

# Bayesian Moment Tensor Inversion

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In collaboration with M. Nafi Toksöz, Youssef M. Marzouk,  
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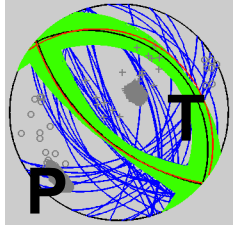
*MIT Earth Resources Laboratory  
2017 Annual Founding Members Meeting  
May 31<sup>st</sup>, 2017*



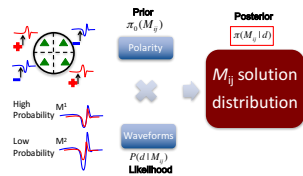
**Massachusetts  
Institute of  
Technology**



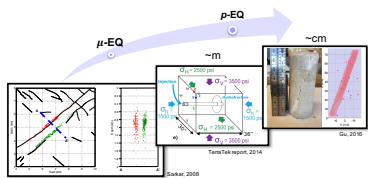
Earth  
Resources  
Laboratory



- Research motivation – Source mechanisms and uncertainty quantification

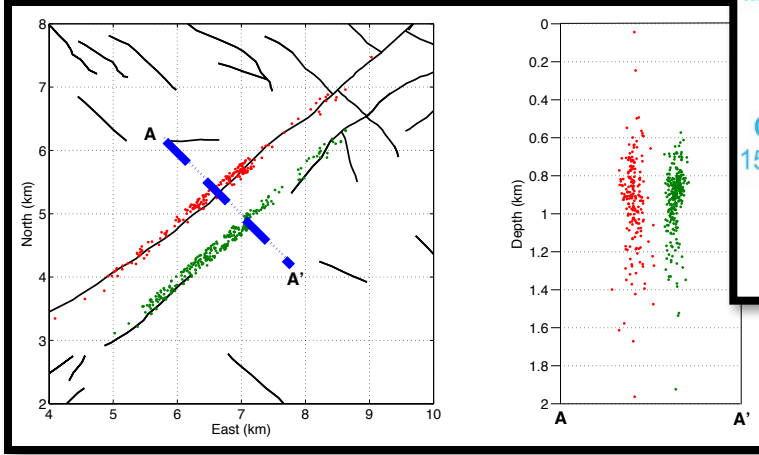
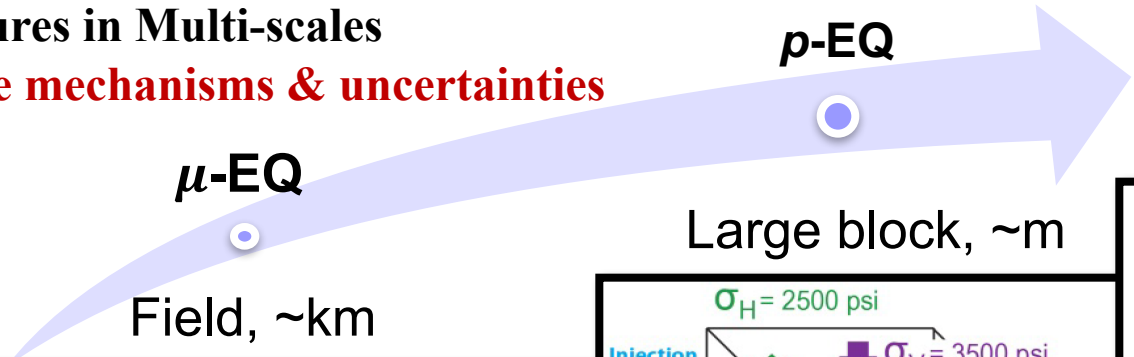


- Method – Waveform-based Bayesian moment tensor inversion

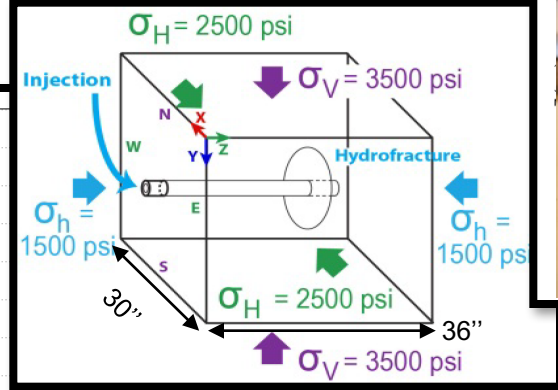


- Examples – From micro-seismicity to pico-seismicity

- Fractures in Multi-scales
- Source mechanisms & uncertainties

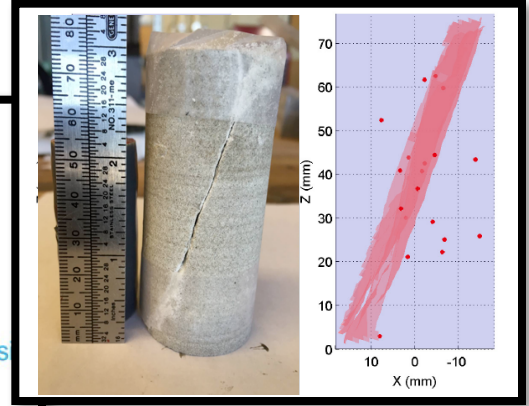


Large block, ~m



TerraTek report, 2014

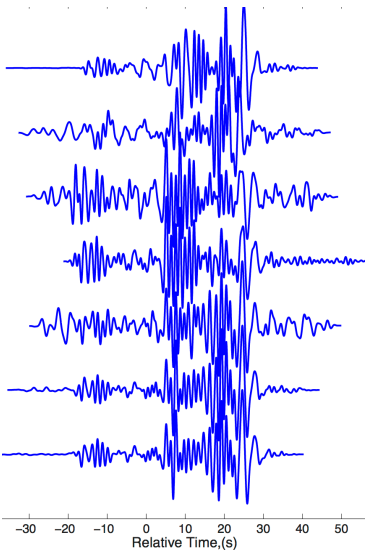
Core Sample, ~cm



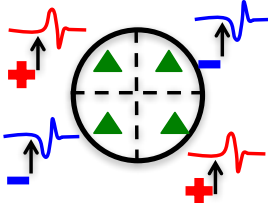
Gu, 2016

Sarkar, 2008

Input



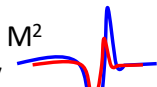
## Simplest Bayesian Formulation



High Probability  $M^1$



Low Probability  $M^2$



Prior  
 $\pi_0(M_{ij})$

Polarity



Waveforms

$P(d | M_{ij})$   
Likelihood

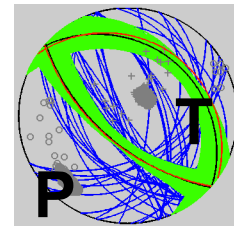
Posterior

$$\pi(M_{ij} | d)$$

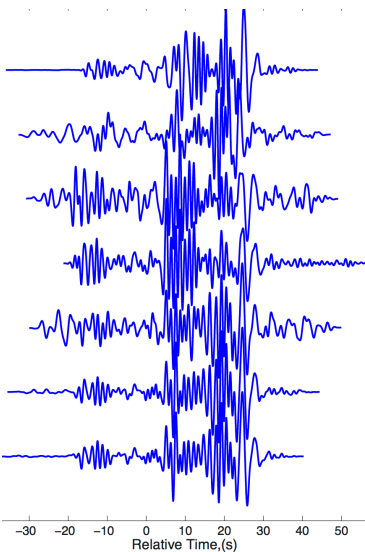
$M_{ij}$  solution  
distribution



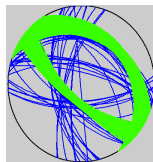
Output



Input

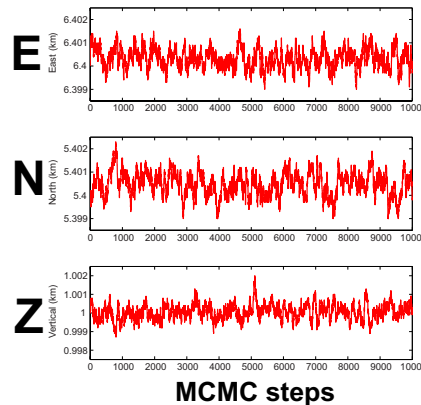
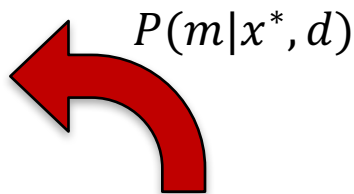
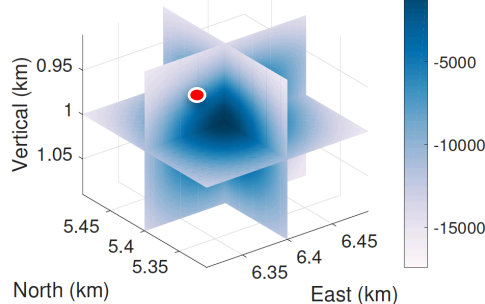


Simplest Bayesian Formulation

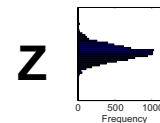
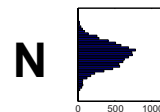
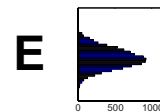
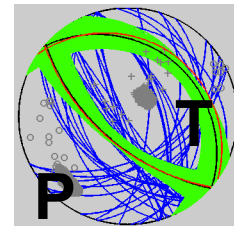


Location Sampling

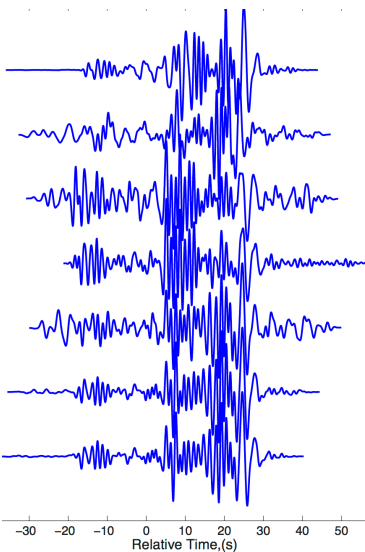
$\log P(x|d)$



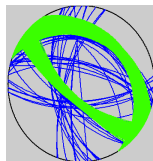
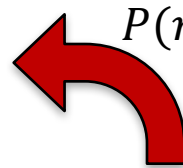
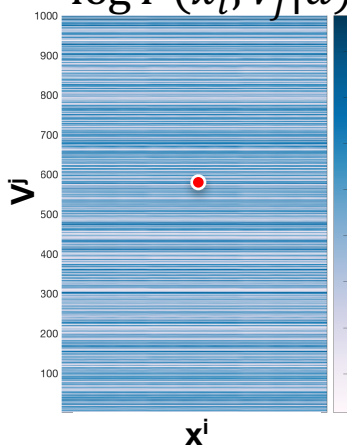
Output



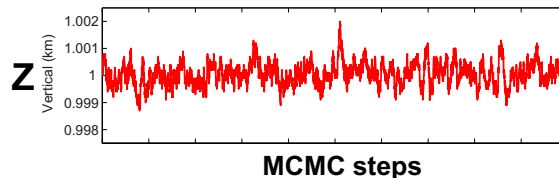
Input



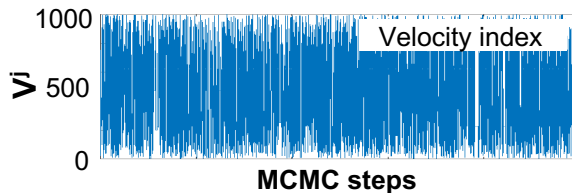
## Simplest Bayesian Formulation

 $\log P(x_i, V_j | d)$  $P(m | x^*, V^*, d)$ 

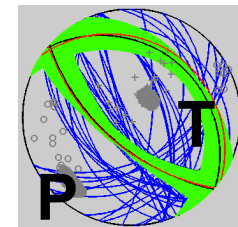
## Location Sampling



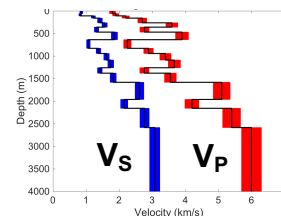
## Velocity Model Sampling



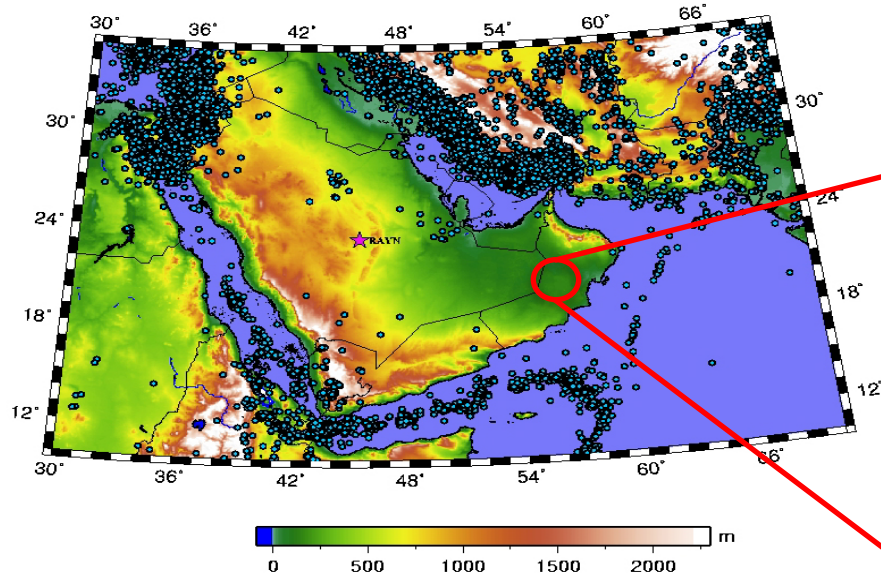
Output



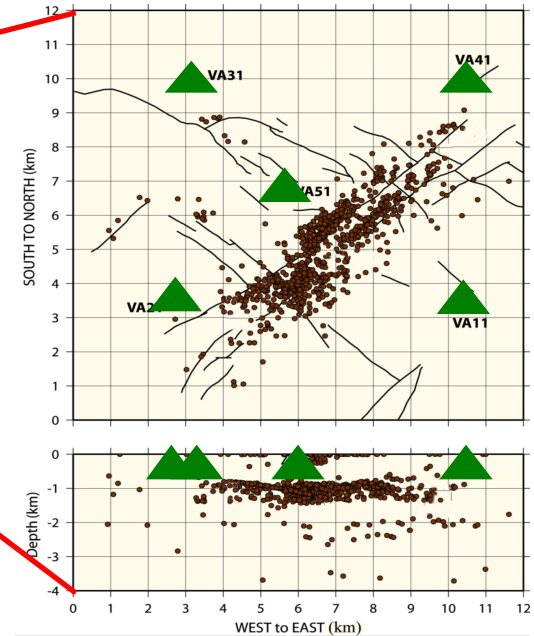
E N Z



# Induced Seismicity in Oman

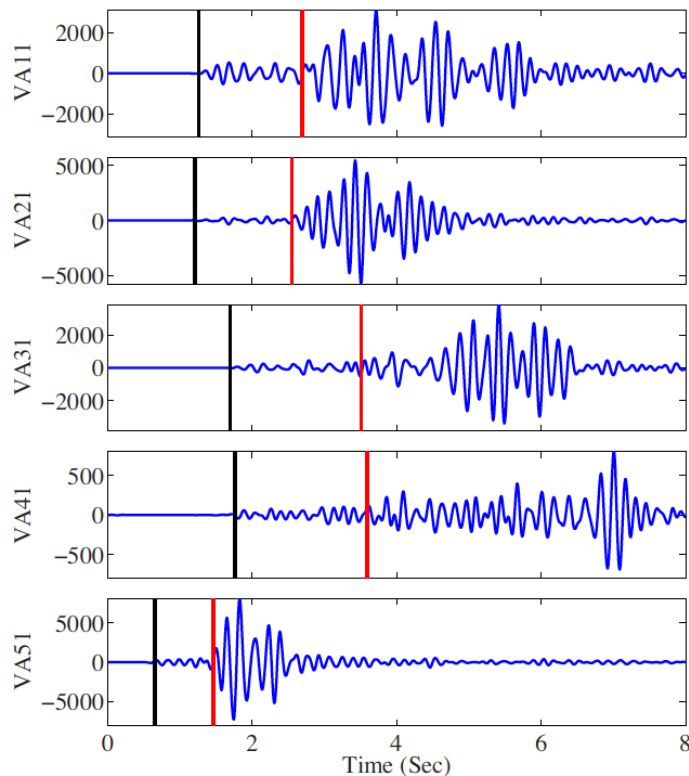
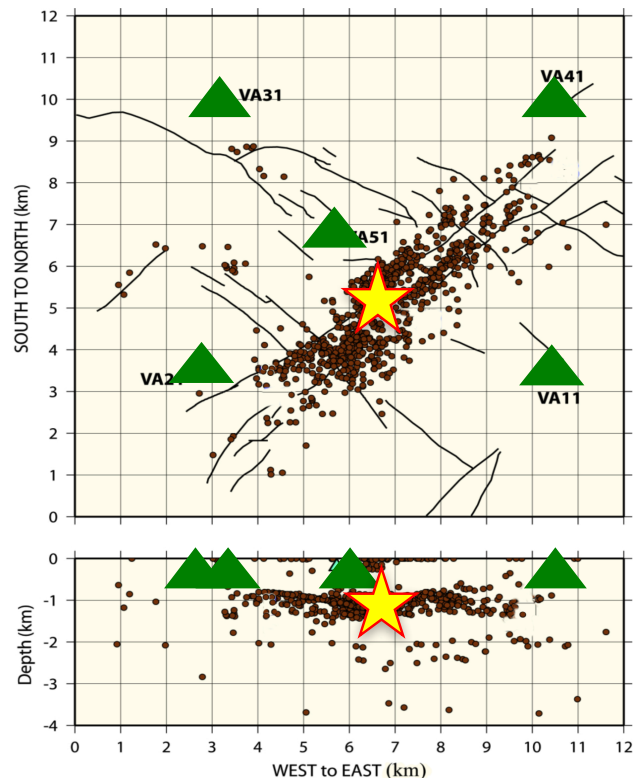


- More high-quality data
- In predictable places



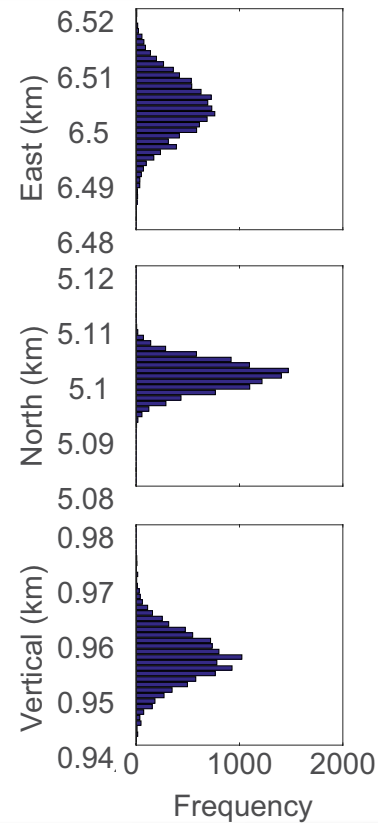
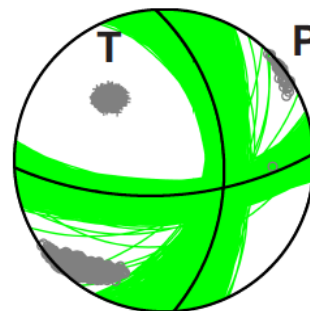
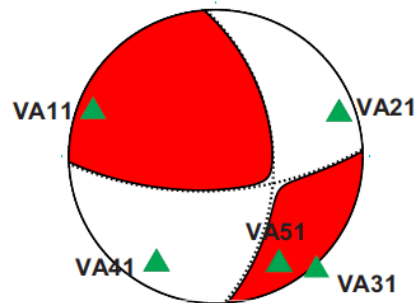
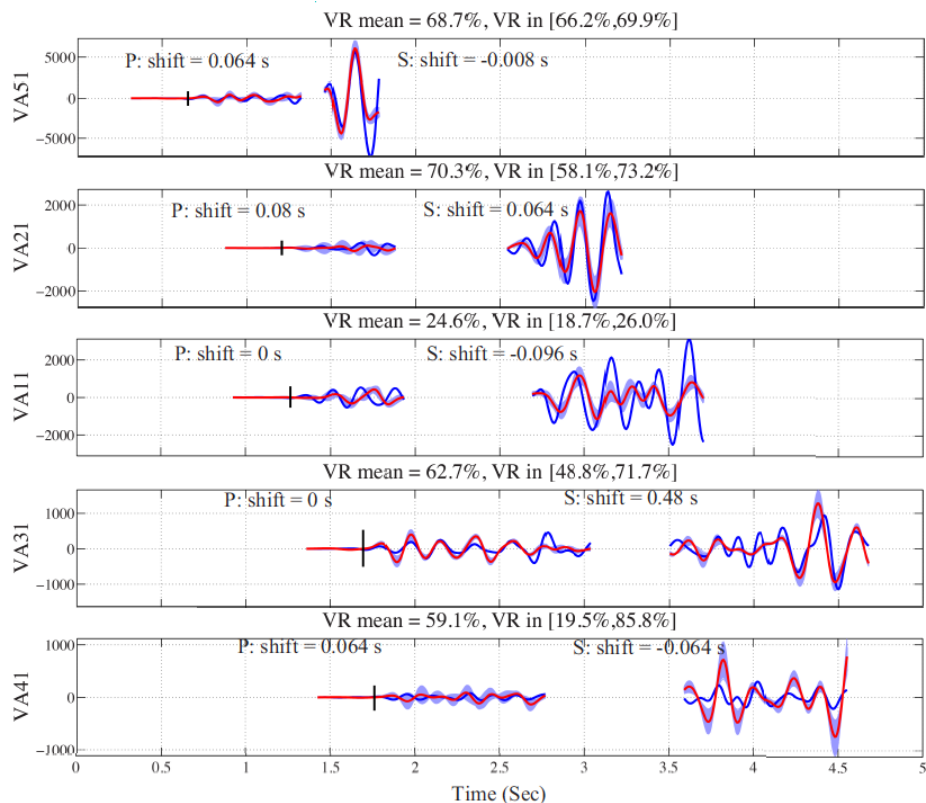
Sarkar, 2008

# Induced Seismicity in Oman

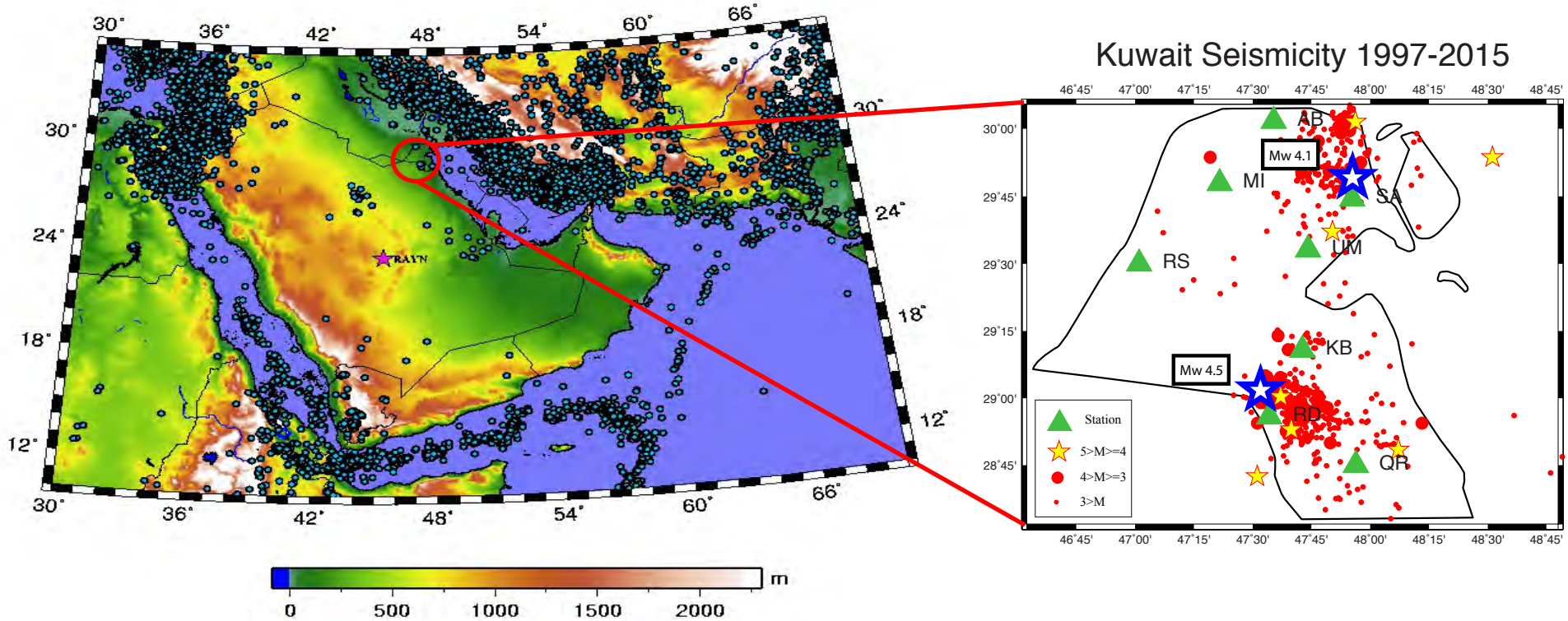




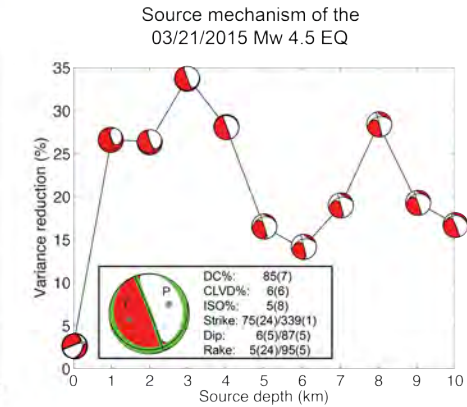
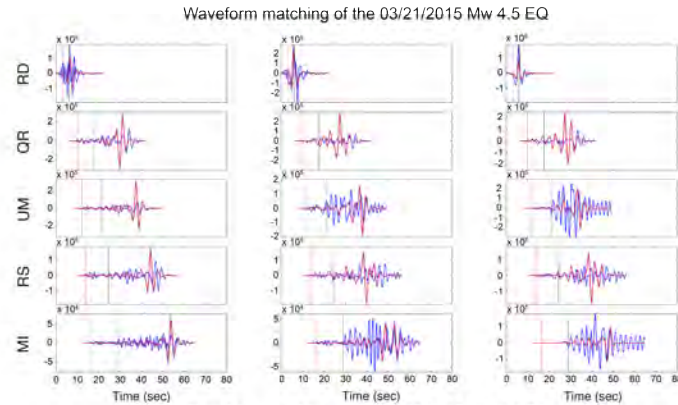
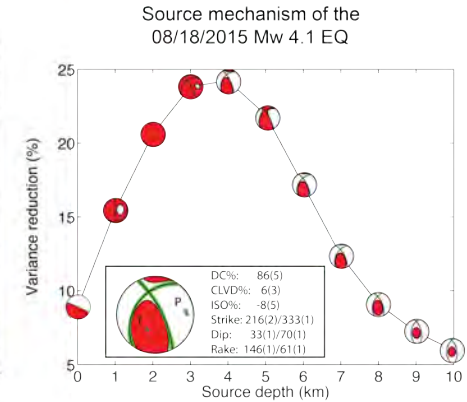
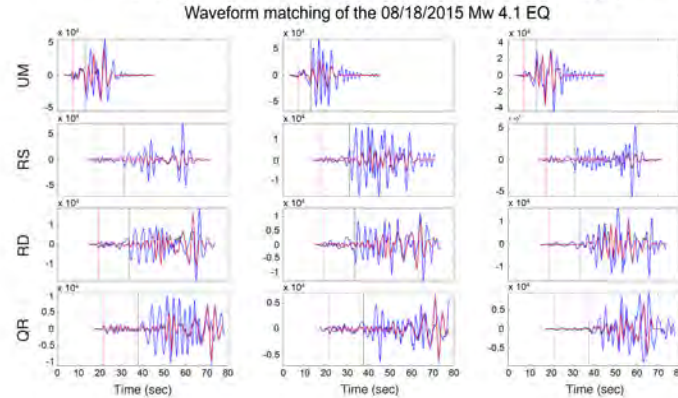
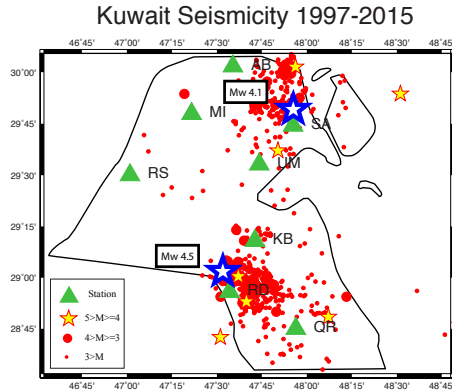
# Induced Seismicity in Oman



# Local Earthquakes in Kuwait



# Local Earthquakes in Kuwait

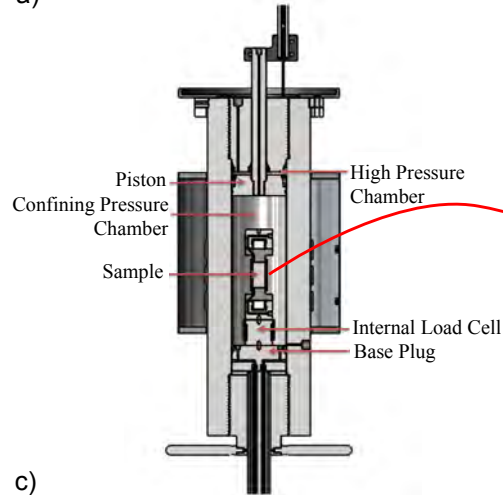




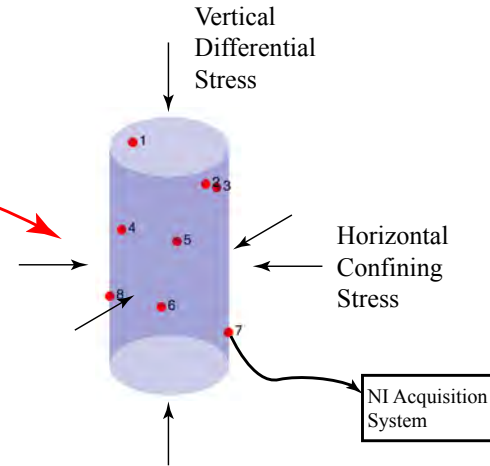
a)



b)



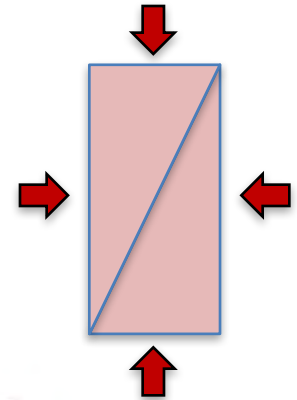
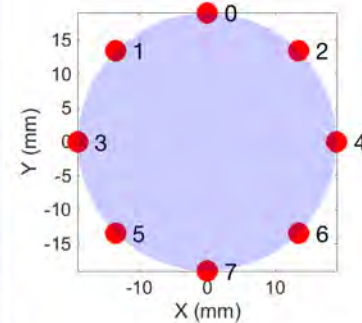
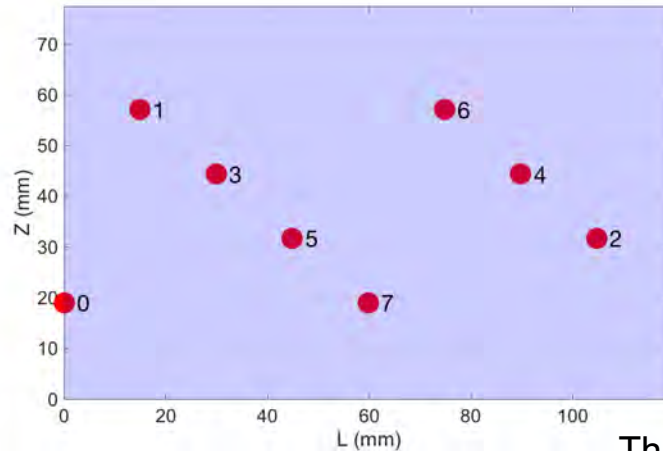
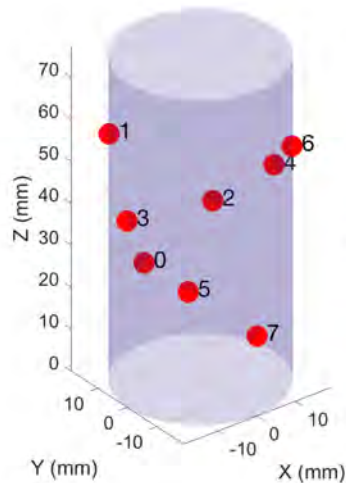
c)



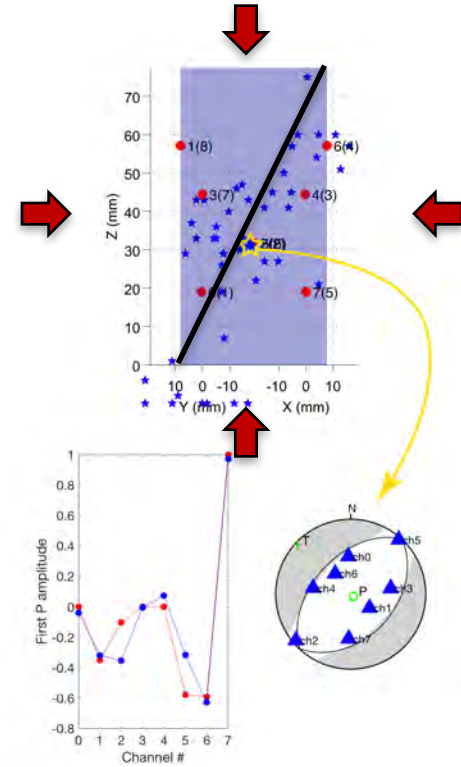
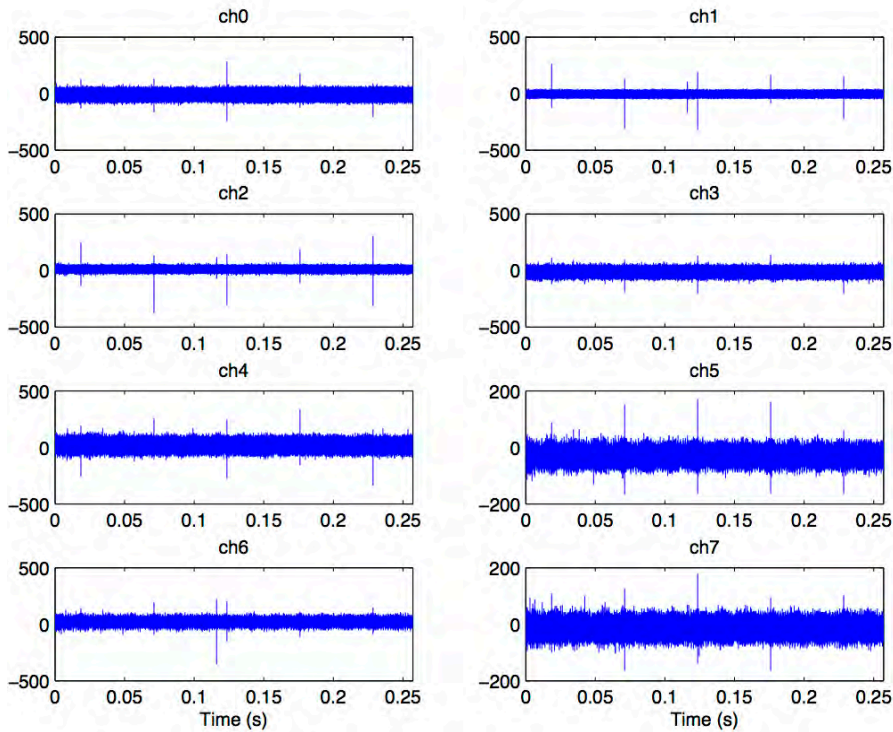
d)

## Slip of a fracture plane in a saw-cut Lucite sample:

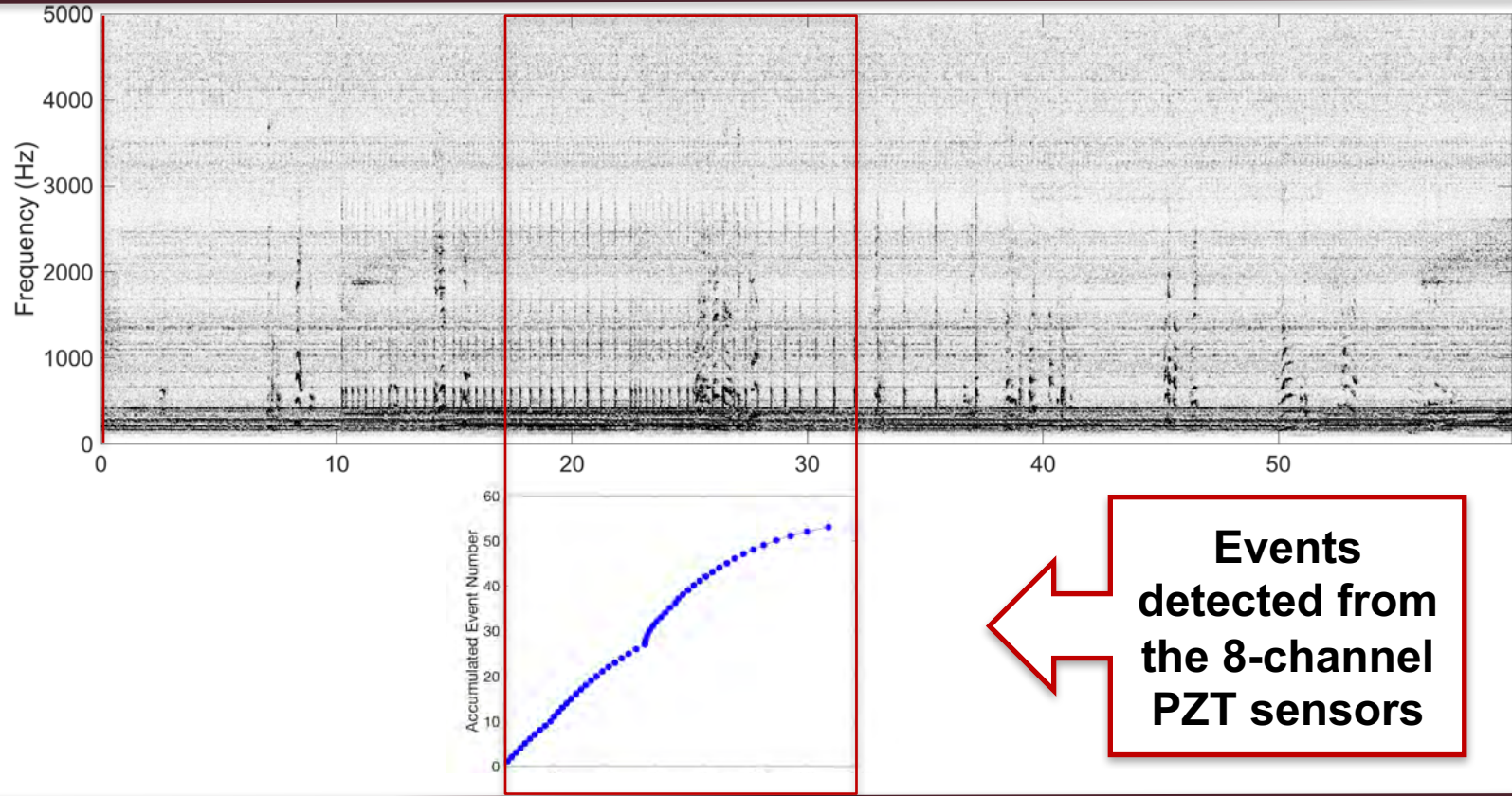
- Acoustic emissions from 8 PZT sensors
- Audio recording (e.g., use an iphone)



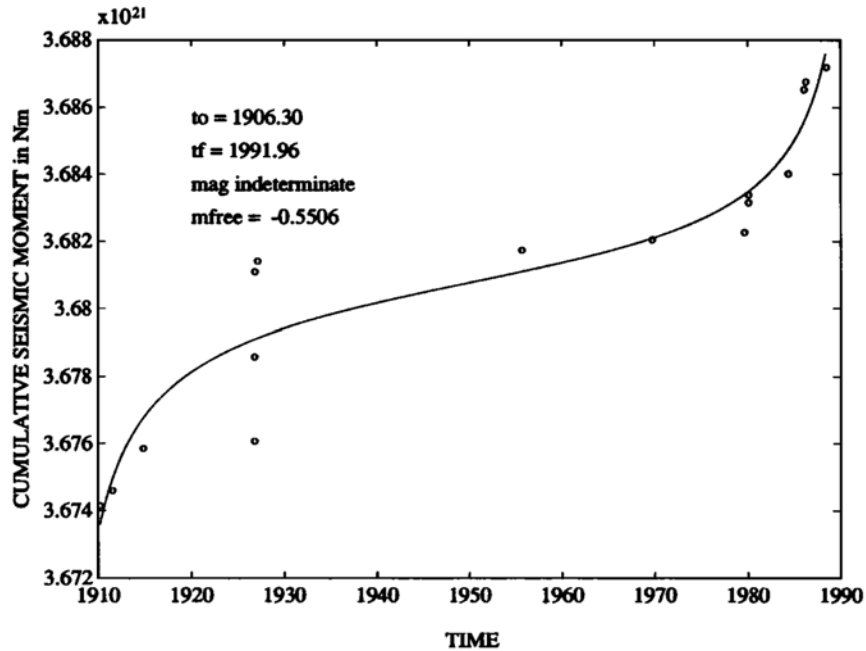
This Experiment is conducted by Saied Mighani.



# Hearing What Fractures Say

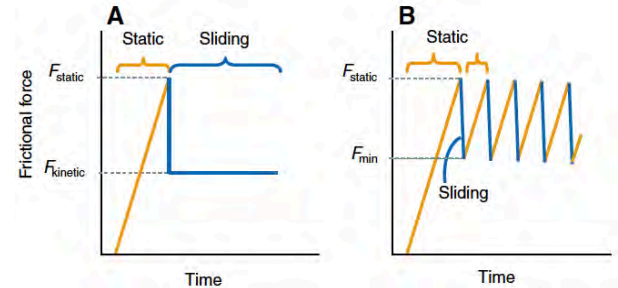
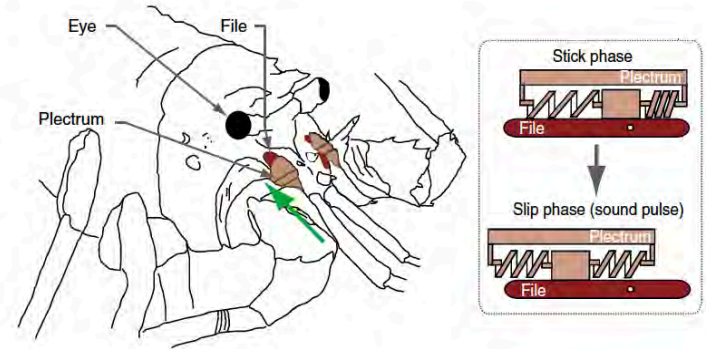


## Real Earthquake Cycle



Bufe and Vanes, 1993

## California Spiny Lobster



Patek and Baio, 2007



- We studied the source mechanisms of micro- and pico-earthquakes occurred in multi-scales, from oil/gas fields in Oman and Kuwait, to small cylinder laboratory rock samples.
- The micro-seismicity that occurred in the oil/gas fields in Oman and Kuwait is probably induced by fluid injection and extraction in oil/gas fields. In both cases, we use a new waveform based Bayesian moment tensor inversion to obtain the source mechanisms, as well as uncertainties. The importance of the regional stress field and local fault networks (Oman) in generating that micro-seismicity is observed.
- Laboratory generated pico-seismicities (AE) can be used to mimic different rupture processes (e.g., hydraulic fracturing, stick-slip). We show a pioneering work of combining PZT and audio signals to characterize laboratory fracturing processes.

- This research is supported by MIT ERL, TOTAL, and Kuwait Foundation for the Advancement of Sciences.

**Thank you!**

- Bayesian moment tensor inversion and uncertainty quantification for induced seismicity -- uncertainties from both the location and velocity model

**Session ID:** PS 2

**Presentation Date and Time:** 9/26/2017 2:15:00 PM

**Room:** 362D, in the George R. Brown Convention Center

- Hearing what fractures say: A combination of seismic and speech recognition methods

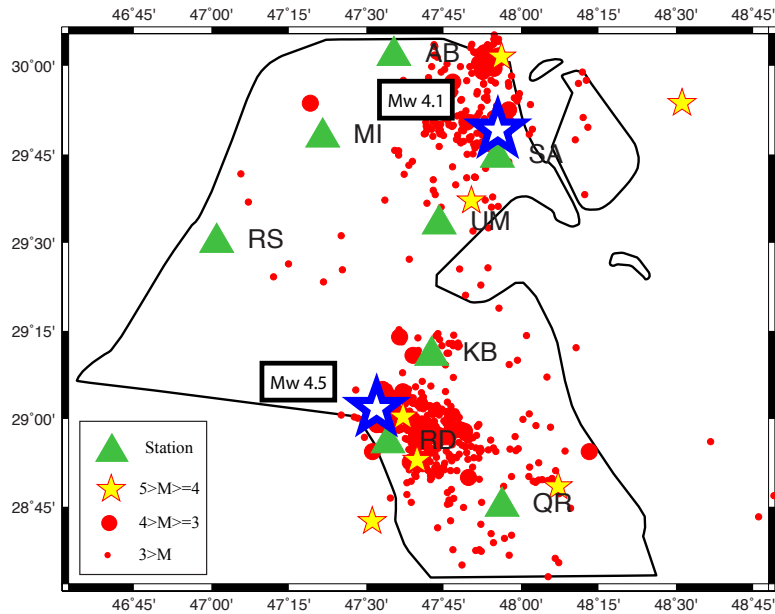
**Session ID:** RP 7

**Presentation Date and Time:** 9/28/2017 11:25:00 AM

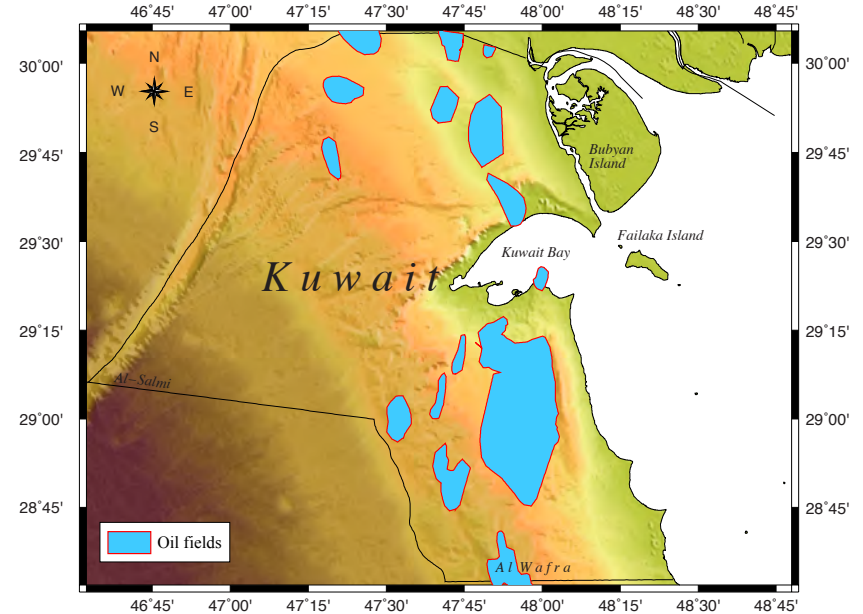
**Room:** 351D, in the George R. Brown Convention Center

- We studied the source mechanisms of micro- and pico-earthquakes occurred in multi-scales, from oil/gas fields in Oman and Kuwait, to small cylinder laboratory rock samples.
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## Kuwait Seismicity 1997-2015

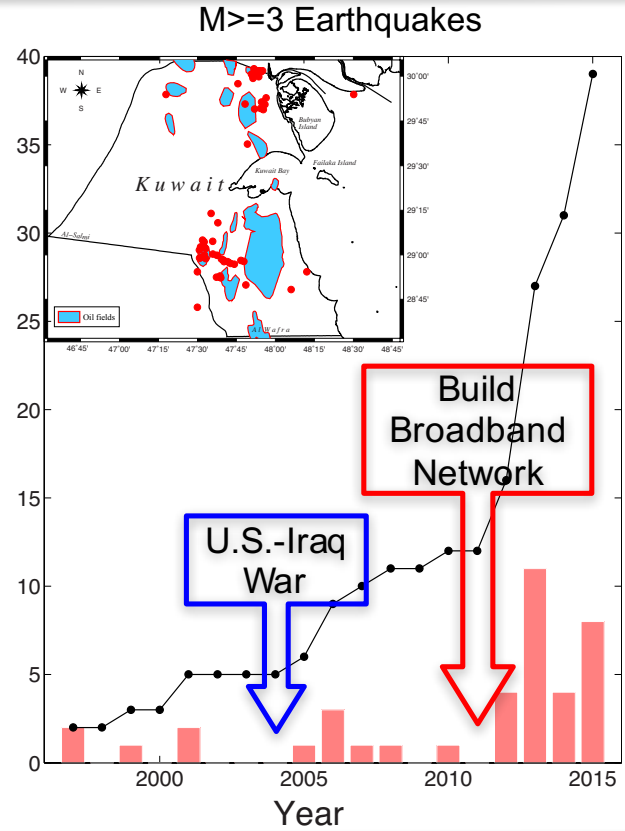
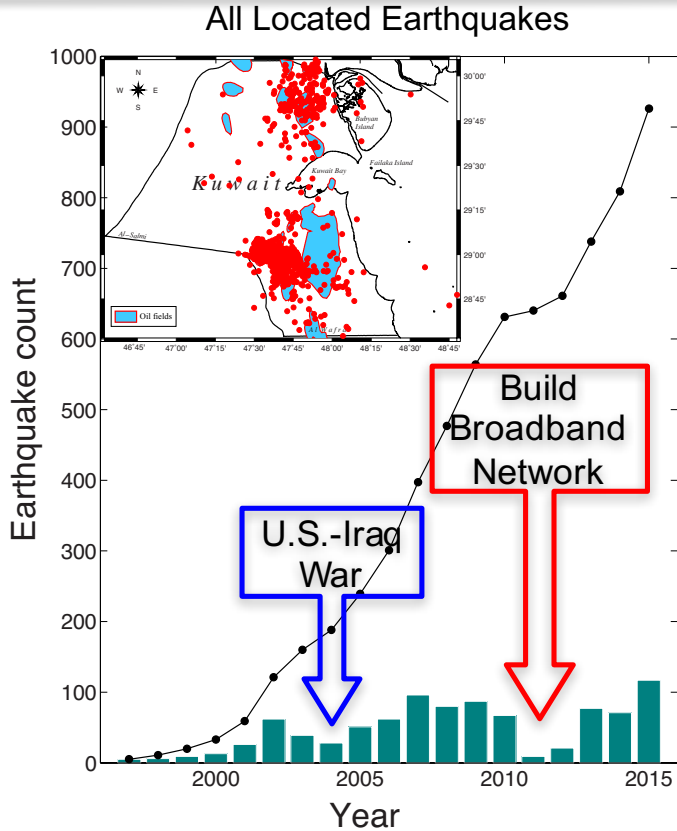


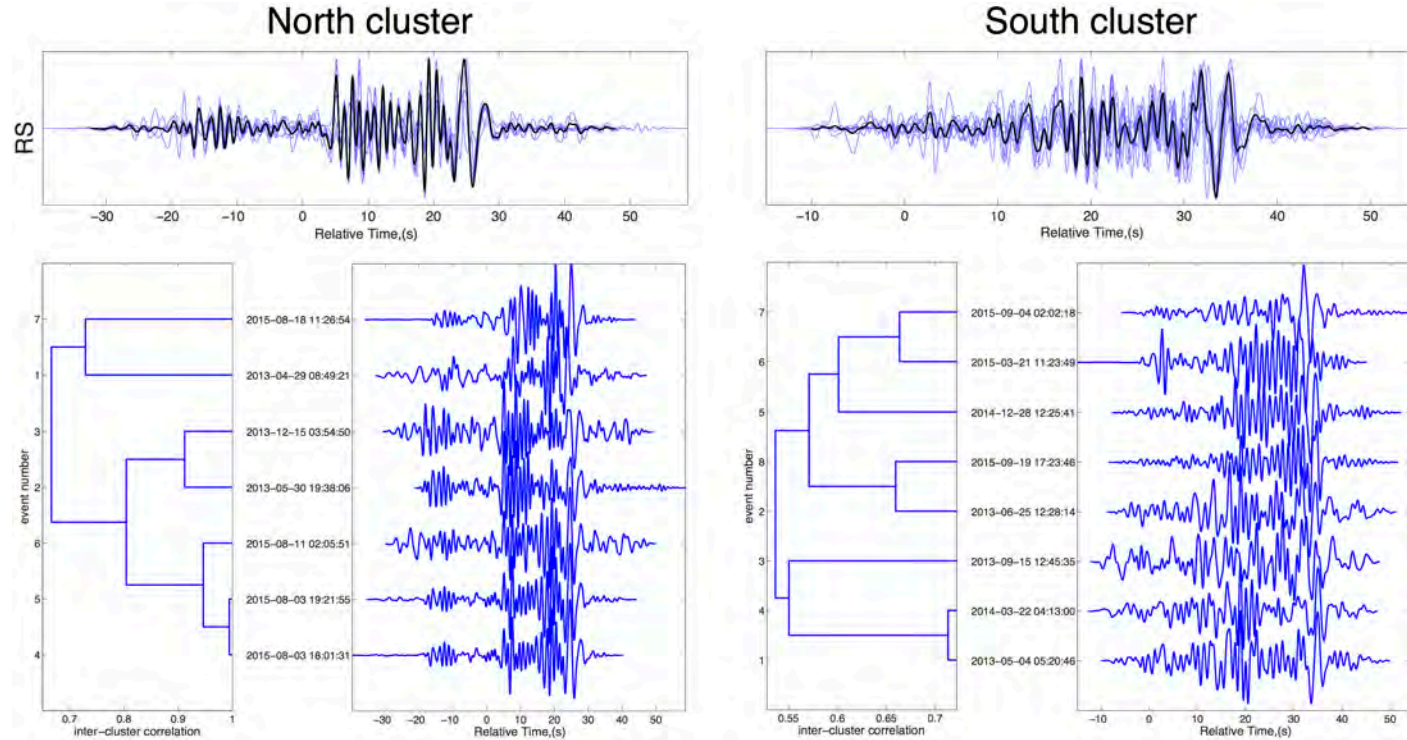
## Kuwait oil fields



Note: Earthquakes occur in the same place of Oil/gas fields

# Local Earthquakes in Kuwait





Waveforms from all the  $M \geq 3$  local earthquakes from station RS from 2013 to 2015