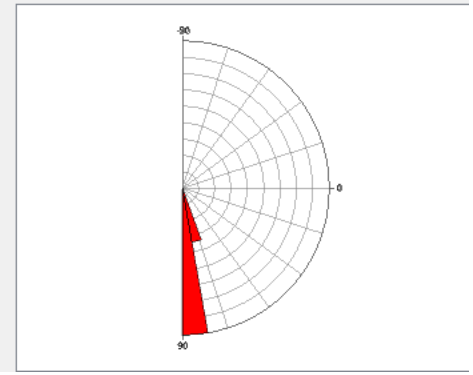
Interpretation of Significant Steam Entries
3D Alignment Analysis

Azimuth / Dip Analysis By Fracture Surface
Schmidt Diagram Lower Hemisphere
Mean Pole and Mean Circle









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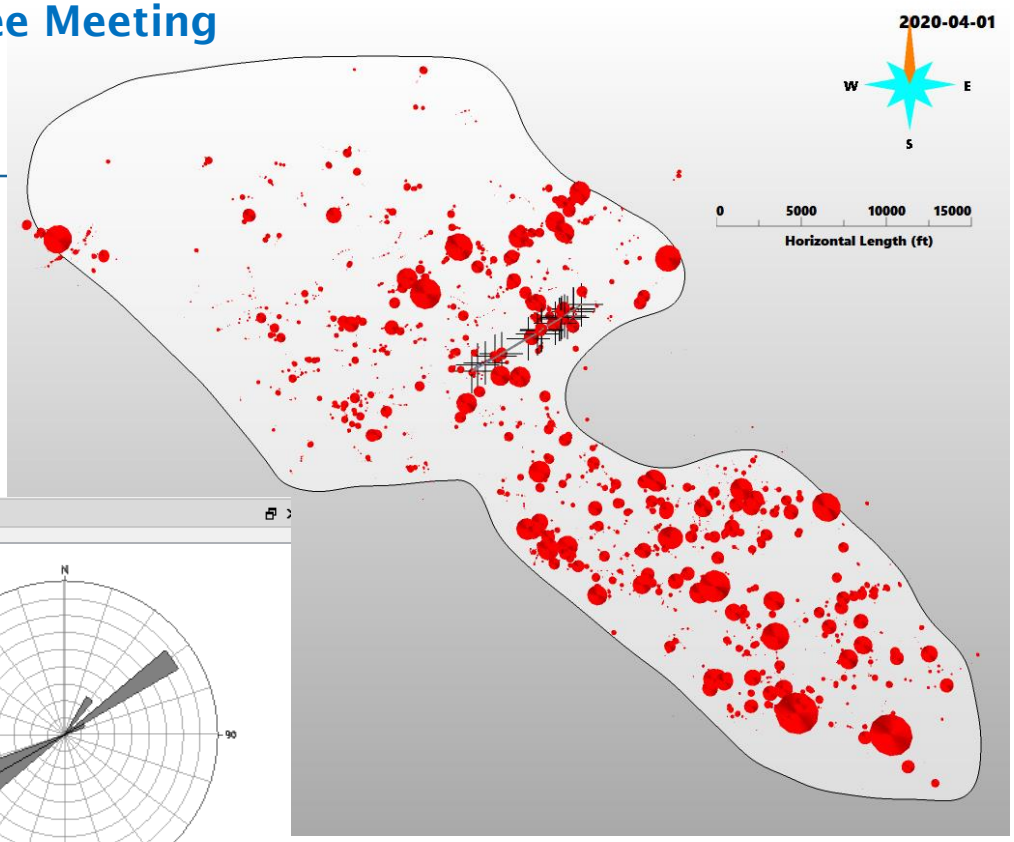
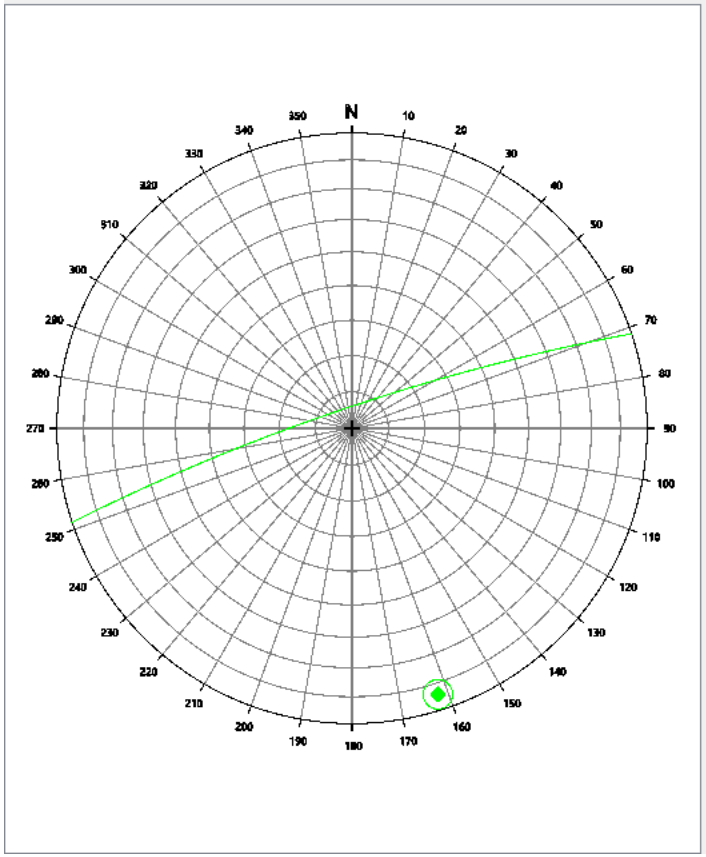
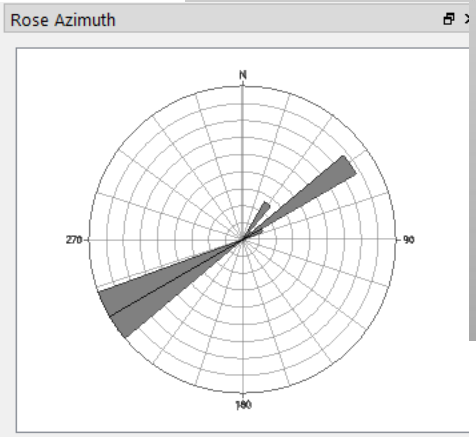
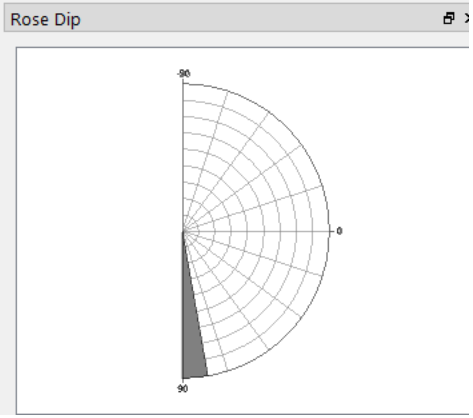
Interpretation of Significant Steam Entries
3D Alignment Analysis

Azimuth / Dip Analysis By Fracture Surface
Schmidt Diagram Lower Hemisphere
Mean Pole and Mean Circle









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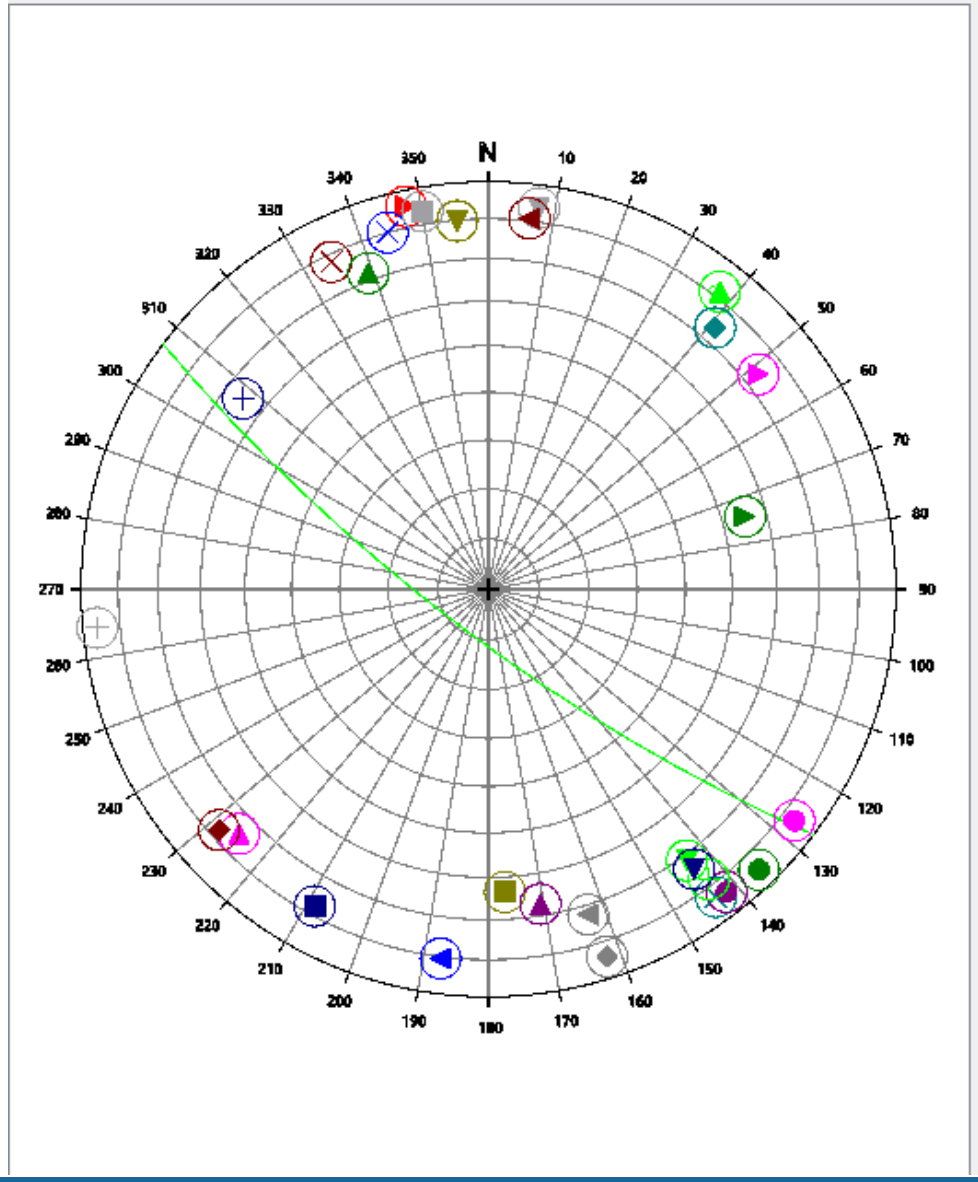
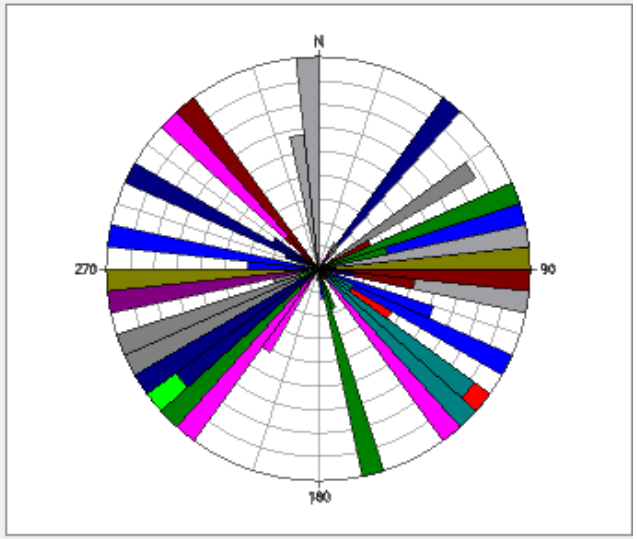
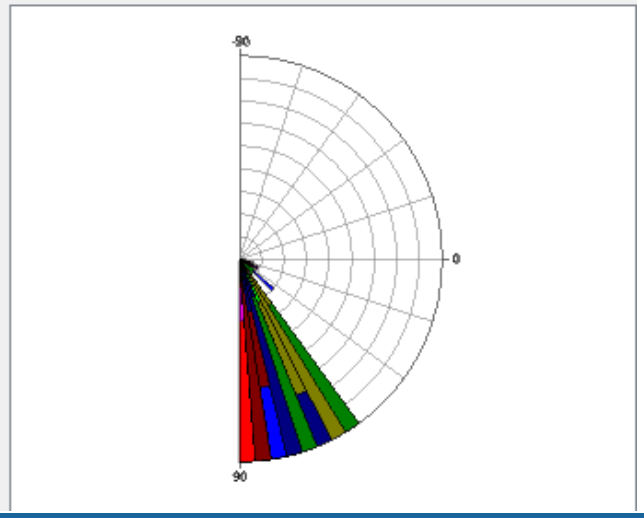
Interpretation of Significant Steam Entries
Azimuth / Dip Analysis For 30 Fracture Surfaces
Schmidt Diagram - Lower Hemisphere With Mean Poles



Rose Azimuth



Rose Dip



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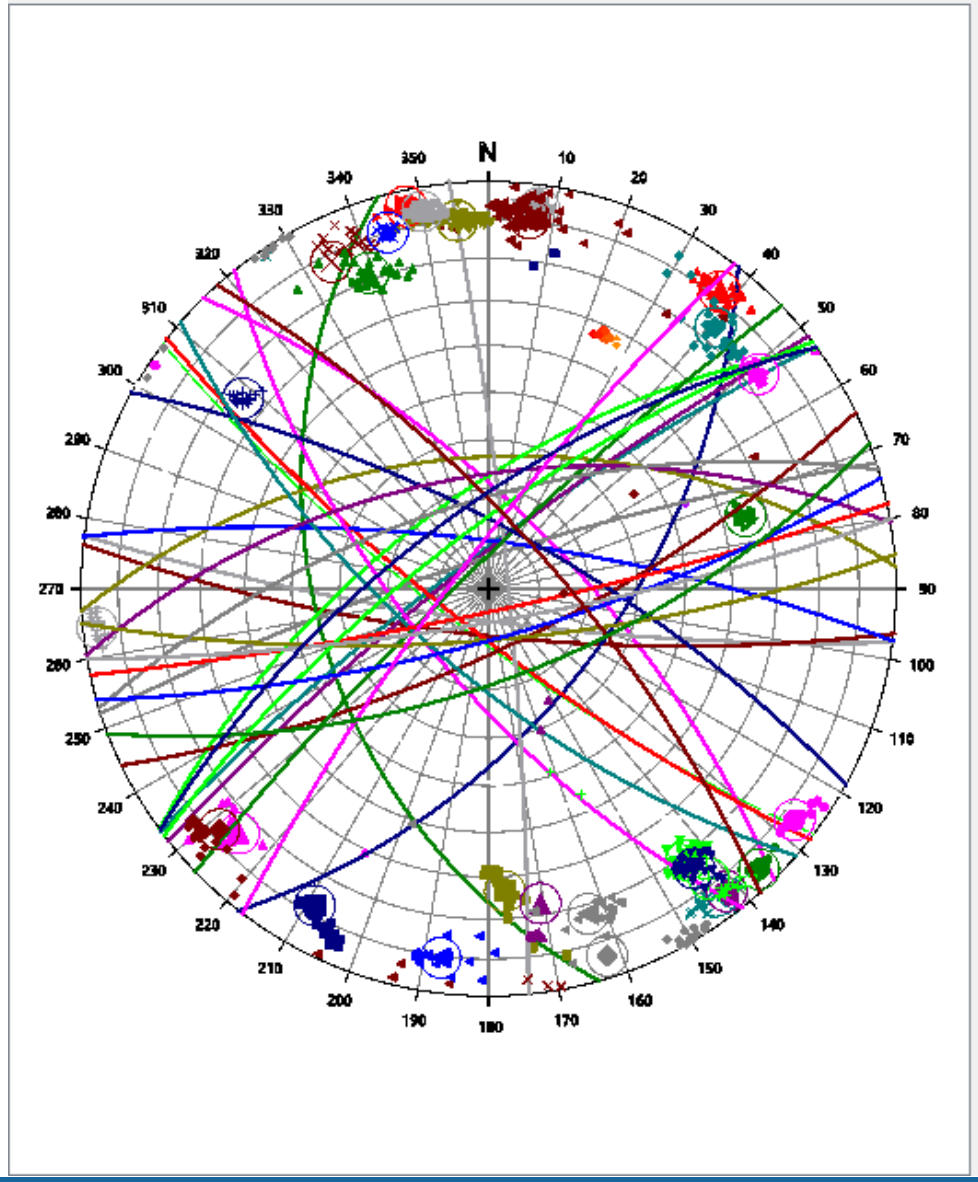
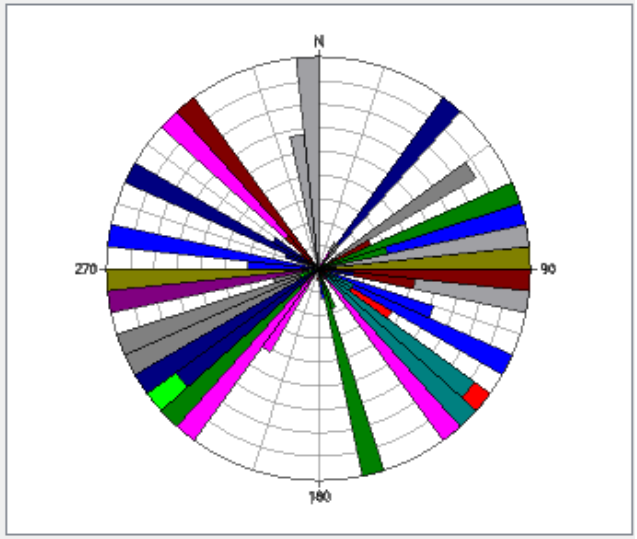
Interpretation of Significant Steam Entries

Azimuth / Dip Analysis For 30 Fracture Surfaces

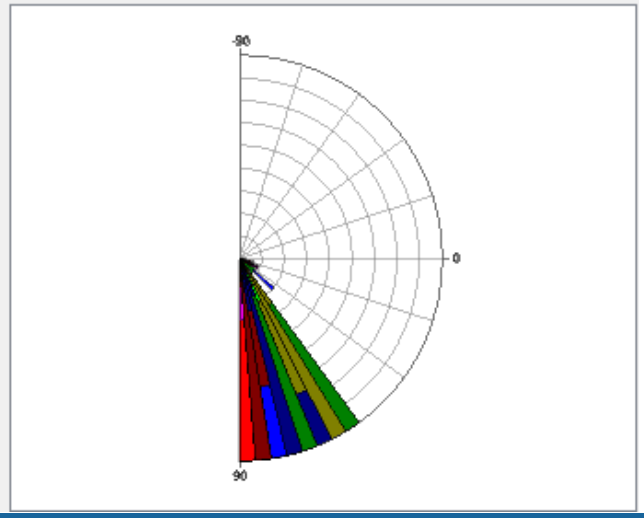
Schmidt Diagram - Lower Hemisphere With Fracture Surface Poles, Mean Poles And Mean Circles



Rose Azimuth



Rose Dip



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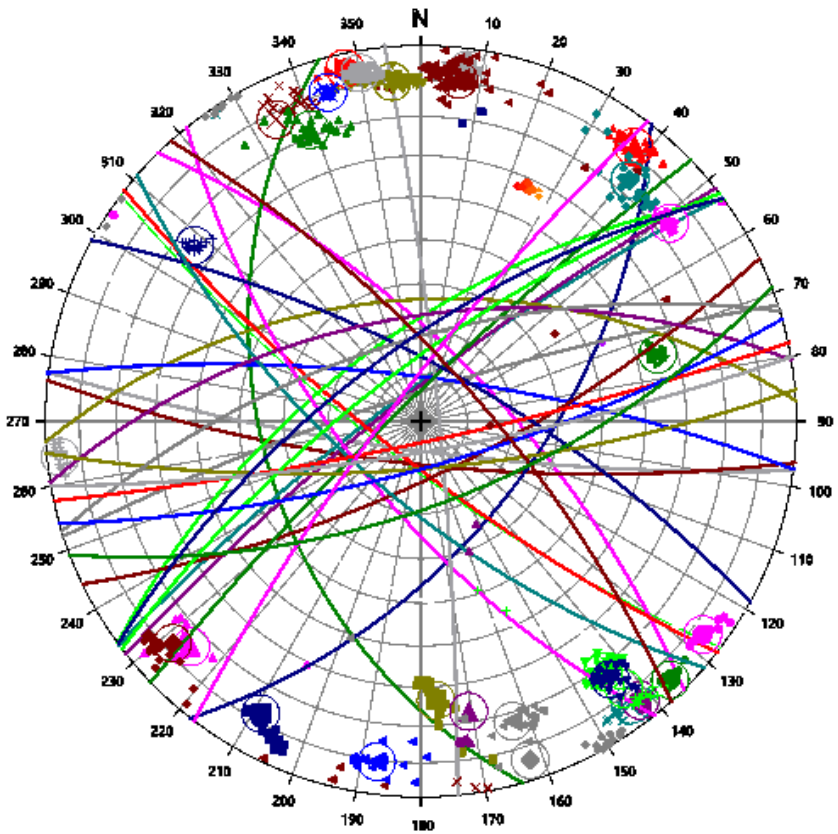
Interpretation of Significant Steam Entries

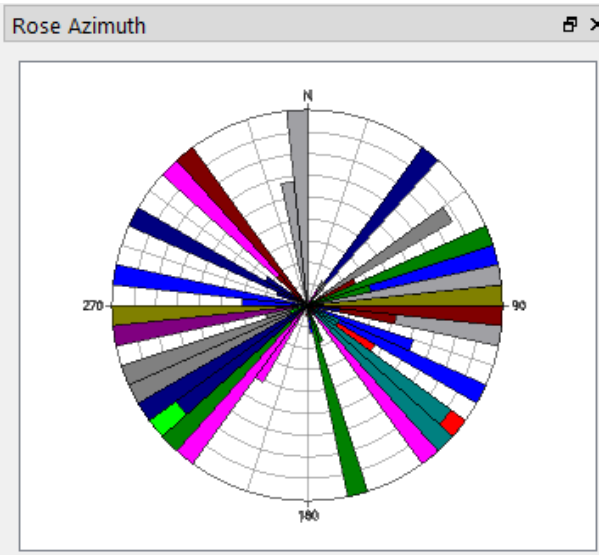
Schmidt Diagram - Lower Hemisphere With Fracture Surface Poles, Mean Poles And Mean Circles

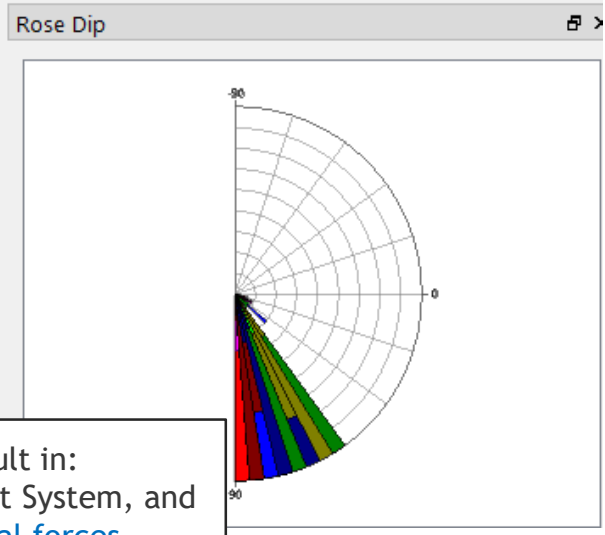
This analysis suggests primarily near-vertical SW-NE to W-E alignment orientations and secondarily near-vertical NW-SE alignment orientations for aligned significant (high PSI) Geysers steam entries (representing open steam-filled fracture zones)

Steam production well drilling programs designed to intersect the existing (interpreted) steam entry alignments may have a higher success rate – if sufficient separation exists to allow access to untapped productive steam reservoir.

Wells intersecting near-vertical SW-NE to W-E oriented fractures appear most likely to (historically) encounter high pressure steam entries.







The regional stress field at The Geysers (N 23°E Maximum Horizontal Principal Stress) result in:
(1) northwest-to-southeast oriented faults/fractures consistent with the San Andreas Fault System, and
(2) southwest-to-northeast oriented potentially open faults/fractures due to transtensional forces
(regional stress field discussed on next slide)

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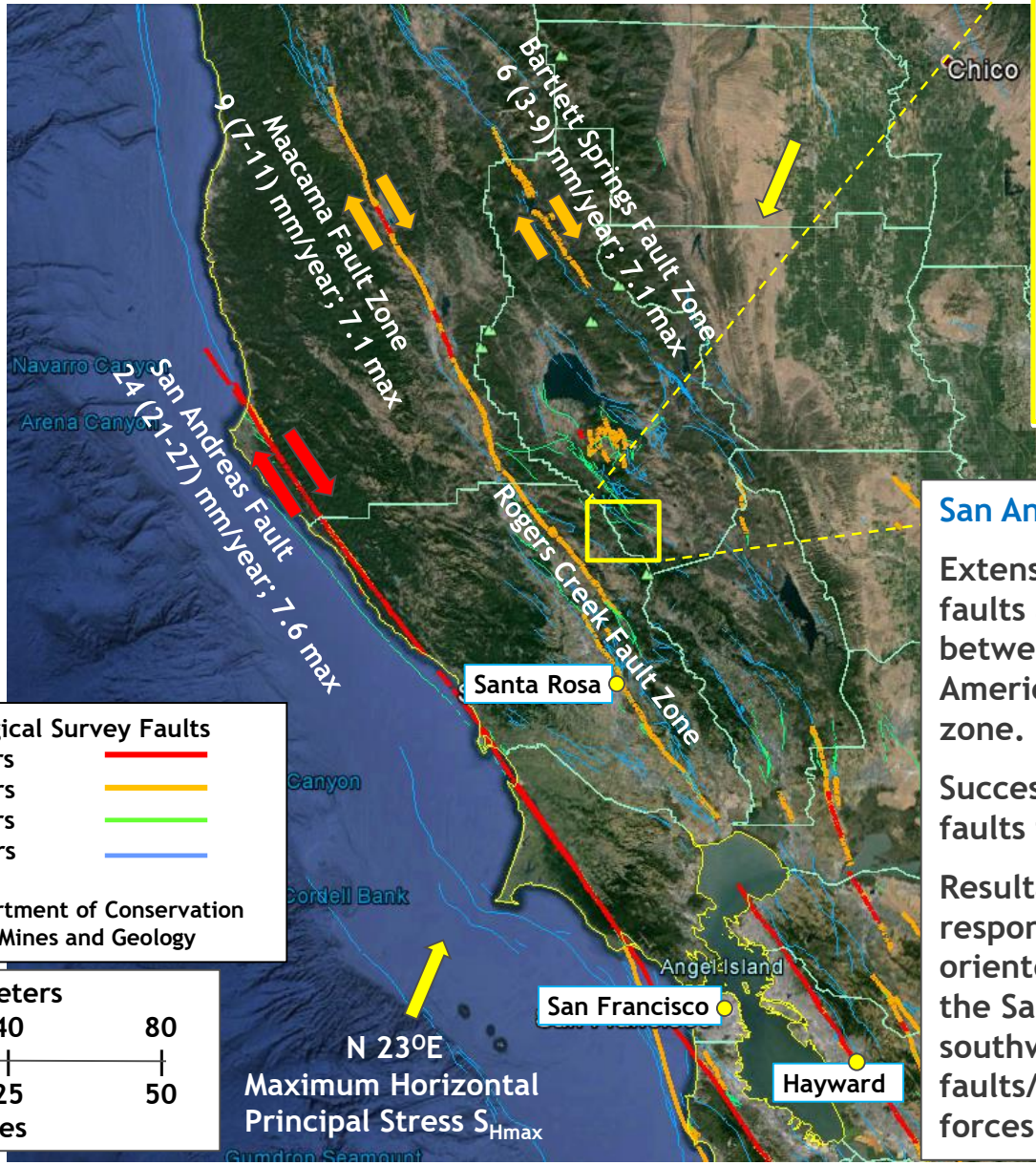
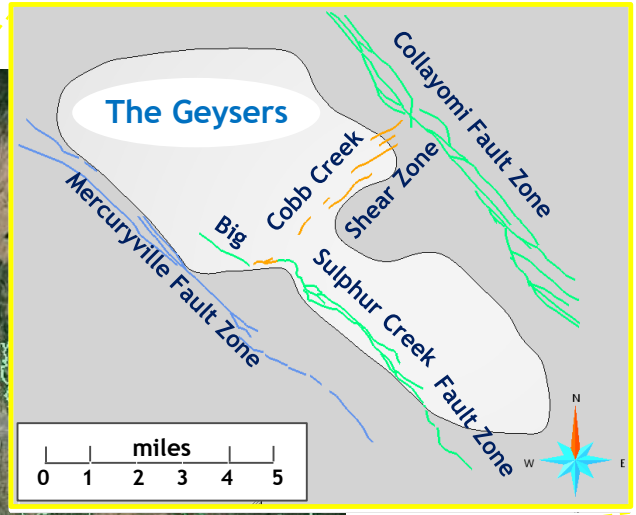
Interpretation of Significant Steam Entries
San Andreas Fault System and Resultant Stress Field



USGS/CGS Mapped Inactive Faults Zones



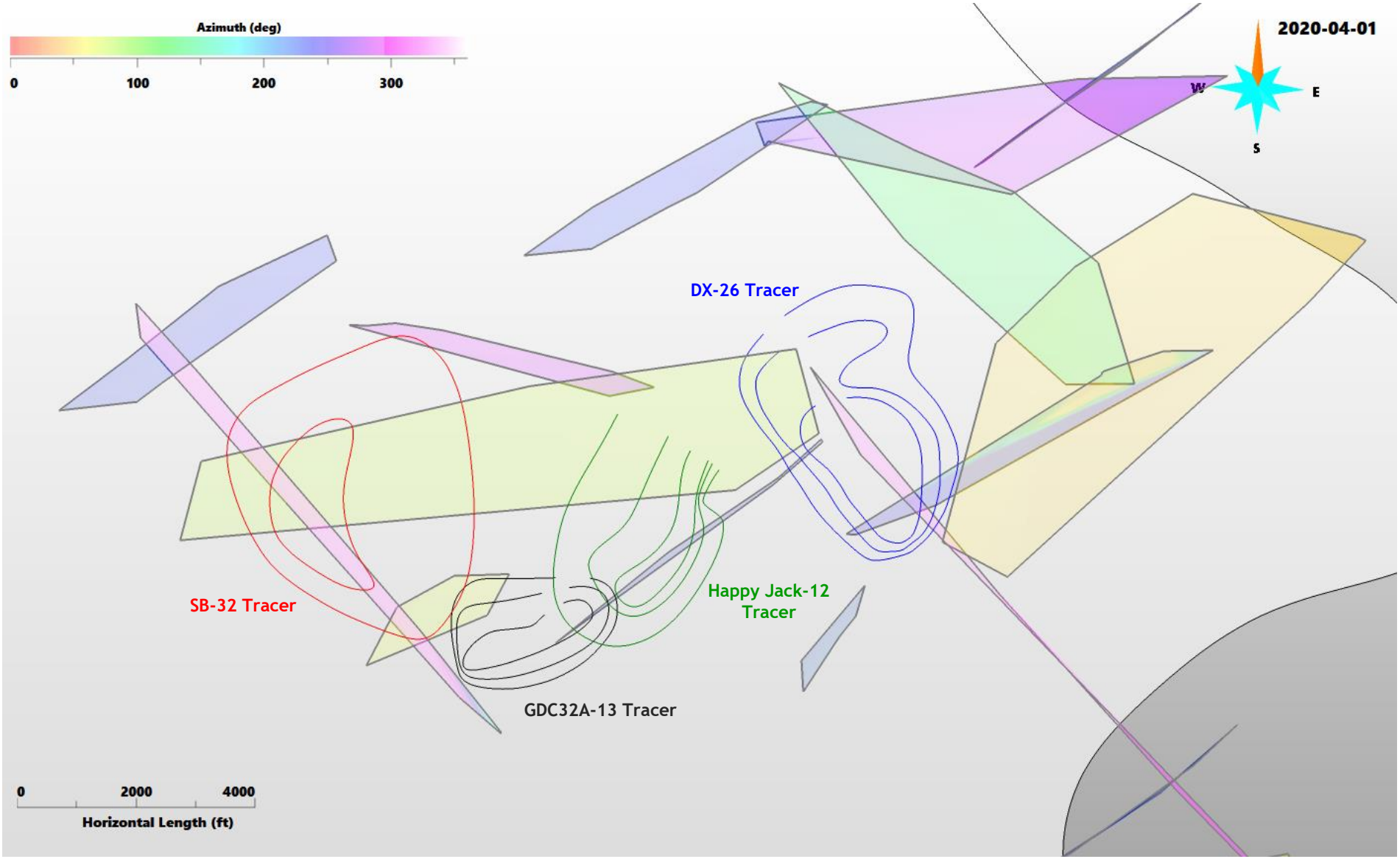
San Andreas Fault System

Extensive system of right-lateral strike-slip faults accommodates the relative motion between the Pacific Plate and North American Plate over a 60 to 180-mile-wide zone.

Successively smaller slip rates for active faults toward the east.

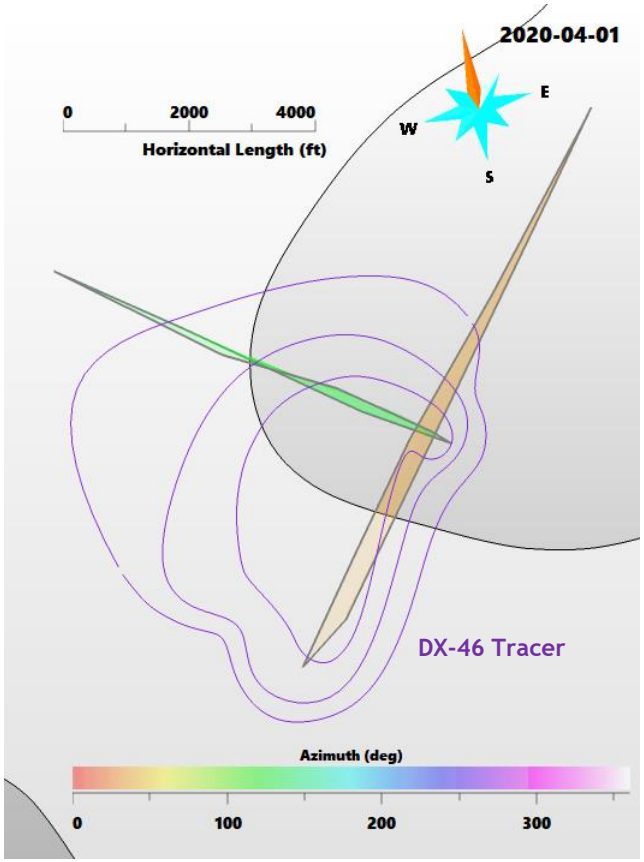
Resultant stress field at The Geysers responsible for (1) northwest-to-southeast oriented faults/fractures consistent with the San Andreas Fault System and (2) southwest-to-northeast oriented faults/fractures due to transtensional forces.

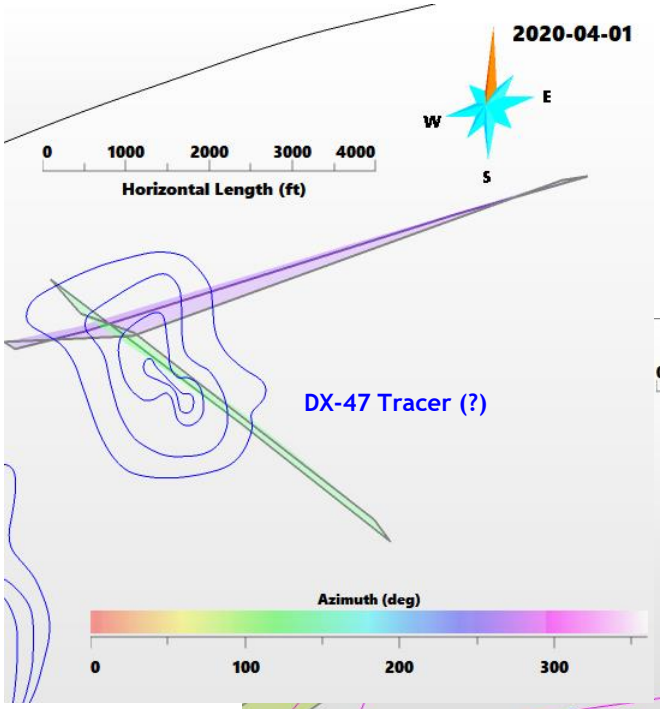
Steam Production Well Targeting Constrained By Significant Steam Entry Alignment Correlation With Tracer Studies Is Very Encouraging …

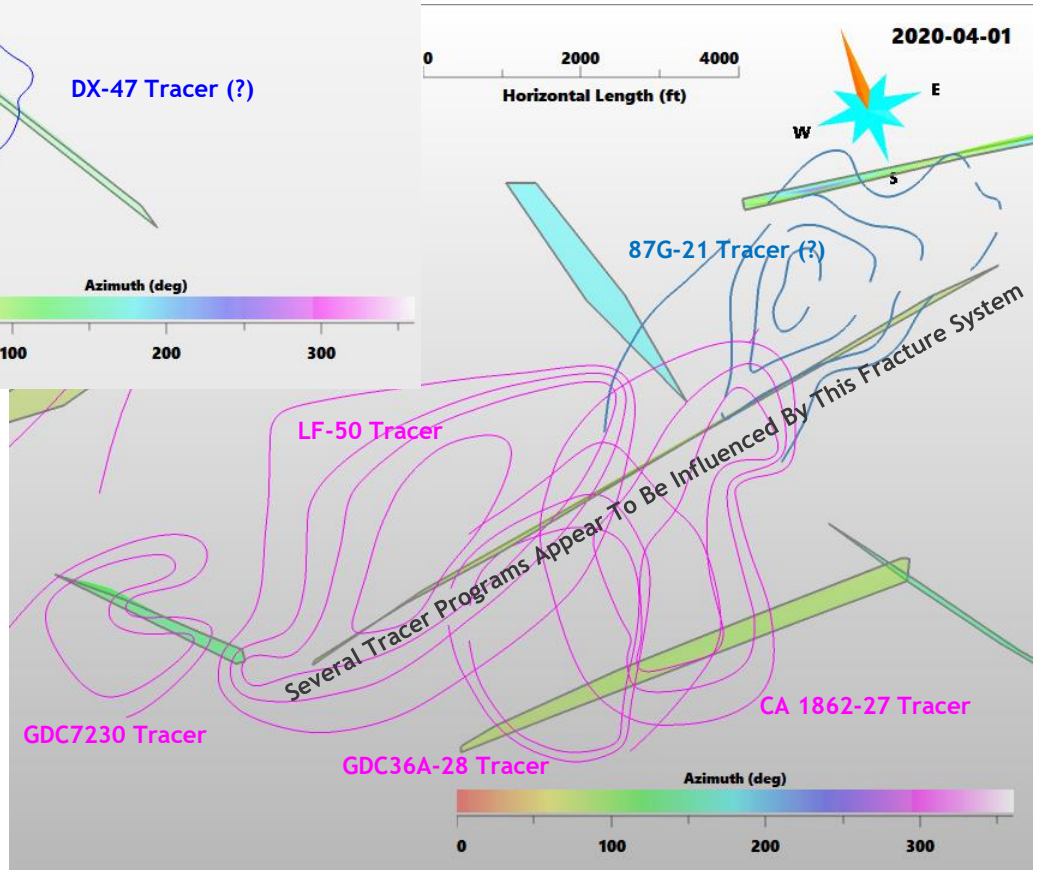


Seismic Monitoring Advisory Committee Meeting

Steam Production Well Targeting Constrained By Significant Steam Entry Alignment Correlation With Tracer Studies Is Very Encouraging …





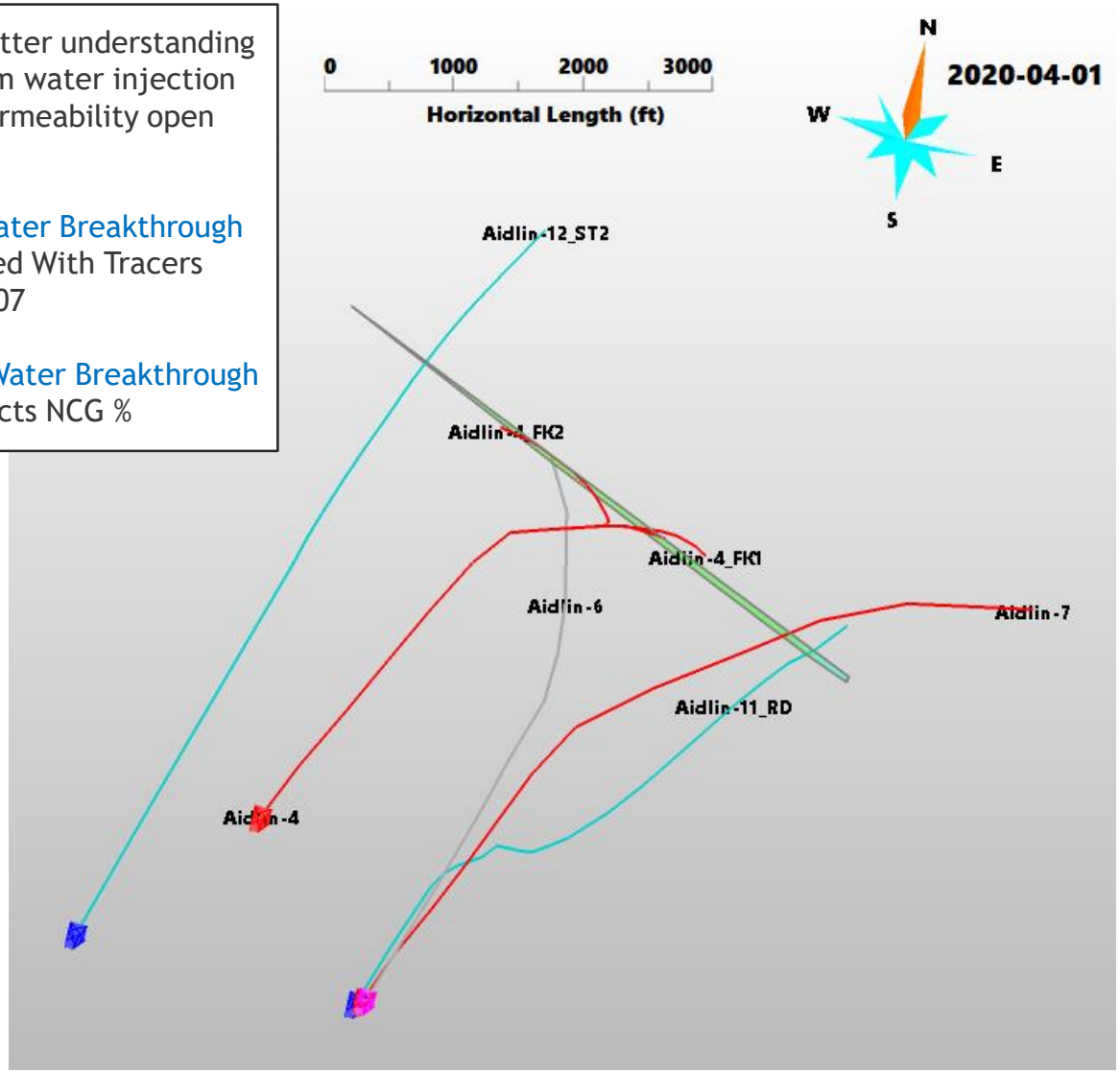


Steam Production Well Targeting Constrained By Significant Steam Entry Alignment Correlation With Water Breakthrough Is Also Very Encouraging …

This analysis/interpretation may also assist in better understanding potential (or existing) water breakthrough* from water injection wells to steam production wells along high permeability open fracture systems.

Aidlin Steam Production Wells With Confirmed Water Breakthrough
Aidlin-6: From Aidlin 11 and Aidlin 12 – Confirmed With Tracers
Aidlin-7: From Aidlin 11 – Due To Injection in 2007

Aidlin Steam Production Wells Watch Listed For Water Breakthrough
Aidlin-4 FK1/FK2: Aidlin 12 Injection Highly Affects NCG %



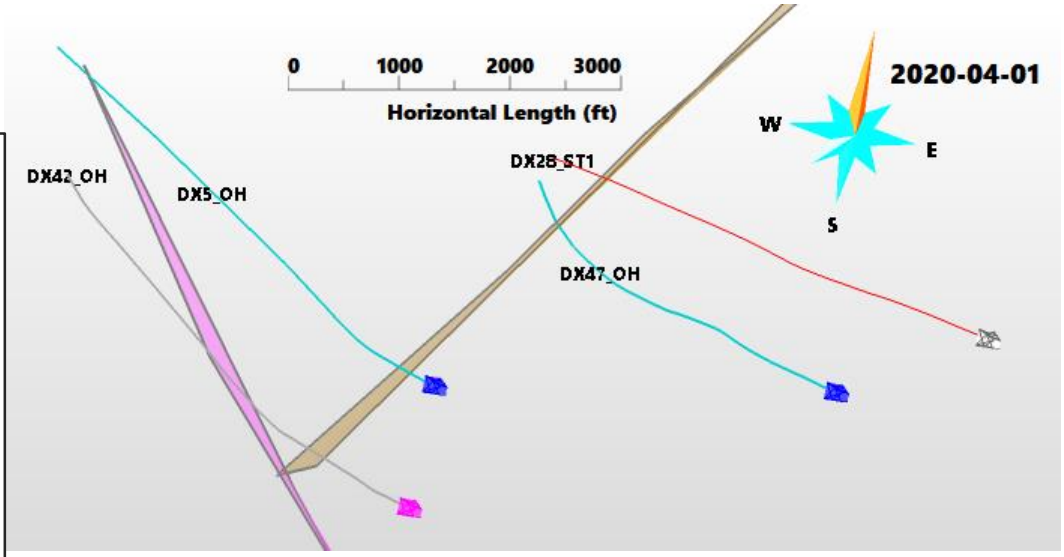
* Senior Geologist Melinda Wright provided information related to water breakthrough studies.

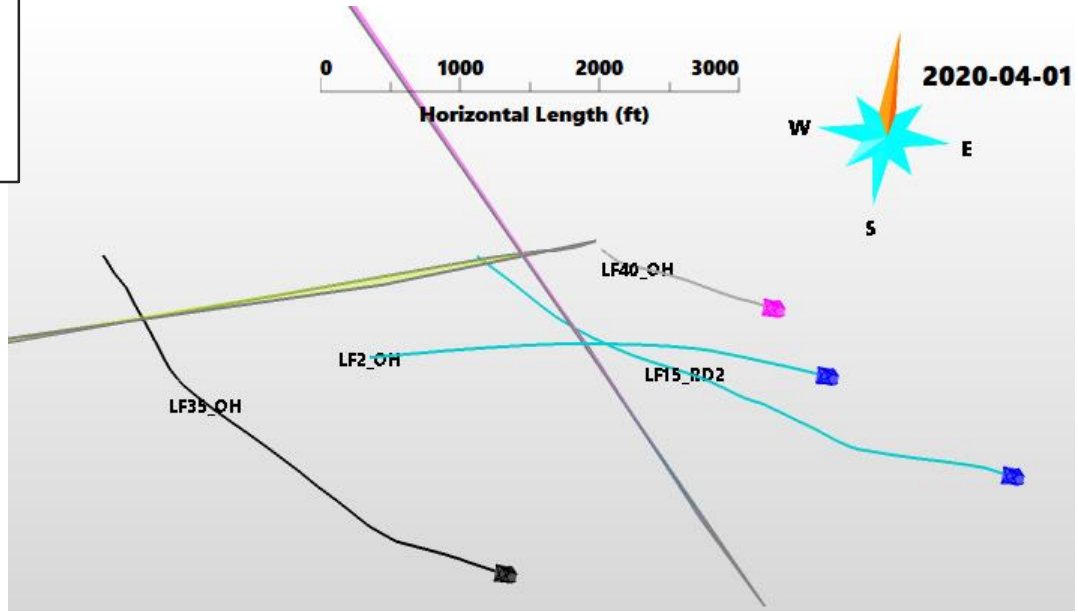
Steam Production Well Targeting Constrained By Significant Steam Entry Alignment Correlation With Water Breakthrough Is Also Very Encouraging …

This analysis/interpretation may also assist in better understanding potential (or existing) water breakthrough* from water injection wells to steam production wells along high permeability open fracture systems.

Steam Production Wells
With Confirmed Water Breakthrough
DX-42: Due To DX-5 Injection (Casing Parted At 5111')
LF-35 OH: With LF-2 injection >/= 350 gpm
LF-40 OH: With LF-15 injection >/= 800 gpm

Steam Production Wells
Shut-In Due To Water Breakthrough
DX-28 ST1: From DX-47 (?)





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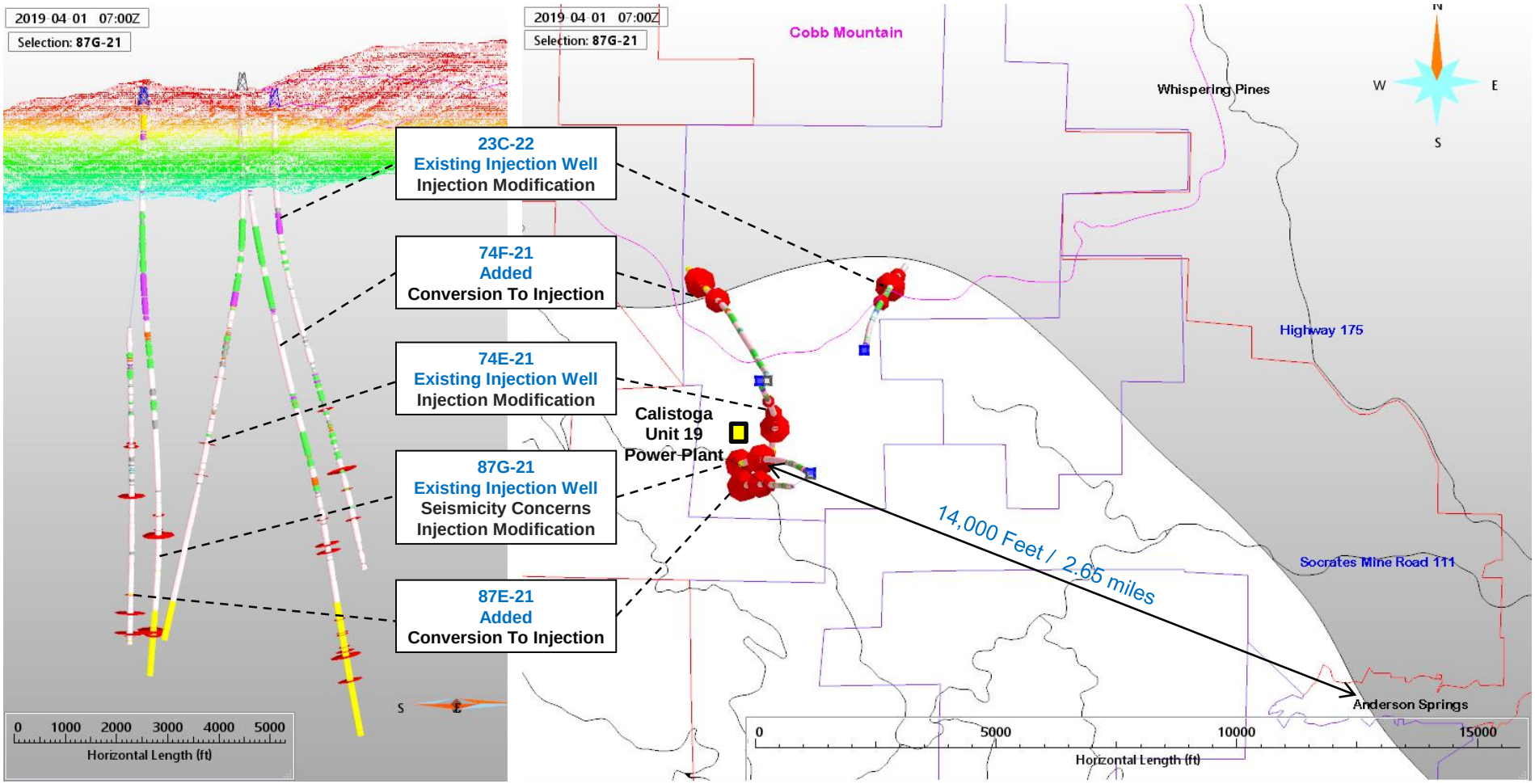
Seismic Monitoring Advisory Committee Meeting

Improved Water Distribution for Seismicity Mitigation
Conversion-To-Injection Drilling Program

Calistoga Power Plant Area

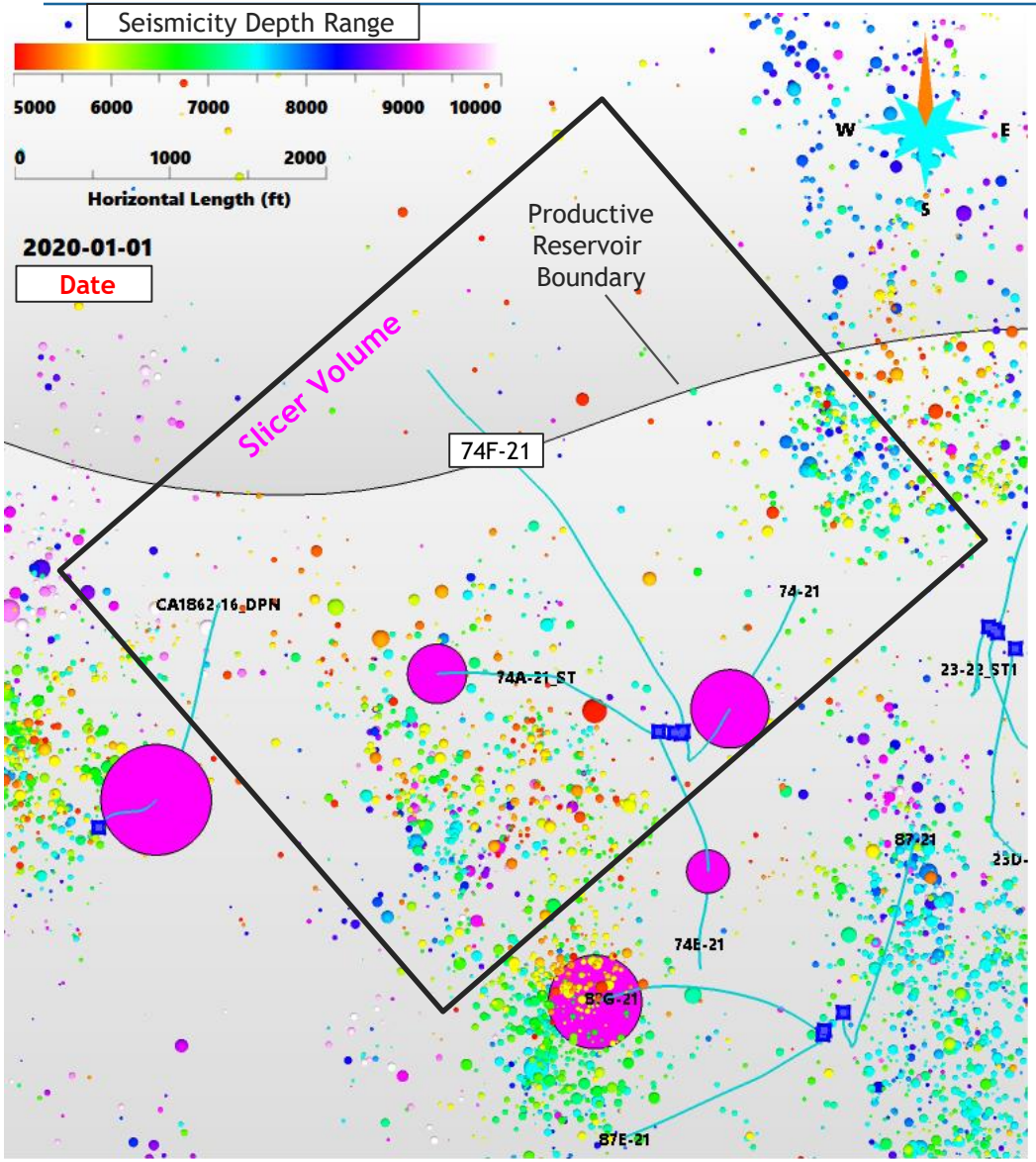
- 74F-21 October 2019 Conversion of Steam Production Well to Injection
- 87E-21 November 2019 Conversion of Steam Production Well to Injection
- 23C-22 Early 2020 Modification to Existing Water Injection
- 74E-21 Early 2020 Modification to Existing Water Injection
- 87G-21 Early 2020 Modification to Existing Water Injection

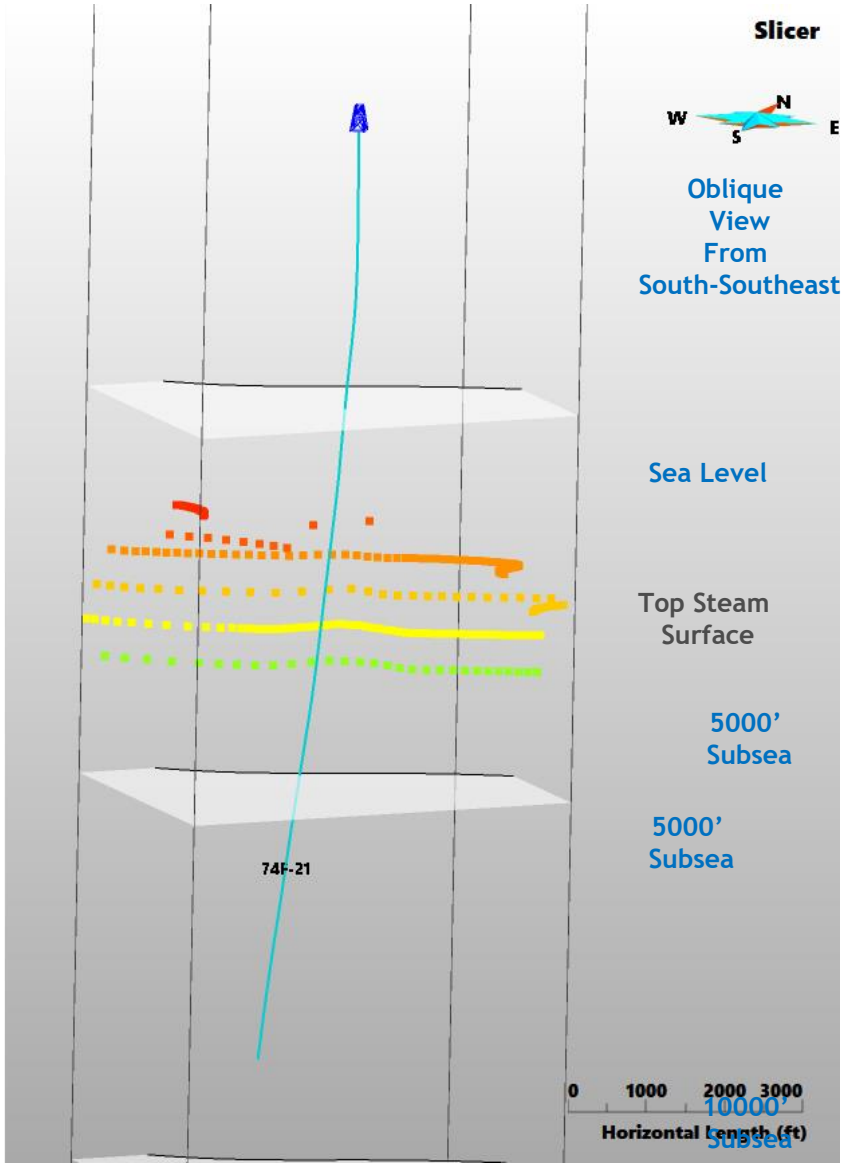


Seismic Monitoring Advisory Committee Meeting

Detailed Analysis of CA74F-21 Water Injection and Seismicity Response

Pre-Injection: Seismicity From 01 January 2005 Through 01 January 2020



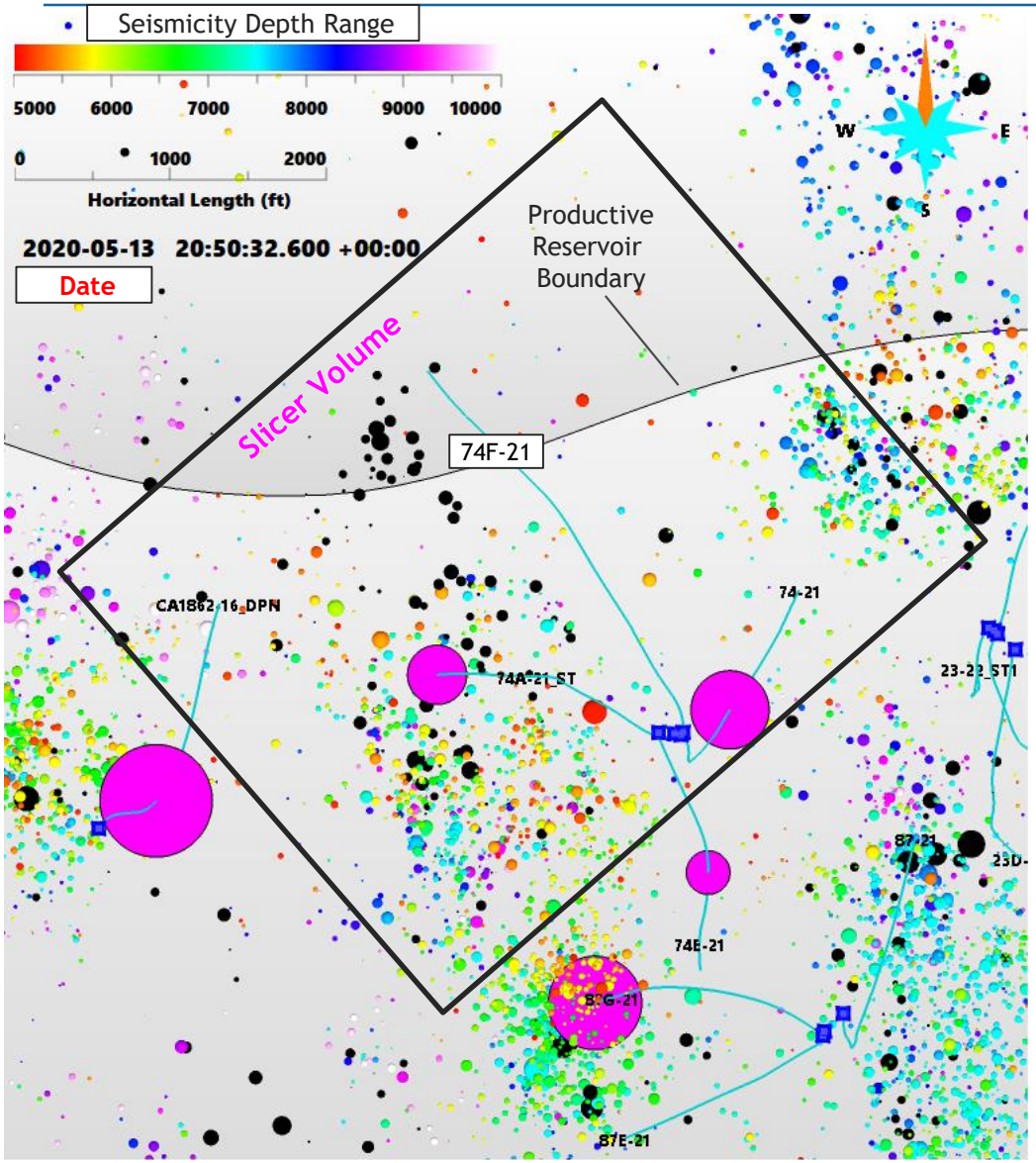


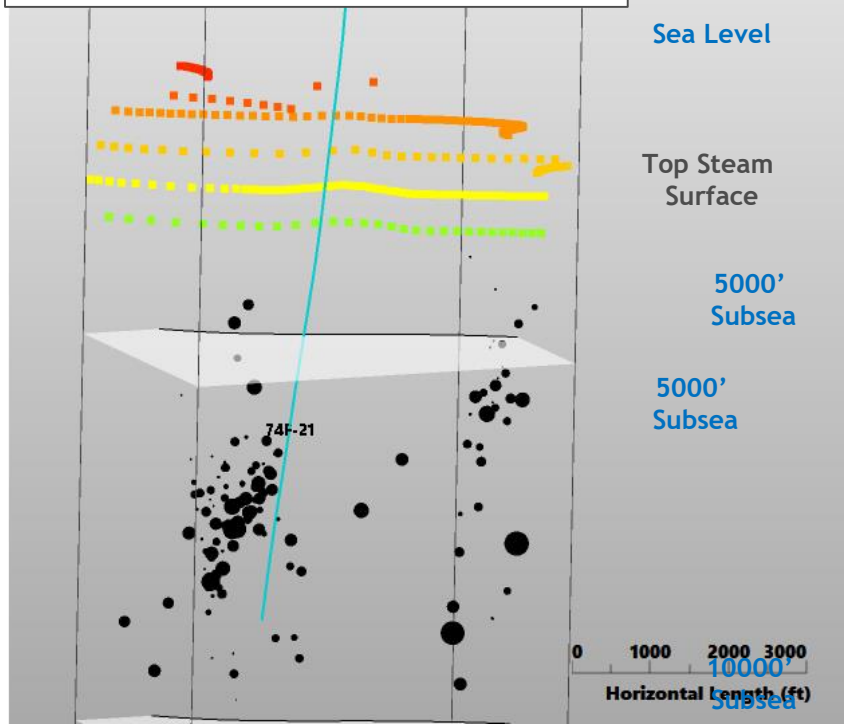
Seismic Monitoring Advisory Committee Meeting

Detailed Analysis of CA74F-21 Water Injection and Seismicity Response During Injection: Additional Seismicity Through 13 May 2020

2020 Seismicity: 2X Black Symbols

74F-21 water injection is creating a relatively diffuse seismic response. However, on close inspection, the recharge area is overlapping with that of 74A-21 and extending further northward (as anticipated). When isolated from the background events, seismicity appears to be "illuminating" a nearly north-south striking and west dipping fracture/fault network.

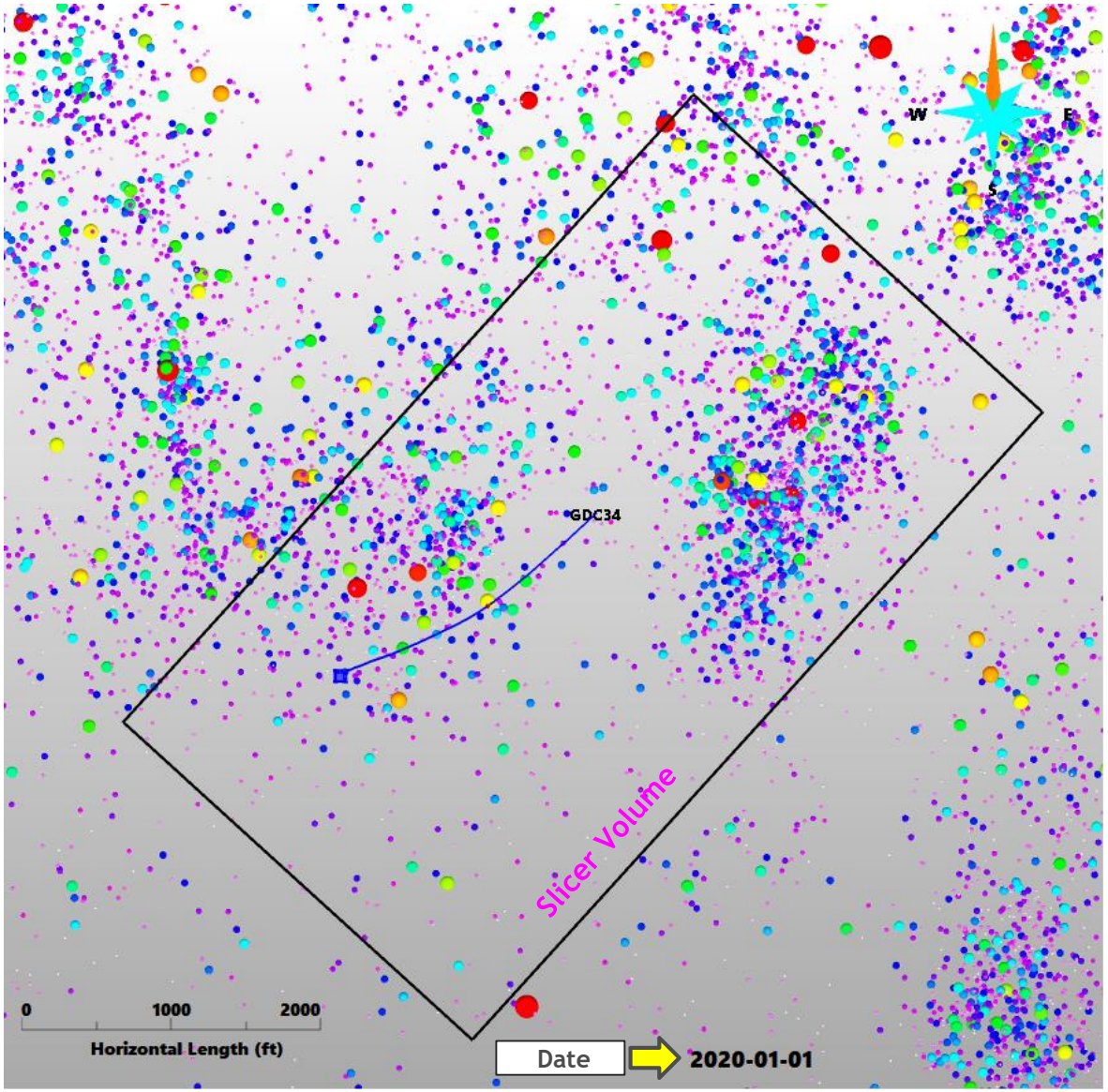


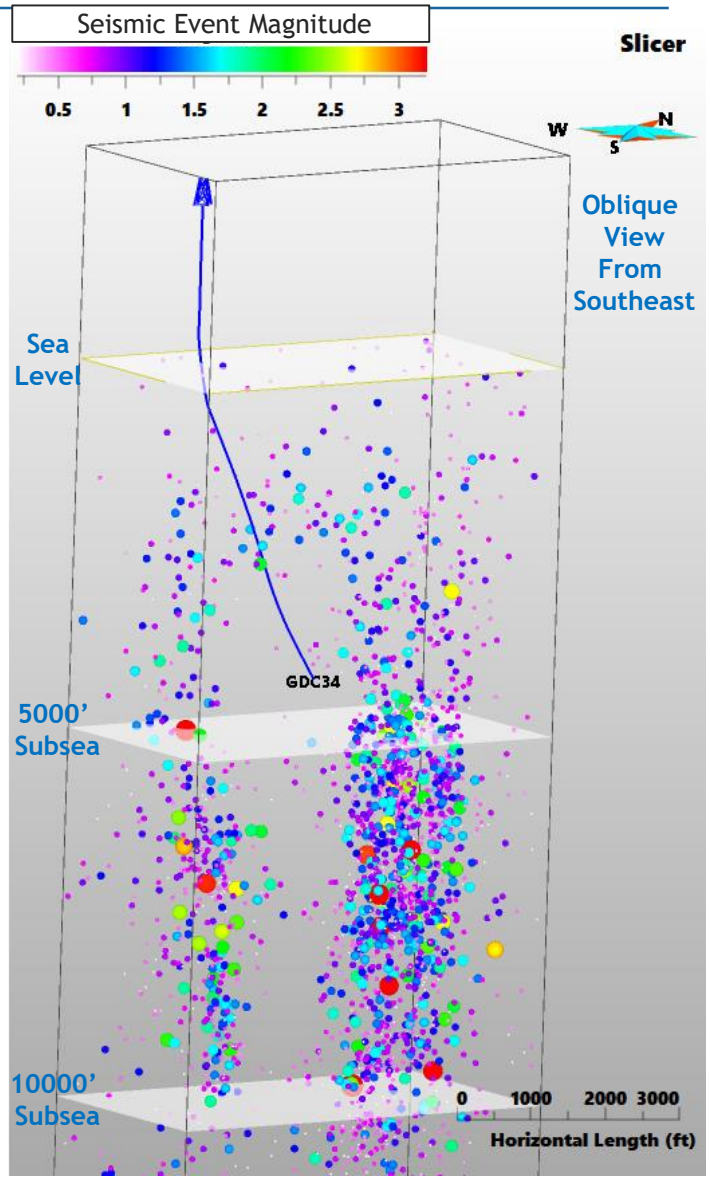


Seismic Monitoring Advisory Committee Meeting

Detailed Analysis of GDC-34 Water Injection and Seismicity Response

Pre-Injection: Seismicity From 01 January 2005 Through 01 January 2020

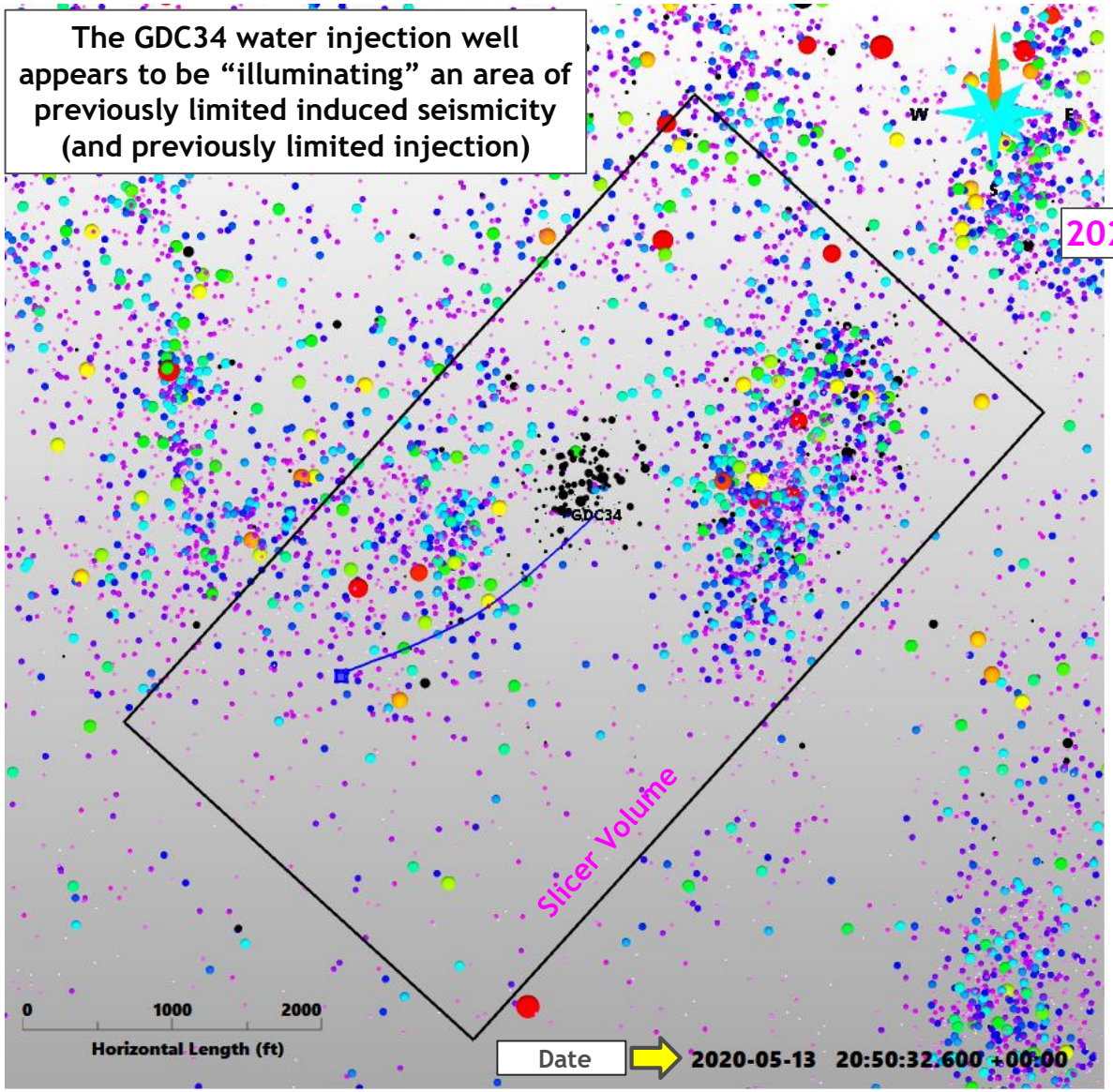


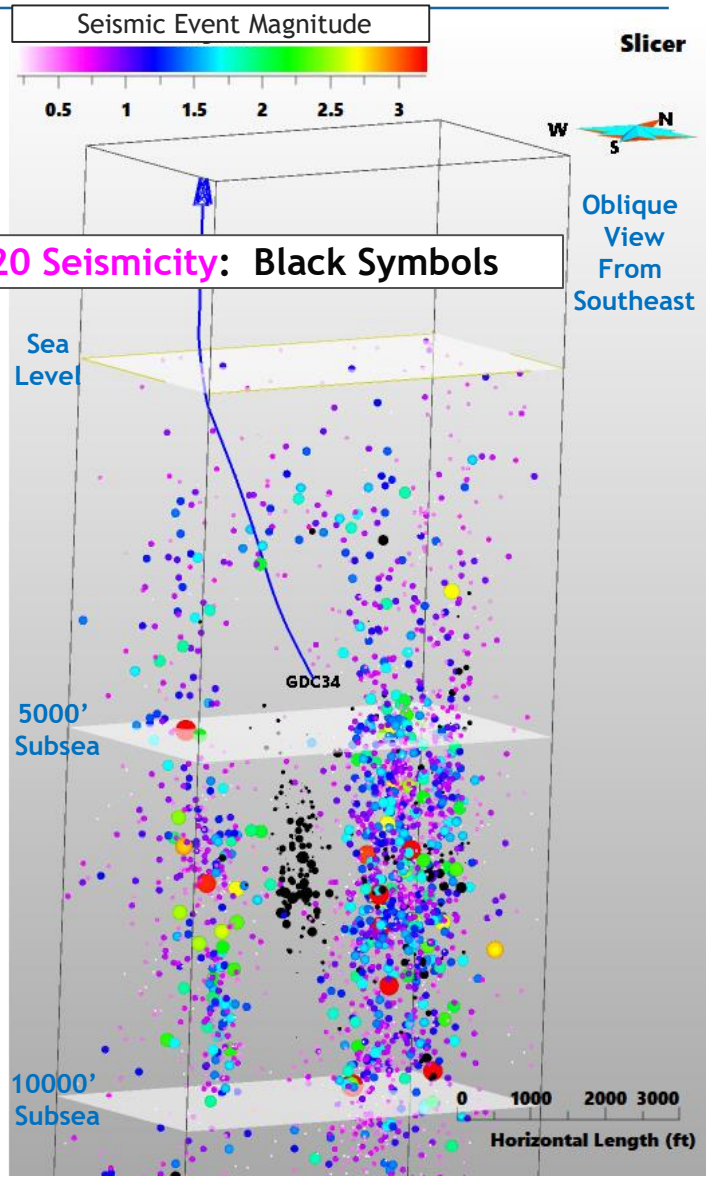


Seismic Monitoring Advisory Committee Meeting

Detailed Analysis of GDC-34 Water Injection and Seismicity Response During Injection: Additional Seismicity Through 13 May 2020

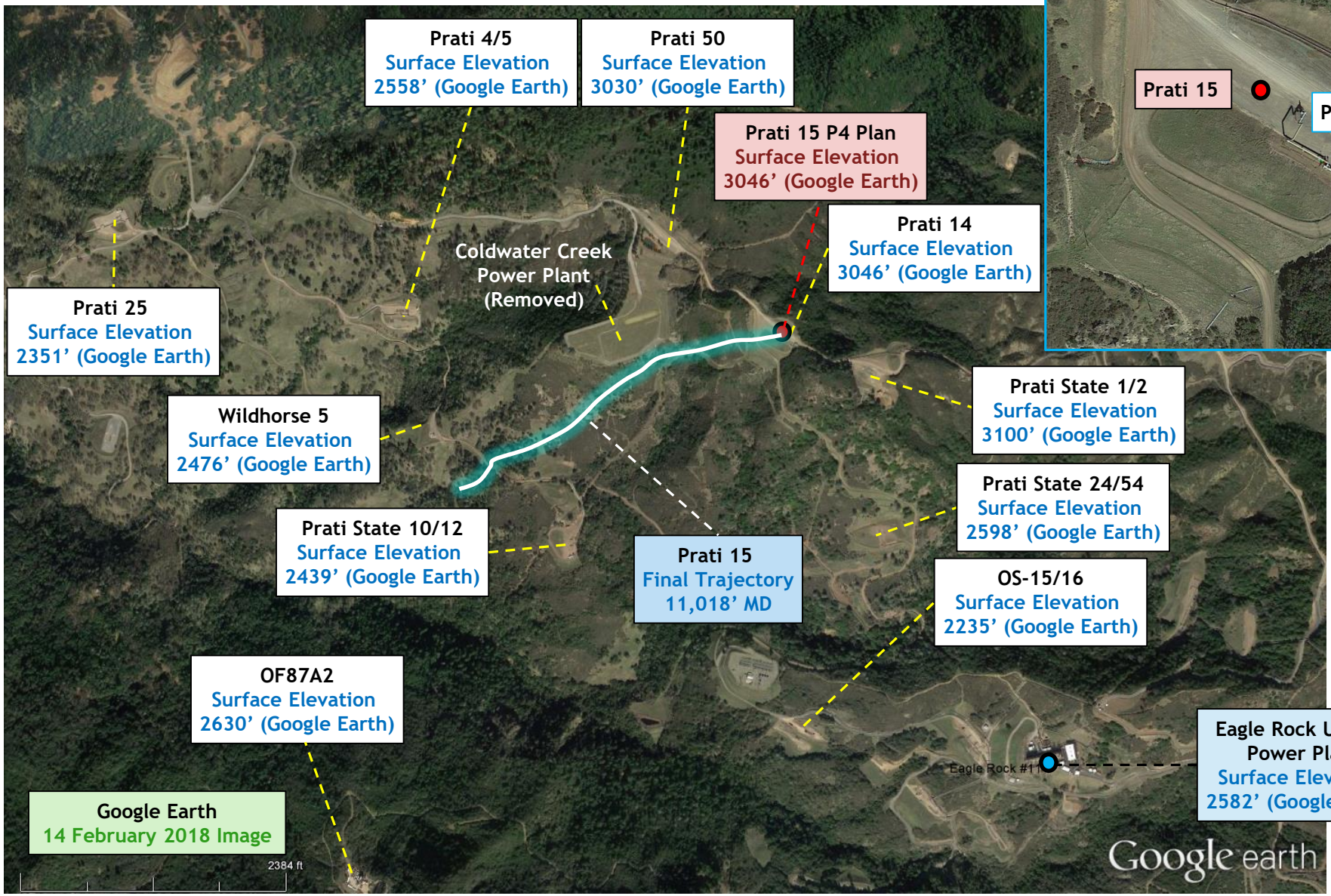
The GDC34 water injection well appears to be "illuminating" an area of previously limited induced seismicity (and previously limited injection)

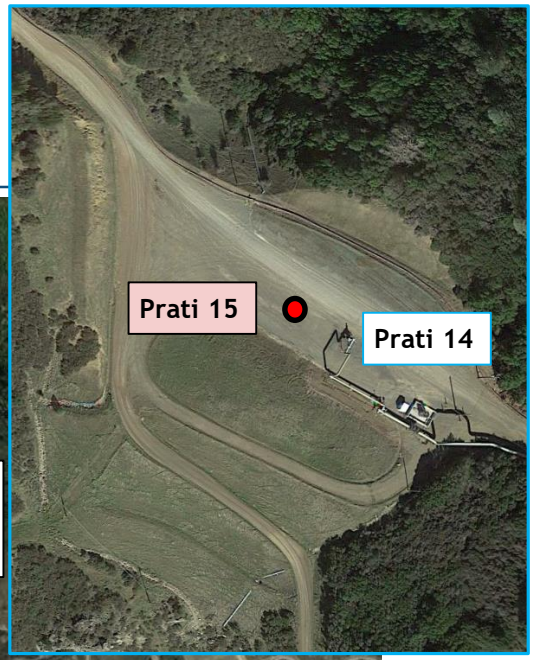




Seismic Monitoring Advisory Committee Meeting

New Prati-15 Water Injection Well Location

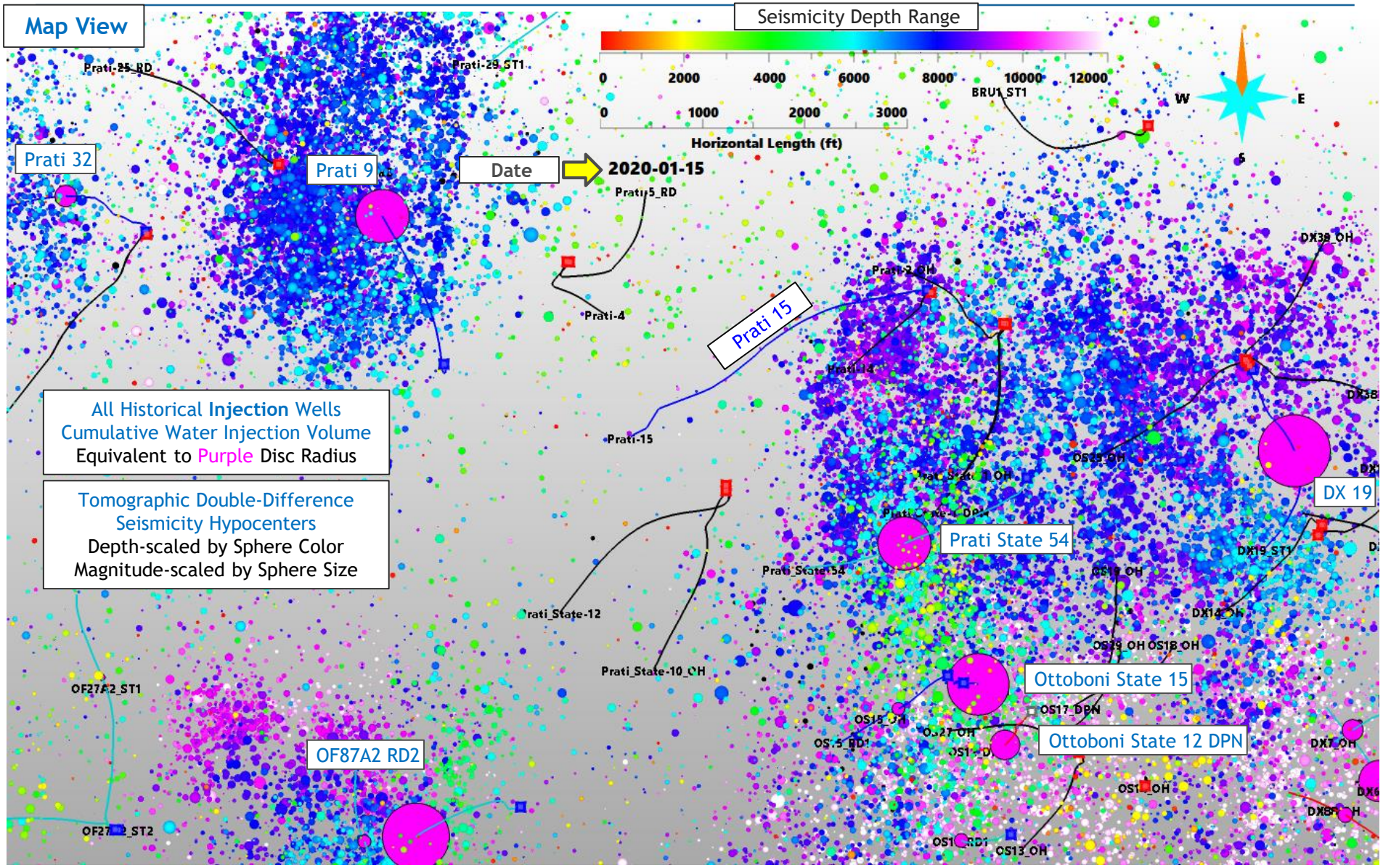




Seismic Monitoring Advisory Committee Meeting

Detailed Analysis of Prati-15 Water Injection and Seismicity Response

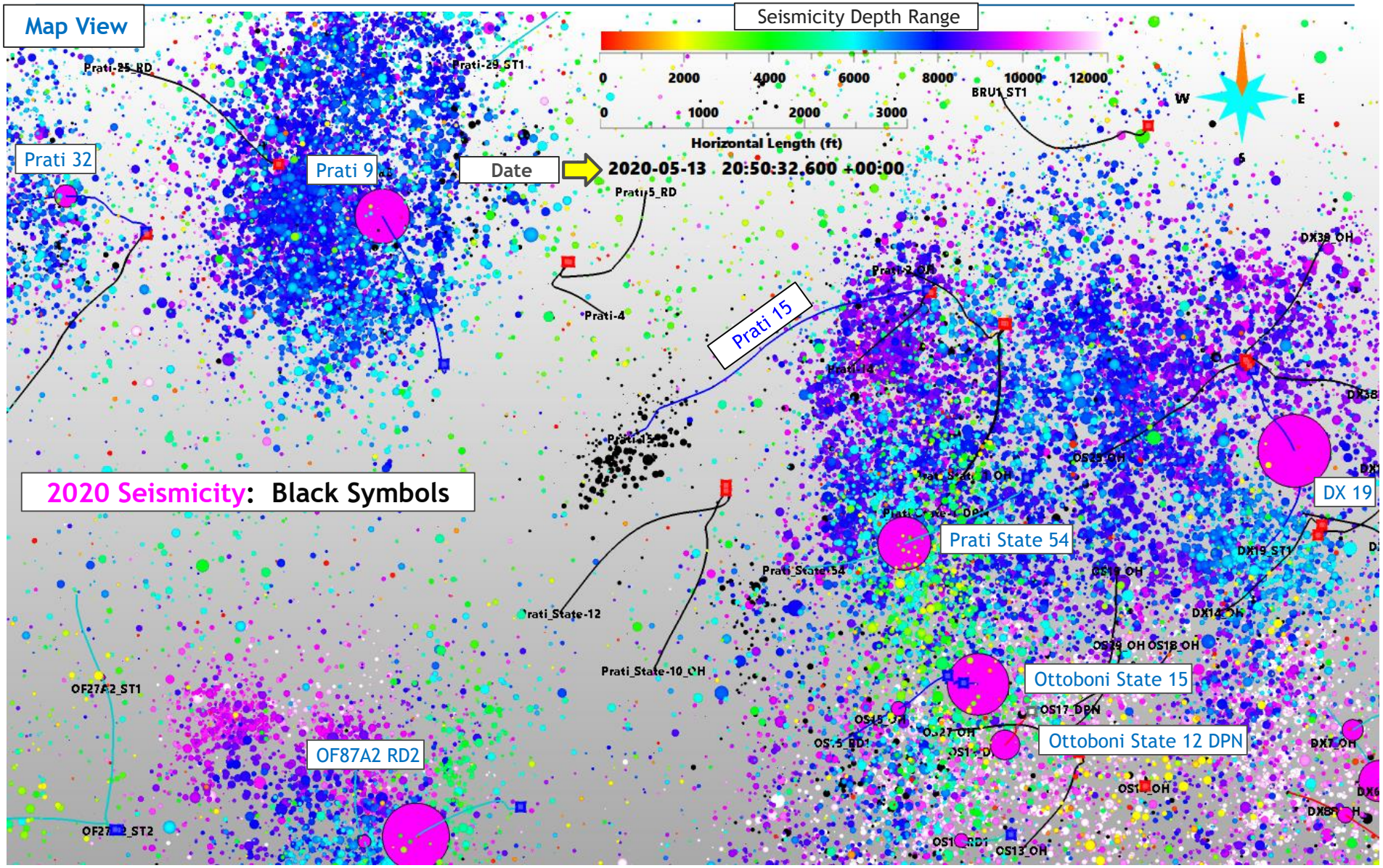
Pre-Injection: Seismicity From 01 January 2005 Through 15 January 2020



Seismic Monitoring Advisory Committee Meeting

Detailed Analysis of Prati-15 Water Injection and Seismicity Response

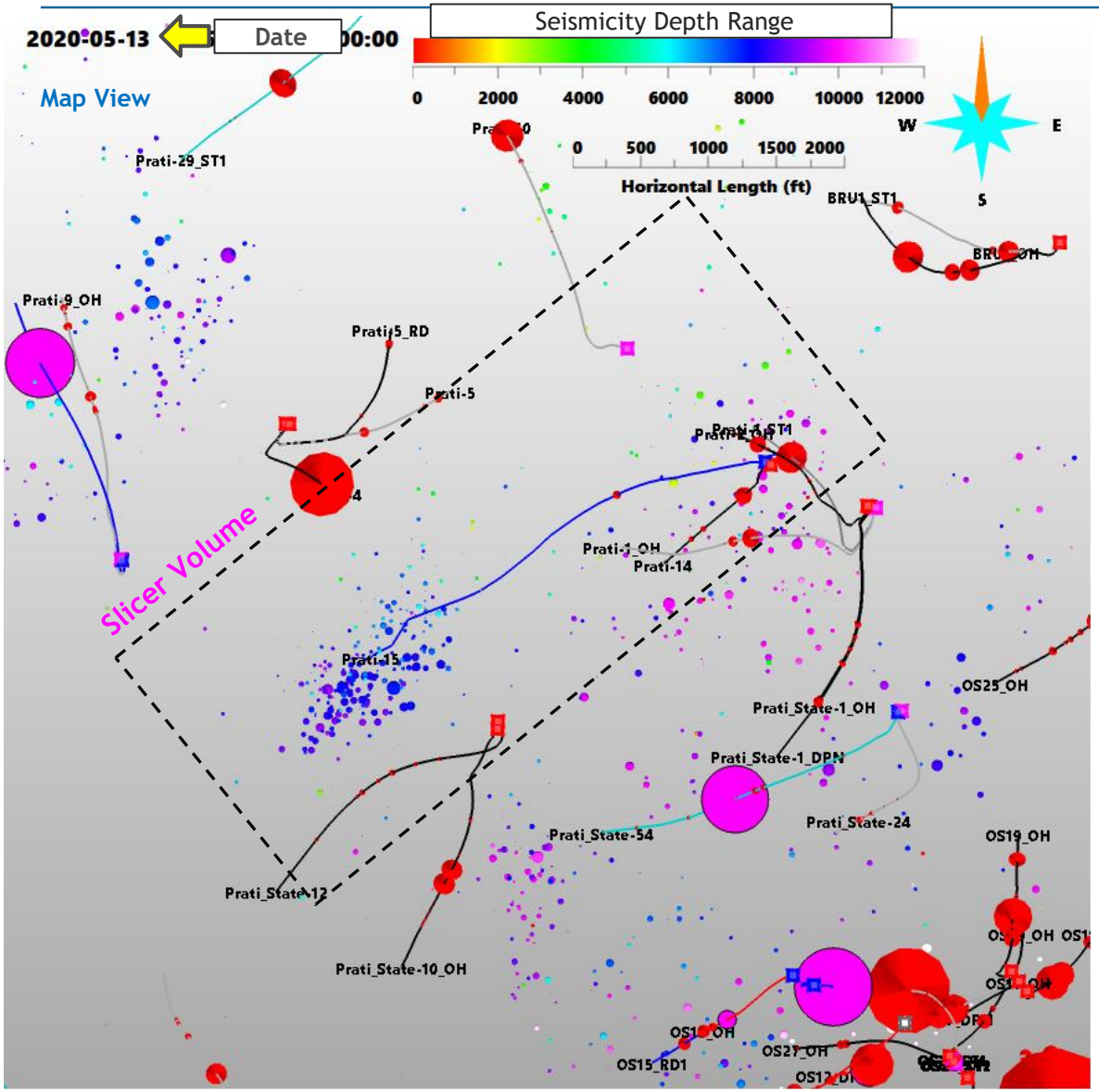
During Injection: Seismicity From 01 January 2005 Through 13 May 2020

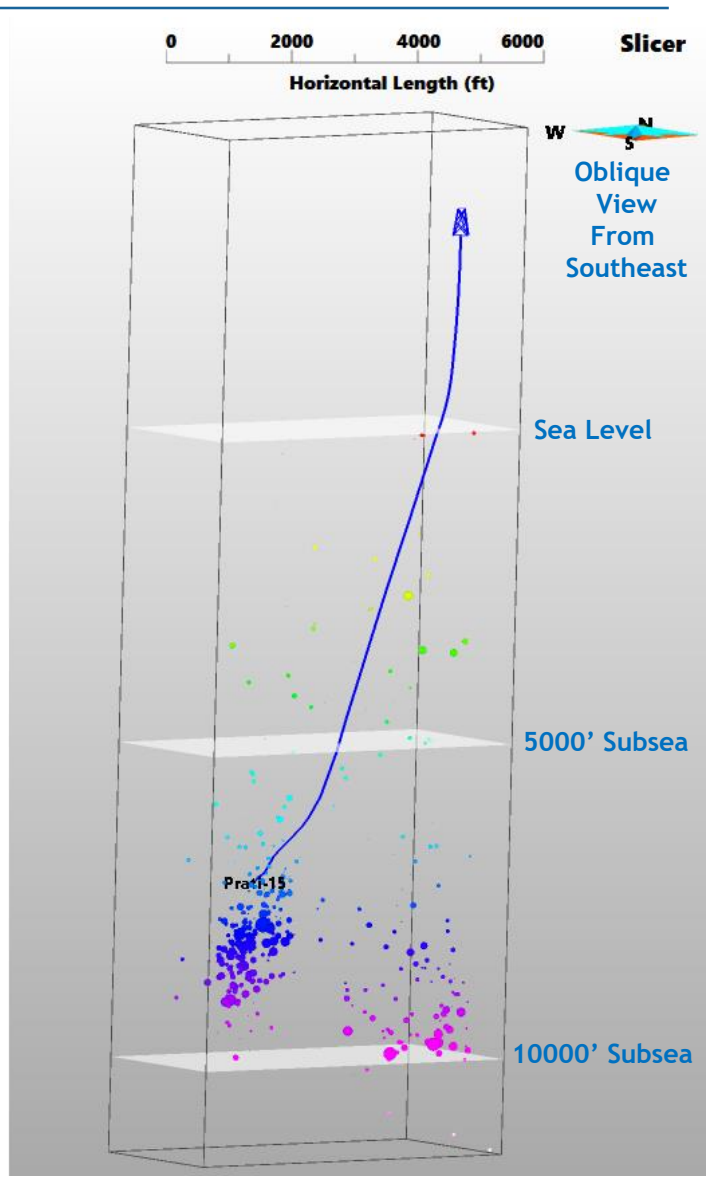


Seismic Monitoring Advisory Committee Meeting

Detailed Analysis of Prati-15 Water Injection and Seismicity Response

Seismicity Animation; Two Week Intervals; 15 January 2020 To 13 May 2020 ONLY

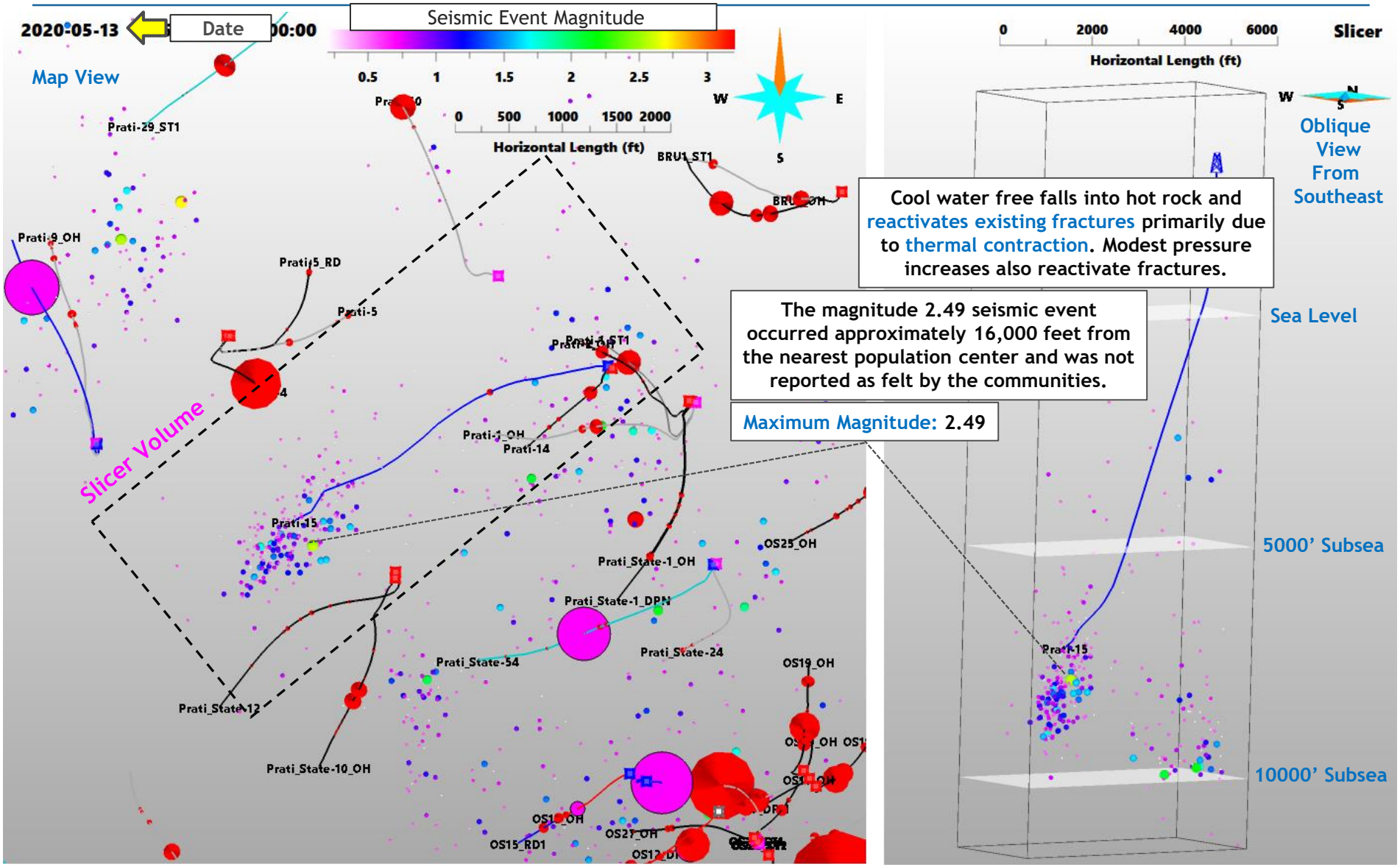




Seismic Monitoring Advisory Committee Meeting

Detailed Analysis of Prati-15 Water Injection and Seismicity Response

Seismicity From 15 January 2020 To 13 May 2020 ONLY

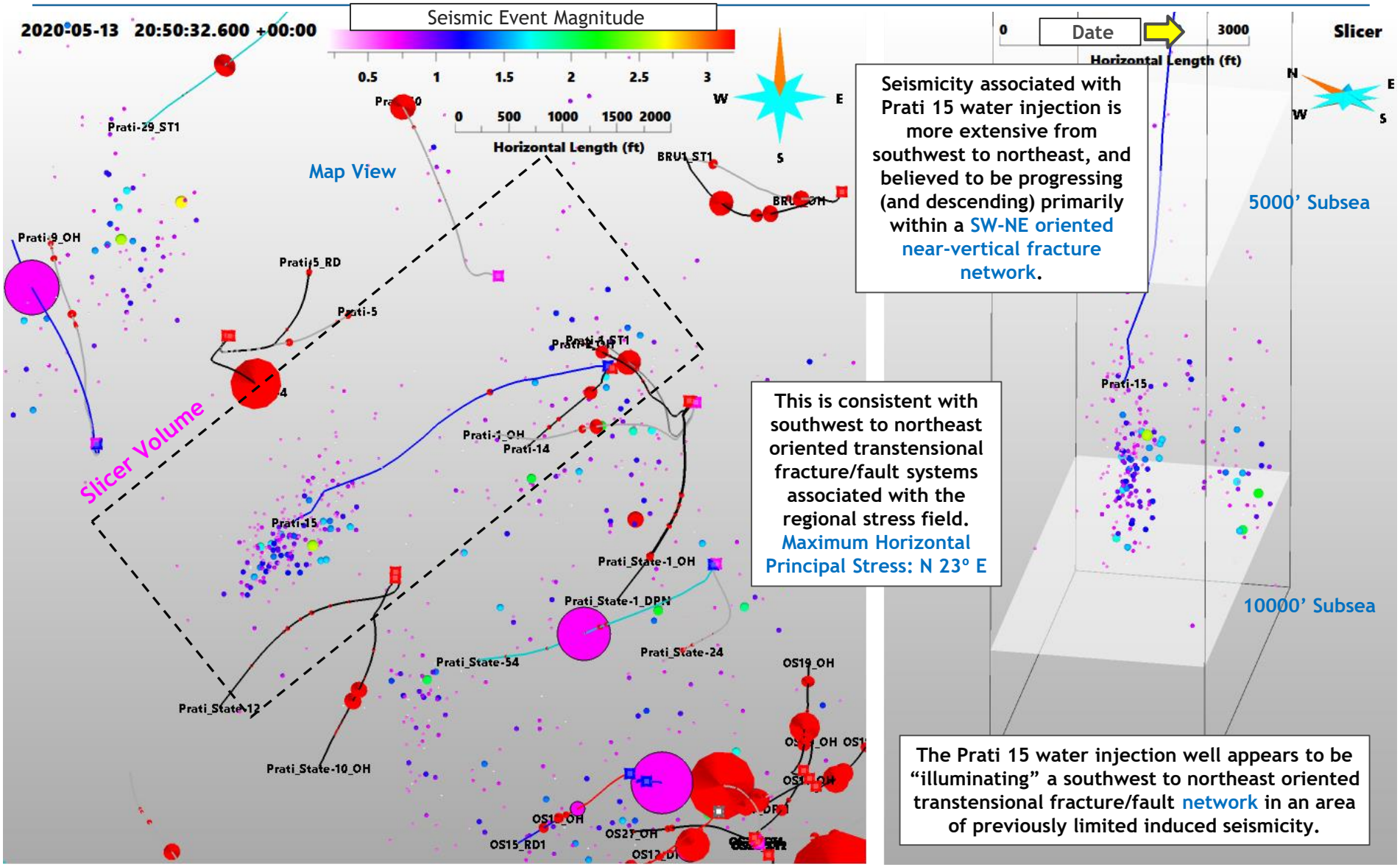


Seismic Monitoring Advisory Committee Meeting

Detailed Analysis of Prati-15 Water Injection and Seismicity Response

Seismicity From 15 January 2020 To 13 May 2020 ONLY

Oblique View
From Southwest



Seismic Monitoring Advisory Committee Meeting

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 * * Additional funding for this effort approved by the California Energy Commission in March 2020 *

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

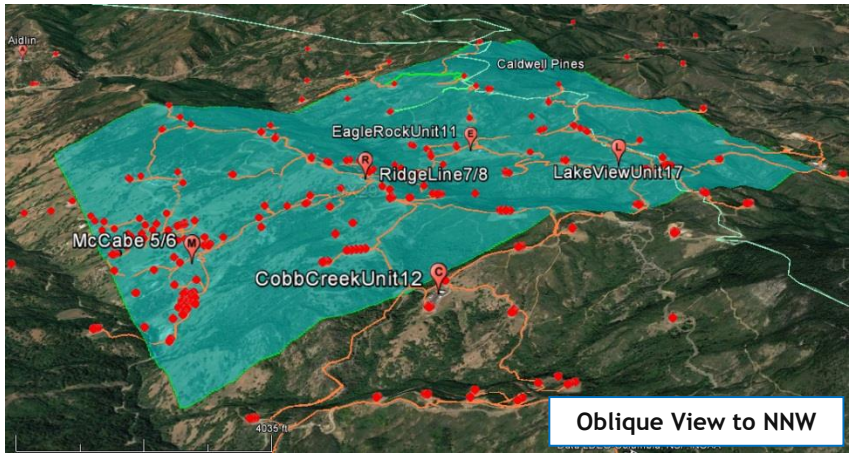
Lawrence Berkeley National Laboratory

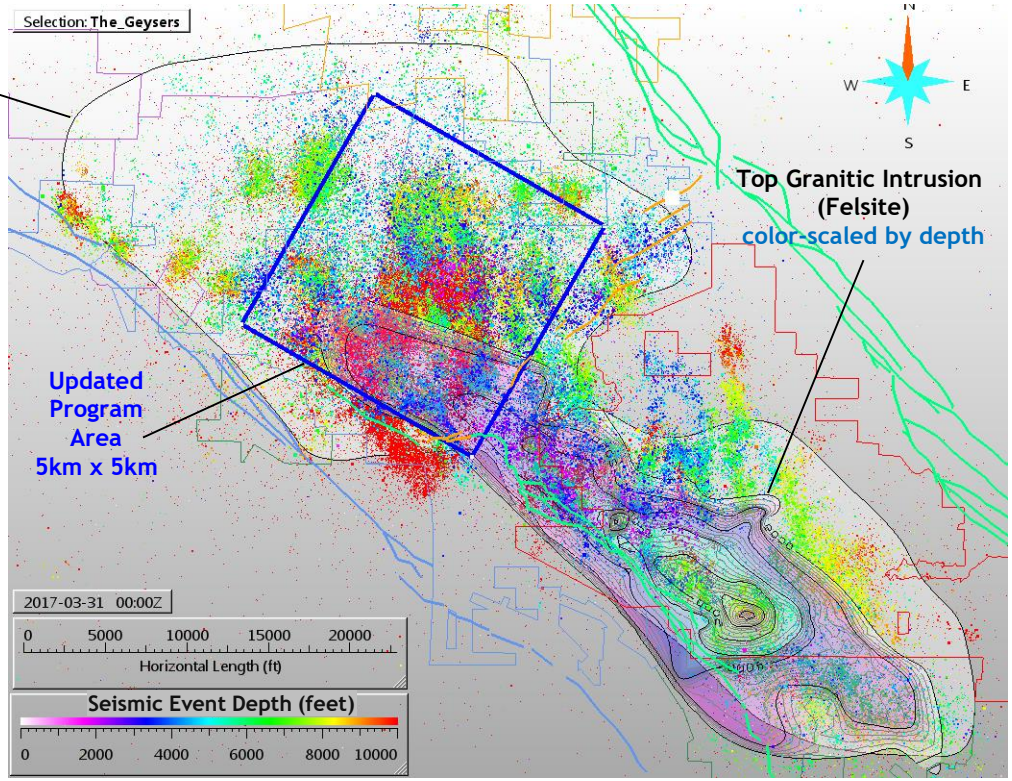
Project Partners

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 EPC-16-021

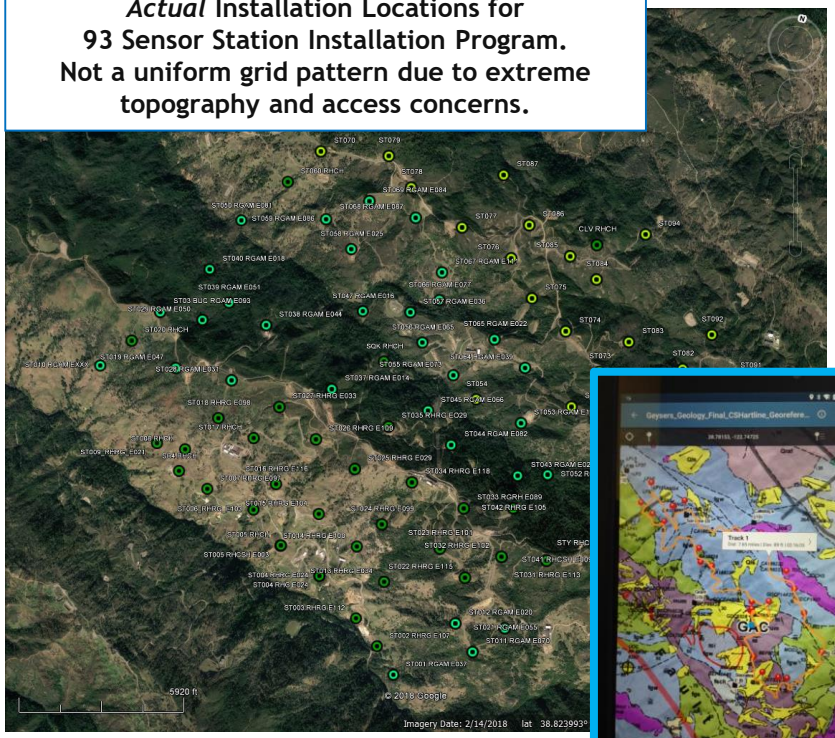
An extensive seismic sensor test program was planned and is being conducted with the project scientists. Additional funding for this effort approved by the CEC in March 2020.

Calpine Corporation has provided:

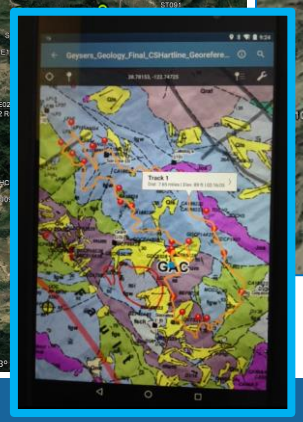
- The field location for this program.
- Technical support with survey design planning.
- On-site assessments including GPS surveying with updated equipment and techniques.
- Assistance to LBNL Contractor Ramsey Haught during 17 seismic sensor test installations.
- Coordination and updating of GPS surveys/maps data recovery at 2-3 month intervals.

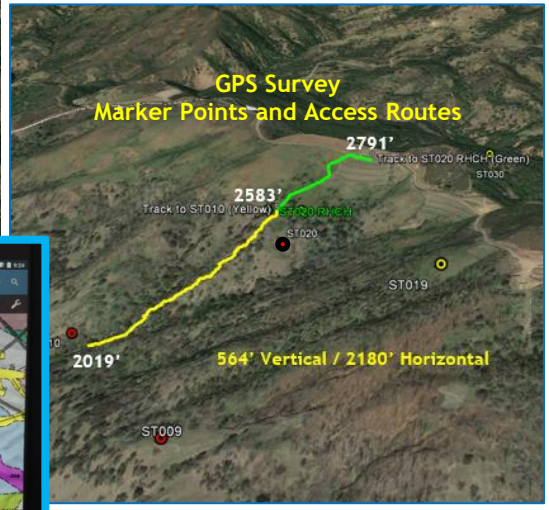
Generation Three Sensor Station

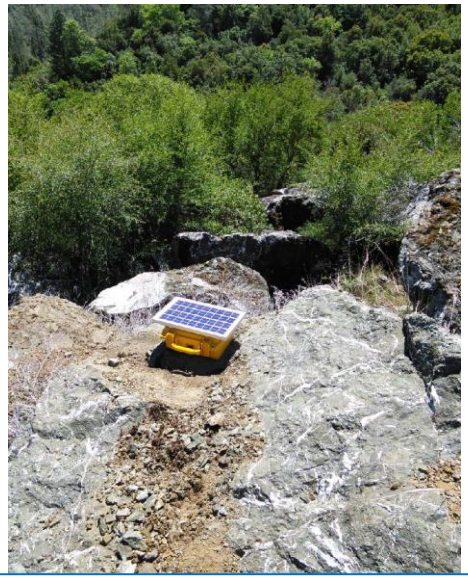
Green Labeled Points
Actual Installation Locations for
93 Sensor Station Installation Program.
Not a uniform grid pattern due to extreme topography and access concerns.



Surveying of 23 Test Sensor Station Locations and Access Routes Completed By Calpine With Samsung Nexus 7 Tablet and Paired Garmin GLO Device.







Sensor Installation on Rock Outcrop