Induced Seismicity
Intersection of Science, Public and Regulation

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IOGCC Annual Meeting

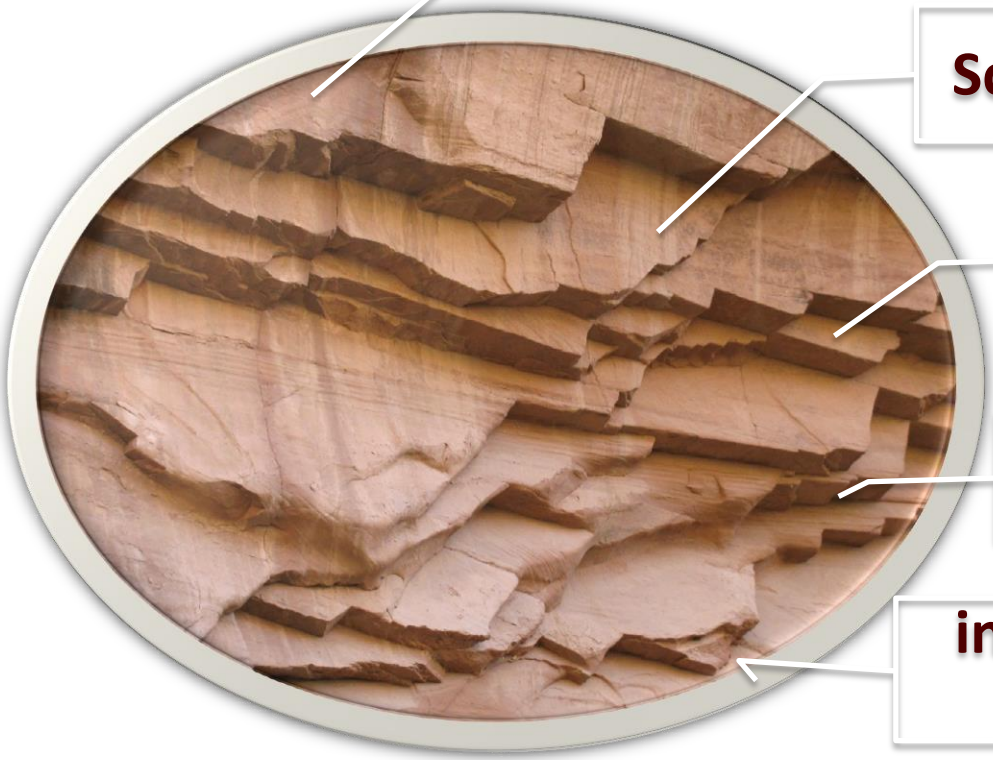
Long Beach, CA

November 5, 2013

USC Viterbi School of Engineering

GEN ISC University of Southern California

Summary



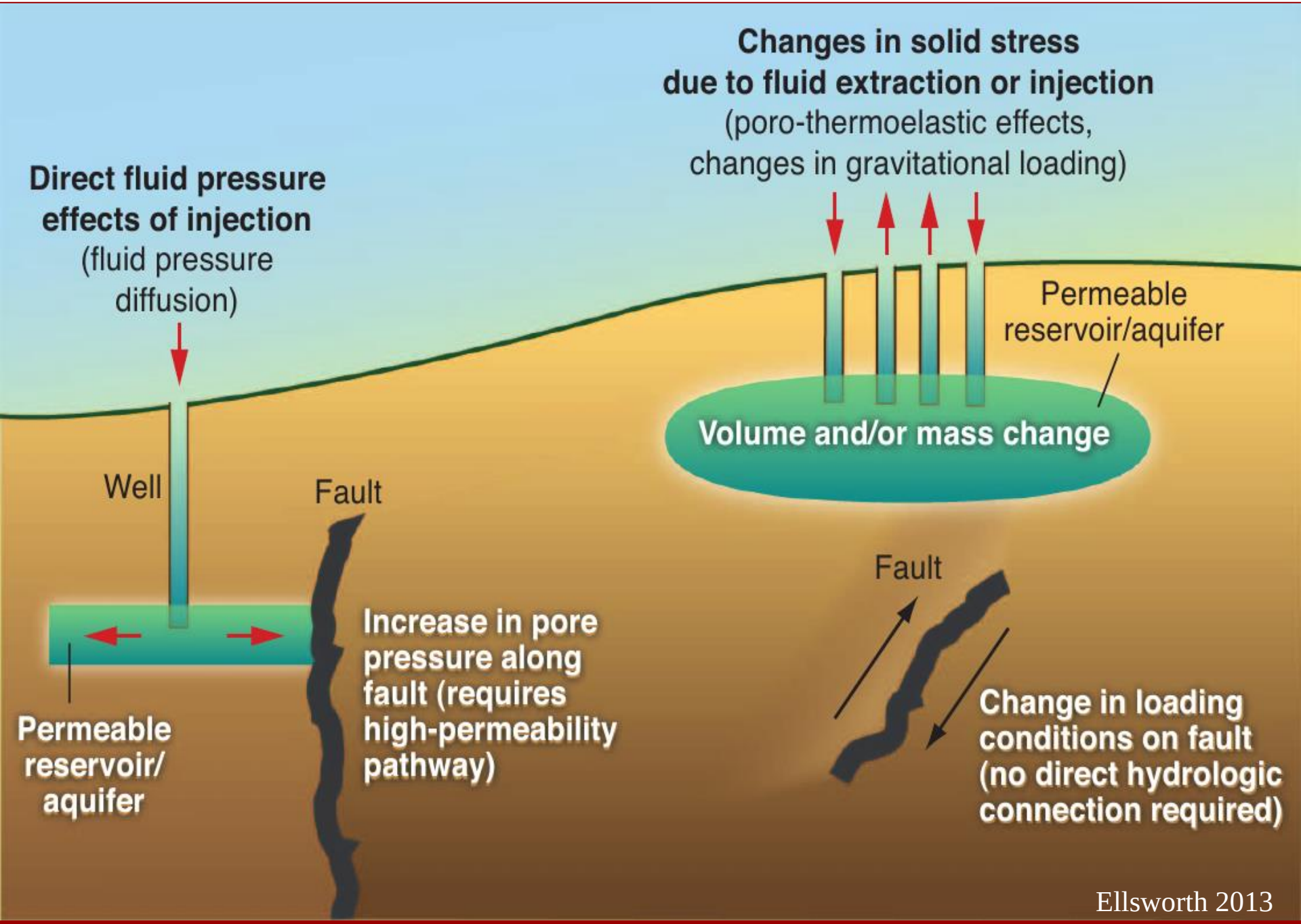
What is Induced Seismicity

Scientific Foundation

Hydraulic Fracturing / SFIP

Induced Seismicity Consortium

intersection of the science, the public, and the regulation



Ellsworth 2013

Definitions

- SFIP
  - Subsurface Fluid Injection and Production, including:
  - Hydraulic Fracturing
- Triggered Seismicity
  - SFIP accounts for only a small fraction of the stress change associated with the earthquakes.
  - Pre-existing tectonic stress plays the primary role
- Induced Seismicity
  - SFIP accounts for most of the stress change or energy to produce the earthquakes

Accurate and Consistent Assessment of Risk is Essential for all SFIP

- What is the largest earthquake expected?
- Will small earthquakes lead to bigger ones?
- Can induced seismicity cause bigger earthquakes on near by and 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

Mechanisms

Production induced

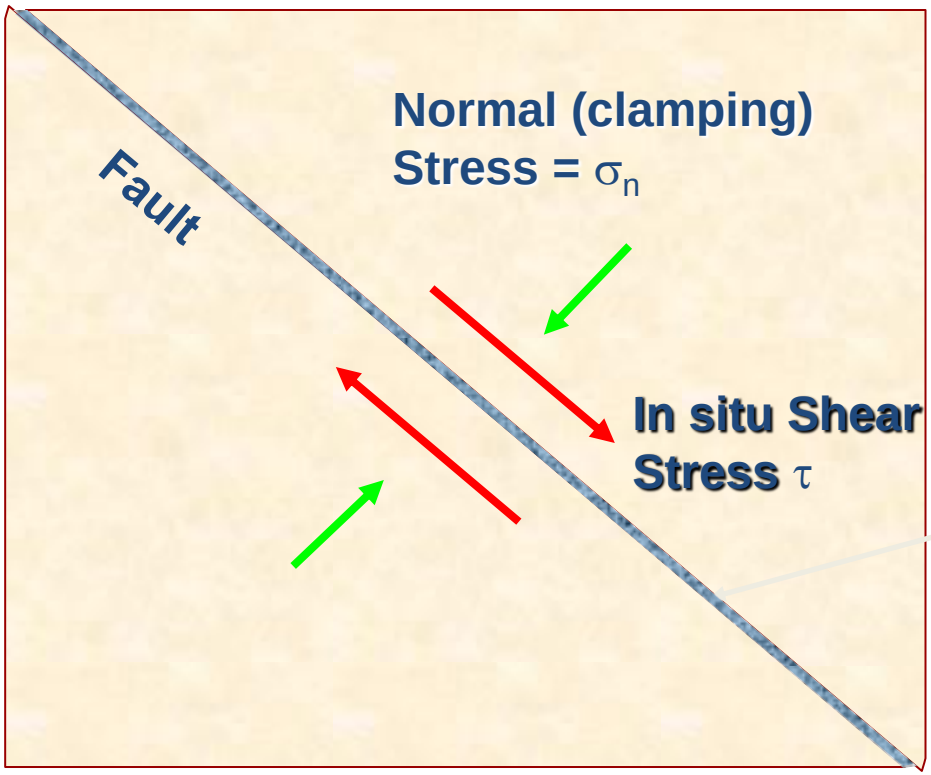
Injection induced

- Thermal stress
- Chemical alteration of slip surfaces
- **Pore pressure increase**

Effective stress changes

- Ambient stress variations
- Volume change (subsidence, inflation)

Role of Fluid Pressure in Earthquake generation



For a microearthquake to occur one must exceed the critical shear stress on the fault:

$$\tau = c + \mu(\sigma_n - p)$$

Water/fluid pressure in fault = **p**

μ= coefficient of friction on fault

Elevated Fluid Pressure:

- Reduces effective normal stress on fault, lowering resistance to shearing. **Implies that if pressure balance can be maintained seismicity can be controlled**

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

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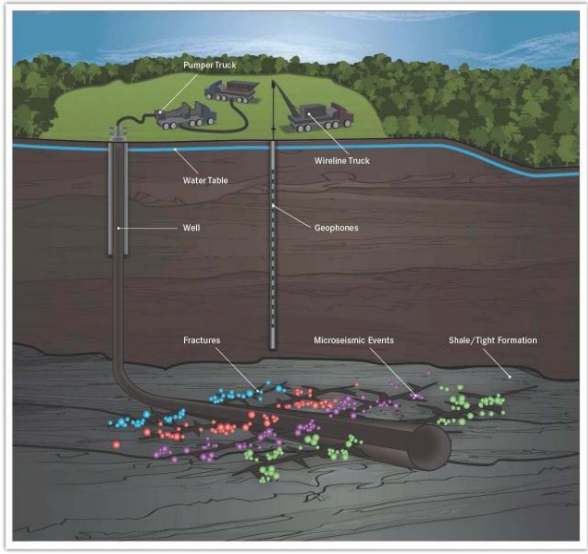
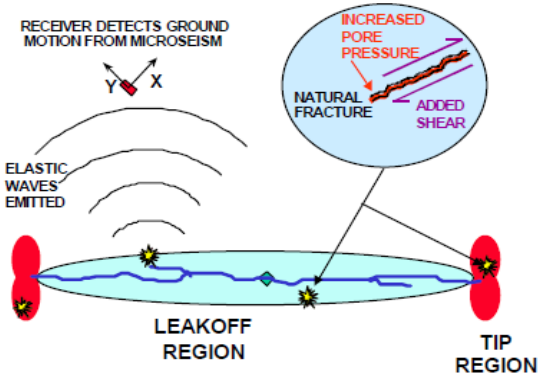
Models-IS Risk Maps





Three main issues

- How to assess risk
- How to minimize risk
- How to use Induced seismicity effectively

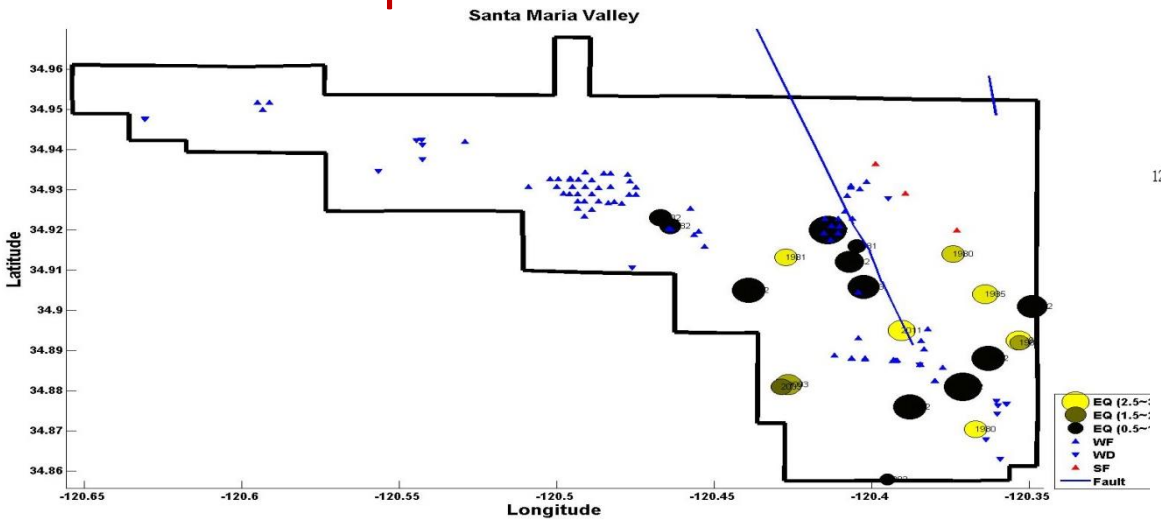
Some of the USC-ISC Ongoing Work

- Real time monitoring
- Regional Studies
  - San Joaquin Valley, CA,
  - Youngstown, Ohio and
  - Prague Oklahoma
- Generating IS hazard maps
- Geo-mechanical modeling:
- Laboratory experiments

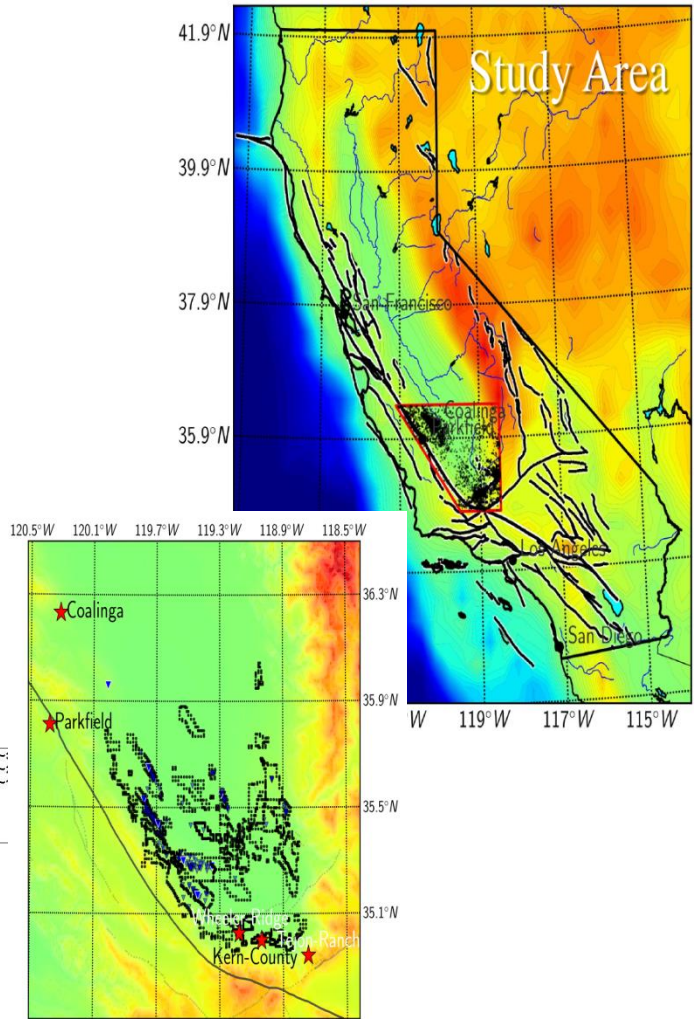
isc.usc.edu

Regional Studies: San Joaquin Valley, CA,

- B-Value Analysis
- Fault related events VS SFIP
- Correlating Seismicity and SFIP
- Hazard maps

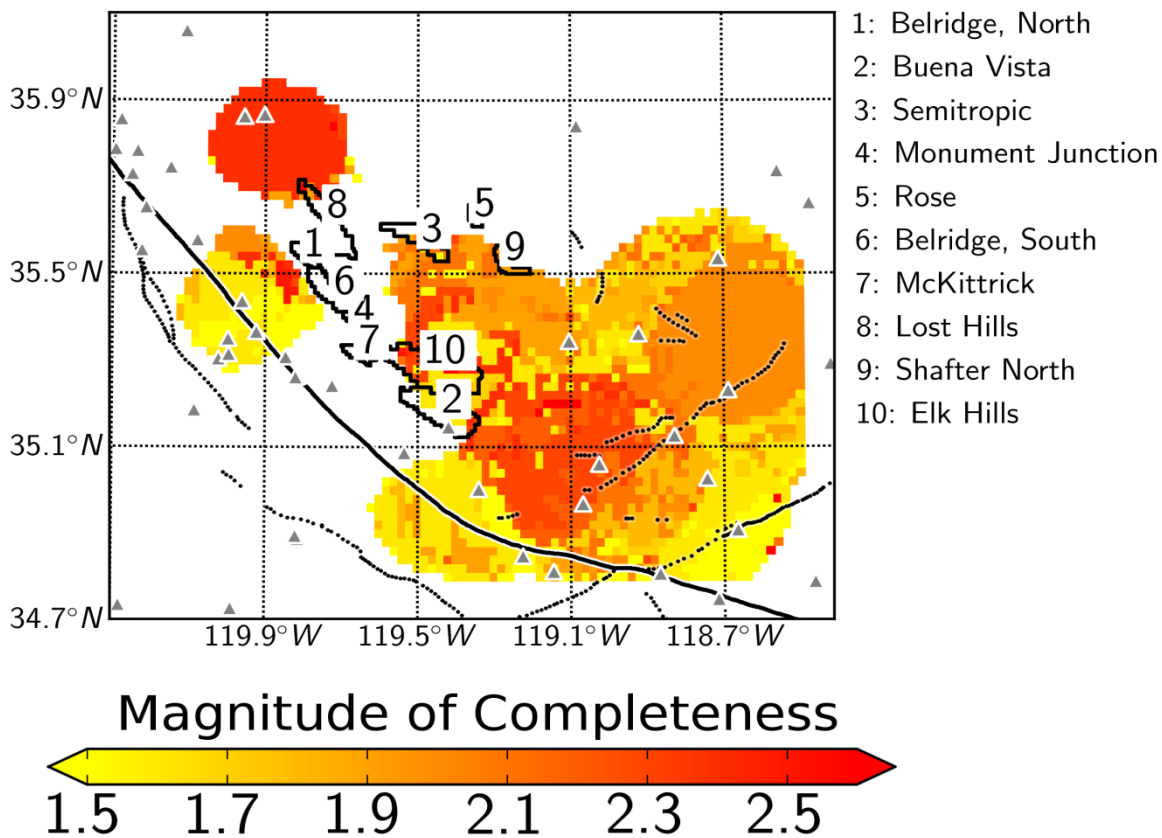


Santa Maria Valley field seismicity and reported SFIP

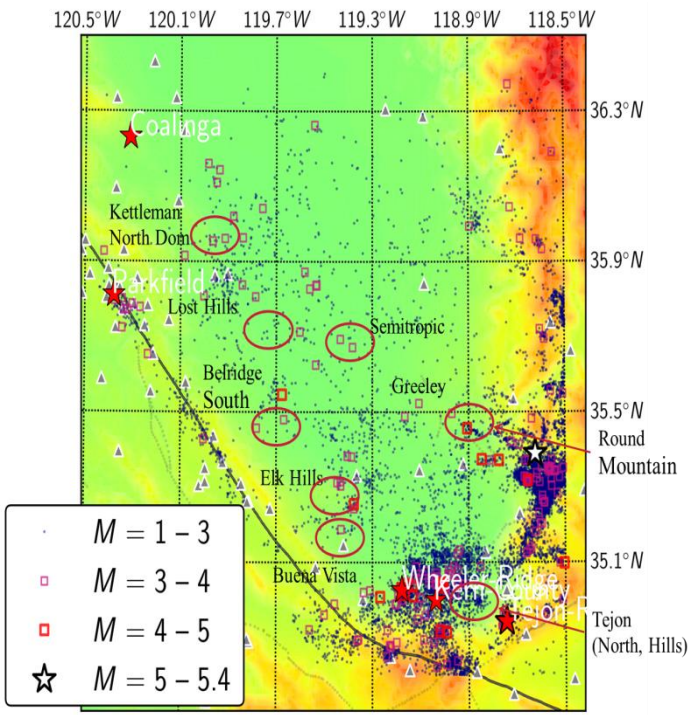


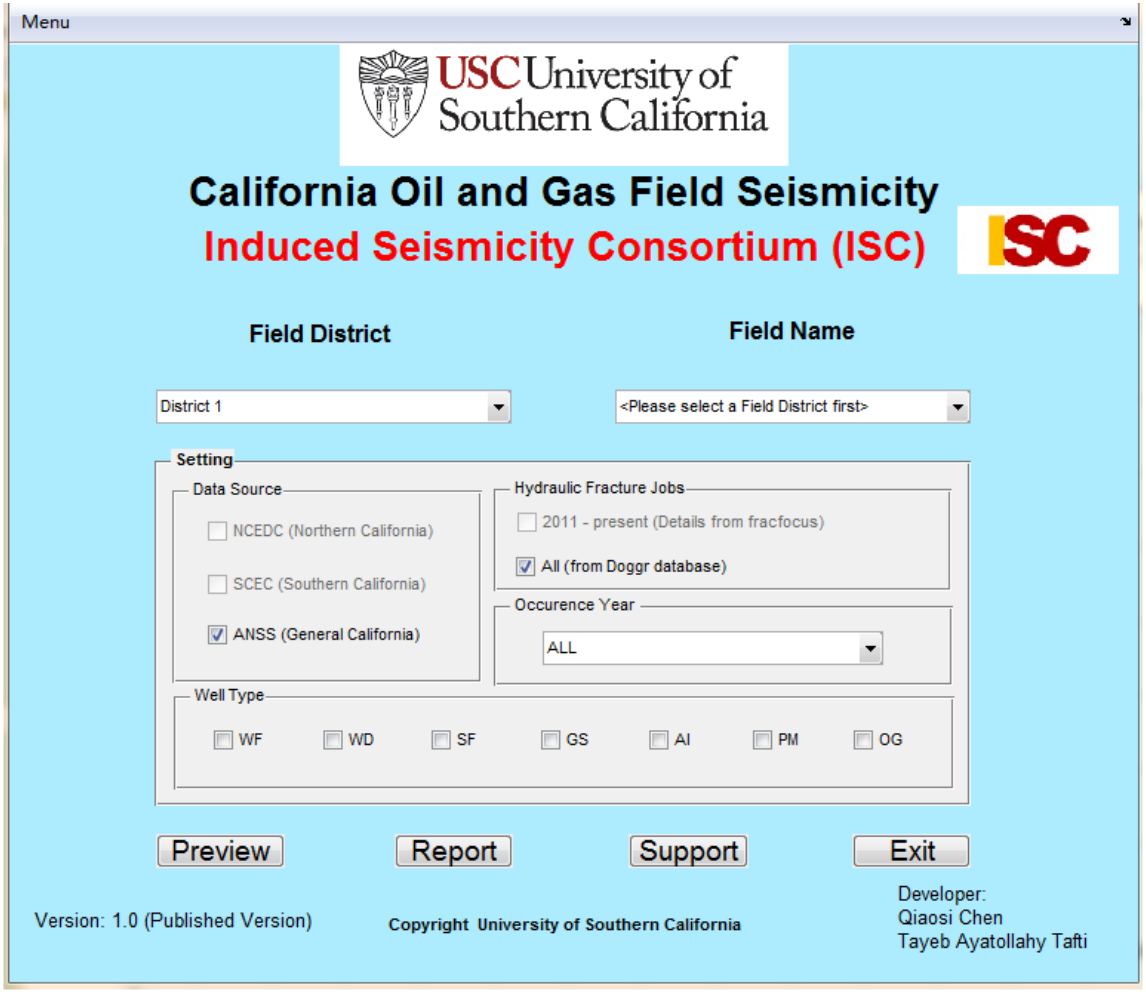
Regional Studies: San Joaquin Valley, CA,

- Spatial variations in the magnitude of completeness
- Oil fields are highlighted in black and labeled according to the legend on the right.
- The gray triangles mark the position of seismic stations.

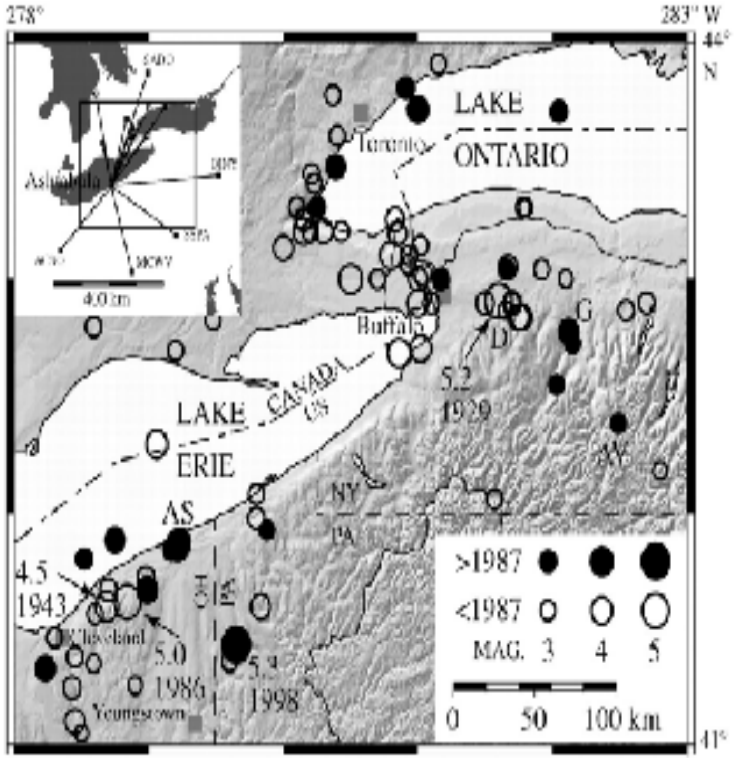


California Oil an Gas Field Seismicity,



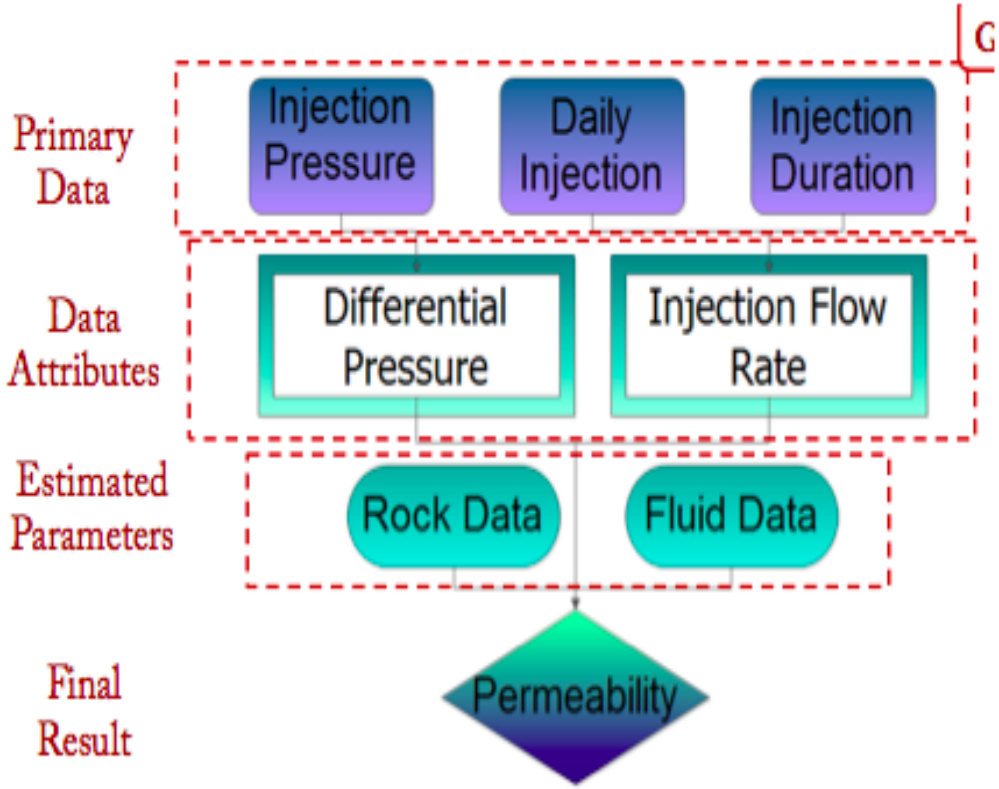


Regional Studies: Youngstown, OH,



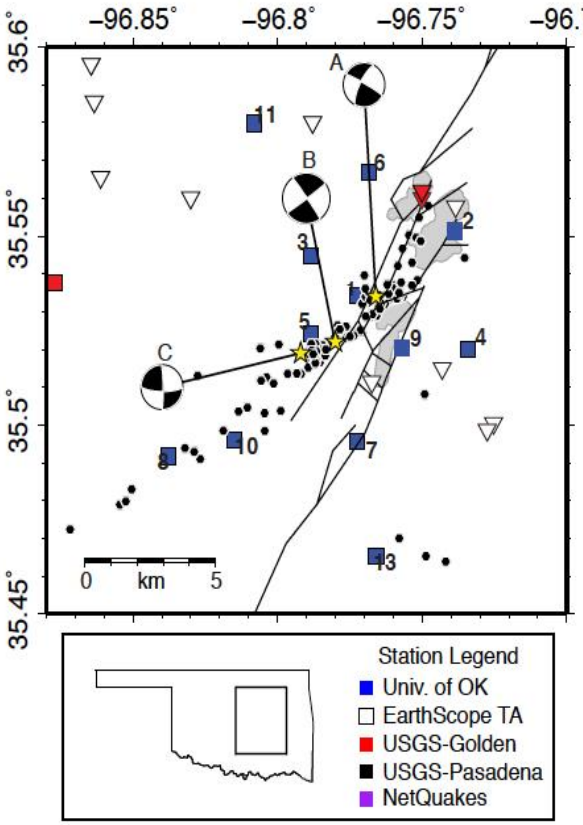
Historic seismicity in the state of Ohio.

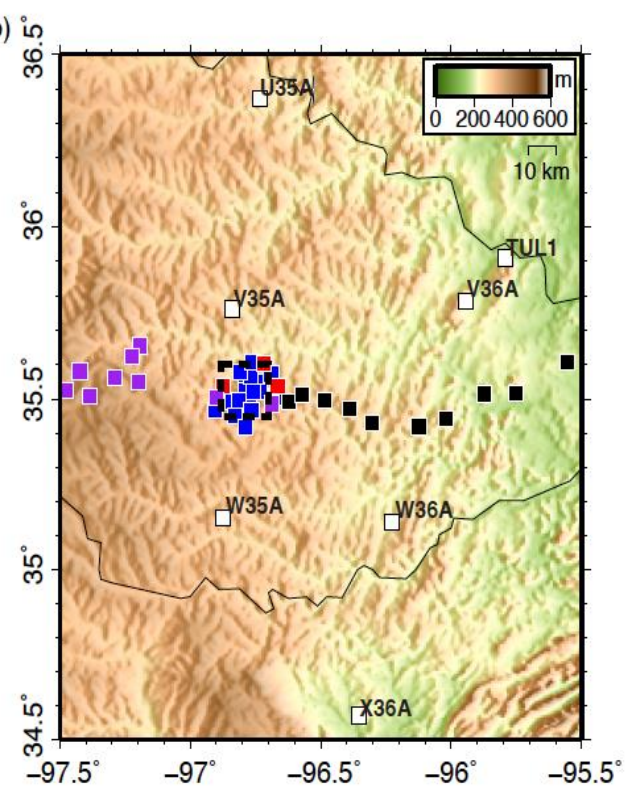
Kim, 2013.

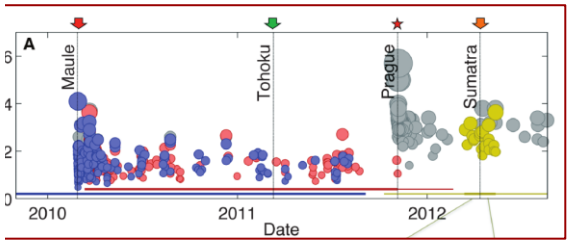


Work flow and goals of subsurface structure analysis in Youngtown, Ohio.

Regional Studies: Prague, OK, 2011:







- Three M>5.0 earthquakes occurred near Prague, Oklahoma in November 2011.
- The USGS and University of Oklahoma deployed both local and regional arrays of seismometers to conduct various analysis related to seismic hazard within OK:

Sumy et al., 2013, Van der Elst et al. 2013

Geo-mechanical modeling

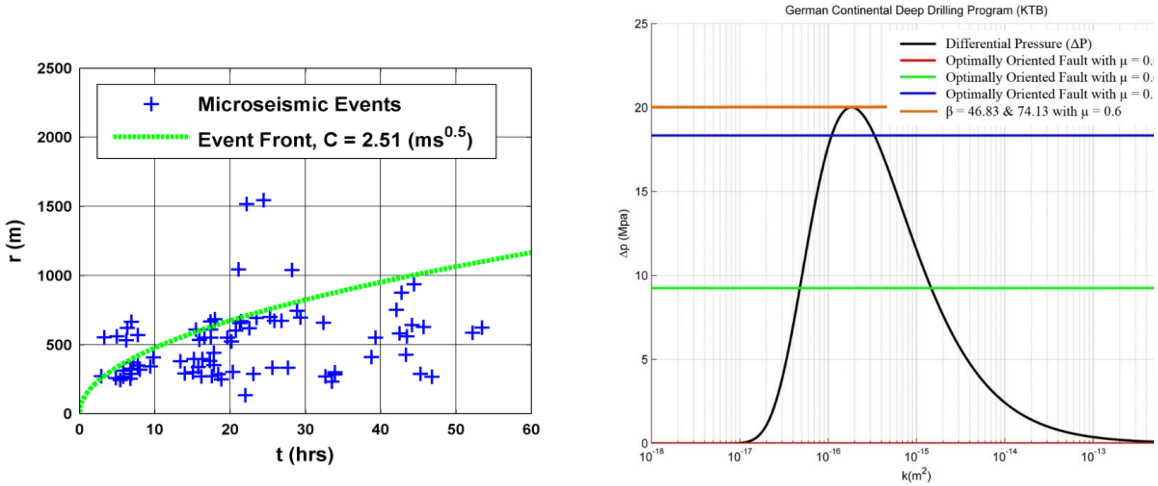
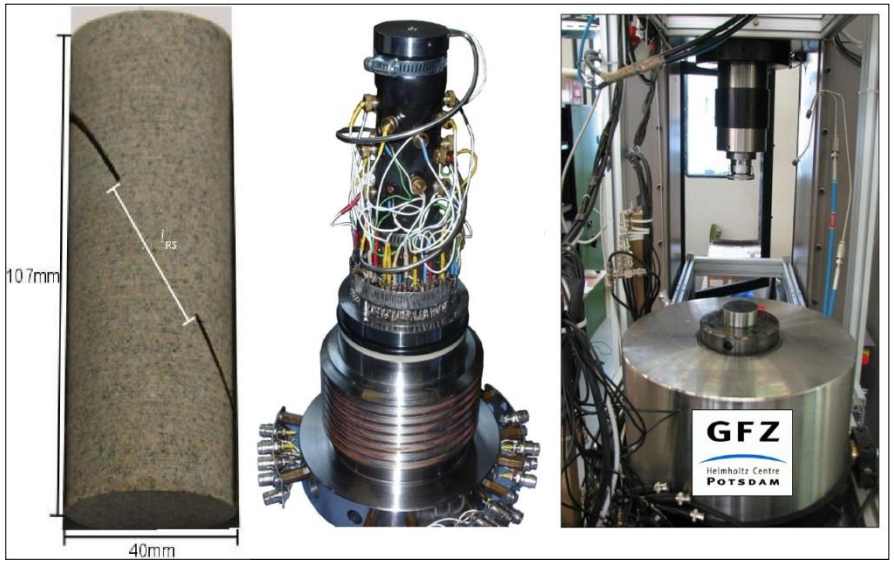
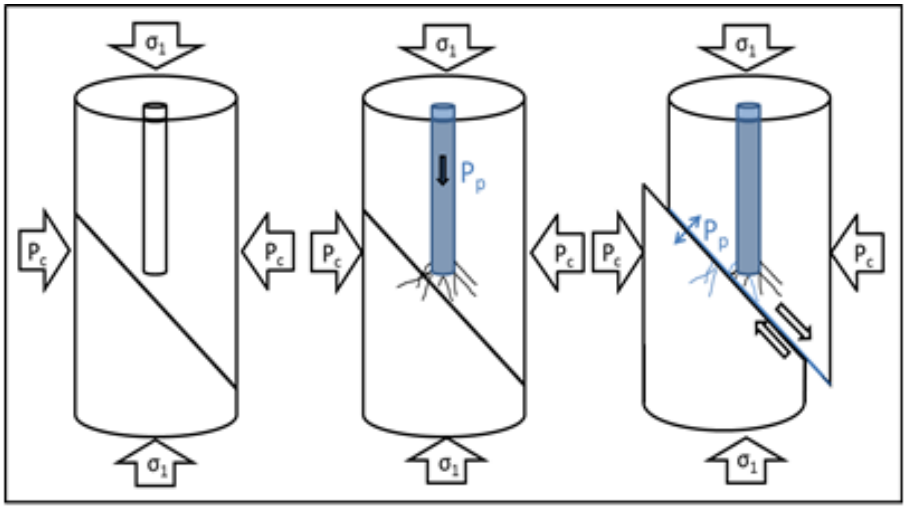


Figure 4: The formation permeability through spatial and temporal analyses of microearthquakes incorporating geomechanics. (Hosseini and Aminzadeh, 2013)

- Model the stress change associated with hydraulic fracturing to assess risk of microseismic activities
- Ethe reservoir permeability from Geomechanical Seismicity Based Permeability Characterization (GSBRC) model to a heterogeneous anisotropic reservoir.

Laboratory experiments





Examine Fault activation due to fluid-injection in an analogue borehole.

Initially pore pressure increase results in fracture of intact rock

The fault starts to slip once the effective stress reach a threshold

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 , shale gas sites
  - CO_2 sequestration sites (various)
- However, industry has successfully 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
  - Scale and distance of influence
- Seismicity is also be useful as a resource management tool

Induced Seismicity: observations on the intersection of science, policy, and the public

- **Framing the Induced Seismicity issue:**
  - Adds to the ongoing discussions with respect shale resource development and its impact
  - Seismicity, whether induced or naturally occurring, is poorly understood by most stakeholder groups
  - When complex issues involve extensive political and societal engagement, a strong science base is almost never sufficient to carry the debate

Induced Seismicity: observations on the intersection of science, policy, and the public

- **Science and technology opportunities:**
  - Develop an integrated approach and community for the supporting science and technology (earthquake seismology + petroleum geology /geophysics + drilling / production engineering)
  - Increase the current state of geological knowledge, including updated regional /local fault mapping, for areas of potential resource development and disposal well operations.
  - Increase the current state of seismic measurement and risk assessment for areas of potential resource development and disposal well operations.

Induced Seismicity: observations on the intersection of science, policy, and the public

- **Policy and regulation opportunities:**
  - Induced Seismicity Risk Assessments from proposed drilling, production, and disposal activities, especially including the impact from likely surface ground motions.
  - Well planning and approval processes which assesses the interaction of well trajectories, injection and fracturing operations with the known natural fault system and relevant geological conditions.
  - Development and implementation of seismic monitoring plans for areas of active development, especially including disposal wells.

Induced Seismicity: observations on the intersection of science, policy, and the public

- **Public outreach and communication opportunities:**
  - Support and engagement with public earthquake education and preparedness programs and processes
  - Properly framing Induced Seismicity into the larger discussion and debate on hydro-fracturing and resource development
- **General comment:**
  - The inherent linkage of development to local / regional geological conditions clearly implies that state geological and regulatory agencies need to lead on setting and supervising regulatory and permitting processes.

Acknowledgements

Sponsors of USC Induced seismicity Consortium (ISC),

AERA British Gas City of Long Beach Incorporated 1897 OXY Paulsson, Sinopec 2020

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