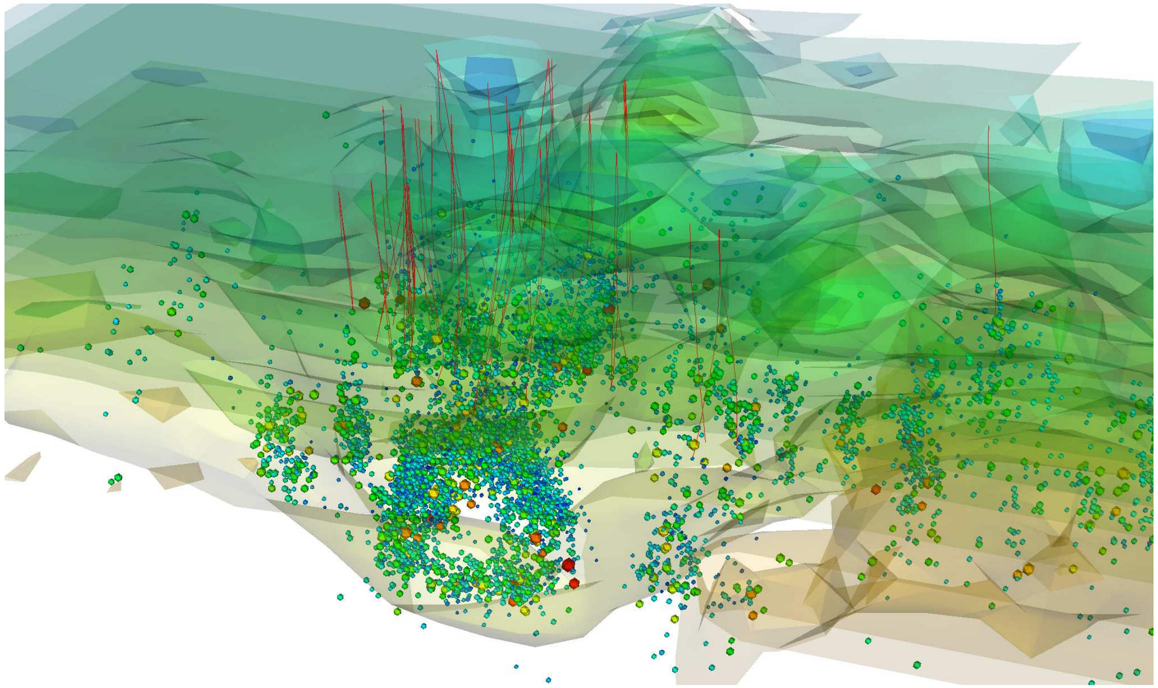
Description and Application of the USDOE Induced Seismicity Protocol/Best Practices: Experiences and Lessons Learned at The Geysers Geothermal Field, California



APEC WORKSHOP ON GEOTHERMAL ENERGY DEVELOPMENT

June 25 - 26, 2013

E.L. Majer DOE/LBNL

Acknowledgements

US DOE Geothermal Technology Program

Craig Hartline, Calpine Corporation,

Importance of Understanding Induced Seismicity

- Technical
  - One of few means to understand volumetric permeability enhancement/fluid paths
  - Proper uses could optimize reservoir performance
- Policy/Regulatory
  - Potential to side track important energy supply
  - Technology must be put on a solid scientific basis to get public acceptance
  - Accurate risk assessment must be done to advance energy projects

Induced Seismicity: Recent Issues

- High-profile press coverage and congressional/regulatory inquiries have focused attention on induced seismicity related to energy projects in the U.S. and Europe
  - The Geysers, CA; Basel, Switzerland; Soultz, France; Landau, Germany
  - Oil and gas: Texas, Ohio, Arkansas, Oklahoma, UK
  - CO_2 sequestration sites (various)
- However, industry has dealt with induced seismicity issues for almost 100 years (mining, oil and gas, waste injections, reservoir impoundment, etc.)
- How does one assess hazard risk and economic risk
  - Investors want to know
  - Regulators want to know
  - Seismicity related to injection cannot be assessed the same as natural seismicity (limited prior seismicity)
  - Scale and distance of influence
- Seismicity can also be useful as a resource management tool
  - Geothermal, Oil and Gas, CO_2 Sequestration

Accurate and Consistent Assessment of Risk is Essential for All Injection Technologies

- What is the largest earthquake expected?
- Will small earthquakes lead to bigger ones?
- Can induced seismicity cause bigger earthquakes on distant faults?
- Even small felt (micro)earthquakes are annoying.
- Can induced seismicity be controlled?
- What controls are (will be) in place to mitigate future induced seismicity?
- What is the plan if a large earthquake occurs?
- Long term response versus short term response

Earthquake Risk

- Risk in this context can be thought of as:

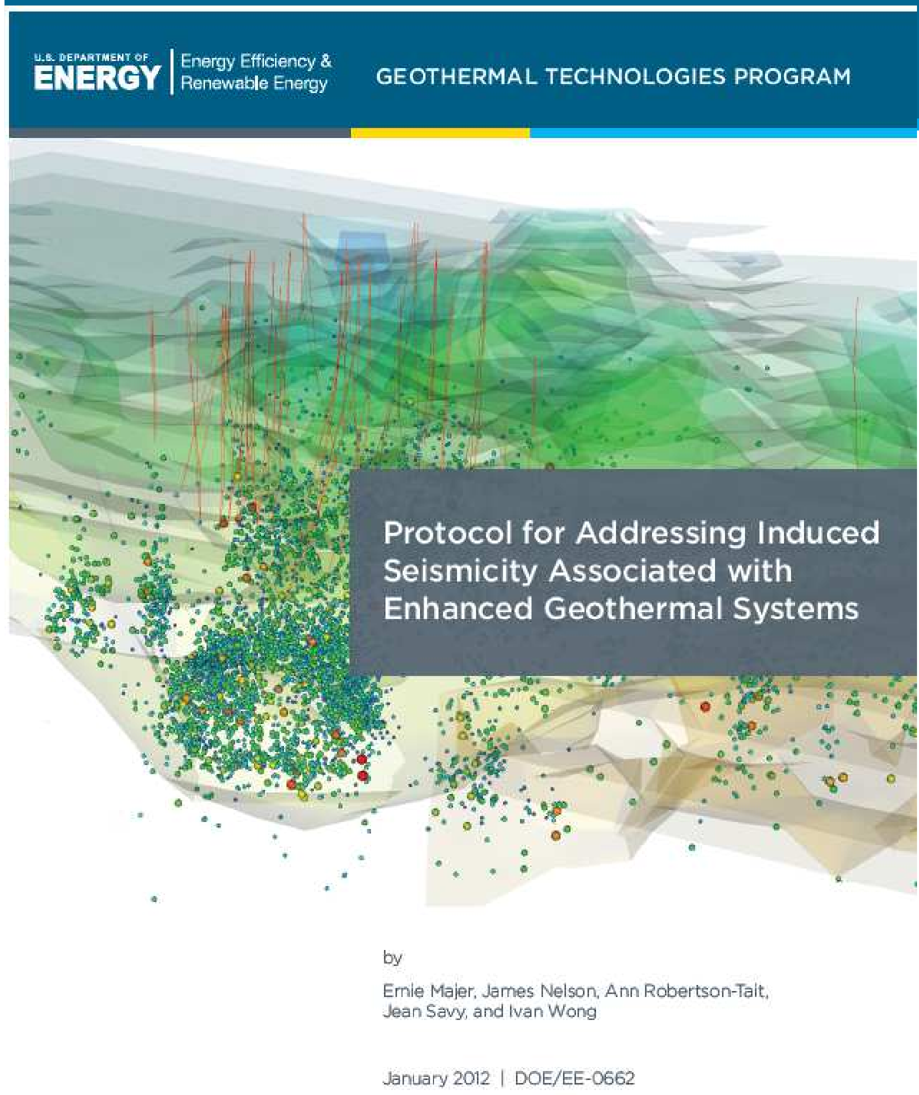
$$R = AF(\boldsymbol{a} \mid eq)*(Pr(f \mid \boldsymbol{a})*C(\$;LL \mid f)$$

Where R="risk", AF= annual frequency of ground motion ***a***, given occurrence of an earthquake(s), Pr(f | ***a***) =probability of failure of something of interest given ground motion ***a***, and C=consequences (dollars, or any metric of interest).

AF developed using Probabilistic Seismic Hazard Analysis (PSHA)

Therefore:

- Three main issues to address to advance EGS Applications
  - How does one assess risk
  - How does one minimize risk
  - How does one effectively utilize induced seismicity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GEOTHERMAL TECHNOLOGIES PROGRAM

Protocol for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems

by

Ernie Majer, James Nelson, Ann Robertson-Tait, Jean Savy, and Ivan Wong

January 2012 | DOE/EE-0662

US NRC Recommends that Protocol could be used for all injection related Induced seismicity

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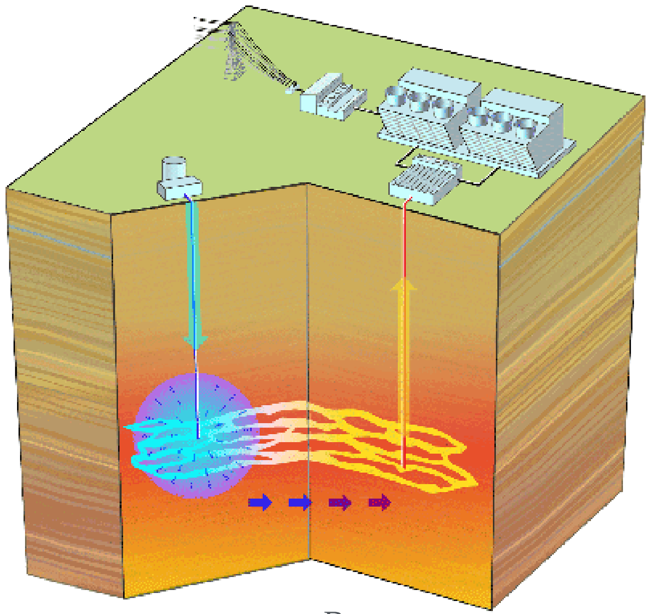
Draft

Best Practices for Addressing Induced Seismicity Associated With Enhanced Geothermal Systems (EGS)



By

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15 May 2013

The Geysers, CA Geothermal Field

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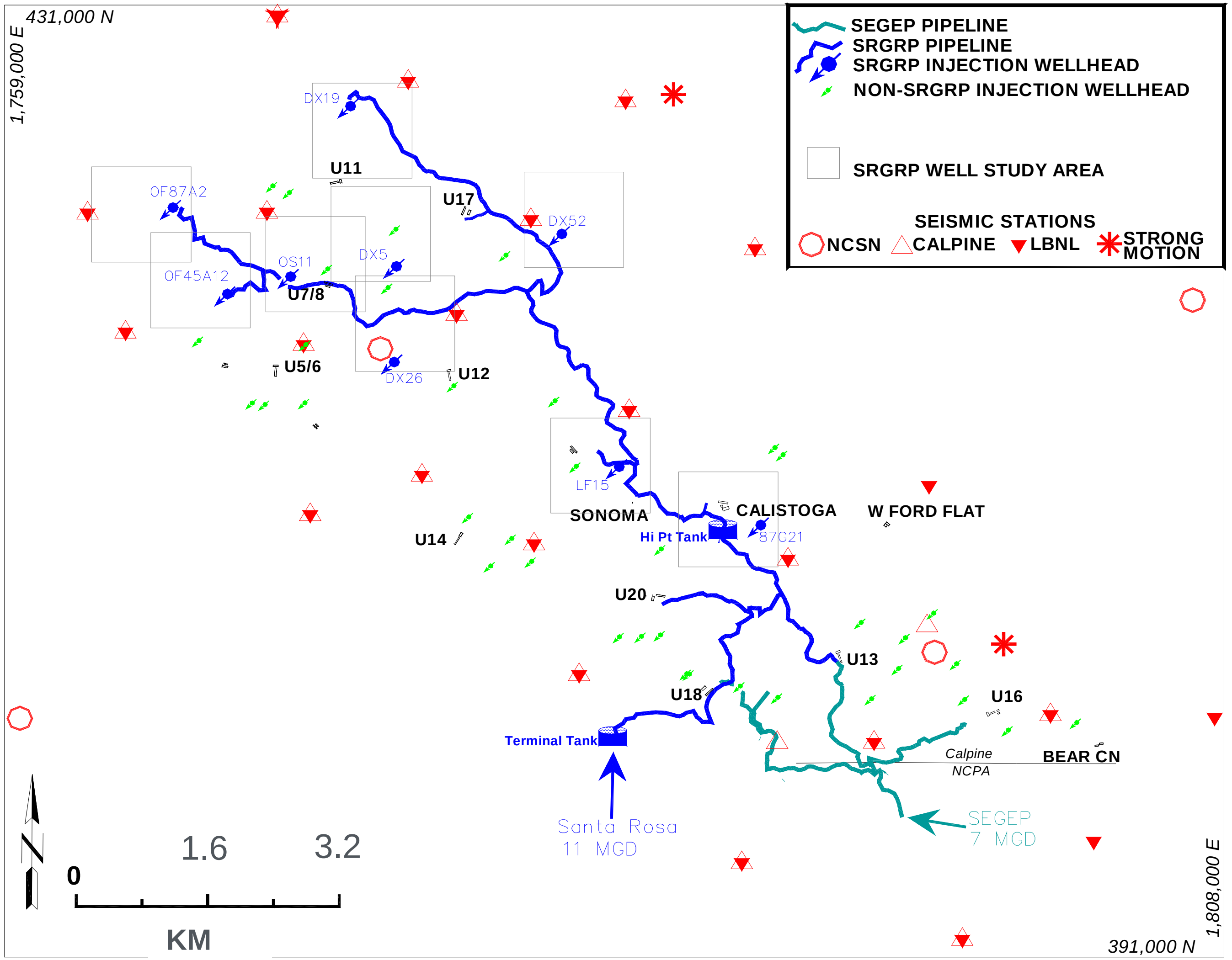

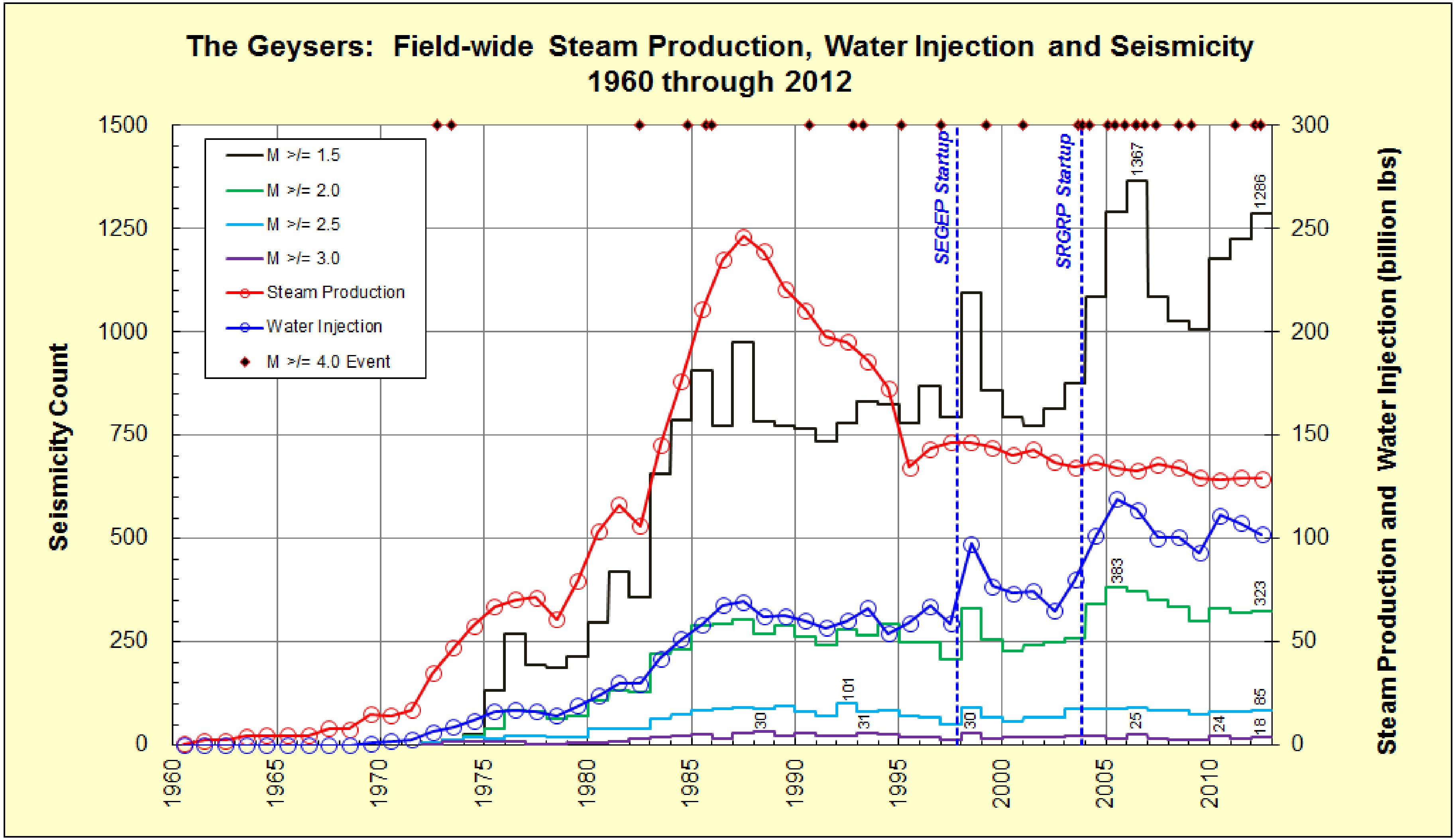
The Geysers: Field-wide Steam Production, Water Injection and Seismicity
1960 through 2012
Seismicity Count
Steam Production and Water Injection (billion lbs)
M >/= 1.5
M >/= 2.0
M >/= 2.5
M >/= 3.0
Steam Production
Water Injection
M >/= 4.0 Event
SEGEP Startup
SRGRP Startup
1367
1286
383
323
101
30
31
30
25
24
18
85
1500
1250
1000
750
500
250
0
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200
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1960
1965
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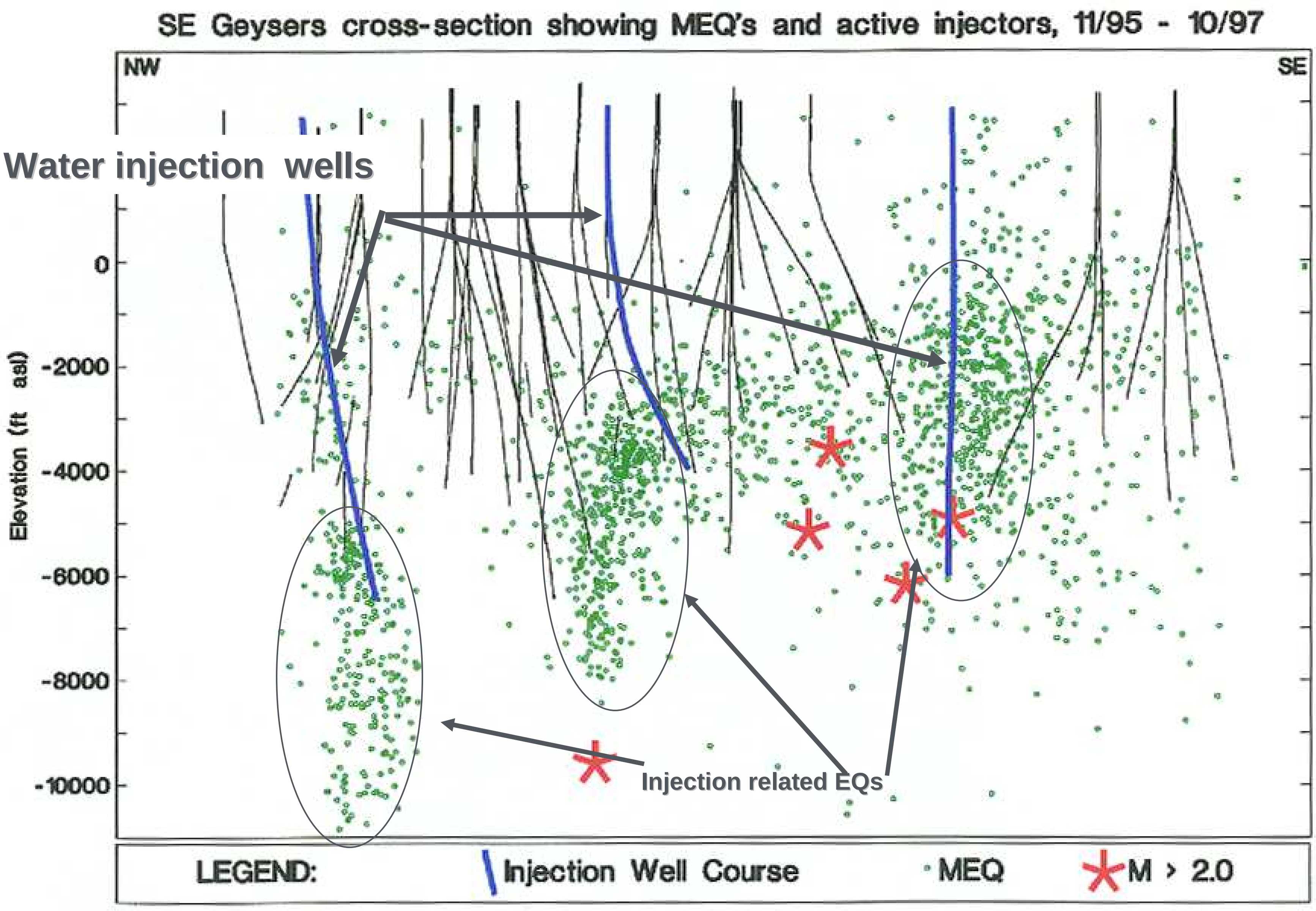
2010

10



SE Geysers cross-section showing MEQ's and active injectors, 11/95 - 10/97
NW
SE
Water injection wells
Elevation (ft asl)
0
-2000
-4000
-6000
-8000
-10000
Injection related EQs
LEGEND:
Injection Well Course
MEQ
M > 2.0

(Stark, 1999)

Protocol/BP: General Approach

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- Not a regulatory document but to be used as a general guideline
  - Operators still required to meet all local, state, and/or federal regulations
- Recognize that "one size does not fit all"
  - Different EGS projects will have different needs and requirements
- Written for all stakeholders
  - Policy makers, regulators, public, developers
- Living document
  - Supplement IEA Protocol and intended to be updated as knowledge and experience gained
- Base recommendations on existing and accepted engineering standards
  - Mining, construction, etc.
- Also suggests when it does not apply
  - Shallow heat pump or shallow injections for water recharge (few hundred meters), etc.

The 7 Main Steps

1) Perform a preliminary screening evaluation
2) Implement an outreach and communication program
3) Identify criteria for ground vibration and noise
4) Seismic monitoring
5) Quantify the hazard from natural and induced seismic events
6) Characterize the risk from induced seismic events
7) Develop risk-based mitigation plans

Protocol/BP Summary

- New protocol developed to update and include latest knowledge and issues associated with EGS IS.
- Similar steps as current IEA, but more detailed
  - 27 pages versus 9
  - Appendix with EGS concepts
  - Best practices in Draft; soon to be added
- Guidelines not regulations
- Risk based
- Meant for all stakeholders and a living document

Examples of Beneficial Uses of Seismicity

- LOCATIONS
  - Areas of stress release
  - Potential fault planes/fluid paths
  - Possible extent of fluids
- Magnitudes
  - Fault sizes (estimating reservoir size and input for mitigation strategies)
  - Distribution of energy release
- Spectral studies
  - Stress drop
  - Source mechanisms
  - Fracture type (pure shear versus volume change)
- Occurrence rates
  - B-values
    - Fracture size distribution
- Imaging
  - Sources of energy to map reservoir properties

Calpine NW Geysers EGS Demonstration
Seismicity Analysis: 09/2011 to 09/2012

LBNL database events with ErH (horizontal error) and ErZ (vertical error) less than 1 km

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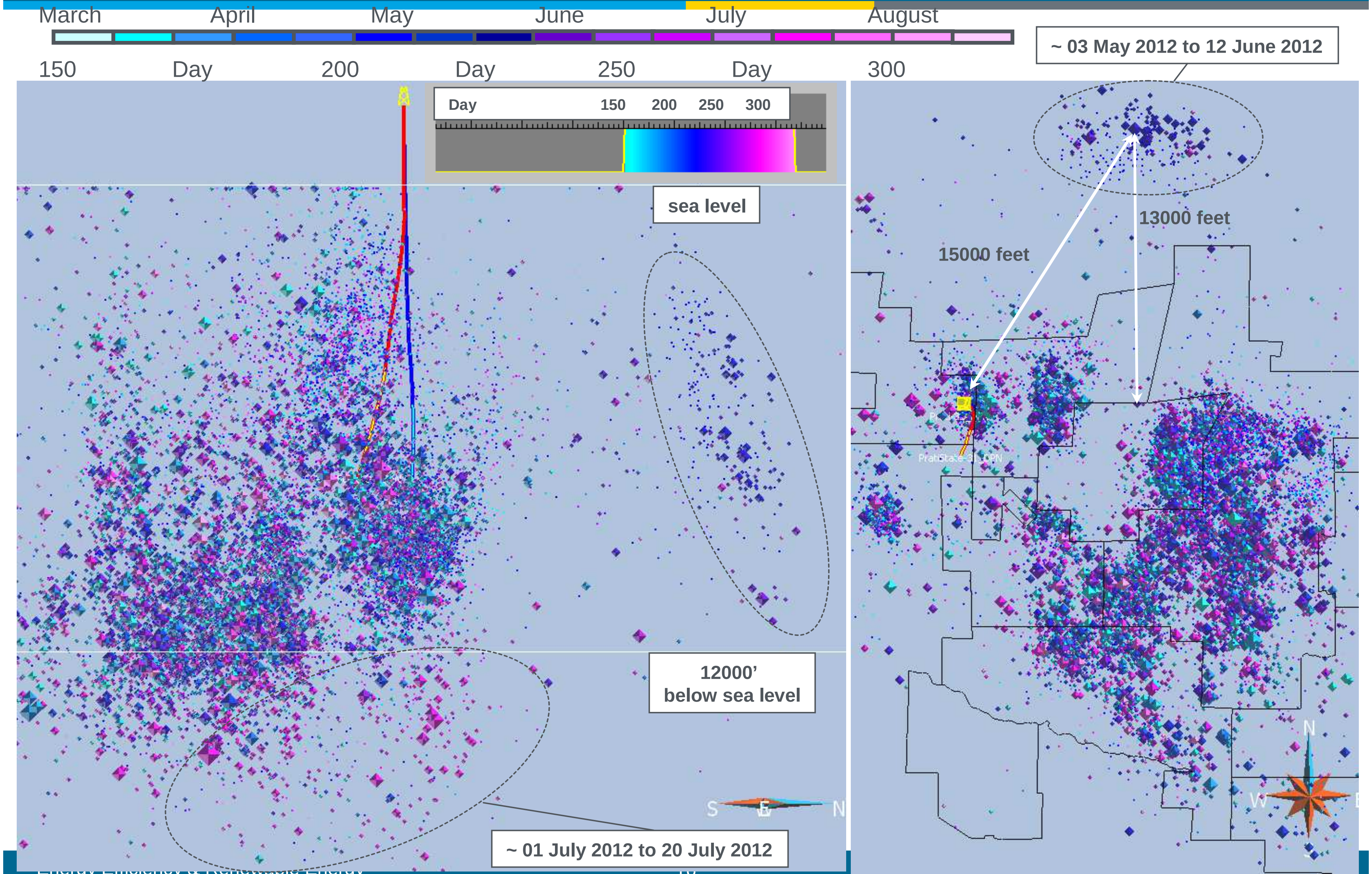

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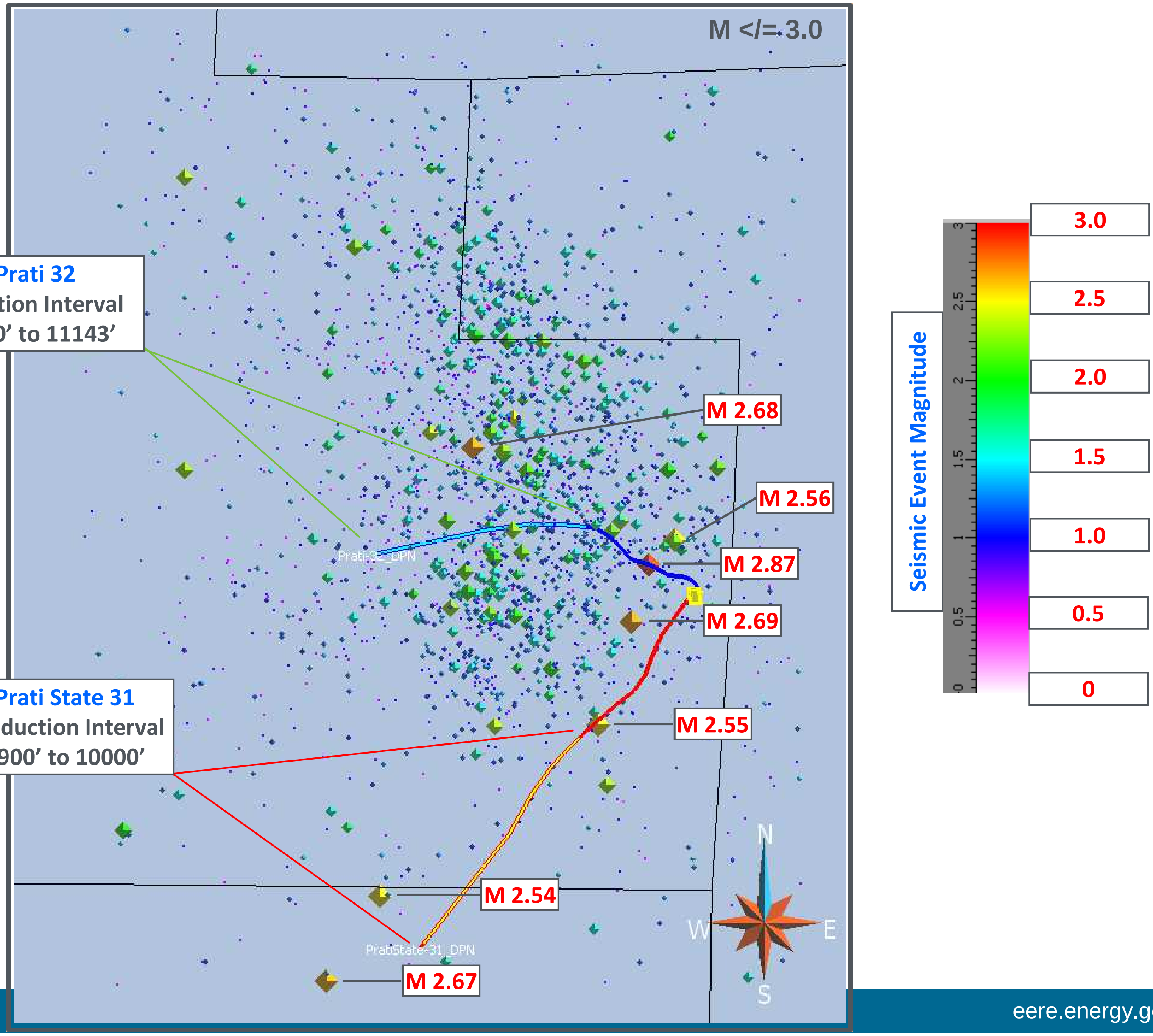

Magnitude >/= 2.5
Seismic Events May
"Define" SE Boundary (?)

Calpine NW Geysers EGS Demonstration Seismicity Analysis: 09/2011 to 09/2012

LBNL database events with ErH (horizontal error) and ErZ (vertical error) less than 1 km

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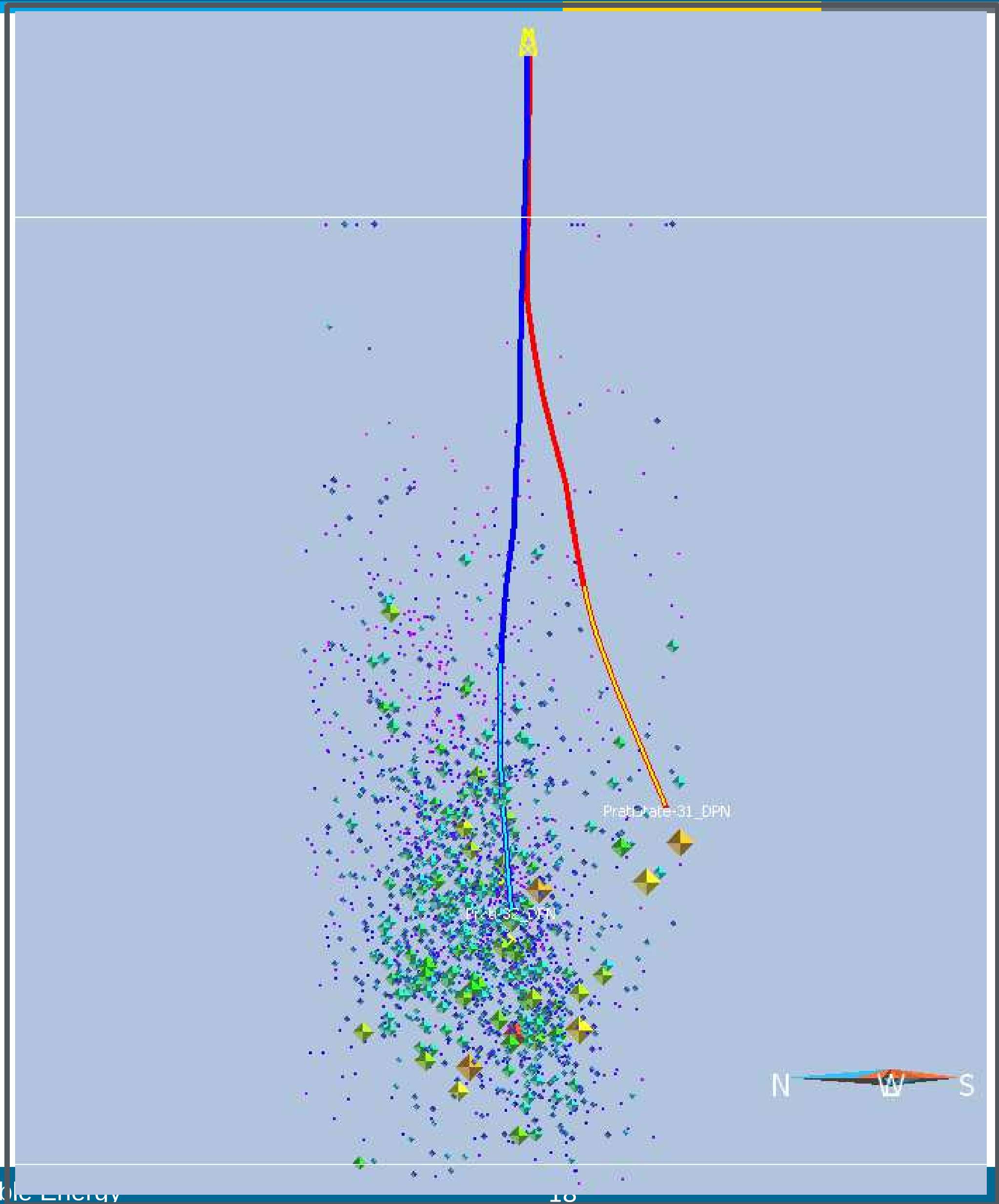

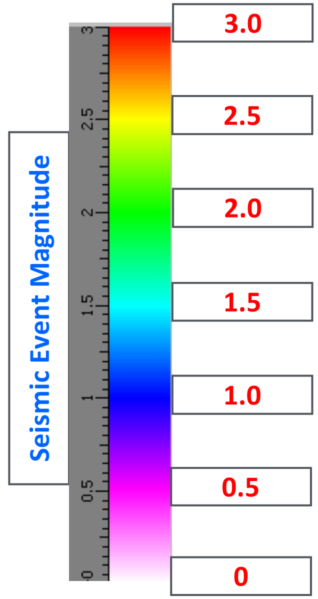

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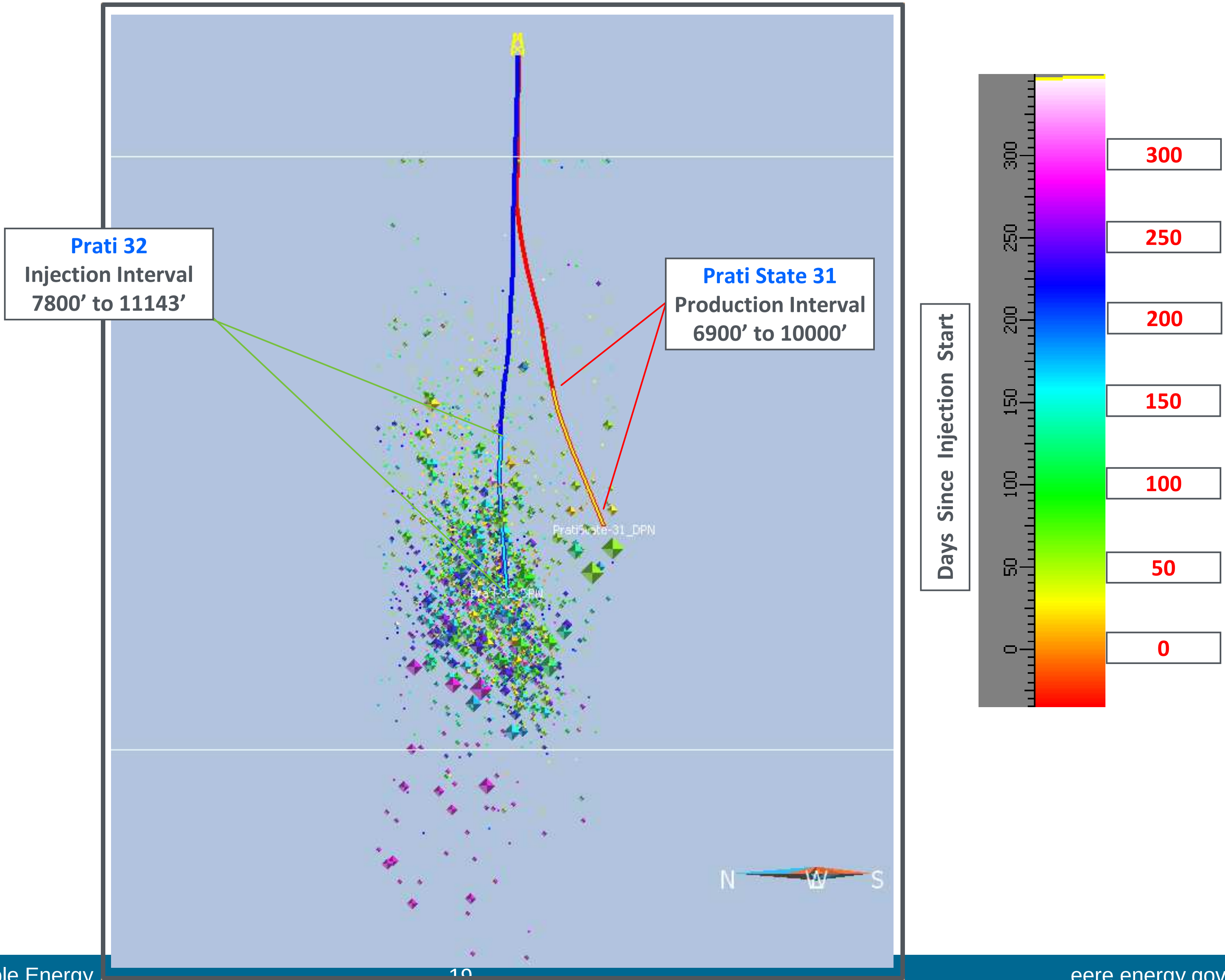

Data Analysis

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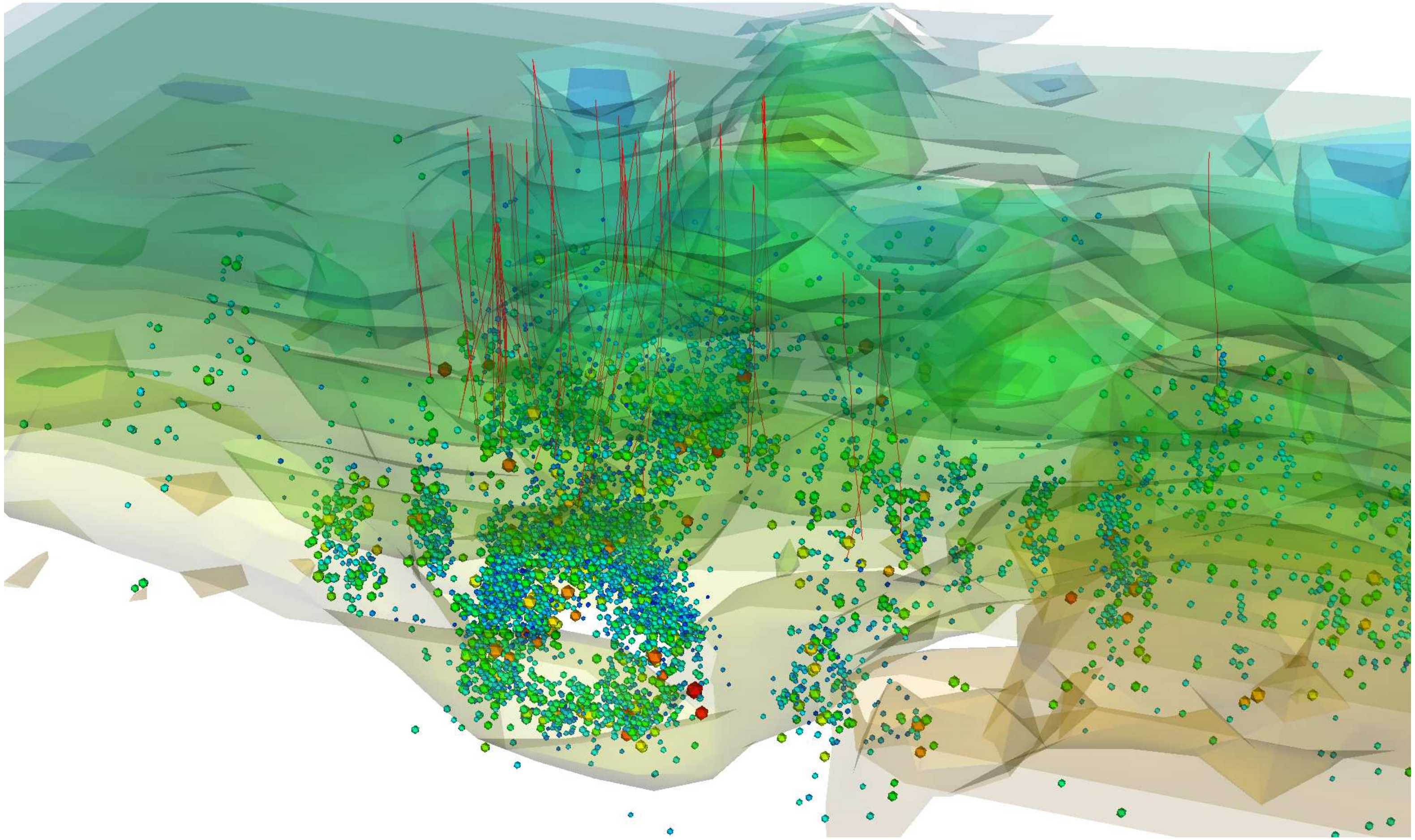

Large volume of data over time allows analysis of:

1. Change in forces acting on reservoir
2. Change in rock/fluid properties

Katie Boyle and Steve Jarpe

LBNL & Jarpe LLC

What could/should we do? - Operational

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- Deploy advanced monitoring systems
  - experimental data
  - continuous data-stream as basis for operational control decisions during development and long-term operation
- Risk-based decision making for operational control
  - adapt probabilistic seismic hazard/risk method coupled with physics-based approach incorporating uncertainty
- Mitigation and Control Procedures
  - Site characterization and selection: faults, communities
  - Engineering design – well locations, injection pressures, etc.
  - Data-driven operational control
- Establish a best practices/protocol based on accepted scientific knowledge in order to allow implementation of energy projects – i.e., set out the rules!! Living Document – change as we learn more
- Keep the stakeholders informed

What should/could be done? – Collaborations and Research Needs

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- Quantify relation between seismicity and permeability enhancement
- Improve means to quantify the relation between stress change and seismicity rate?
- Is there time dependence or stressing rate dependence in stress-seismicity rate changes/ or is the theory of effective stress all we need to know?
- Determine the role of slip-dilatancy (slip-permeability) in fault zones in EQ generation?
- Determine role of mechanical processes (fault healing, permeability reduction) versus other changes in the induced seismicity generation
  - What do we need to know about fault zone poroelasticity?
  - What do we need to know about chemical processes?
- Do induced earthquakes follow the same decay relations as tectonic earthquakes in the same province? (why or why not)
- Active experiments to manipulate seismicity without compromising production
  - reservoir performance assessment
  - integrated reservoir analysis

Dedicated test sites for exploring research issues?

Conclusions

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- Induced seismicity issues are not new (over 50 yrs)
- Induced seismicity is a useful tool for EGS reservoir management
- Generally, causes are known and have been mitigated
- New EGS protocol developed for US could serve as a model for other injection-related technologies (with best practices "handbook") Per New study by National Research Council on Induced Seismicity
- Key research has the potential to lower the uncertainty associated with induced seismicity as well as add to utility
- To optimize production causes and effects of induced seismicity associated with energy applications must be placed on a solid scientific basis

- Must move forward on a collaborative path at actual field test sites
  - Current international efforts are with 18 countries as part of IEA and IPGT
  - Data are open and are shared with the public
- DOE currently collaborating with regulatory bodies (BLM) by providing technical assistance