Managing CO_2 fault migration hazard for Safe, Large-Scale Geologic Carbon Storage

Lluís Saló-Salgado

PhD Candidate, Civil and Environmental Engineering

In collaboration with Josimar A. Silva, J. Steven Davis, Ruben Juanes

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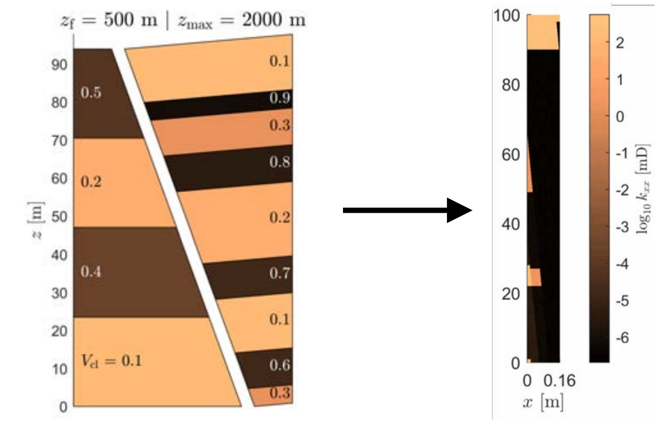
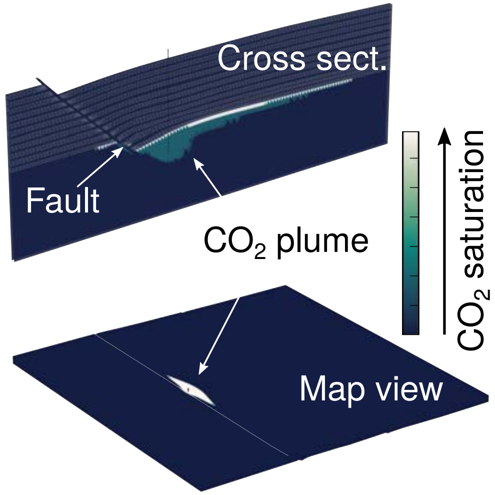
Stochastic property prediction



Faulted stratigraphy　　Fault

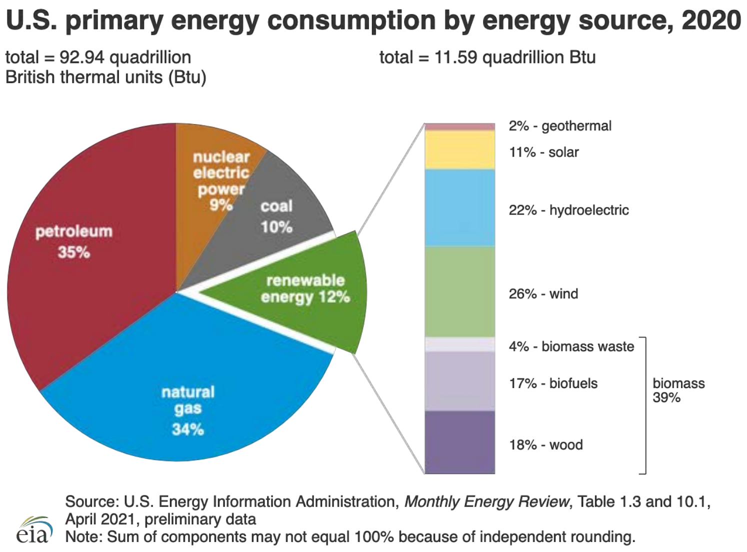
Physics-based modeling



MIT Earth Resources Laboratory
Annual Founding Members Meeting 2022

Carbon Capture, Utilization and Geologic Storage (CCUS): A Key Player to Meet Global Climate Goals

- GHG and CO_2 emissions peak this decade in modeling pathways that limit global warming to 1.5 or 2ºC (IPCC, 2022)
  However, fossil fuels still provide ~80% of primary energy (EIA, 2021)



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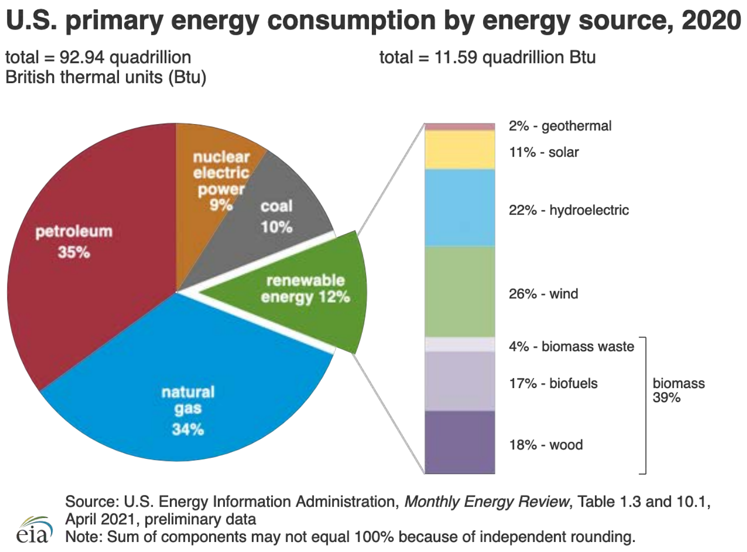
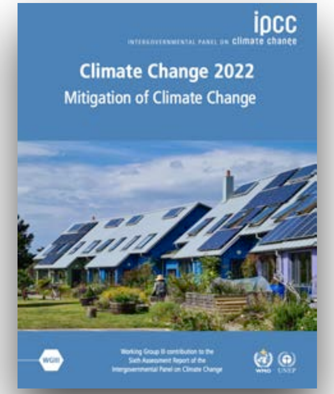
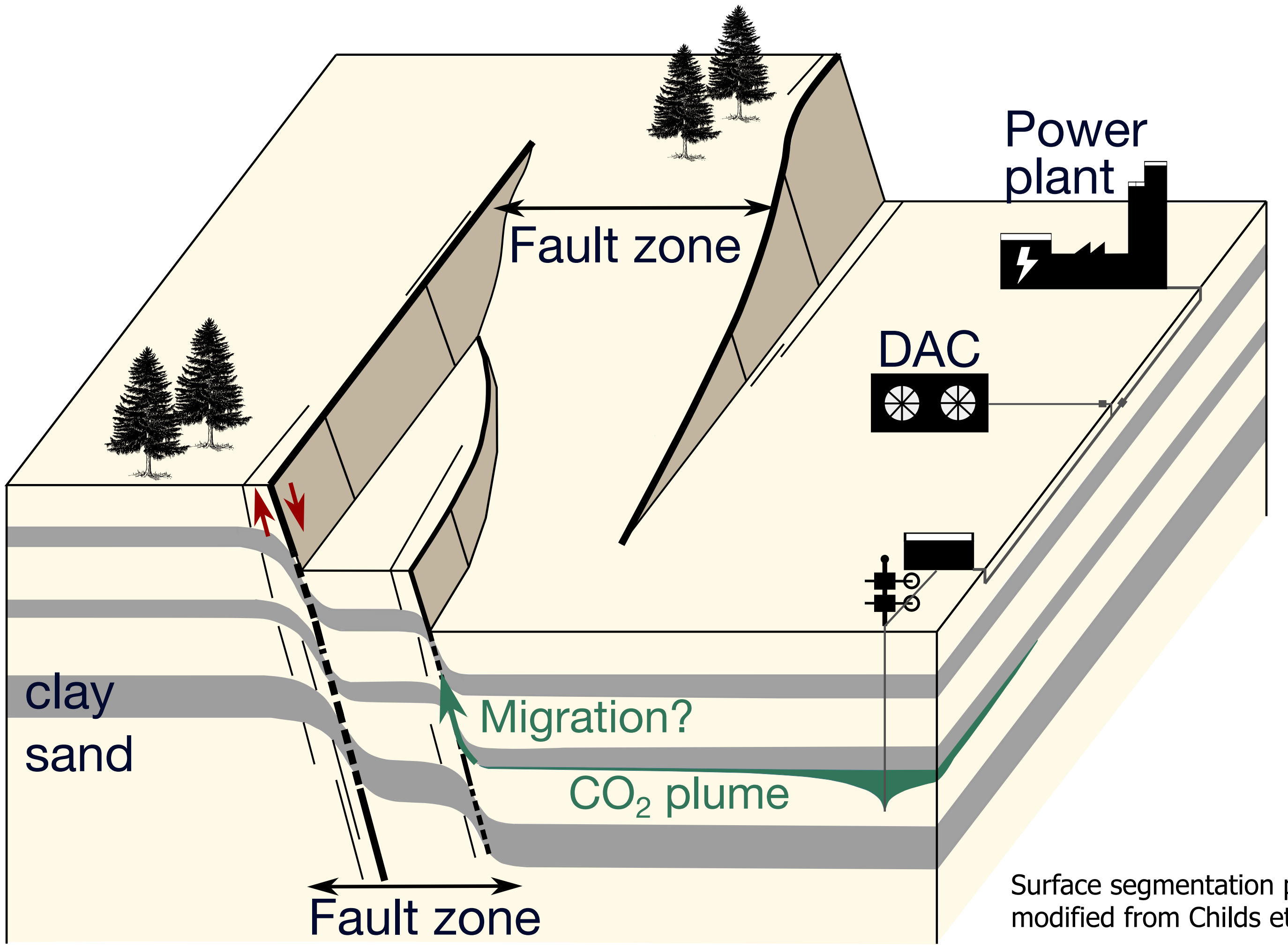


- Mitigation strategies include carbon dioxide removal (IPCC, 2022)
  CCUS is an integral part of negative-emissions technologies
  such as BECCS or DAC (EASAC, 2018)



Migration of CO_2 through faults and leakage into overlying units and/or the surface is a concern in large-scale Geologic Carbon Storage (GCS)

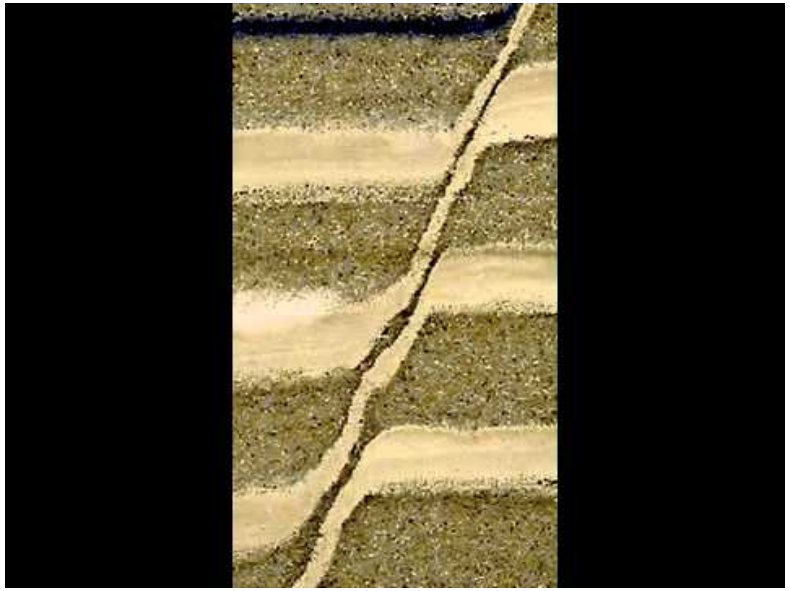


Surface segmentation pattern modified from Childs et al., JSG 2009

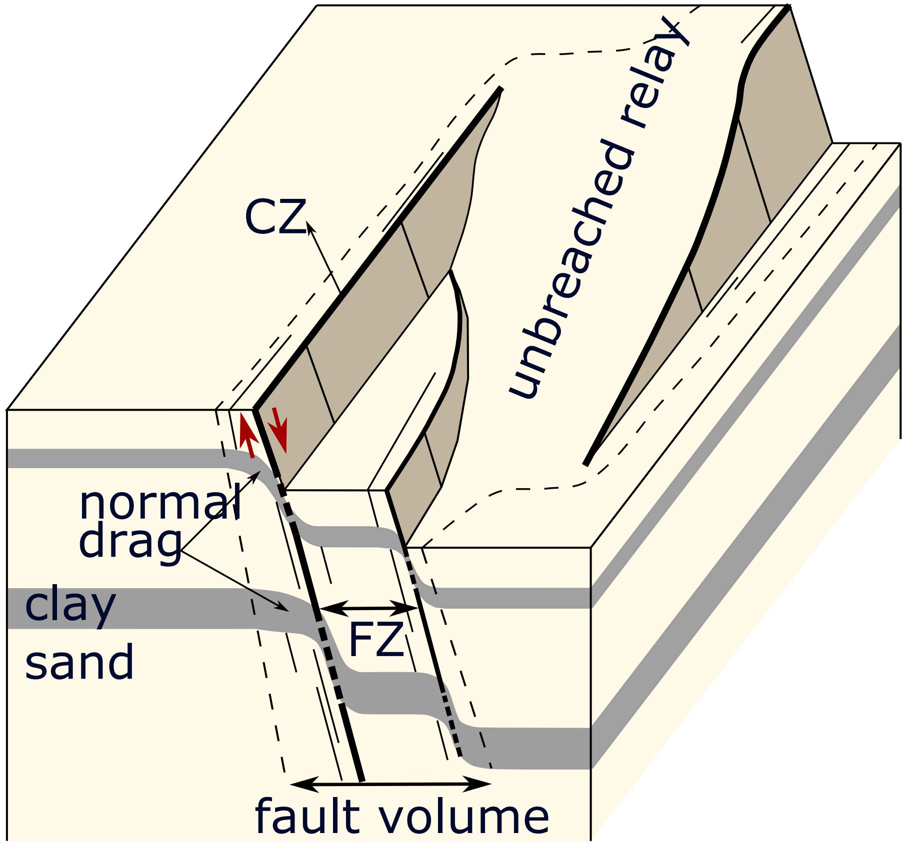
We focus on faults in soft siliciclastic basins, best suited to diminish the hazards of induced seismicity and fault leakage

- Soft siliciclastic basins have advantageous rheological properties for large-scale GCS

Juanes et al., PNAS 2012
Vilarrasa & Carrera, PNAS 2015



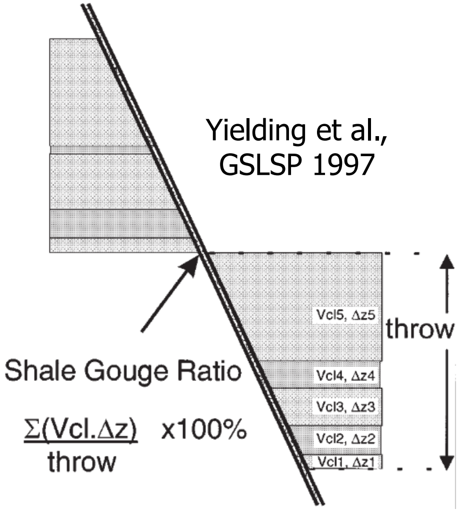
Schmatz, Urai, et al. (RWTH Aachen)
Video from StrucGeology Youtube channel



Surface segmentation pattern
modified from Childs et al., JSG 2009

Previous approaches cannot quantify the fault permeability tensor. This makes it difficult to understand fault CO_2 migration hazard

Industry workflow



Yielding et al., GSLSP 1997

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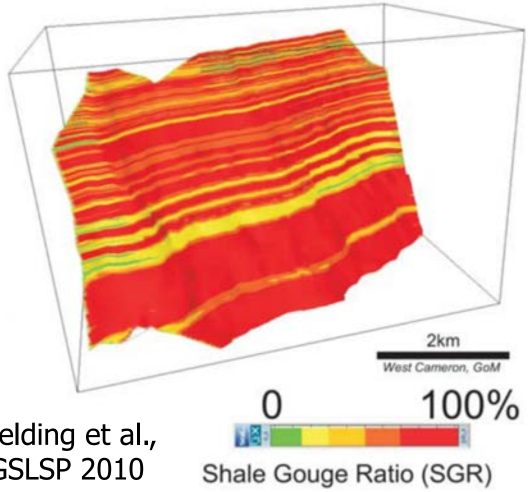

Yielding et al., GSLSP 2010

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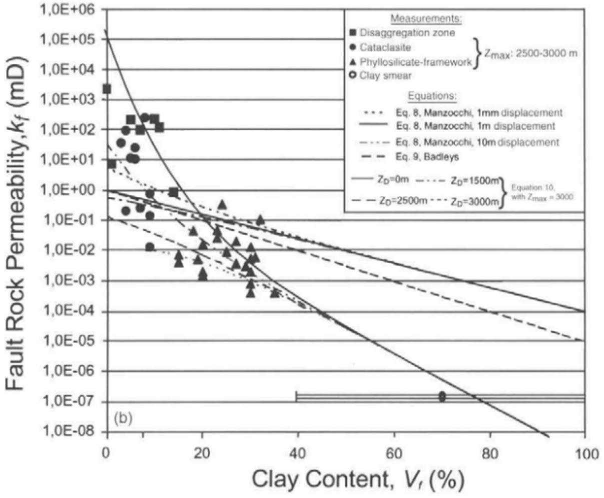
Sperrevik et al., NPSSP 2002



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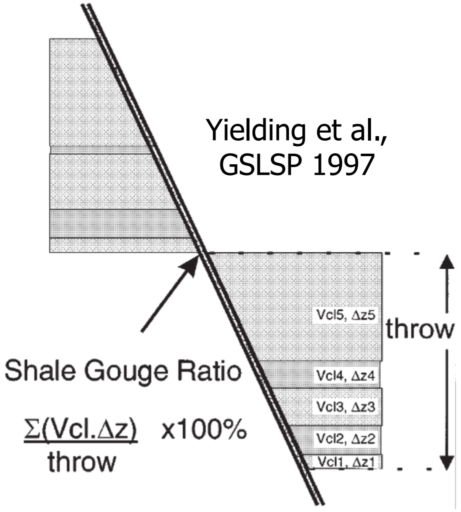

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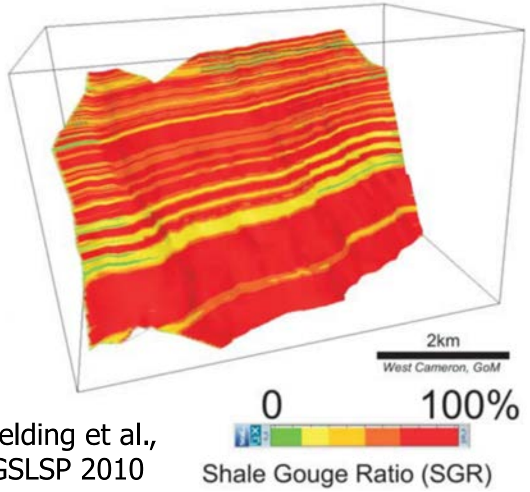

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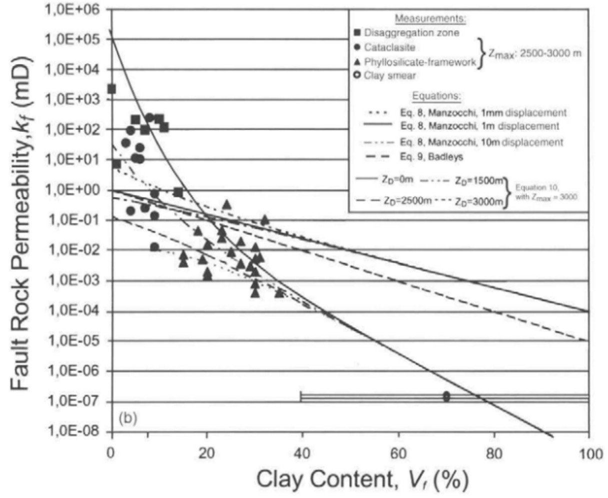
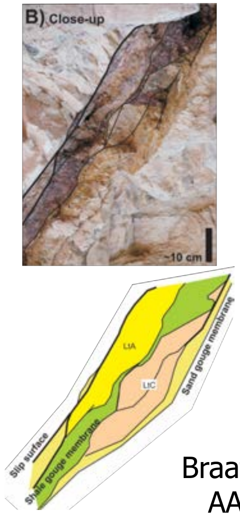
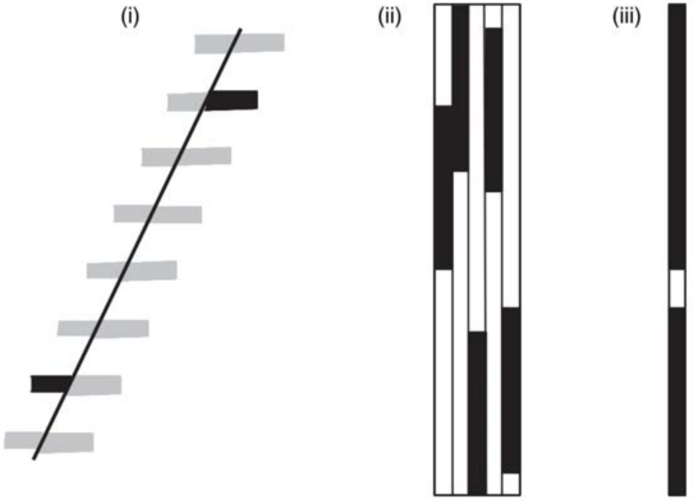


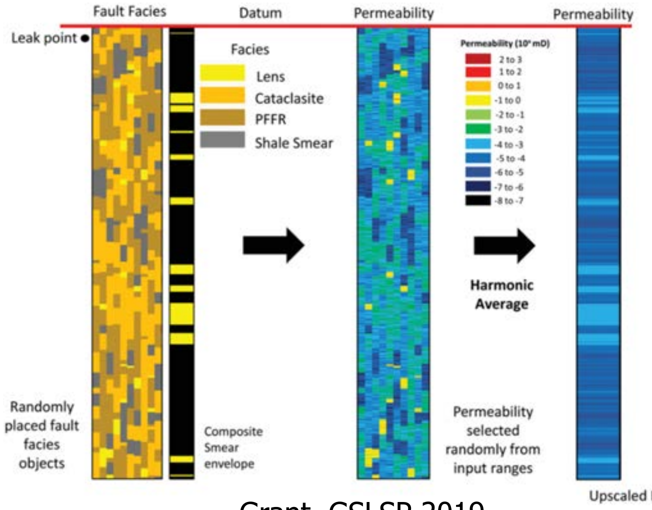
Alternative approaches



Braathen et al., AAPG 2009



Childs et al., GSLSP 2007



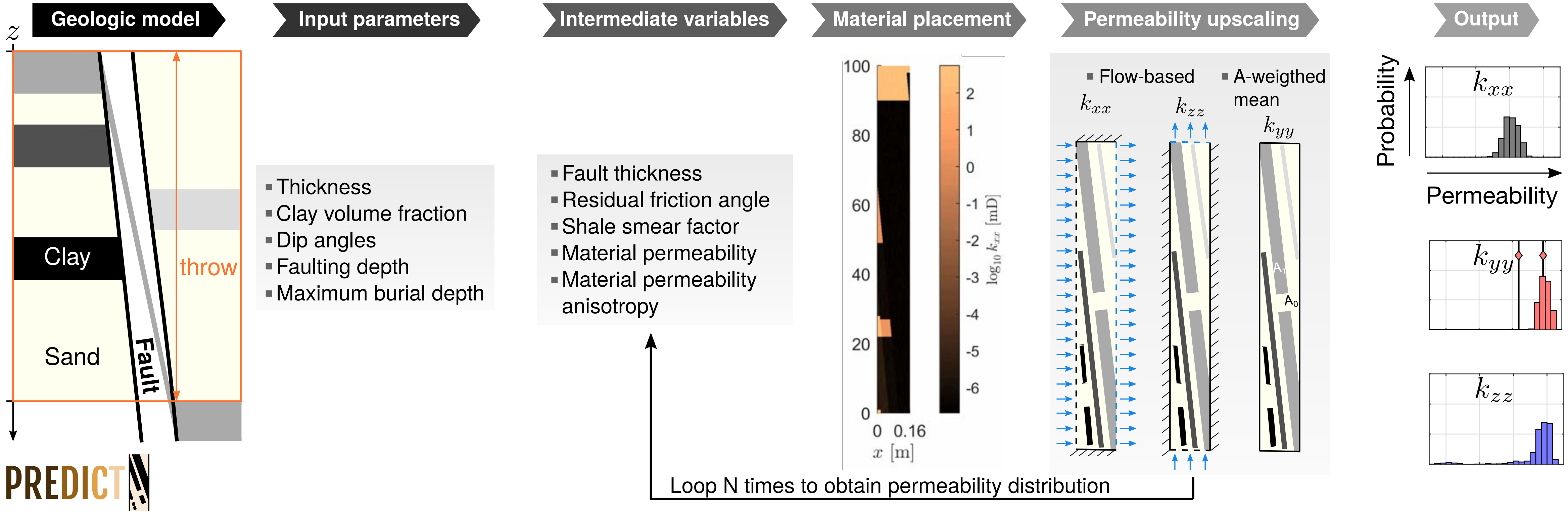
Grant, GSLSP 2019

We want to understand and model the effect of clay smears on fault zone permeability

We approach the modeling of fault permeability with the following goals:

1. Include a physics-based description of clay smears
2. Quantify uncertainty
3. Include anisotropic permeability (k_{xx}, k_{yy}, k_{zz})

We developed a new methodology, PREDICT, which uses a physics-based, probabilistic approach to modeling the directional components of the fault permeability tensor.

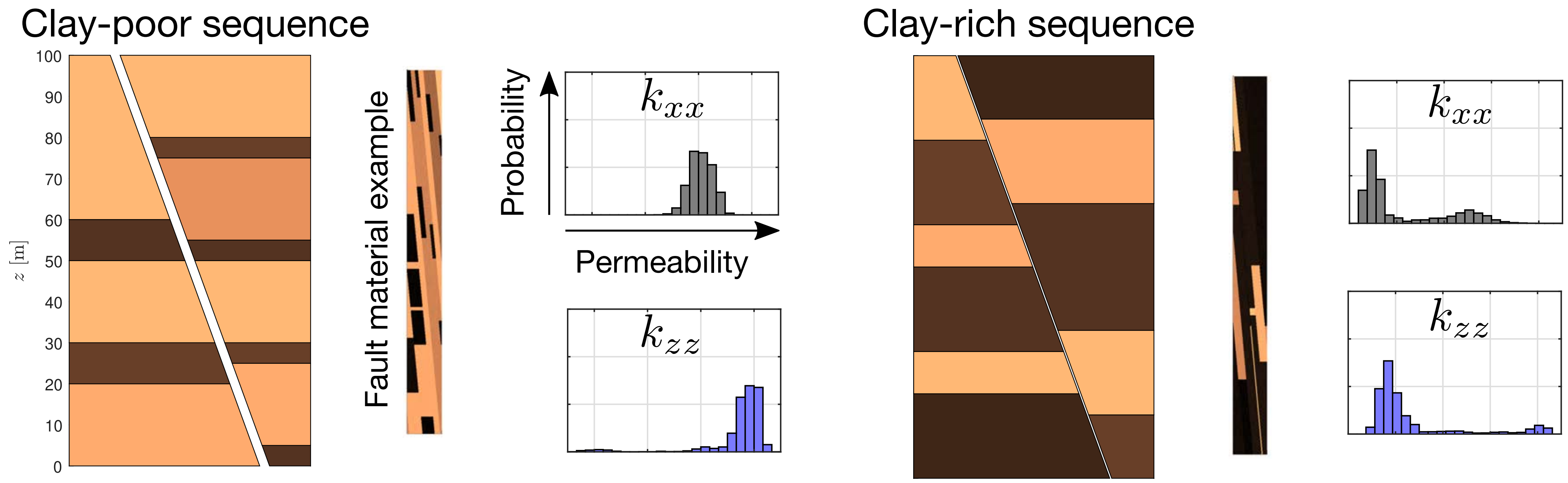


Saló-Salgado et al., in preparation

PREDICT allows understanding the relationship between the faulted stratigraphy, the fault core materials, and the resulting anisotropic fault permeability

The output considers uncertainty in the geologic variables influencing permeability,

and is best suited for fault permeability scenario modeling and hazard assessment.



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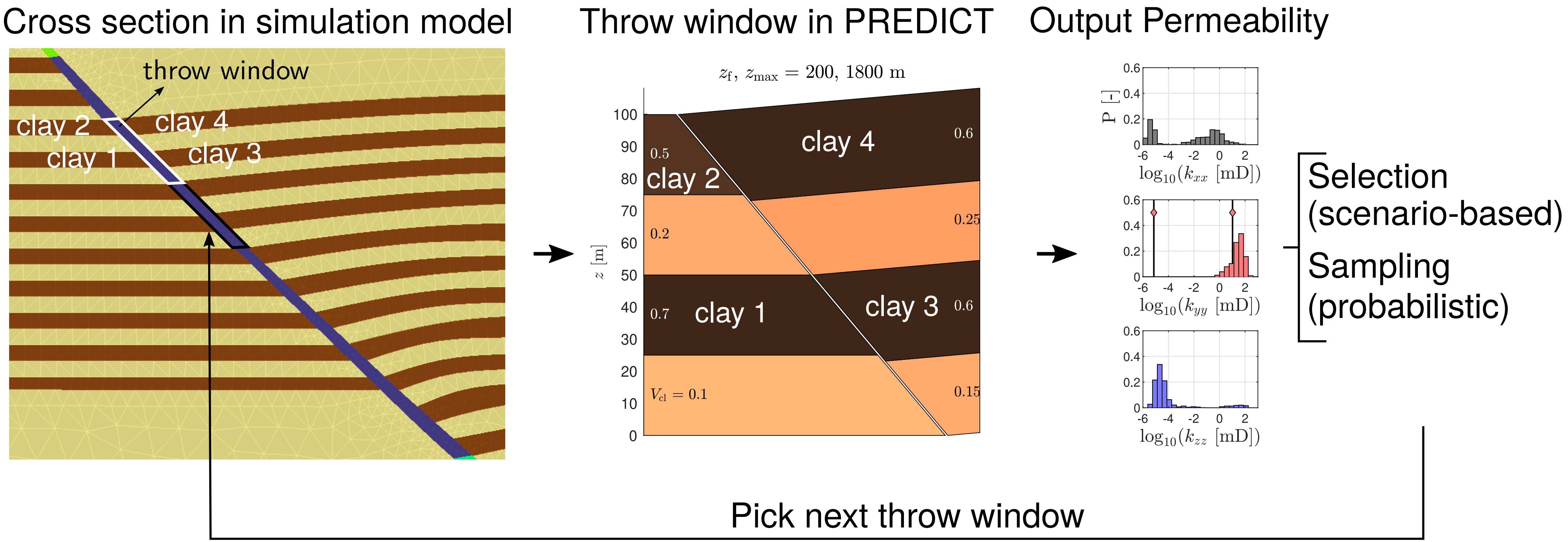


- Obtain the 3-component upscaled permeability distribution for each throw window
- The output is suitable for either scenario-based modeling or sampling in a fully probabilistic framework

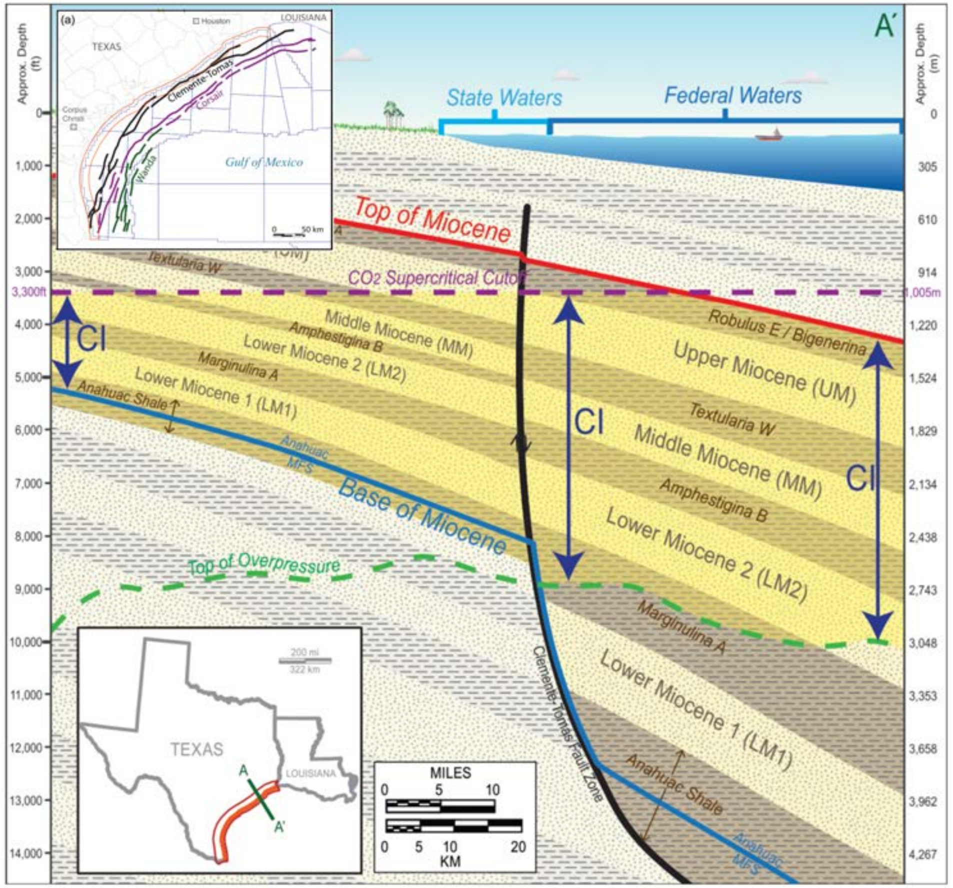
Saló-Salgado et al., in preparation

Next steps

1. Multi-cell upscaling
2. Validation with field and laboratory measurements
3. Extension to 3D

Fault Zone CO_2 migration in the Miocene section offshore Texas (Gulf of Mexico)

Goal: Assess potential migration of CO_2 through a fault partially offsetting the caprock



Carr et al., GoM Atlas (2017)

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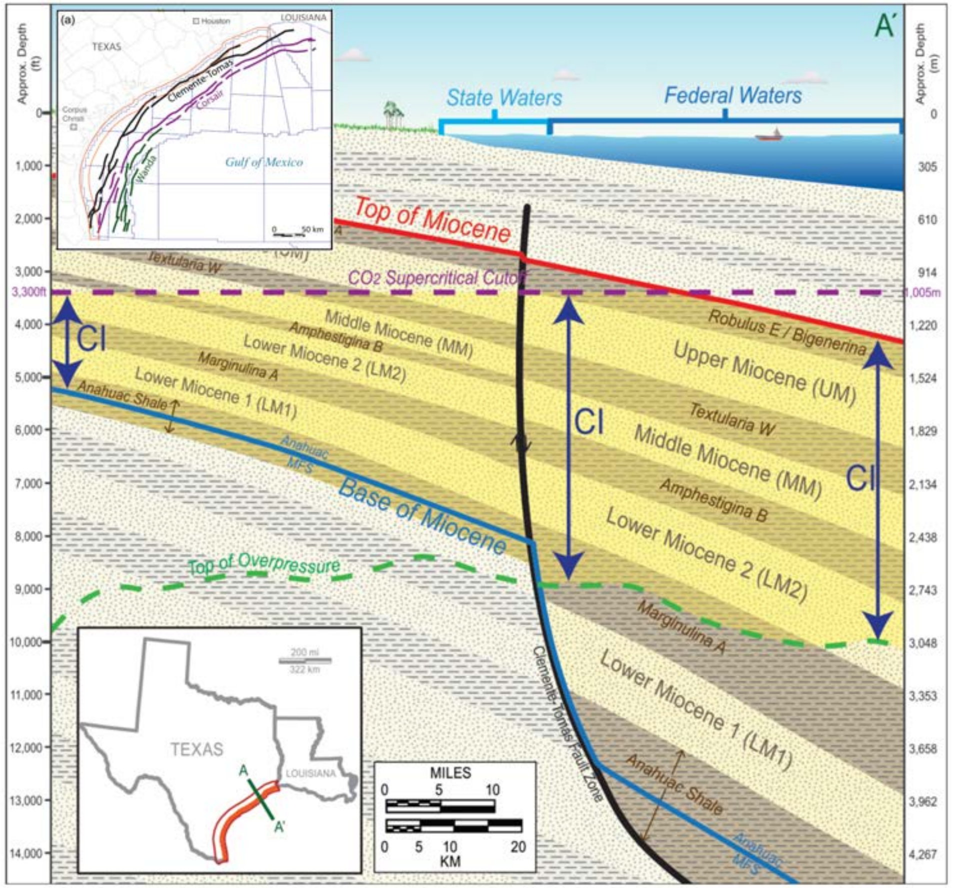

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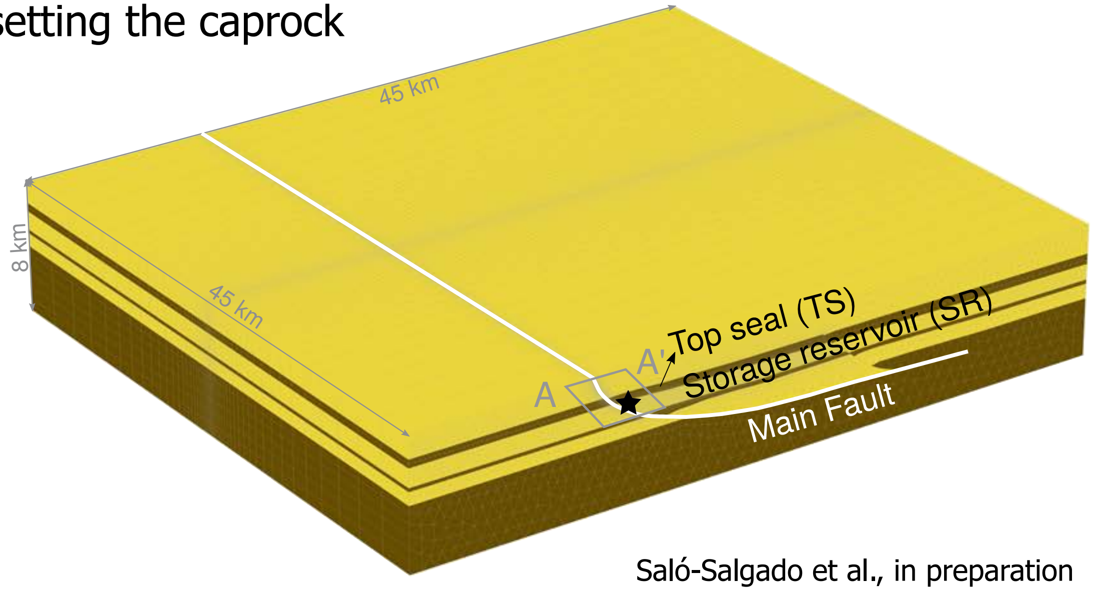
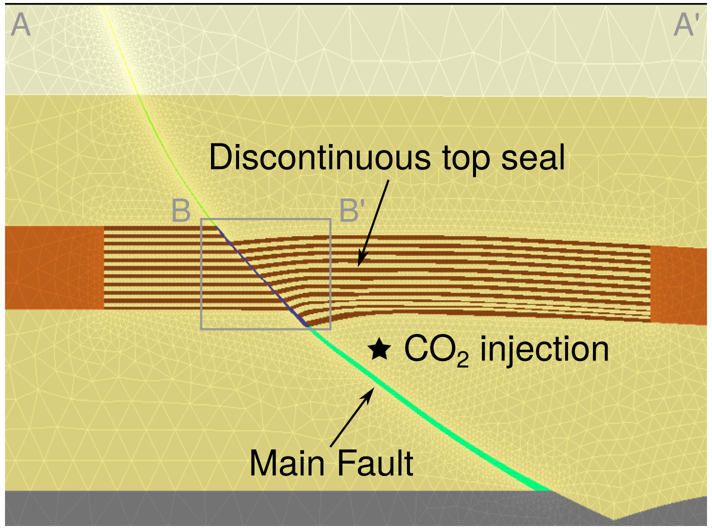


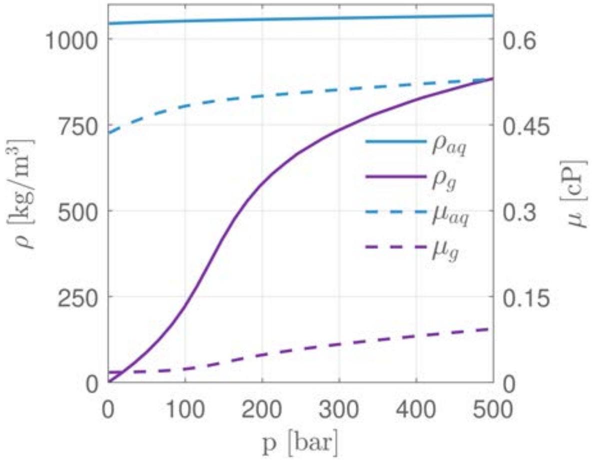
Saló-Salgado et al., in preparation

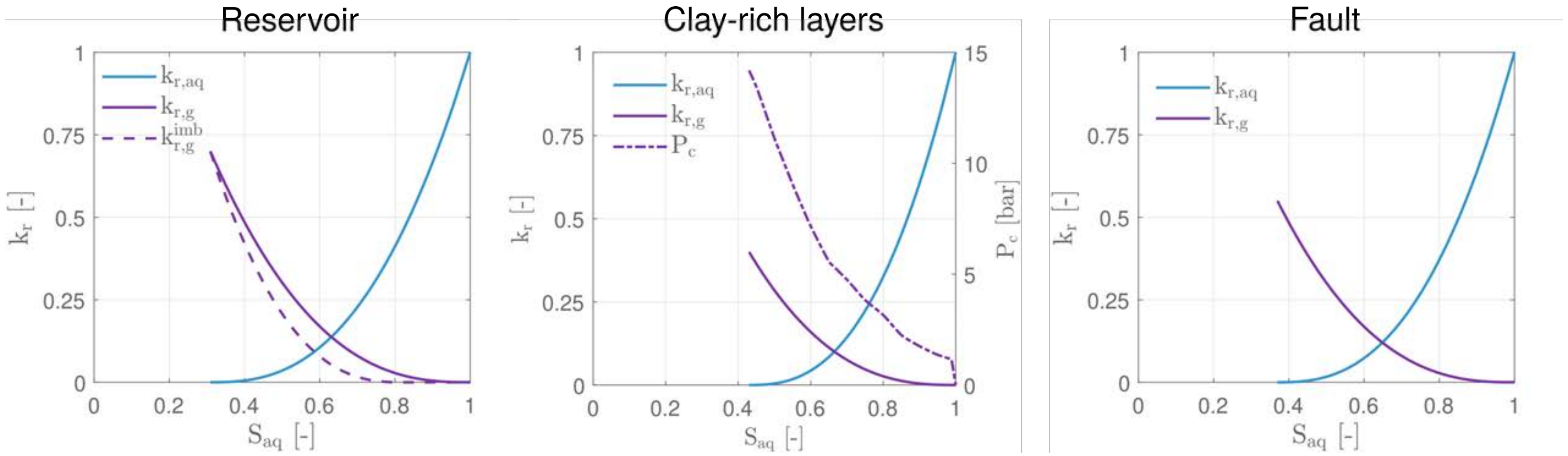


Fault Zone CO_2 migration in the Miocene section offshore Texas (Gulf of Mexico): Base-case fluid properties

- We used a black-oil formulation with a thermodynamic model that considers CO_2 dissolution in the brine (Hassanzadeh et al., IJGGC, 2008)

- Relative permeability data are Corey-type curves that were synthetically generated. They are consistent with those previously used in the Gulf of Mexico (e.g. Ghomian et al., Energy, 2008). We consider hysteresis in the gas phase.

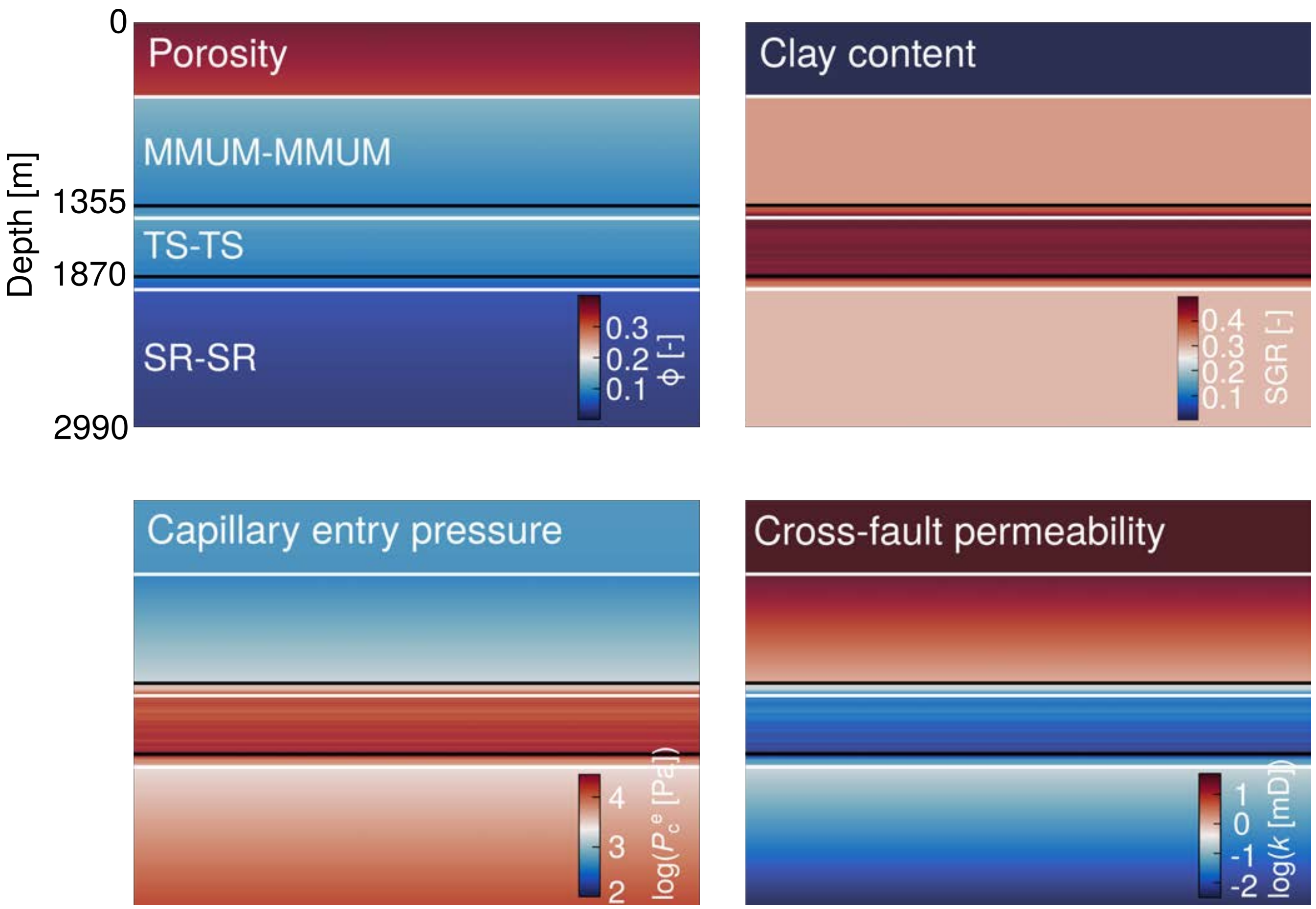




Saló-Salgado et al., in preparation

Fault Zone CO_2 migration in the Miocene section offshore Texas (Gulf of Mexico): Base-case fault properties

- Porosity based on an ideal packing model of sand and clay (Revil et al., JGR 2002)
- Capillary pressure curves were scaled based on porosity and permeability using a Leverett-J function. The reference curve is from UT Austin's GoM atlas (Treviño & Meckel, eds, 2017)
- Cross fault permeability using the SGR-based empirical relationship by Sperrevik et al. NPSSP (2002). Anisotropy = 10.

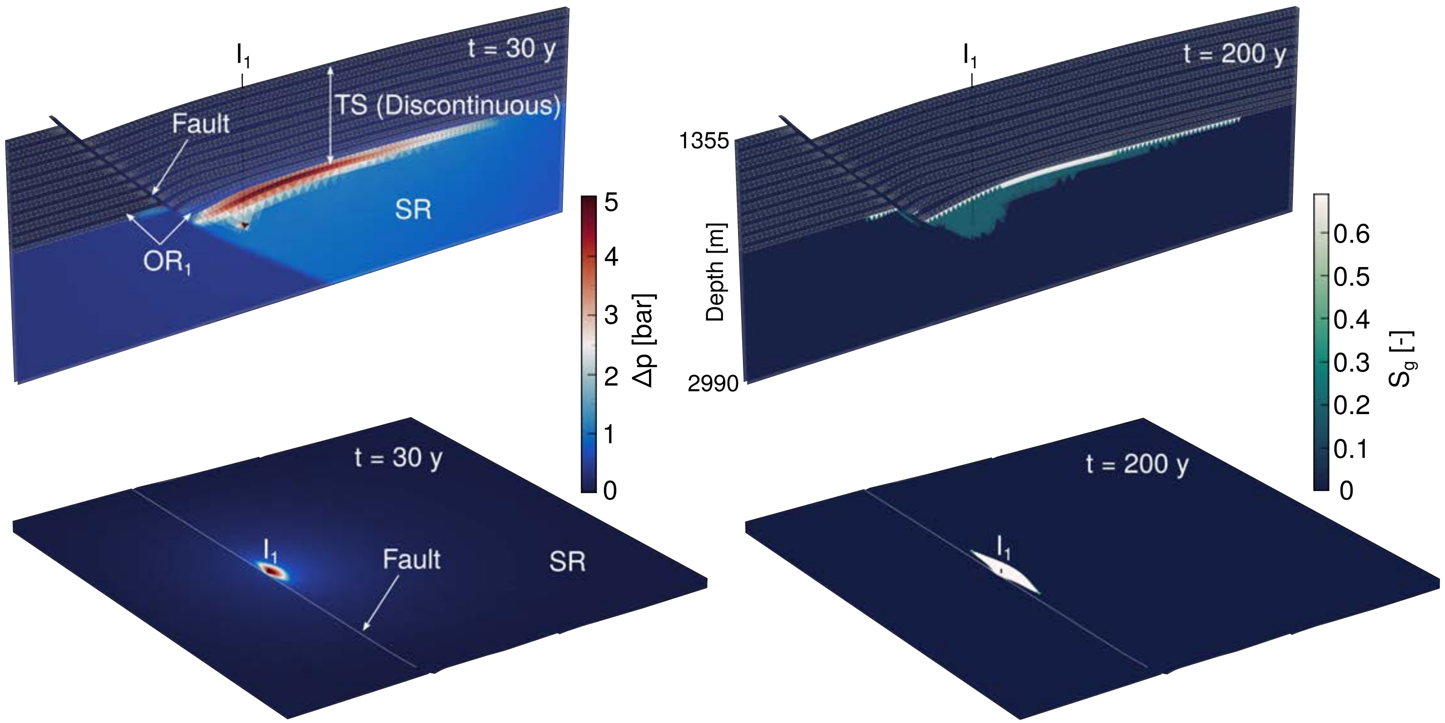


Saló-Salgado et al., in preparation

Fault Zone CO_2 migration in the Miocene section offshore Texas (Gulf of Mexico): Base-case result

- After 200y, a small amount of CO_2 has traveled along the fault and into the first overlying reservoir (OR_1). The CO_2 saturation in OR_2 is almost 0, and no CO_2 is observed above.
- **Hypothesis**: Faults that partially offset a discontinuous caprock may act as partial vertical conduits. Updip migration through the whole caprock interval is very unlikely.

CO_2 injection rate: 1 Mt/y
t_{inj} = 30 y; **t_{sim}** = 200 y



Saló-Salgado et al., in preparation

Next steps

1. Application of PREDICT to determine fault permeability
2. Upscaling of fault capillary pressure based on high-resolution material distributions and invasion-percolation simulations
3. Upscaling of relative permeabilities in both end-member flow regimes (viscous and capillary limits)

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Thank you!