Monitoring for Faults at a Critical State of Stress – Application to Carbon Storage

Ting Chen
Los Alamos National Laboratory

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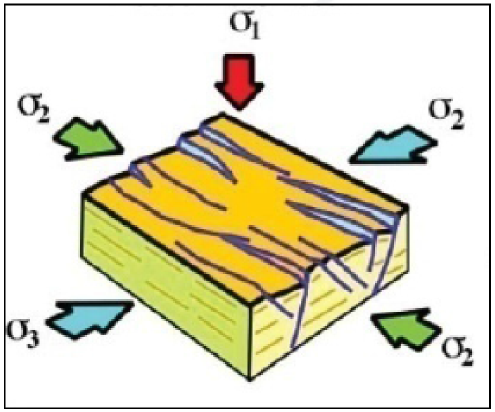
Research Team/Synergy

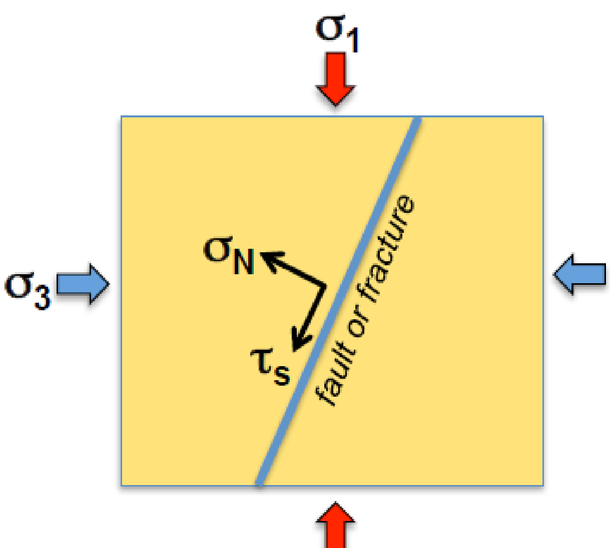
- **LANL**
  - Ting Chen, George Guthrie, Paul. Johnson, Youzuo Lin, Andrew Delorey, Claudia Hulbert, Bertrand Rouet-Leduc
- **External partners (leveraging with)**
  - Penn State, U. Tenn., USGS, ETH [Zurich], ENS [Paris]. U. Rochester, Georgia Tech
- **Funding leveraging**
  - Institutional support at Los Alamos (LDRD, 2017-2019)
  - Center for Space and Earth Sciences, Los Alamos (2017-2018)
  - University partner support (DOE, NSF…)
  - Foreign NSF equivalent (Switzerland, France)

Presentation Outline

- Introduction
- Approach
- Example of method application
- Summary

State of Stress

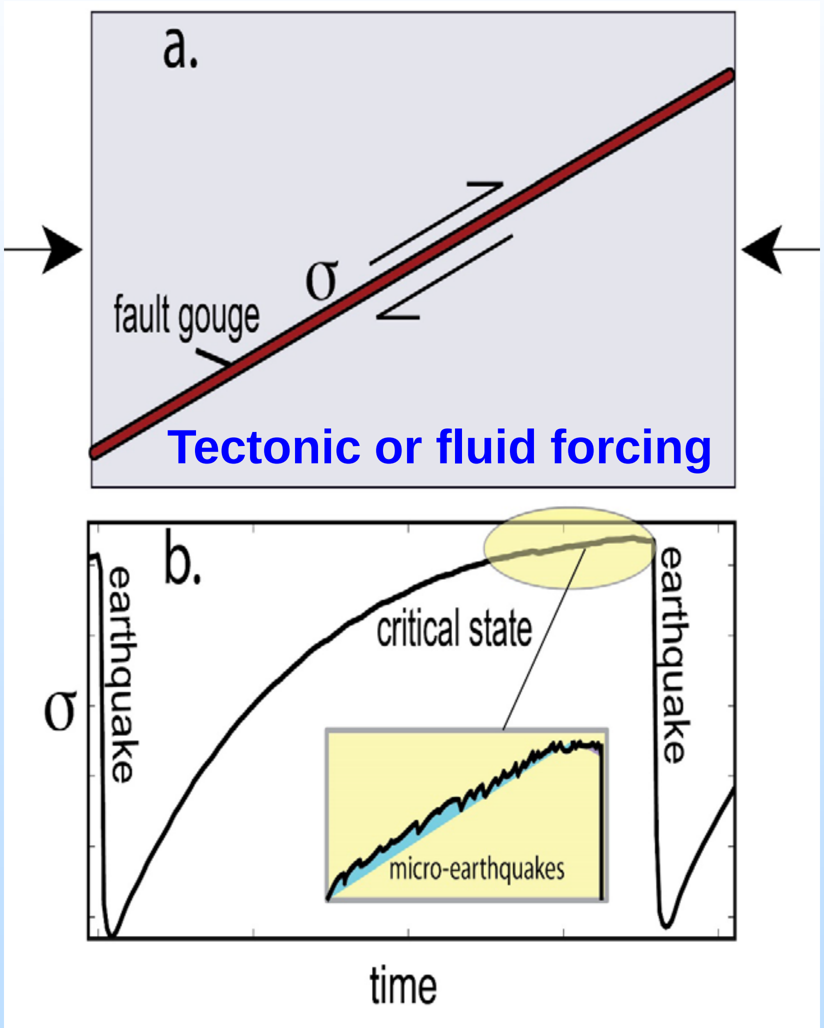




- The state of stress determines “when-and-where” for geomechanical process of energy-related operations
  - Fracturing / faulting

    Induced seismicity

Critical State of stress



- All brittle failure experiments exhibit precursors
- All shear experiments exhibit precursors
- Many avalanches exhibit precursors
- Many earthquakes exhibit precursors (but not all!)

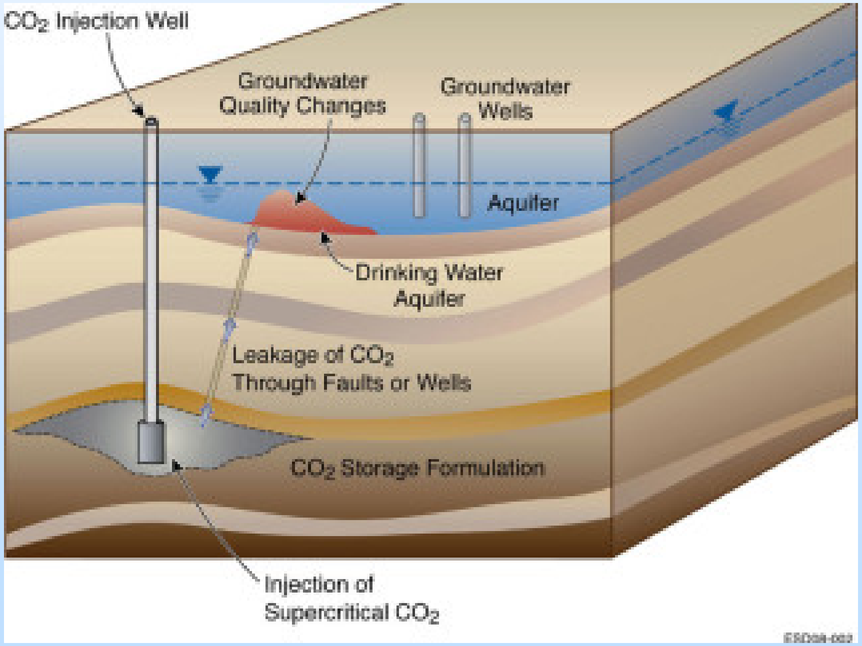
We posit that all slip events exhibit precursors but that we cannot always record or identify them.

Objectives

Monitoring for faults at a critical state of stress

Goal: ensure safe and long-term CO2 storage

- Pre-injection characterization
  - Identify faults of concern in the region
- During-injection monitoring
  - Avoid induced seismicity



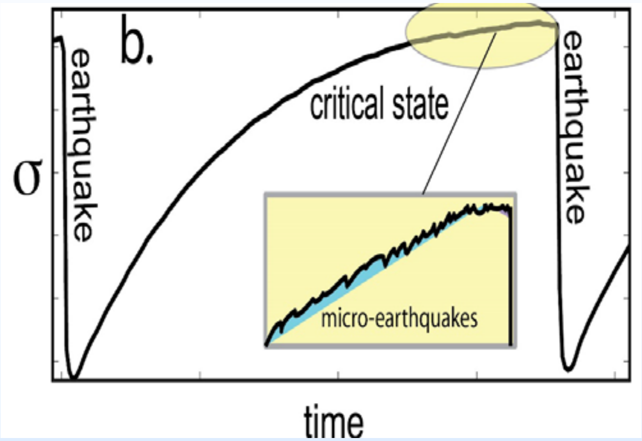
Approach

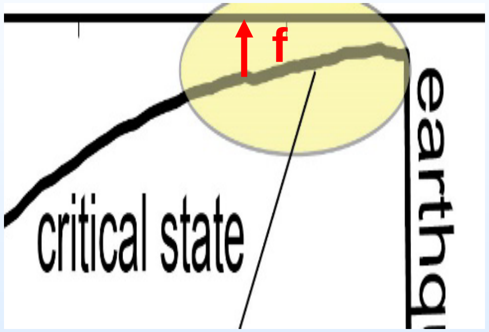
Idea: small seismic signals (previously unidentified) may reveal important information regarding the evolution of state of stress on the fault due to CO_2 injection

- Detect small seismic events related to critical state
- Analyze small signals that may inform us of upcoming fault failure

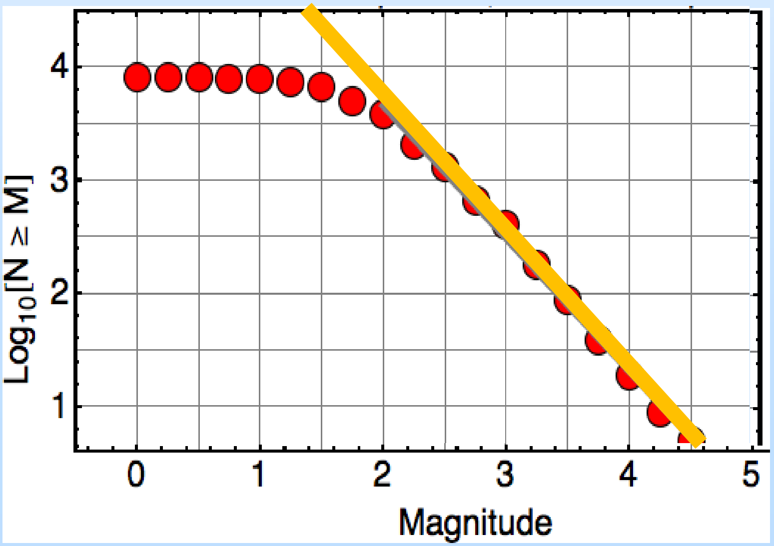
Approach (I)

- Critical state
  - precursor
  - triggering



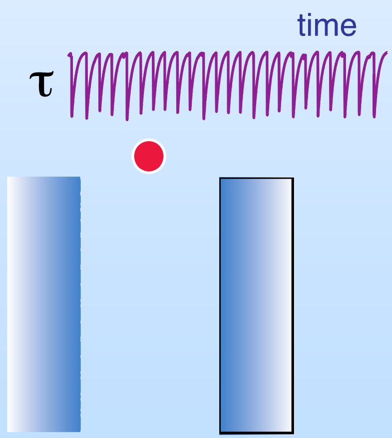


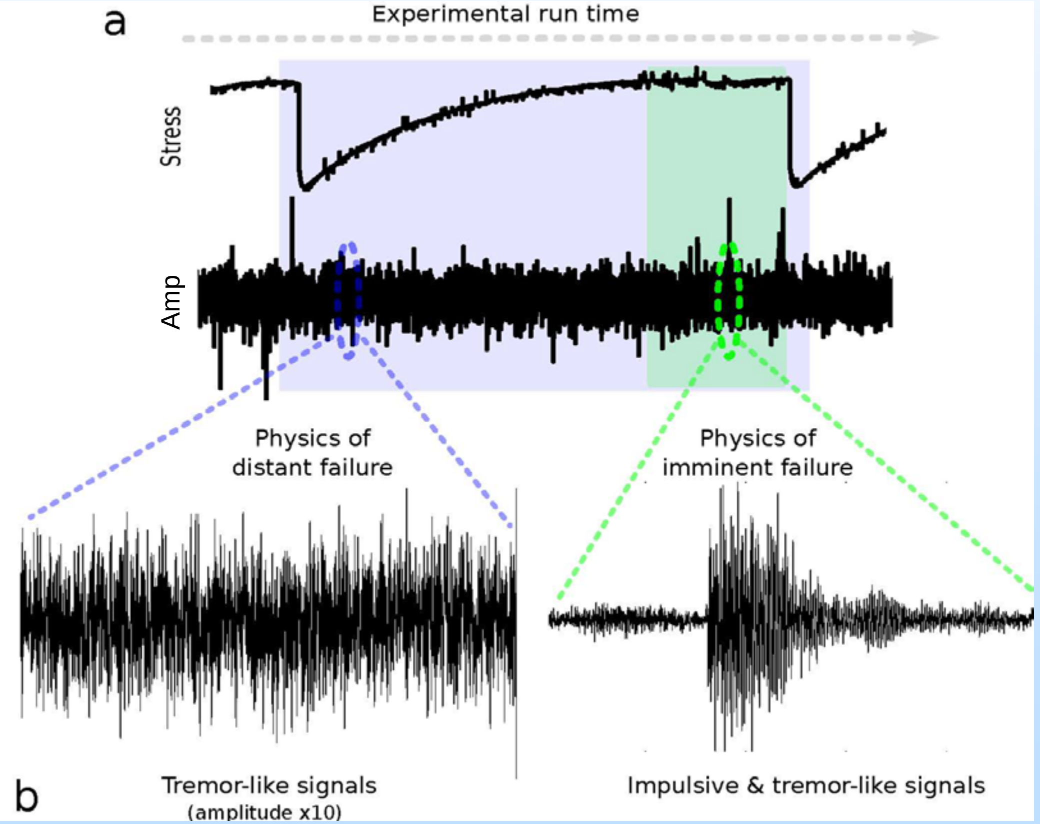
- Small seismic events
  - Abundant small events can provide a more robust path for:
    - Testing our hypothesis
    - A practical field monitoring approach



Approach (II)

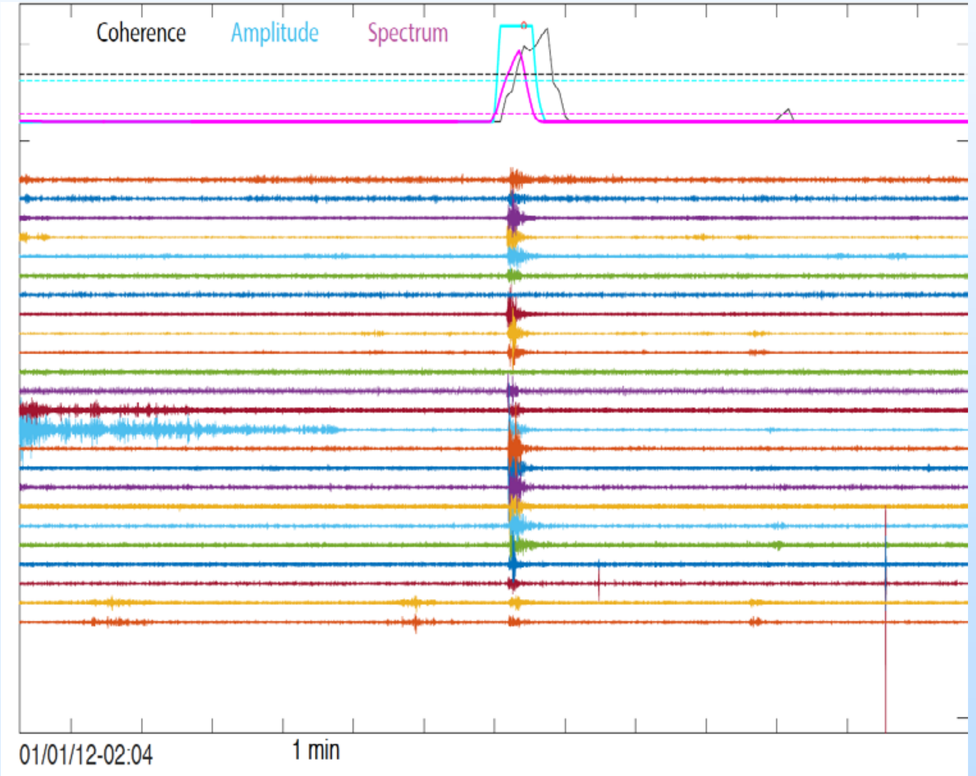
- Small signals before the fault failure
  - Numerical modeling
  - Laboratory experiment
  - Machine learning





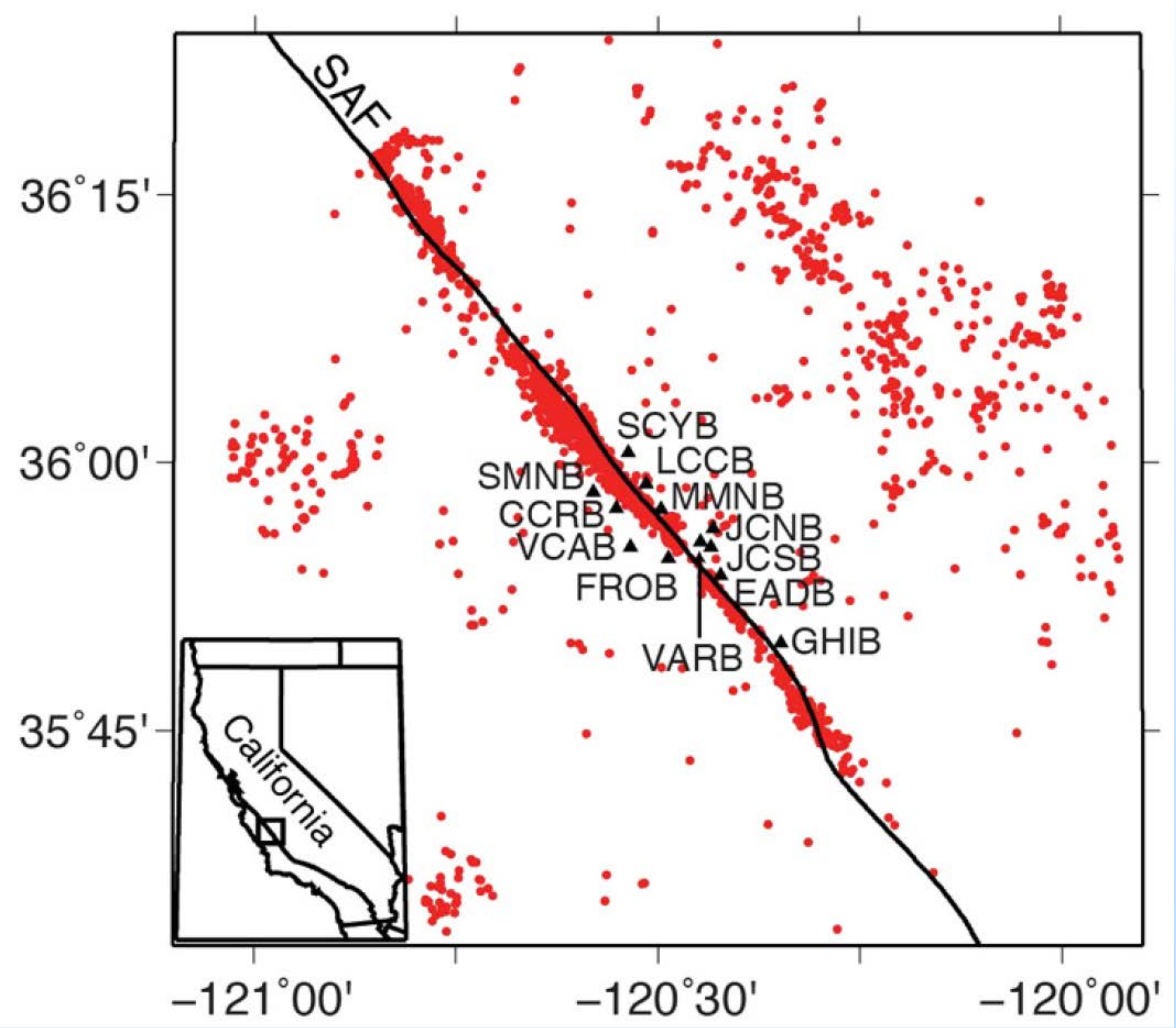
Technique

- Challenge: rapid detection of small signals in a noisy background
- Inter-station Waveform Coherence (IWC)
  - array characteristics of local earthquakes
  - amplitude
  - spectrum
  - coherence



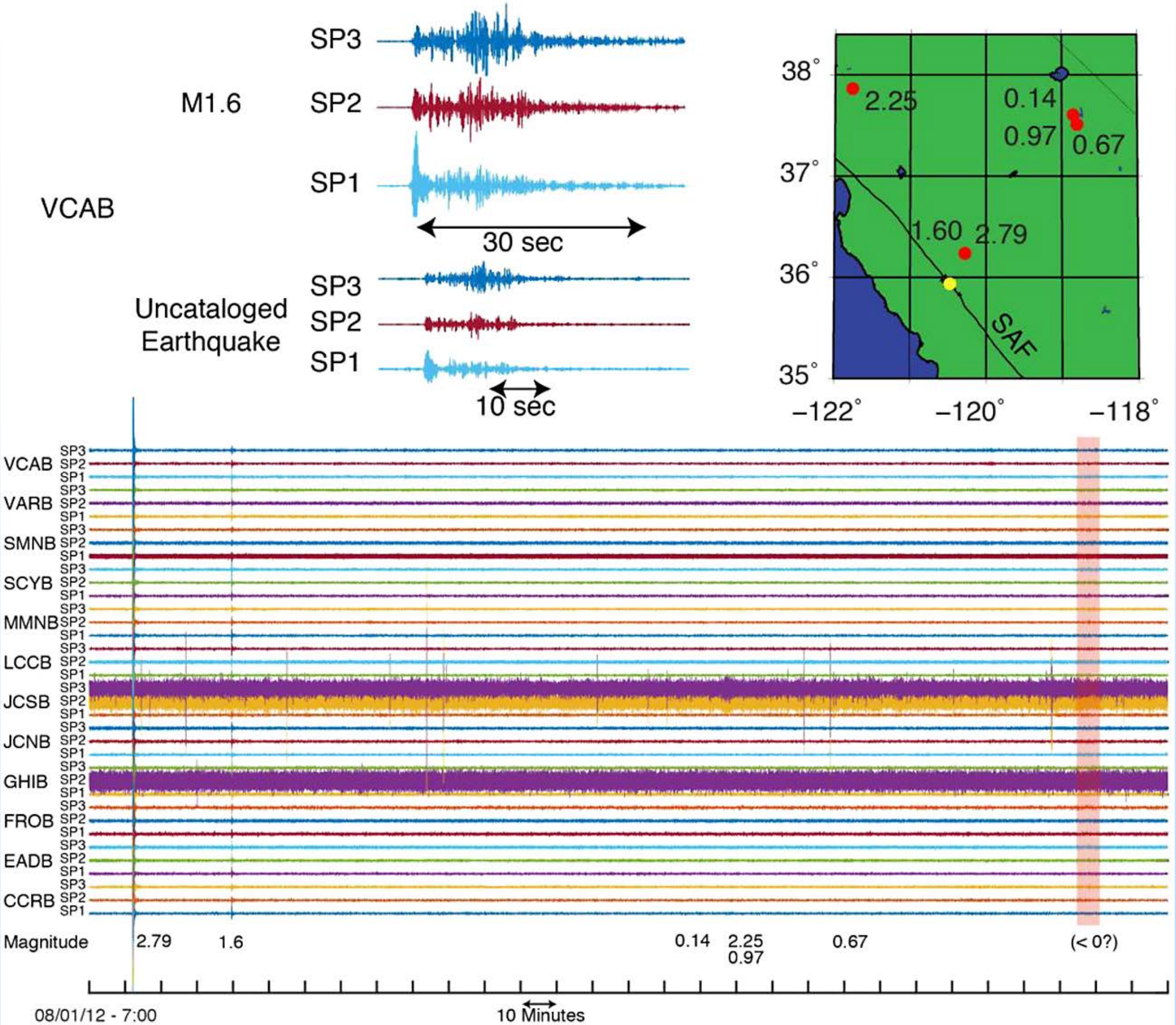
Demonstration of IWC

- Tectonic region - Parkfield
- HRSN
- 2012-2014
- NCSN catalog

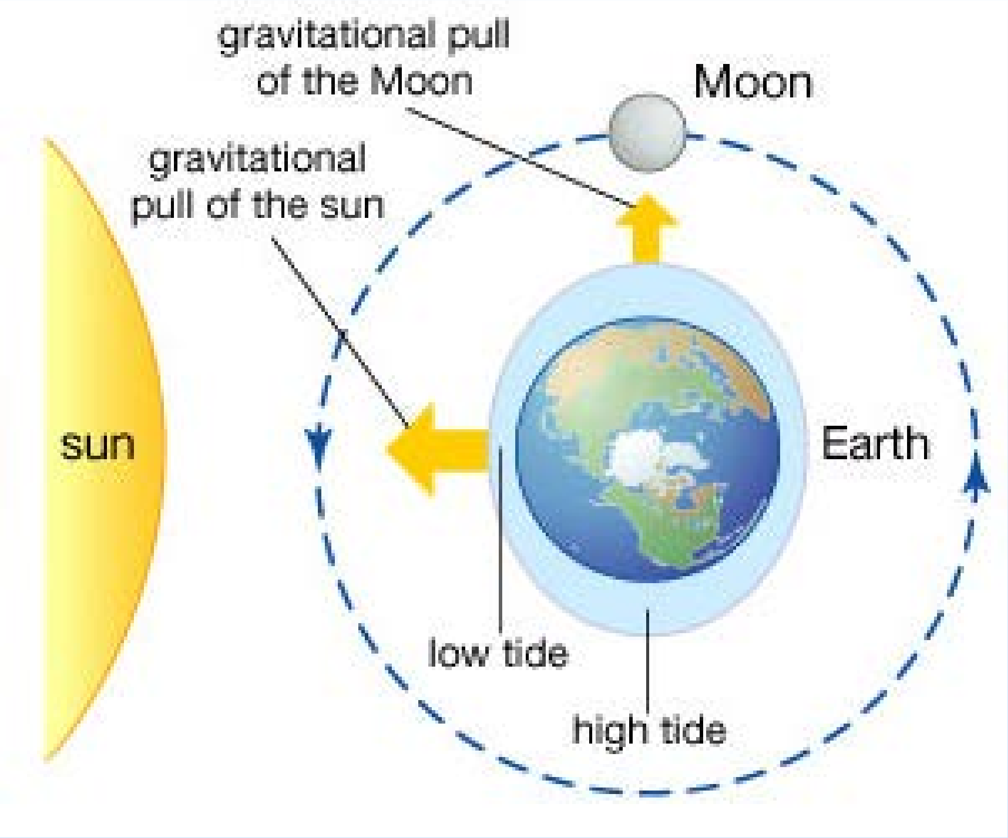


Detect small events

- 6735 events

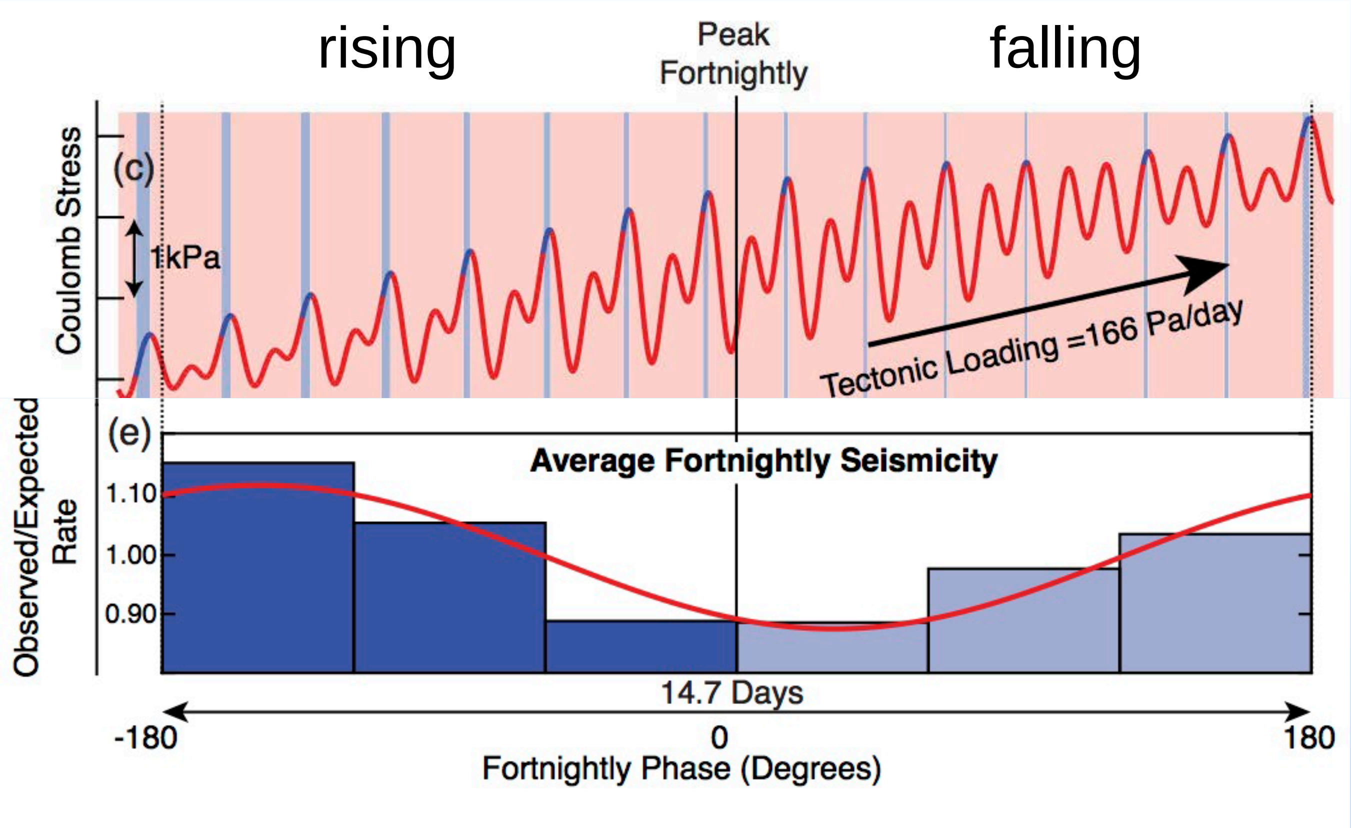


Solid earth tide



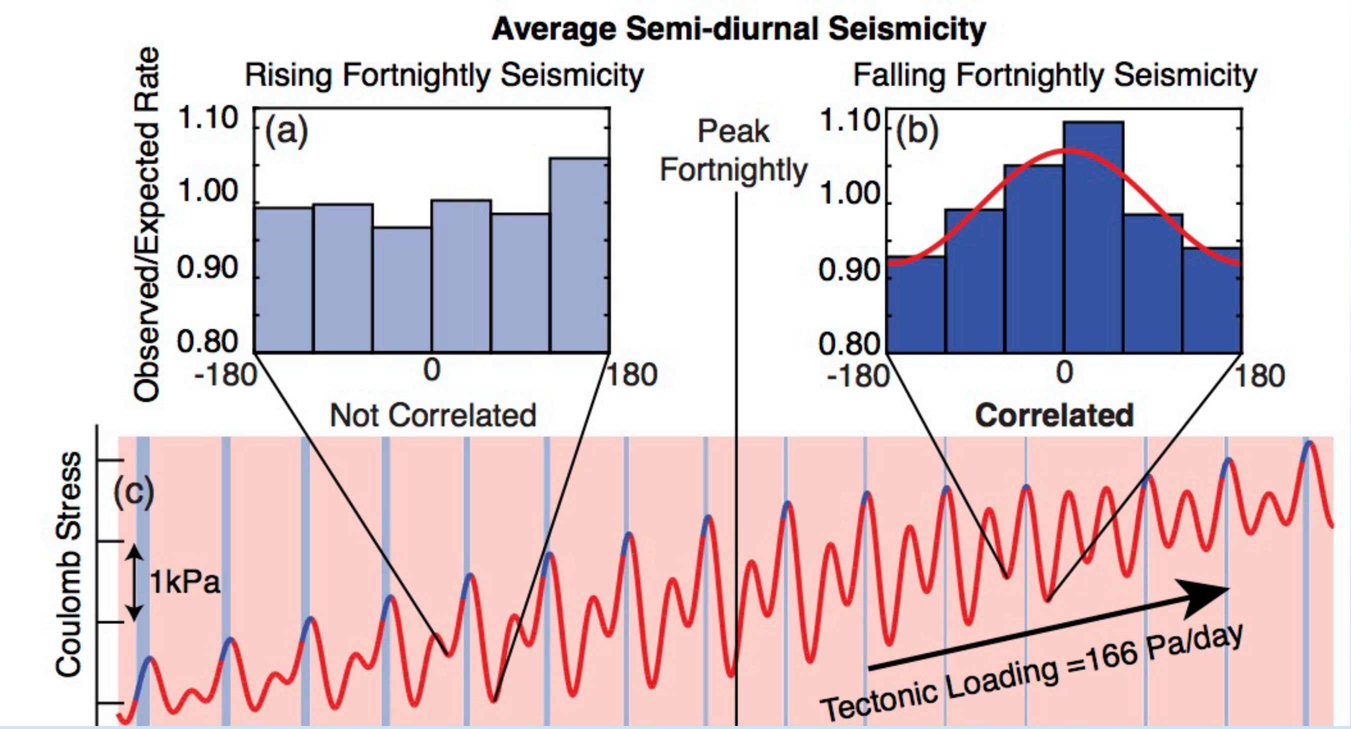
- semi-diurnal period (12.4 hr)
- fortnightly period (14.7 day)

Tidal triggering of events



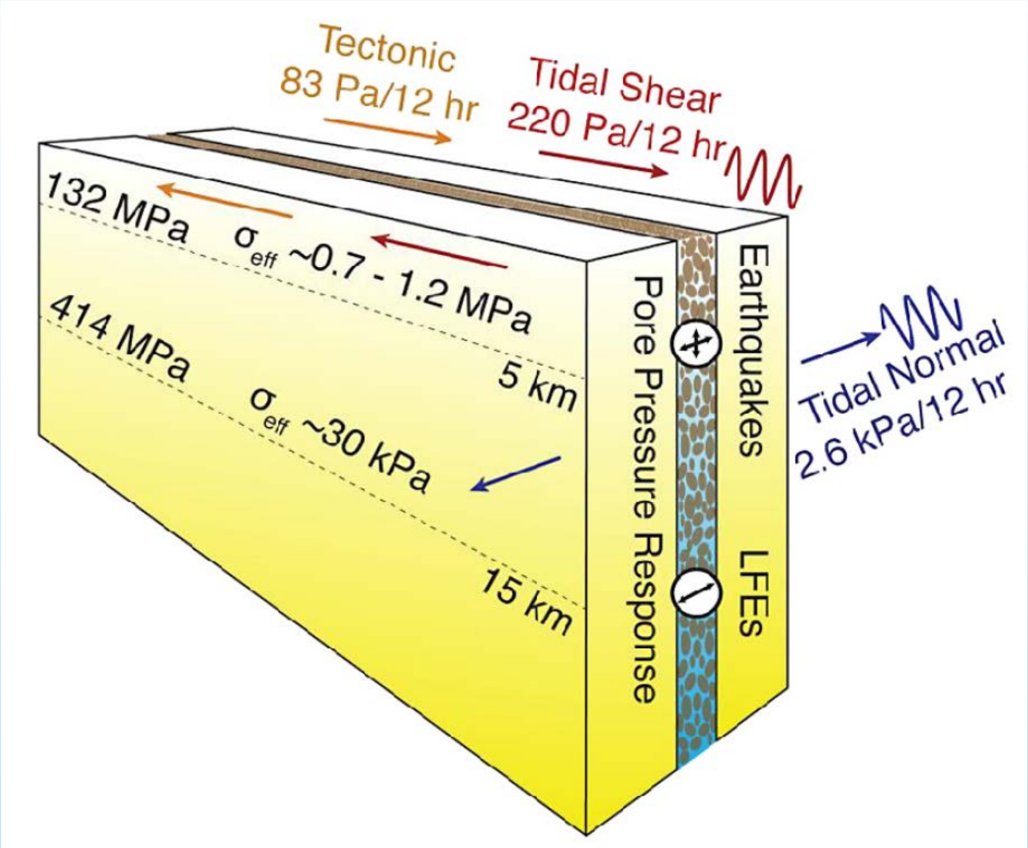
- Higher seismicity rate during rising fortnightly tides
- Threshold stress behavior drives seismicity

Tidal triggering of events



- During falling fortnightly tides, earthquakes preferentially coincide with the peak semi-diurnal stress.
- Semi-diurnal stress drives seismicity

Interpretation



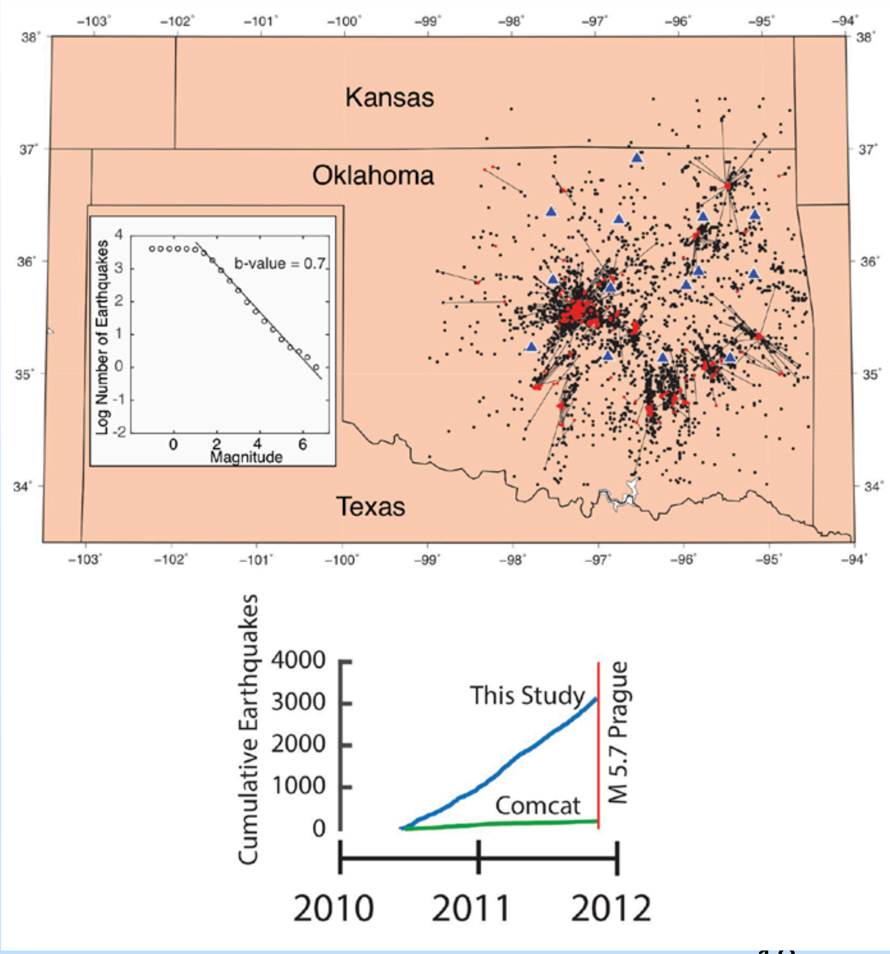
- tidal triggering of earthquakes transition from occurring during peak tidal extensional normal stresses to peak tidal shear stresses as pore pressures increase from below lithostatic pressure to near lithostatic pressure.

Summary

- We are developing methodologies to probe the state of fault (e.g., IWC, machine learning)
- These methods can provide information on the fault, such as pore pressure and effective normal stress
- By monitoring the change in state of stress on the fault, we may provide time bound on fault failures, and reduce the risk of induced seismicity

Next Step

- Apply to proper dataset
  - tectonic
  - water injection
  - CO_2



Appendix

Benefit to the Program

- Identify the Program goals being addressed.
  - Improve the risk assessment of induced seismicity in carbon sequestration.

- Insert project benefits statement.
  - The research project is developing new methodology to identify and monitor faults at a critical state of stress. If successful, the proof-of-concept work will demonstrate at field scale a transformational approach to both identifying potential faults of concern during site pre-characterization and monitoring a site during injection such that induced seismicity is minimized or even avoided.

Project Overview
Goals and Objectives

– Present information on how the project goals and objectives relate to the program goals and objectives.
    - The stress state of the fault is related to risk level of induced seismicity. Monitoring faults at critical state of stress enables advanced risk assessment of induced seismicity for carbon storage.
– Identify the success criteria for determining if a goal or objective has been met. These generally are discrete metrics to assess the progress of the project and used as decision points throughout the project.
    - New methodology for monitoring the stress state of faults
    - Successful application of the methodology to CO_2 storage field

Organization Chart

LANL

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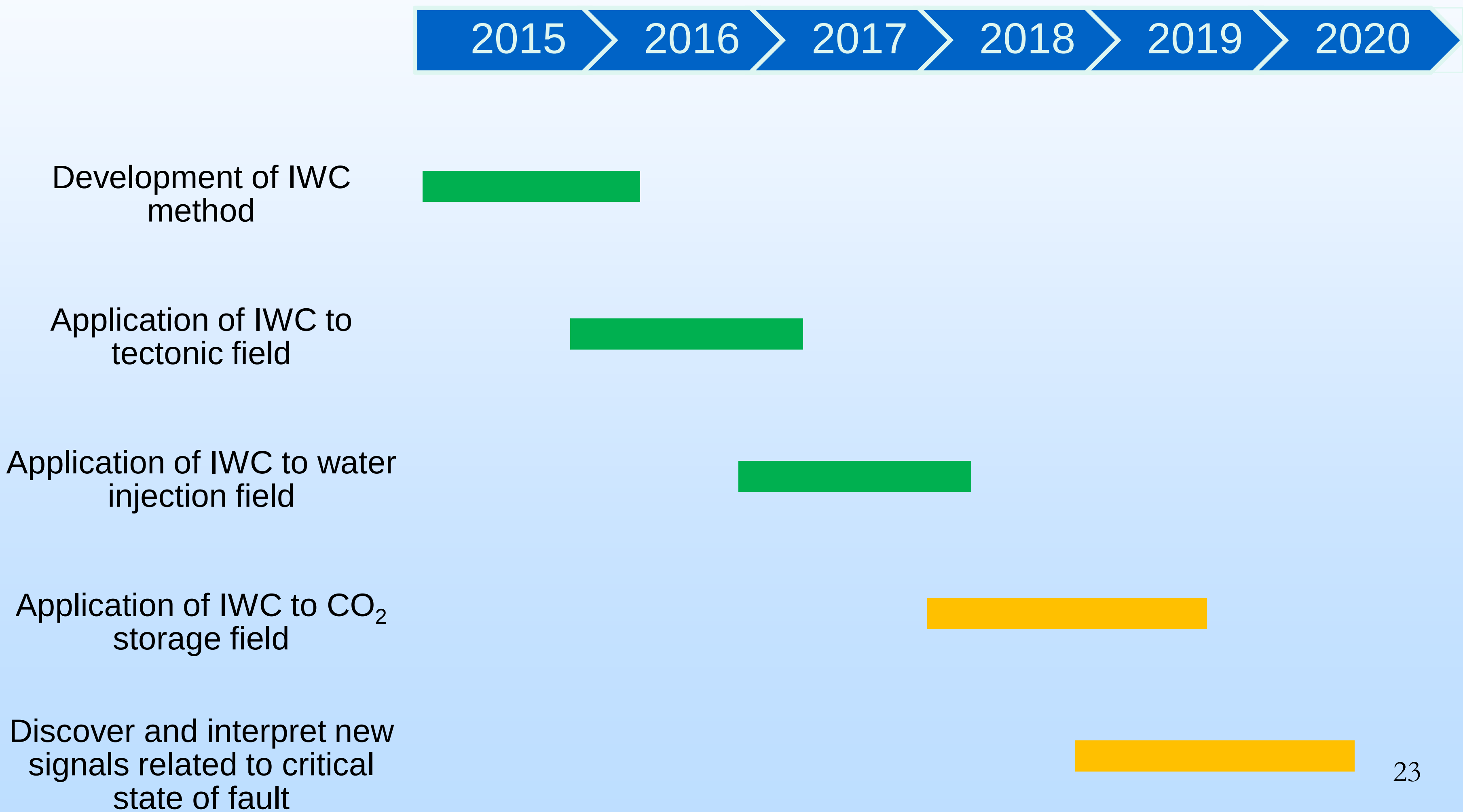
Gantt Chart


2015
2016
2017
2018
2019
2020
Development of IWC method
Application of IWC to tectonic field
Application of IWC to water injection field
Application of IWC to CO_2 storage field
Discover and interpret new signals related to critical state of fault

Bibliography

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