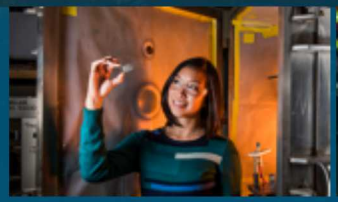
SAND2020-10638PE

Sandia National Laboratories

Multiphysics-driven Instability along Geological Discontinuities:
Implications for subsurface energy activities



PRESENTED BY

Kyung Won (K-Won) Chang

U.S. DEPARTMENT OF ENERGY NNSA

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Geological Discontinuity

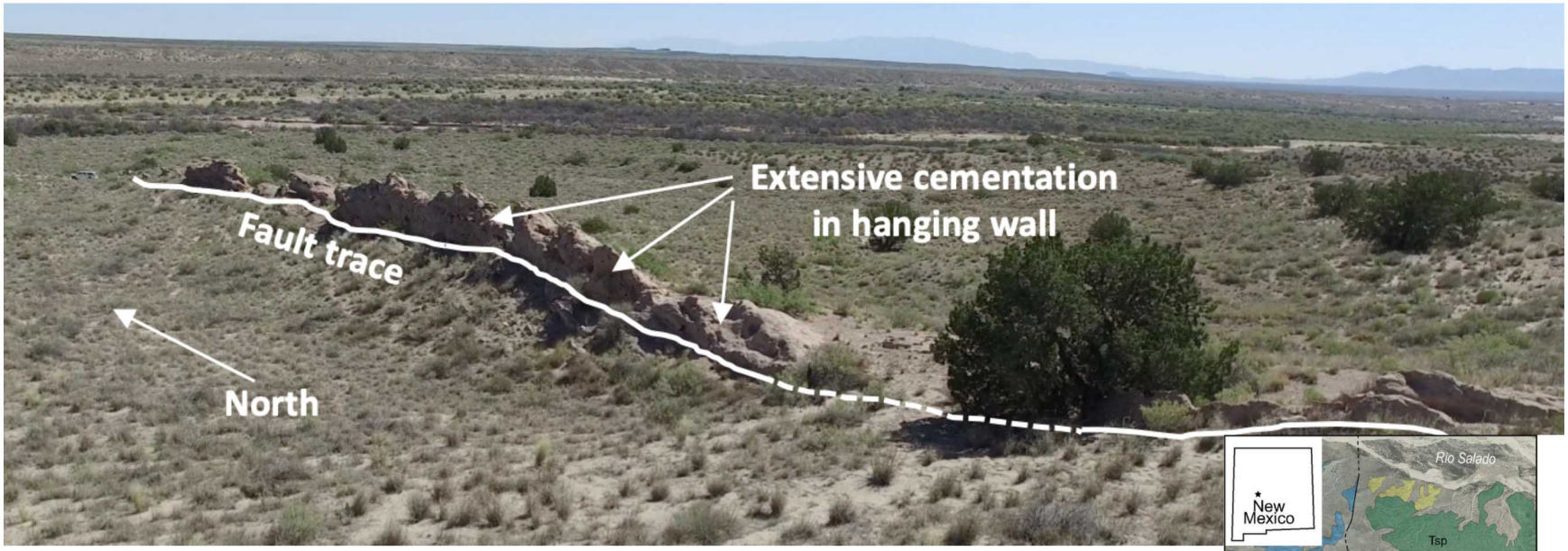
Kasha-Katuwe Tent Rocks National Monument
New Mexico (NM), USA

- Layers of volcanic rock
- 6 to 7 millions years
- Weathering/erosion created canyons and tent rocks

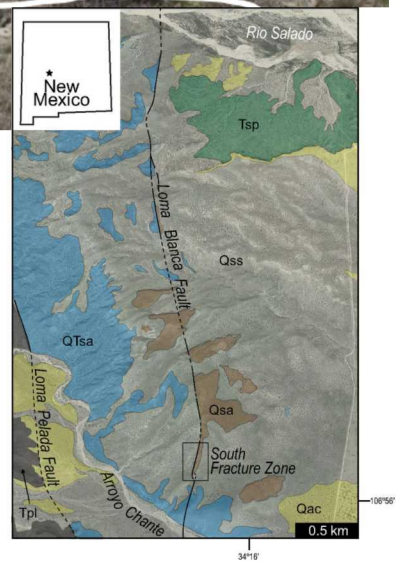
Geological Discontinuity: Fault

Kasha-Katuwe Tent Rocks National Monument
New Mexico (NM), USA

Geological Discontinuity: Fault

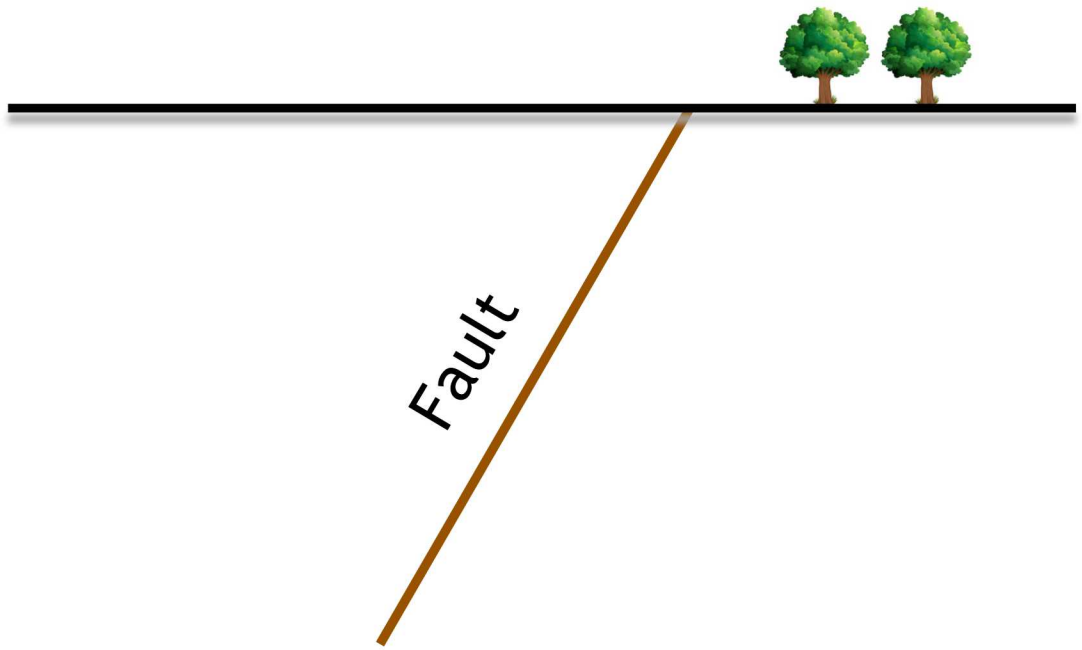


- Loma Blanca fault, Rio Grande rift
  - Central NM, USA
  - 70°E normal faulting
- Subsurface flow causes cementation, which hinders fluid flow across the fault (sealing fault)



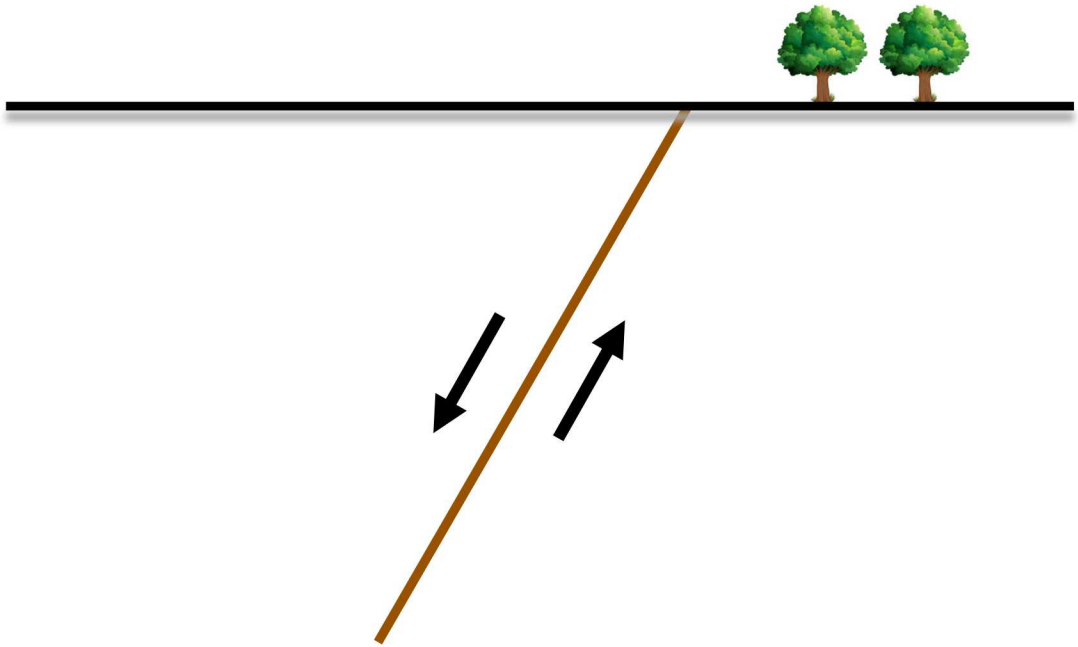
Williams et al. (2017) *PNAS*

Geomechanical Failure Mechanisms



Geomechanical Failure Mechanisms

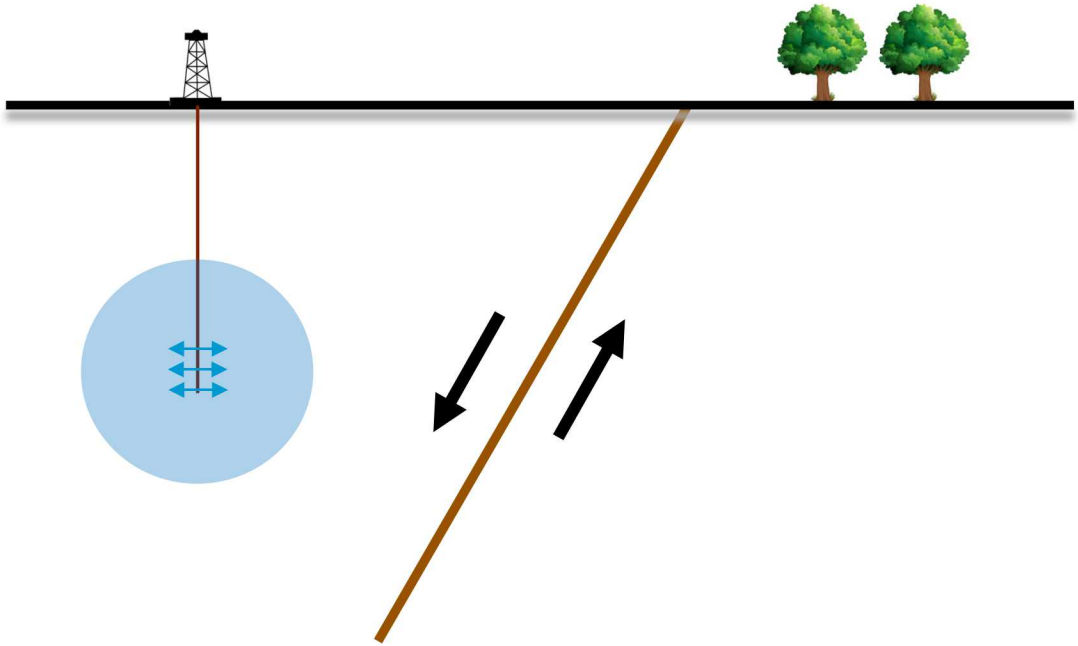
Tectonics



Δ(In-situ stress)

Geomechanical Failure Mechanisms

Tectonics + Human activity

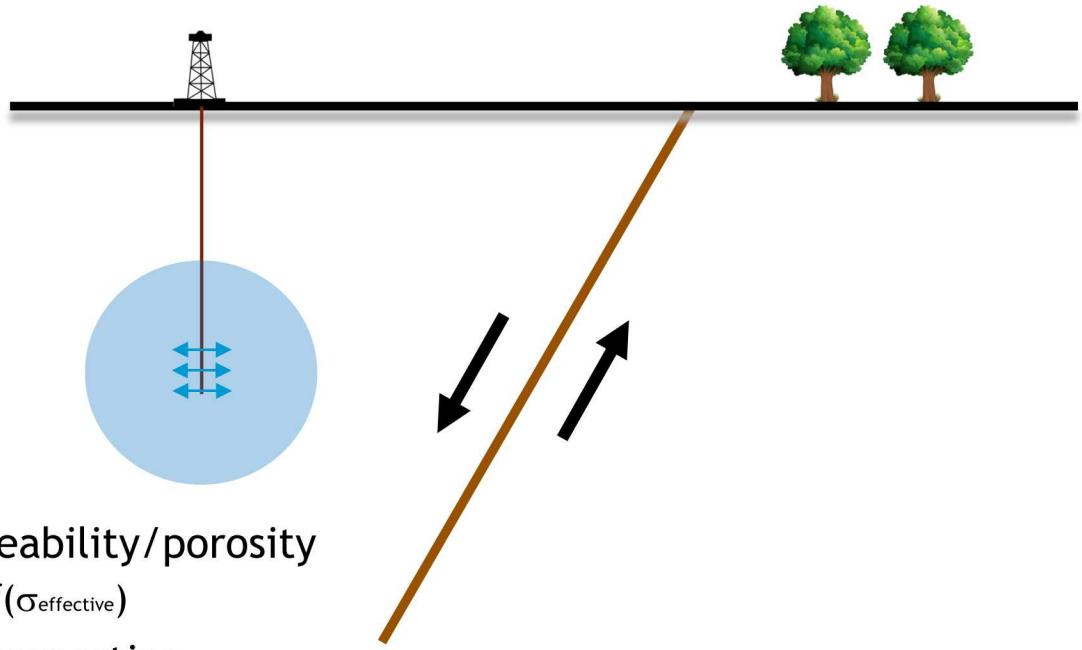


Δ(In-situ stress) + Δ(p,T,c)

p: Pressure
T: Temperature
c: Concentration

Geomechanical Failure Mechanisms

Tectonics + Human activity + Dynamics



- Fault permeability/porosity

  κ or $\phi \sim f(\sigma_{effective})$

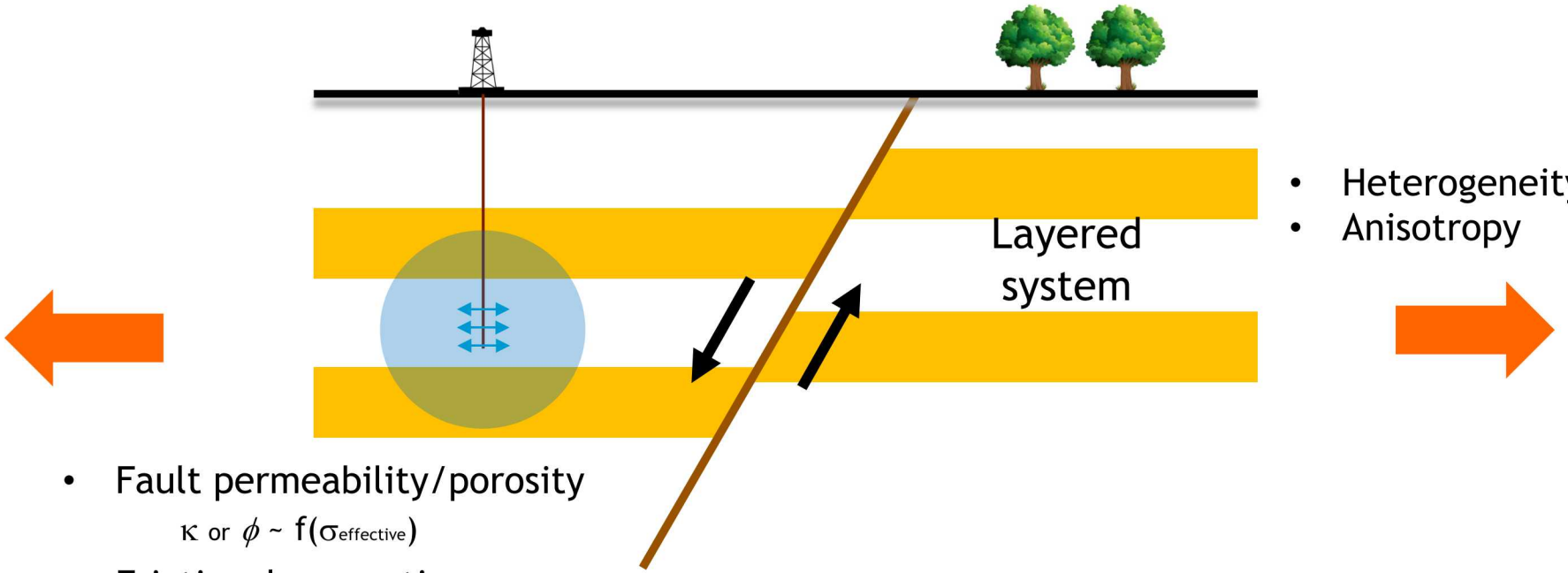
- Frictional properties

  Rate and state friction

Δ(In-situ stress) + Δ(p,T,c) + Δ(Material characteristics)

Geomechanical Failure Mechanisms

Tectonics + Human activity + Dynamics + Architecture



- Heterogeneity
- Anisotropy

- Fault permeability/porosity

  κ or $\phi \sim f(\sigma_{effective})$

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  Rate and state friction

Δ(In-situ stress) + Δ(p,T,c) + Δ(Material characteristics)

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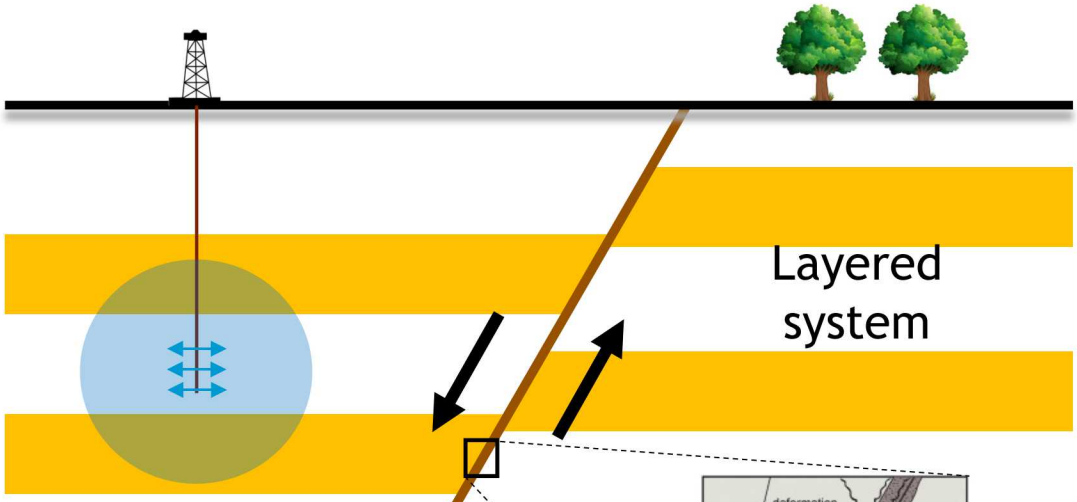


- Heterogeneity
- Anisotropy

- Fault permeability/porosity
  κ or $\phi \sim f(\sigma_{effective})$
- Frictional properties
  Rate and state friction

- Flow pathways
- Deformation
- Mineral precipitation

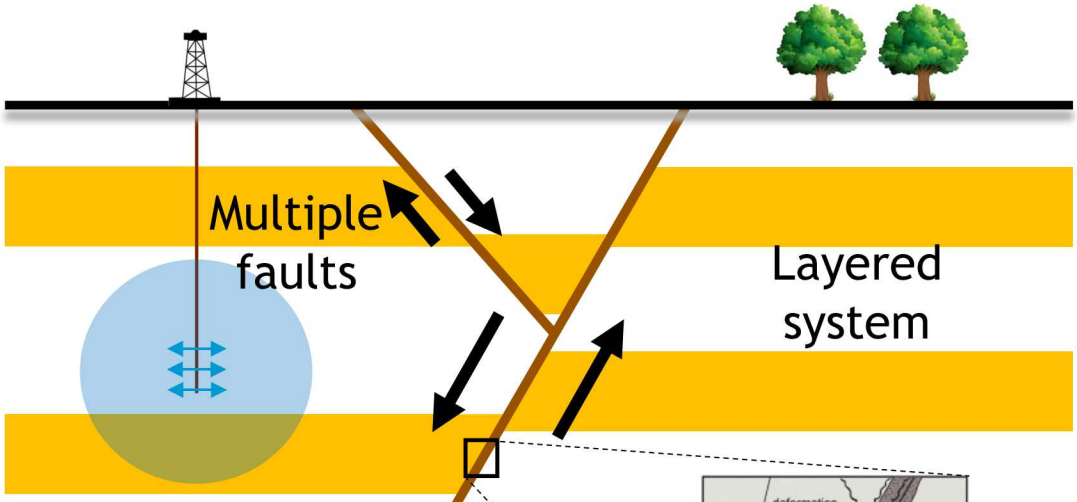
Bauer et al. (2015)

Δ(In-situ stress) + Δ(p,T,c) + Δ(Material characteristics)

Geomechanical Failure Mechanisms

Tectonics + Human activity + Dynamics + Architecture

- Mixed polarity
- Connectivity



- Heterogeneity
- Anisotropy

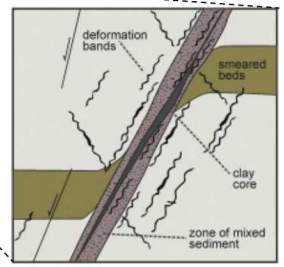
- Fault permeability/porosity

  κ or $\phi \sim f(\sigma_{effective})$

- Frictional properties

  Rate and state friction

Internal Architecture



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Bauer et al. (2015)

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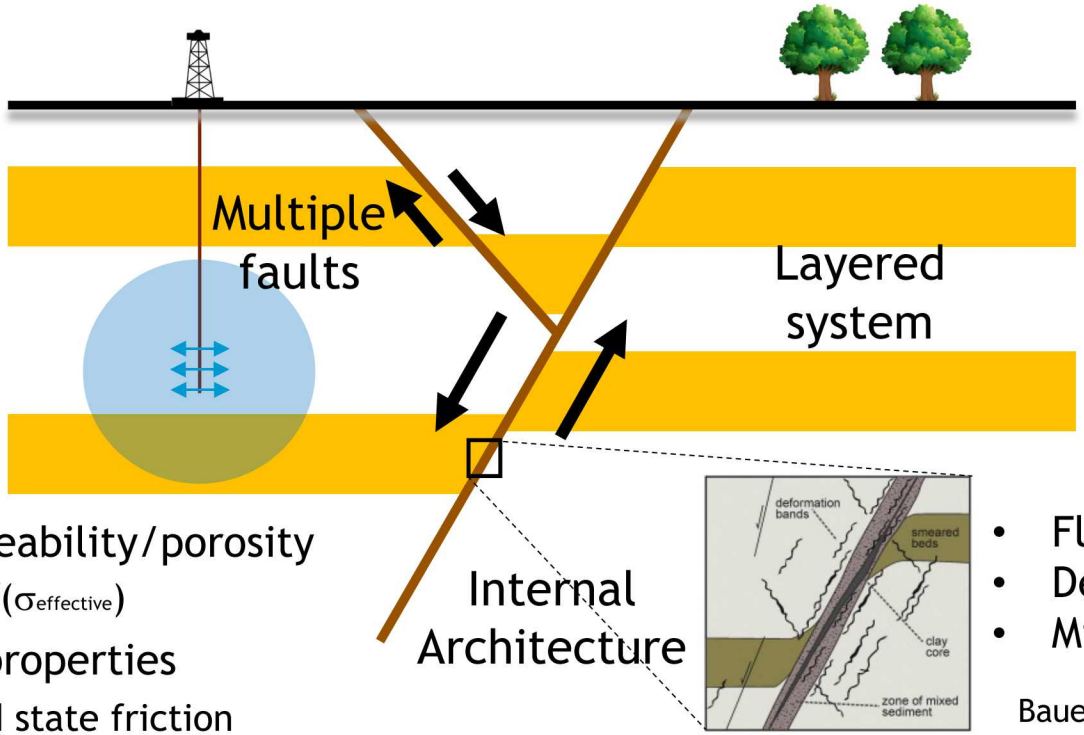

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Bauer et al. (2015)

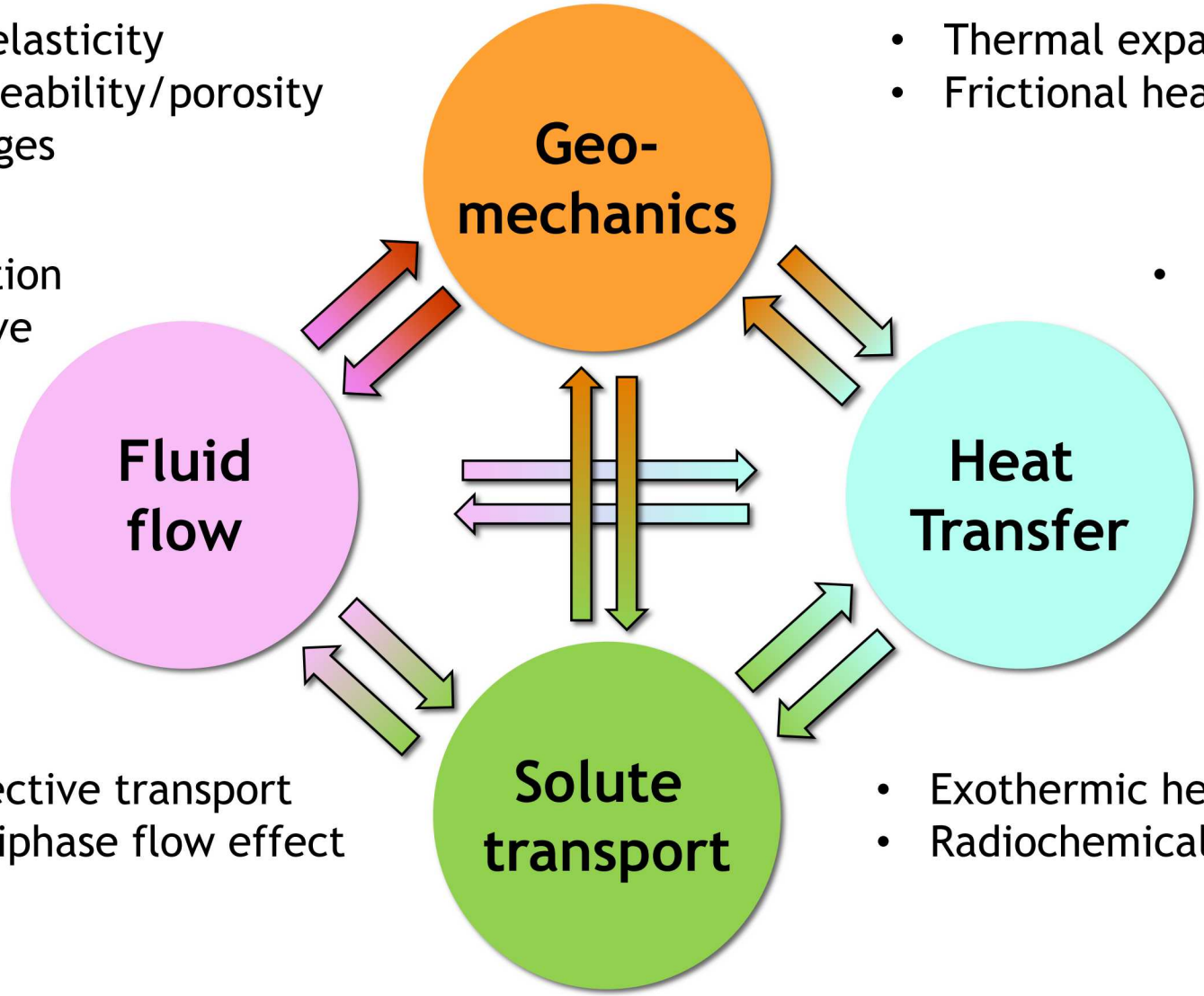
Δ(In-situ stress) + Δ(p,T,c) + Δ(Material characteristics)

Multiphysics coupling processes in **multi-scale**

Multiphysics coupling

- Poroelasticity
- Permeability/porosity changes

- Thermal expansion
- Frictional heating



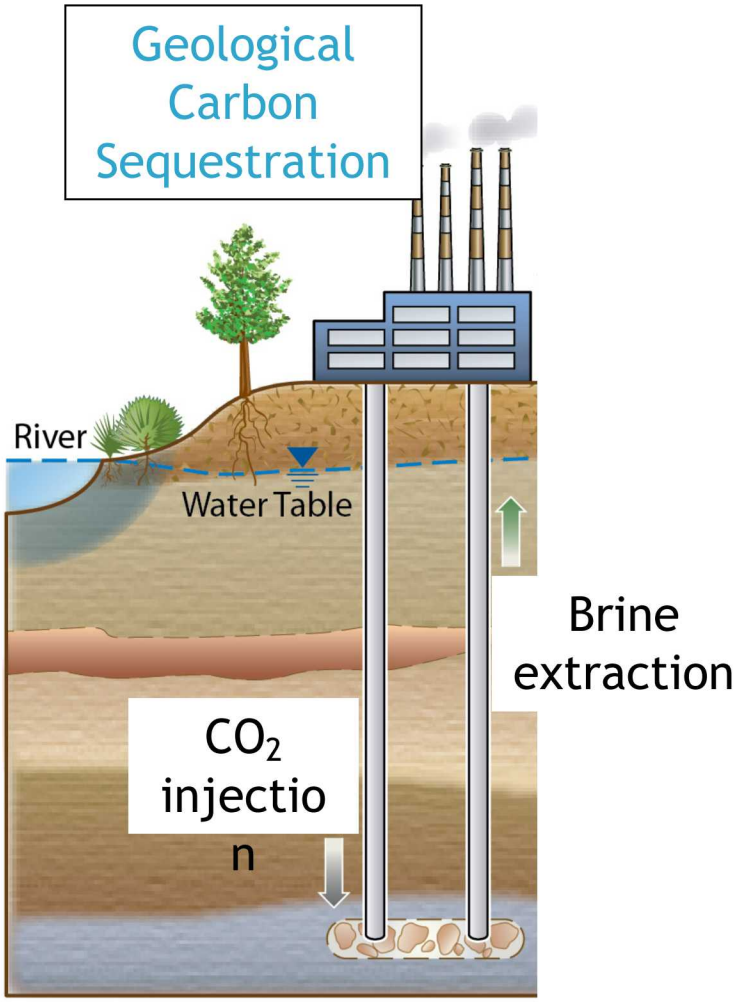
- Deformation of reactive surface

- Convective heat transport

- Advective transport
- Multiphase flow effect

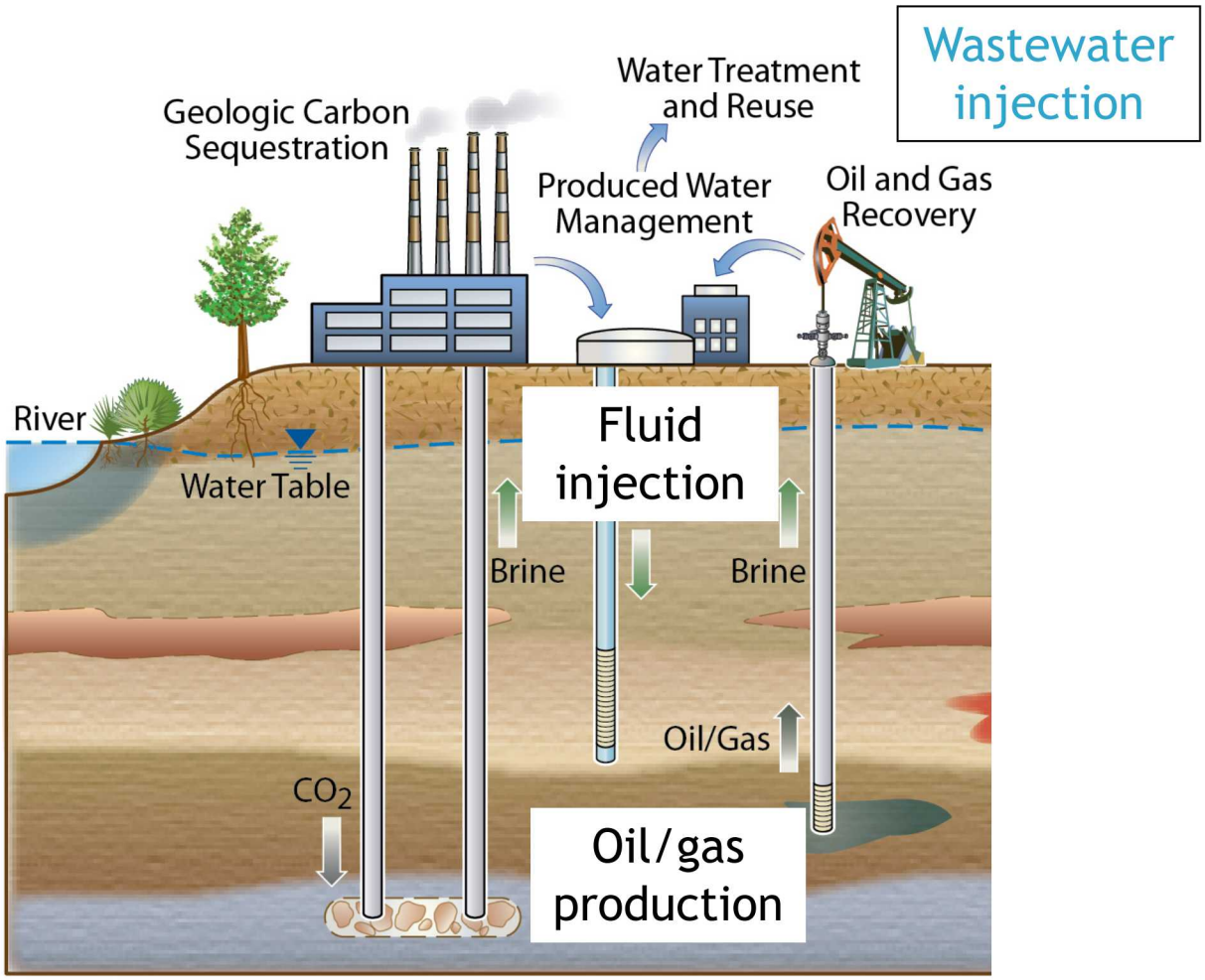
- Exothermic heat
- Radiochemical reaction

Subsurface energy activities

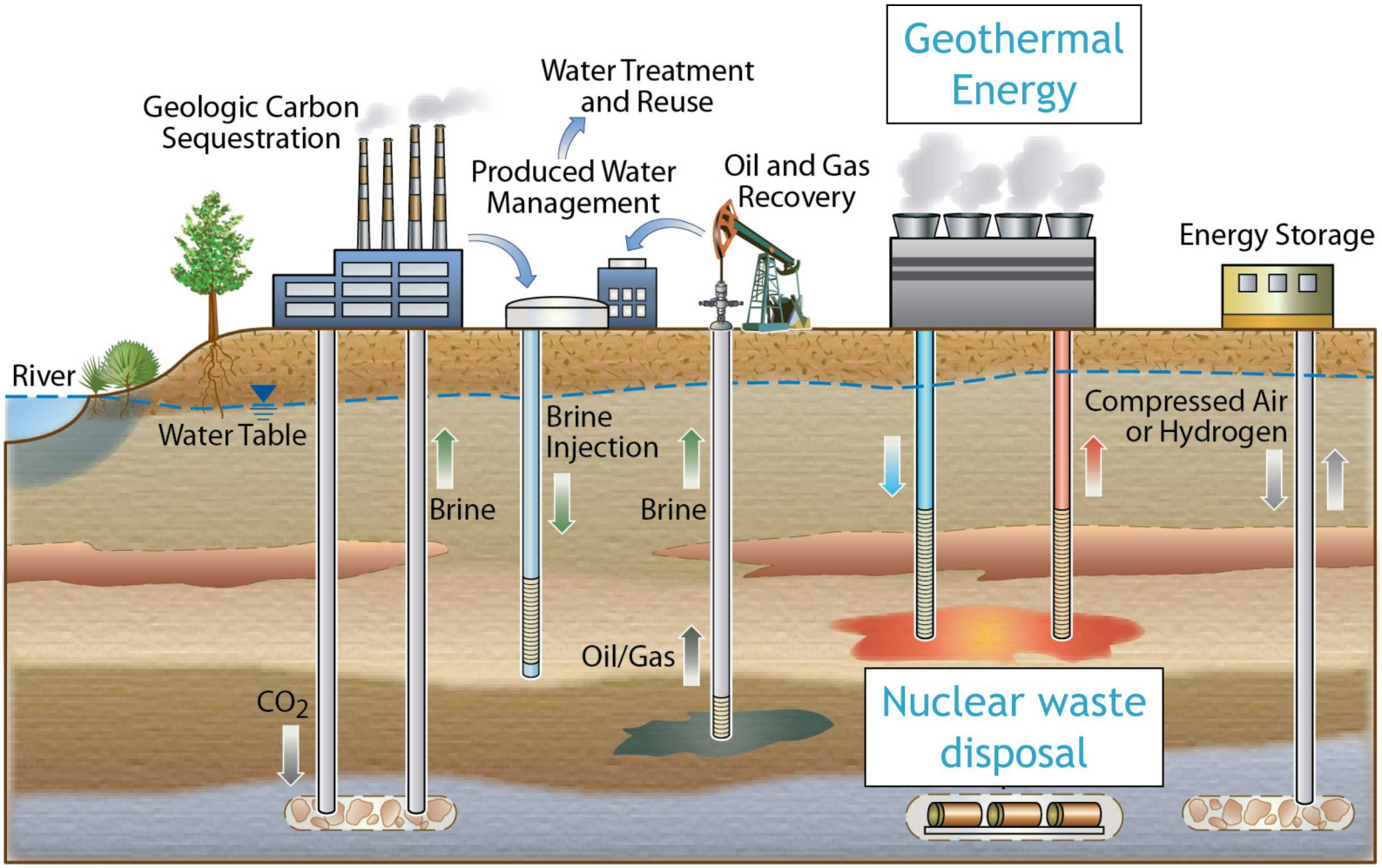


Modified figure (https://eesa.lbl.gov/wp-content/uploads/2017/02/Subsurface-Energy-Storage.jpg)

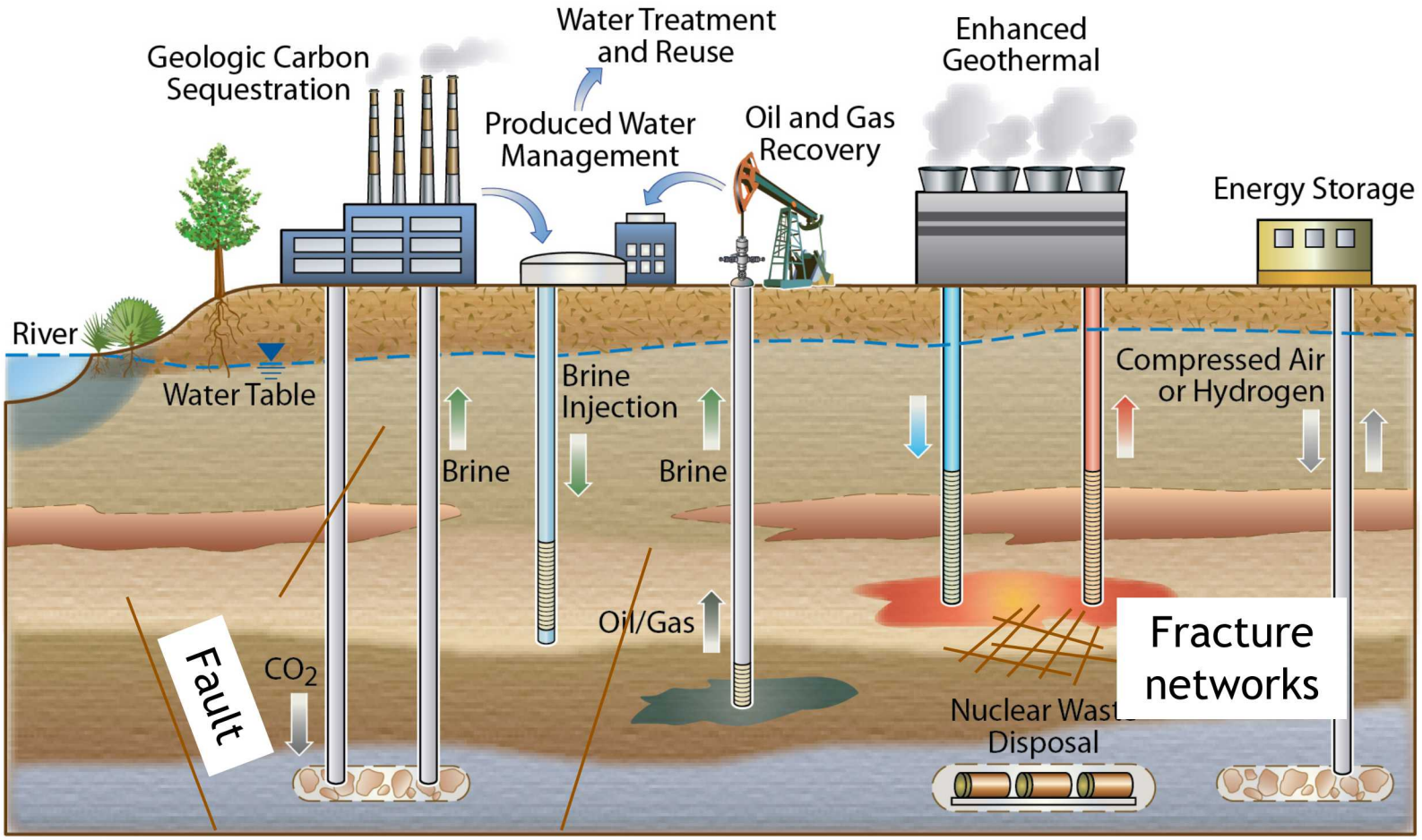
Subsurface energy activities



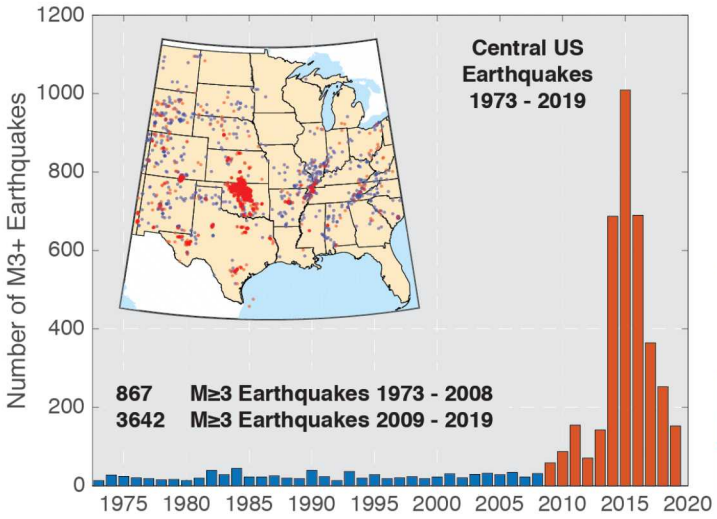
Subsurface energy activities

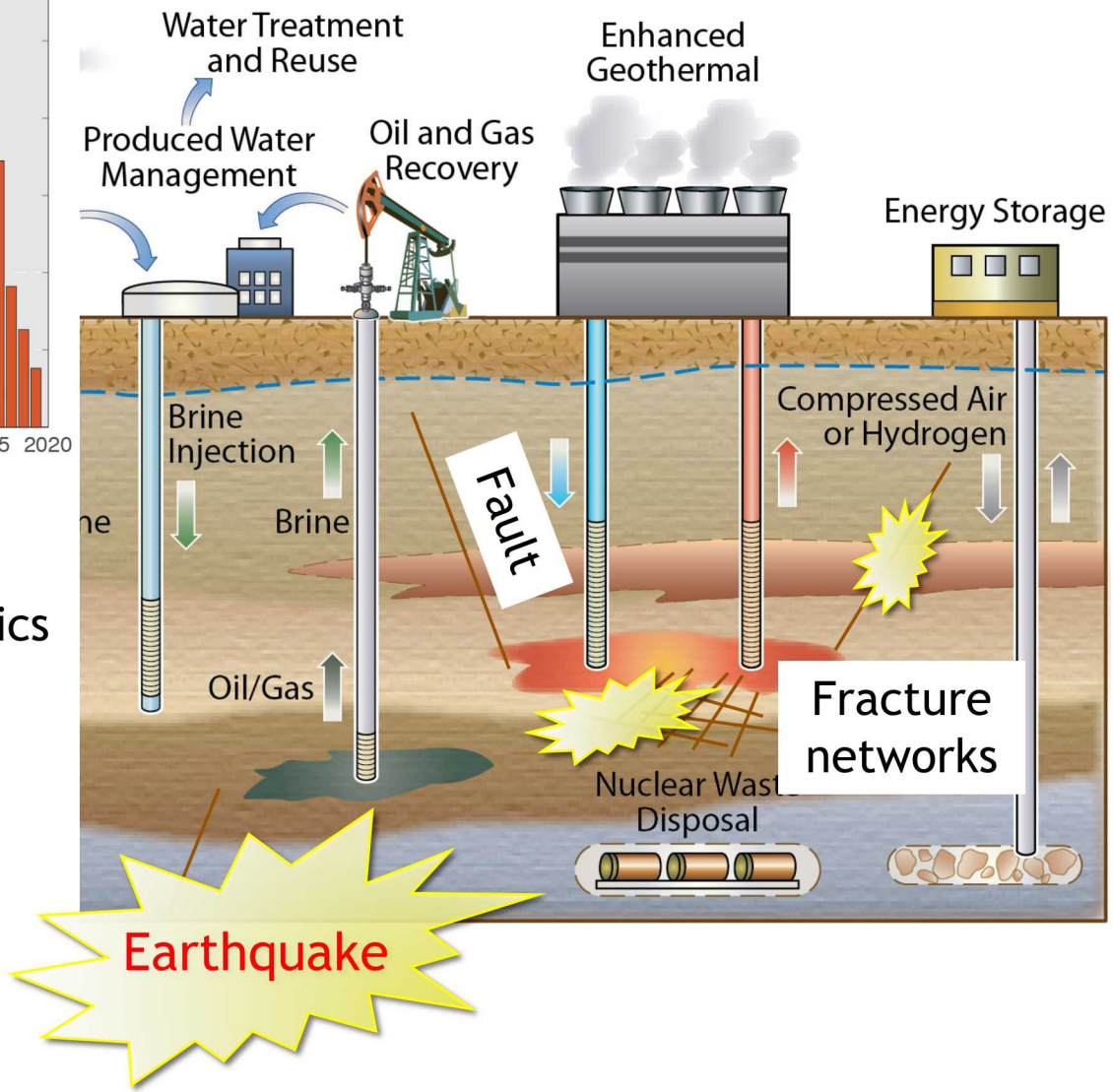


Geological uncertainties



Can Multiphysics Processes Explain the Mechanism Inducing Earthquakes?





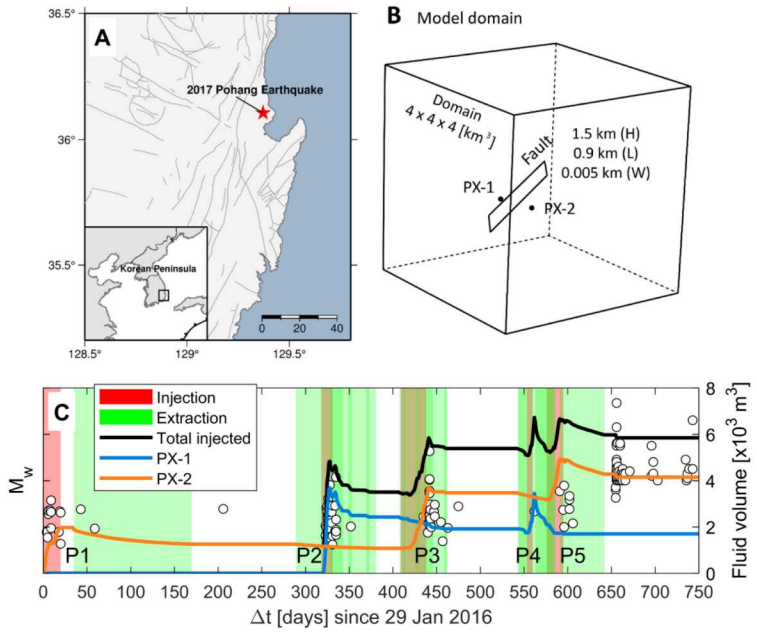
- Site-specific features

: Fault/fracture characteristics
  - Material properties
  - Geometry/orientation

: Formation rock properties
  - Heterogeneity
  - Anisotropy

: Regional stress states

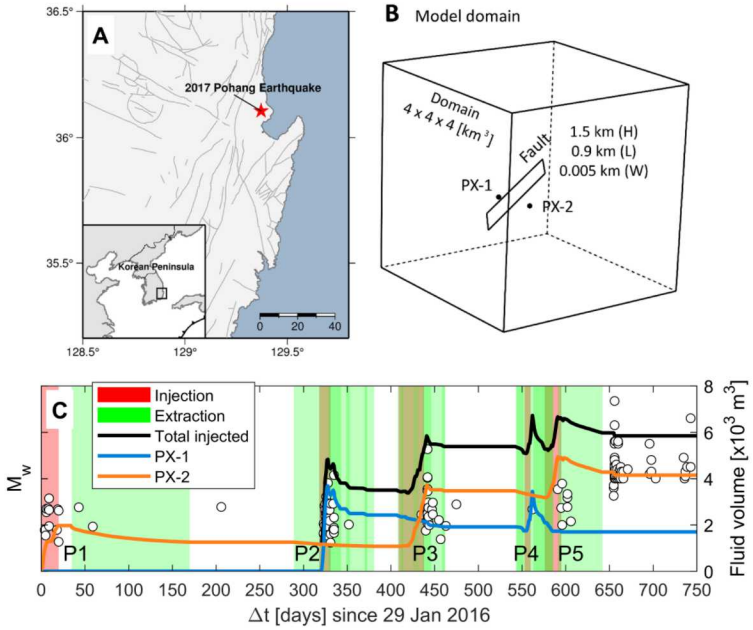
Application: 2016-2018 Pohang

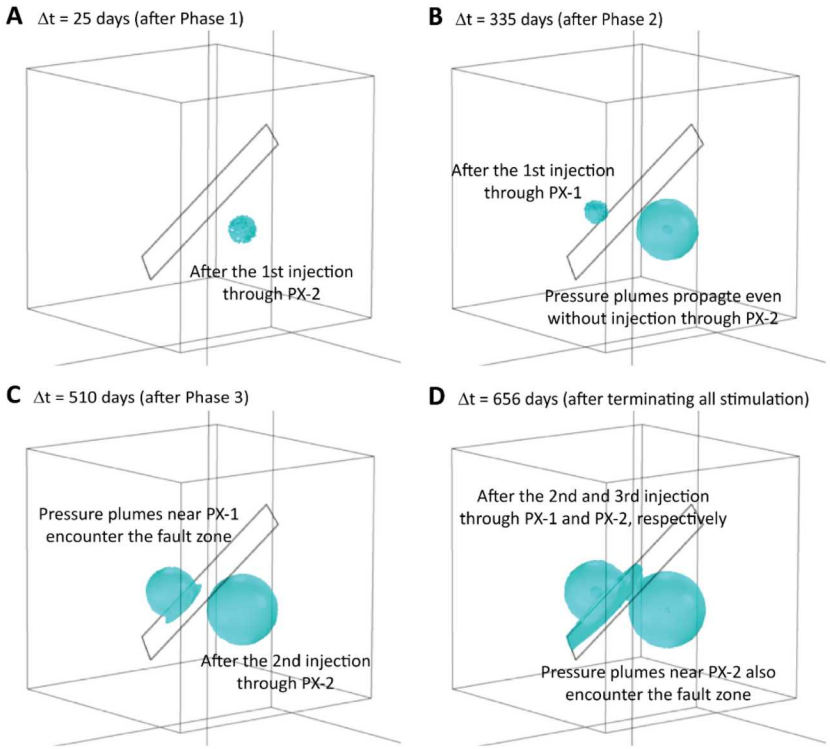


- Poroelastic coupling effects on induced earthquakes quantified by Coulomb stress change

$$\Delta\tau = \underbrace{(\Delta\tau_s + f\Delta\sigma_n)}_{\text{Poroelastic stress}} + \underbrace{f\Delta p}_{\text{Pore pressure}}$$

Application: 2016-2018 Pohang





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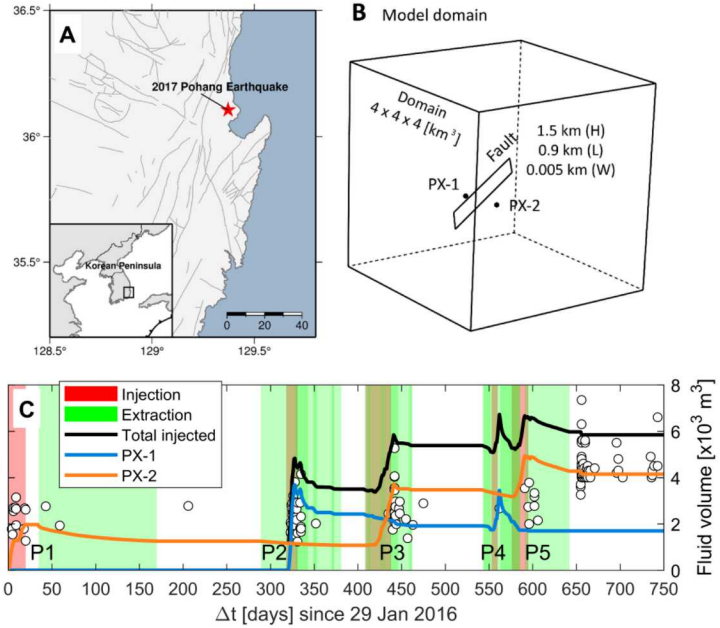

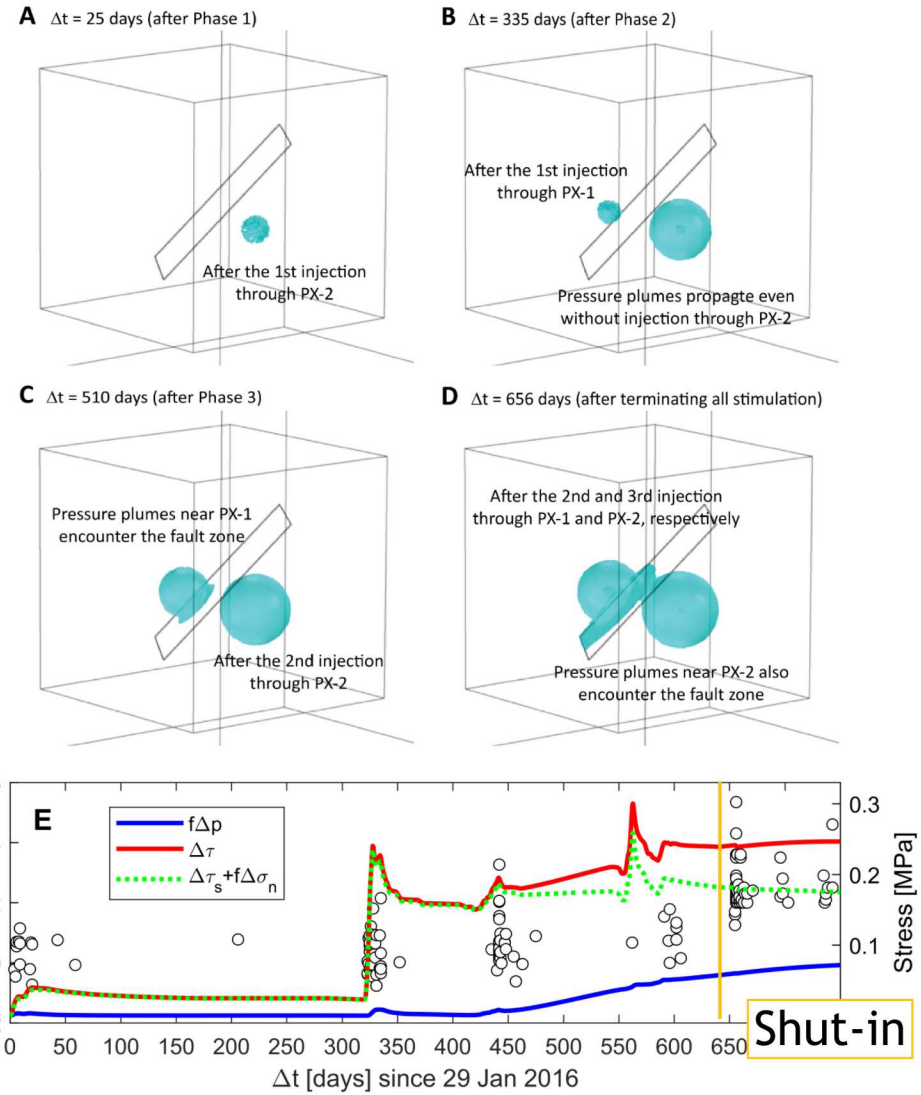

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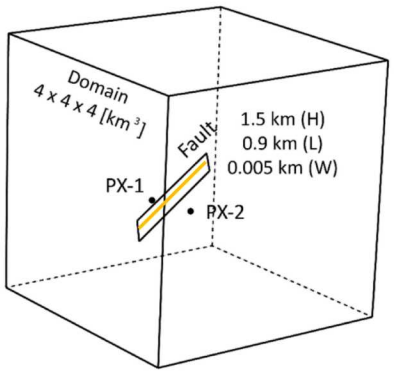
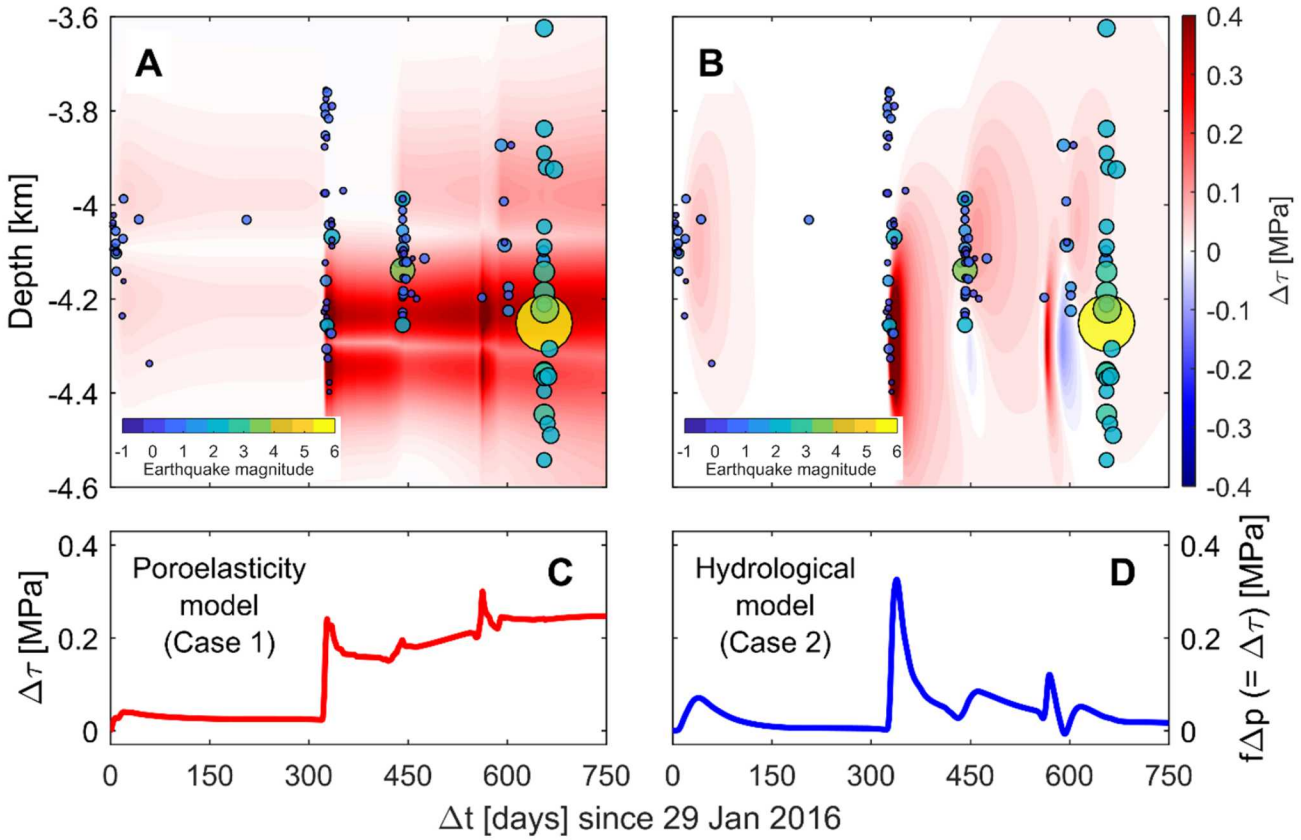
Coupled vs. Uncoupled Systems

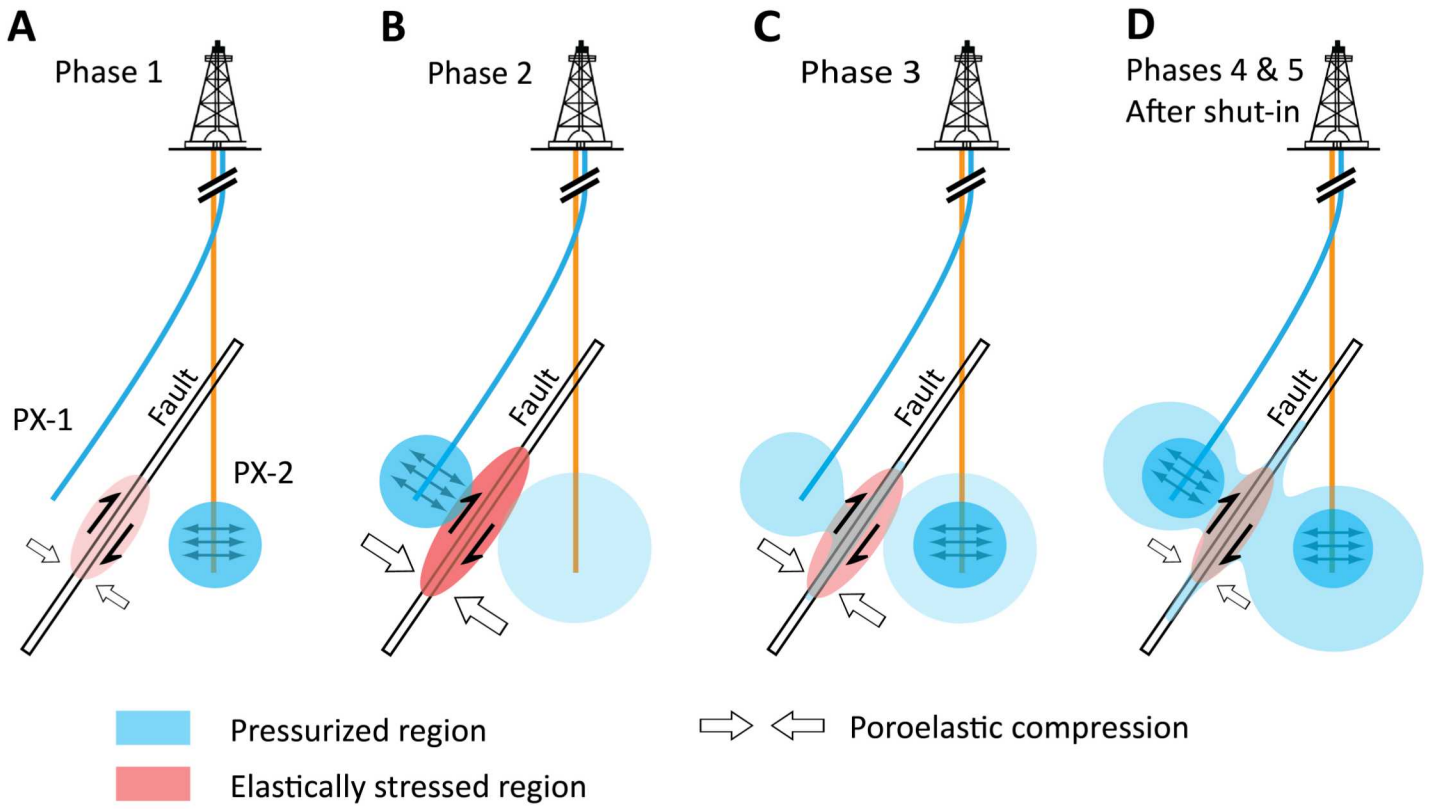




Chang et al. (2020) Sci. Rep.

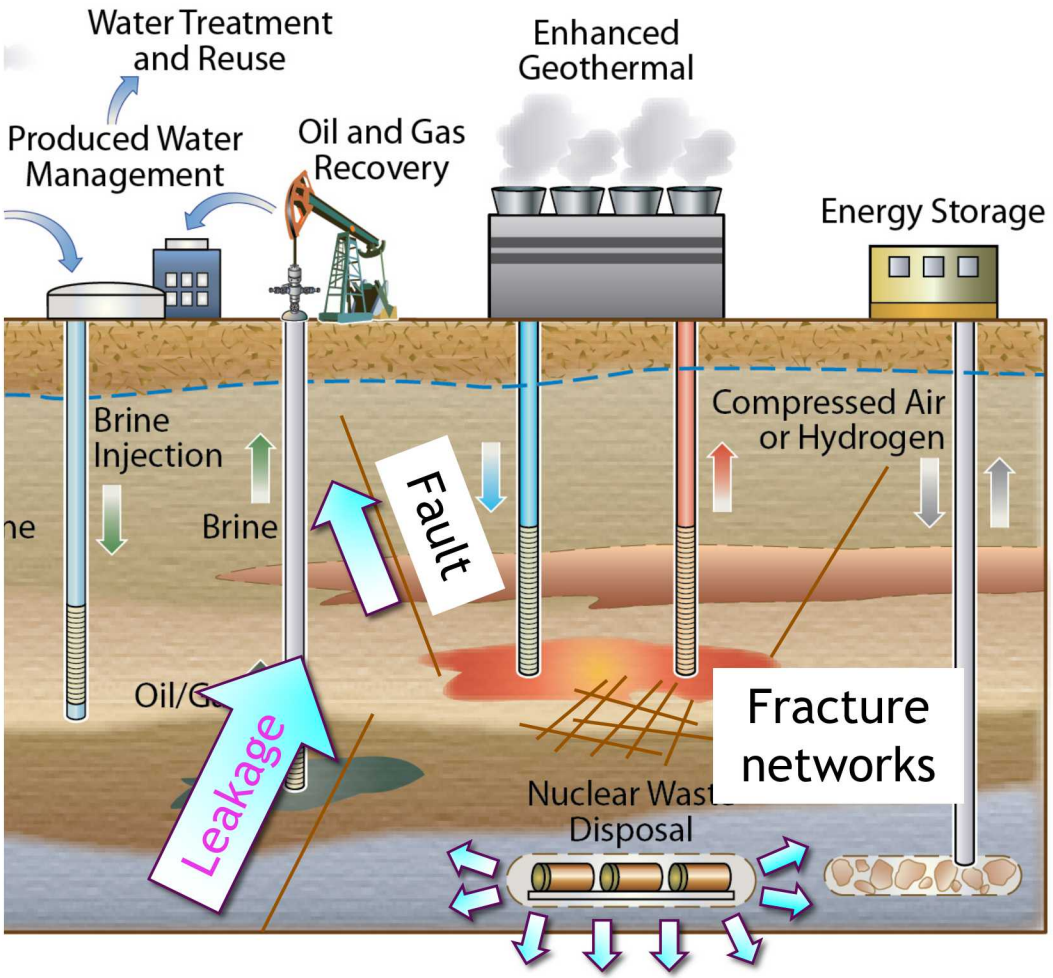
- In addition to regional tectonics and/or nearby natural earthquake nucleation, human activities may induce large magnitude earthquakes after shut-in by accumulating poroelastic stressing as well as pore pressure along the fault.

Sequential Mechanisms

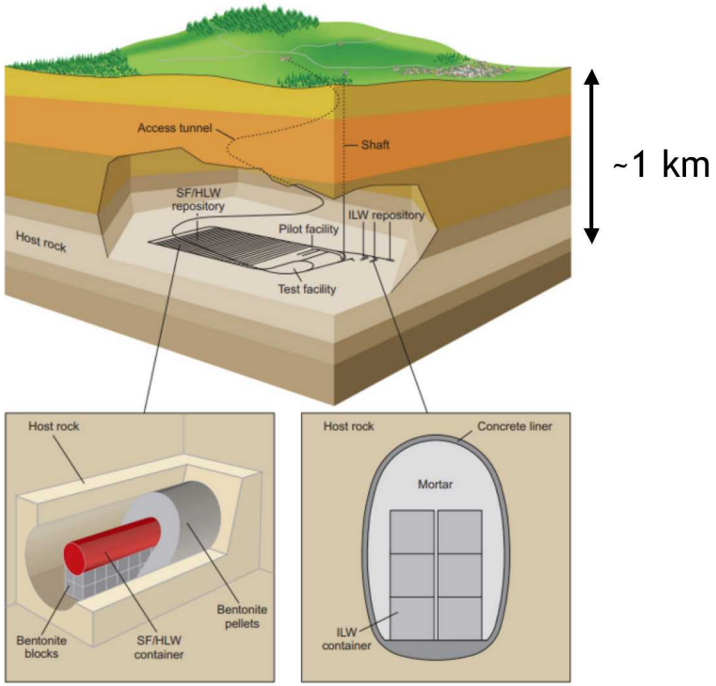


How Does Multiphysics Affect Leakage of contaminants in Geological Formations?

- Short-term thermal/mechanical stressing
- Long-term chemical reaction
- Three rock types for nuclear waste disposal
  - Argillaceous
  - Crystalline
  - Bedded or dome salt
- Depending on the rock type, different dynamics or behaviors of rock are engaged, thus proper site selection as well as buffer construction are required

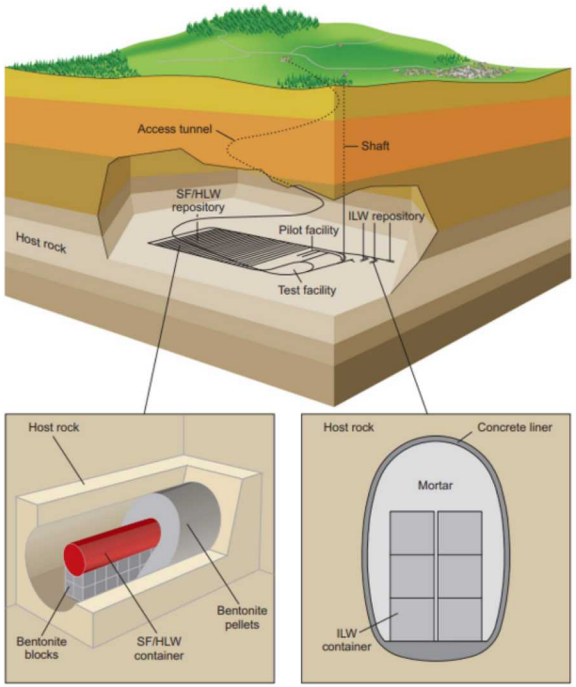


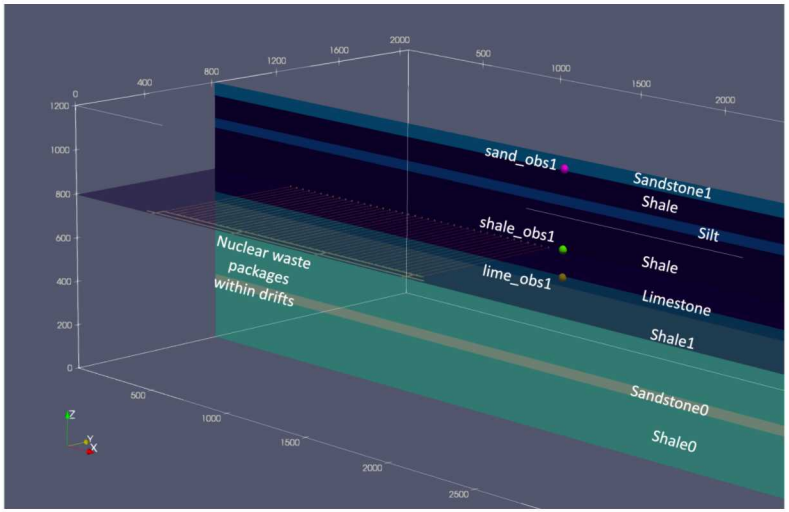
Nuclear Waste Disposal: Field-scale Model



- Field-scale simulations aim for safe disposal more than 10^6 years

Nuclear Waste Disposal: Field-scale Model

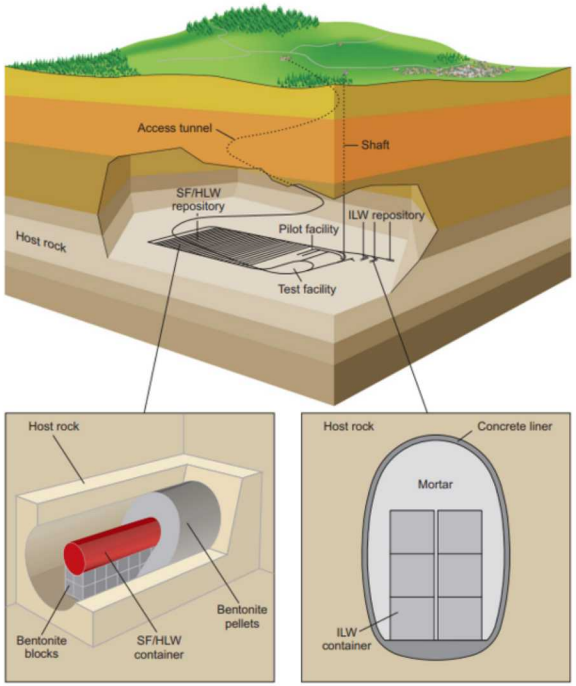


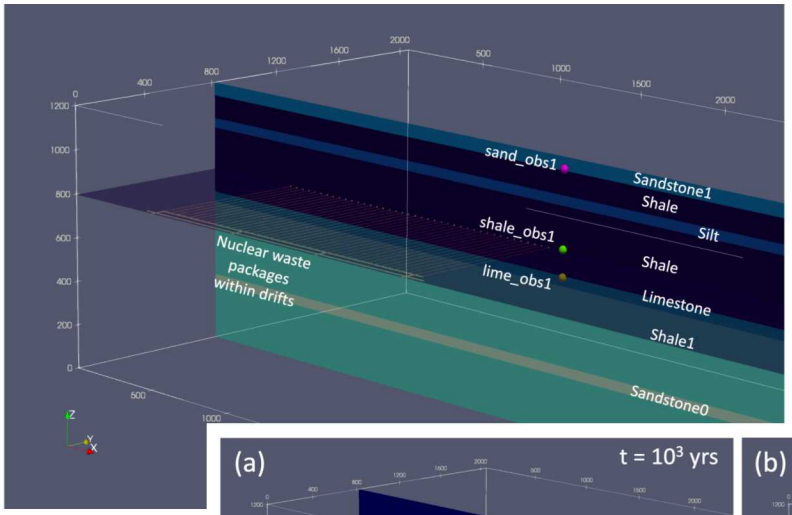


- 2575 nuclear waste packages are emplaced in a layered shale system
- THC coupling

- Field-scale simulations aim for safe disposal more than 10^6 years

Nuclear Waste Disposal: Field-scale Model





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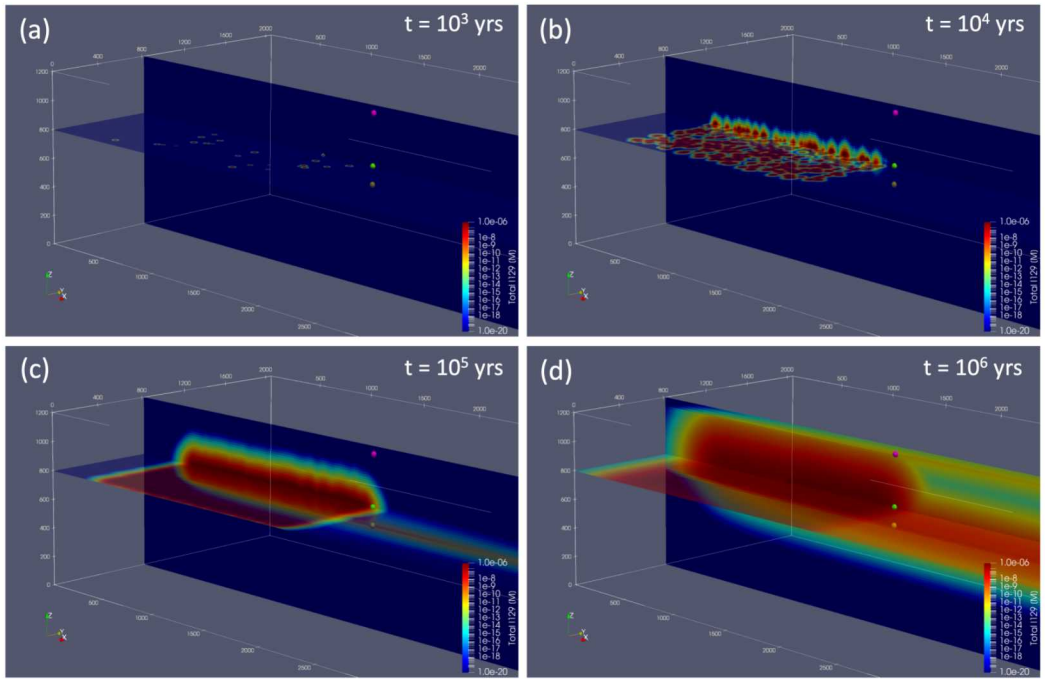
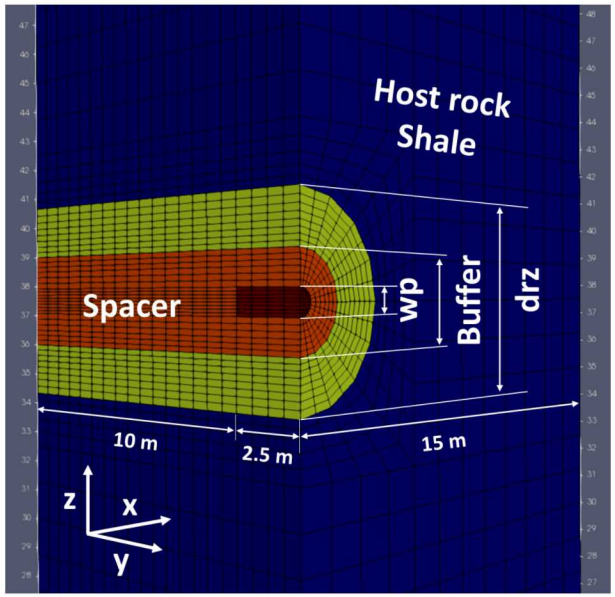
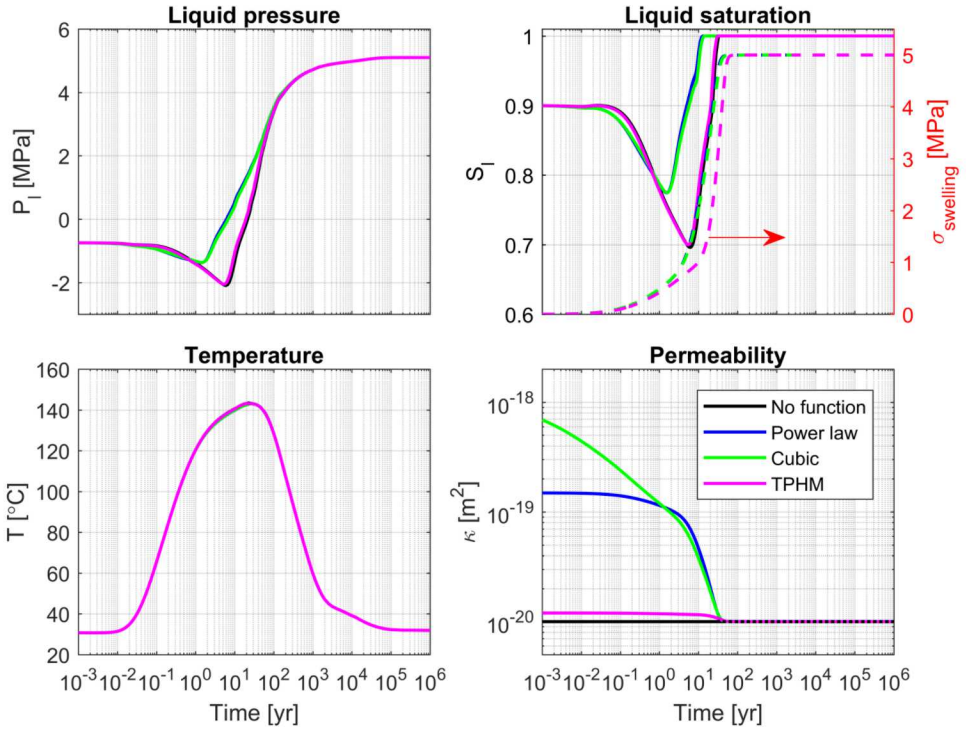


- Field-scale simulations aim for safe disposal more than 10^6 years
- Near-field multiphysical behaviors of rock corresponding to local flows or heat transfer should be considered

^{129}I (Iodine) distribution after 103, 10^4, 10^5, 10^6 years

Nuclear Waste Disposal: Near-field Model



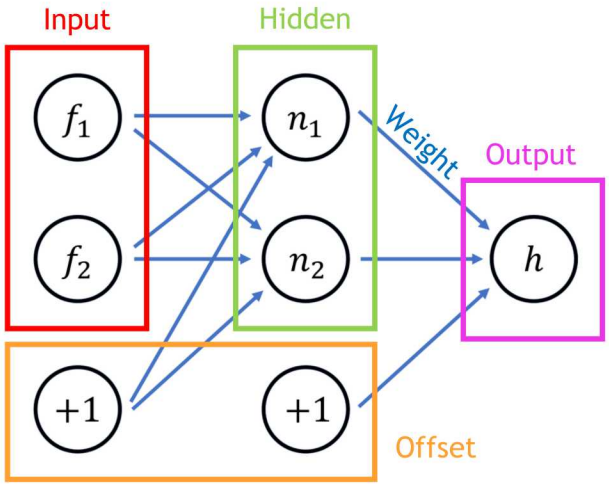


- As DRZ heated, precipitation occurs (decrease in S_l) at early time.
- During re-saturation, buffer swelling exerts normal stresses to compact fractures in DRZ which reduced DRZ permeability:

$$\Delta\sigma_{swelling} = 3K\Delta S_l\beta_{sw} = \Delta\sigma_{eff} \quad \rightarrow \quad \kappa \sim f(\Delta\sigma_{eff})$$

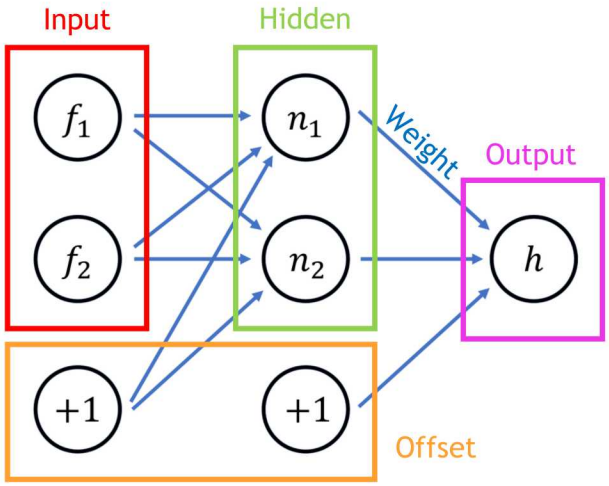
- To see how THM process affects geochemical transport of radio-nucleoids and ultimately support site selection as well as construction plans.

Nuclear Waste Disposal: Surrogate Model



Single-layer Feed-forward Neural Network

Nuclear Waste Disposal: Surrogate Model



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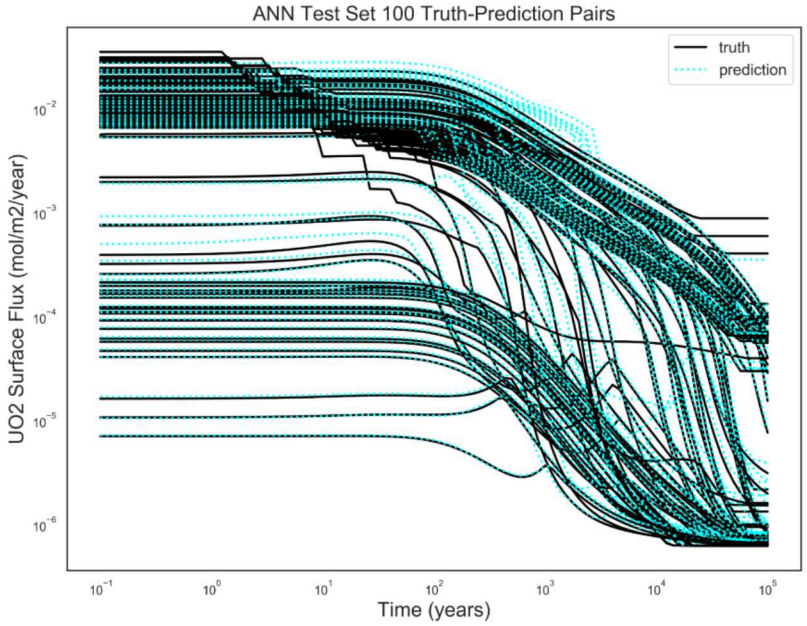
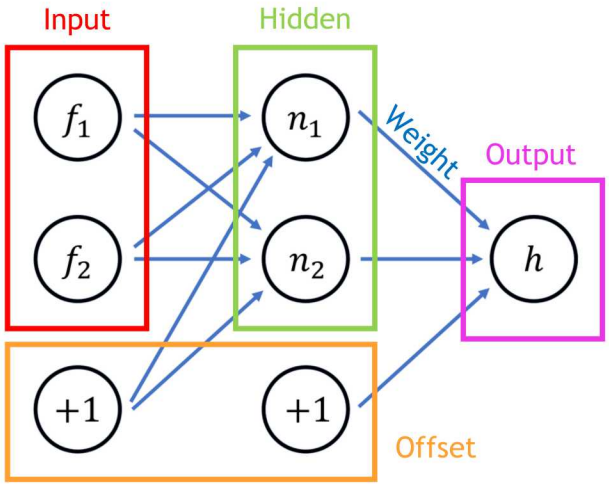


- Standalone model, calculating fuel matrix degradation (FMD) rates, provides data for training
- Trained Artificial Neural Network (ANN) with 100 neurons provides prediction
  - **Input:** Concentration of 4 environmental species (O2(aq), CO3-, H2(aq), and Fe++), temperature, radioactive dose rate
  - **Output:** Spent fuel degradation rate

Nuclear Waste Disposal: Surrogate Model



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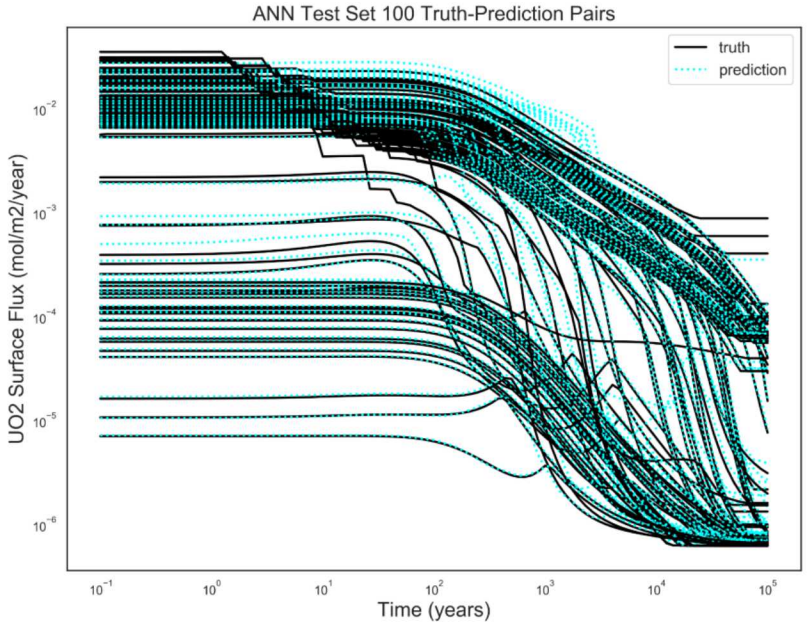
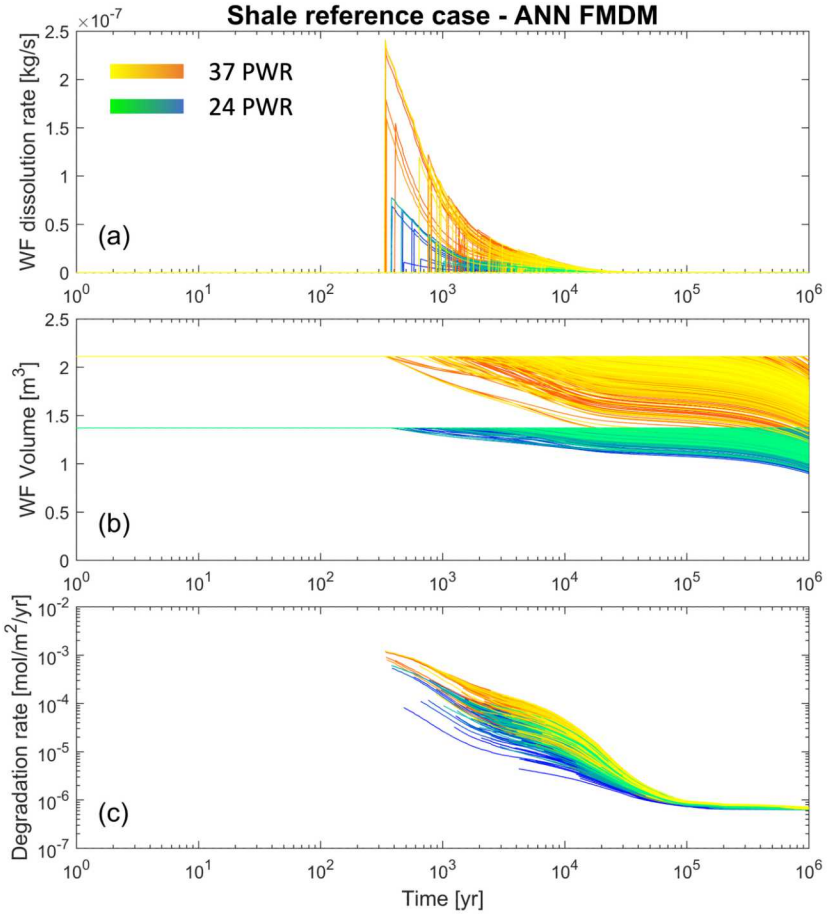
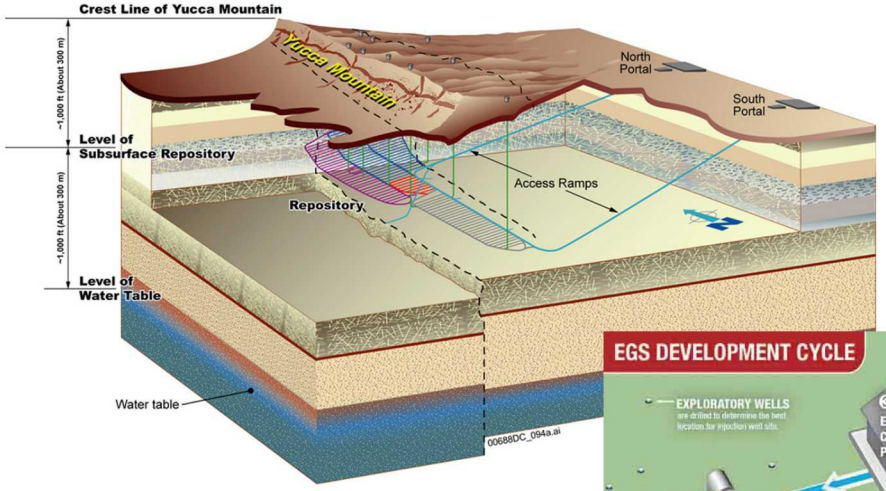


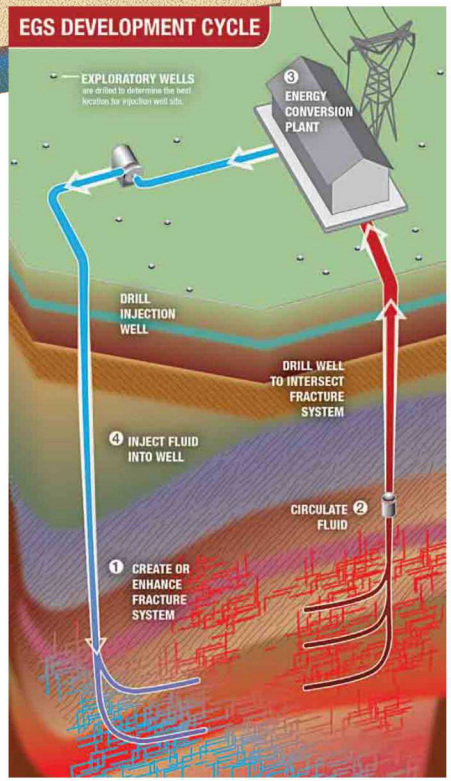


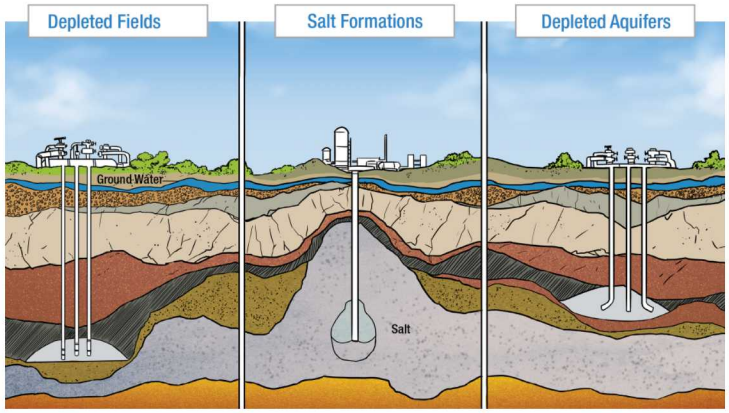
- Implementing surrogate FMD mechanism into a field-scale simulation
- Inexpensive, but accurate, prediction of fuel degradation rates of each waste package

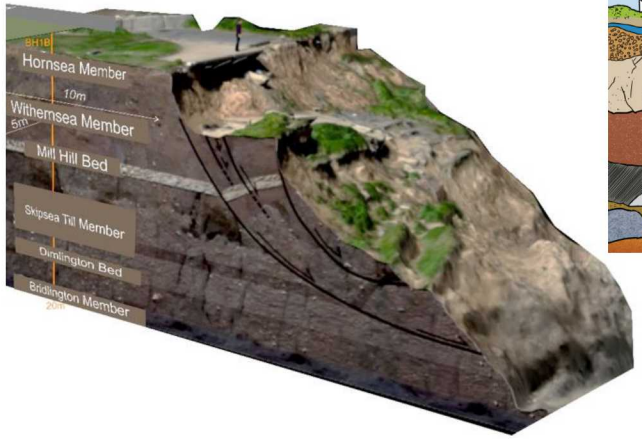
Future Research Plan

- Geological engineering applications
  - ✓ Nuclear waste disposal
  - ✓ Geological storage of natural gas
  - ✓ Geothermal energy exploration
  - ✓ Landslides
  - ✓ Leakage of industrial contaminants









Question & Answer

Chang, K.W., H. Yoon, Y.-H. Kim, and M.Y. Lee (2020), Operational and geological controls of coupled poroelastic stressing and pore-pressure accumulation along faults: Induced earthquakes in Pohang, South Korea, ***Scientific Reports***, 10:2073

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