Workshop Objectives and Induced Seismicity Consortium (ISC)

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Hydraulic Fracturing- Induced Seismicity Workshop

Los Angeles, CA
June 28, 2012

USC University of Southern California

Workshop Objectives

- To have a platform for discussion on different aspects of induced seismicity (IS)
- To Introduce USC capabilities on IS from a variety of disciplines
- To discuss the main sources of IS from different Energy Related Operations (ERO)
  - Hydraulic fracturing (HF)
  - Fluid Injection or Removal (Production, Waste Disposal, etc.)
  - CO2 Capture and Sequestration (CCS)
- To highlight the state of the art on IS and highlight the recent NRC Report on the subject

Workshop Objectives (Cont.)

- To provide a platform for direct communication among
  - State officials,
  - Oil and Gas operators,
  - Service Companies,
  - National Laboratories,
  - USC Researchers
- To highlight different challenges
  - Technical Challenges
  - Operators Challenges
  - Regulatory and Public Policy Challenges
- To Introduce USC Induced Seismicity Consortium (ISC) and to discuss the Research Education and Public Outreach Plans

Introduction to Induced Seismicity

fracture treatment / Fluid Injection / CCS

Increase in stress and pore Pressure

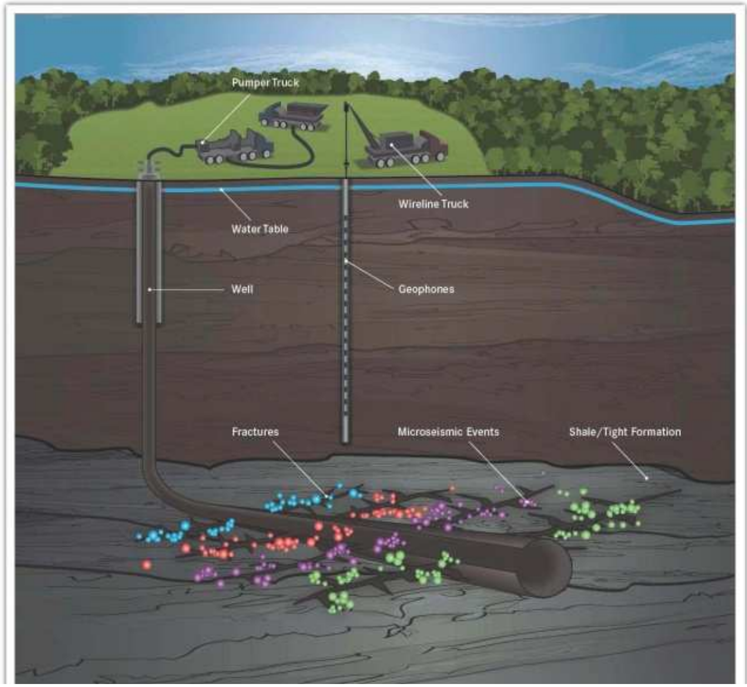
Decrease the stability of existing weak planes (natural fractures, bedding planes)

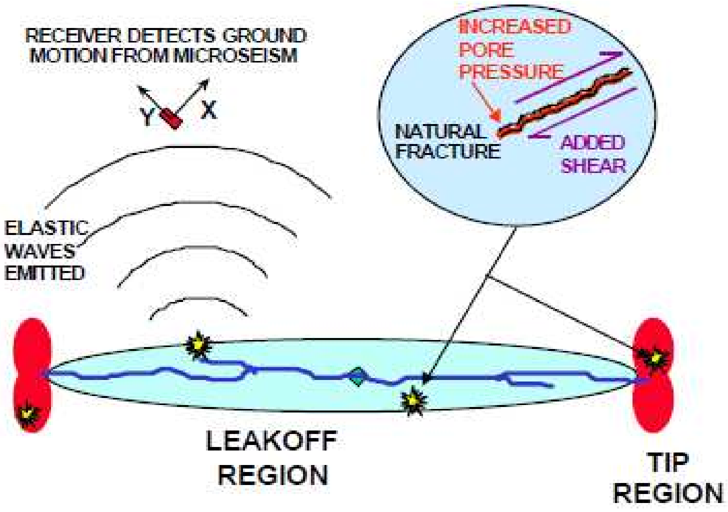
slip and fail, similar to earthquakes along faults

slippages emit elastic waves (stimulated seismicity)

Induced Seismicity Data Base

Models-IS Risk Maps





Bloomberg

Fracking Tied to Unusual Rise in Earthquakes in U.S.

By Mark Drajem - Apr 12, 2012 12:32 PM PT

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A spate of earthquakes across the middle of the U.S. is “almost certainly” man-made, and may be caused by wastewater from oil or gas drilling injected into the ground, U.S. government scientists said in a study. Researchers from the U.S. Geological Survey said that for the three decades until 2000, seismic events in the nation’s midsection averaged 21 a year. They jumped to 50 in 2009, 87 in 2010 and 134 in 2011. Those statistics, included in the abstract of a research paper to be discussed at the Seismological Society of America conference next week in San Diego, will add pressure on an energy industry already confronting more regulation of the process of hydraulic fracturing.

An energy plant along the southern San Andreas earthquake fault near Calipatria, California. In northern California, engineers are drilling to great depths to force water into bedrock, a process that causes slippage and small earthquakes. Photographer: David McNew/Getty Images

“Our scientists cite a series of examples for which an uptick in seismic activity is observed in areas where the disposal of wastewater through deep-well injection increased significantly, "David Hayes, the deputy secretary of the U.S. Department of Interior, said in a blog post yesterday, describing research by scientists at the U.S. Geological Survey

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‘Fairly Small’ Quakes

The earthquakes were “fairly small,” and rarely caused damage, Hayes said.

He said not all wastewater disposal wells induce earthquakes, and there is no way of knowing if a disposal well will cause a temblor.

Last month, Ohio officials concluded that earthquakes there last year probably were caused by wastewater from hydraulic fracturing for natural gas injected into a disposal well.

In hydraulic fracturing -- or fracking -- water, sand and chemicals are injected into deep shale formations to break apart underground rock and free natural gas trapped deep underground. Much of that water comes back up to the surface and must then be disposed of. There’s “a difference between disposal injection wells and hydraulically fractured wells,” Daniel Whitten, a spokesman for the America’s Natural Gas Alliance, which represents companies such as Chesapeake Energy Corp. (CHK) and Cabot Oil & Gas Corp. (COG), said in an e-mail. “There are over 140,000 disposal wells in America, with only a handful potentially linked to seismic activity.”

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'Committed to Monitoring'

"We are committed to monitoring the issue and working with authorities where there are concerns, but it should be noted that currently there is no scientific data associating hydraulic fracturing with earthquakes that would cause damage," he said.

An abstract of the federal study, which was led by William Ellsworth, Earthquake Science Center staff director for the U.S. Geological Survey in Menlo Park, California, was published online earlier this month. A full version of the study wasn't immediately available.

The area studied included a swath of the country running from Ohio to Colorado and Oklahoma, the study said.

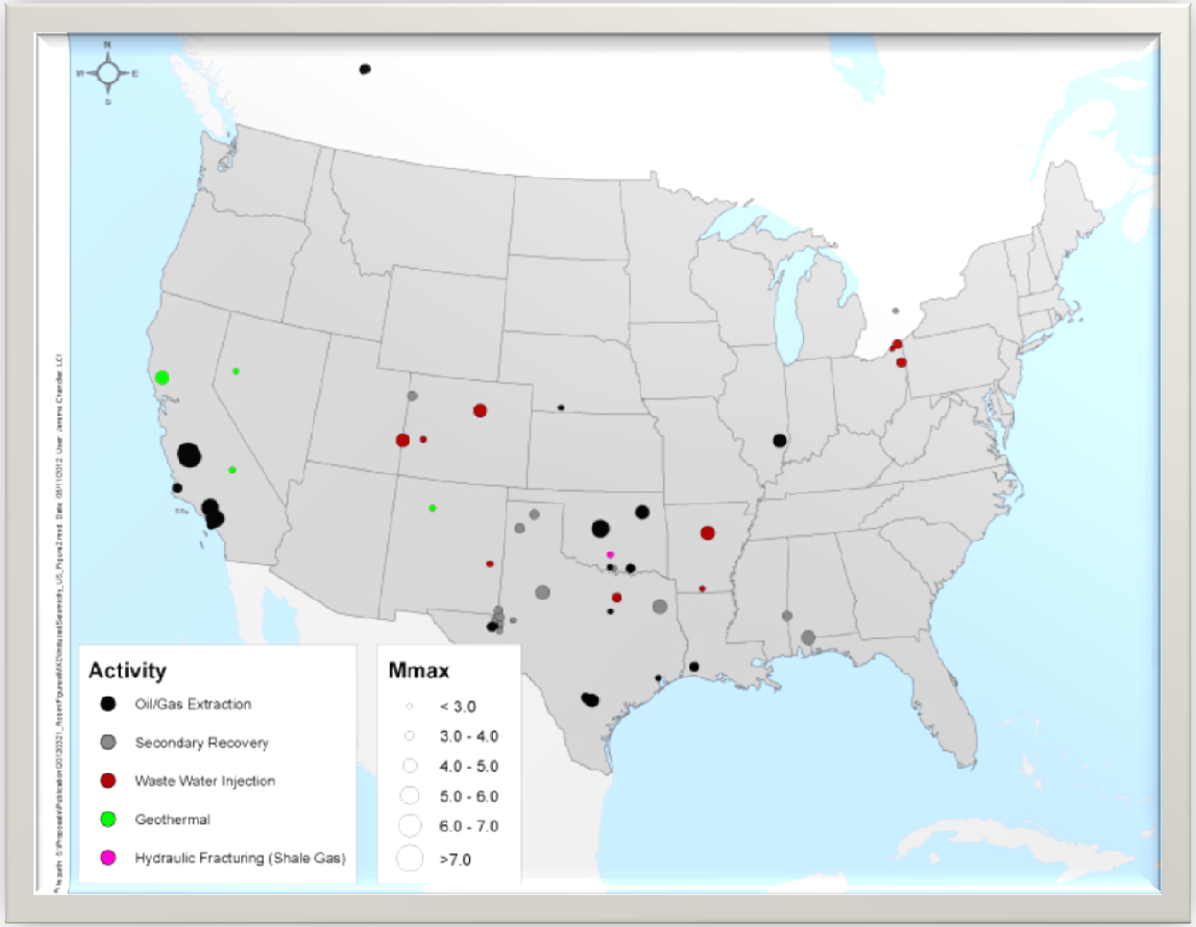
"A naturally-occurring rate change of this magnitude is unprecedented outside of volcanic settings or in the absence of a main shock, of which there were neither in this region," Ellsworth and his colleagues wrote.

The Environmental Protection Agency is preparing to release rules on air pollution from gas wells and on the treatment of wastewater. Other state and federal rules could force more disclosure of the chemicals used by the drilling companies.

The Interior Department is considering rules to update well-design standards and require disclosure of the chemicals in fracking on public lands.

Documented Induced Seismicity of Energy Related Operations (ERO)

- Seismic events have been measured and felt at a limited number of energy development sites in the United States.
- Seismic events caused by or likely related to energy development have been documented in Alabama, Arkansas, California, Colorado, Illinois, Louisiana, Mississippi, Nebraska, Nevada, New Mexico, Ohio, Oklahoma, and Texas



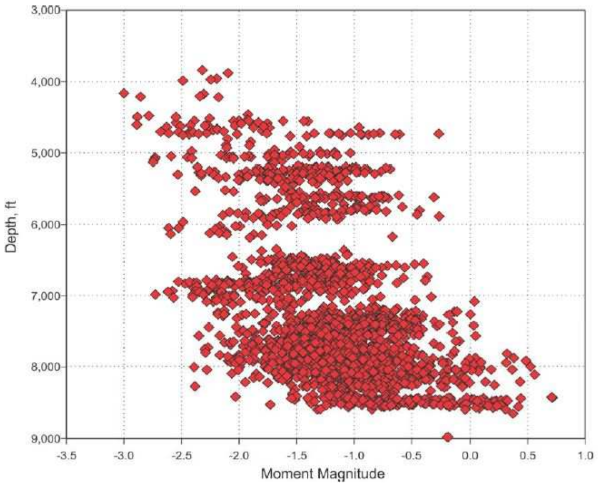
NRC Report, June 2012

What Are the Key Factors for Induced Seismicity

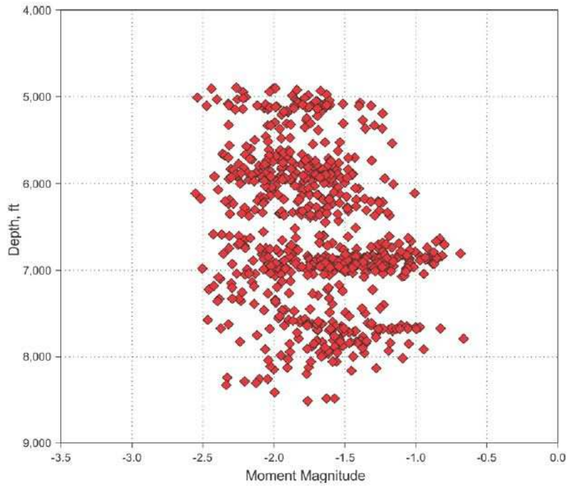
- Stress field
- Pressure
- Temperature
- Formation Depth
- Fluid Saturation
- Formation Thickness
- Faulting / Fracture Network
- Geology and Rock Type
- Injection Rate
- Injection Volume

NRC Report, June 2012

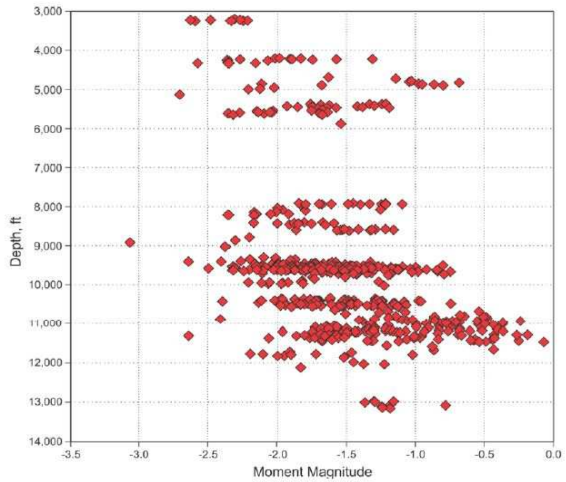
Review of past fracture treatments to identify induced seismicity characteristics: Effect of Depth



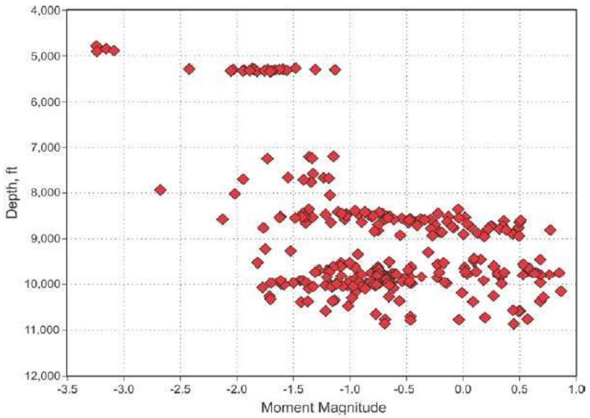
Barnett



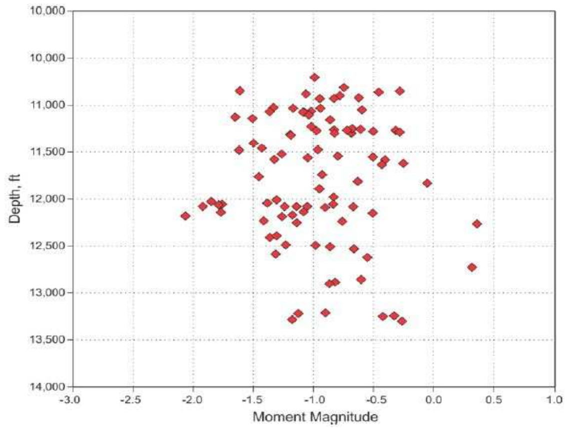
Marcellus



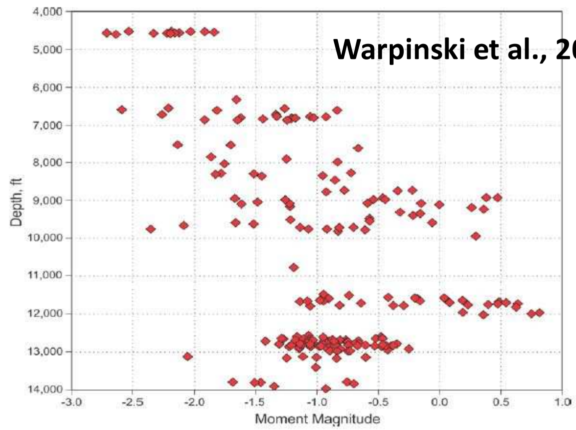
Eagle Ford



Woodford



Haynesville



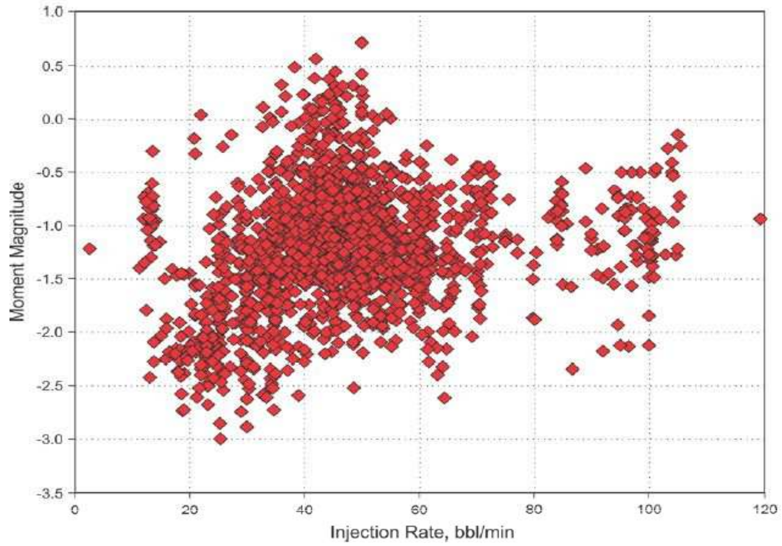
Warpinski et al., 2012

Muskwa/ Evie

Moment magnitude ->Seismic moment -> f (shear modulus, fault plane slip distance, slip area)

Decreasing magnitude with decreasing depth: Association with stress conditions

Review of past fracture treatments to identify induced seismicity characteristics: Effect of Rate/ Volume



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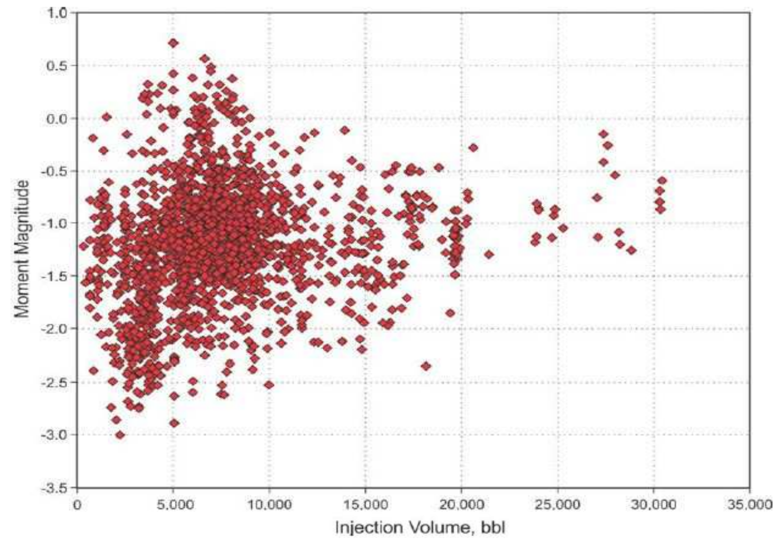

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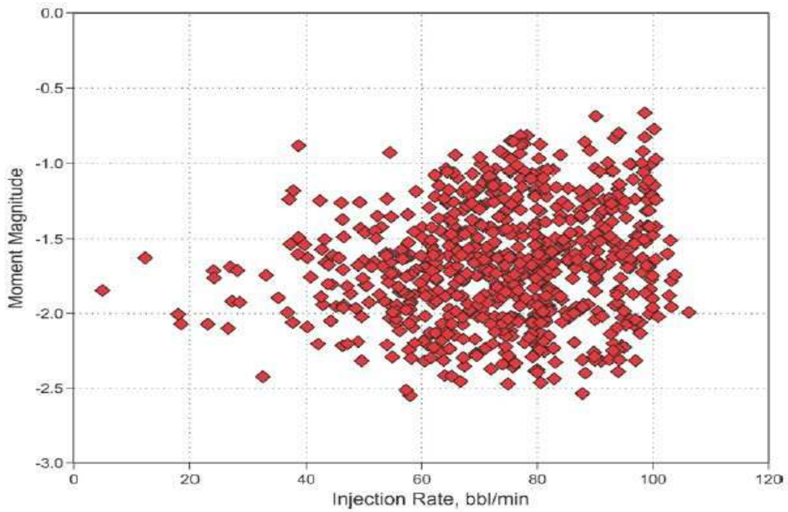

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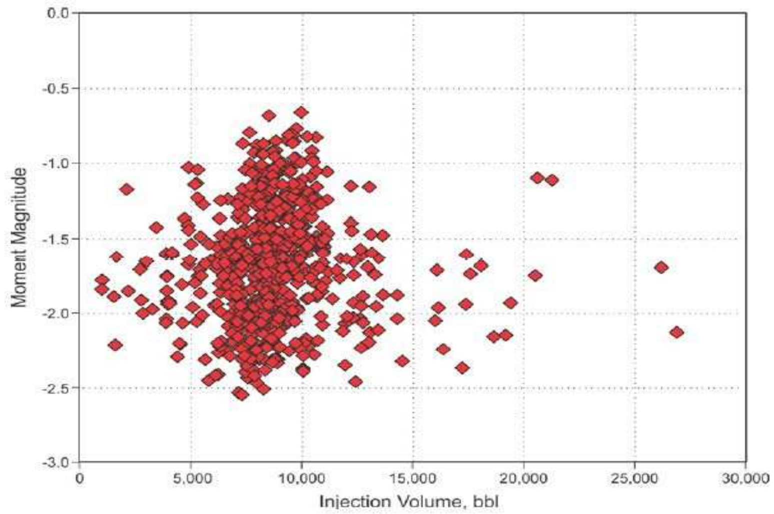
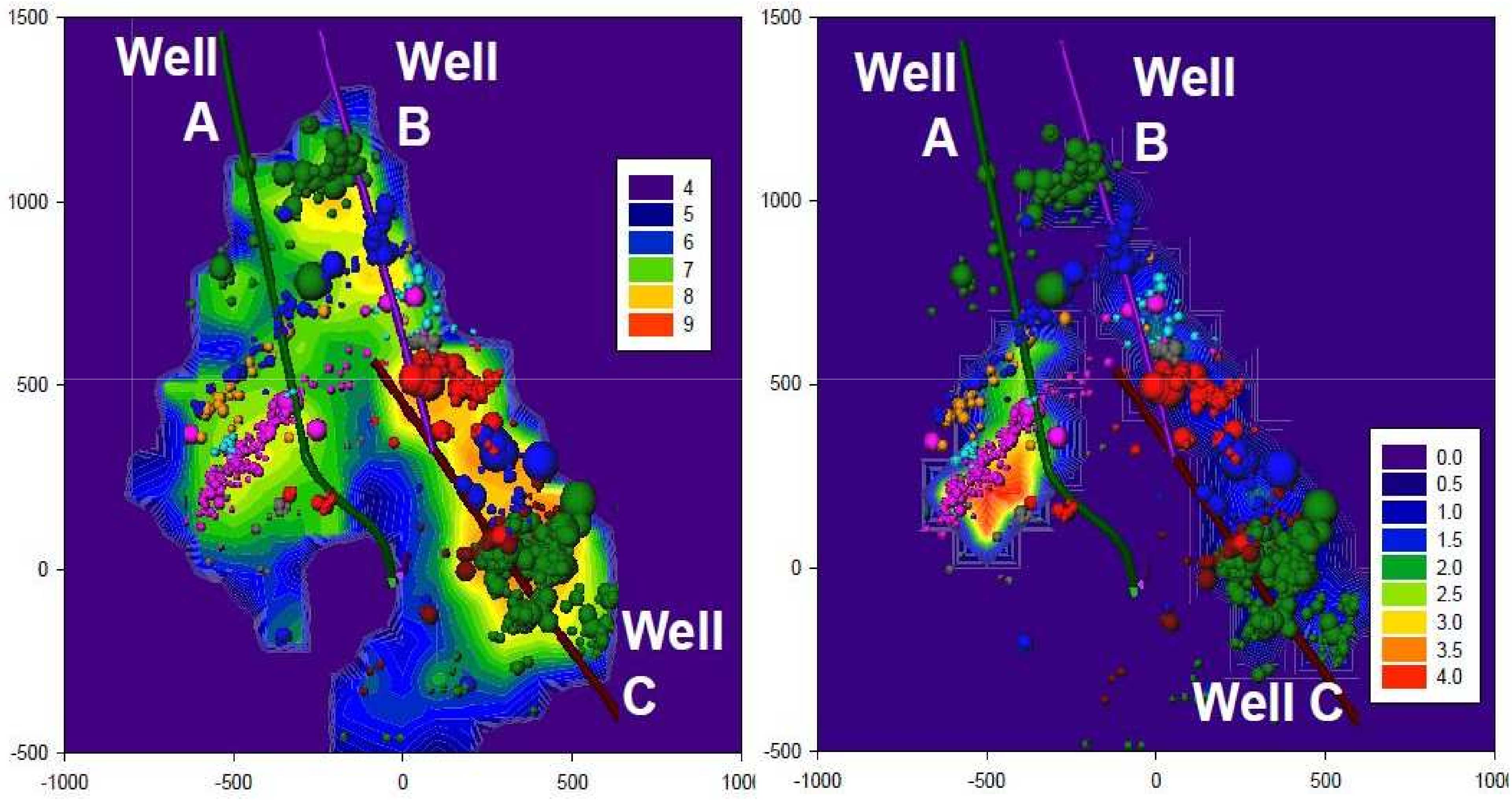


Marcellus

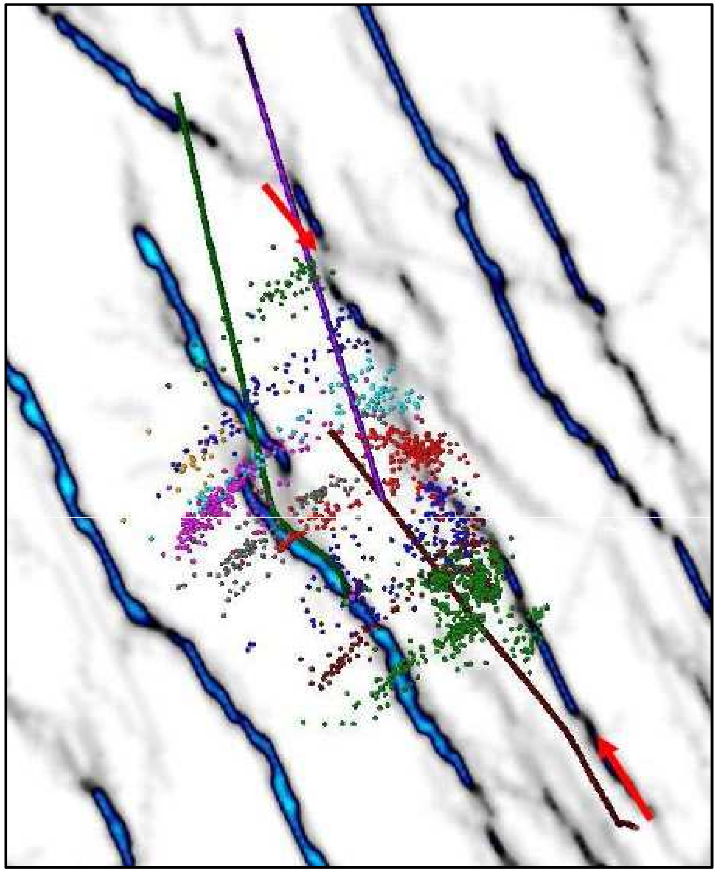
Warpinski et al., 2012

Seismic moment density and b-value for microearthquake characterization

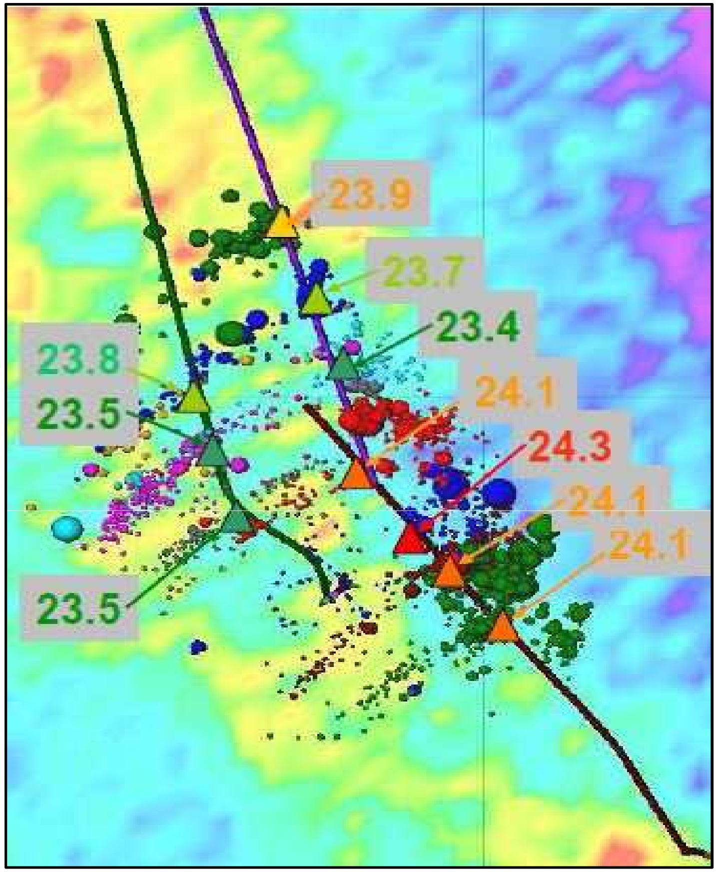


Maxwell et al., 2011

Integration with conventional seismic derived properties for verification



Fault map

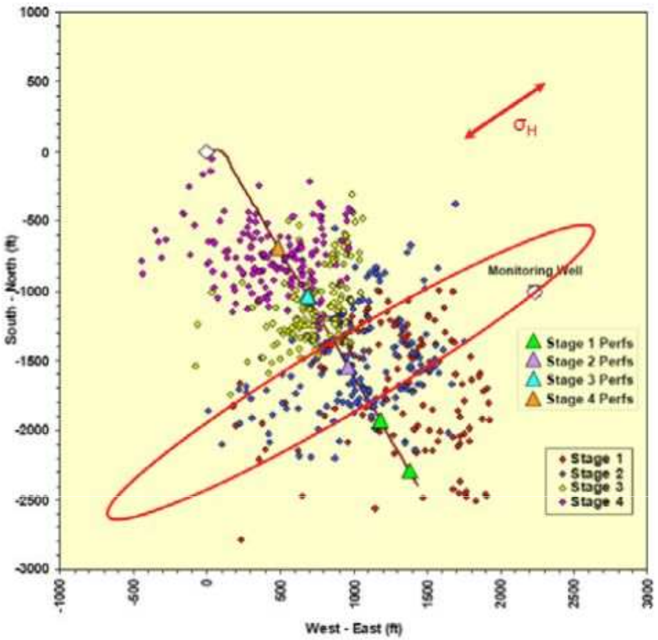


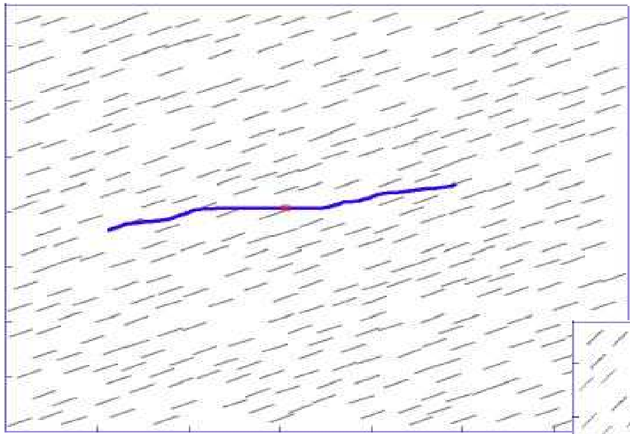
ISIP (instantaneous shut in pressures)

High ISIP's -> high poisson's ratio ->high tress regions?
high ISIP's -> larger MEQ -> supporting fault activation.

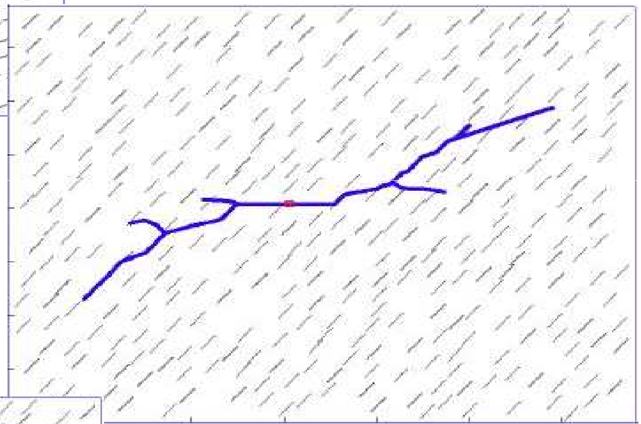
Maxwell et al., 2011

Theoretical approach to understanding fracture branching/ segmentation

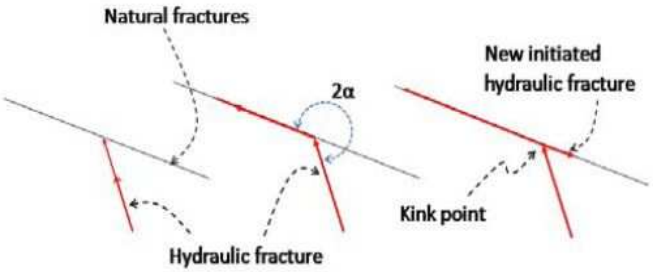




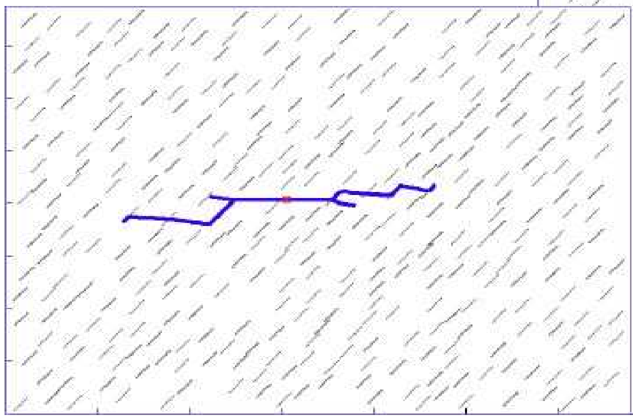
No fracture initiation with fractures oriented at 30° from max horizontal stress



Fracture initiation with fractures oriented at 60° from max horizontal stress



Growth mechanism



Diffused fracture initiation with differential stress regime

Dahi Taleghani, 2010

Fractal & b- value analysis in detecting induced vs tectonic events

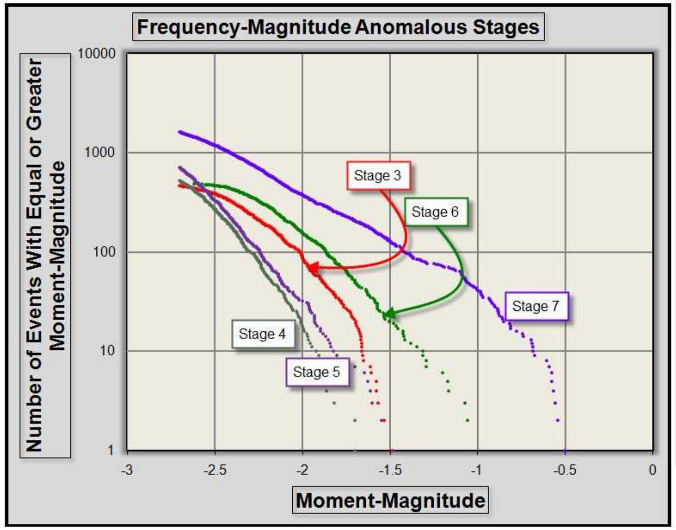
Stimulated Seismicity

Triggered

- Fractal Dimension ~ 2
- b - value < 1.2

Induced

- Fractal Dimension ~ 2.5
- b -value> 1.2



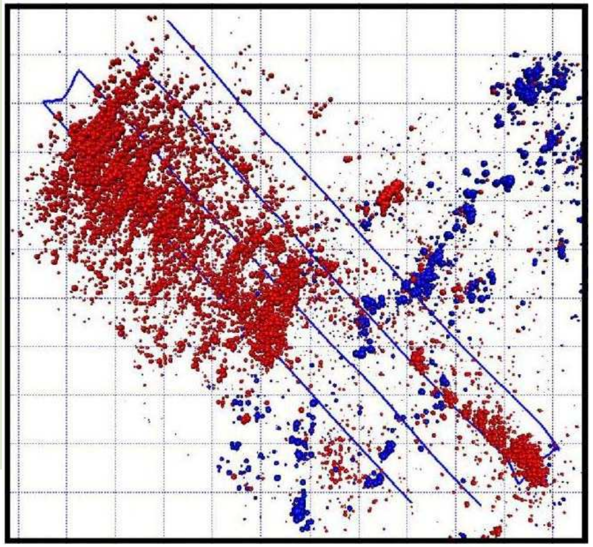
(Downie, 2010)

Higher b-value

Lower Stress Regime

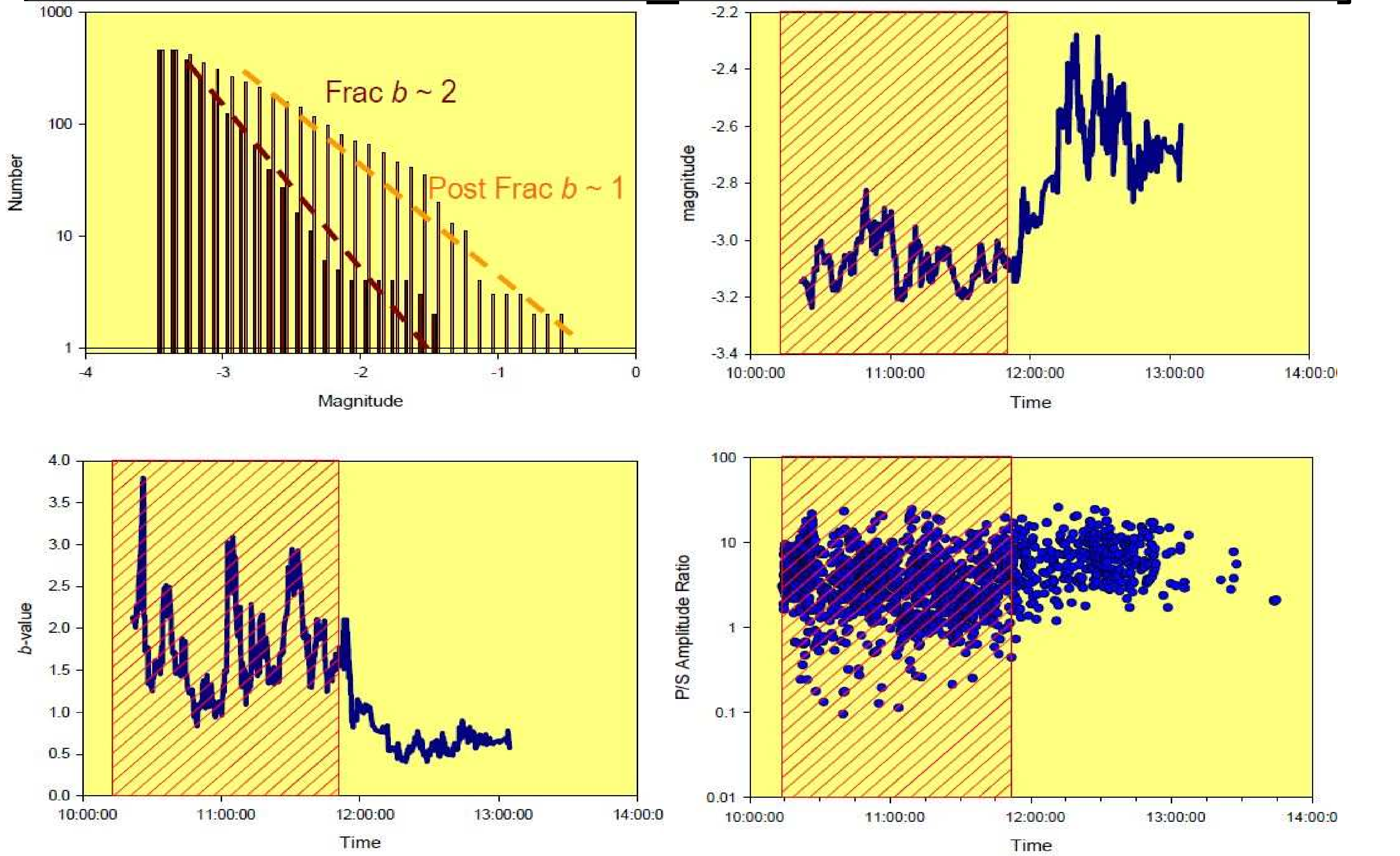
Smaller events

$$\log_{10} N = a - bM$$



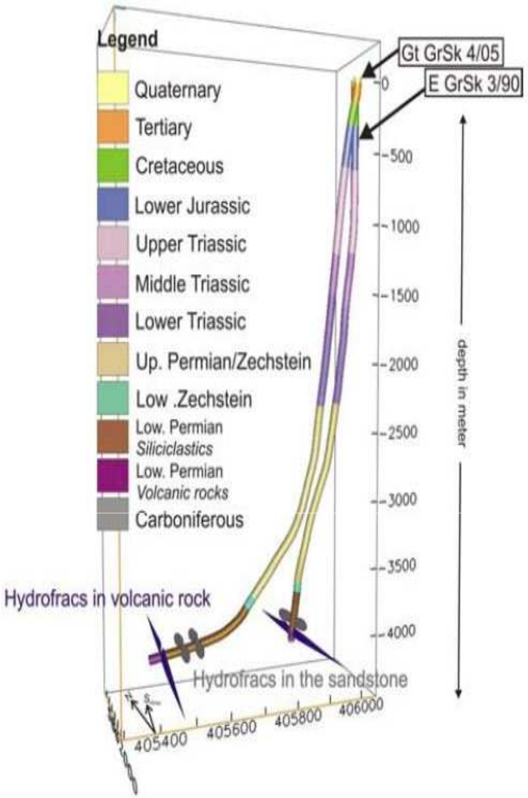
(Wessels et al., 2011)

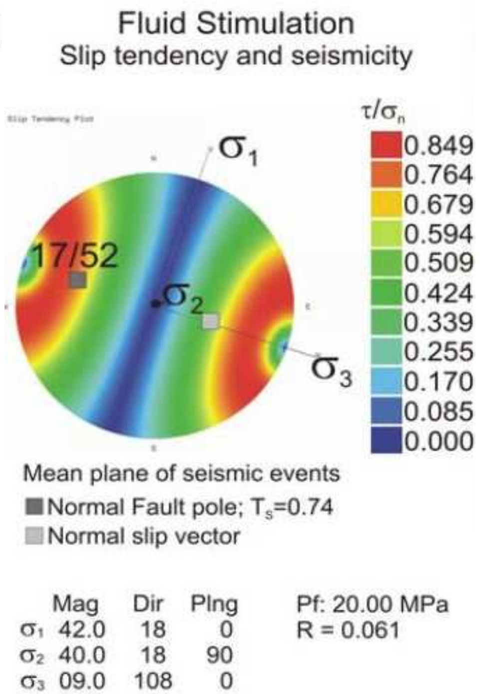
Use of temporal b-value mapping (before and after treatment) to identify activation

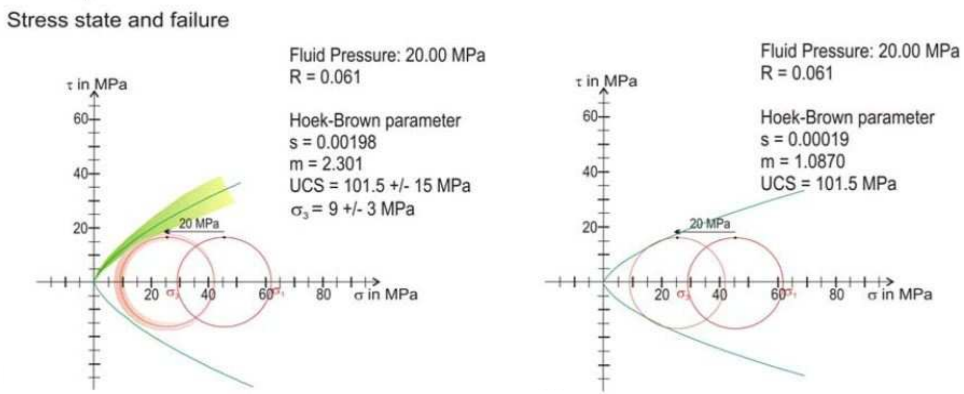


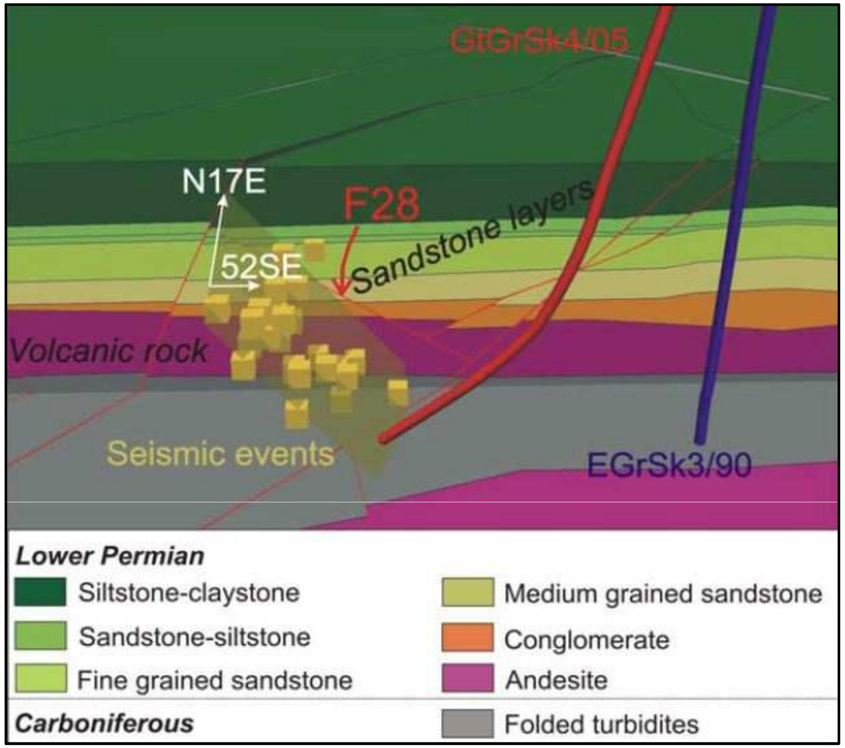
Maxwell et al., 2009

Fracture reactivation potential using slip tendency analysis based on stress calculations





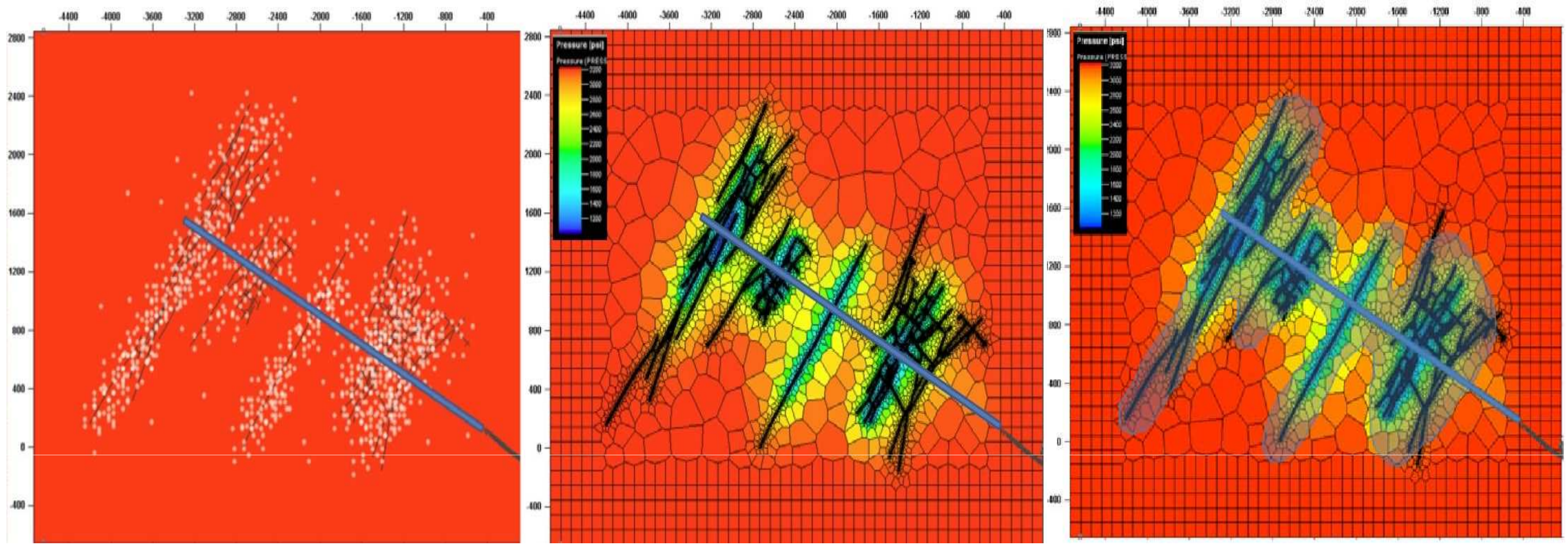


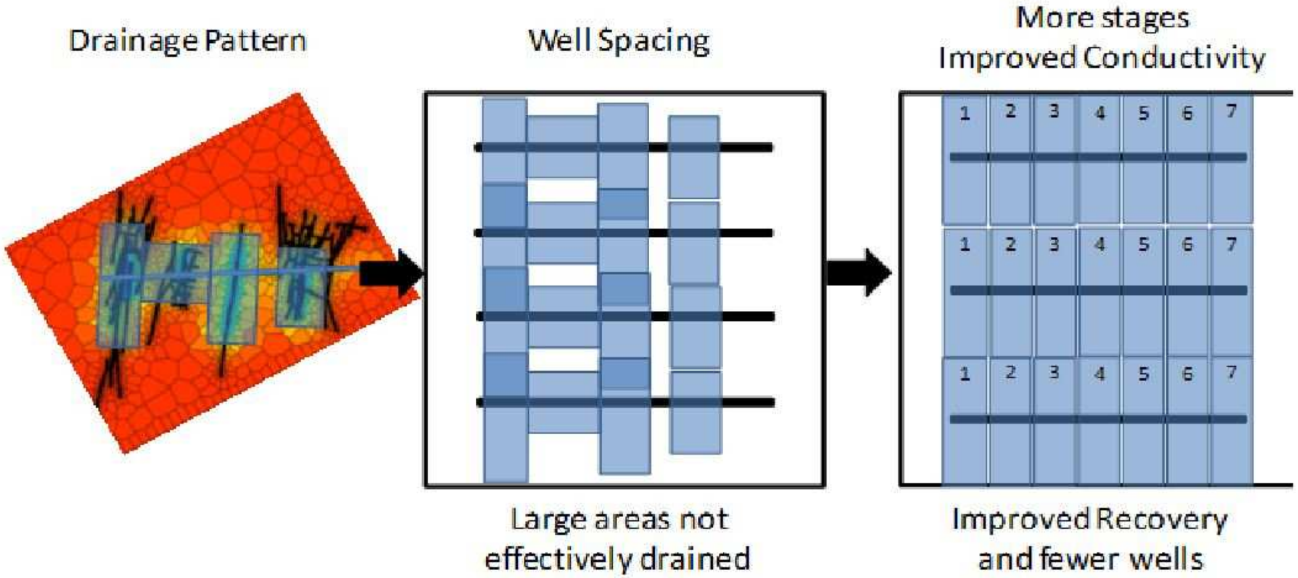


Distribution of seismicity fits orientation of F28 fault. Mohr circle diagrams show reactivation during stimulation. The stereo plot shows the slip tendency of recorded microseisms.

Moeck et al., 2009

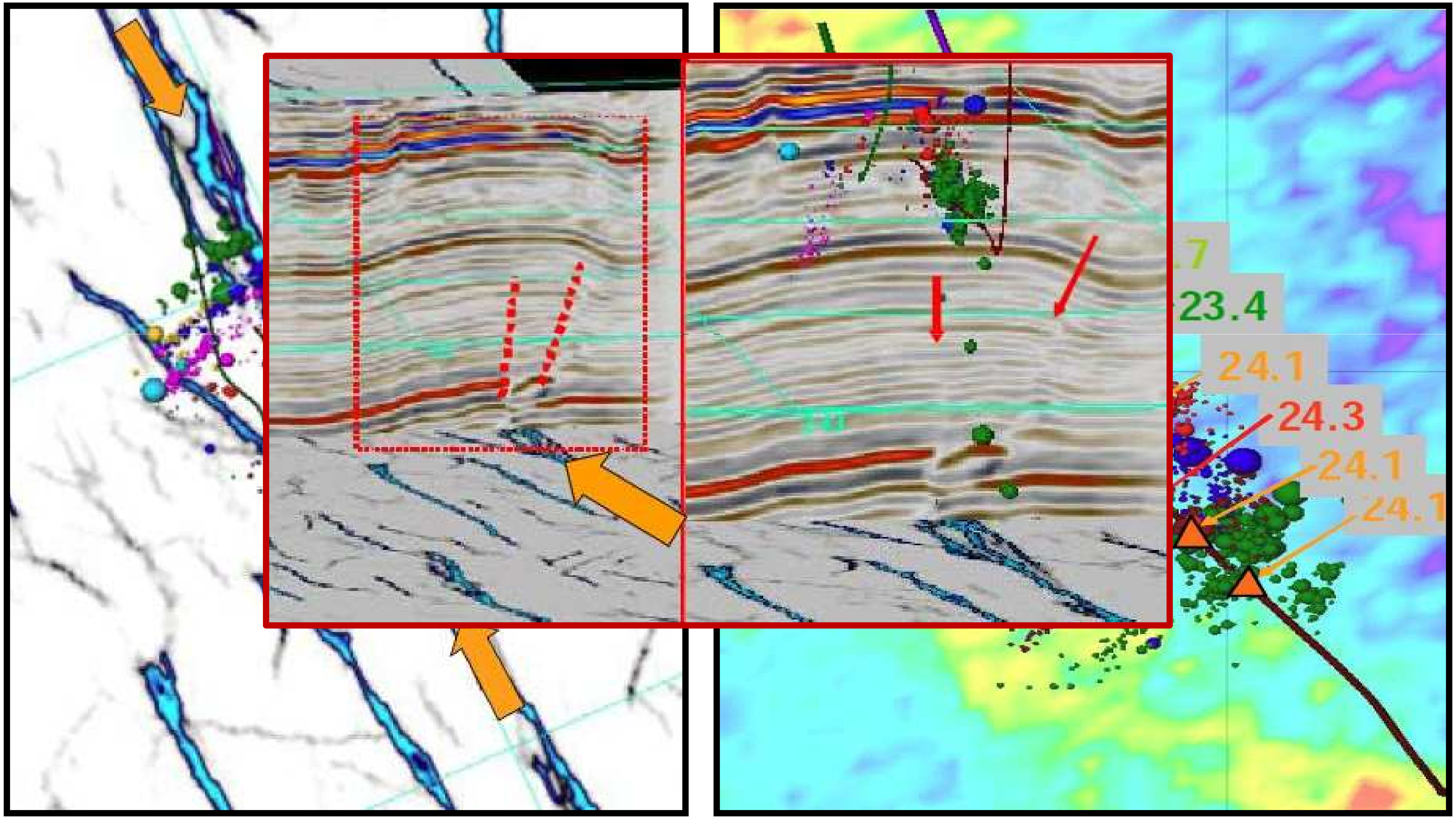
Complex hydraulic fracture geometry compared with MEQ cloud and modeled 20 year pressure depletion for un-propped zones





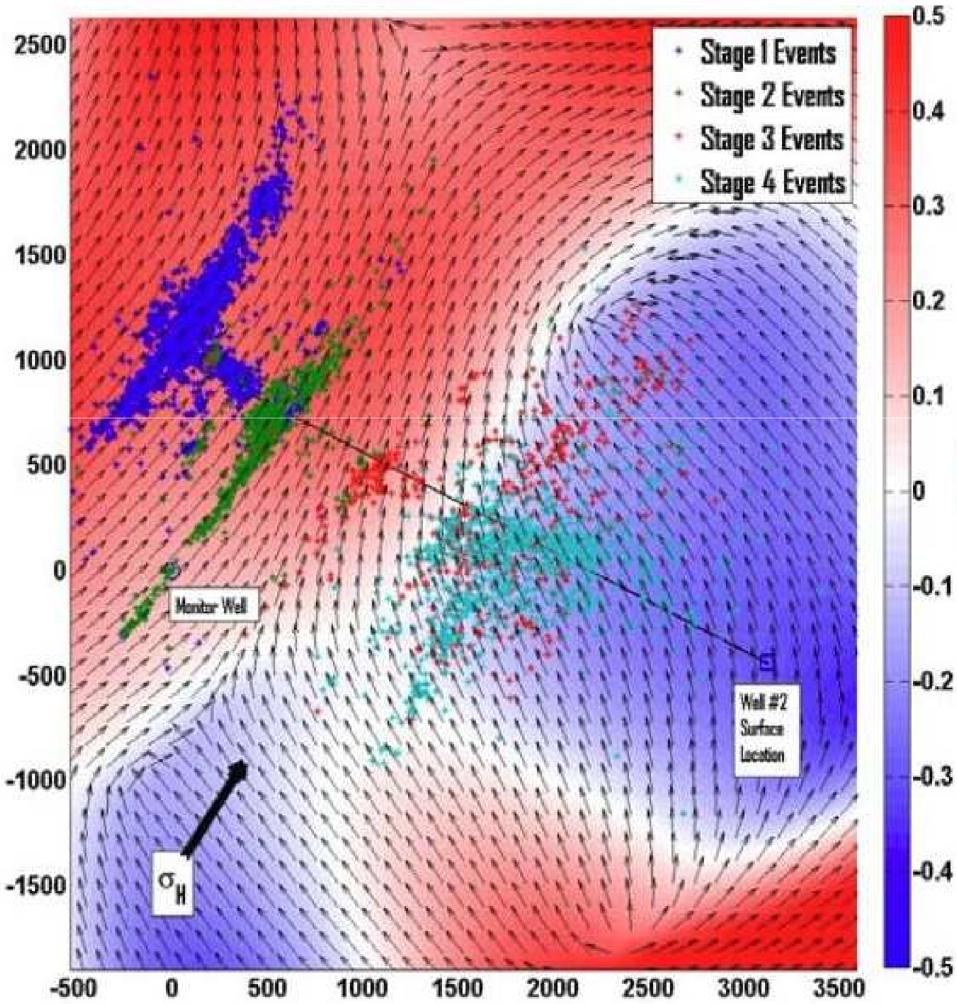
Cipolla et al., 2012

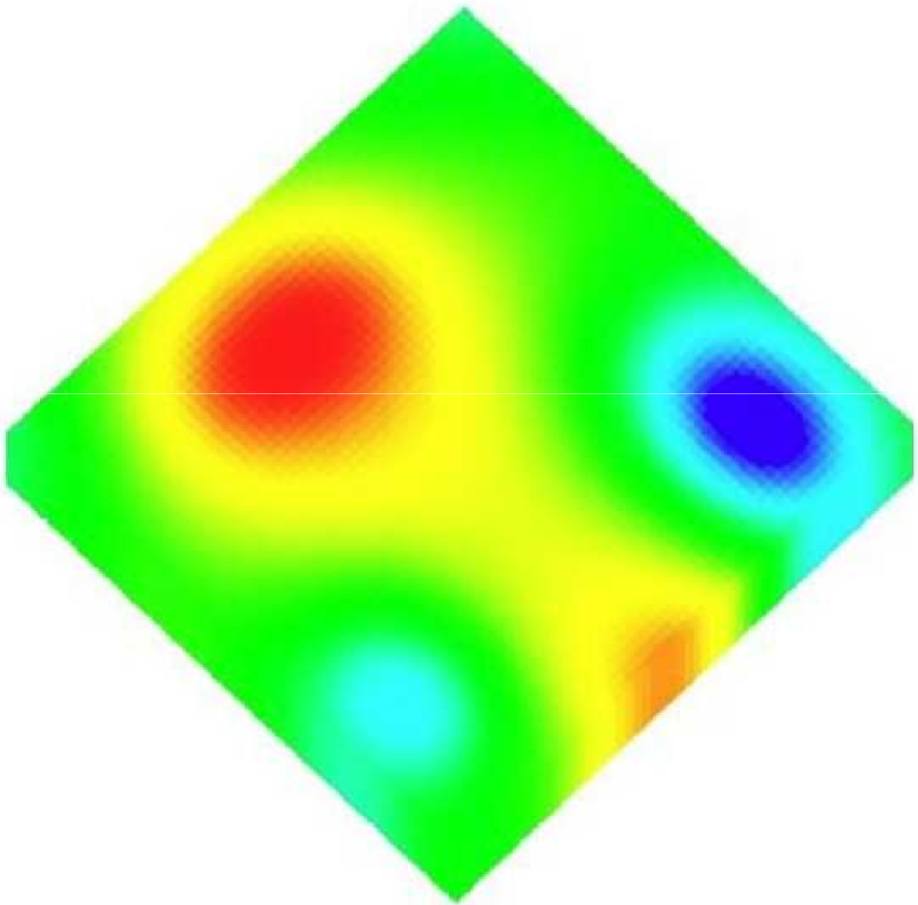
Microseismic (event locations) integrated with seismic derived attributes/ properties



Maxwell et al., 2011 & Cipolla et al., 2012

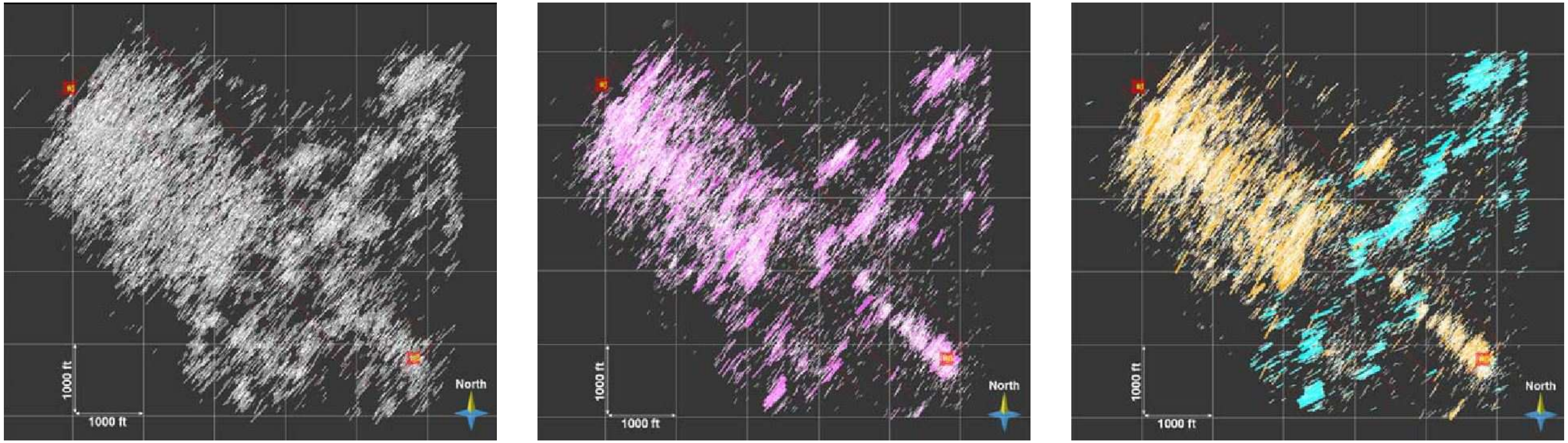
Integrated evaluation using stress anisotropy, seismic curvature & seismic fabric direction to determine fracture zone complexity



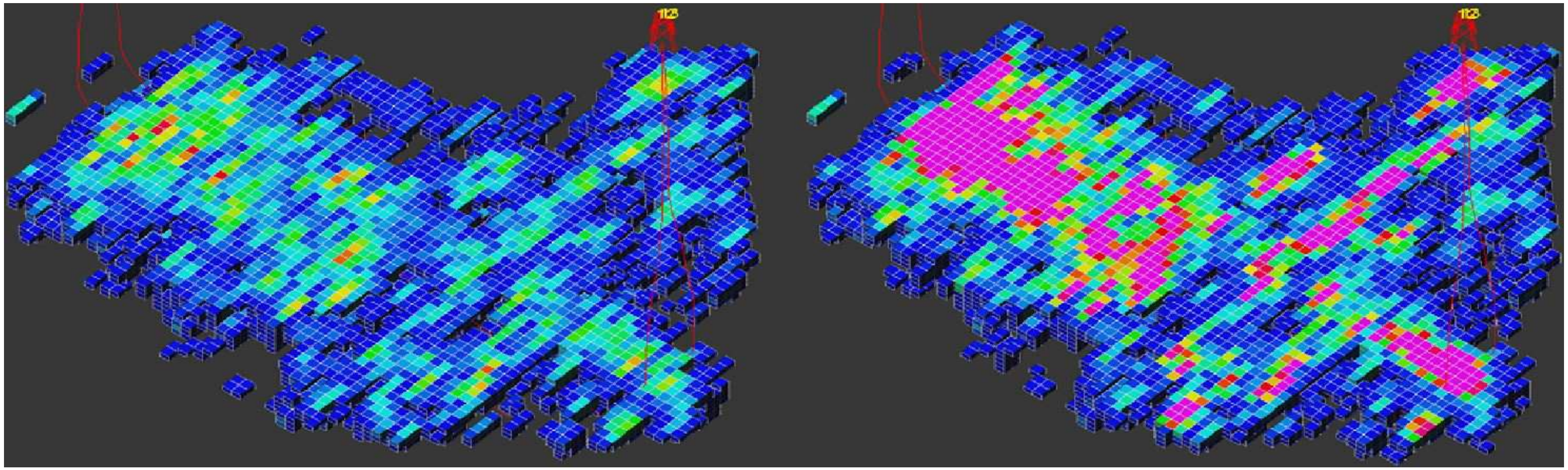


Cipolla et al., 2012

Fracture model refinement using passive seismic data

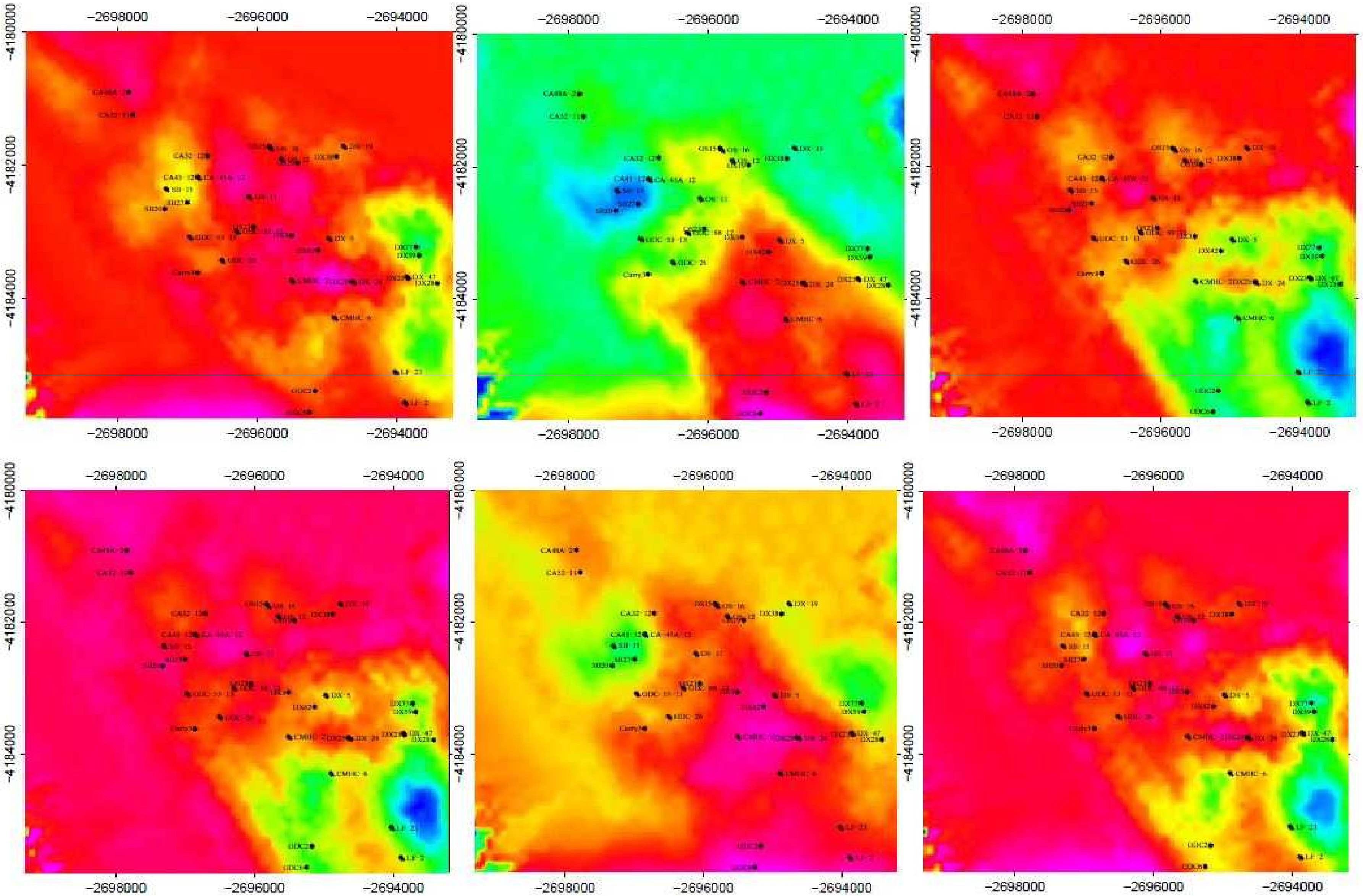


Iteration 1 | Iteration 2 | Iteration 3

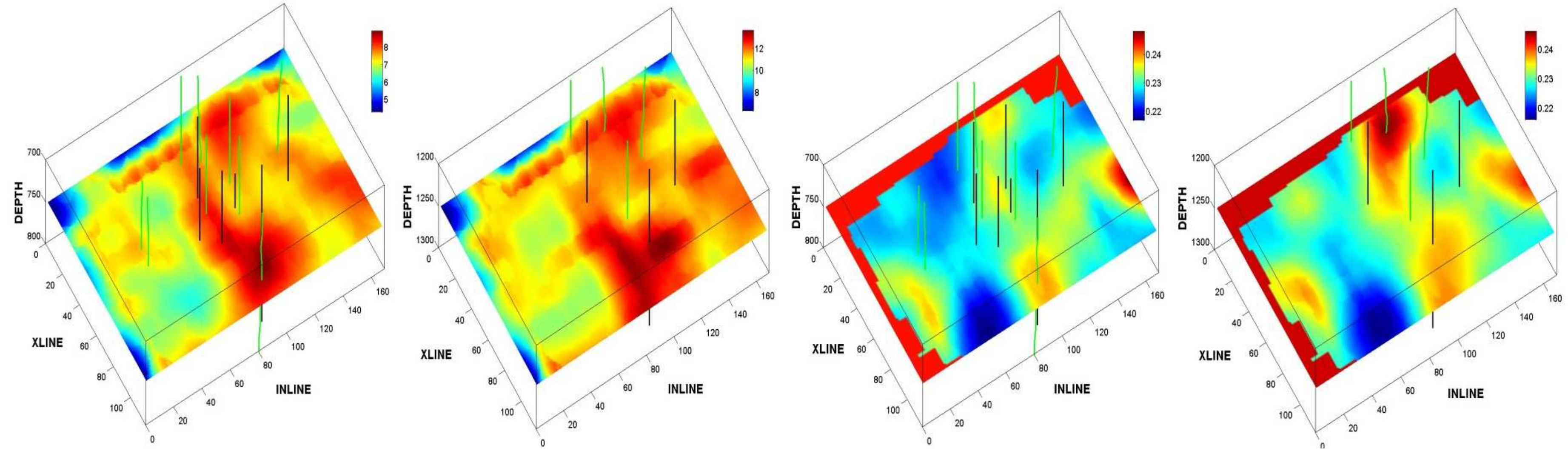


Cornette et al., 2012

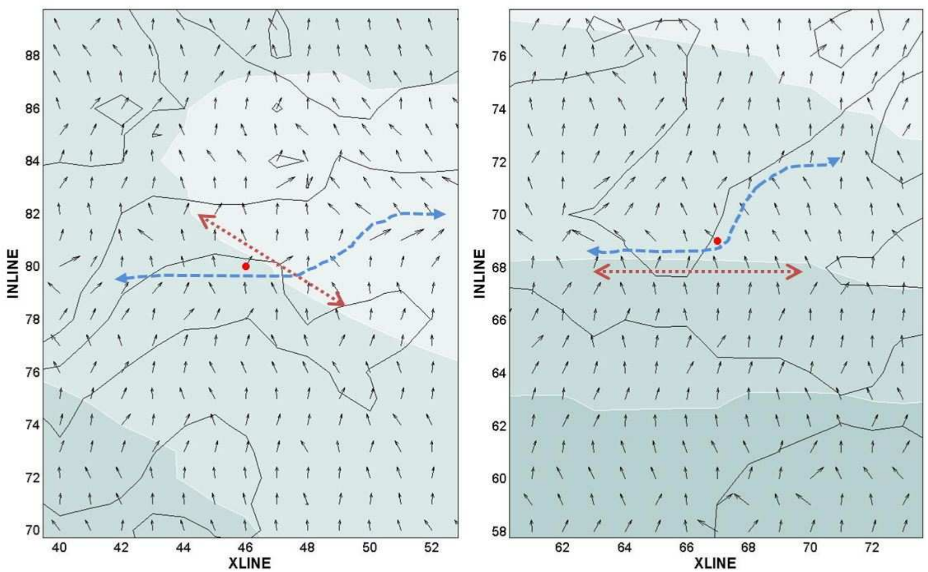
High resolution velocity inversion and elastic property estimation



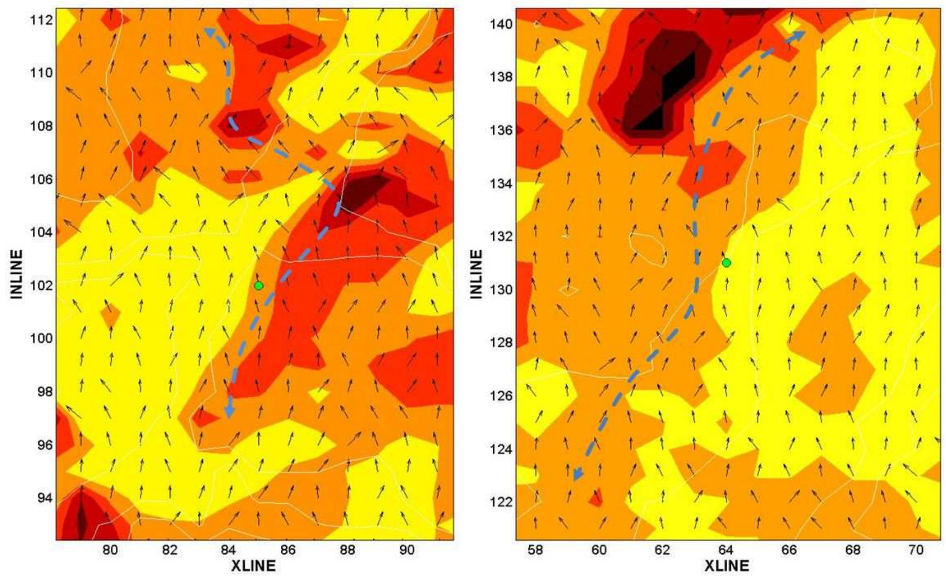
HR property estimation: Integrating microseismic, seismic & logs



Extensional stress maps & tangential weakness maps with well tracks for reference



Discontinuity gradient, extensional stress & edge maps



Discontinuity gradient, ANN derived FZI & edge maps

Induced Seismicity Consortium (ISC)

"To better understand, limit, and respond to induced seismic events, work is needed to build robust prediction models, to assess potential hazards, and to help relevant agencies coordinate to address them." *NRC2012*

ISC will focus on the risk assessment of induced seismicity in connection with HF, WD and CCS. It will attempt to build predictive tools and models. The goal is to develop IS hazard probability and deliver an effective science-based roadmap for best operational practices, policy decisions, regulatory processes, as well as public education and communication on induced seismicity in energy related activities worldwide.


USC University of Southern California

Induced Seismicity Consortium (ISC)

A Proposal

Fred Aminzadeh, PI, Petroleum Engineering Program

Behnam Jafarpour CO- PI, Petroleum Engineering Program

Charles Sammis, and Meghan Miller, CO-PI

Department of Earth Sciences and Southern California Earthquake Center

Lucio Soibelman, and Roger Ghanem, CO-PI,

Department of Civil and Environmental Engineering

Advisory Board

TBD

Recommendation for Future Study

Field and Laboratory Data Collection and Analysis

1. Collect MEQ data from existing stations and add new higher resolution stations in the vicinity of ERO
2. Analyze the data Conduct research to establish the means of making in situ stress measurements non-destructively.
3. Conduct additional field research
4. Conduct focused research on the effect of temperature variations on stressed jointed rock systems.
5. Conduct research that might clarify the in situ links among injection rate, pressure, and event size

(NRC, 2012)

Recommendation for Future Study (Contd.)

Instrumentation

Conduct research to address the gaps in current knowledge and availability of instrumentation

Hazard and Risk Assessment

Direct research to develop steps for hazard and risk assessment for single energy development projects

(NRC, 2012)

Recommendation for Future Study (Contd.)

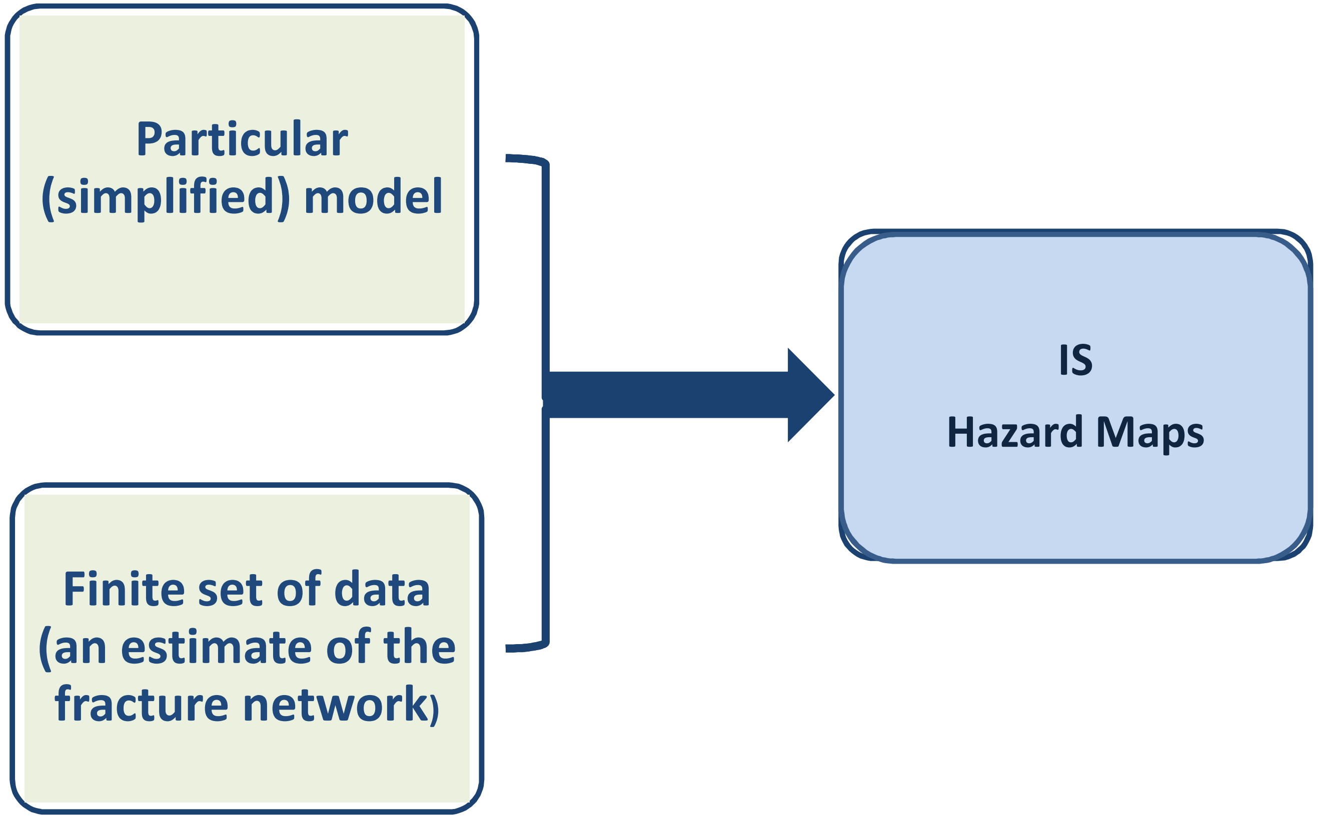
Modeling

1. Create scaled simulation models to make the required predictions of the field observations reported.
2. Focused research to advance development of linked geomechanical and earthquake simulation
3. Use currently available and new geomechanical and earthquake simulation models
4. Develop simulation capabilities that integrate existing reservoir modeling capabilities with earthquake simulation modeling for hazard and risk assessment.
5. Develop capabilities with coupled reservoir fluid flow and geomechanical simulation codes

6. (NRC, 2012)

Hierarchical Probabilistic Model for Operational Parameters

- Probabilistic models to predict failure from a particular injection strategy in a particular site
- Prediction process:



Hierarchical Probabilistic Model for Operational Parameters

- Hazard maps are a function of the selected model and data
- Data acquisition efforts and model refinement are designed based on the sensitivity of the hazard maps
- A ***Hierarchical Probabilistic Model*** the parameters of which reflect subscale effects
- Sensitivity of the hazard maps with respect to these parameters define the value of additional measurements and additional model complexity

Hierarchical Probabilistic Model for Operational Parameters

- Hazard associated with ERO can be traced to 3 components:
  1. Events taking place along a fault
  2. The propagation of these events in the subsurface
  3. The interaction of subsequent motion with structures and features either buried or on the ground surface
- Uncertainties in each component

Fracture density and orientation (characterized from microseismic data) + **Fuzzy clustering algorithm (fuzzy sets and probabilistic models)**

- a probabilistic model will also be deduced from the data using maximum entropy principles (MaxEnt).

Hierarchical Probabilistic Model for Operational Parameters

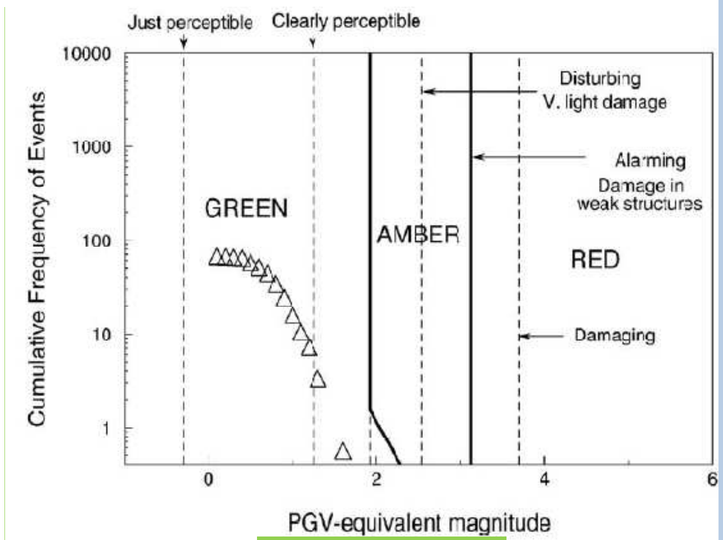
- The probabilistic evidence of the initial fractures will be propagated through physics-based models whose parameters are treated as random variables → a predicted probabilistic fracturing behavior

- The behavior depends on: uncertainty in initial fractures and wave propagation in the heterogeneous medium

- Utilizing MAxEnet to describe the uncertainty in the random model and to define the constraints associated with physics (symmetry, positivity, and upper/lower bounds on effective behavior) and data (in the form of statistical moments)

A System to Control the Hazard Associated with Induced Seismicity

- The monitoring system comprises of seismograph network, strong motion accelerographs and a center to gather the whole data on a real-time basis.
- A real-time data acquisition system would be a beneficial tool to address hazard issues associated with tectonic activities of faults
- Ground movements caused by induced seismicity can be monitored and managed dynamically



(Bommer et al. 2006)

- Red Zone - Stop the injection process because of the high hazard potential of the accompanying seismic activities
- Amber Zone- Make adjustments in operational parameters since the level of IS reaching the thresholds which are sensed by human or potentially dangerous to structures.
- Green zone: Continue the injection process , the HF process and all the elements of system are perfectly in operation.

Conclusions

- Hydraulic Fracturing (HF), and normal and sustained production or disposal of produced creates Induced Seismicity (IS) . The key question is the size of the IS and the associated risk.
- There is also evidence for the triggering of small tectonic earthquakes. But, the vast majority of the detected MEQ by seismic monitoring are the result of shear fracturing and induced.
- Probability of triggering a damaging earthquake is normally very low depending on the geology and subsurface properties.
- Formation with less consolidated rocks and active faults blocks are more likely to generate large triggered events.
- In the absence of large faults and tectonic stress, HF is not likely to induce catastrophic earthquakes. This is specially true for targets below 10, 000 ft.

Conclusions (Contd.)

- The type of stress release in HF is more of a tensile based which is different from the shear stress which makes the rocks to move along the fault.
- The energy level which is released is large enough to be recorded, but too low to directly create major seismic events. The source volume defined by the migration distance of the fluid in the HF process is too small to generate a large damaging event
- Real time monitoring of micro earthquakes and real time analysis such as b-value, fractal, and stress can prevent triggering large damaging earthquakes during or after the ERO
- Much more modeling, statistical analysis and research needs to be done to substantiate some of the preliminary conclusions
- Similar to the “Earthquake Hazard Maps”, IS hazard maps can alleviate the concerns for IS risk of ERO in the majority of cases.

Induced Seismicity Consortium (ICS)

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A Proposal

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