Hydraulic Fracturing and Induced Seismicity
Current State of the Art

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Introduction

fracture treatment / Fluid Injection

↓

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

↓

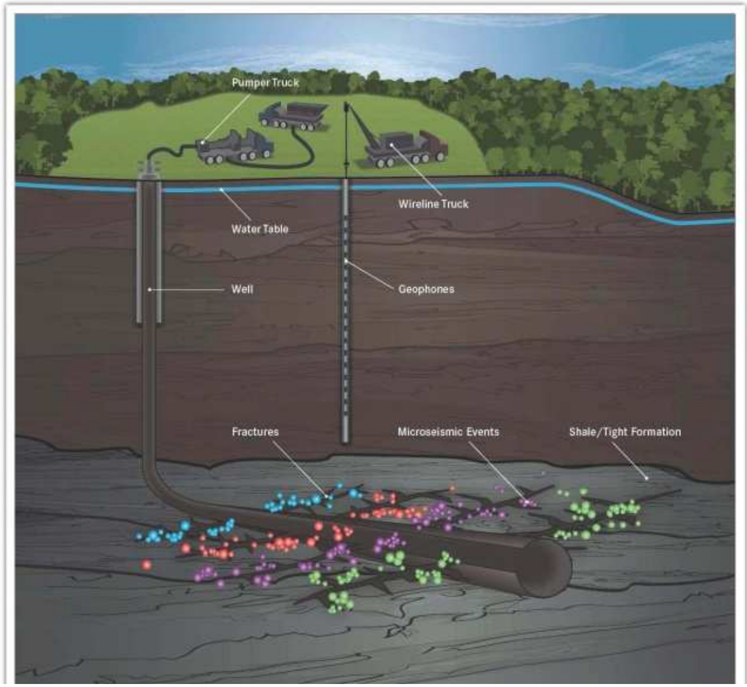
slippages emit elastic waves (stimulated seismicity)

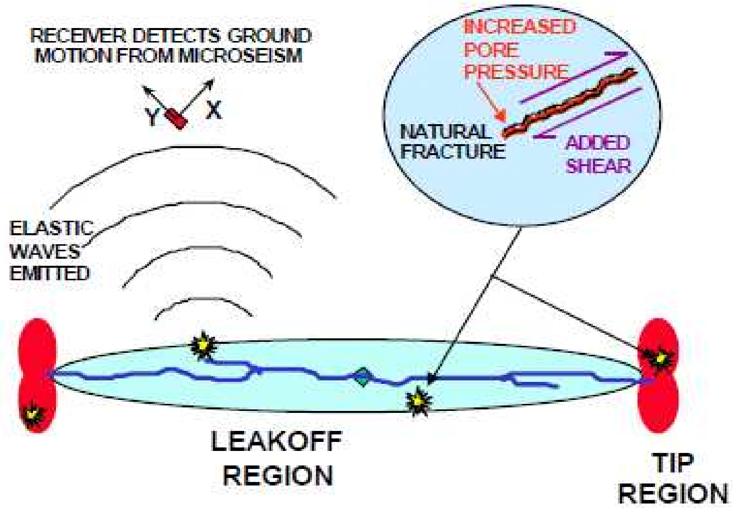
↓

Induced or Triggered

↓

HF-IS Map





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.

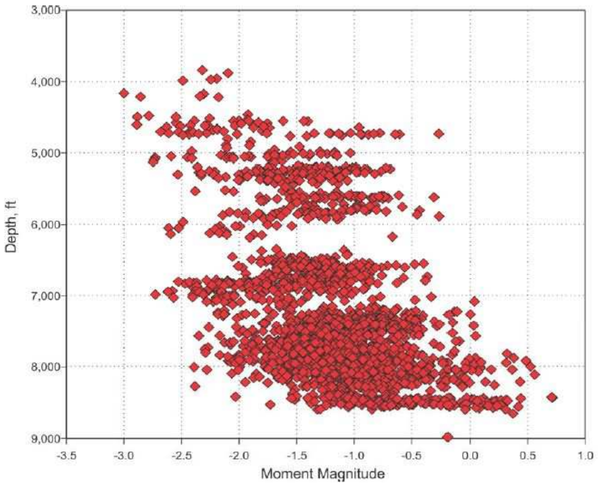
The area studied included a swath of the country running from Ohio to Colorado and Oklahoma, the study said.

“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.

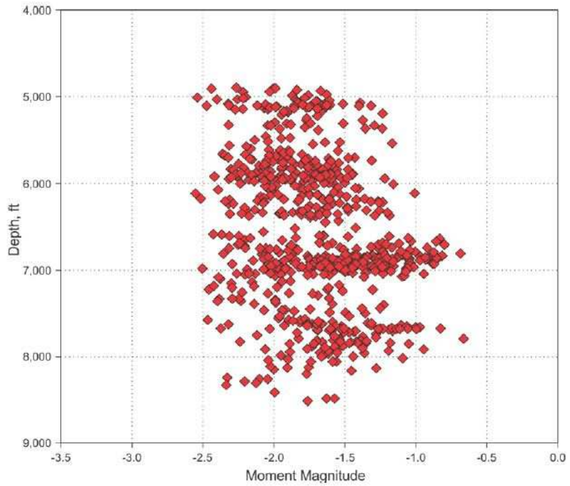
The Environmental Protection Agency is preparing to release rules on air pollution from gas wells and on the treatment of wastewater. Other state and federal rules could force more disclosure of the chemicals used by the drilling companies.

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

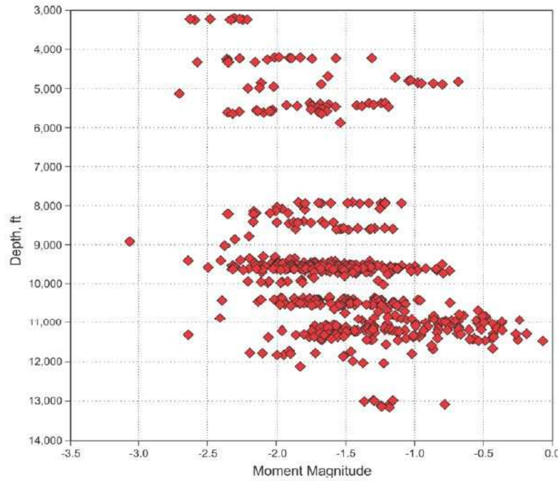
Review of past fracture treatments to identify induced seismicity characteristics: Effect of Depth



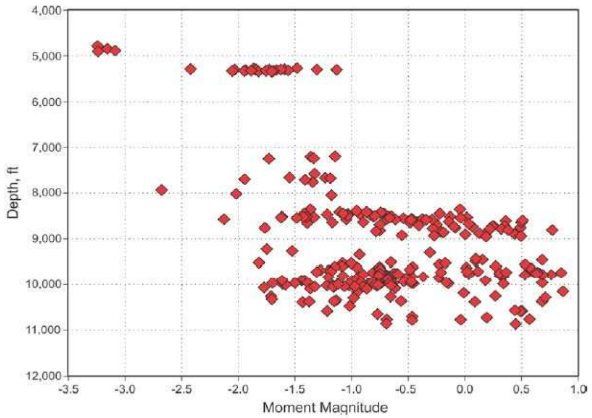
Barnett



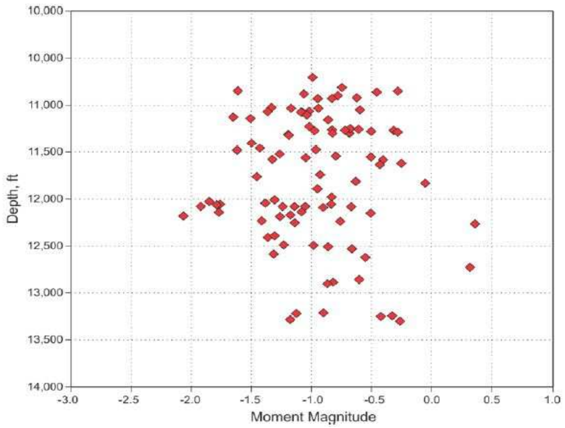
Marcellus



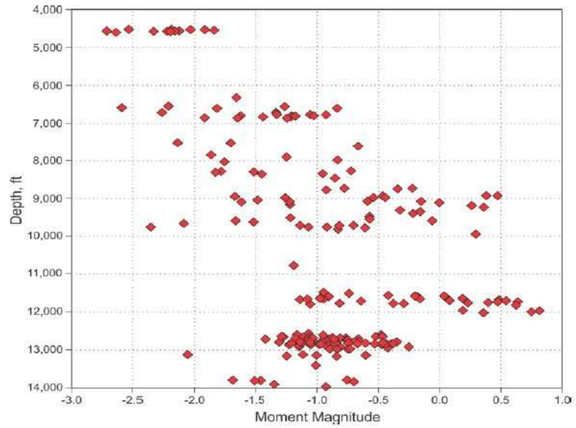
Eagle Ford



Woodford



Haynesville

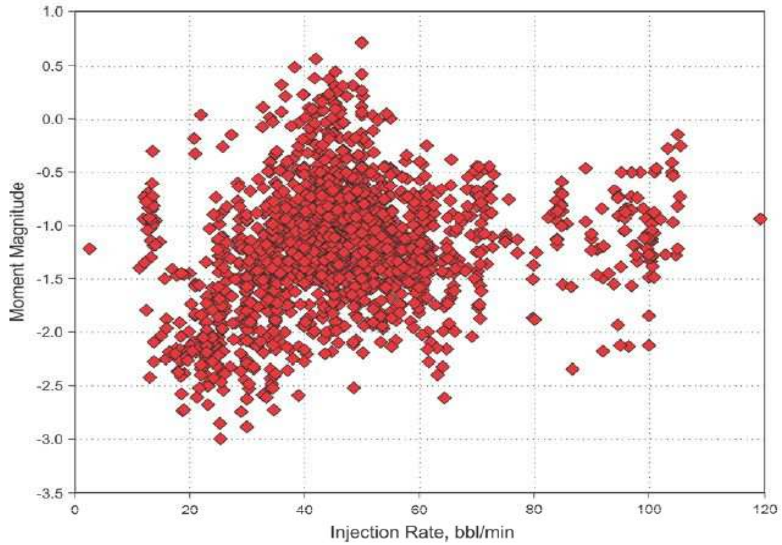


Muskwa/ Evie

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

Warpinski et al., 2012

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



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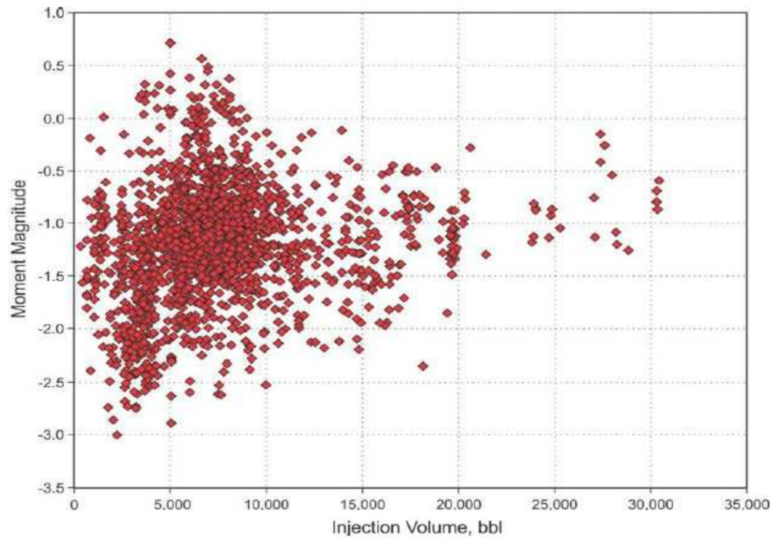

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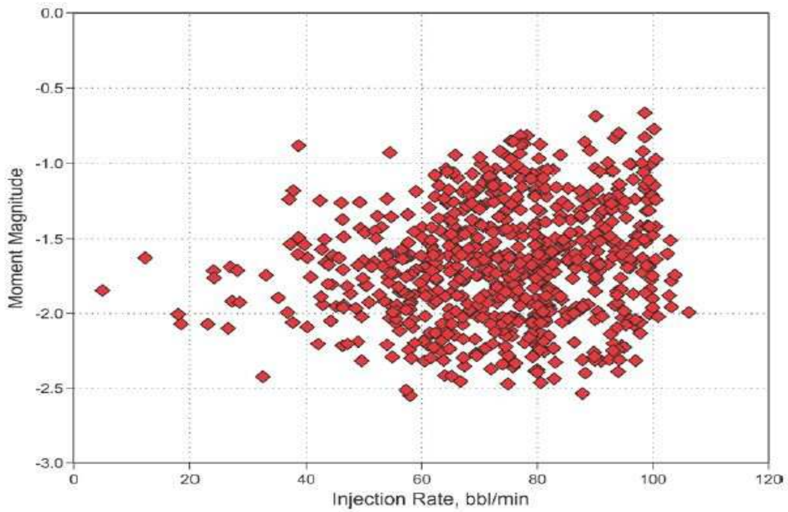

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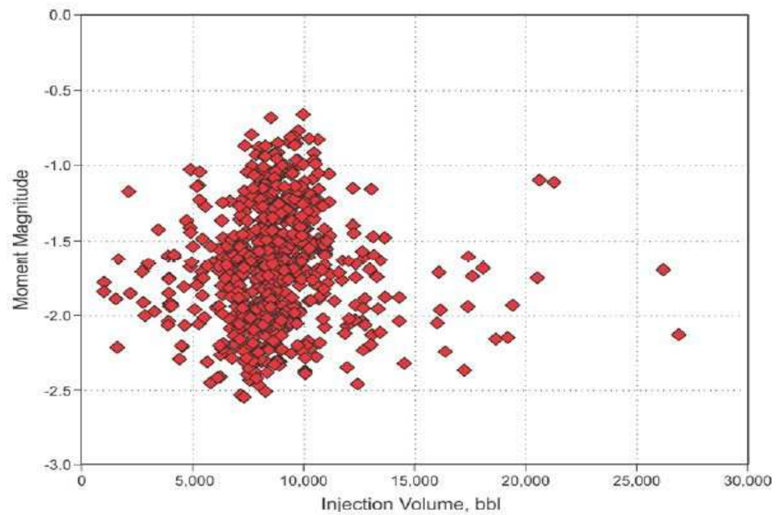
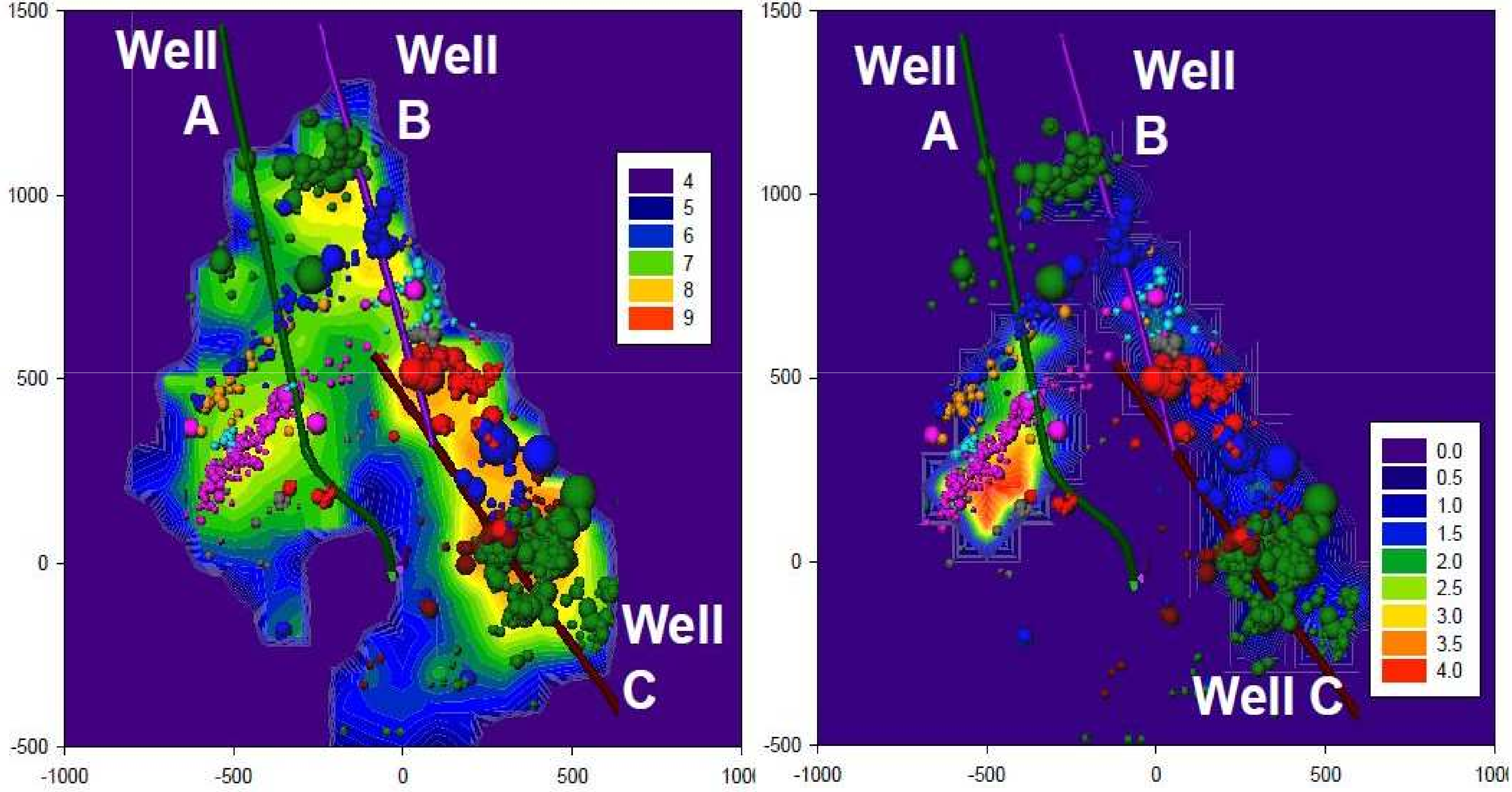


Marcellus

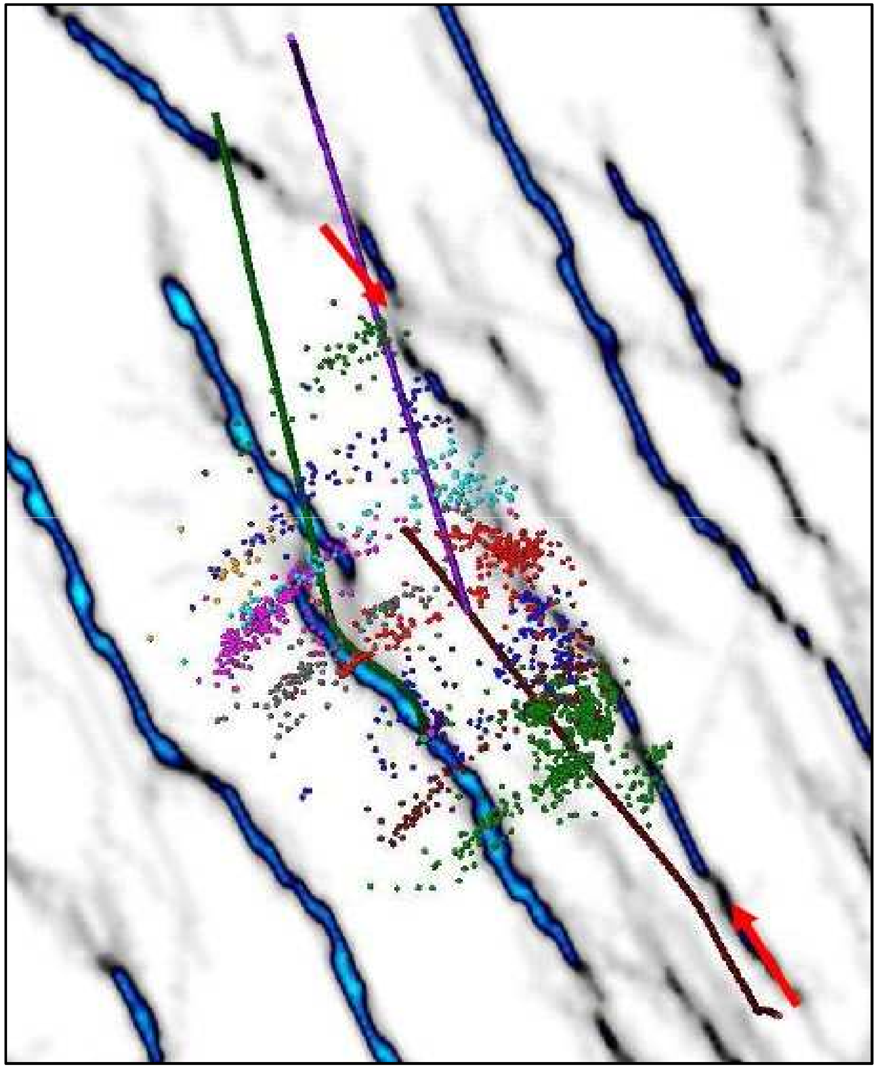
Warpinski et al., 2012

Seismic moment density and b-value for microearthquake characterization

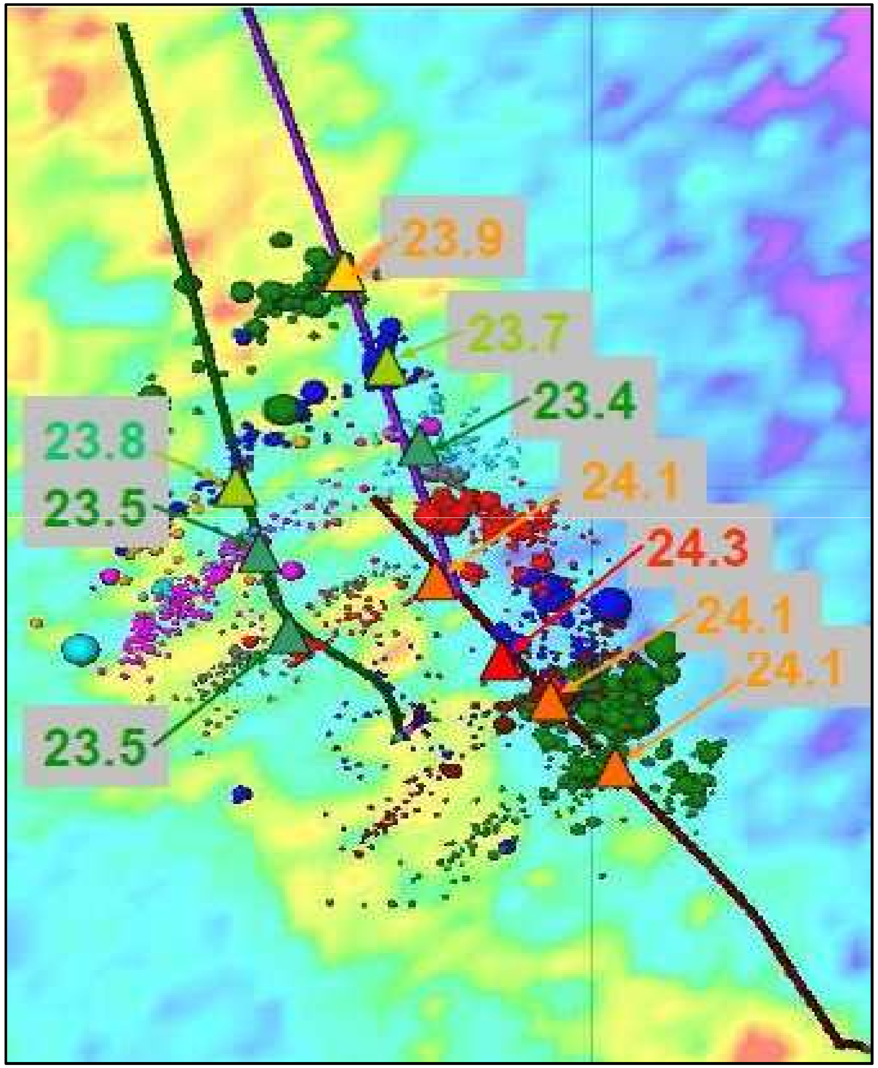


Maxwell et al., 2011

Integration with conventional seismic derived properties for verification



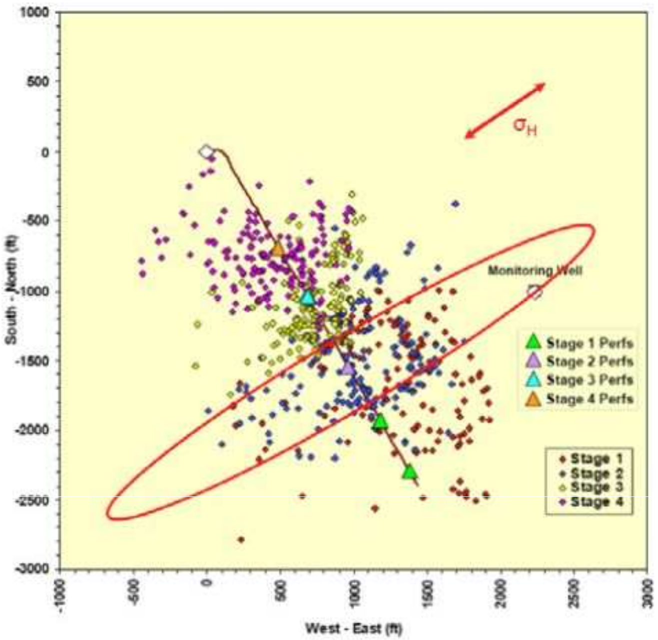
Fault map

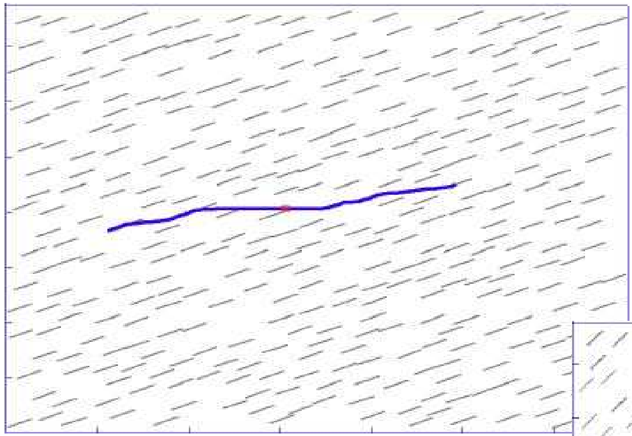


ISIP (instantaneous shut in pressures)

Maxwell et al., 2011

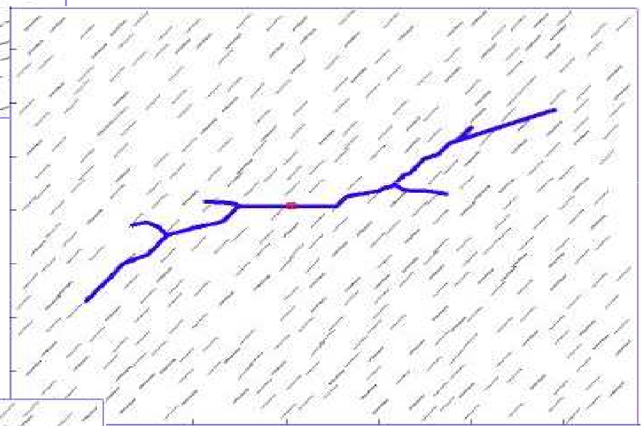
Theoretical approach to understanding fracture branching/ segmentation

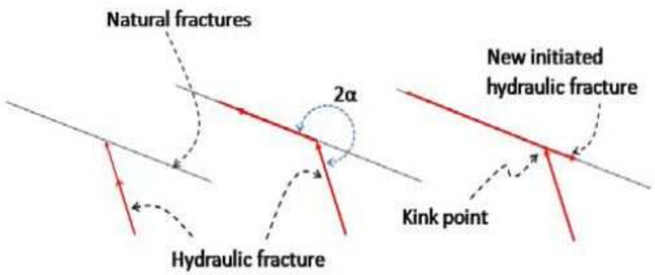




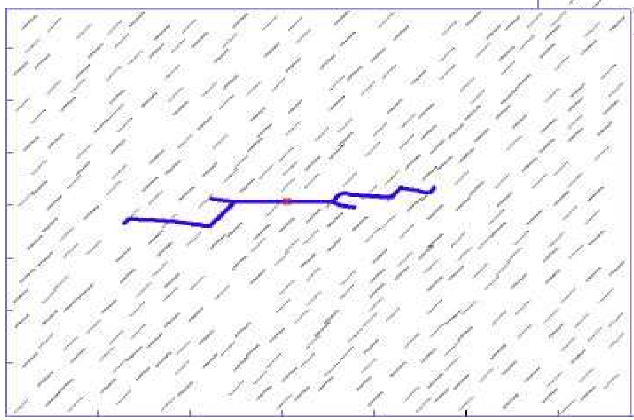
No fracture initiation with fractures oriented at 30° from max horizontal stress

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





Growth mechanism



Diffused fracture initiation with differential stress regime

Dahi Taleghani, 2010

Application of Fractal and b- value analysis in detecting induced and tectonic events

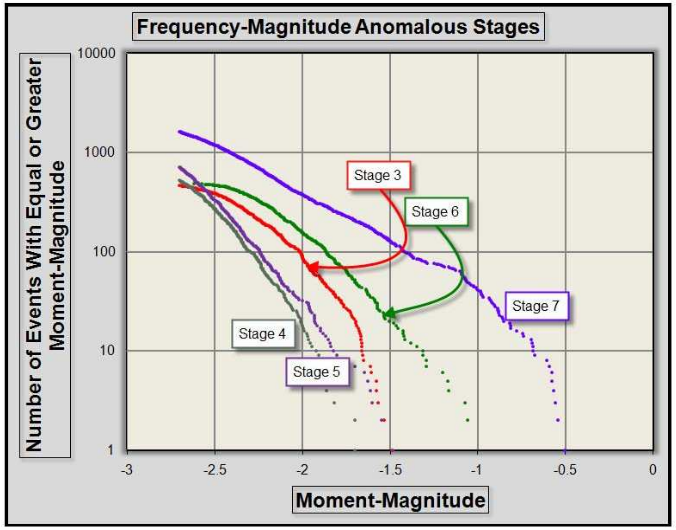
Stimulated Seismicity

Triggered

- Fractal Dimnesion ~ 2
- b - value < 1.2

Induced

- Fractal Dimension ~ 2.5
- b -value> 1.2

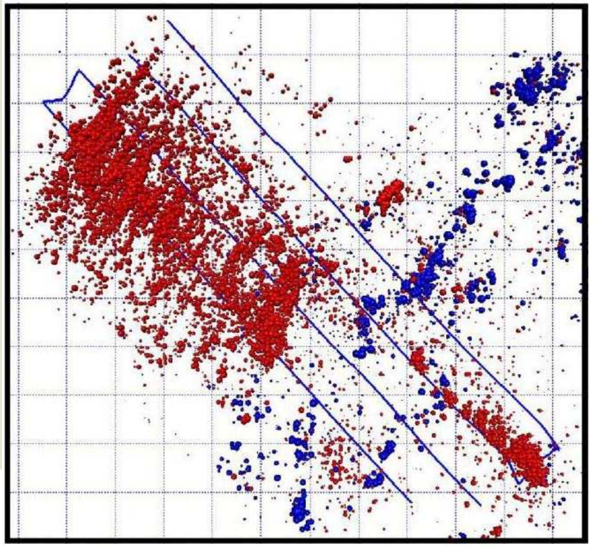


(Downie, 2010)

Higher b-value

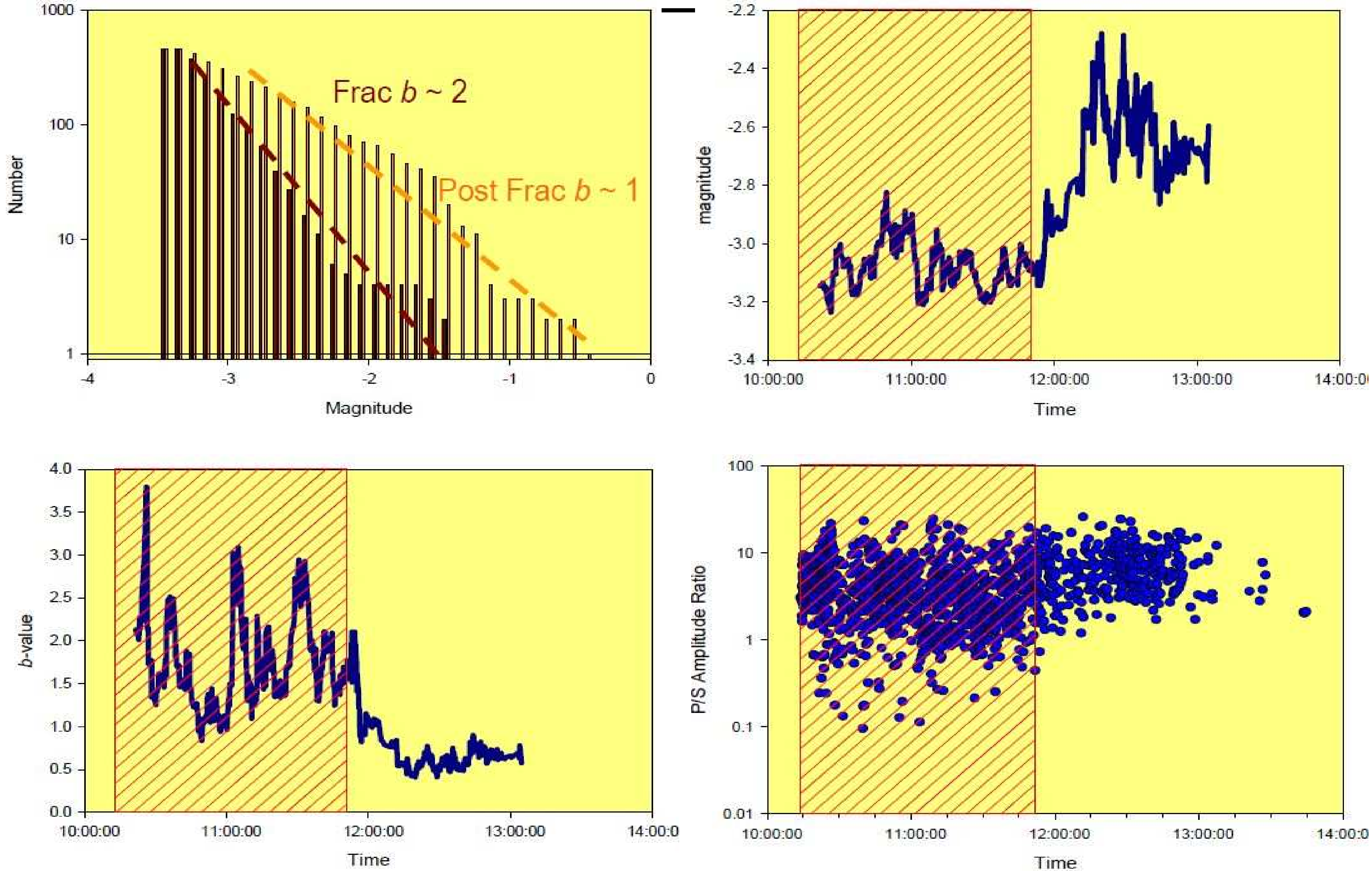
Lower Stress Regime

Smaller events



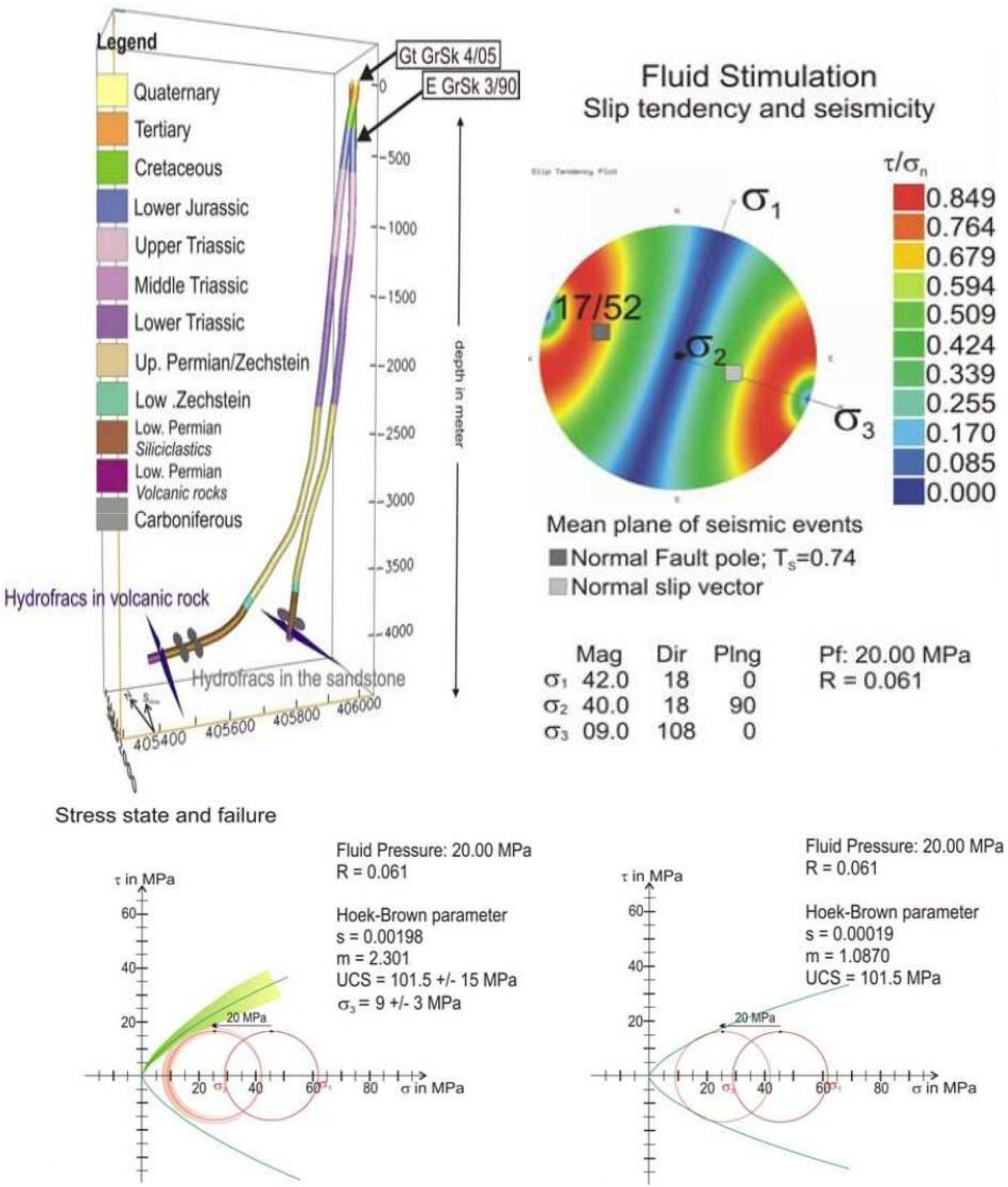
(Wessels et al., 2011)

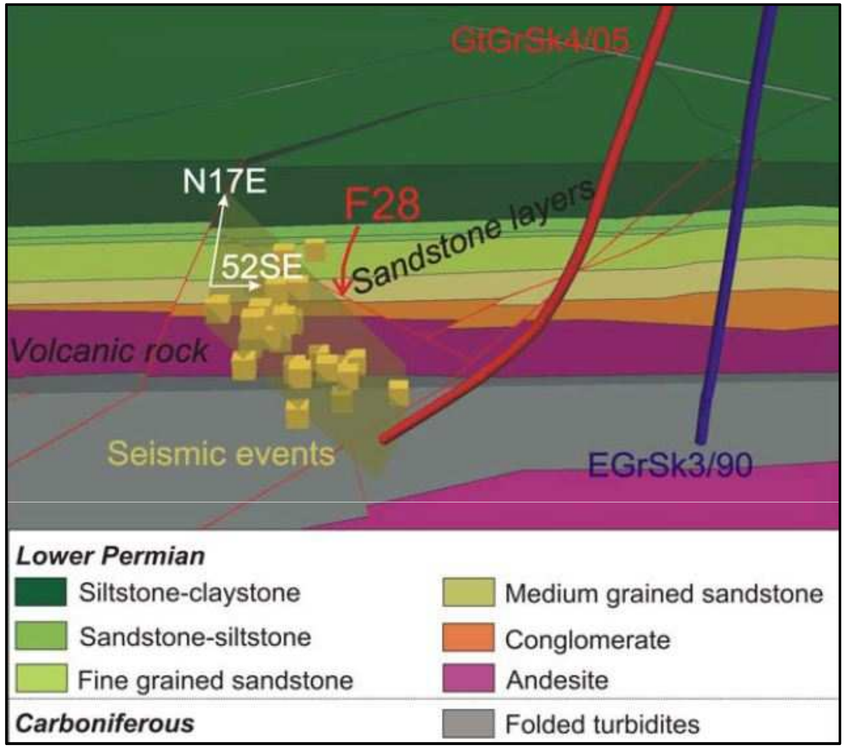
Use of temporal b-value mapping (before and after treatment) to identify activation



Maxwell et al., 2009

Fracture reactivation potential using slip tendency analysis based on stress calculations

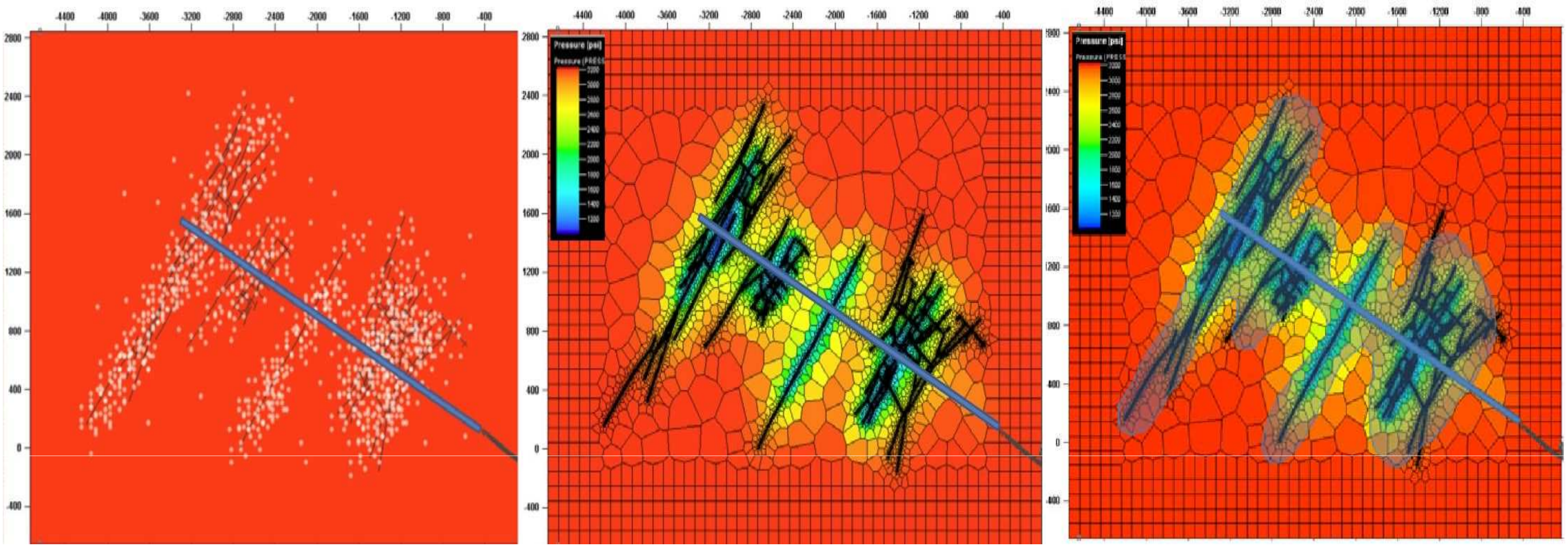


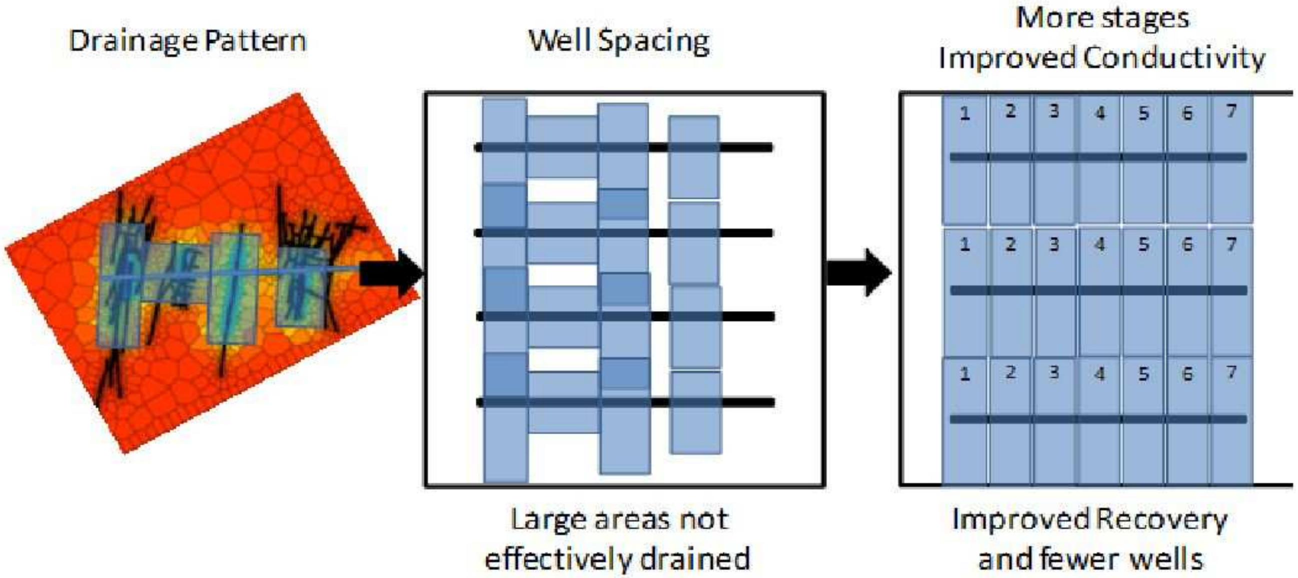


Distribution of seismicity fits orientation of F28 fault. Mohr circle diagrams show reactivation during stimulation. The stereo plot shows the slip tendency of recorded microseisms.

Moeck et al., 2009

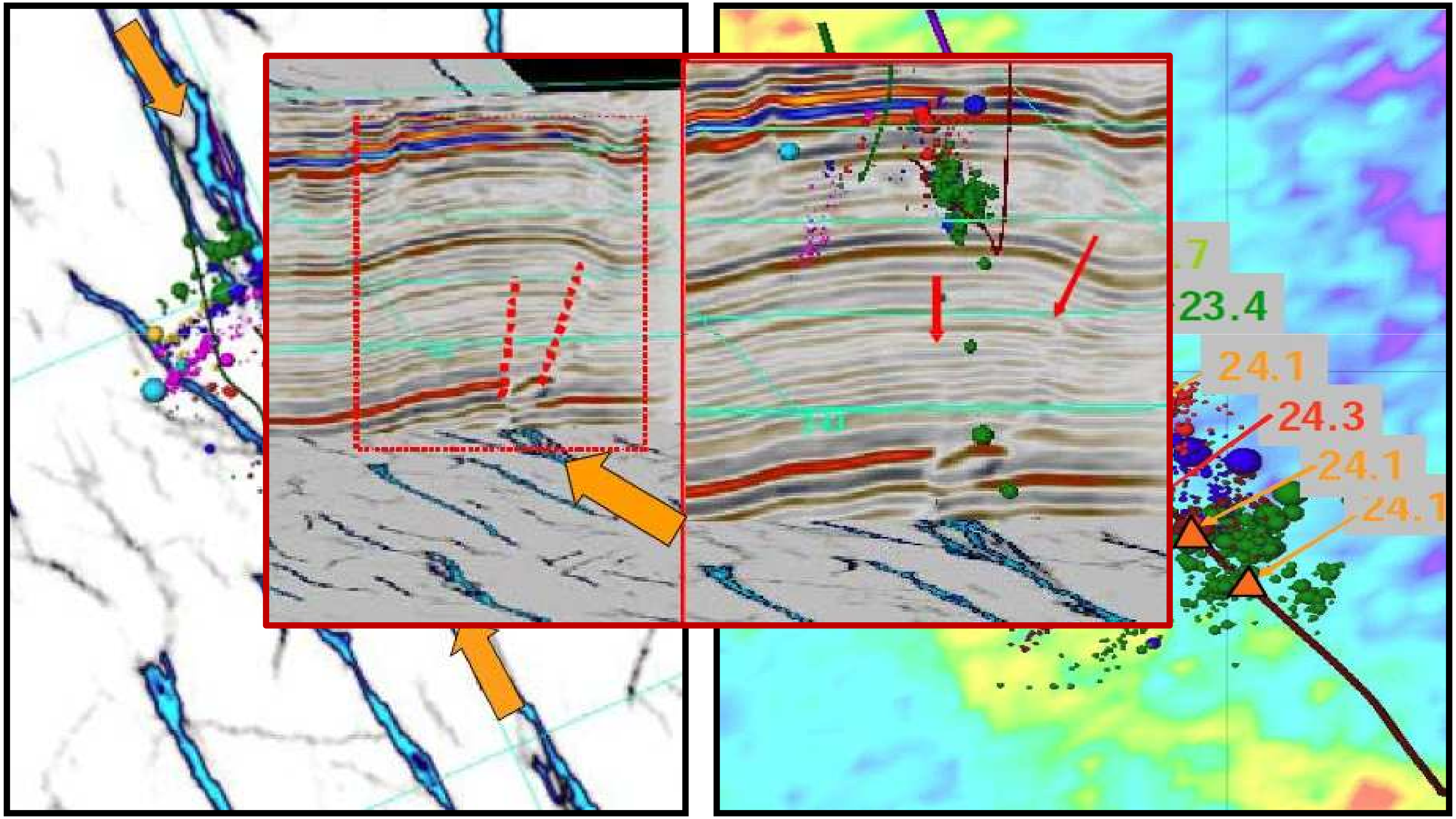
Complex hydraulic fracture geometry compared with MEQ cloud and modeled 20 year pressure depletion for un-propped zones





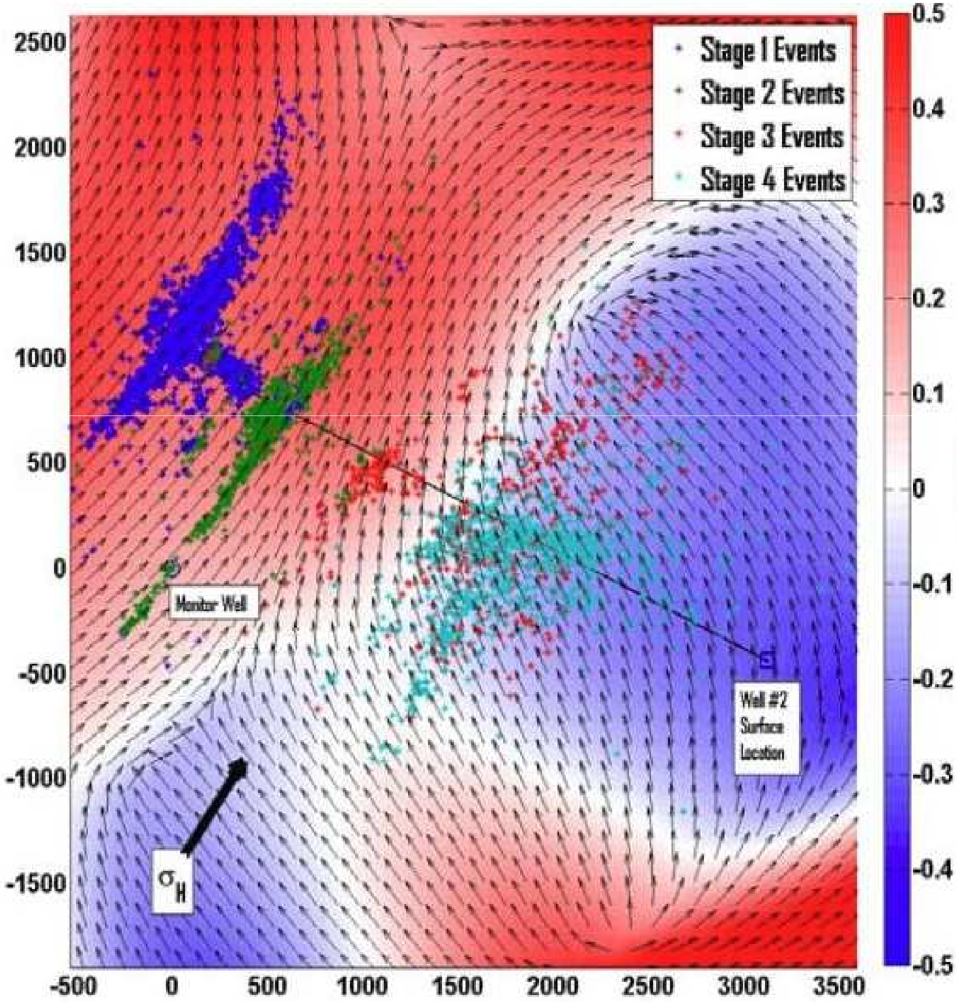
Cipolla et al., 2012

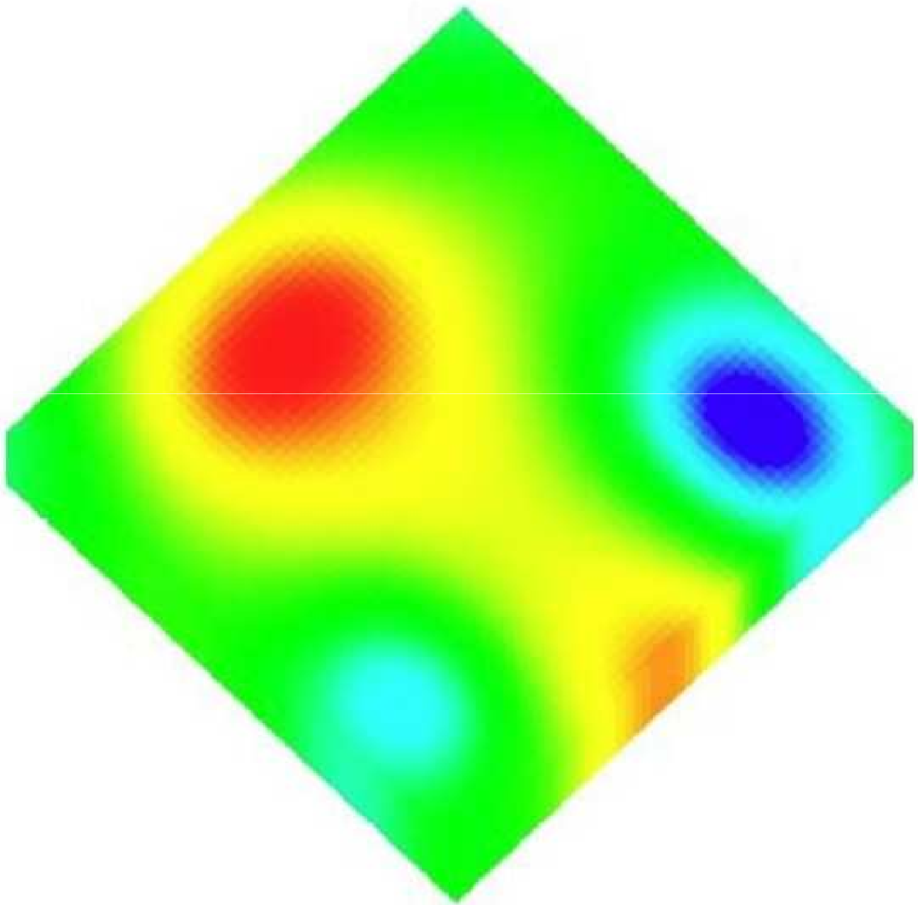
Microseismic (event locations) integrated with seismic derived attributes/ properties



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

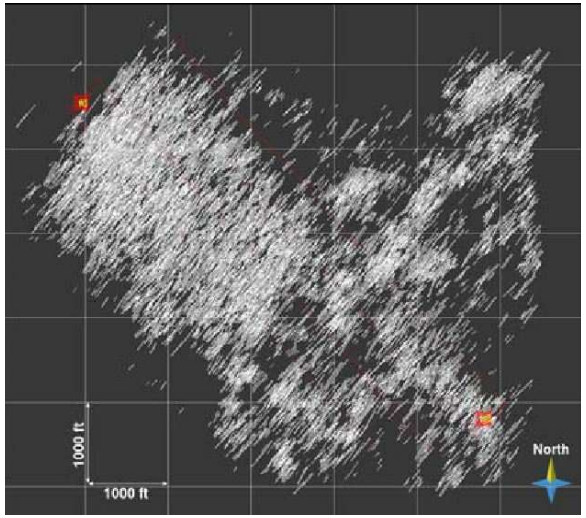
Integrated evaluation using stress anisotropy, seismic curvature & seismic fabric direction to determine fracture zone complexity



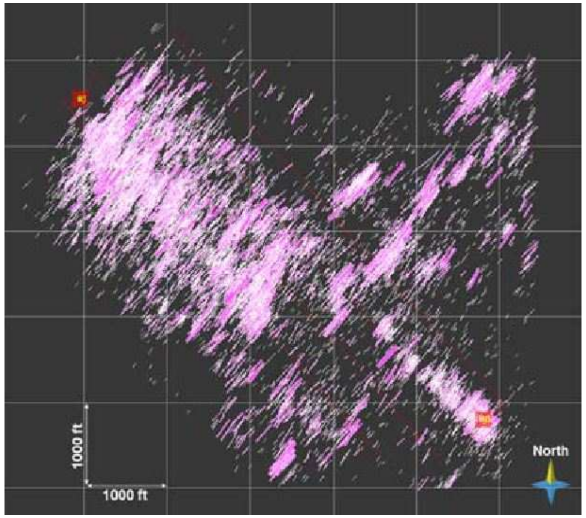


Cipolla et al., 2012

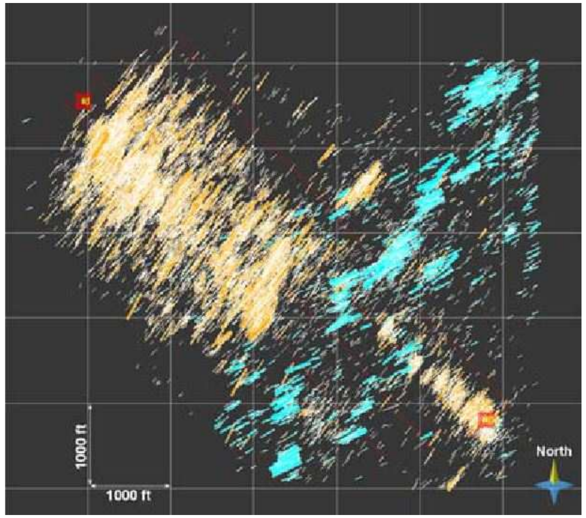
Fracture model refinement using passive seismic data



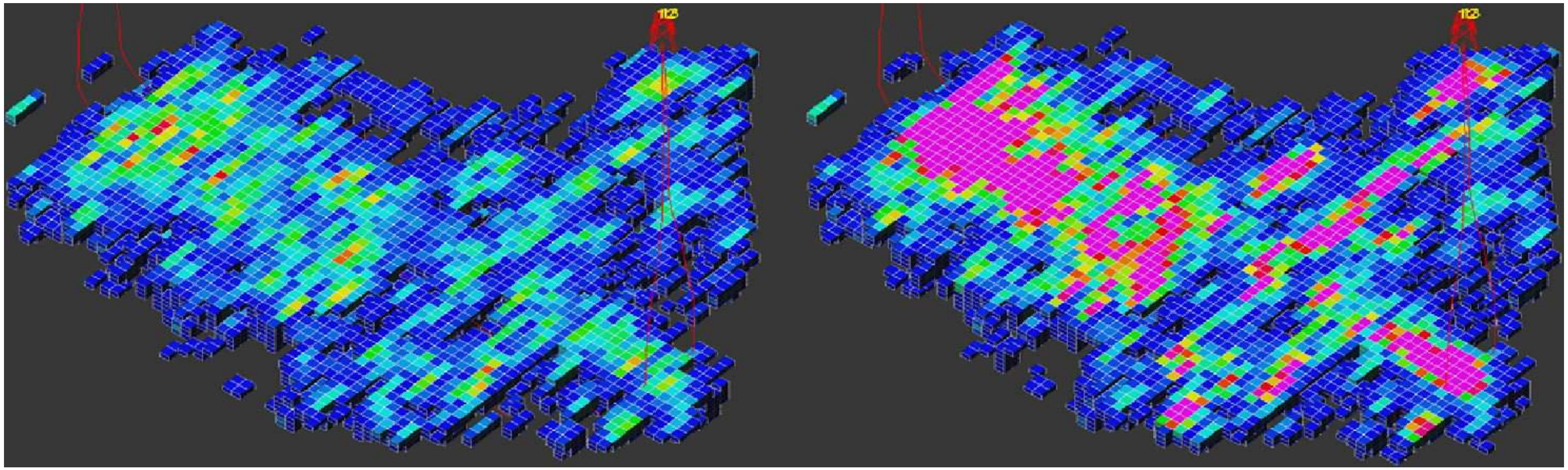
Iteration 1



Iteration 2

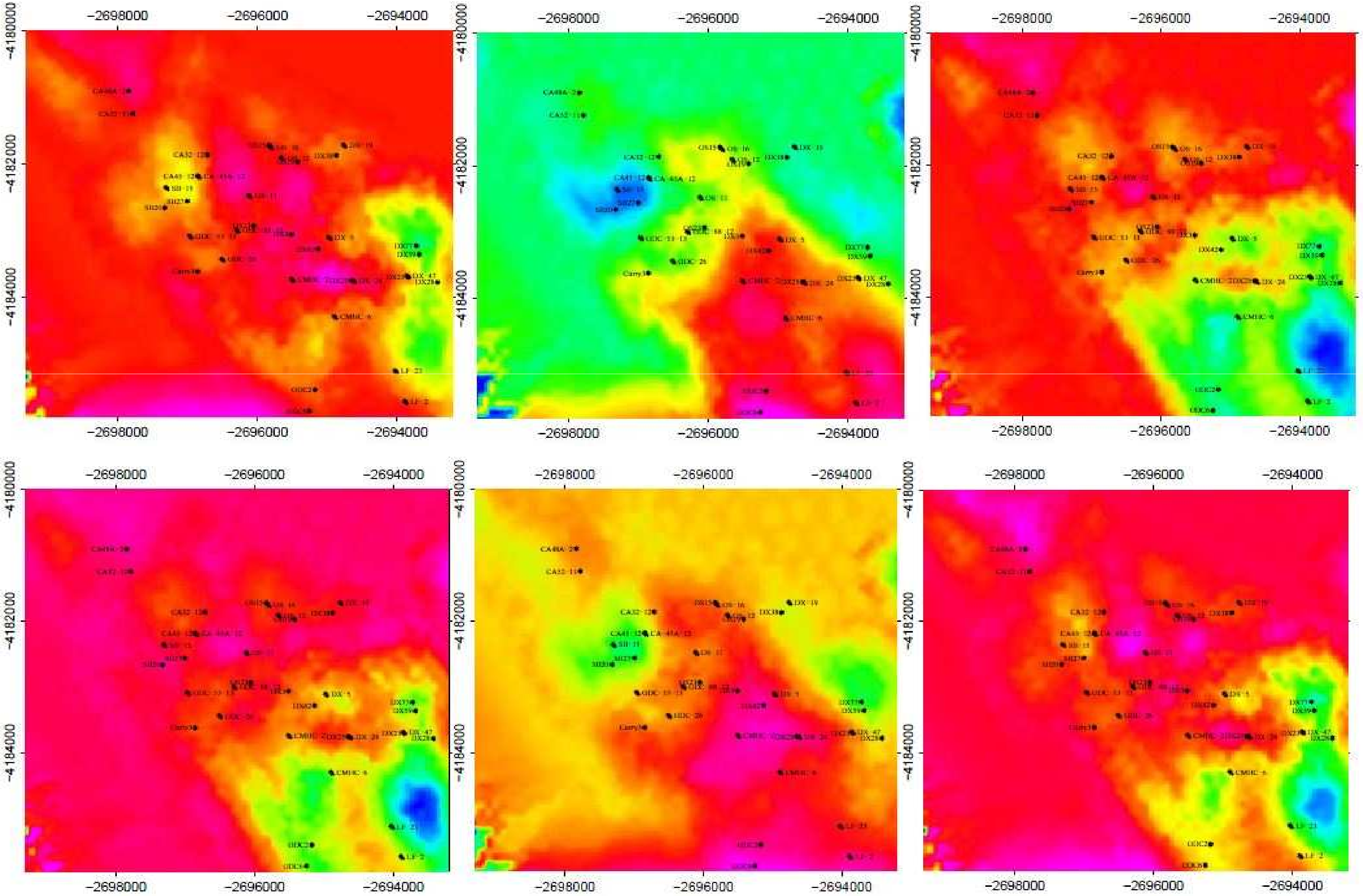


Iteration 3

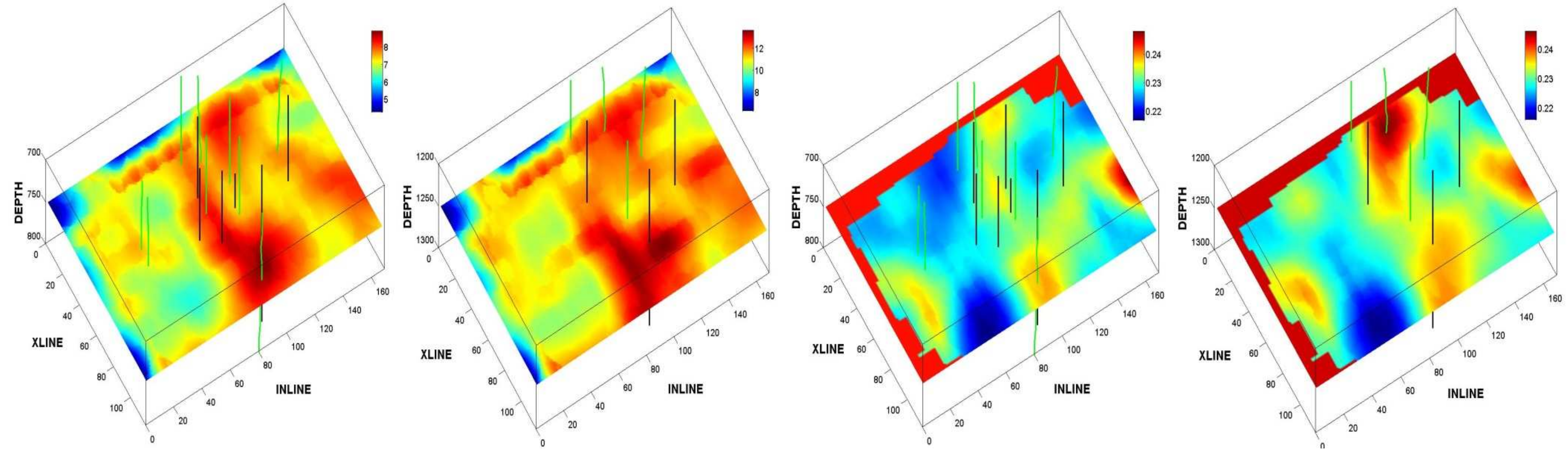


Cornette et al., 2012

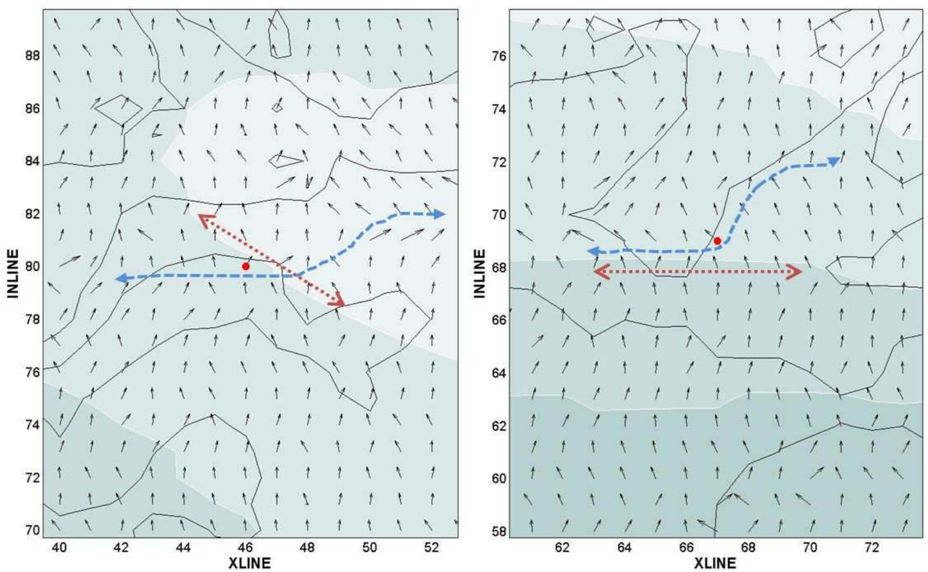
High resolution velocity inversion and elastic property estimation



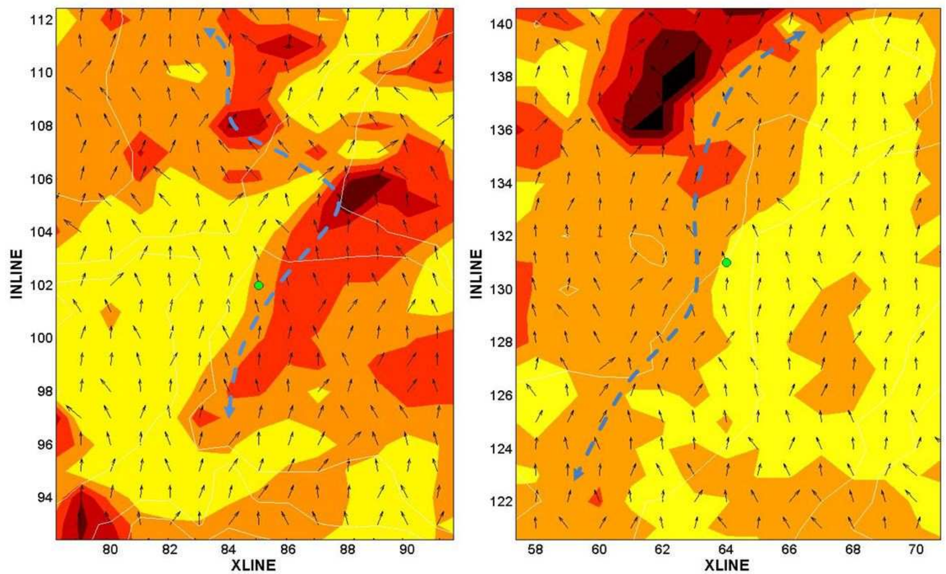
HR property estimation: Integrating microseismic, seismic & logs



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



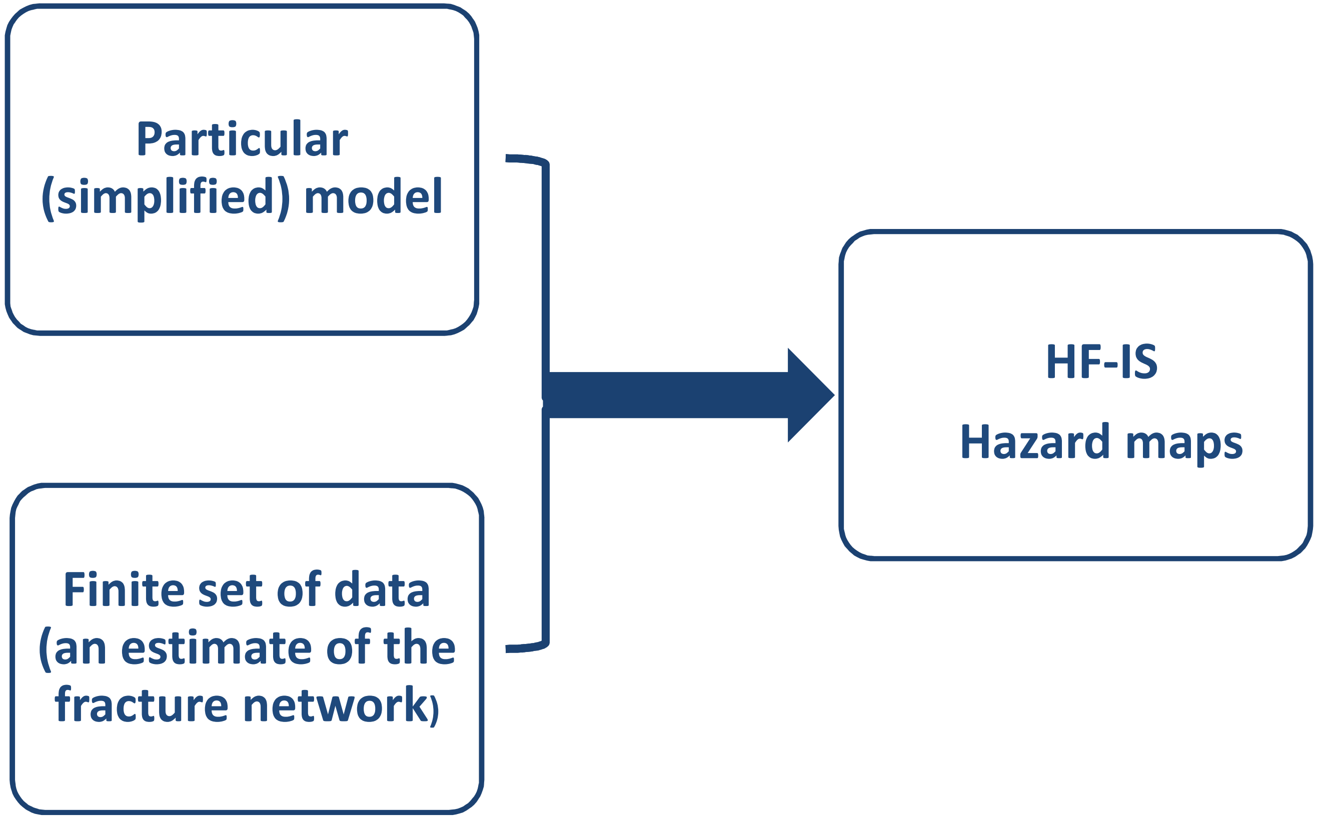
Discontinuity gradient, extensional stress & edge maps



Discontinuity gradient, ANN derived FZI & edge maps

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 fracking 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

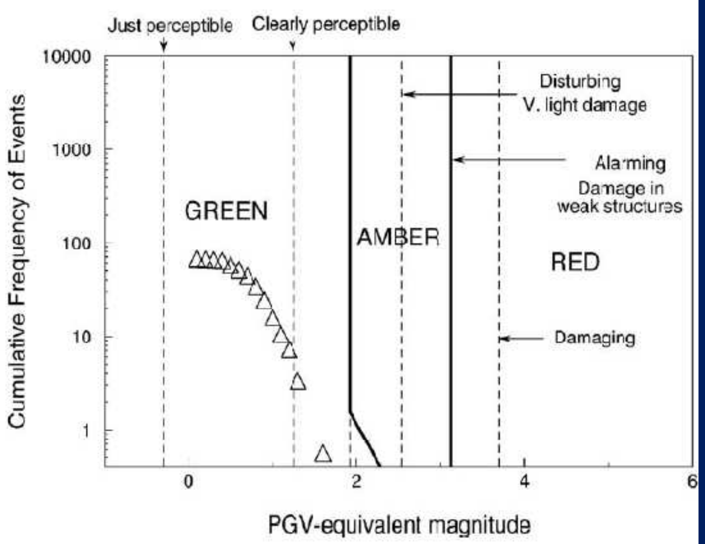
- The probabilistic evidence of the initial fractures will be propagated through physics-based models whose parameters are treated as random variables ➡ a predicted probabilistic fracking behavior

- The behavior depends on: uncertainty in initial fracks 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.

Some 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.

Some Conclusions (cont.)

- 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 HF
- Much more modeling, statistical analysis and research needs to be done to substantiate some of the preliminary conclusions
- Similar to the "Earthquake Hazard Maps", HF-IS hazard maps can alleviate the concerns for HF-IS risk in the majority of cases.

Hydraulic Fracturing vs Induced Seismicity (HF-IS)

A consortium is being formed at the University of Southern California (USC) to develop a set of predictive tools and models for assessing the impact of hydraulic fracturing (HF) on induced seismicity (IS) or earthquakes for various geographical areas of the U.S. and elsewhere. We will examine the extent of potential risk of different hydraulic fracturing processes in different geologic regimes and develop a "HFIS" hazards maps to quantify the expected risk factors.

- **Characterizing Fracture Network Using Microseismic Data**
- **Developing ANN Model to Correlate MEQ Events and Microseismic Attributes**
- **Developing a Hierarchical Probabilistic Model for Operational Parameters**
- **Developing a System to Control the Hazard Associated with Induced Seismicity**
- **Science-based Sensible Regulation**

USC University of Southern California

Hydraulic Fracturing vs Induced Seismicity (HF-IS)

- To introduce the USC program, we will organize the HF-IS Forum at USC
- During this forum we will have information sharing sessions bringing scientists, operators and regulators together to chart our path forward for addressing this important problem.
- USC team will be comprised of faculty and investigators from
  - USC Viterbi School of Engineering Petroleum Engineering Program
  - Civil and Environmental Engineering Department
  - Southern California Earthquake Center (SCEC)
  - USC Price School of Public Policy
  - A former assistant secretary of the DOE and a State regulator
- Input and active participation from other R&D groups and operators and regulatory groups will be sought.
- For more information or to join USC-HF-IS contact Fred.Aminzadeh@usc.edu