Proactively Addressing Induced Seismicity

Tim Tyrrell
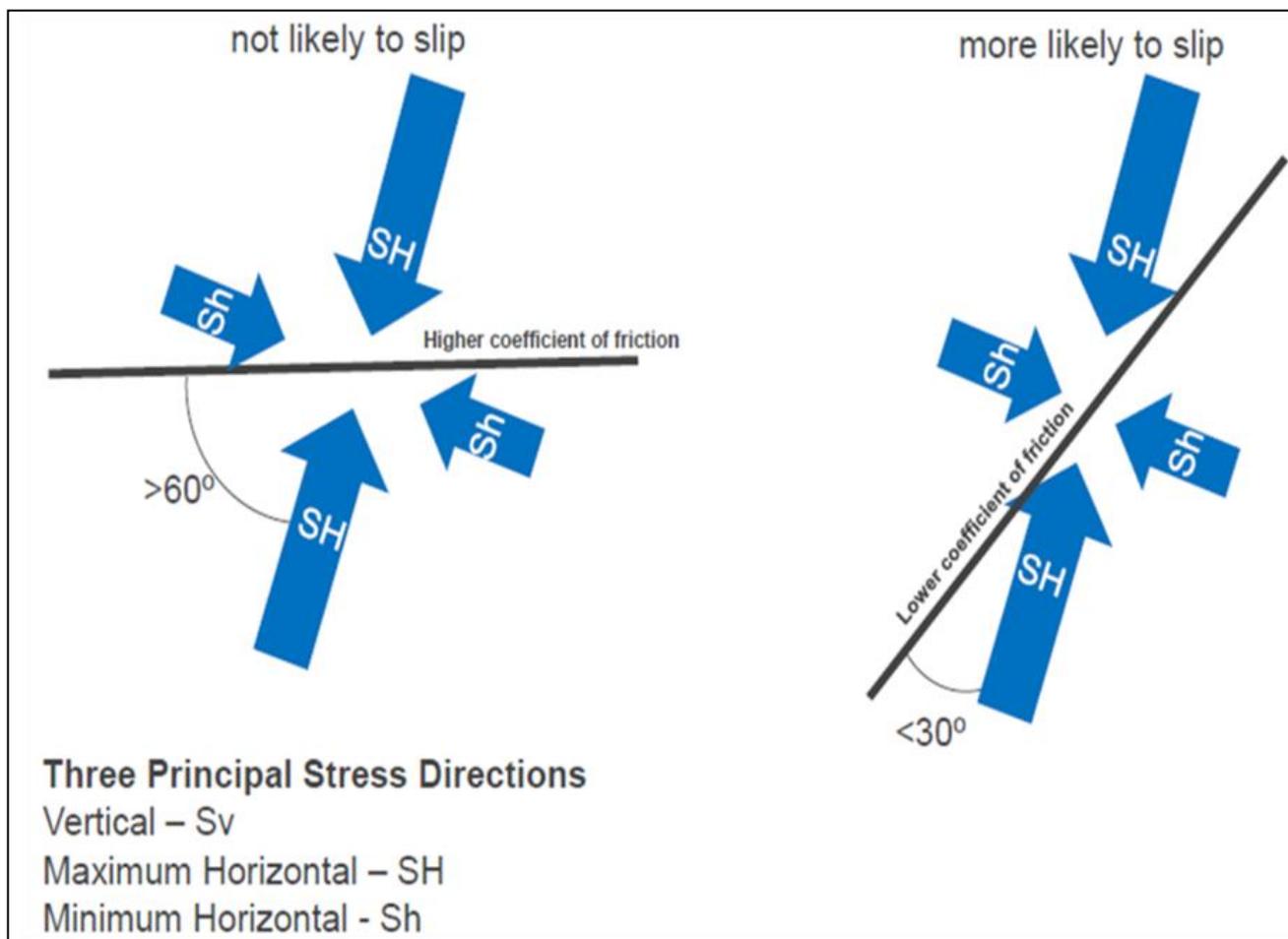**May 2017**

An **ExxonMobil** Subsidiary

What Causes a Fault to Slip?

Changes in stress

- Shear stress
- Pore pressure change
- Some faults are easier to 'move' than others

not likely to slip

more likely to slip

Higher coefficient of friction

Lower coefficient of friction

$>60°$

$<30°$

Three Principal Stress Directions
Vertical – Sv
Maximum Horizontal – SH
Minimum Horizontal - Sh

What can Cause Stress to Change?

Dominant cause

Natural tectonics

Unique circumstances

Aquifer level changes

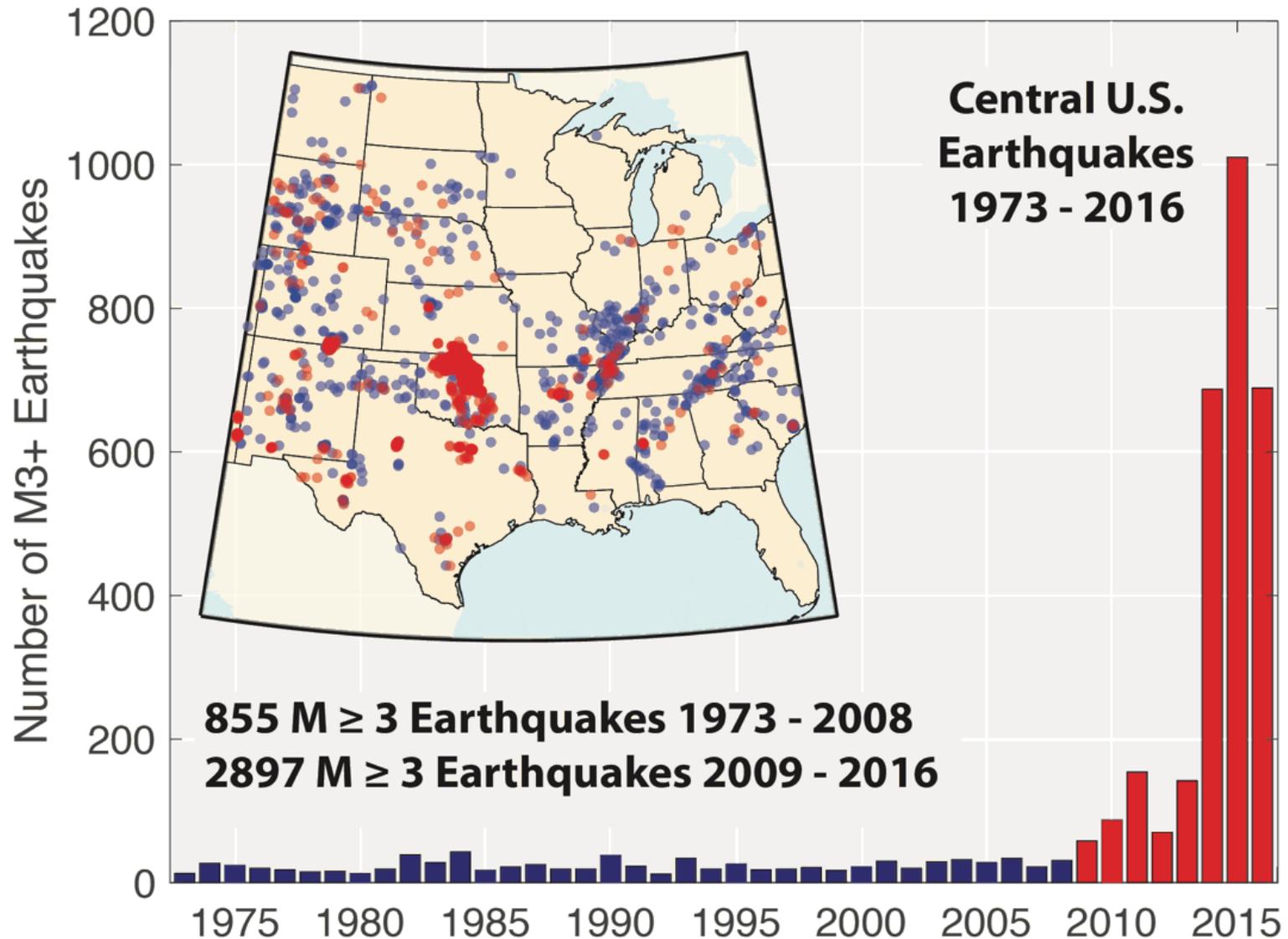Dam/reservoir impoundment

Mining

Waste water disposal wells

O&G injection/extraction
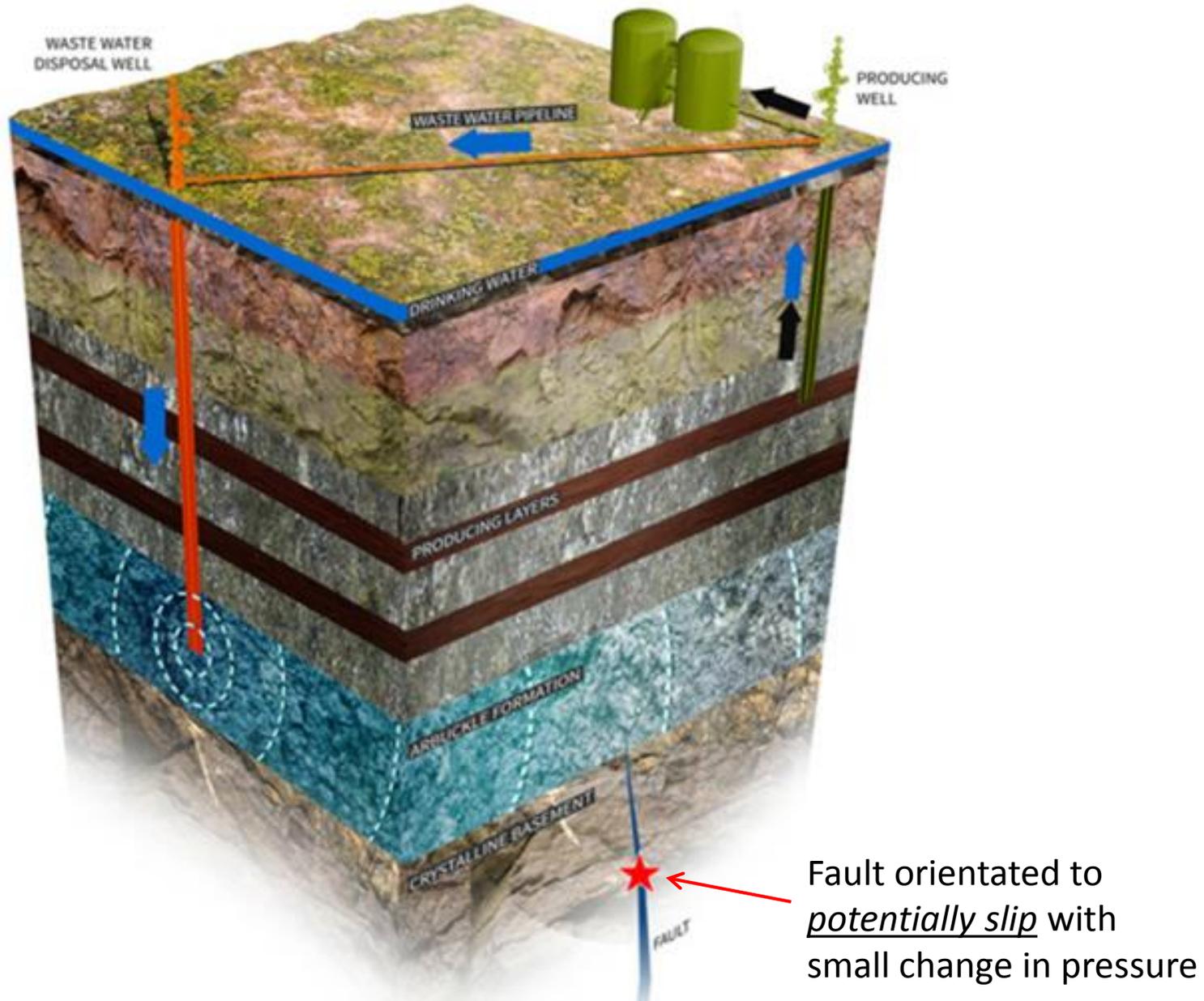
Hydraulic fracturing

Lake

Aquifer

Injection Well

Production Well

Faults
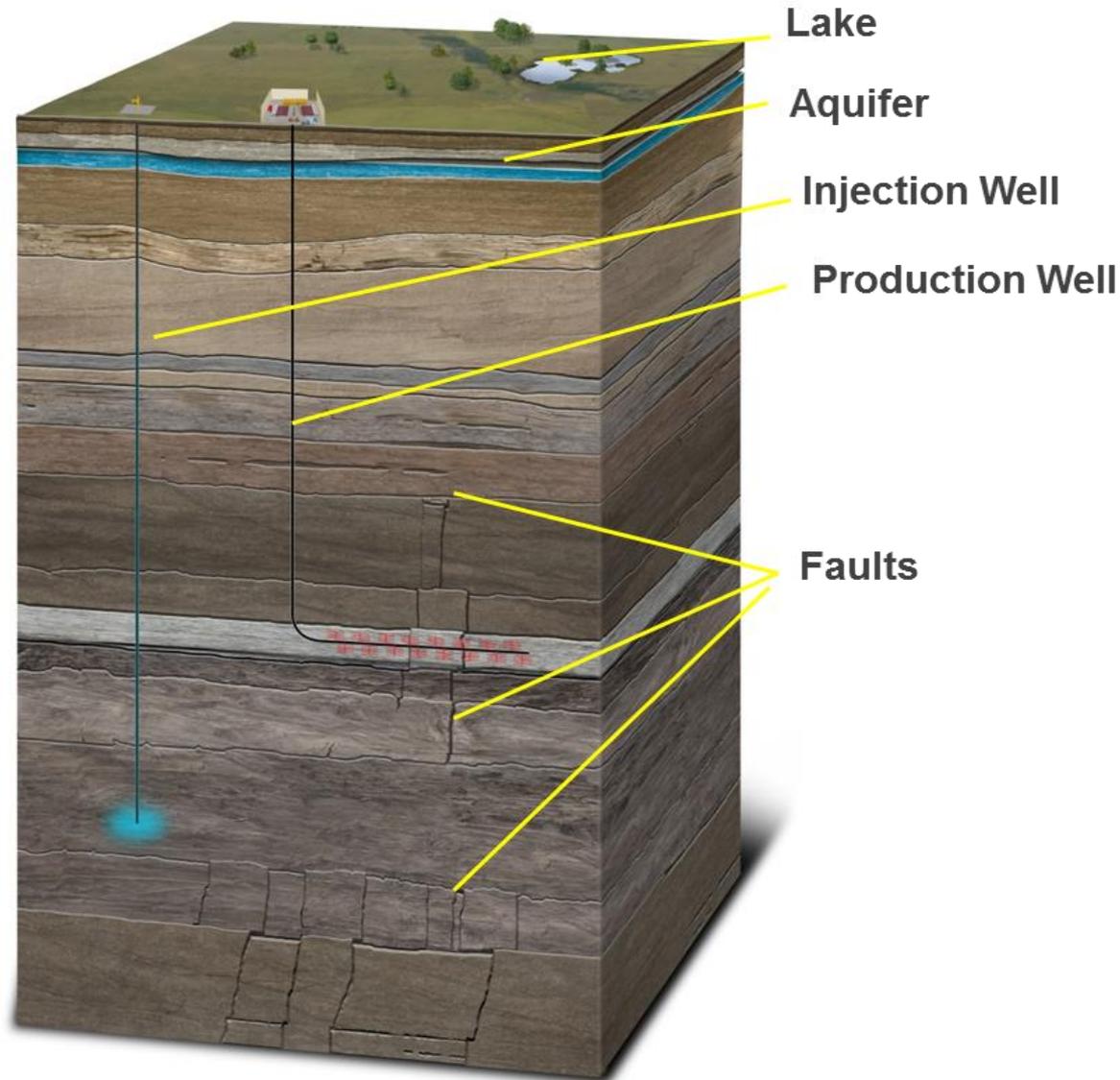
Most Cited Example of Salt Water Disposal Seismicity

The Exception – Not the Rule

Central U.S. Earthquakes 1973 - 2016

855 M ≥ 3 Earthquakes 1973 - 2008
2897 M ≥ 3 Earthquakes 2009 - 2016

Walsh *et al.* Sci. Adv. 2015;1:e1500195   18 June 2015

What's Happening in the Subsurface?

Fault orientated to *potentially slip* with small change in pressure

Oklahoma Seismicity

Walsh *et al.* Sci. Adv. 2015;1:e1500195   18 June 2015
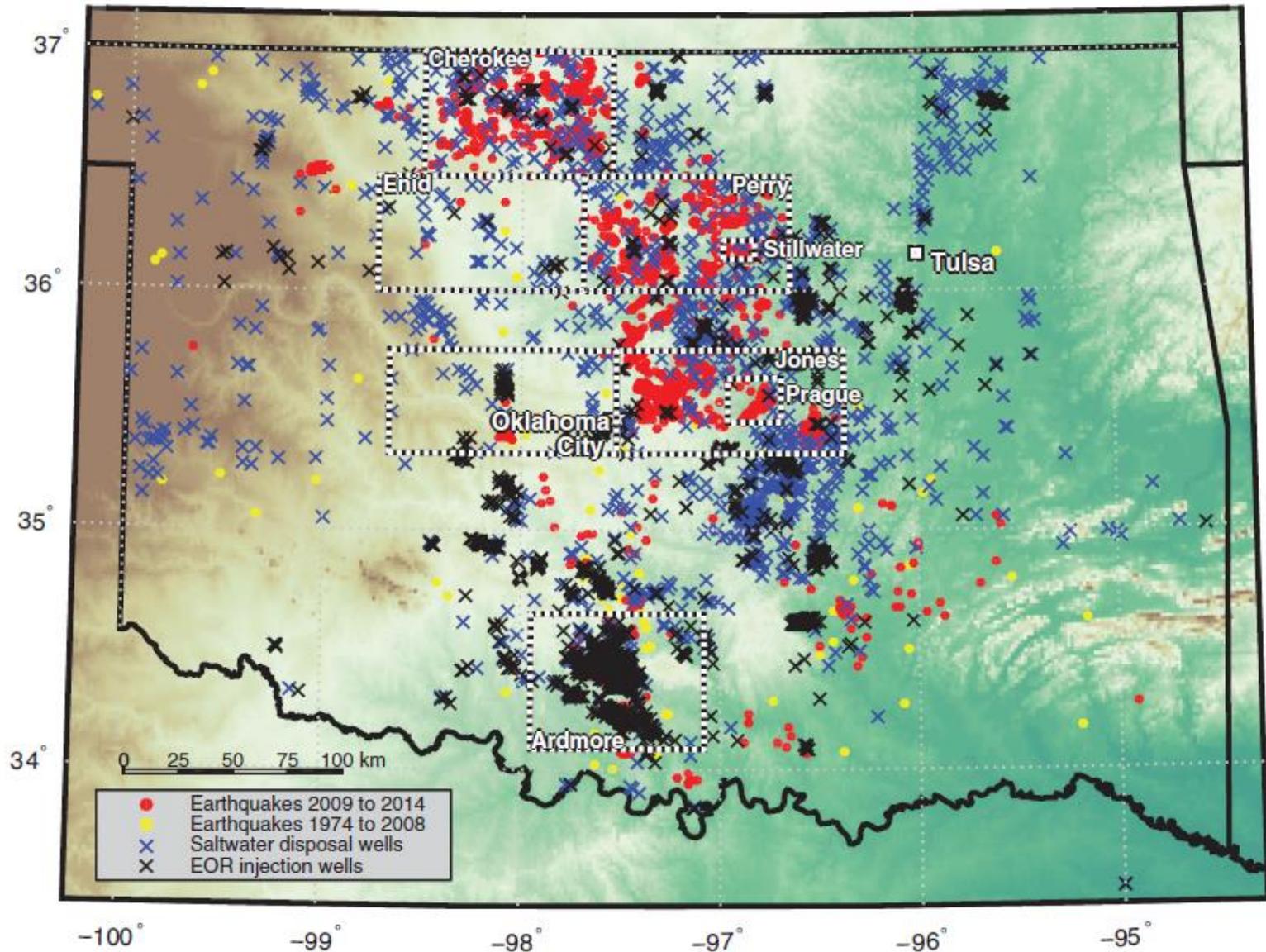
Produced Formation Water Relationship

Walsh *et al.* Sci. Adv. 2015;1:e1500195   18 June 2015
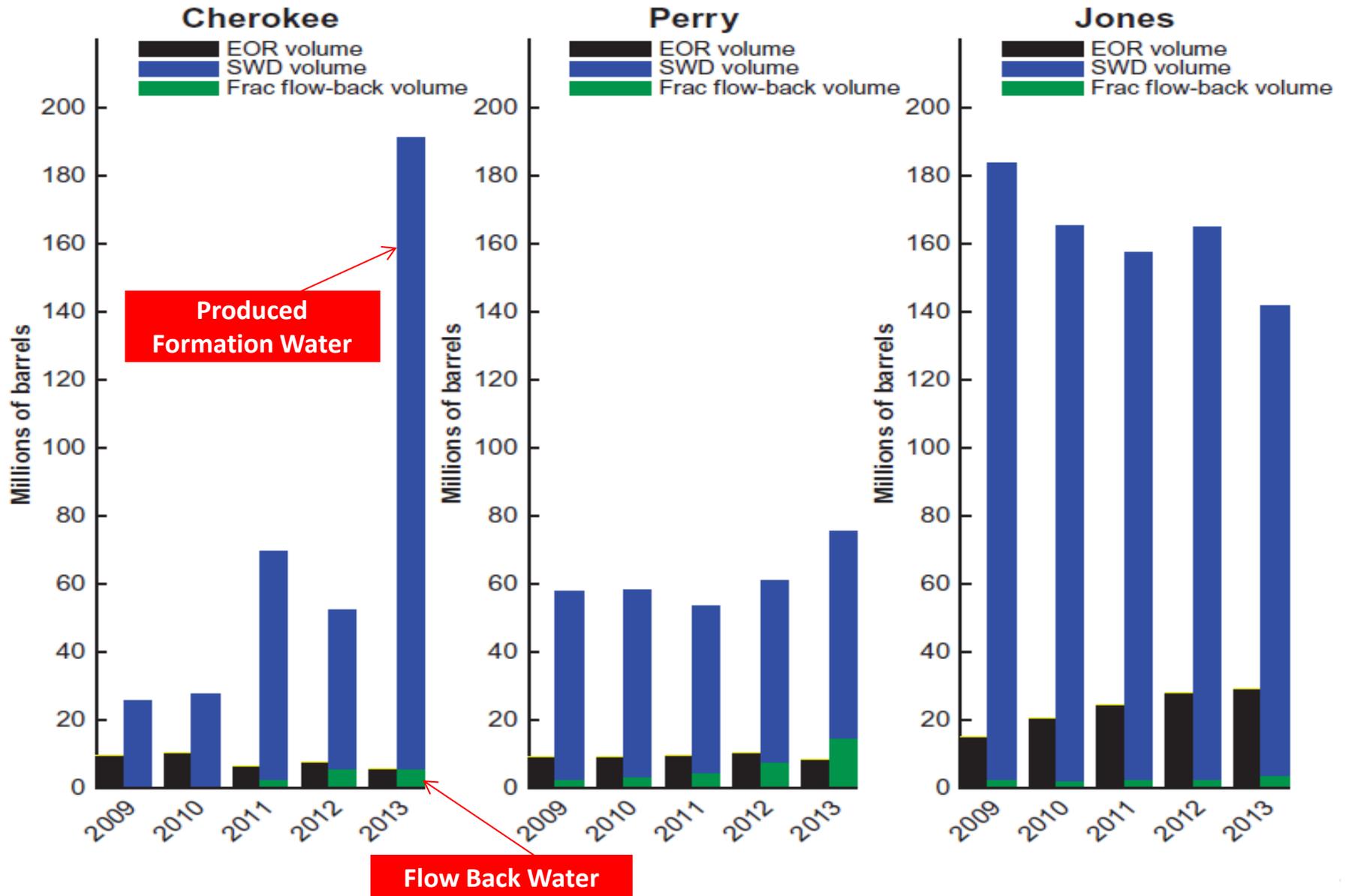
Hydraulic Fracture Induced Seismic Events

Alberta, Canada
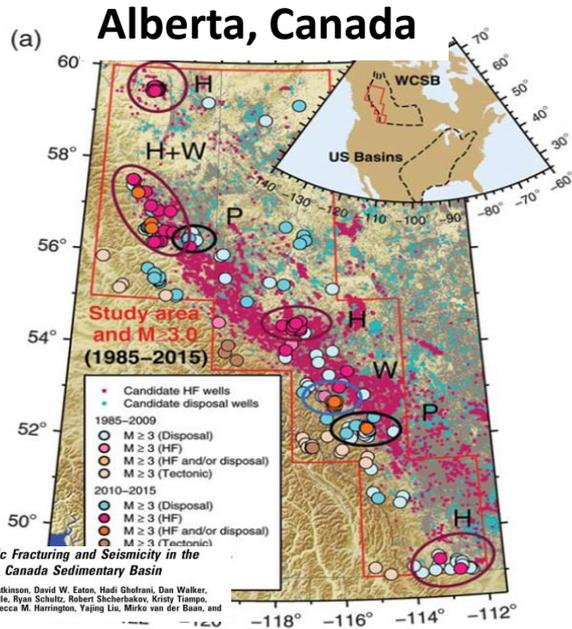
Ohio / Pennsylvania
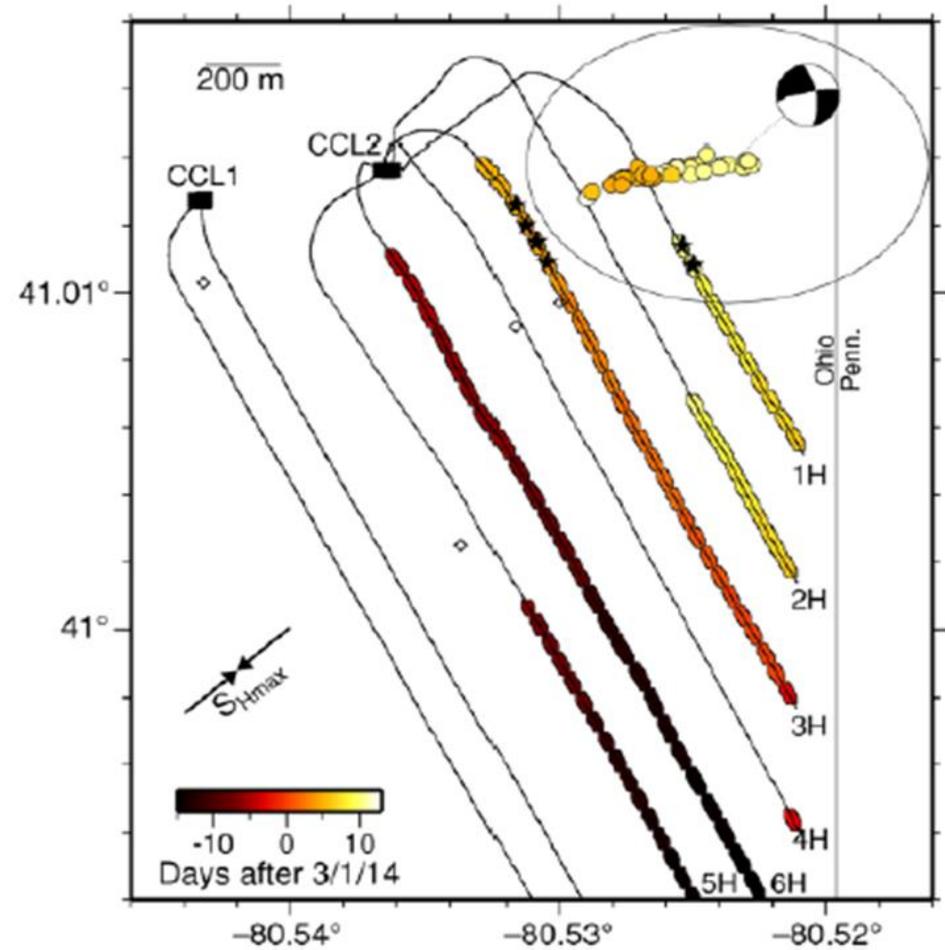

After Skoumal 2015
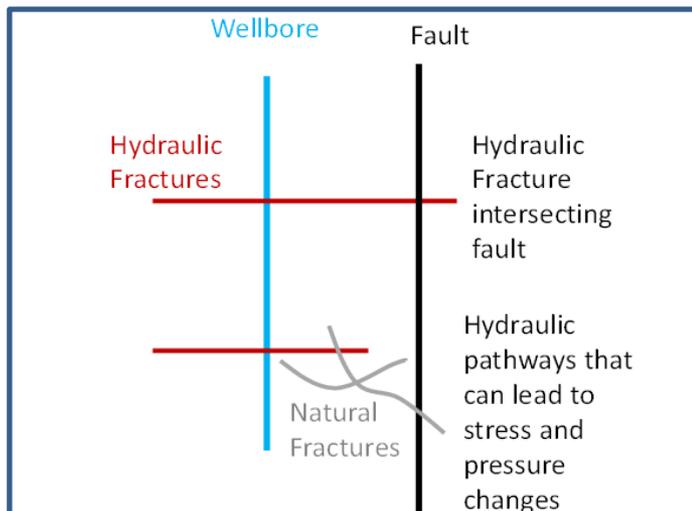
Pennsylvania – Ohio Unconventional Development

Salt Water Disposal

- Flow back water

- Shallow and deep disposal zones

- Smaller volumes and lower rates than Oklahoma

- A few deeper wells have been linked to induced seismicity

Hydraulic Fracturing

- Very rare - Instances limited to one area

  - Utica stimulation

- No events associated with Marcellus stimulation

  - Isolation from deep seated faults?
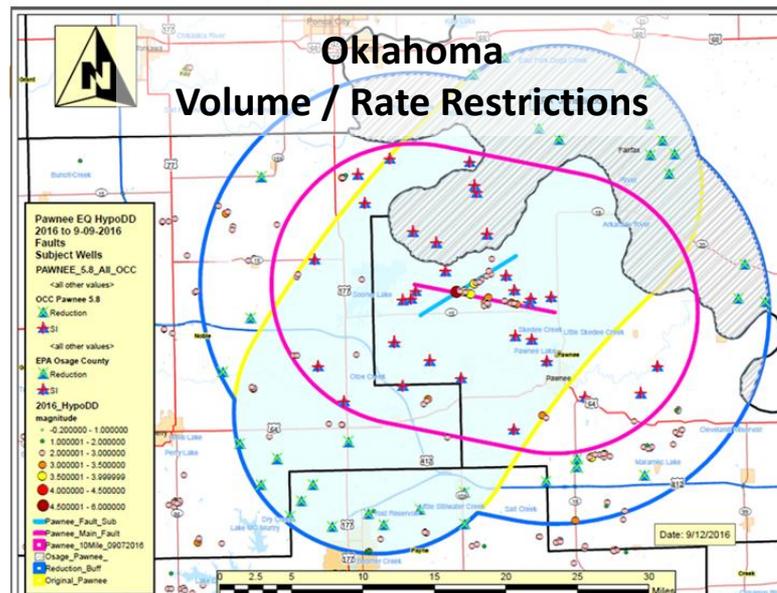

Disposal Zones
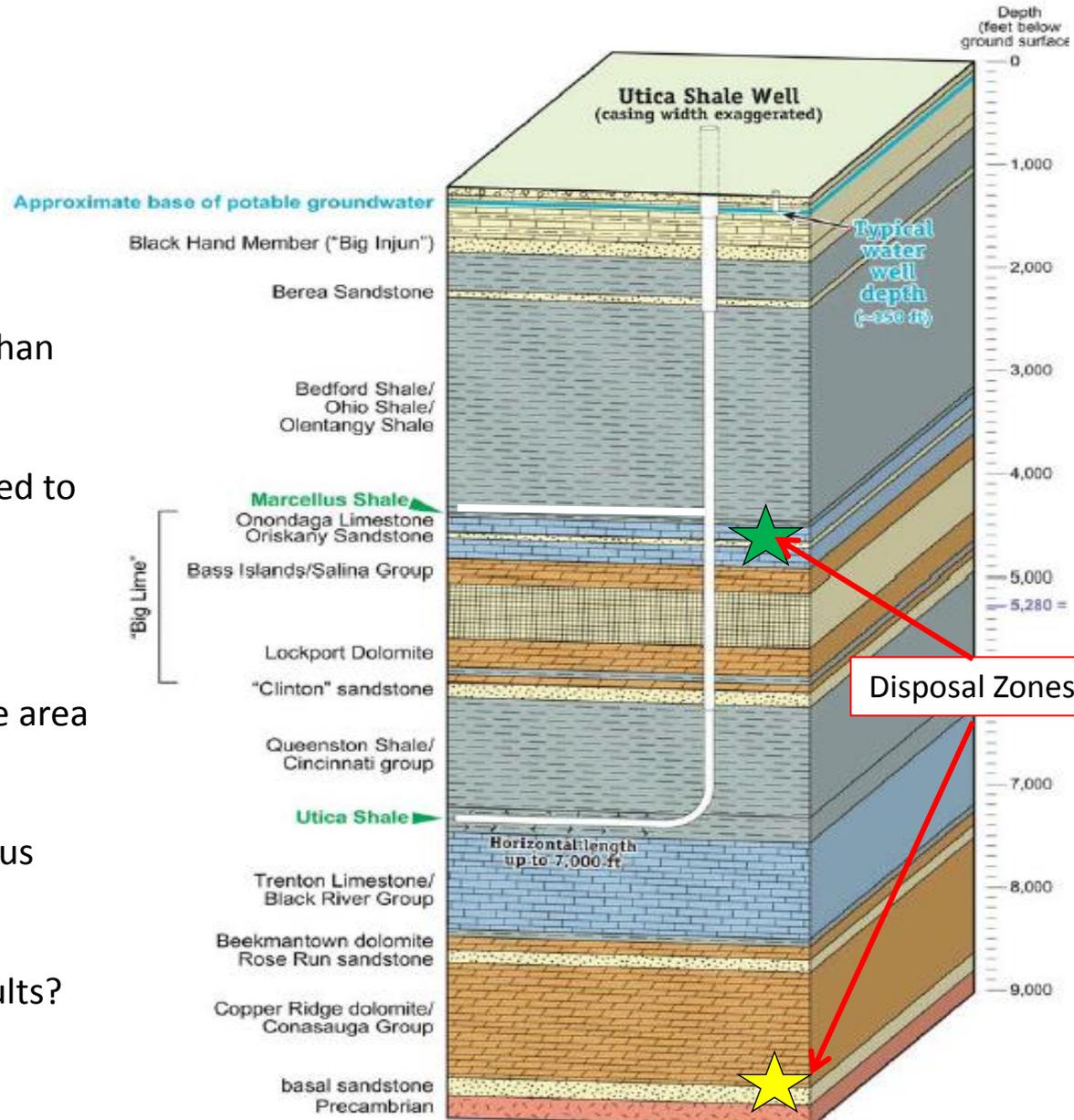
After Wickstrom et al

Regulatory Responses in Higher Risk Areas
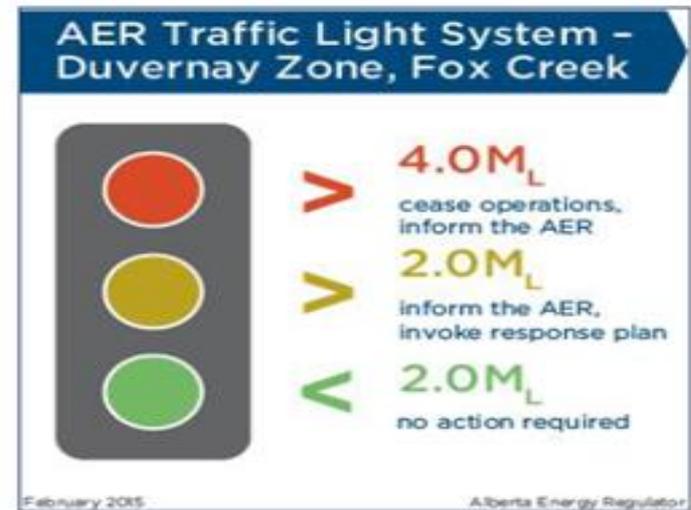
Salt Water Disposal

- Volume/rate restrictions

- Revised permitting conditions

- Enhanced monitoring requirements

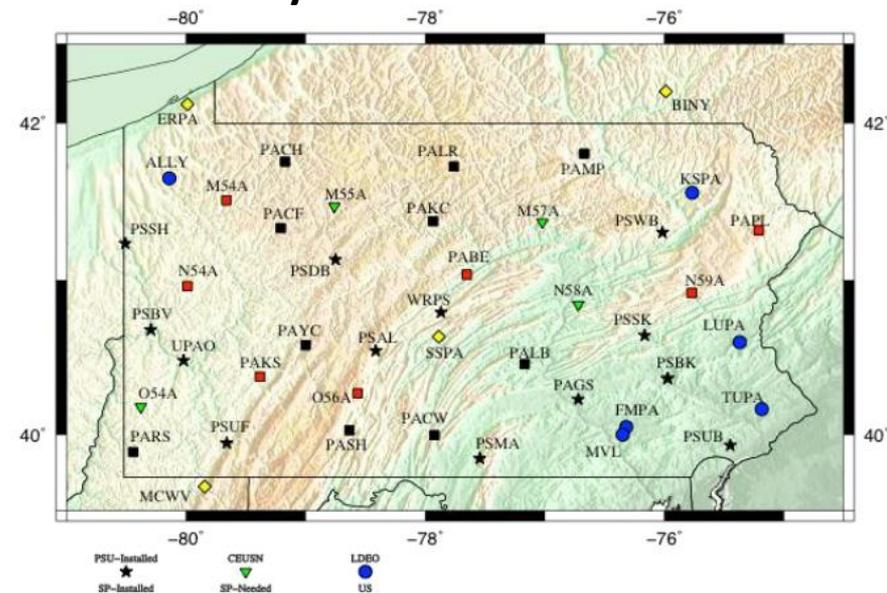- Traffic light systems

Hydraulic Fracturing

- Enhanced monitoring requirements

- Traffic light system

Alberta

Pennsylvania State Network

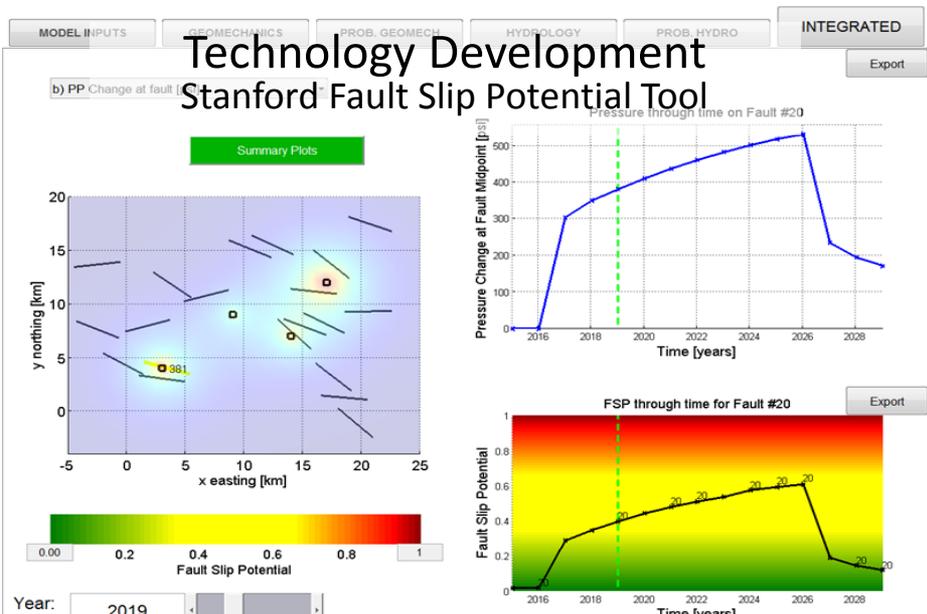**Oklahoma
Volume / Rate Restrictions**

Industry's Response

- Installation of proprietary arrays

- Limiting volumes / shutting in wells

- Proprietary Research

- Supporting University consortia

- Working with Regulators

  - States First Collaboration - Seismicity Primer

Research Consortia

3D Geomechanical Model
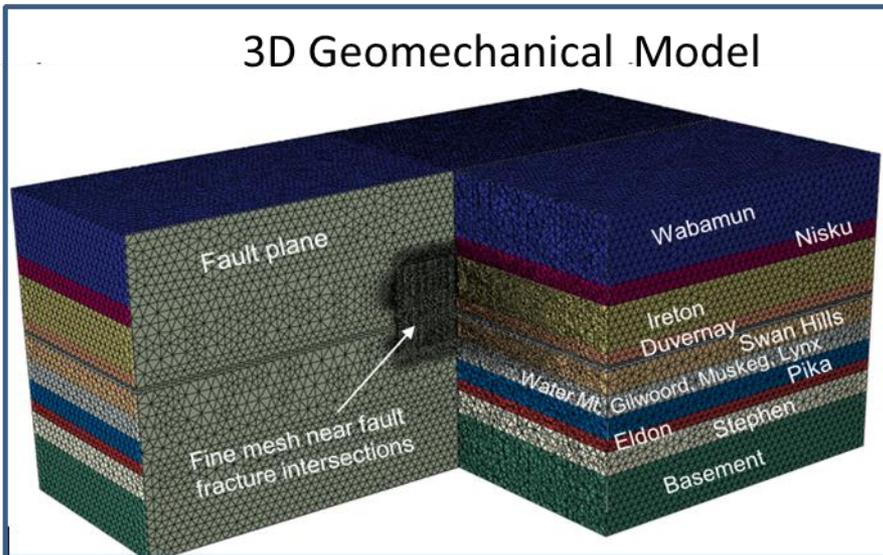
Technology Development
Stanford Fault Slip Potential Tool

Thank You!