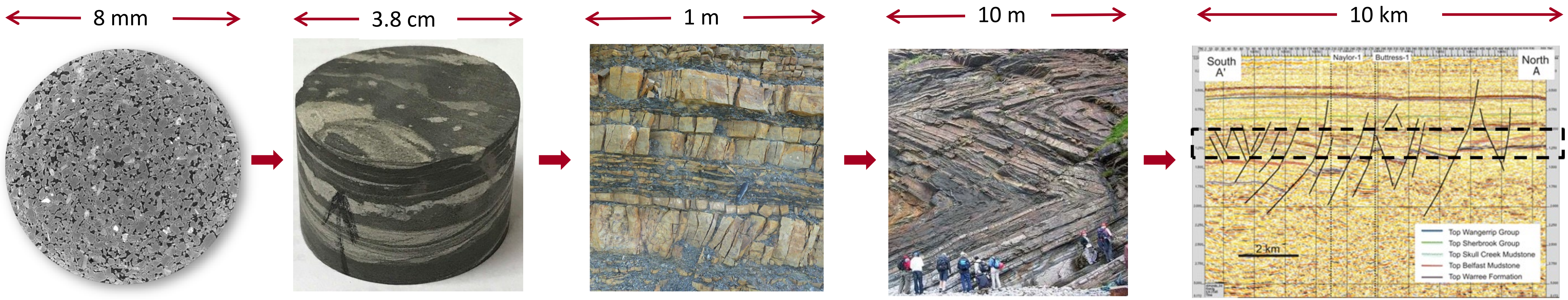
Building a low emissions future

GeoCquest Field Validation Project: Investigating the role of geological heterogeneity on plume migration and trapping

Sally M. Benson[a], Mitch Allison[b], David Bason[b], Catherine Callas[a], Julie Dickinson[c], Louis J. Durlofsky[a], Ralf Haese[c], Stephan Matthai[c], Achuyt Mishra[c], Ahmad Mortazavi[c], Aman Raizada[a], Catherine Spurin[a], Hamdi Tchelepi[a], Oleg Volkov[a], Max Watson[b], and Peter Cook[c]

[a]Stanford University, Stanford, California, 94305, U.S.A.
[b]CO2CRC, Melbourne, VIC, 3002, Australia
[c]University of Melbourne, Melbourne, VIC, 3002, Australia

Geological Heterogeneity Exists from the Pore to Field Scale



Pore scale | Core scale | Log scale | Outcrop scale | Field scale

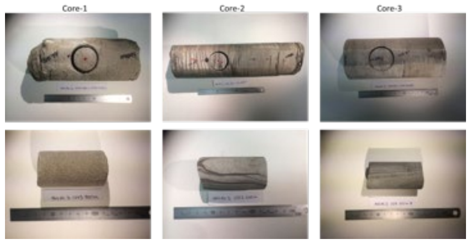
Questions addressed in this work:

- How does multi-scale geological heterogeneity affect plume migration and trapping?
- Can a practical workflow be developed to accurately characterize and simulate the influence of multi-scale heterogeneity on plume migration and trapping?

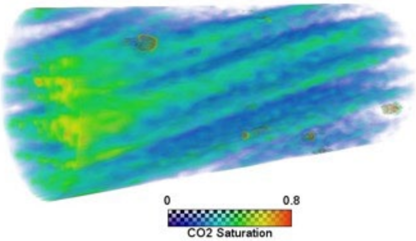
GeoCquest Stanford University The University of Melbourne GeoCquest ExxonMobil bp BHP CO2CRC BUILDING A LOW EMISSIONS FUTURE Chevron

GeoCquest (2016-2020)

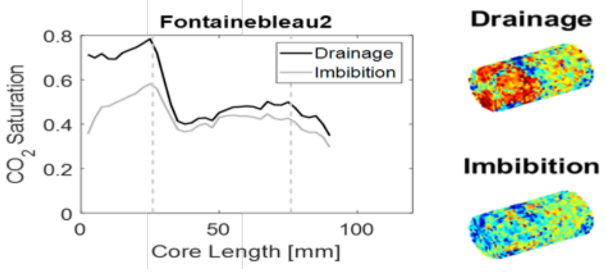
GeoCquest developed an integrated workflow which provides unprecedented accounting for geological heterogeneity effects in prediction of plume migration and trapping



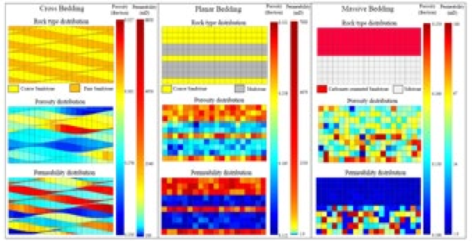
Core sampling and characterization



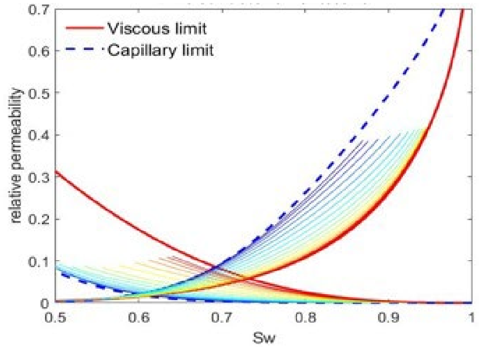
Multiphase flow experiments



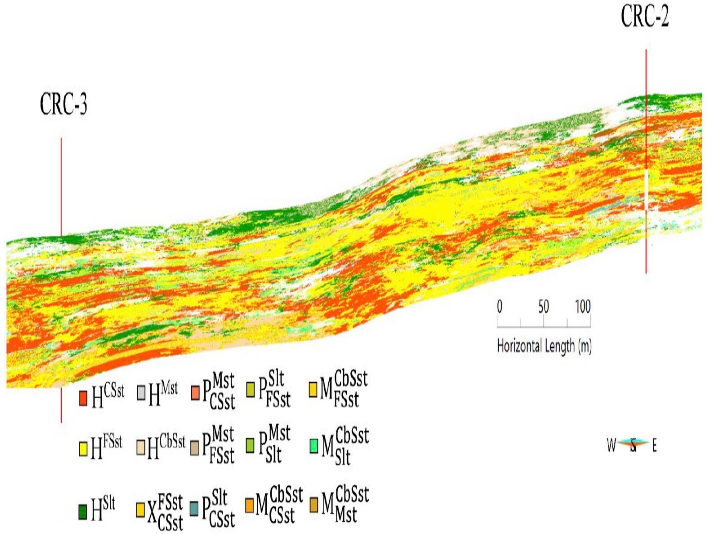
Measure trapping ability



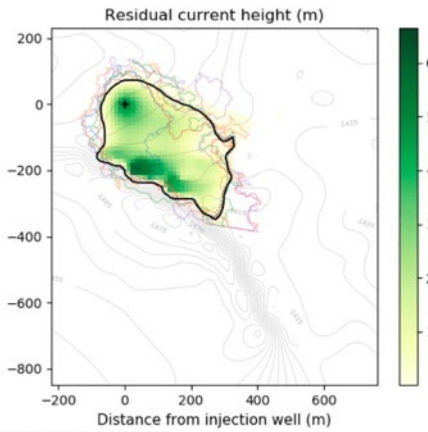
Identify **composite rock types**



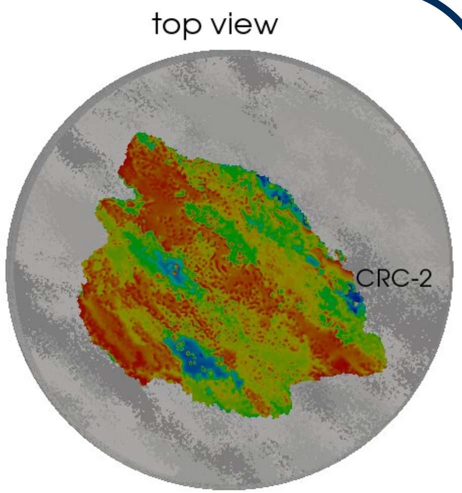
Calculate **directional and rate dependent "effective" relative permeability & capillary pressure curves**



Populate high resolution geomodel with composite rock types



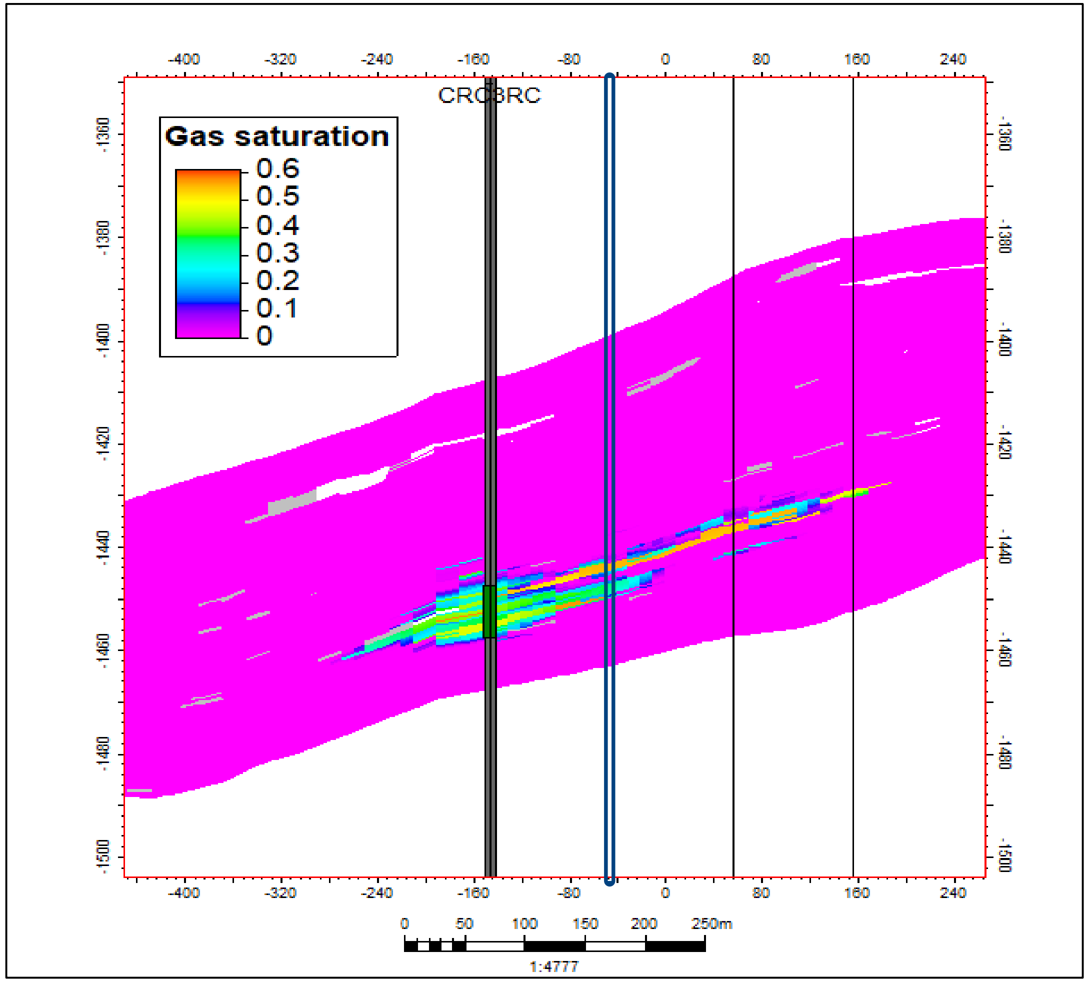
Reduced-physics models



Full-physics models

GFV: CO_2 Migration and Trapping Experiment

- 10,000 tonne CO_2 + CH_4 (80-20 mixture) injection into CRC-3 over a period of ~2 months
- High spatial and temporal monitoring of plume migration during injection:
  - Pulsar logging at CRC-8
  - Continuous VSP and passive seismic monitoring
  - Strain and temperature with behind-casing fiber
- 3-month post-injection observation of plume migration and trapping
  - Pulsar PNL logging at CRC-8 and CRC-3
  - Geochemical sampling at CRC-3
  - Continued seismic and strain measurements



Modelled CO_2 saturation @ end injection

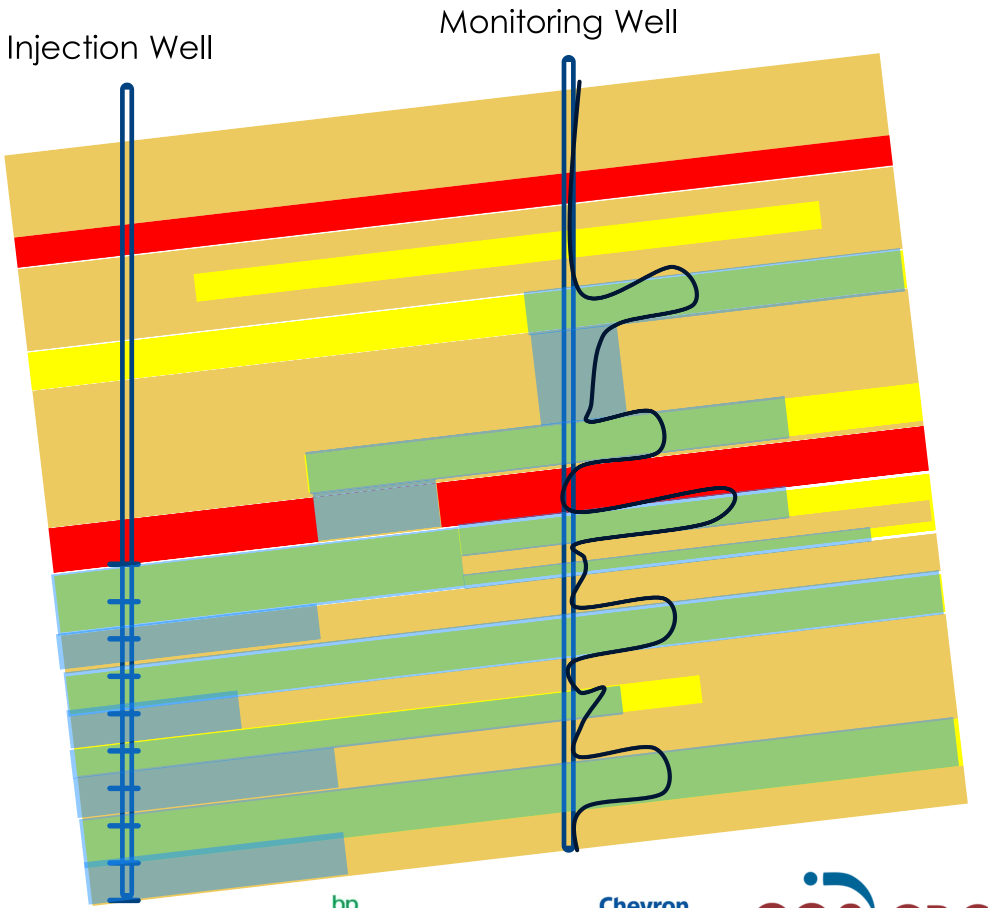
GeoCquest

CO2CRC
BUILDING A LOW EMISSIONS FUTURE

Expected Consequences of Accounting for Transport Properties of Highly Heterogeneous Reservoirs

Hypothesis

- CO_2 plume migration is faster
- Average CO_2 saturations lower
- CO_2 retained deeper in the reservoir
- Plume immobilization is faster
- Trapping efficiency is higher



GeoCquest Field Validation Experiment

A proof-of-concept field experiment to….

- Obtain an exceptionally high-resolution data set to enable a more precise assessment of the behaviour of a CO_2 plume in a **highly heterogeneous reservoir**

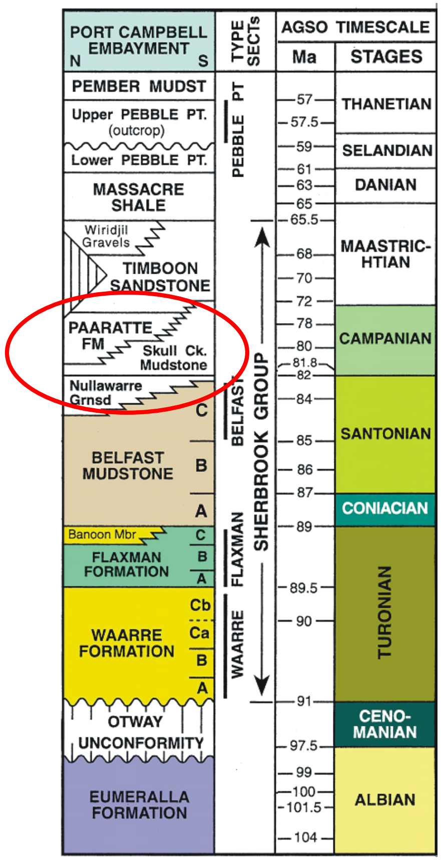
- Improve modeling and prediction of CO_2 flow dynamics and trapping

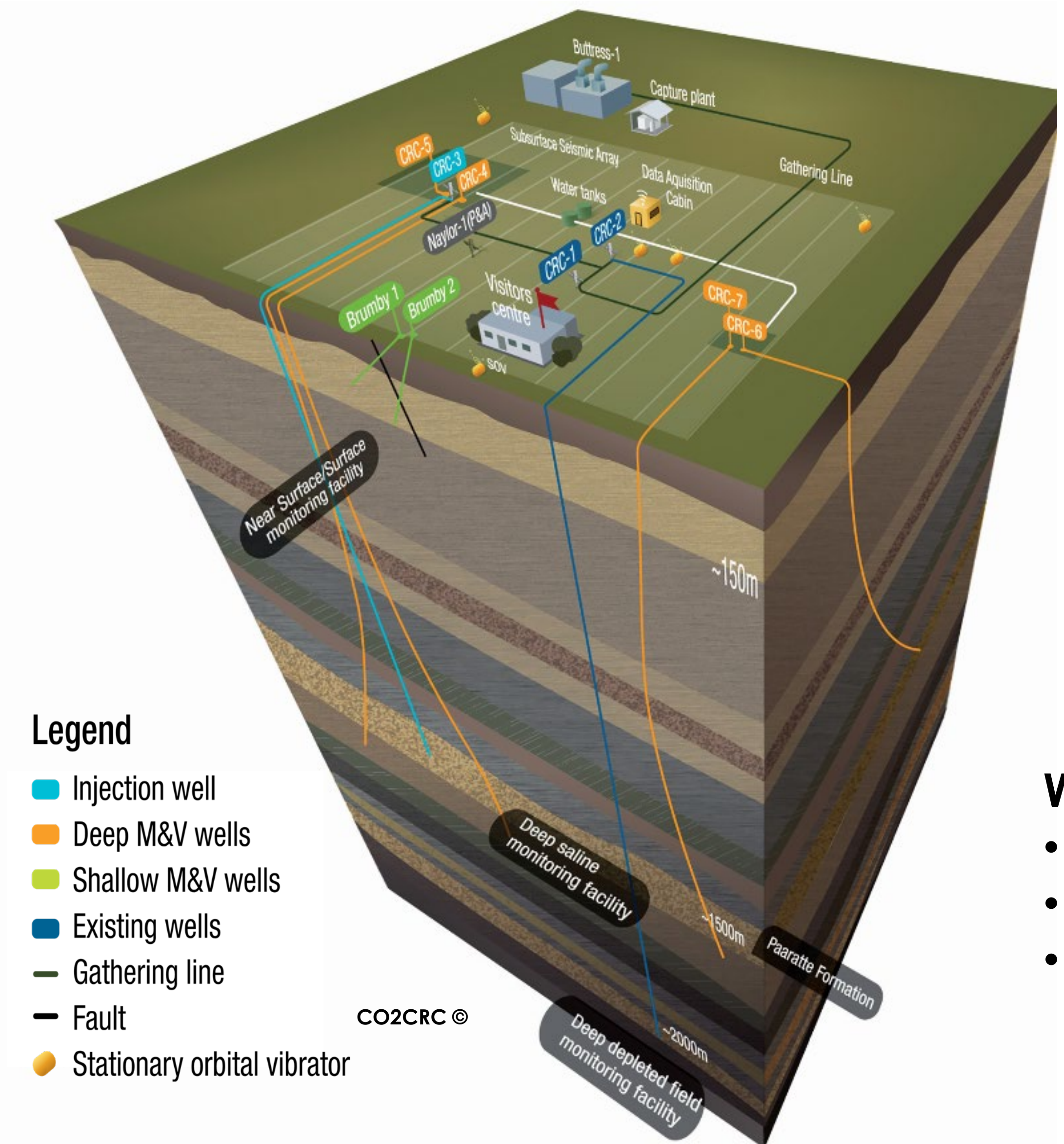
- Test and validate the GeoCquest workflow accounting for small-scale lithological heterogeneity in geo-models and resulting in more accurate CO_2 migration and trapping prediction.

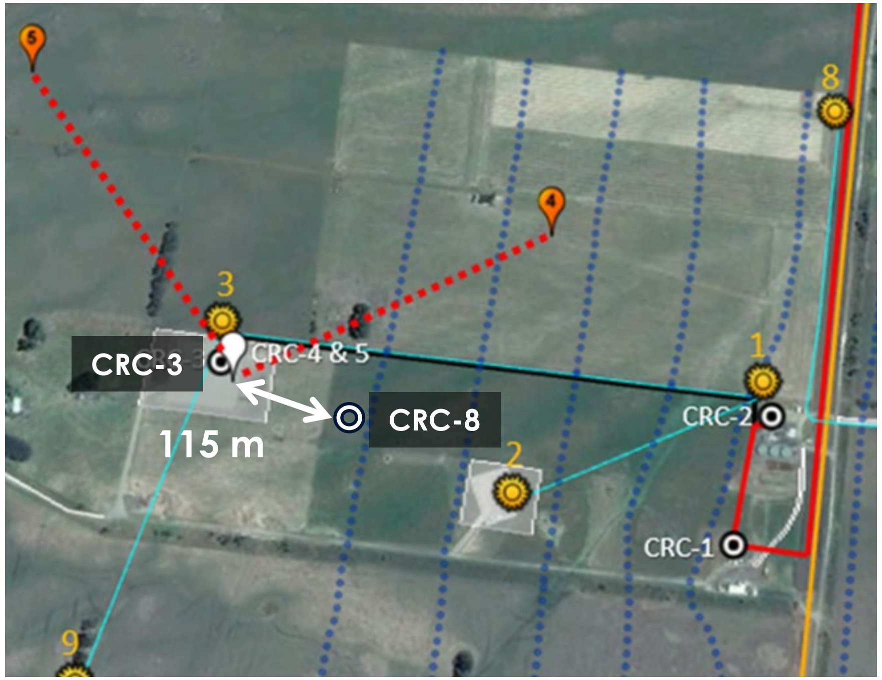
- Generate a unique dataset for the calibration and validation of future model development

GeoCquest CO2CRC BUILDING A LOW EMISSIONS FUTURE Stanford University THE UNIVERSITY OF MELBOURNE GeoCquest ExxonMobil bp BHP

Otway International Test Center







CO2CRC

BUILDING A LOW EMISSIONS FUTURE

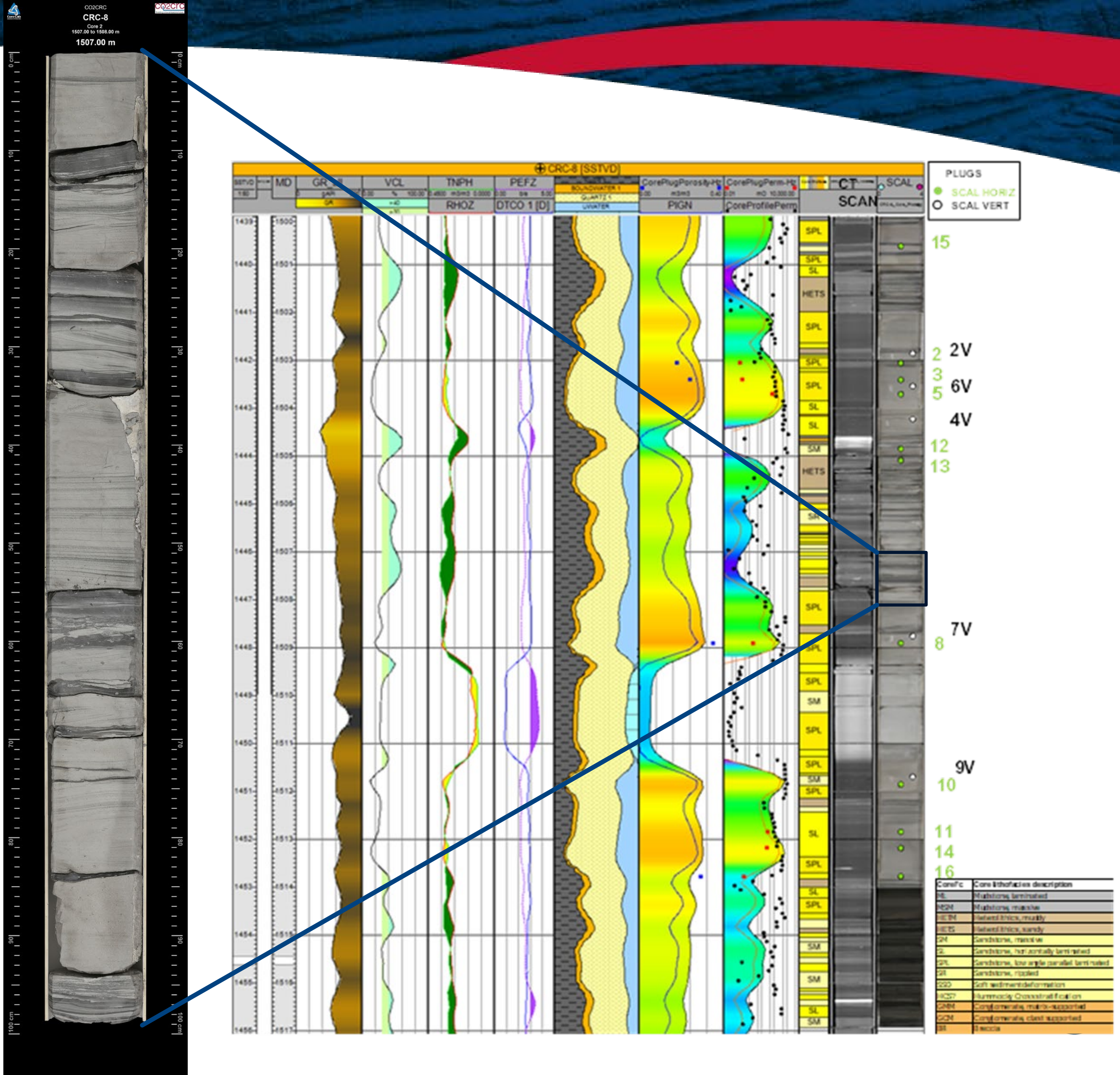
Wells

- Primary monitoring well: (new) CRC-8
- Injection well CRC-3
- CRC-2, 4, 5, 6, and 7 used for pressure and seismic monitoring

Formation Characterization

- Delta front depositional environment: distributary channels, mouth bars, and carbonates
- Well logs from CRC-3 and 8
- Continuous core from both wells, including X-Ray CT for CRC-8
- Minipermeameter and routine core analysis for CRC-8 and CRC-3
- Special core analysis for CRC-8 and limited sampling from CRC-3
- Chemscans for mineralogy on thin sections from CRC-8

1 m grid resolution



GeoCquest

CO2CRC
BUILDING A LOW EMISSIONS FUTURE

Rock Type Identification and Properties

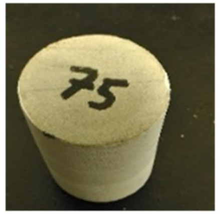
Homogenous Rocks

Coarse sandstone

Fine sandstone

Siltstone

Mudstone



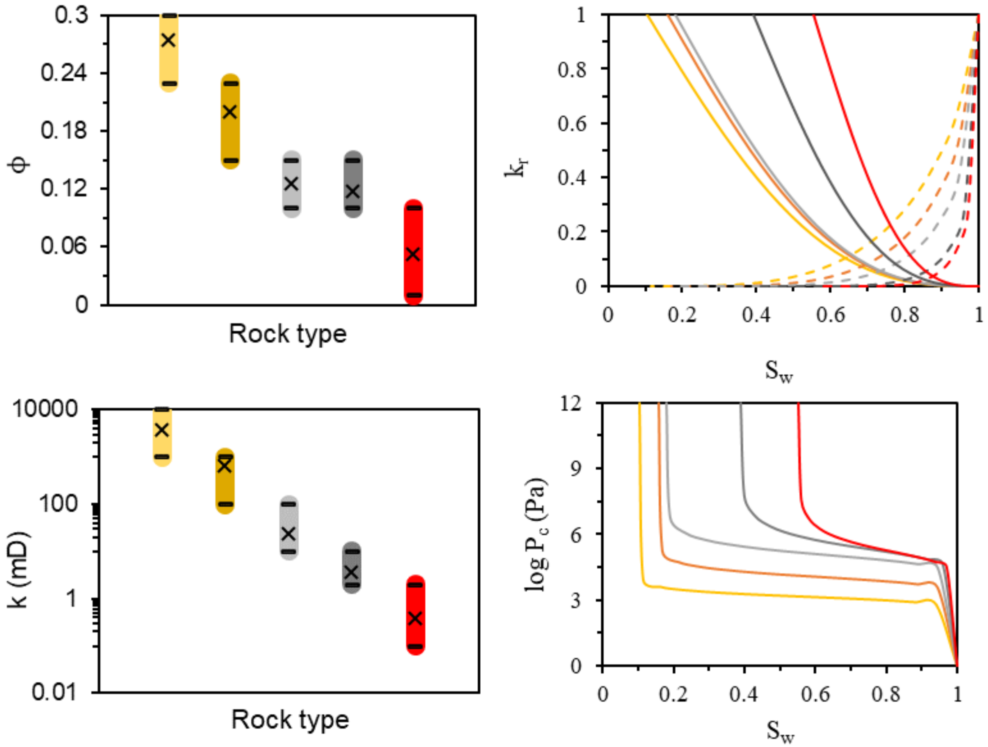
Carbonate-cemented sandstone

Composite Rocks

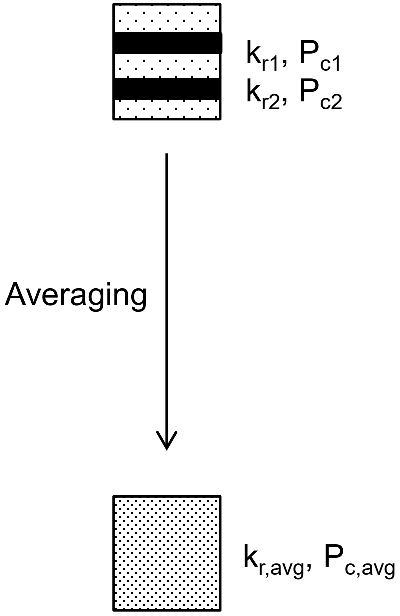
Composite of fine sandstone and mudstone

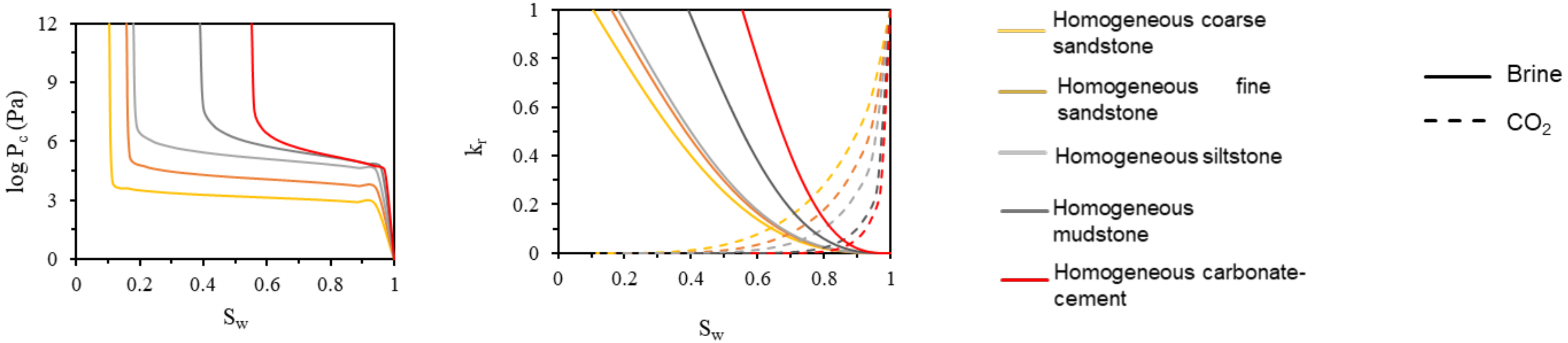
Composite of coarse sandstone and mudstone

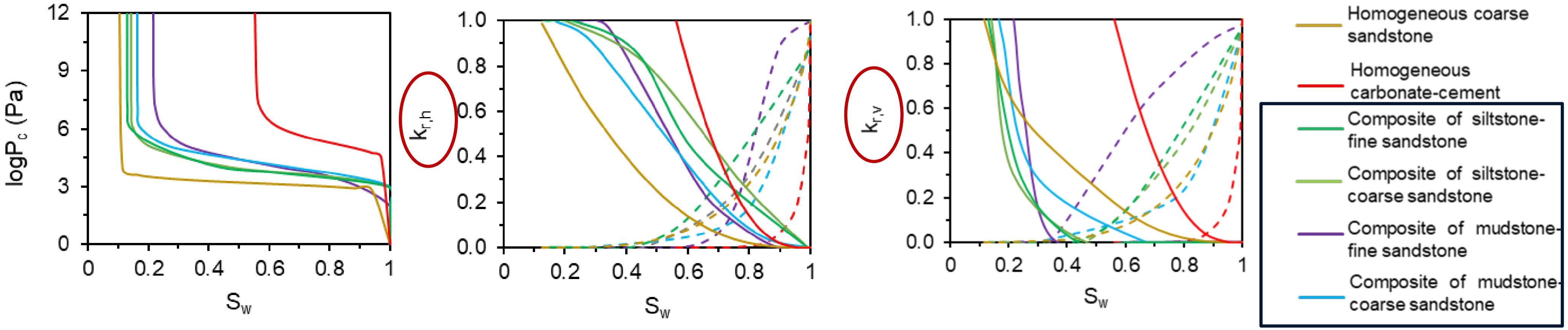
Sample ID	Depth (m)	Porosity (%)	Permeability (mD)	Mineral composition		
				Framework (%)	Clay (%)	Carbonate (%)
98	1462.85	28.80	324	80.93	18.50	0.57
92	1464.80	28.50	141	77.81	21.28	0.91
93	1477.20	26.90	7410	91.49	7.77	0.74
97	1480.55	13.10	0.55	39.03	55.22	5.75
91	1486.45	29.70	1010	82.99	16.80	0.21
81	1502.90	24.00	357	93.28	6.49	0.23
82	1505.00	14.10	0.9	48.39	50.00	1.61
79	1506.92	29.30	262	88.08	11.47	0.45
77	1508.80	26.60	353	73.39	25.94	0.67
75	1513.60	23.40	198	79.02	7.19	13.79
72	1518.45	27.10	109	87.53	11.59	0.88



Petrophysical Properties of Composite Rock Types



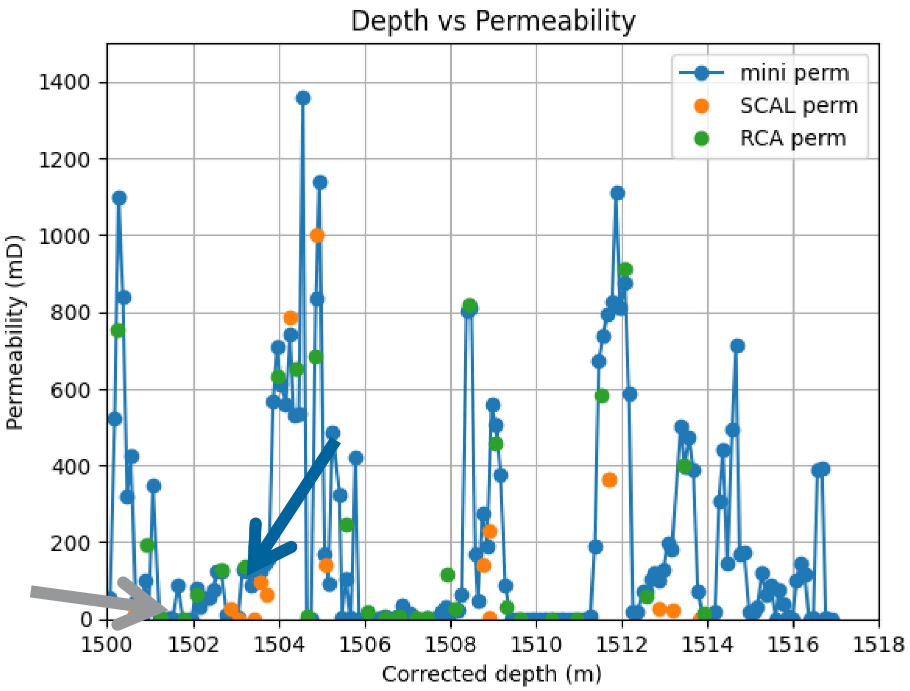




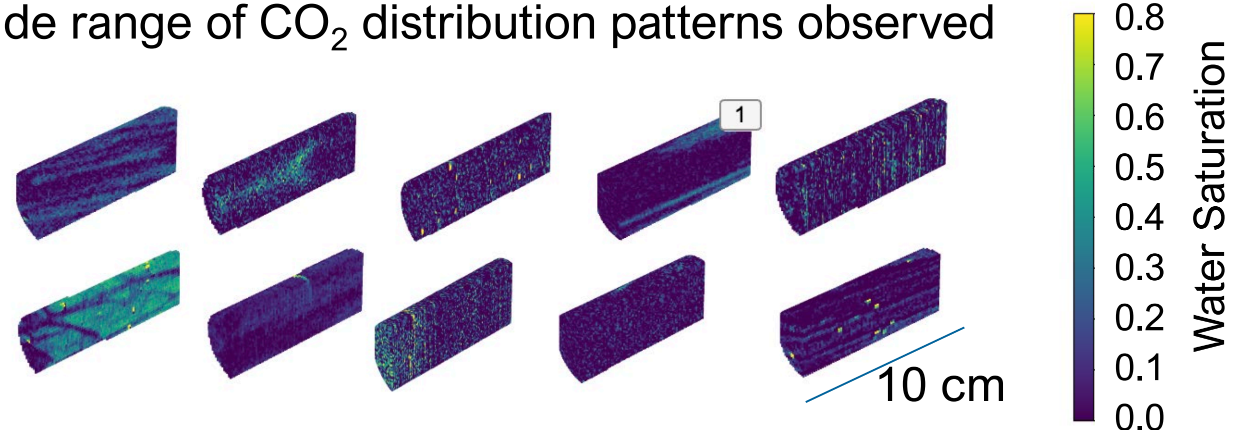
Mishra, A., Kurtev, K. D., & Haese, R. R. (2020). Composite rock types as part of a workflow for the integration of mm-to cm-scale lithological heterogeneity in static reservoir models. *Marine and Petroleum Geology*, *114*, 104240.
Boon, M., & Benson, S. M. (2021). A physics-based model to predict the impact of horizontal lamination on CO_2 plume migration. *Advances in Water Resources*, *150*, 103881.

Petrophysical Measurements: Highly Heterogeneous Rocks Display a Variety of Multi-Phase Flow Characteristics

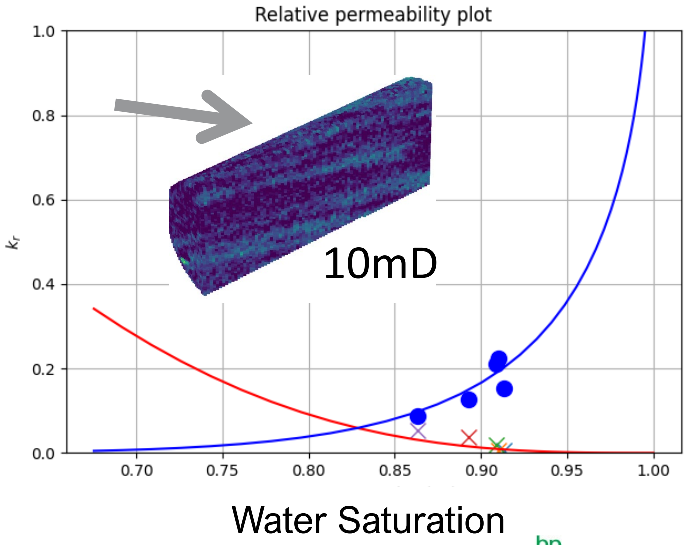
Large variations in permeability

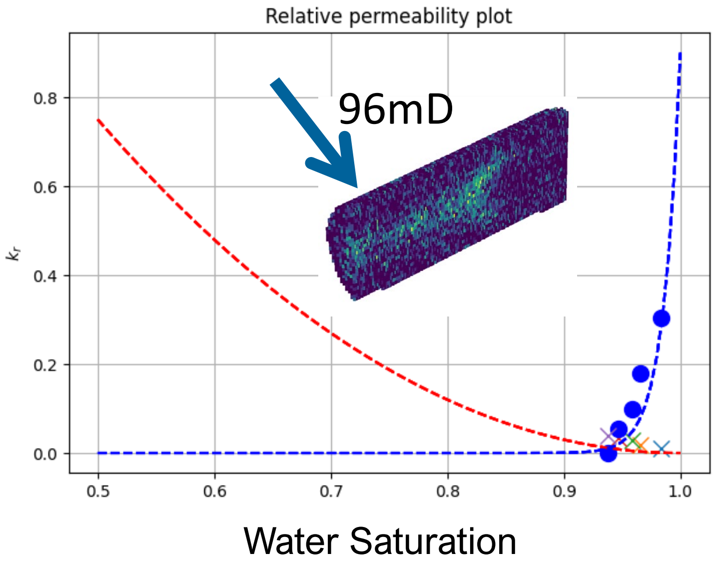


A wide range of CO_2 distribution patterns observed



This is reflected in the relative permeability curves





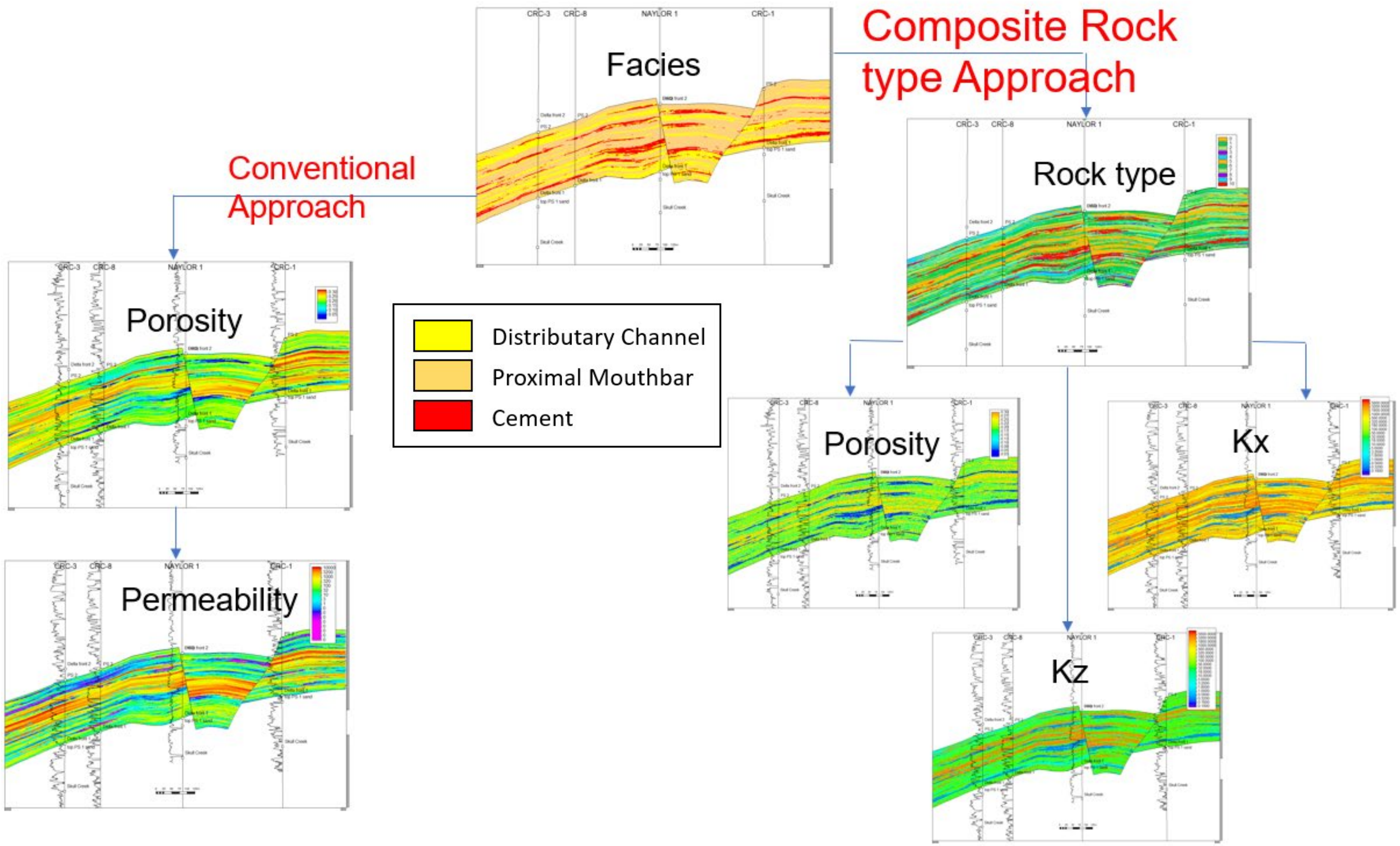
Geo-Modelling

Modeling Methods

- Using Sequential Indicator Statistics (SIS) for facies and rocktypes
- Gaussian distributions phi, kx and kx based on with well logs and core analyses and conditioned to wells

Model Resolution

- Super high-resolution 1x1x0x.3 m
- High resolution 3 x 3 x 0.3 m
- Low resolution 10 x 10 x 2 m



GeoCquest CO2CRC BUILDING A LOW EMISSIONS FUTURE Stanford University THE UNIVERSITY OF MELBOURNE GeoCquest ExxonMobil bp BHP Chevron

GEOS Dynamic Model

- GEOS CO_2 reservoir simulator

  Multi-physics : coupled flow and geomechanics

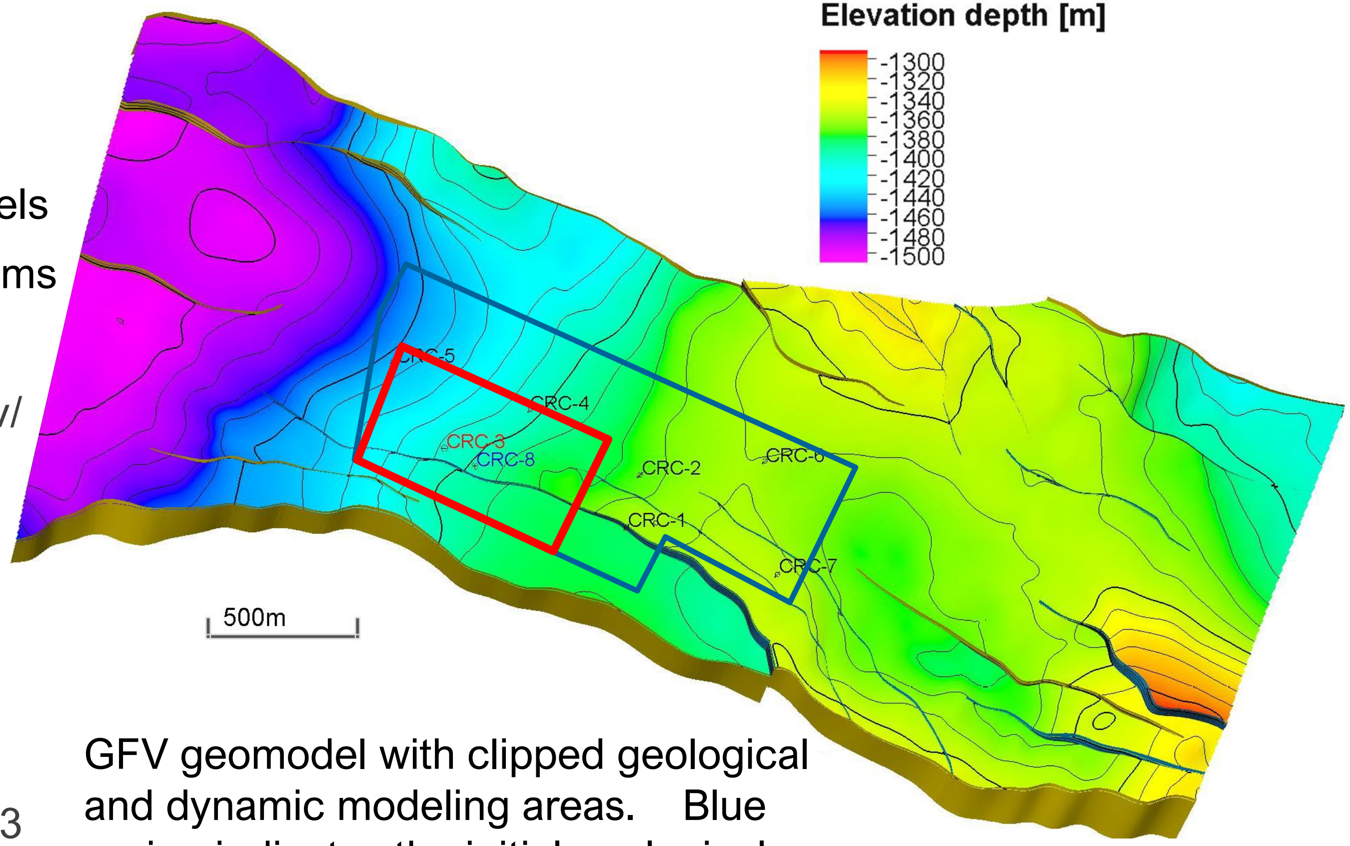
  Fast : massive CPU/GPU parallelization, large models

  Cost effective : open source, portable across systems

  Transparent : auditable by experts, regulators

  Open Source: available to all, https://www.geos.dev/

Lawrence Livermore National Laboratory · TotalEnergies · Chevron · Stanford University



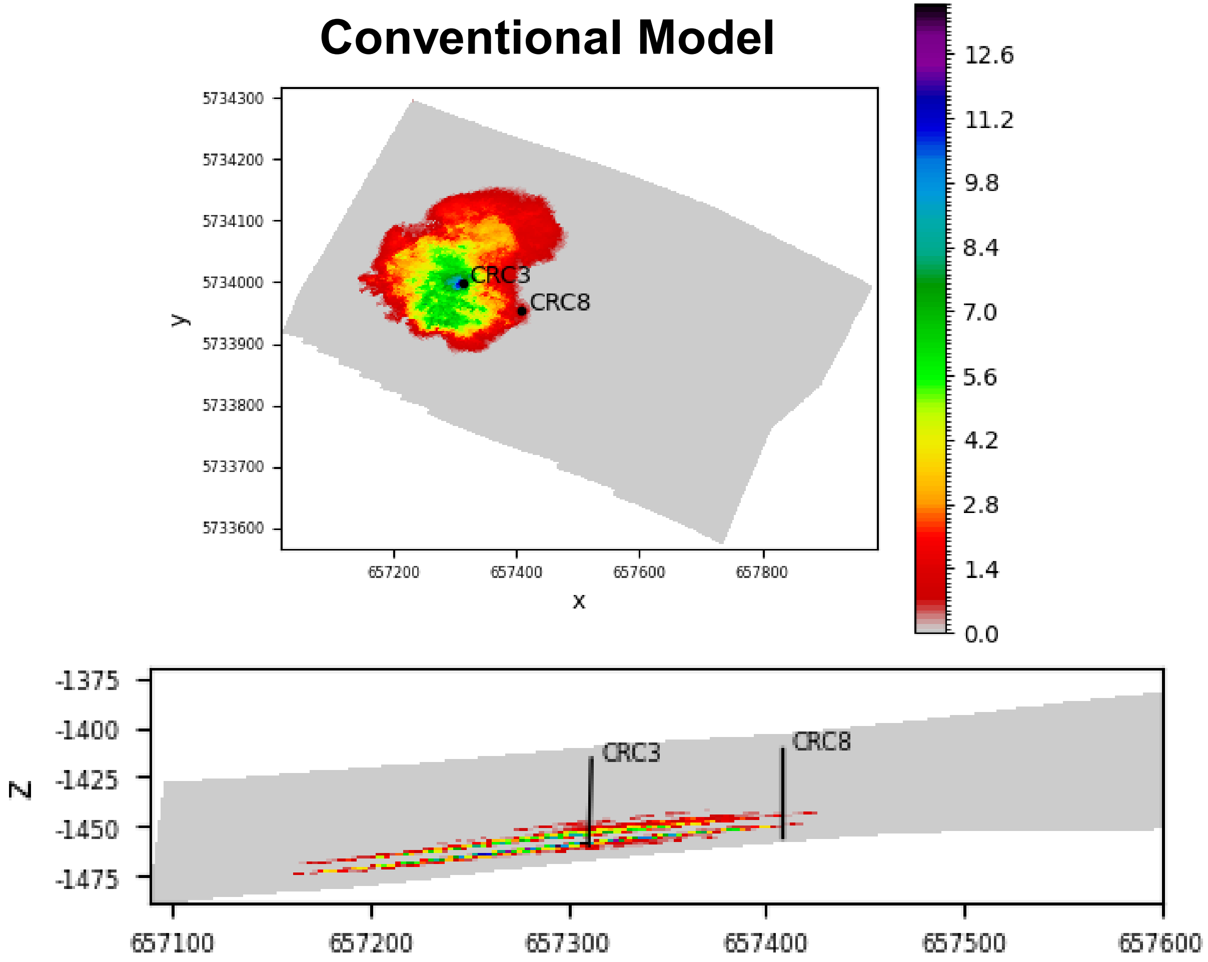
GFV geomodel with clipped geological and dynamic modeling areas. Blue region indicates the initial geological model domain, and red region indicates dynamic model domain

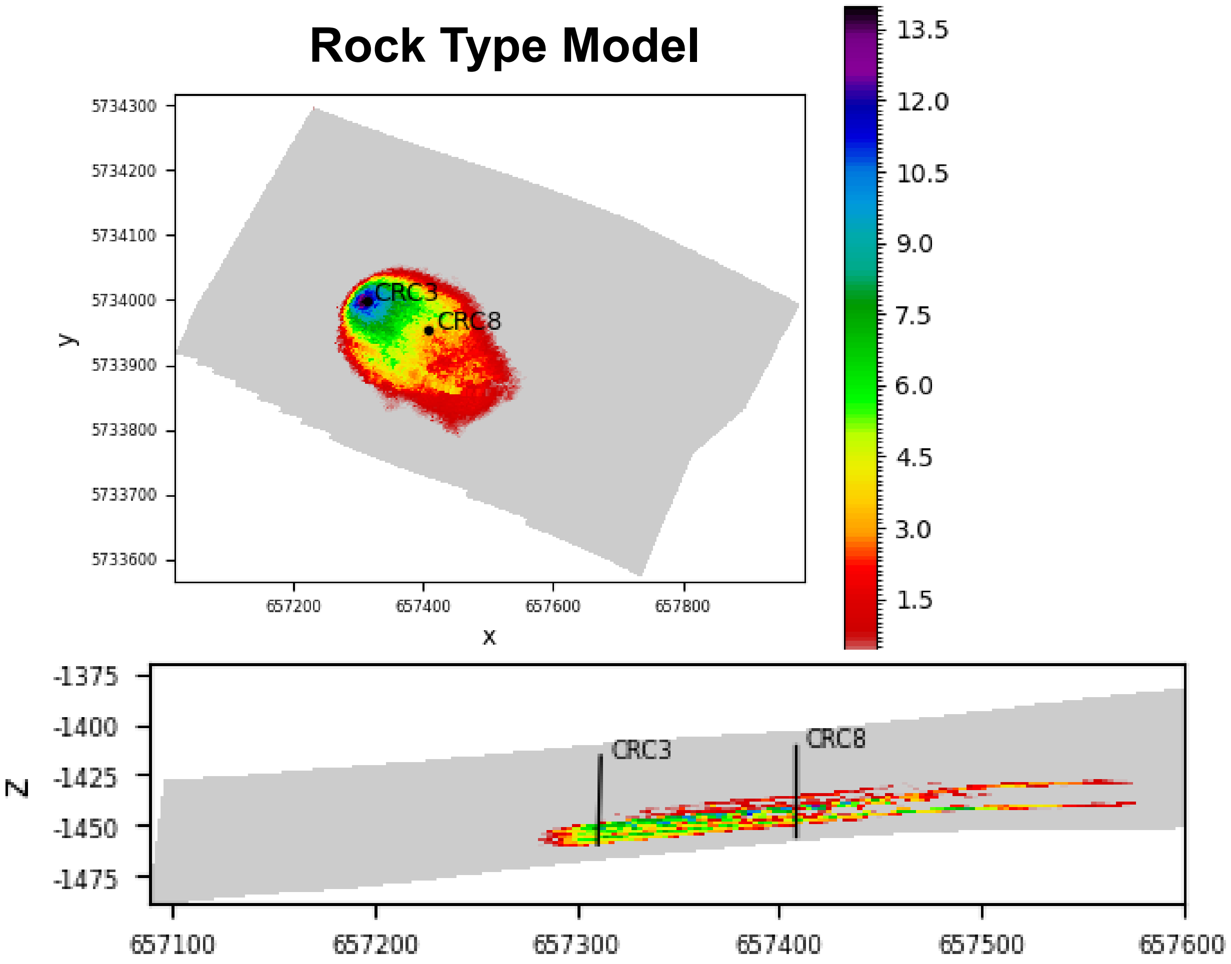
- Model setup and options

  Grid : 4.5×10^6 active cells of size 3.3 m x 3.3 m x 0.3

  Fluid model : two-component two-phase formulation compatible with Eclipse 300 CO2STORE

Plume Migration at the End of Injection

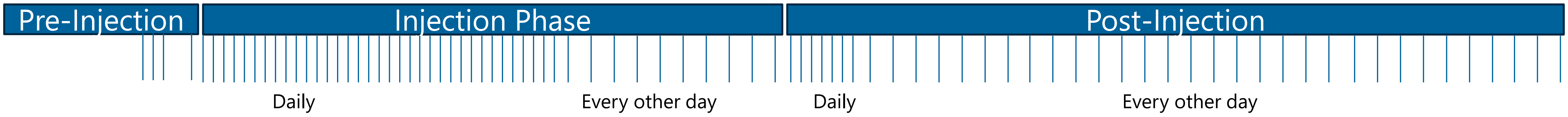




GeoCquest CO2CRC BUILDING A LOW EMISSIONS FUTURE Stanford University THE UNIVERSITY OF MELBOURNE GeoCquest ExxonMobil bp BHP Chevron

PNL (SLB Pulsar Tool) Logs Will Be Used to Track Saturations During Injection and Trapping Phases of the GFV

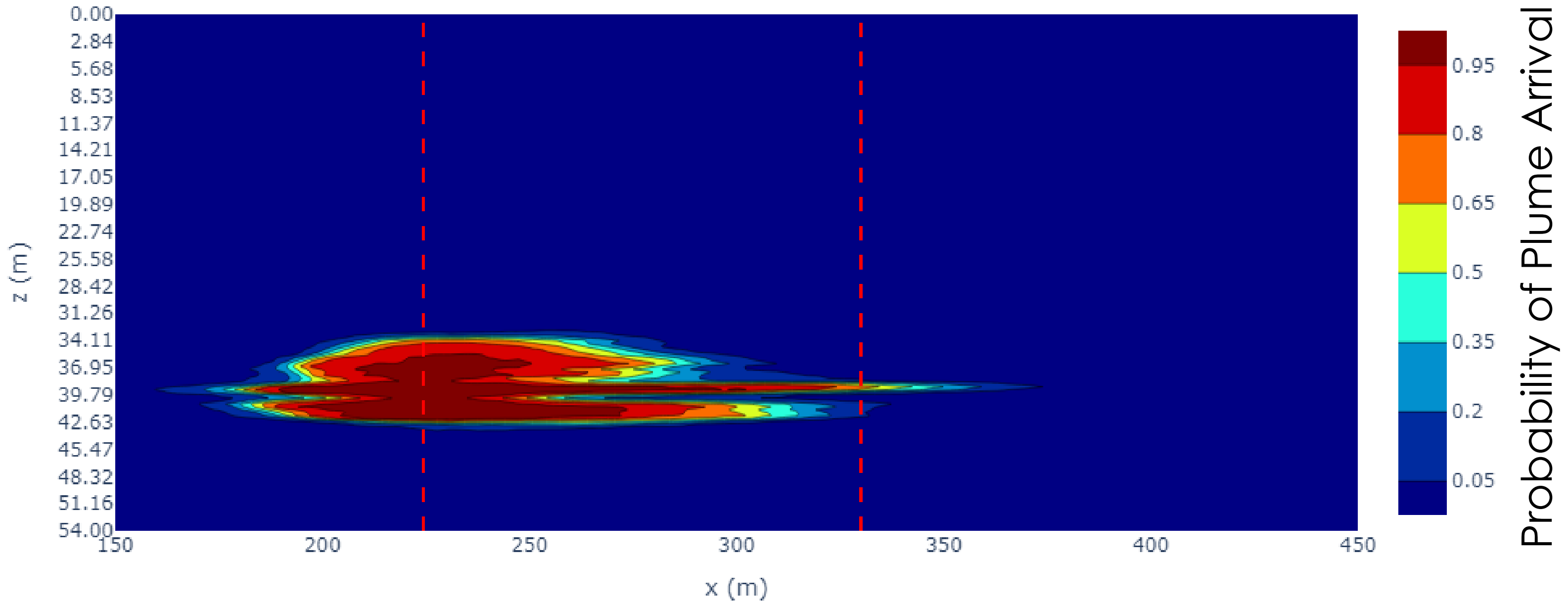
- **Purpose-built passive monitoring well** for PNL and Distributed Acoustic Sensors
- Plan for sampling frequency during 70-day injection period
  - Baseline acquired prior to CO_2 injection (multiple passes to establish optimal logging parameters and high-quality baseline)
  - Daily until the plume arrives at CRC-8
  - Reduce logging rate to once every two days if the CO_2 saturation stabilizes
- Plan for sampling frequency during the 3-month post-injection period
  - Daily for the week after injection stops
  - Twice per week until the end of the experiment



CO2CRC Building a low emissions future · Stanford University · The University of Melbourne · GeoCquest · ExxonMobil · bp · BHP · Chevron

CCSNet.ai*: Machine-Learning Model for Fast Prediction and Optimization

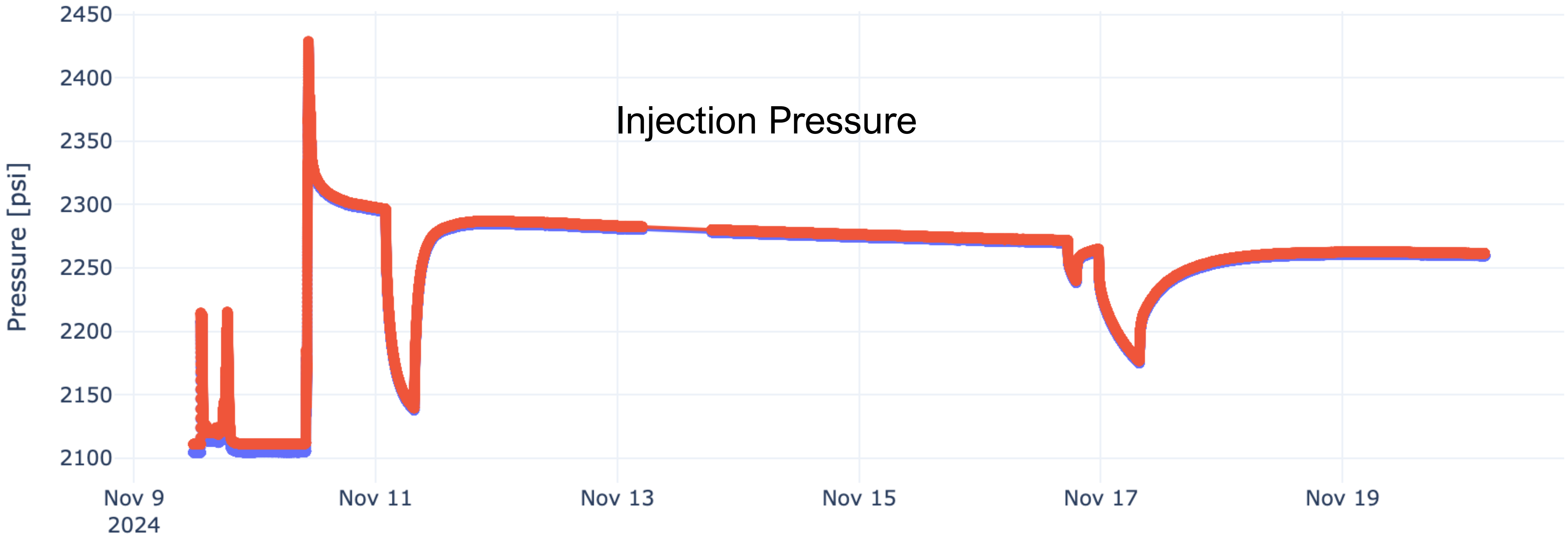
- Provides **full-physics** multiphase flow simulation predictions with high resolution and comparable accuracy to numerical simulation
- Results in **80,000 x** average speed up in runtime



*Wen, G., Li, Z., Long, Q., Azizzadenesheli, K., Anandkumar, A., & Benson, S. M. (2023). Real-time high-resolution CO_2 geological storage prediction using nested Fourier neural operators. *Energy & Environmental Science*, *16*(4), 1732-1741.

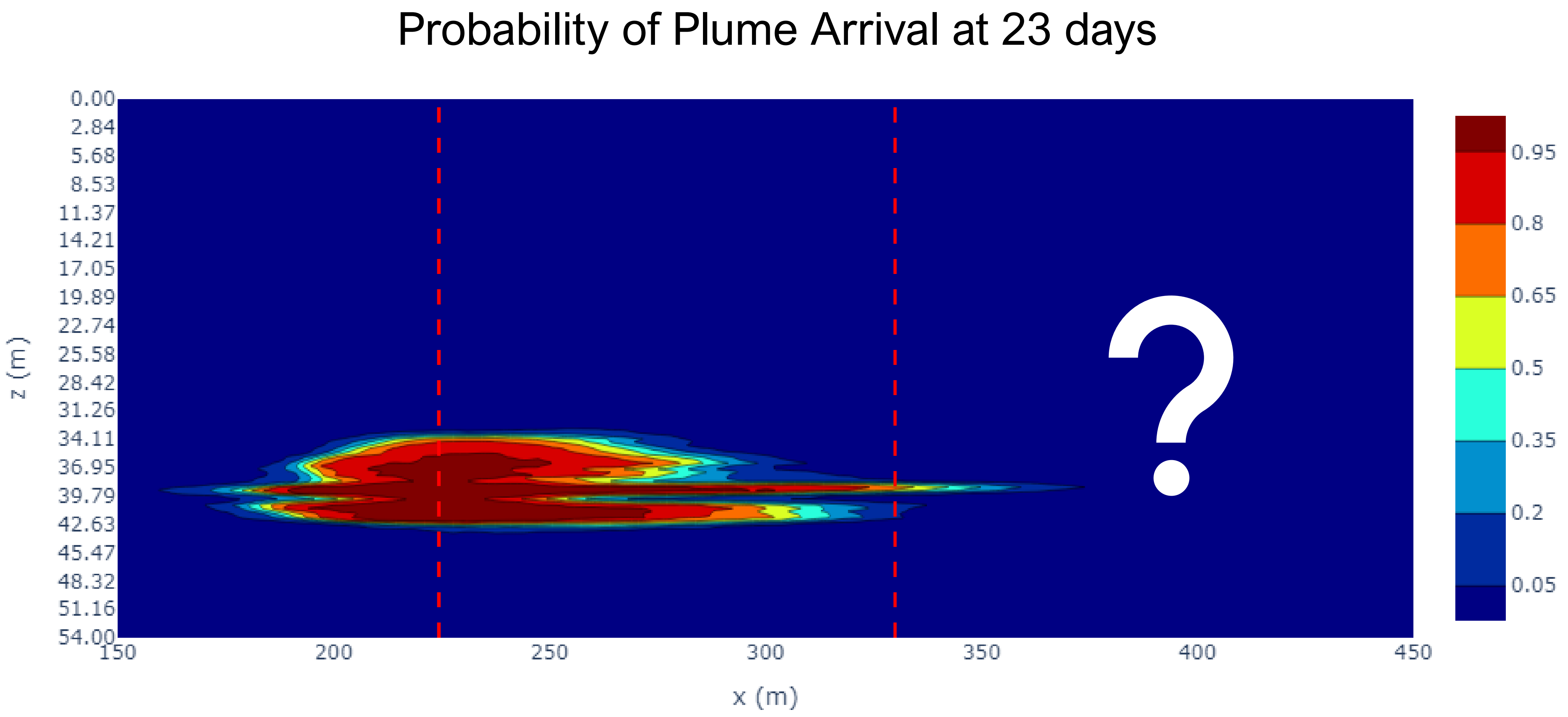
The Experiment Has Begun!

- Injection began first week of November 10 at 140 tonnes/day
- Injection through mid-January
- Post-closure monitoring through March



co2crc Building a low emissions future
Stanford University
The University of Melbourne
GeoCquest
ExxonMobil
bp
BHP
Chevron

What’s Next?



co2crc Building a low emissions future · Stanford University · The University of Melbourne · GeoCquest · ExxonMobil · bp · BHP · Chevron

Talks Coming Up About GFV Experiment

- **Oleg Volkov**: Simulation of GFV models using GEOS
- **Catherine Callas**: Probabilistic plume migration prediction using ML
- **Aman Raizada**: Pulsed-Neutron Logging for gas saturation monitoring in highly heterogeneous rock formations
- **Catherine Spurin**: GeoCquest Field Validation project: the role of heterogeneity of CO_2 trapping in core scale experiments

Thank you to our Partners and Sponsors