MIT EARTH RESOURCES LABORATORY
ANNUAL FOUNDING MEMBERS MEETING 2018

Earth Resources Laboratory

Geomechanical assessment of the induced seismicity experiment at Rangely, CO

Josimar A. da Silva Jr[1], Hannah Byrne[2], John Shaw[2], Ruben Juanes[1,3]

1. DEPARTMENT OF EARTH, ATMOSPHERIC AND PLANETARY SCIENCES (EAPS), MIT
2. DEPARTMENT OF EARTH AND PLANETARY SCIENCES (EPS), HARVARD UNIVERSITY
3. DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING (CEE), MIT

Increase in seismicity in the central U.S.

inducedearthquakes.org

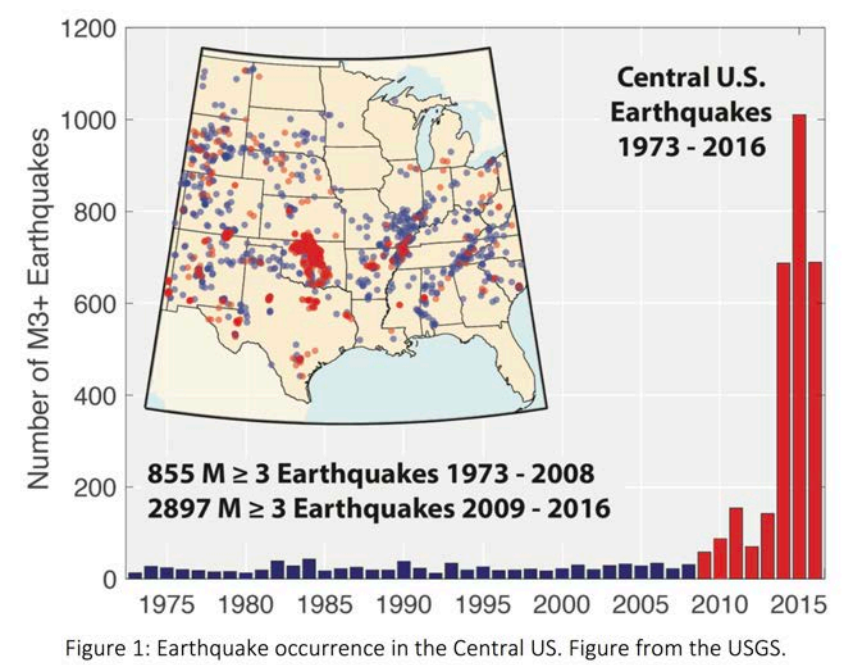
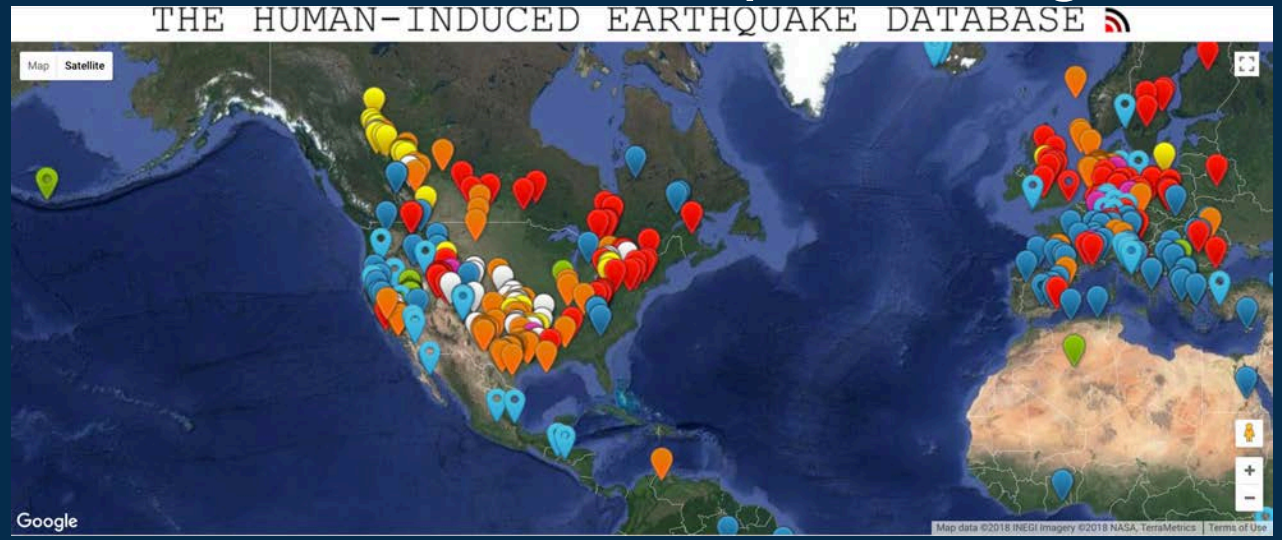


Figure 1: Earthquake occurrence in the Central US. Figure from the USGS.

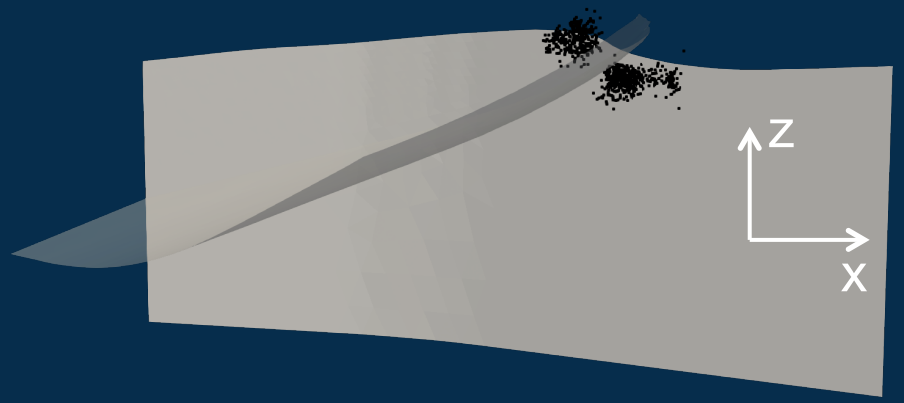


induced earthquakes: stresses acting on the fault at the time of failure are largely derived from human activities

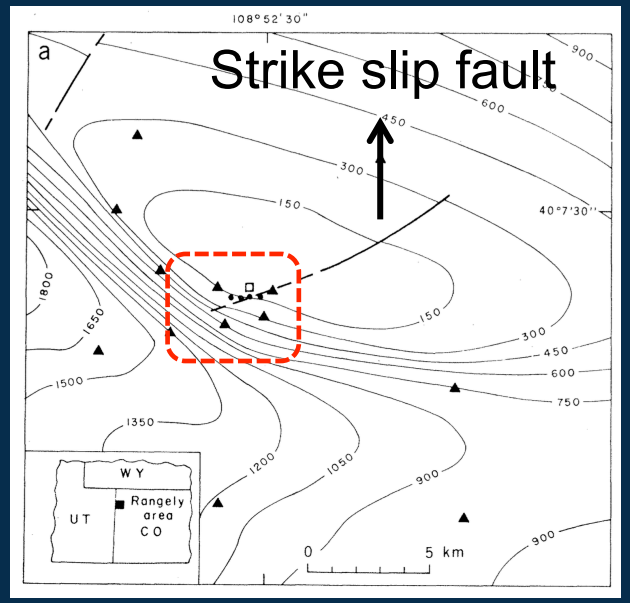
triggered earthquakes: stresses on the fault are largely tectonic but the timing of the earthquakes was affected by anthropogenic activities.

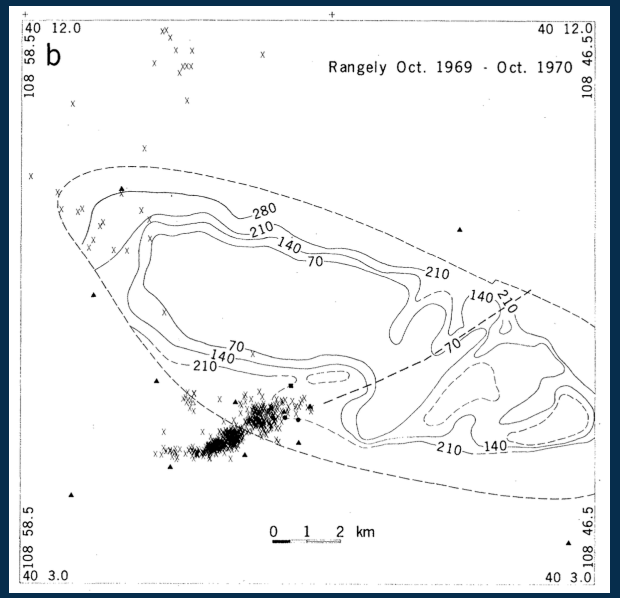
Rangely injection experiment, Colorado (1970)

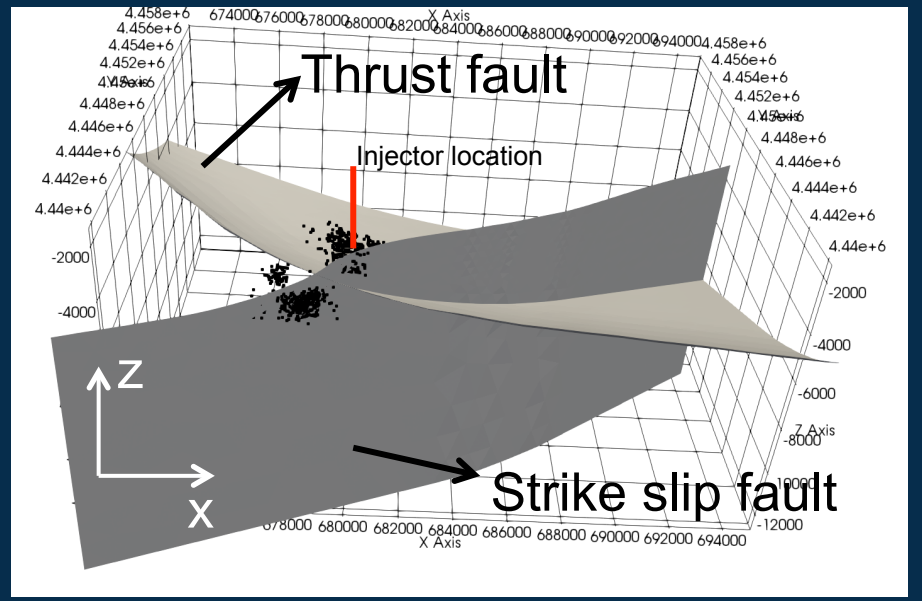
1. Four wells were drilled near known strike slip fault
2. Water was injected until earthquakes occurred
3. Earthquakes stopped when injection ceased



Raleigh, Science, 1976

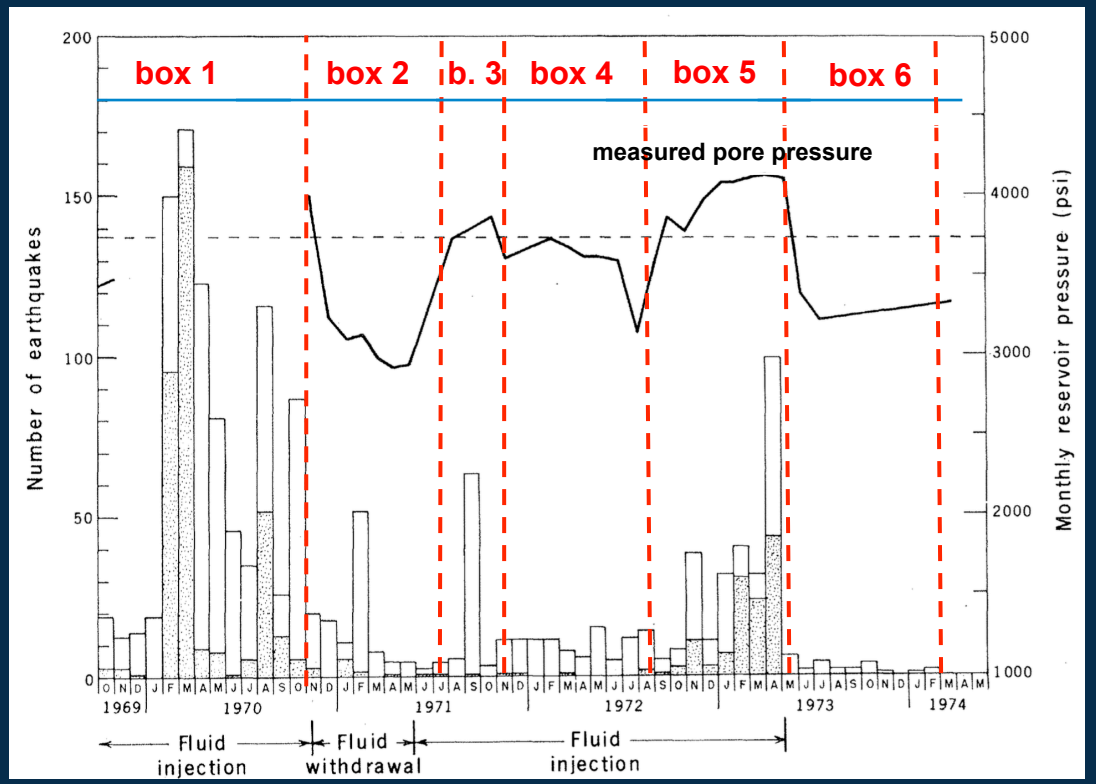


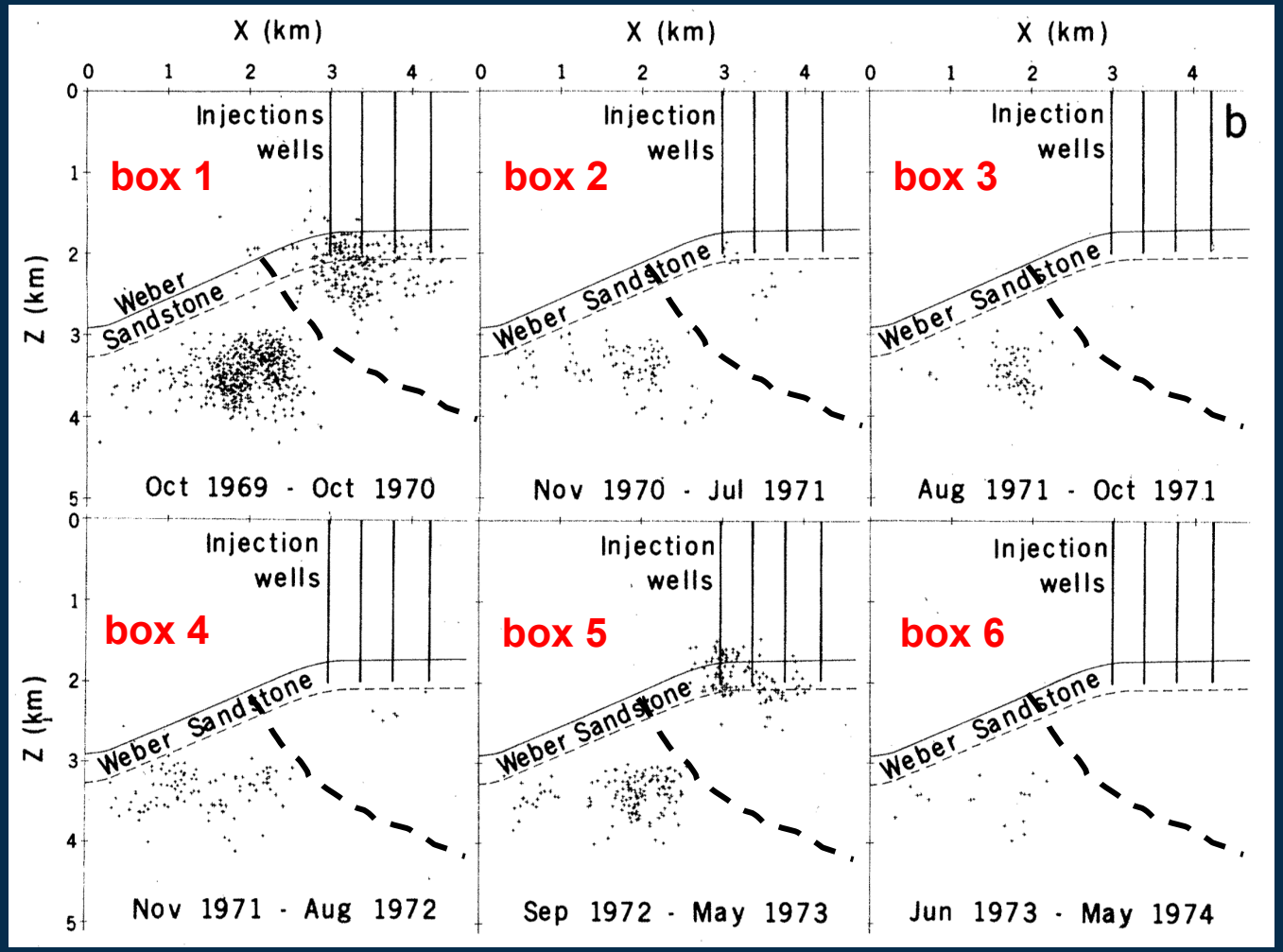




Rangely injection experiment, Colorado (1970)

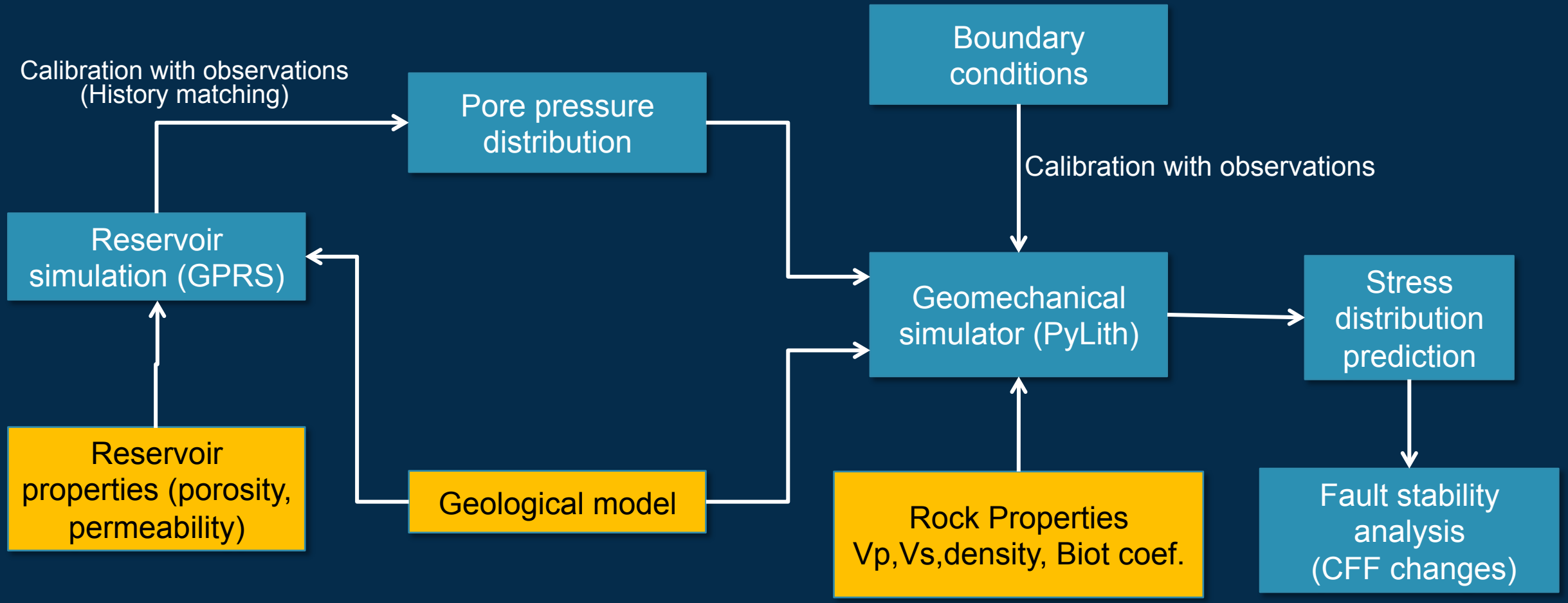
1. Pioneer work showing correlation between increase in reservoir pressure and EQ. occurrence



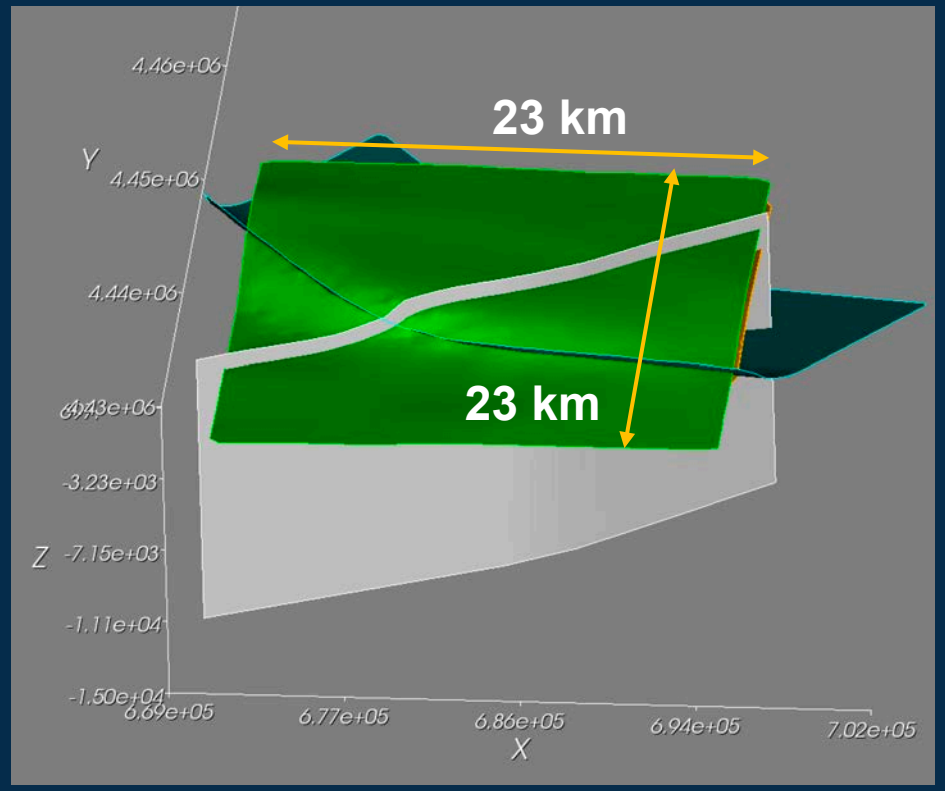


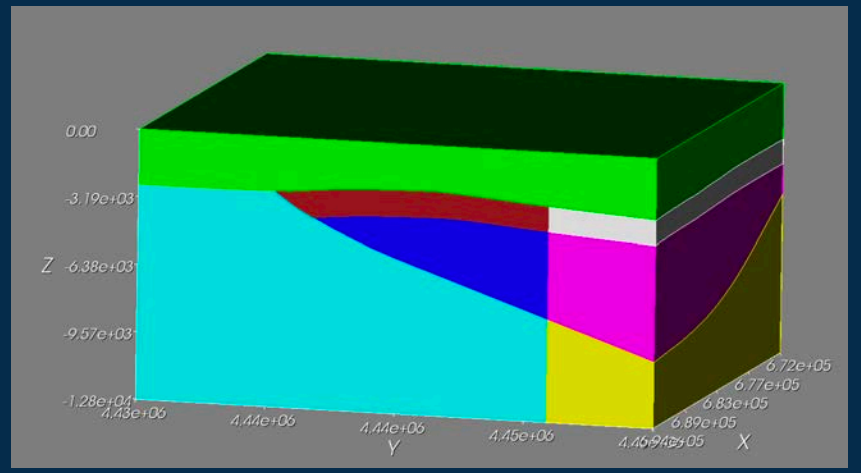
All figures are from Raleigh et al. (1976)

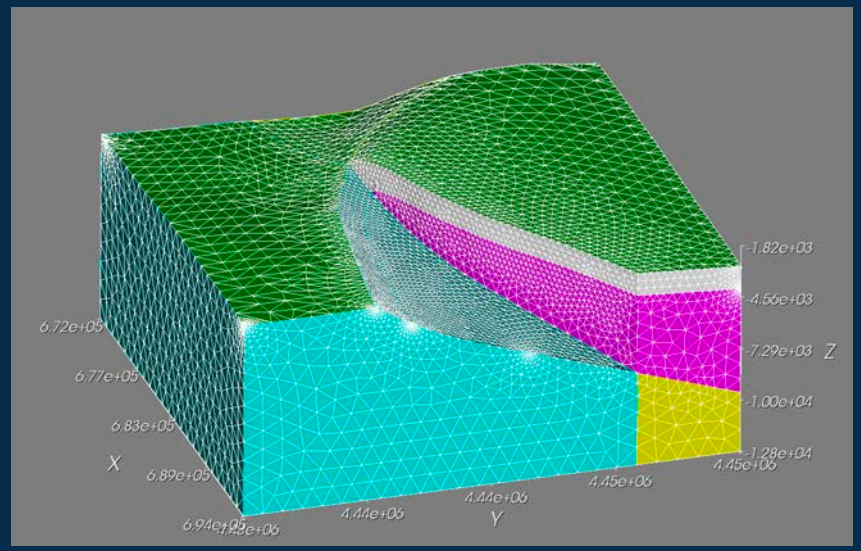
Simulation workflow



Structural model and finite element mesh



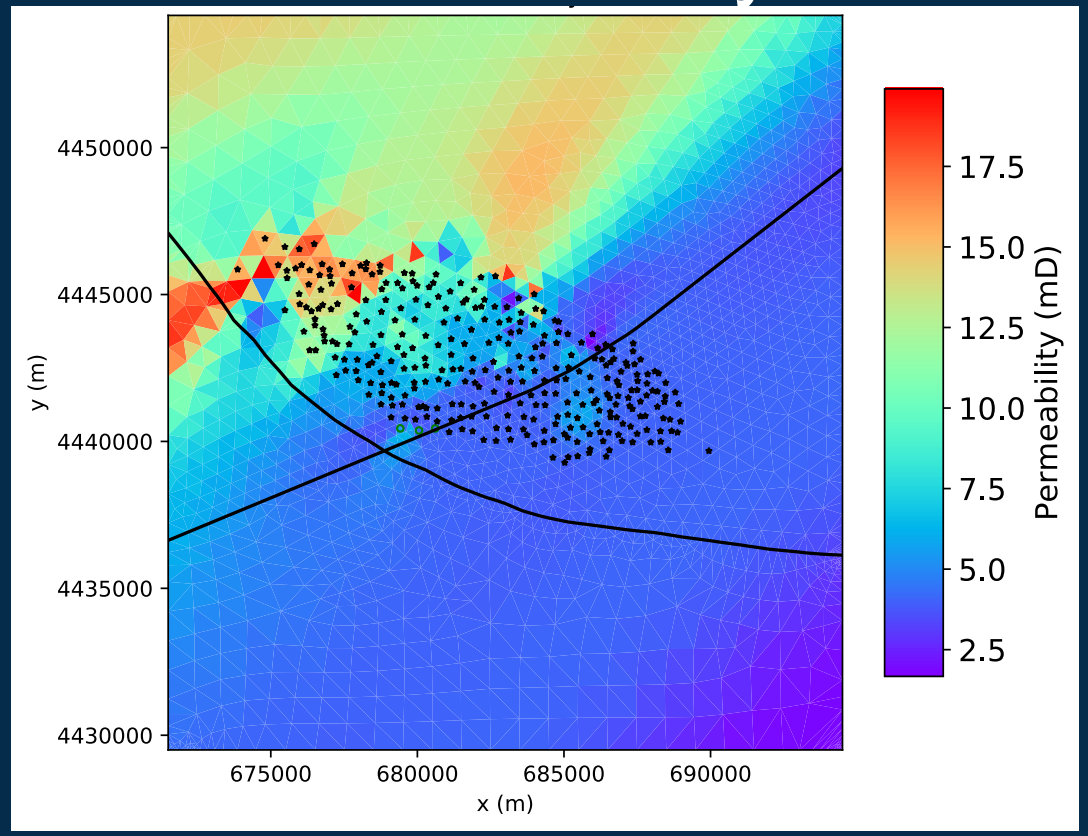




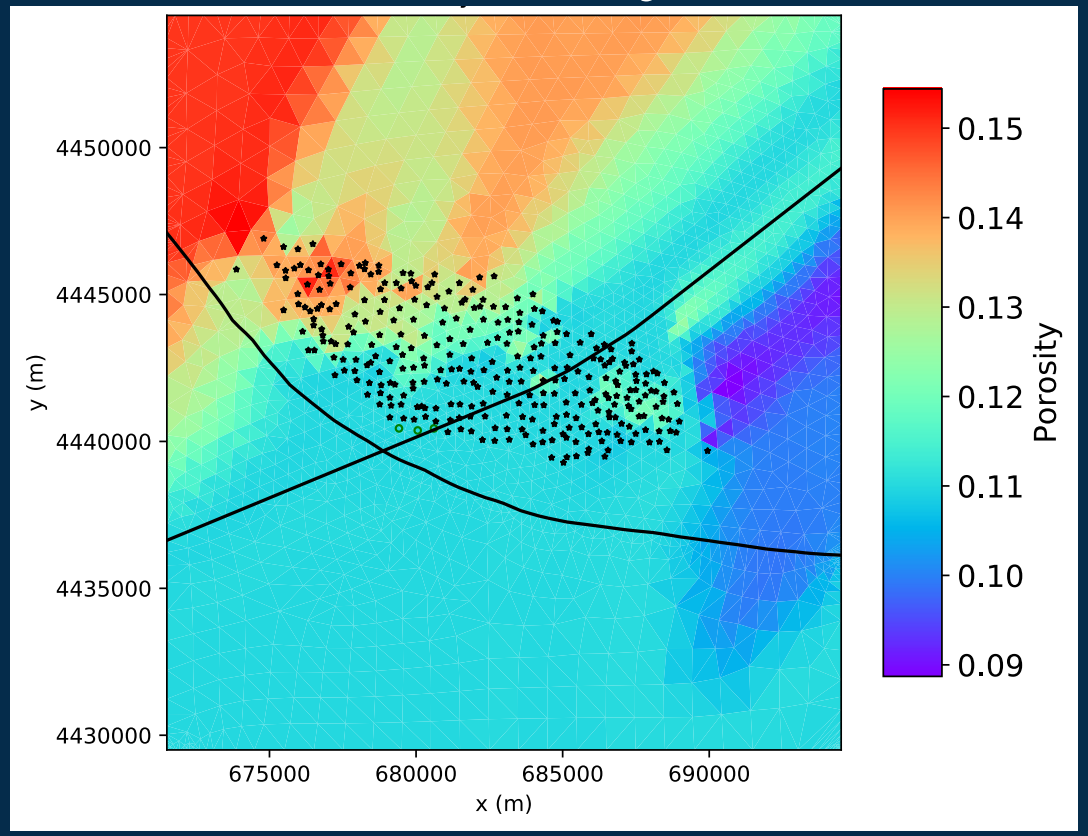
1. Number of mesh elements ~150K
2. Minimum mesh element size: 300 m

Reservoir properties

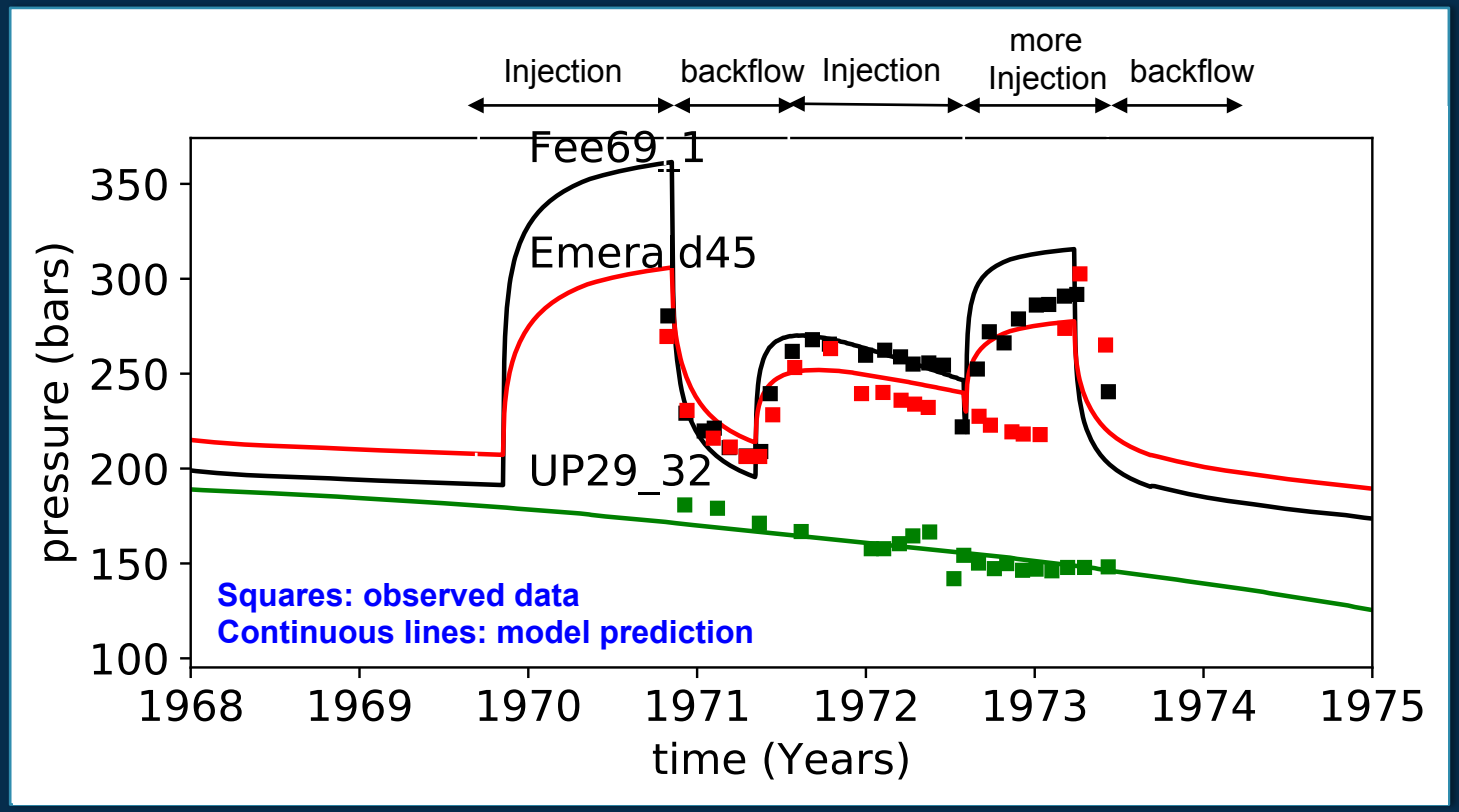
Permeability

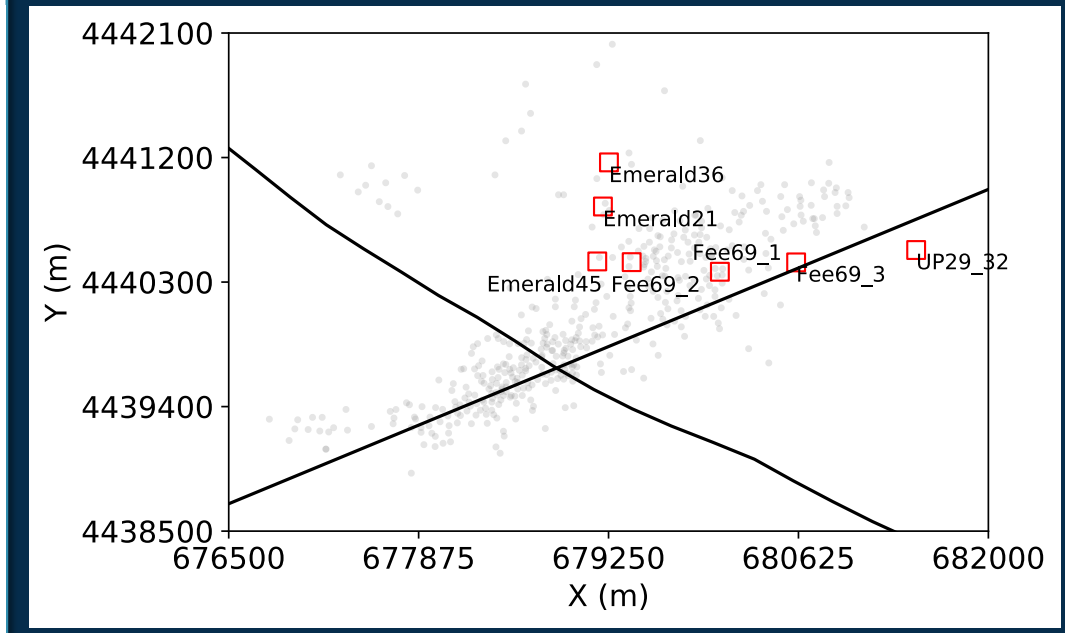


Porosity

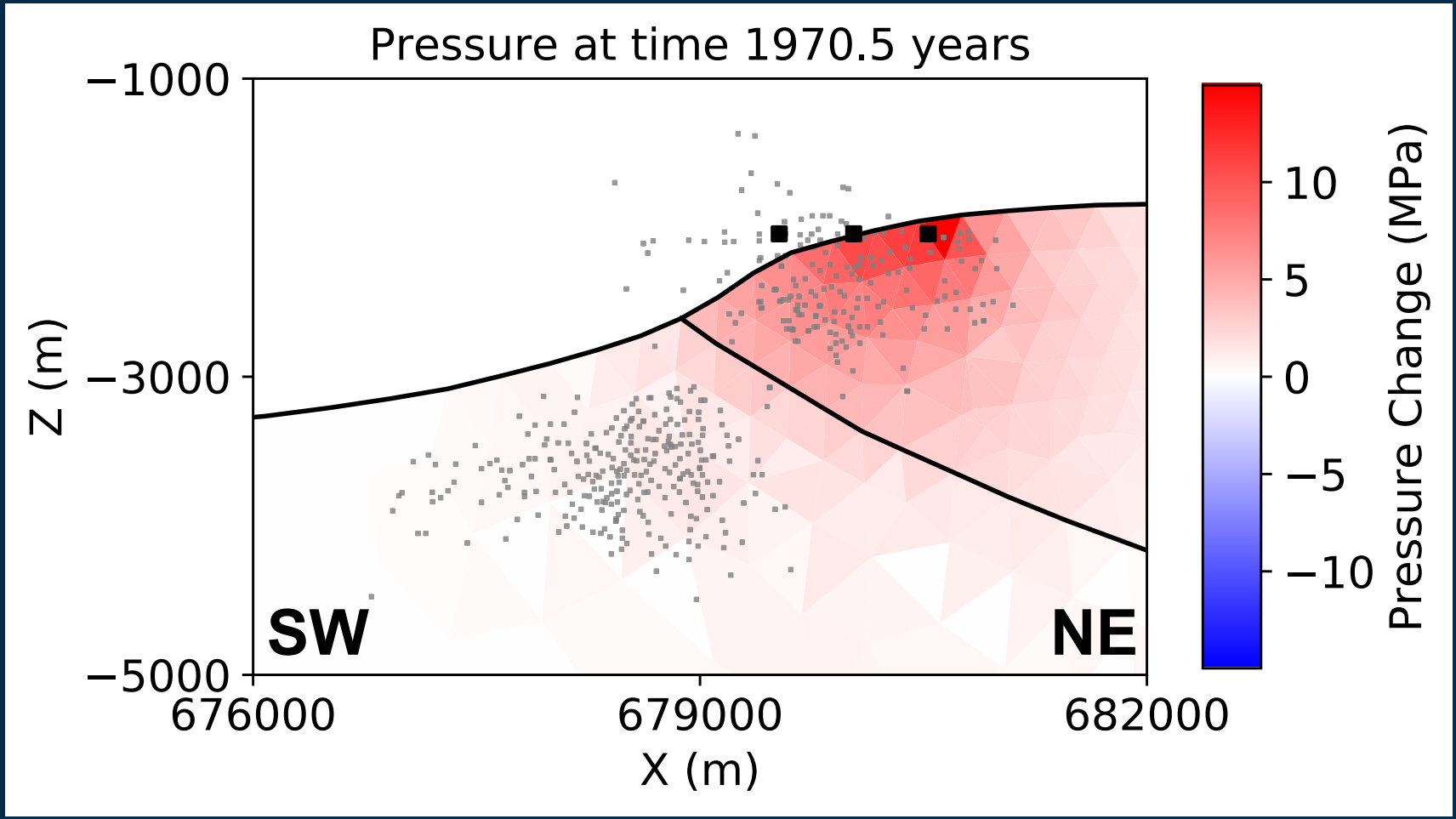


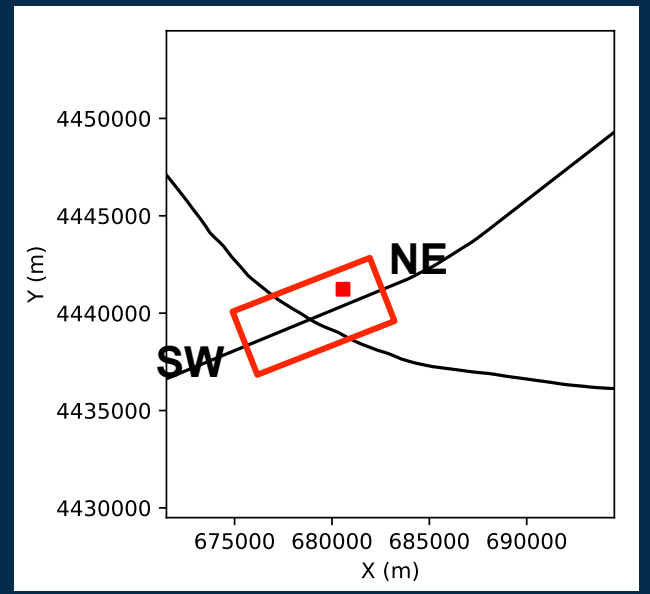
Reservoir simulation results



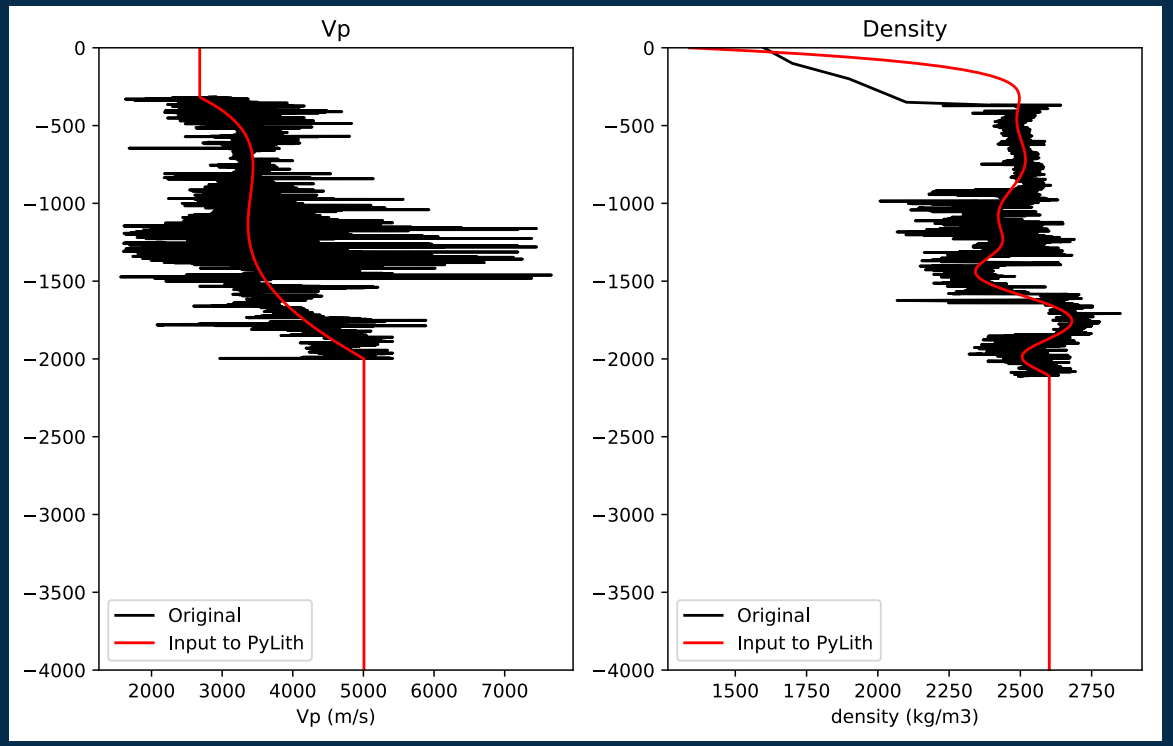


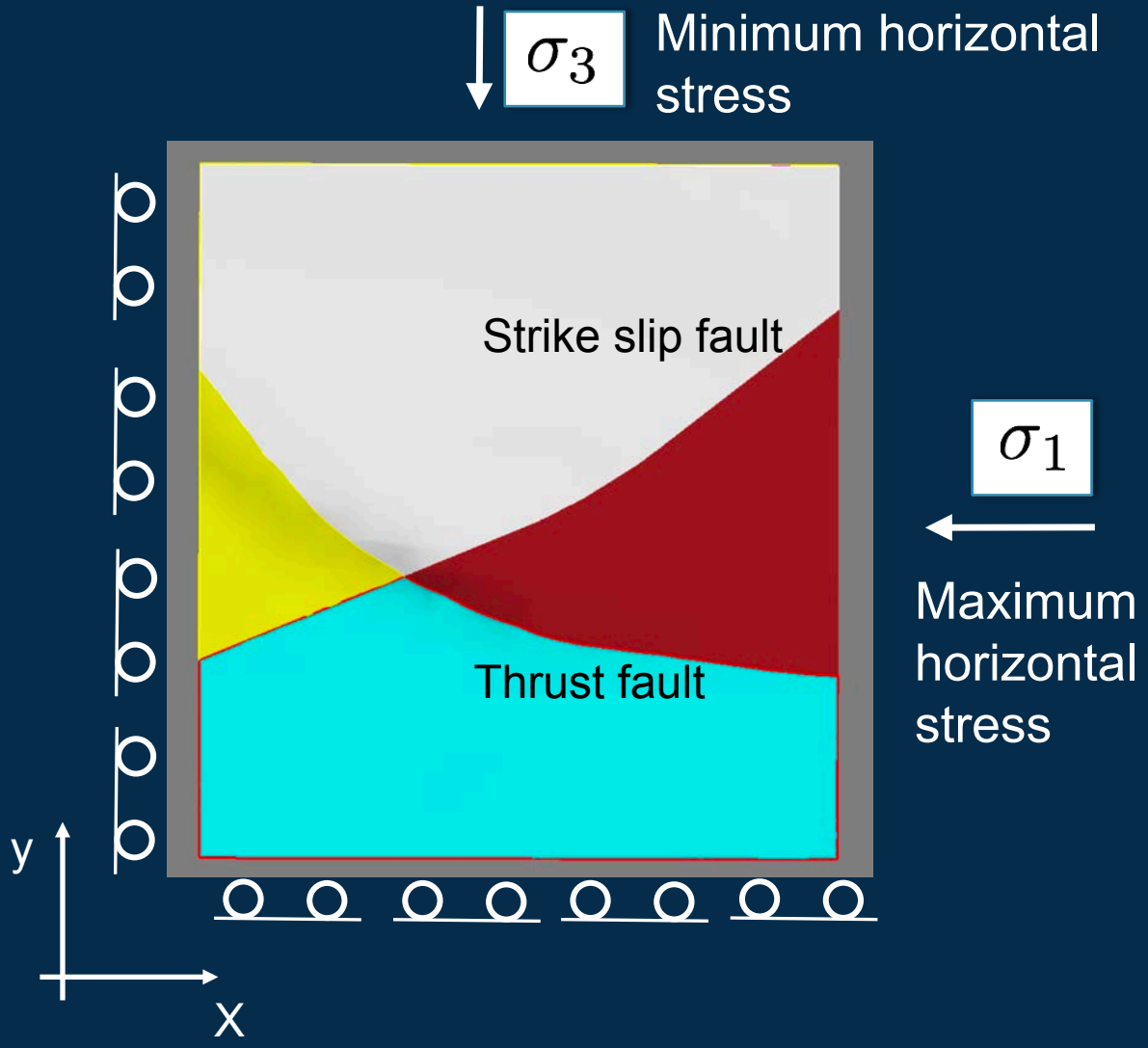
Pore pressure at the strike slip fault





Rock properties and boundary conditions





Coulomb failure function

$$CFF = |\tau| - \mu_f(-\sigma')$$

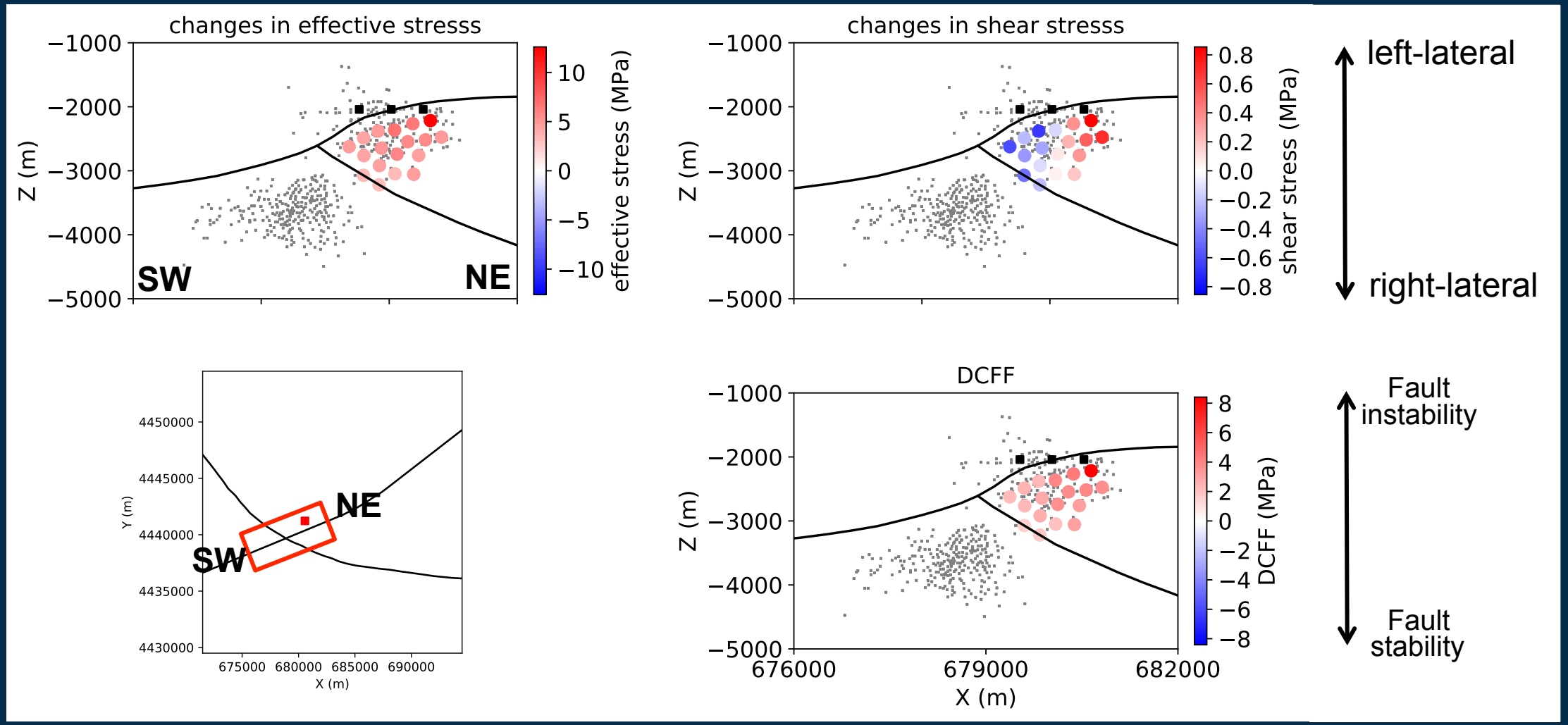
$$DCFF = CFF_{t_1} - CFF_{t_{ref}}$$

$$\mu_f = 0.6 \qquad t_{ref} = 1969.86 \qquad \sigma' = \sigma_n + P_p$$

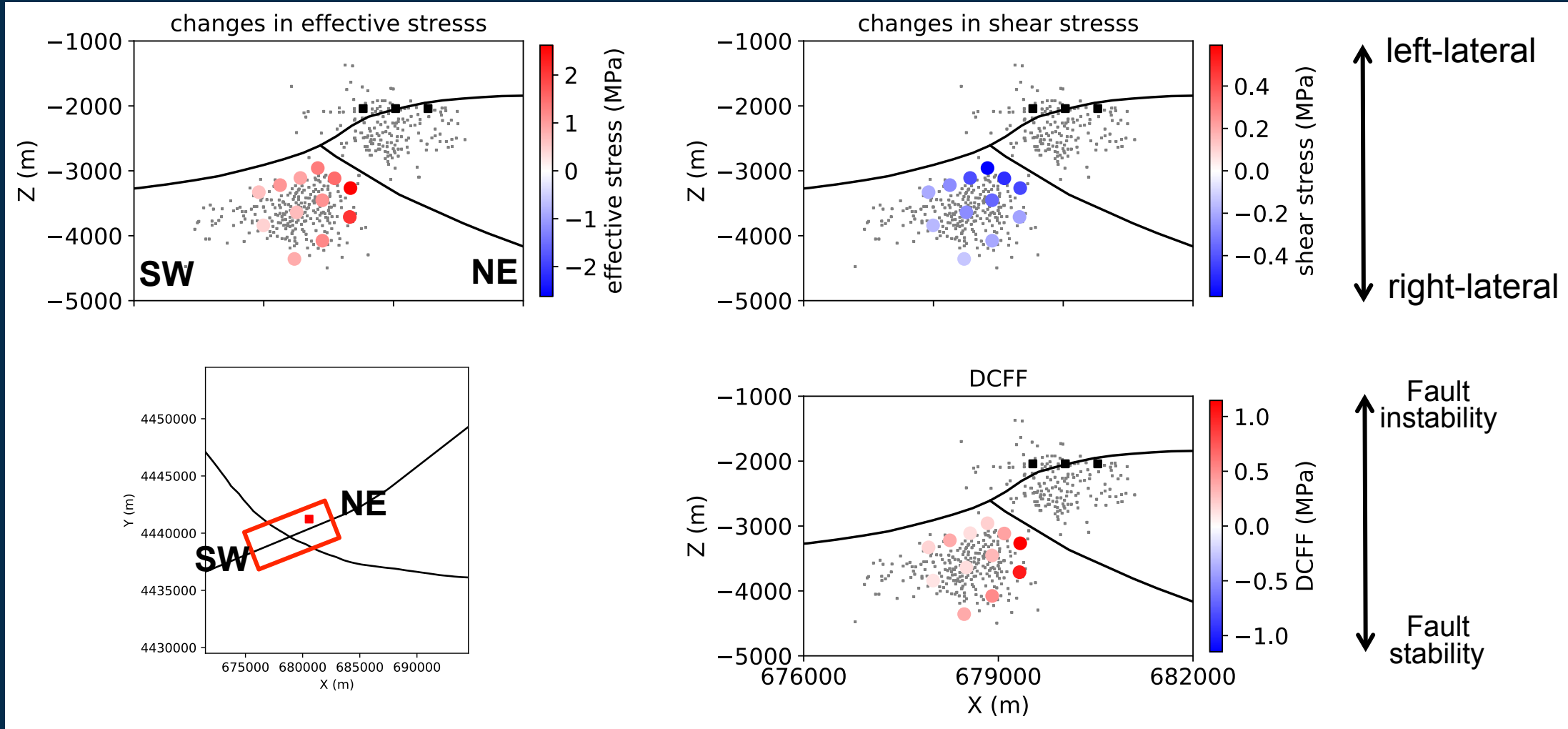
$$DCFF > 0 \implies \text{fault destabilization}$$

$$DCFF < 0 \implies \text{fault stabilization}$$

Stress changes during injection



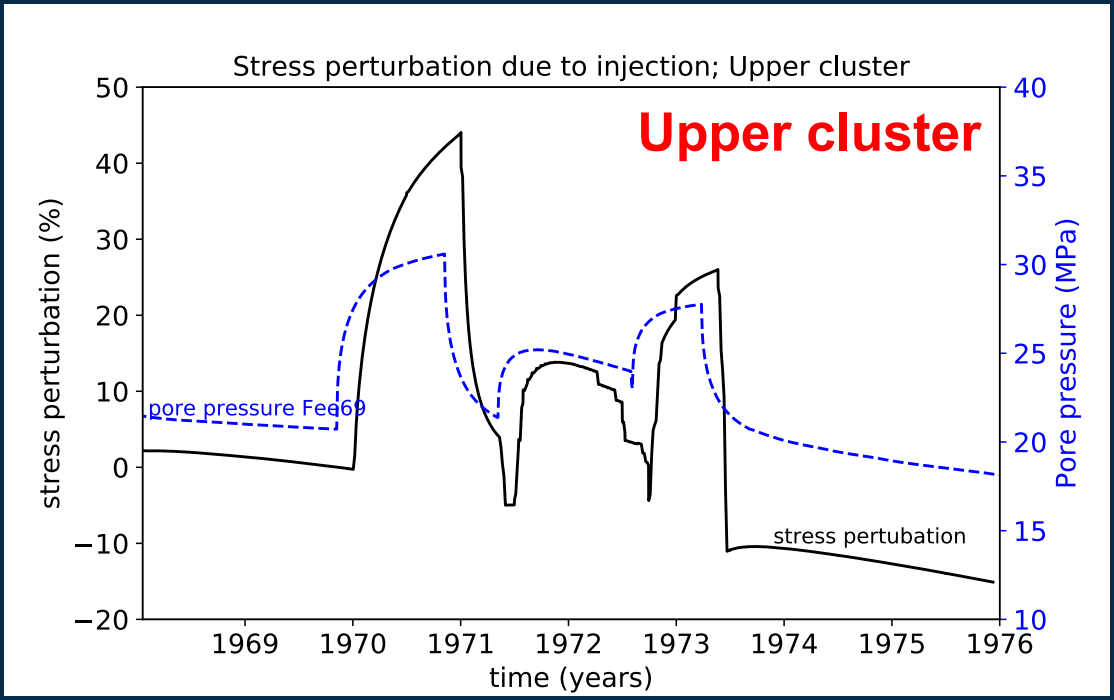
Stress changes during injection

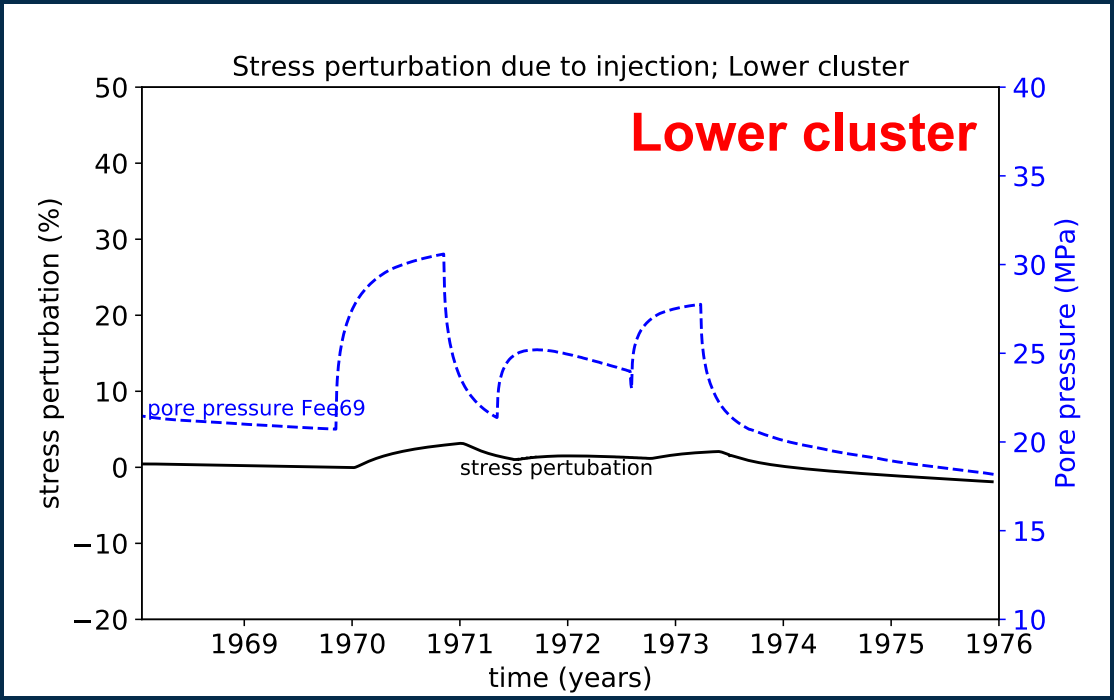


Triggered vs induced seismicity

$$\text{stress perturbation} = \frac{DCFF}{CFF + DCFF}$$

Upper cluster: induced seismicity (due to reservoir depletion)
Lower cluster: triggered seismicity





Conclusions

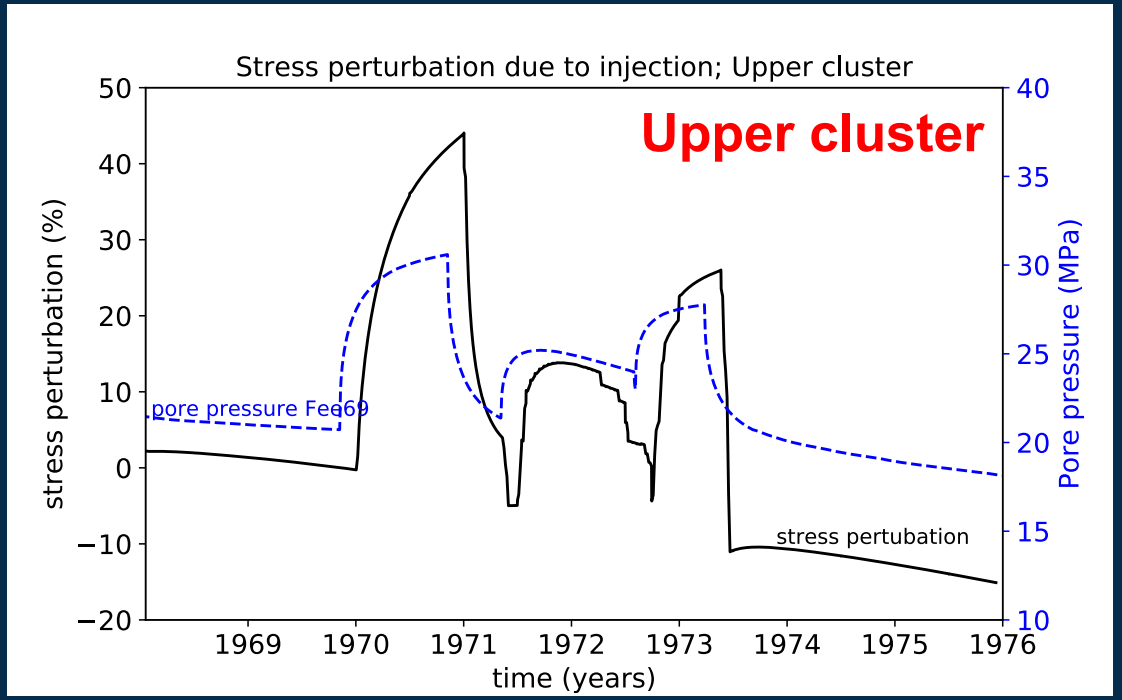
1. Our results mechanistically confirm the conclusion that was made by Raleigh et al. (1976) that fluid injection caused the earthquakes observed in the Rangely Oil Field

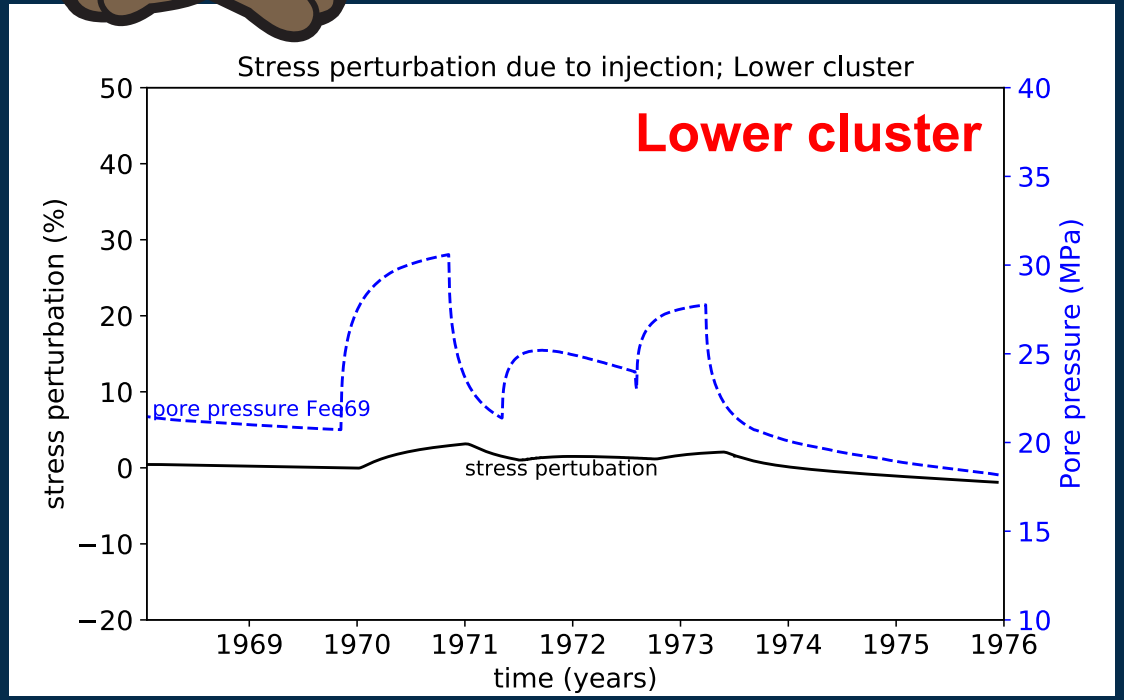
2. In Rangely, earthquakes away from the injector wells (lower cluster) should be classified as “triggered” and not “induced”

3. We show that the strike slip fault is near critical instability

4. Our results support the hypothesis that the crust is critically stressed throughout, including in tectonically inactive regions (Zoback, 1992)

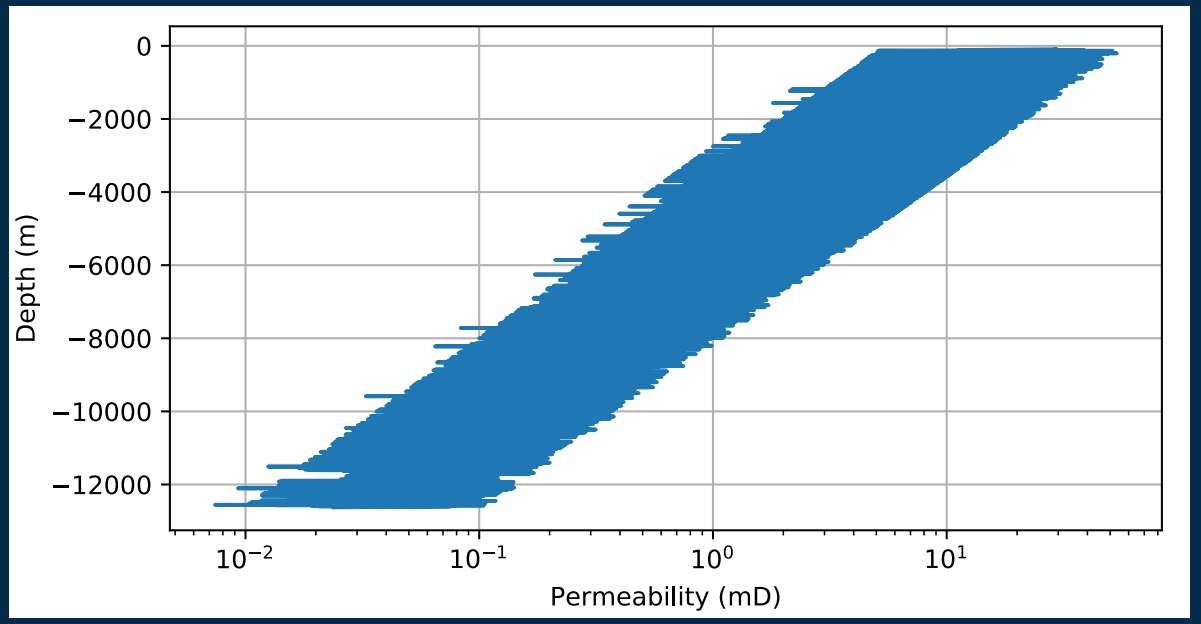
THANK YOU !!!


Stress perturbation due to injection; Upper cluster
Upper cluster
stress perturbation (%)
Pore pressure (MPa)
time (years)
pore pressure Fee69
stress pertubation
50
40
30
20
10
0
−10
−20
40
35
30
25
20
15
10
1969
1970
1971
1972
1973
1974
1975
1976


Stress perturbation due to injection; Lower cluster
Lower cluster
stress perturbation (%)
Pore pressure (MPa)
time (years)
pore pressure Fee69
stress pertubation
50
40
30
20
10
0
−10
−20
40
35
30
25
20
15
10
1969
1970
1971
1972
1973
1974
1975
1976

Reservoir properties vs depth

Permeability



Porosity