Models for Production vs. Storage

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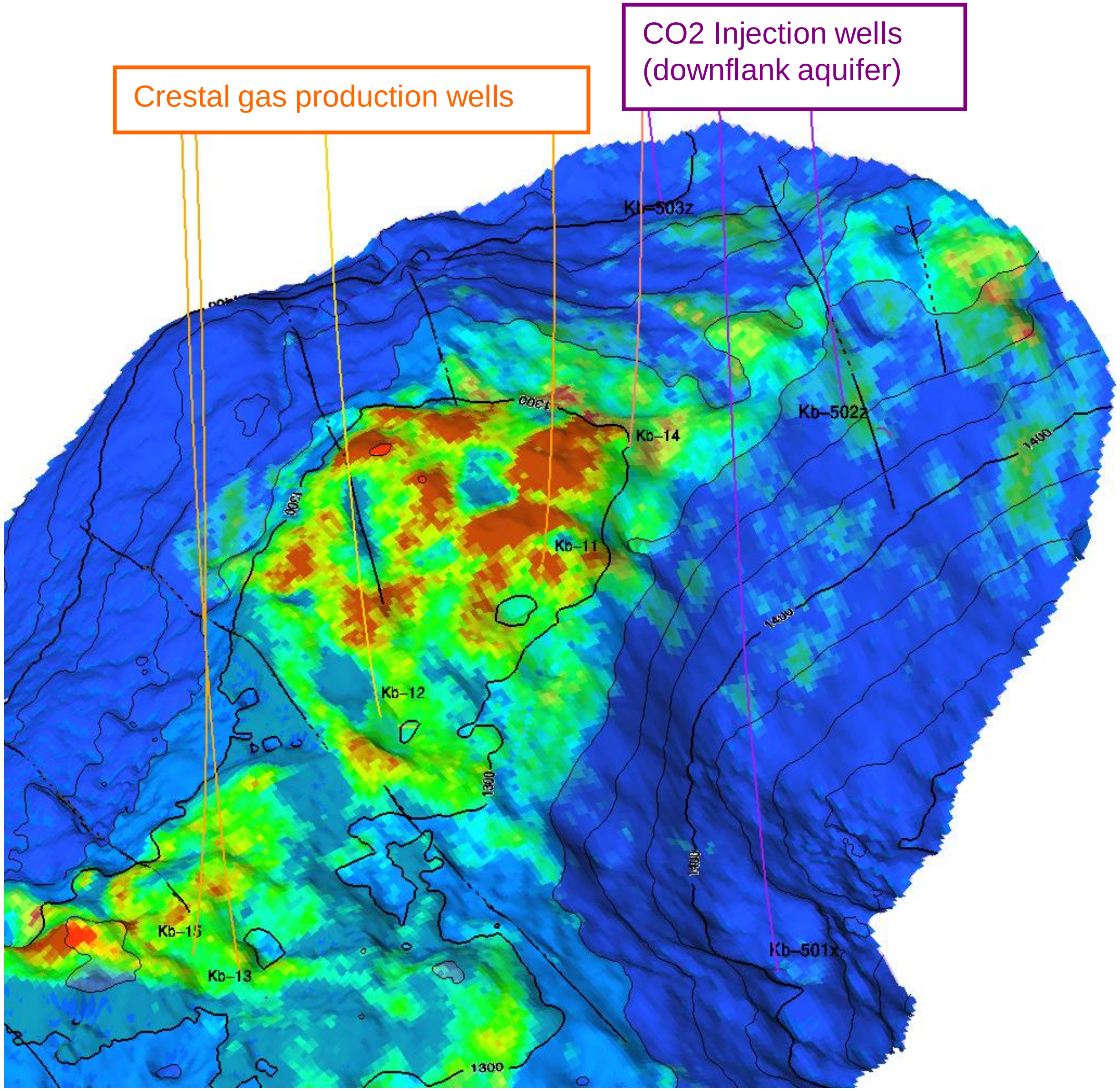
TRACS & Heriot-Watt

with Phil Ringrose (NTNU),
Gillian Pickup & Eric MacKay (Heriot Watt)

DEVEX
June 2021

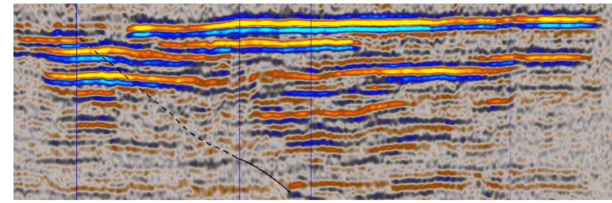
“We need a model for CO_2 injection”

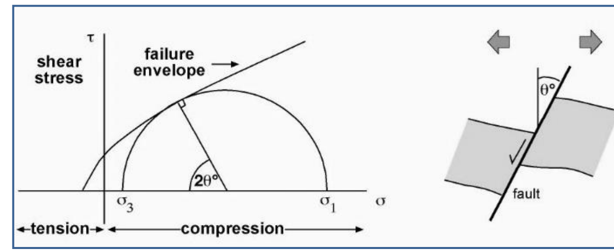


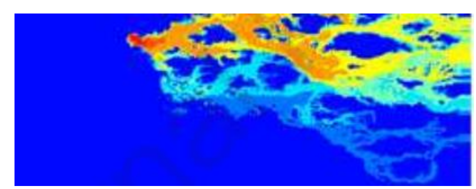
So what’s missing?

Models for Storage vs. Production

Study volume	*It's bigger*
Geomechanics	*Side-burns*
Fluids	*Supercritical*
Physics & Chemistry	*The Force*
Lost Heterogeneity	*Friend or foe?*
Monitoring	*Happy ever after*
Presentation	*Better be careful*



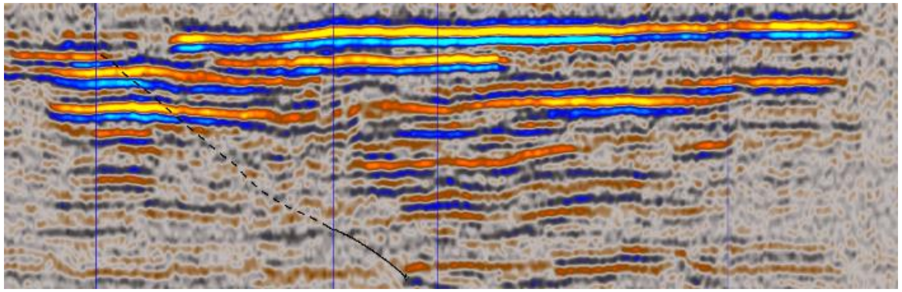




Models for Production vs. Storage

STUDY VOLUME

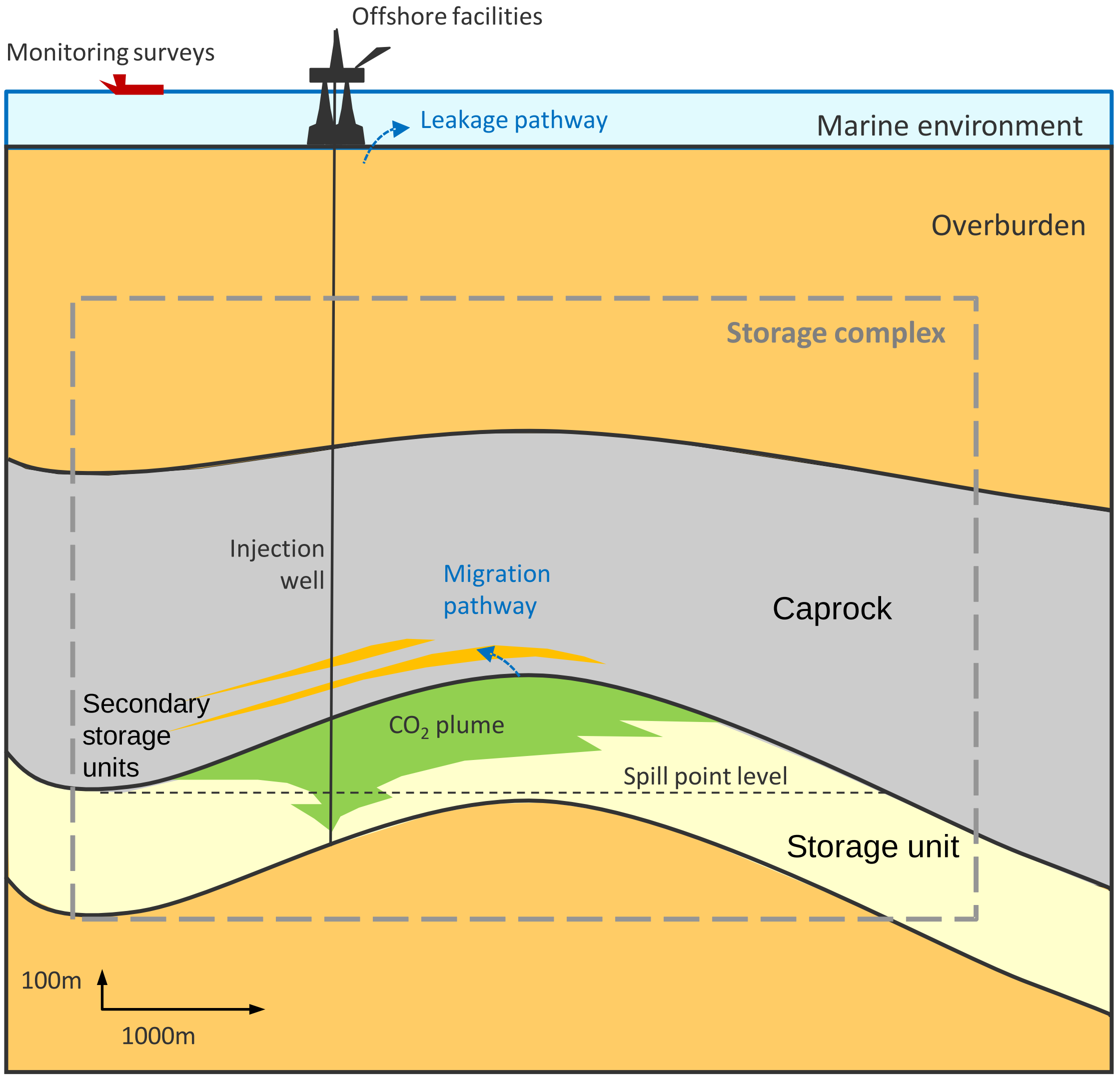
It’s bigger



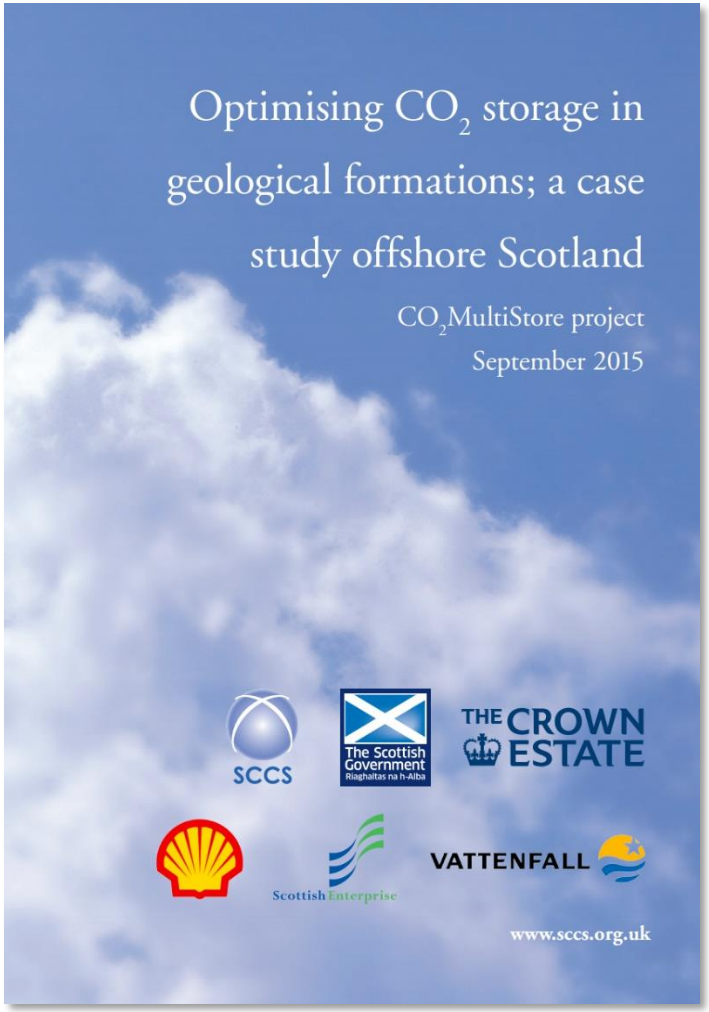
The ‘Storage Complex’

EU CCS Directive (EC 2009; annex 1):

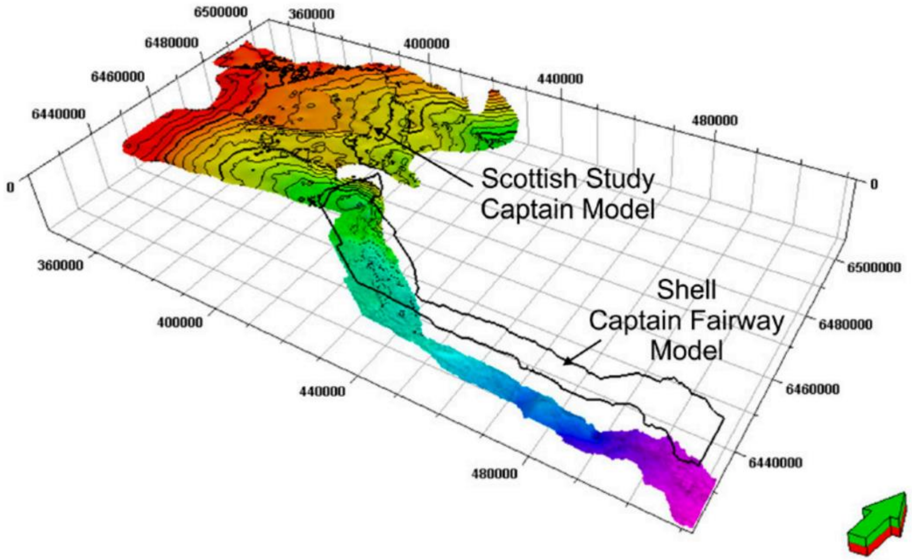
“Sufficient data shall be accumulated to construct a volumetric and 3-D static earth model for the storage site and storage complex, including the caprock, and the surrounding area, including the hydraulically connected areas”



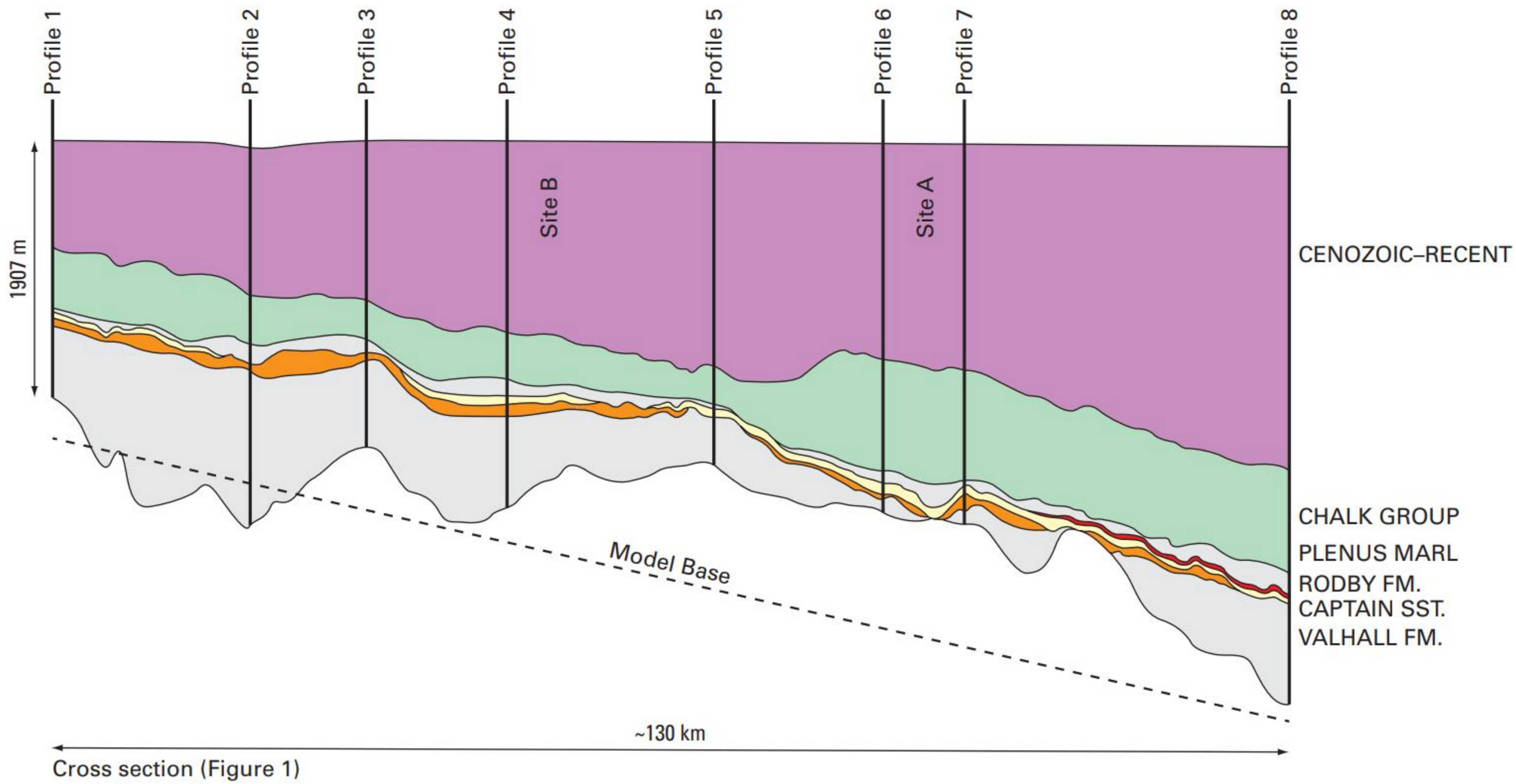
Storage Volume



360 MT CO_2 over 35 years



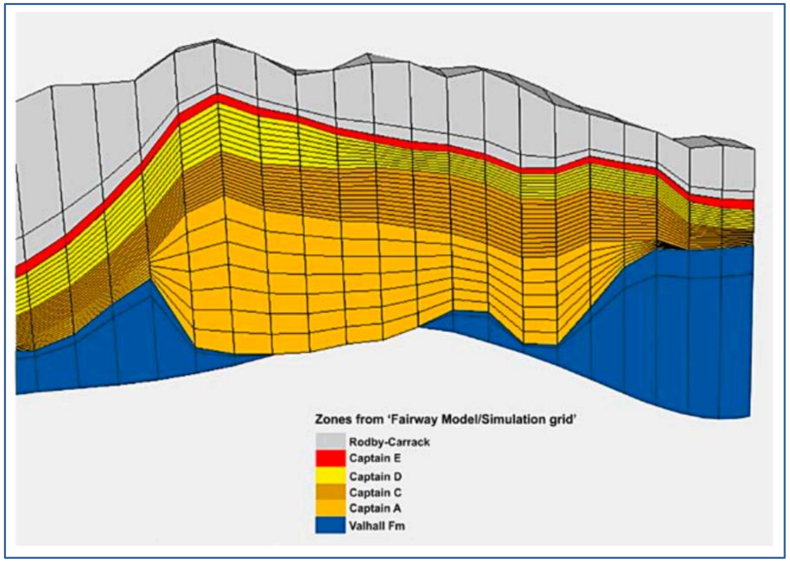
Multi-store model for geomechanics



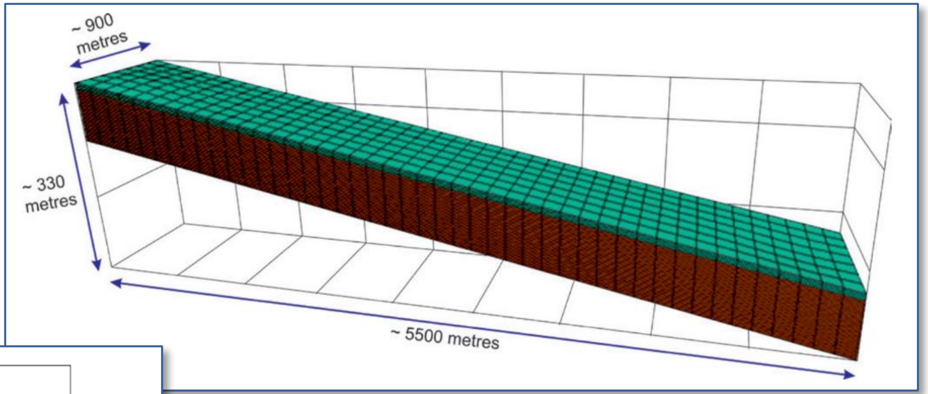
… large scale dynamic models

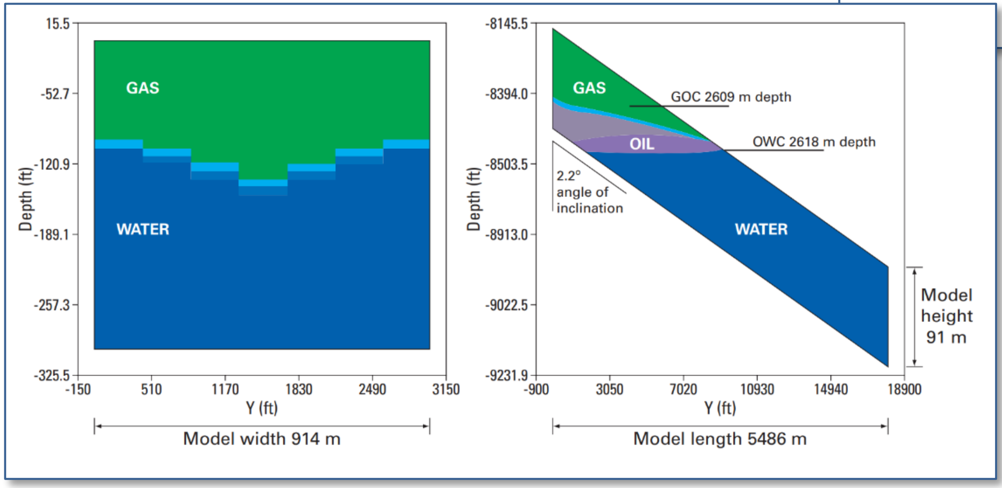
… with most of the action happening away from the drill centres

The requirement for multi-scale modelling



Injection site static model (all sands)





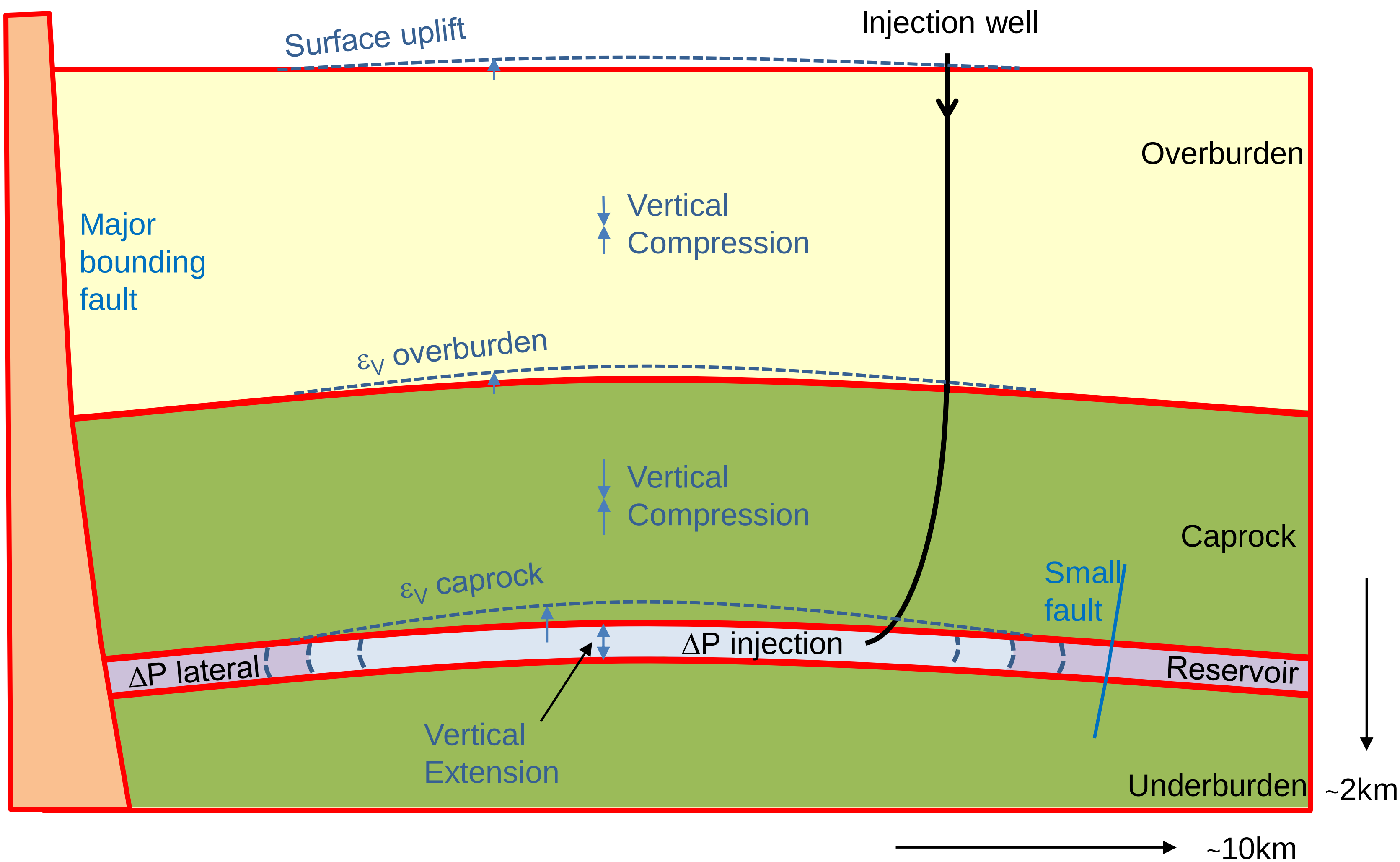
Captain D/E sand box model

Models for Production vs. Storage

GEOMECHANICS

Sideburns

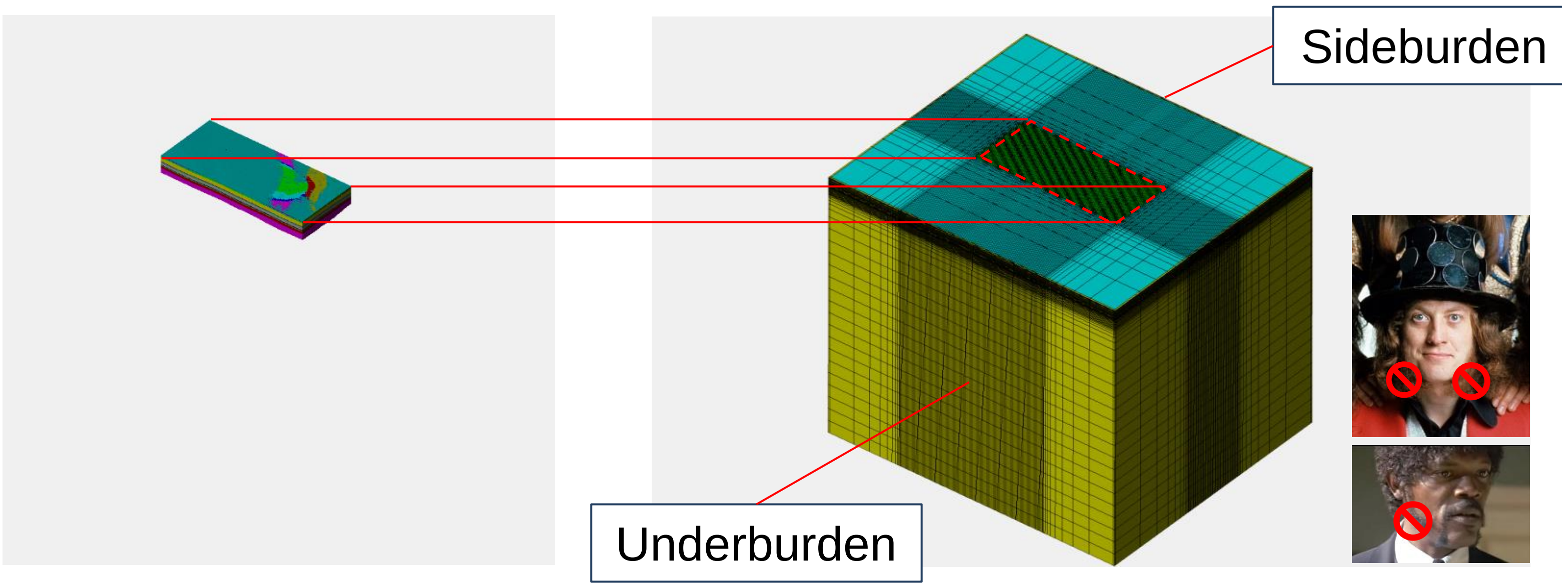
Geomechanics



Building a 3D geomechanical model

Start with a normal grid

Add geomechanical boundary elements



H1:V1 scaling

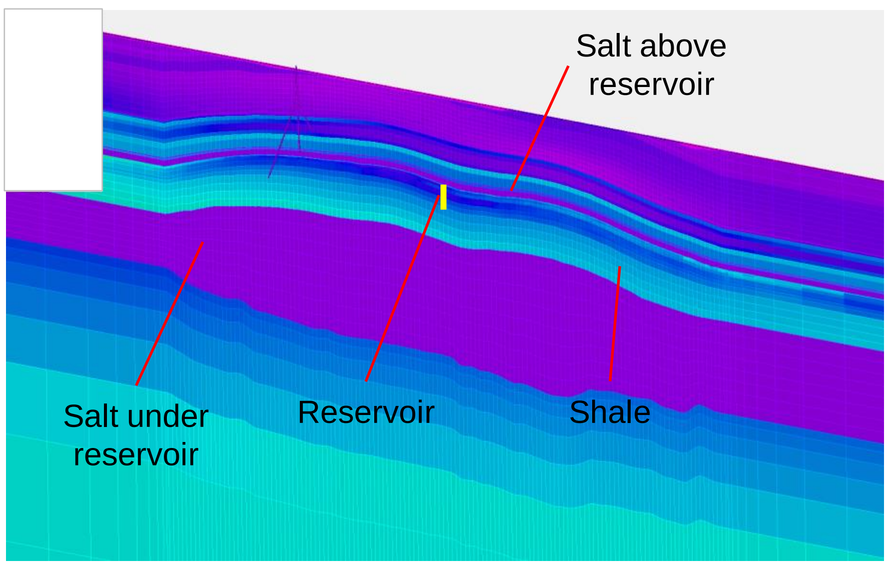
Cellular modeling – different properties

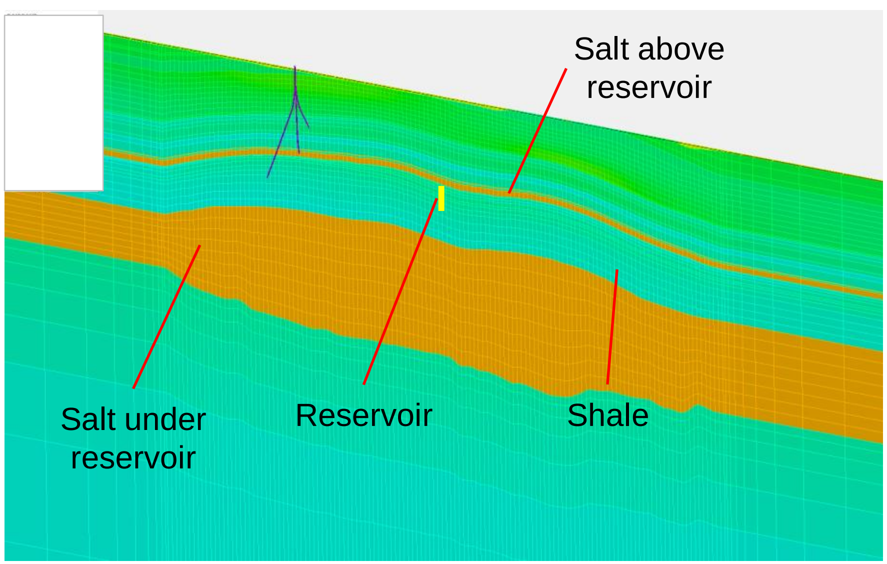
Upscaled from logs with core calibration

(or derive from seismic attributes, but will be dynamic)

Young's Modulus

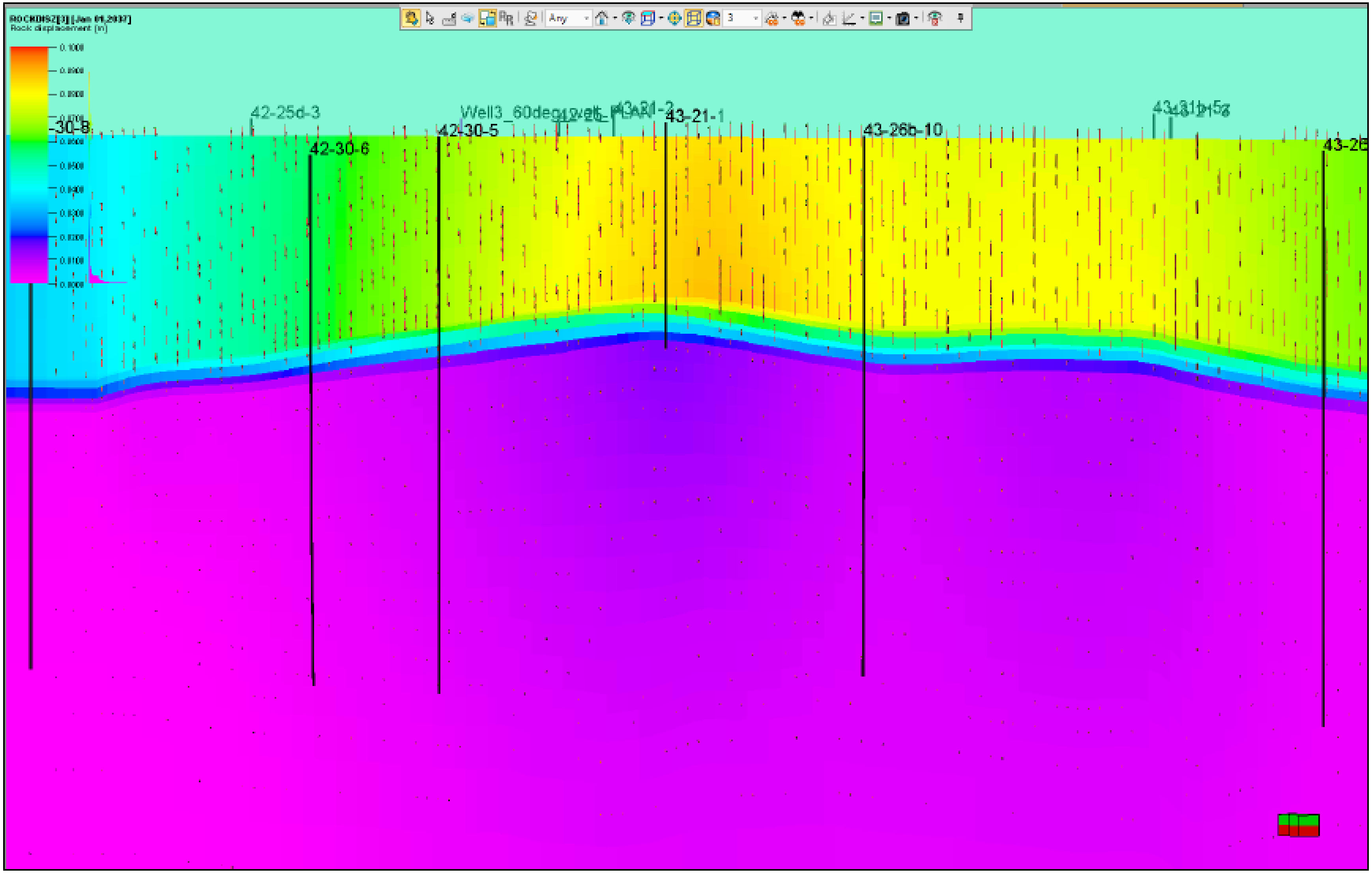
Poisson's Ratio





H1:V3 scaling

Geomechanics – modelled vertical uplift



From White Rose K43 Technical Report 2016

Geomechanics – extras needed for modelling storage

Accurate measurements of in-situ stress, elastic moduli & rock strength

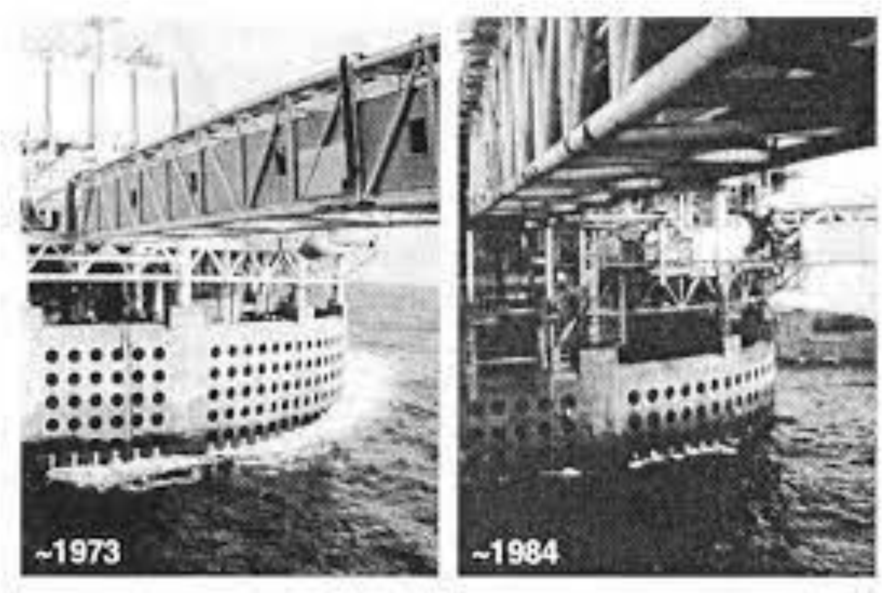
Model appropriate timesteps – not too fine, not too coarse

Two way coupling.

Update properties (perm, elastic moduli …) with each time step

Explicit induced fracture models, thermal effects – especially near wellbore and/or short timeframes.
Sector models are our friend

Not generally required for production



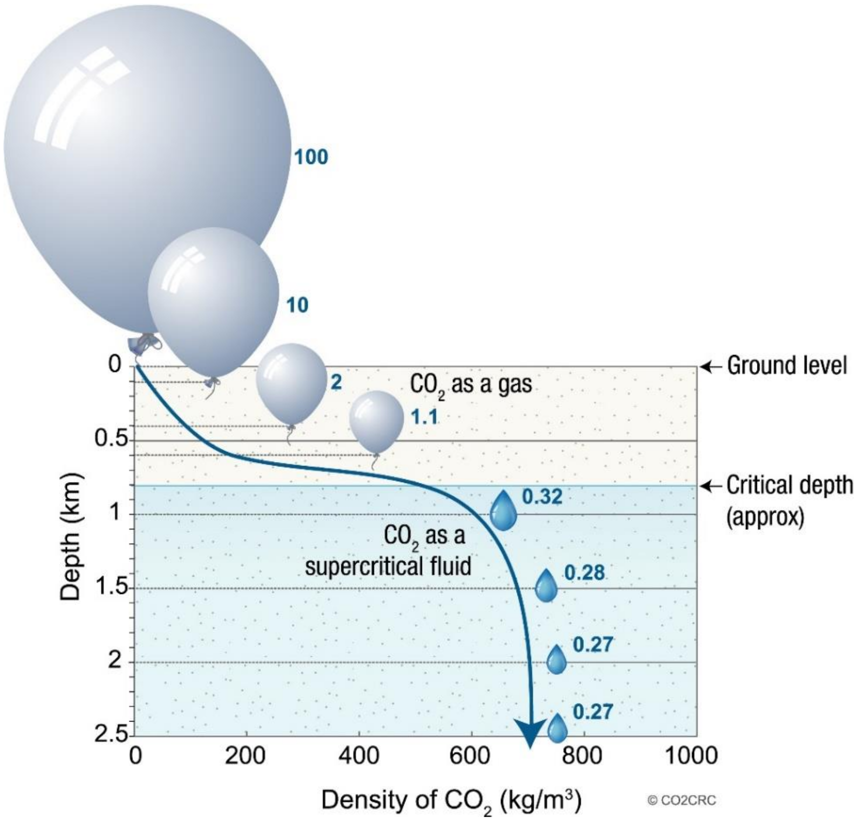
… or maybe they were

Models for Production vs. Storage

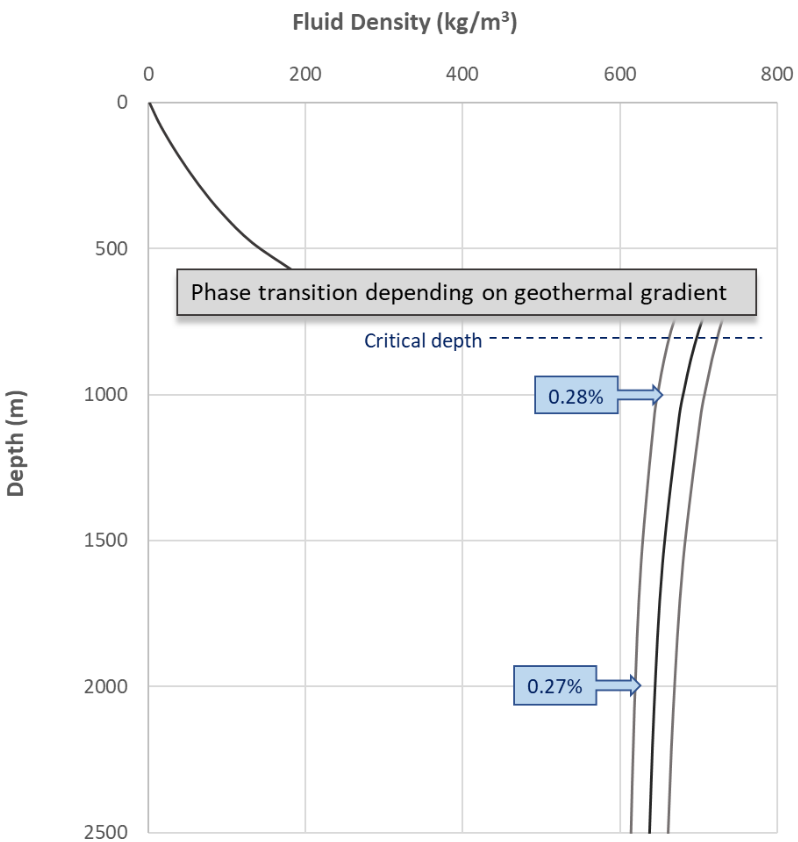
FLUIDS

Supercritical

Fluids



It's not gas (for long)



Post-carbon volumetrics

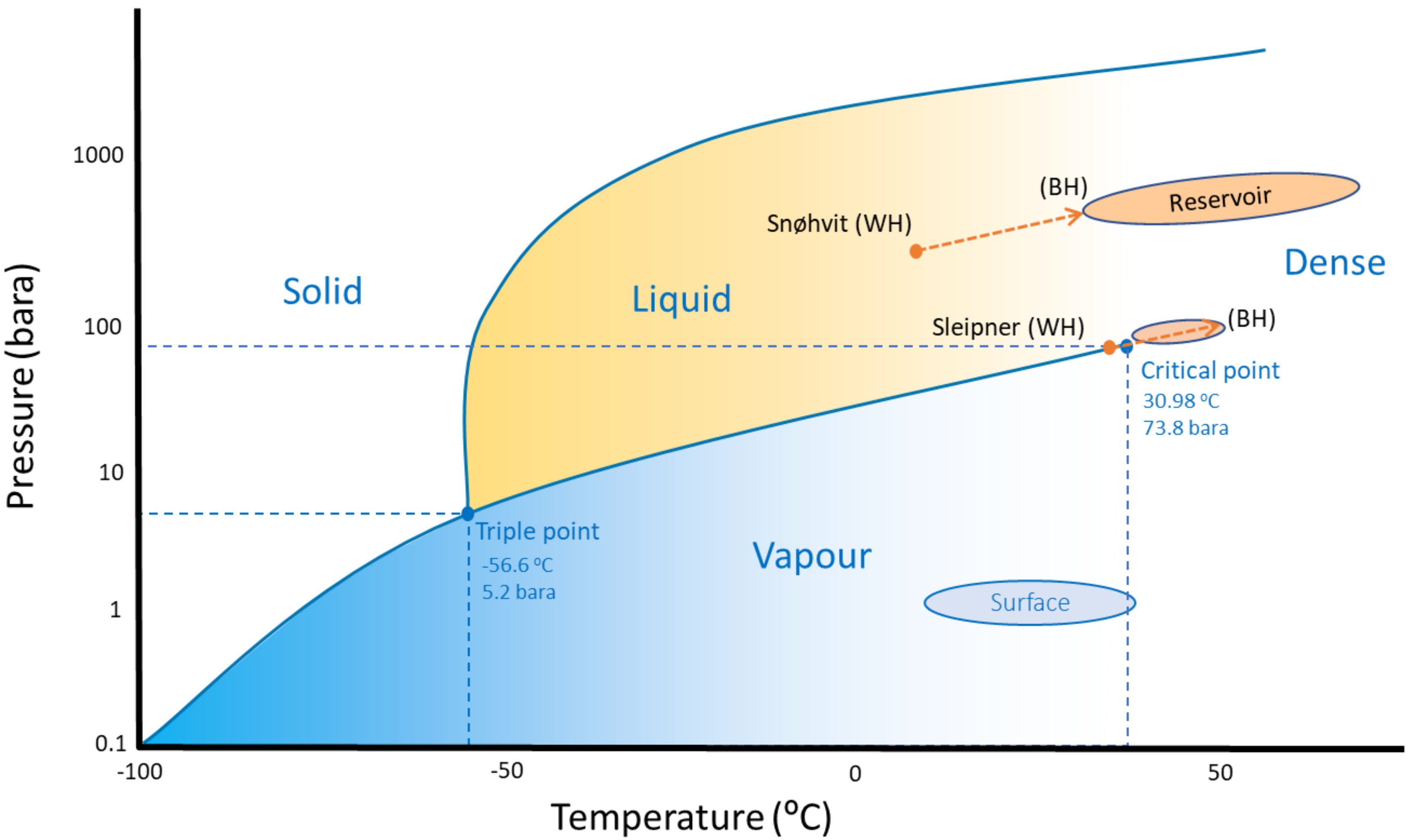
Fluids – mass rather than volume (so we talk tonnes) ….

What's a 1000 tonnes of CO_2?

At standard conditions (ISA) (1.013 Bar & 15^{o}C)

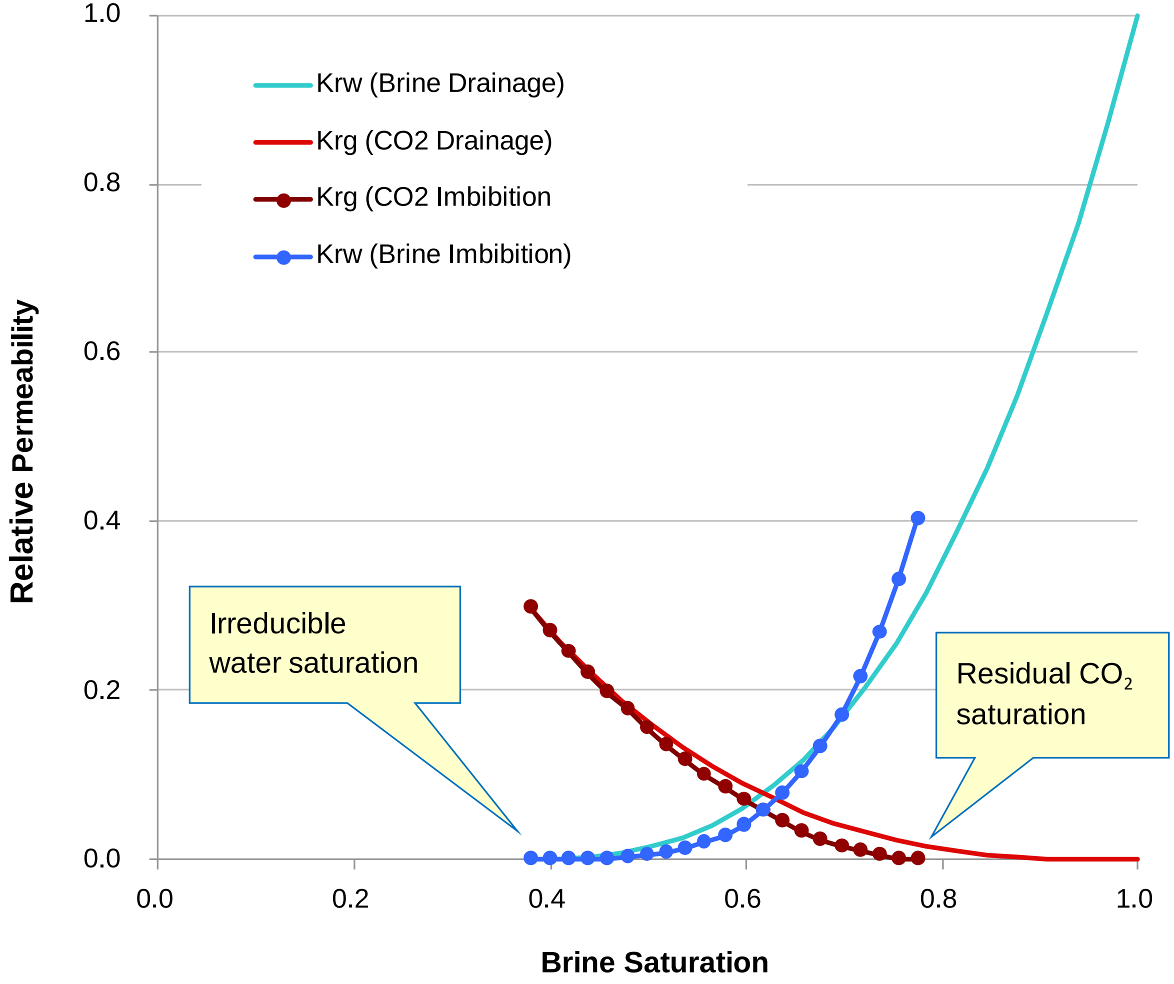
- 1 m^3 of CO_2 has a mass of 1.87 kg
- 1bscf = 28.32 $x10^6$ m^3
- Mass of 1Bscf = 52959.5 tonnes
- Mass of 1MMscf = 52.96 tonnes
- So a single well injecting 20 MMscf per day is injecting about 1000 tonne of CO_2 per day

Fluid PVT



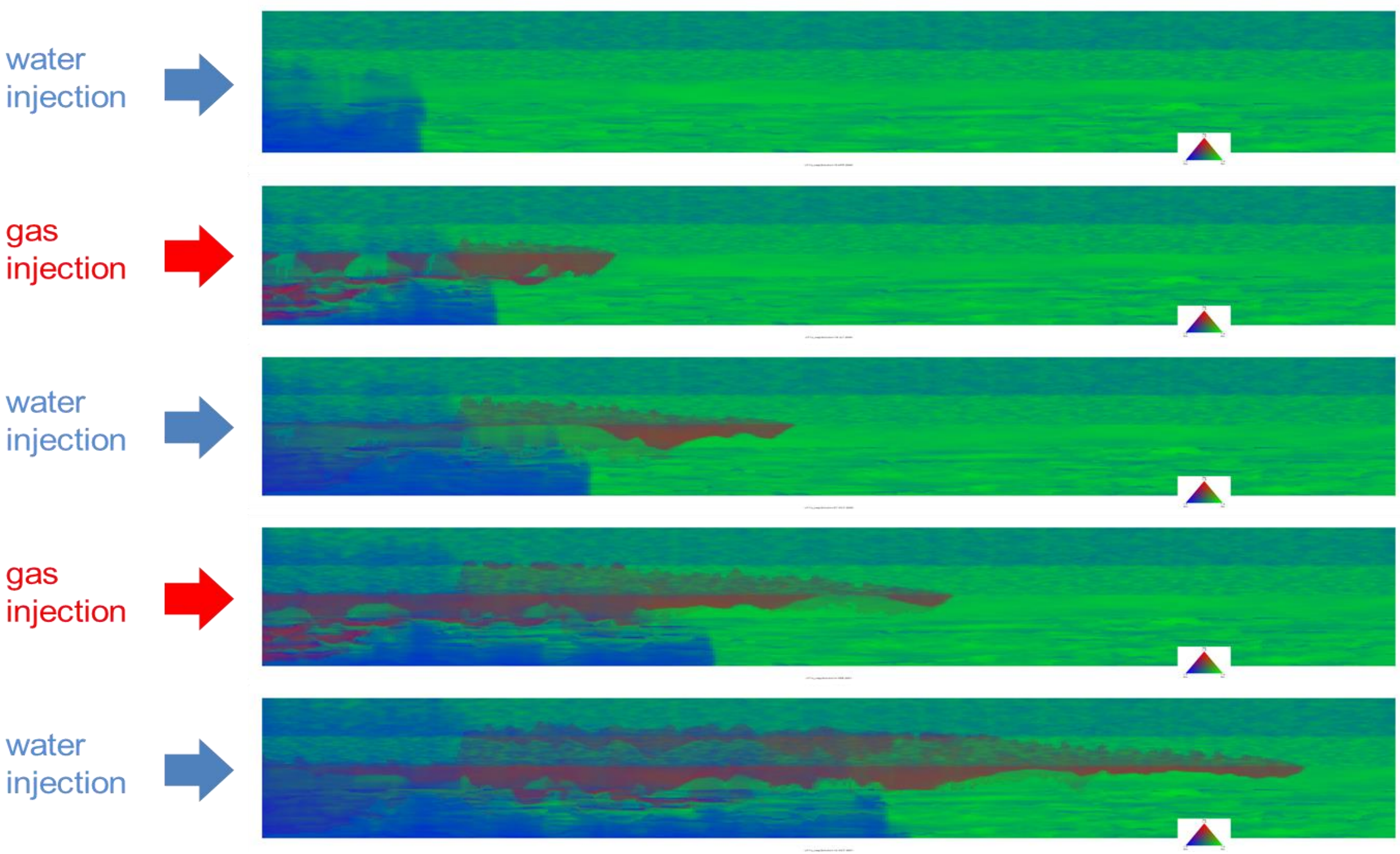
Pressure (bara)
1000
100
10
1
0.1
-100
-50
0
50
Temperature (°C)
Solid
Liquid
Vapour
Dense
Snøhvit (WH)
(BH)
Reservoir
Sleipner (WH)
(BH)
Critical point
30.98 °C
73.8 bara
Triple point
-56.6 °C
5.2 bara
Surface

Fluids



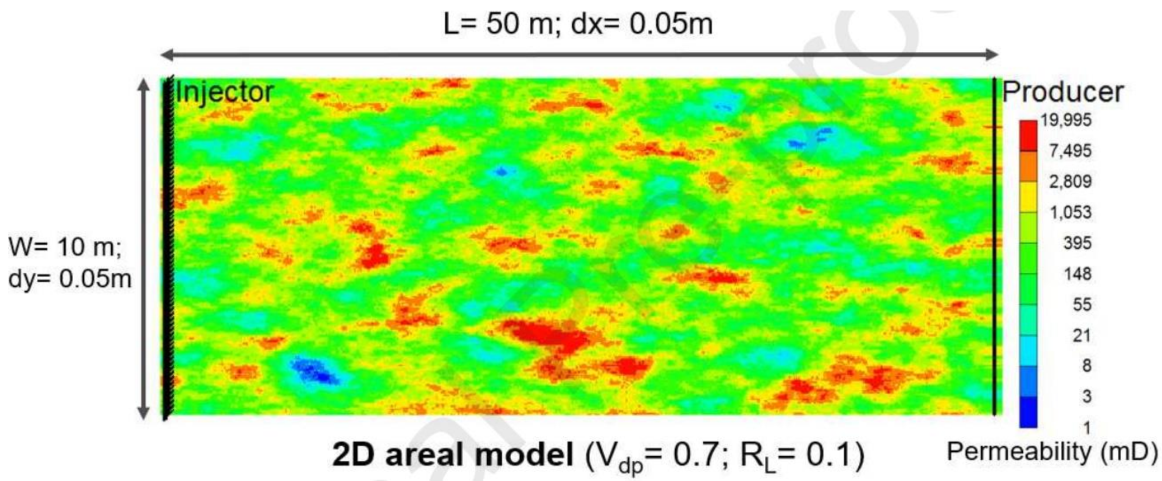
1.0
0.8
0.6
0.4
0.2
0.0
Relative Permeability
Krw (Brine Drainage)
Krg (CO2 Drainage)
Krg (CO2 Imbibition
Krw (Brine Imbibition)
Irreducible
water saturation
Residual CO2
saturation
0.0
0.2
0.4
0.6
0.8
1.0
Brine Saturation

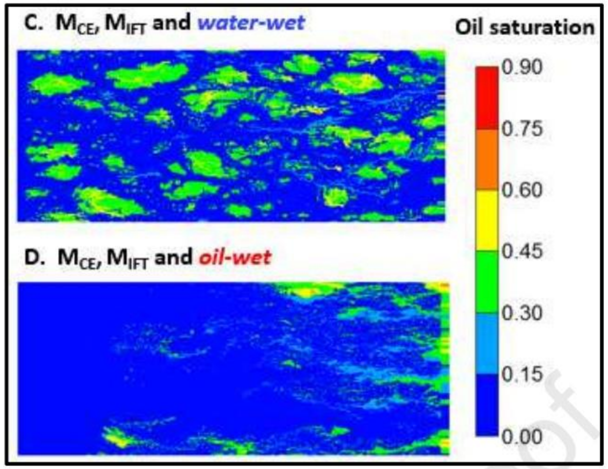
Truth models for complex multiphase flow

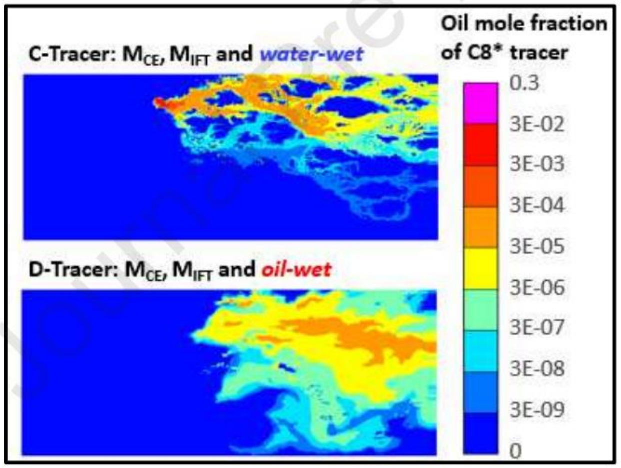


Ed Stephens, TRACS

CO2 for CCUS







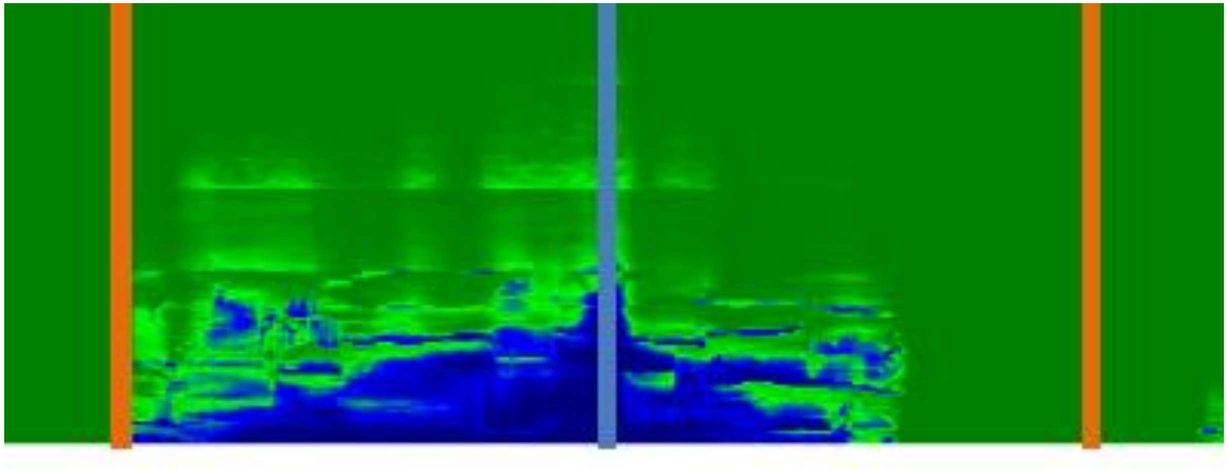
Wang, Pickup, Sorbie, Mackay & Skauge, 2021

Critical order of magnitude perm contrasts – Flora plus

Injection of a low viscosity fluid (CO_2) into a higher viscosity fluid

Mobility ratio indicates unstable displacement

Inherently leads to viscous-fingering behaviour



" … to a much greater extent than we are familiar with in oil reservoirs as the viscosity contrast is more marked … "

Critical order of magnitude perm contrasts – Flora plus

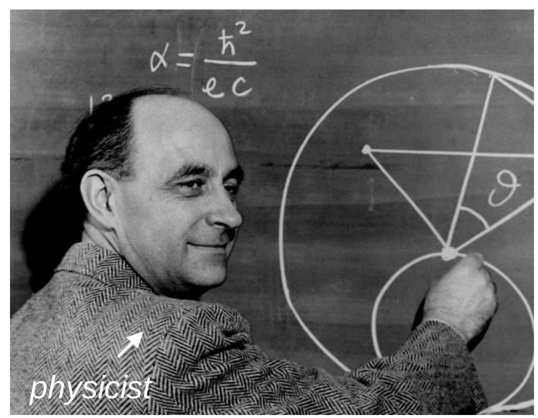
Critical permeability contrast	3 orders	2 orders	1 order		1/2 order ?
Fluid fill	dry gas	wet gas	light oil	heavy oil	aquifer, residual gas
Production mechanism	depletion (no aquifer)	depletion (with aquifer)	water injection	gas/steam injection	CO_2 injection

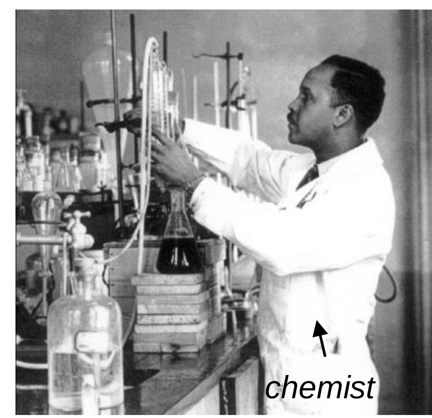
" … a much greater extent … "

Models for Production vs. Storage

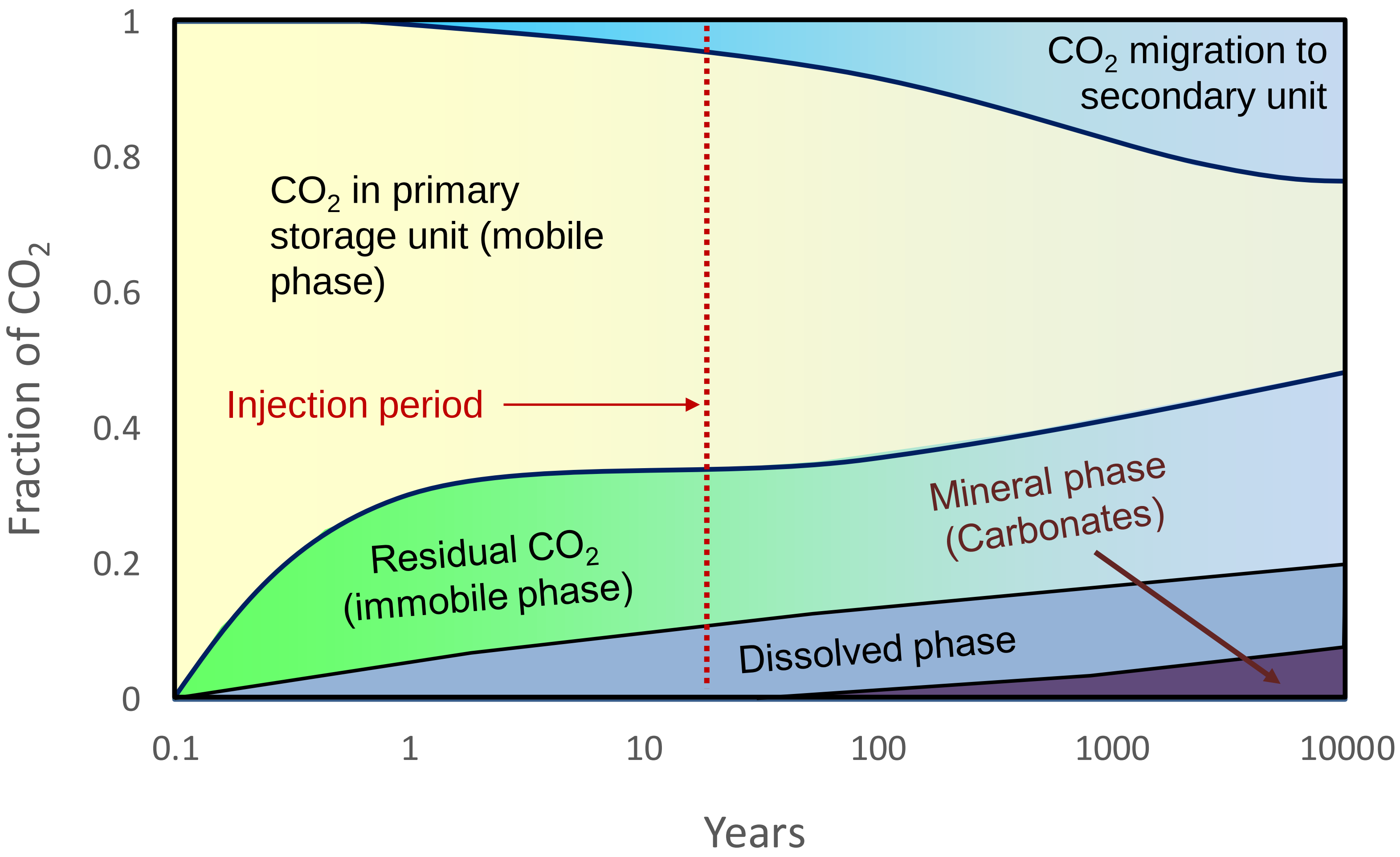
PHYSICS & CHEMISTRY

More thought required



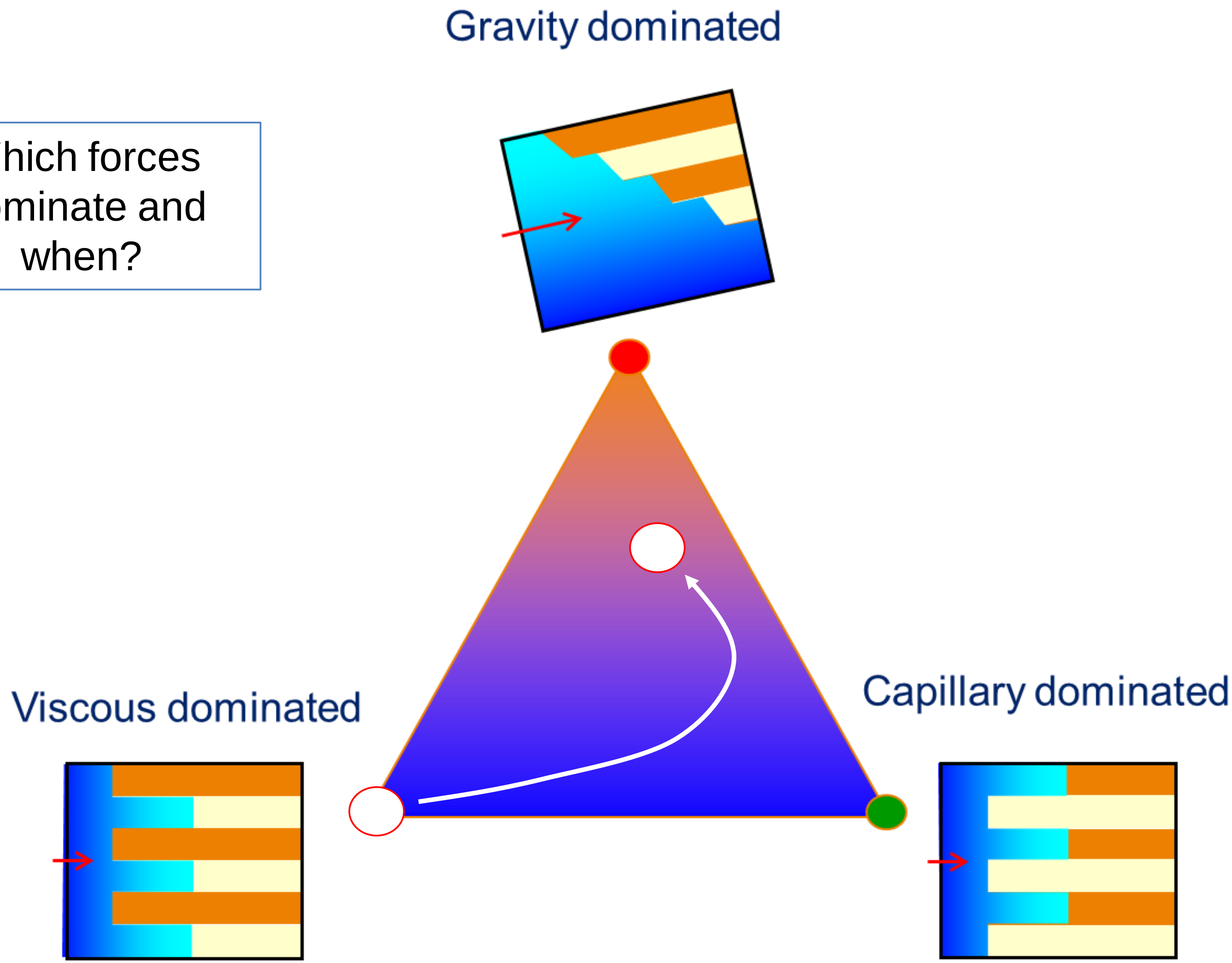


What physics, what chemistry?

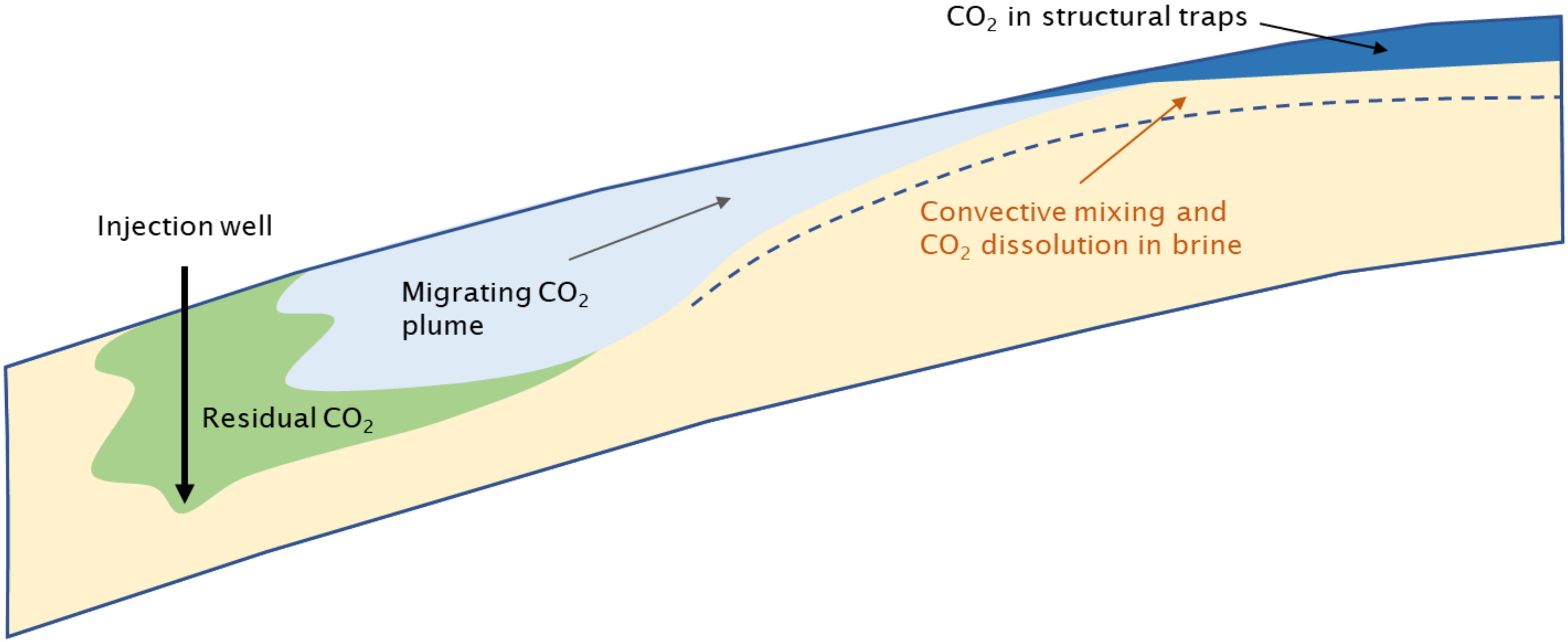


Physics – balance of forces

Which forces dominate and when?



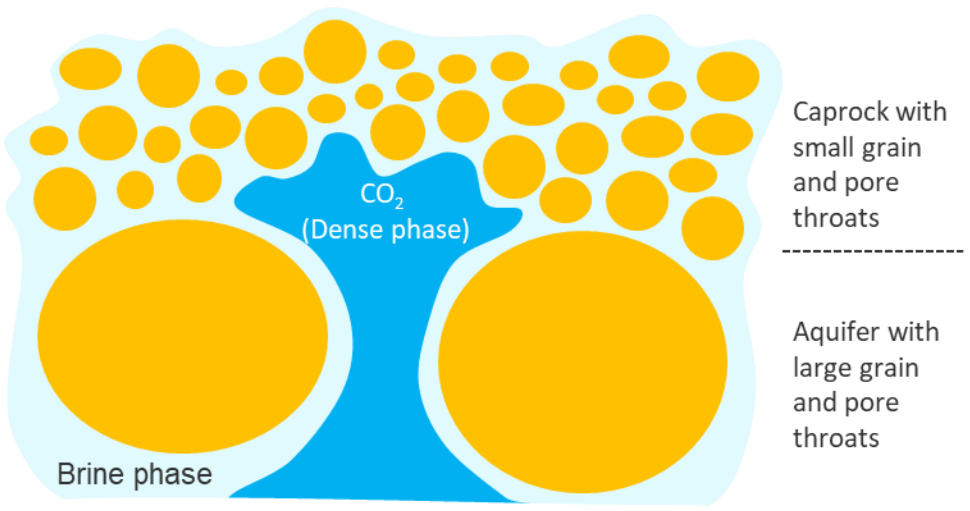
Capillary Effects

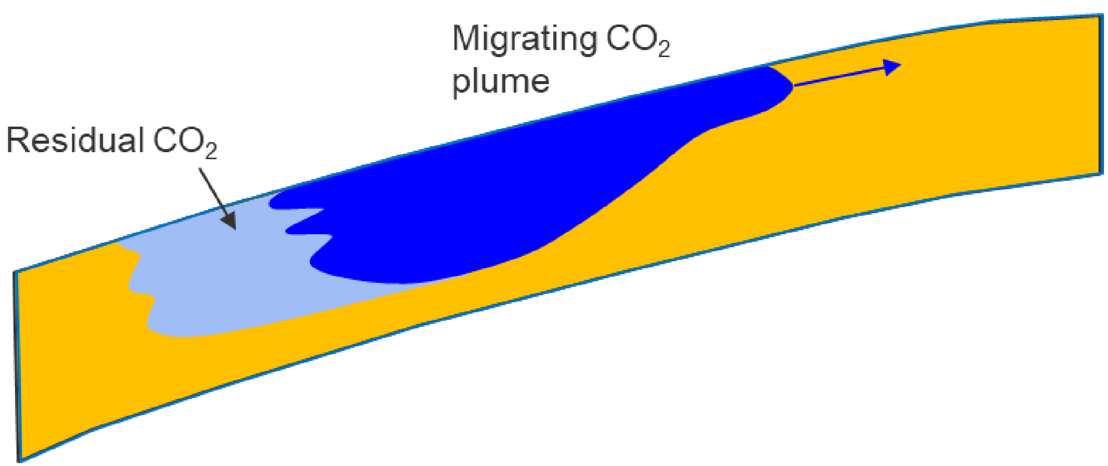


Capillary Effects

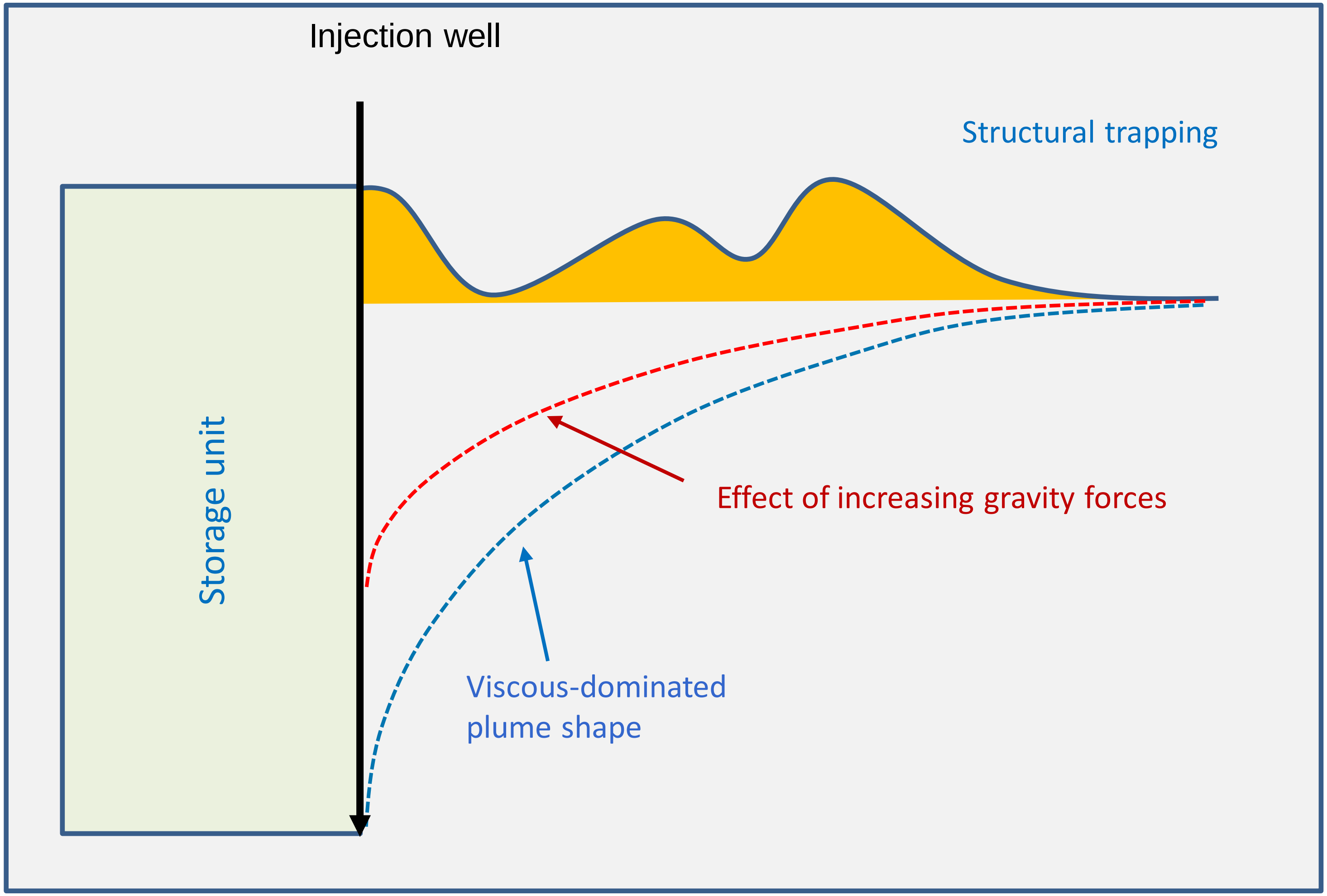
Capillary forces (interfacial tension) play an important role in trapping of CO_2:

- Both at the caprock interface (structural trapping)
- And as residual CO_2 (as the plume migrates upwards)





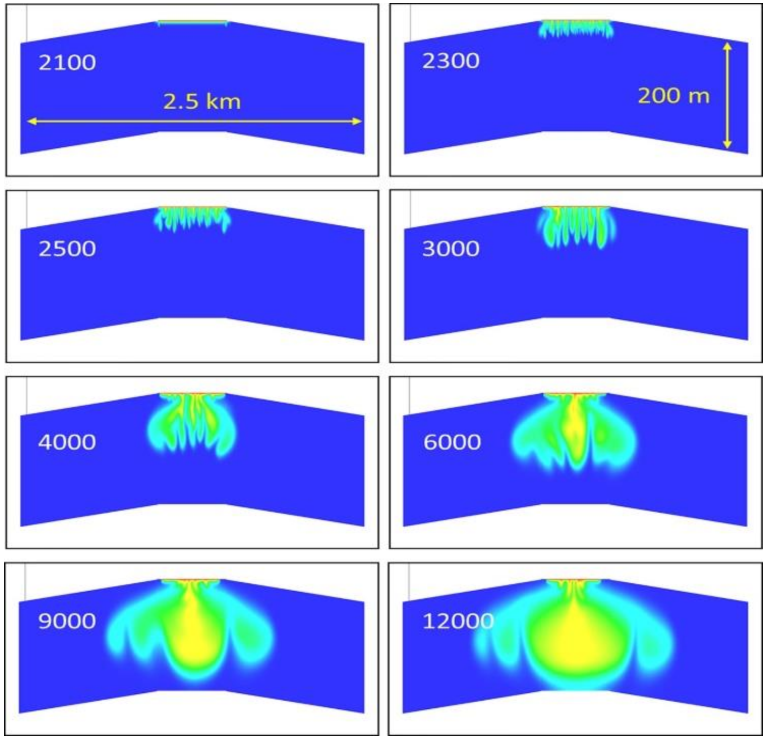
Balance of forces – plume shape



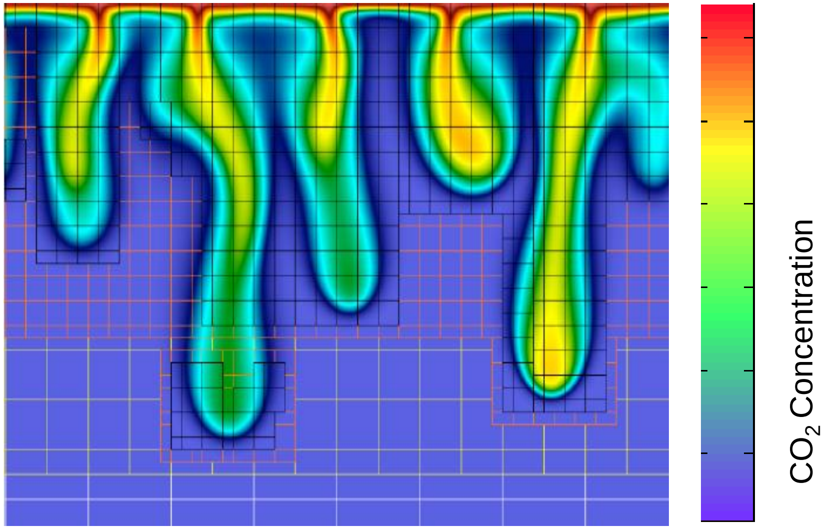
Chemistry – dissolution

Critical time (t_c) for onset of convection and the characteristic wavelength (λ_c) are estimated to be in the range of:

10 days < t_c < 2000 Years; 0.3 m < λ_c< 200 m *Riaz et al., 2006*



Density-driven flow in CO_2 storage in saline aquifer, Steve Furnival



Density-driven flow in CO_2 storage in saline aquifer, Pau et al, 2010.

Chemistry – gas mixing

Injected CO_2 remobilises residual methane

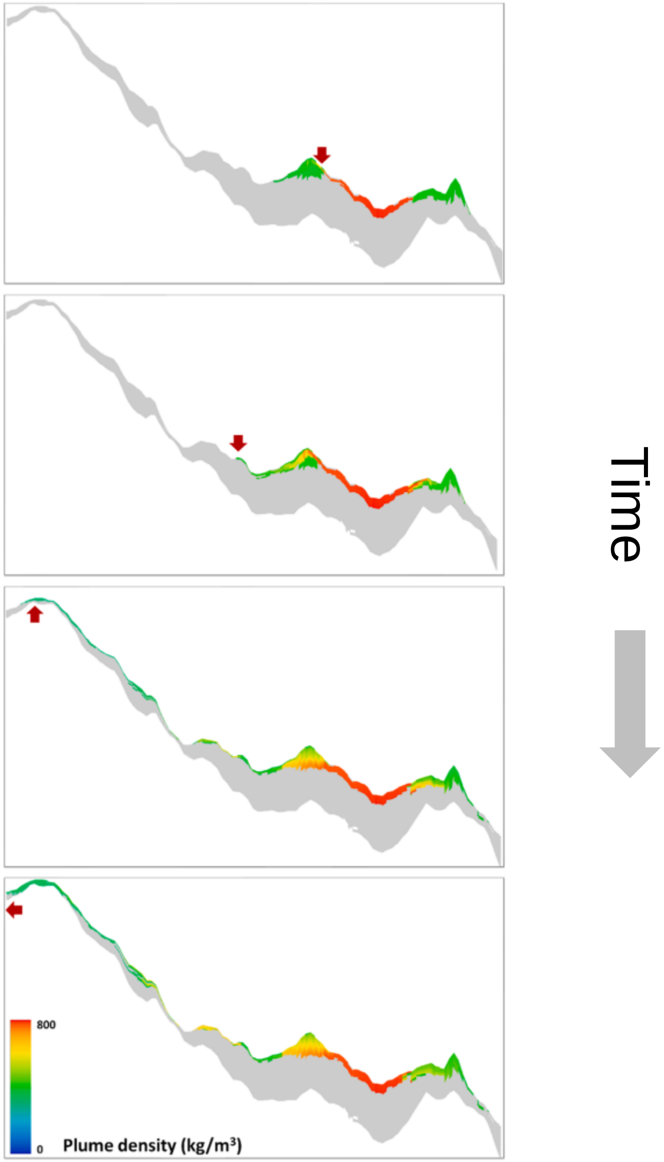
This changes the mass of the plume: 50% methane mixture increases plume mobility by 90%

Mobile plume reduces storage capacity

Gas density varies within the plume

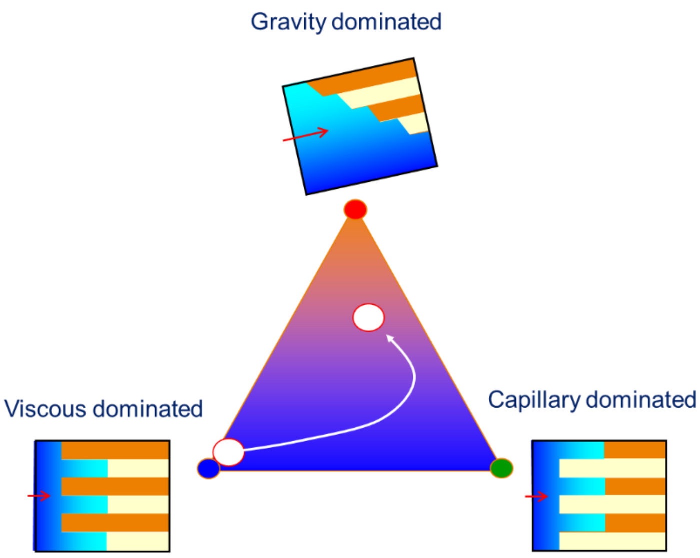
red = CO_2-rich

green = methane rich)



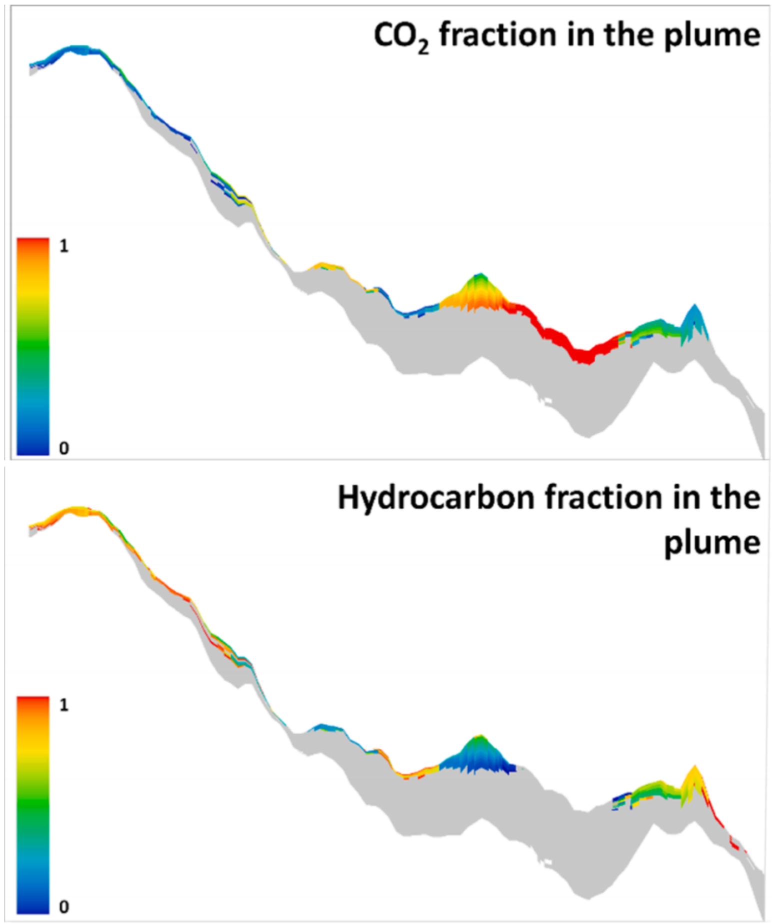
Saaed Ghanbari, Eric Mackay, Niklas Heinemann, Juan Alcalde, Alan James, Michael Allen, 2021

Which gas ends up where?

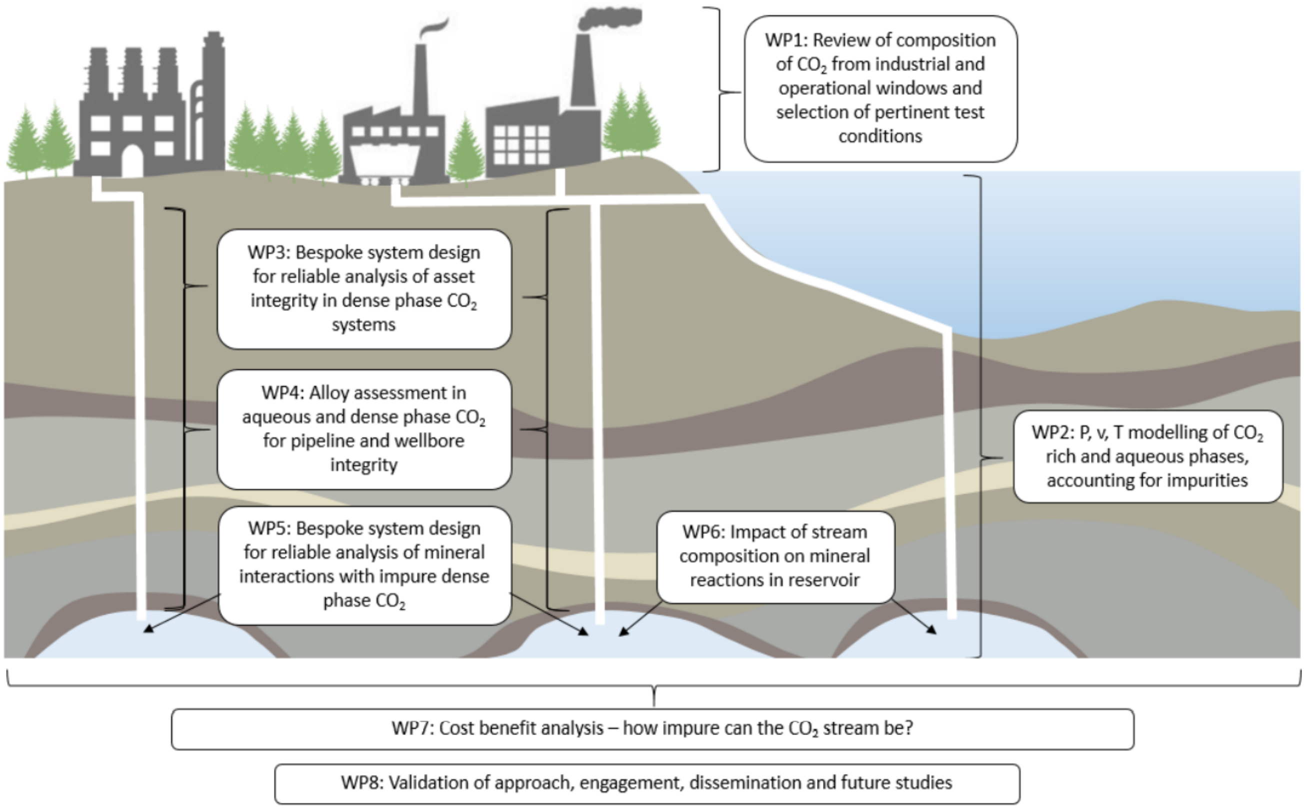


1000 years later ….

- Bouyancy takes over
- Remobilised methane ends up at the trap margin more quickly than forecast
- Overall storage capacity is reduced



Chemistry – impact of impurities



Impact on …

CO_2 phase properties, flow assurance, geochemical reactions, storage characteristics
AND … *mixing to enhance CO_2 storage*

Eric Mackay's Heriot-Watt research group

Models for Production vs. Storage

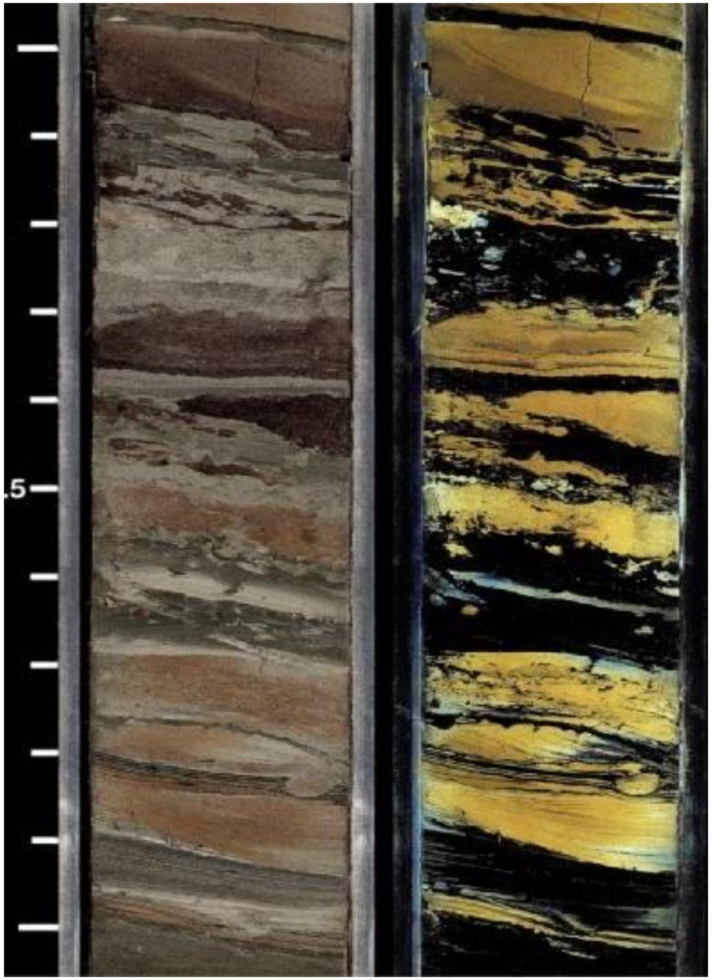
LOST HETEROGENEITY

Need it back

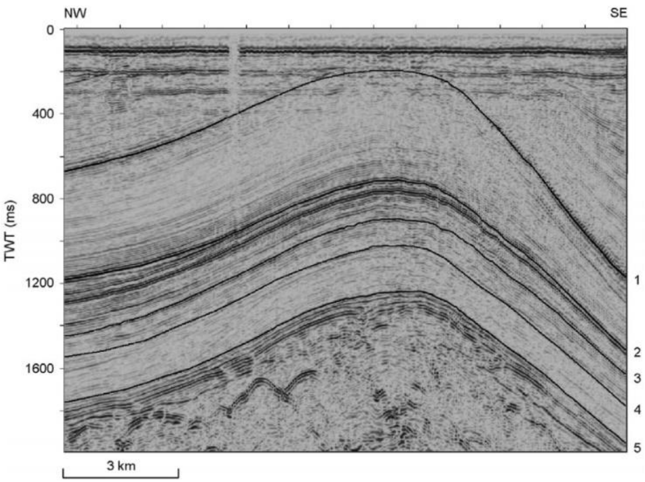
Heterolithics – suddenly helpful

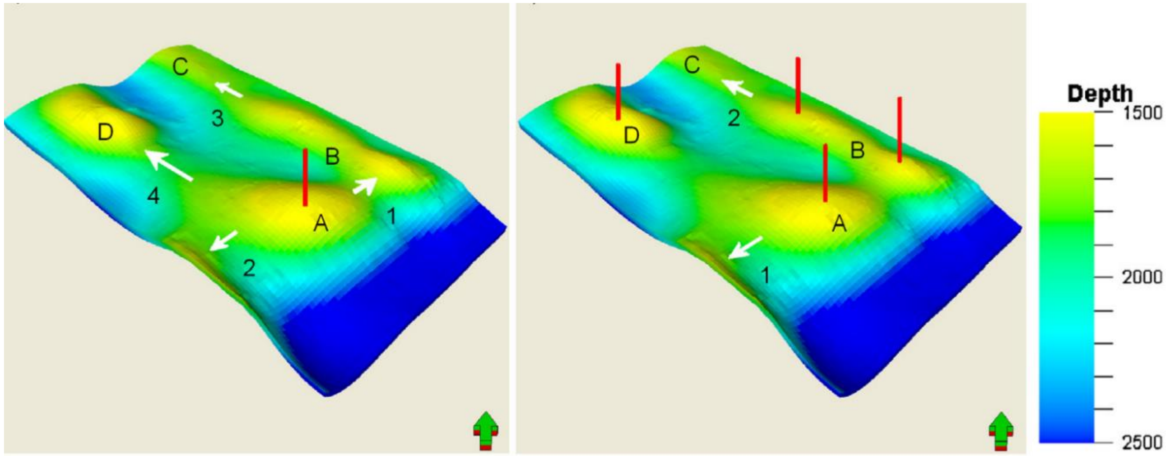
In production, ‘heterolithics’ are almost universally a disadvantage

In storage, ‘heterolithics’ are a storage opportunity, due to capillary trapping capacity



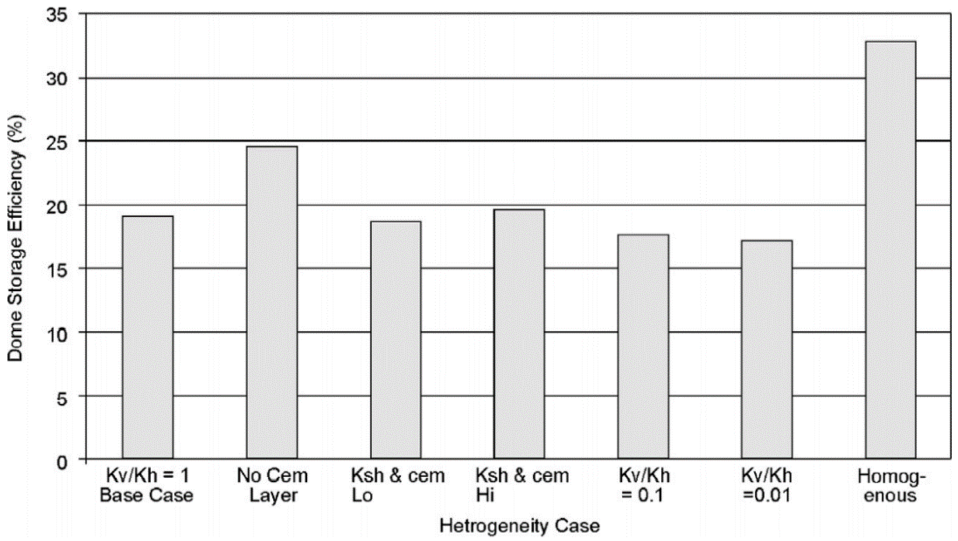
Lost heterogeneity





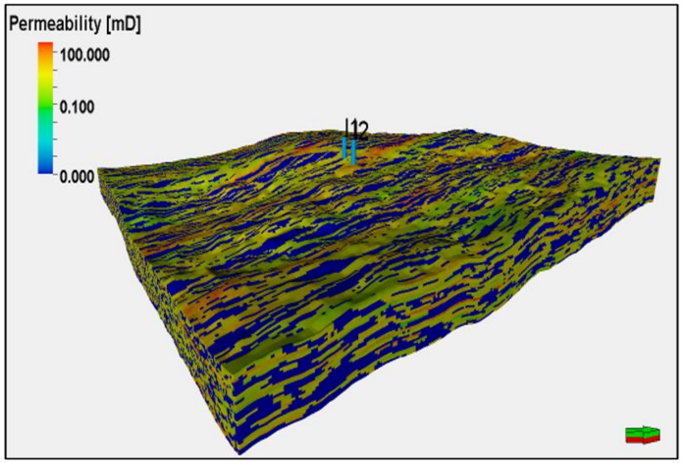
Impact of heterogeneity on storage efficiency
(Bunter case)

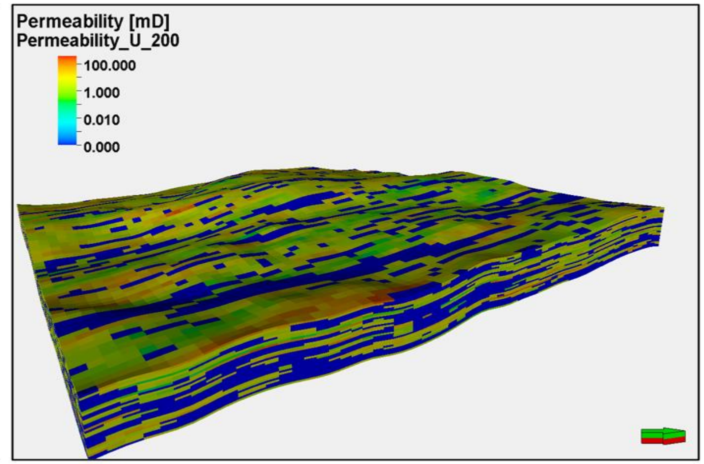
Williams,Jin, Benthama, Pickup, Hannis, Mackay, 2013

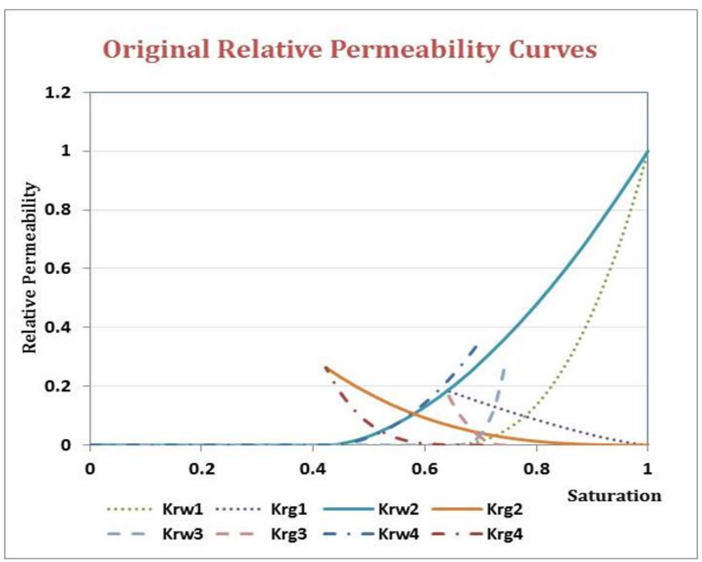


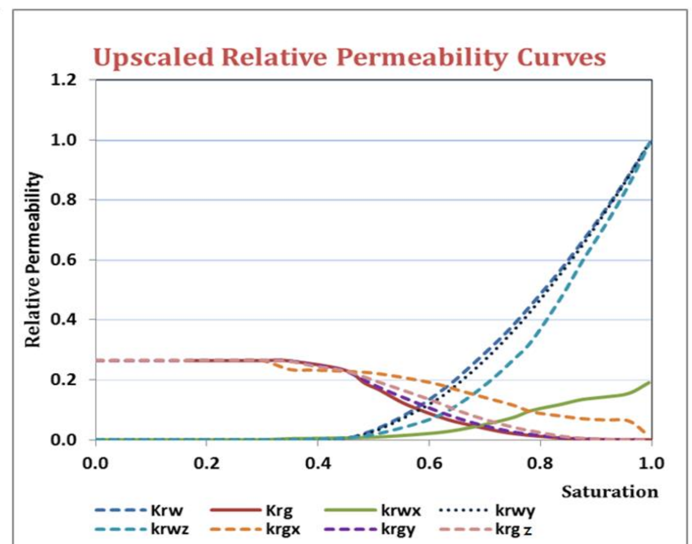
My, what a big simulator you've got…

Traditional upscaling issues - unavoidable



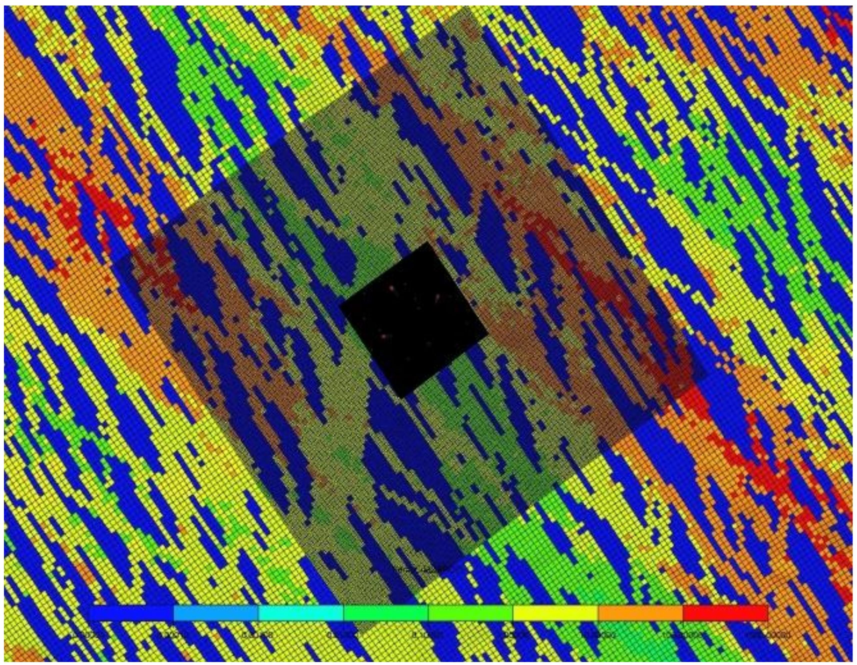


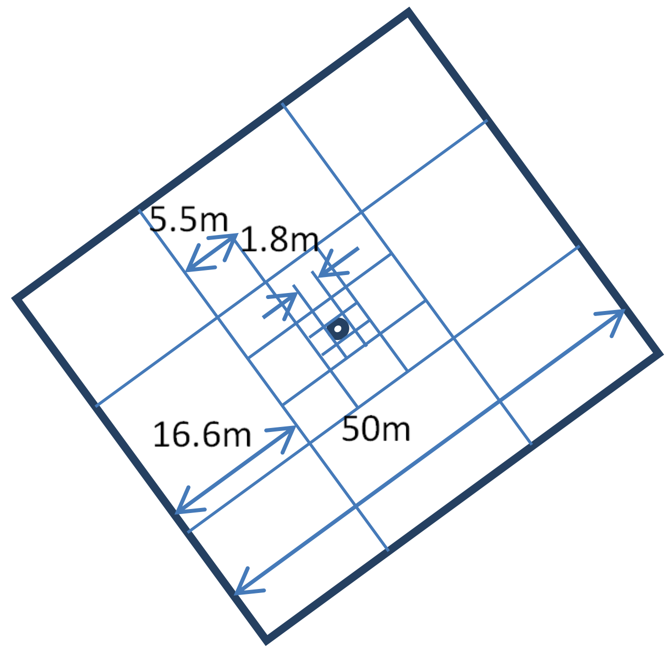




Min Jin 2015
Heriot-Watt

Increasing heterogeneity means …





Min Jin 2015, Heriot-Watt

Increasing heterogeneity means …

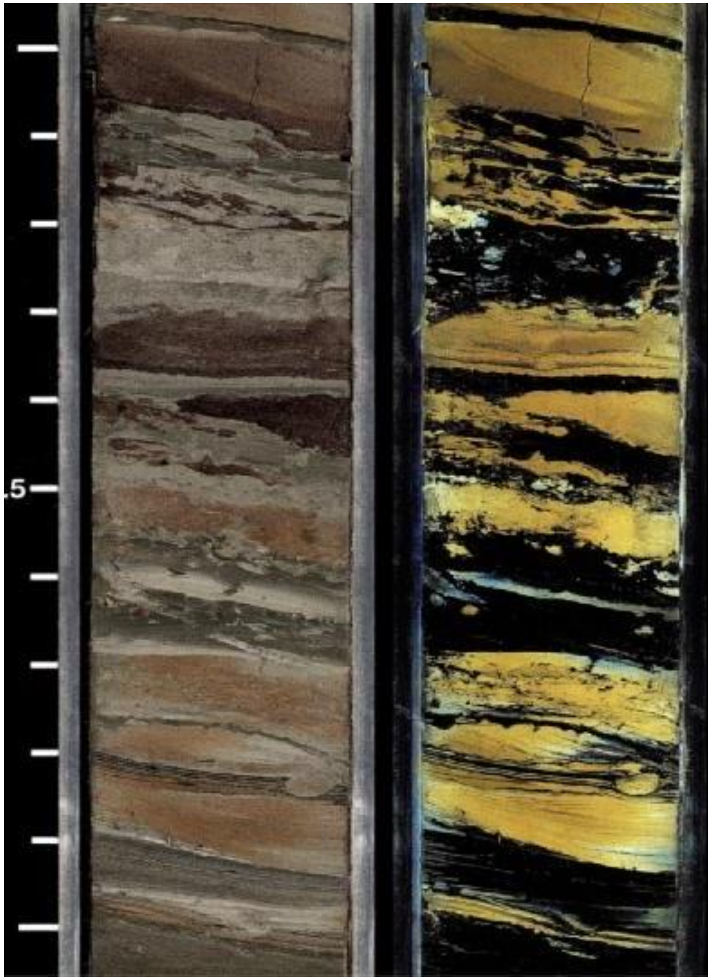
Increased injection pressures

Decreased injection rates

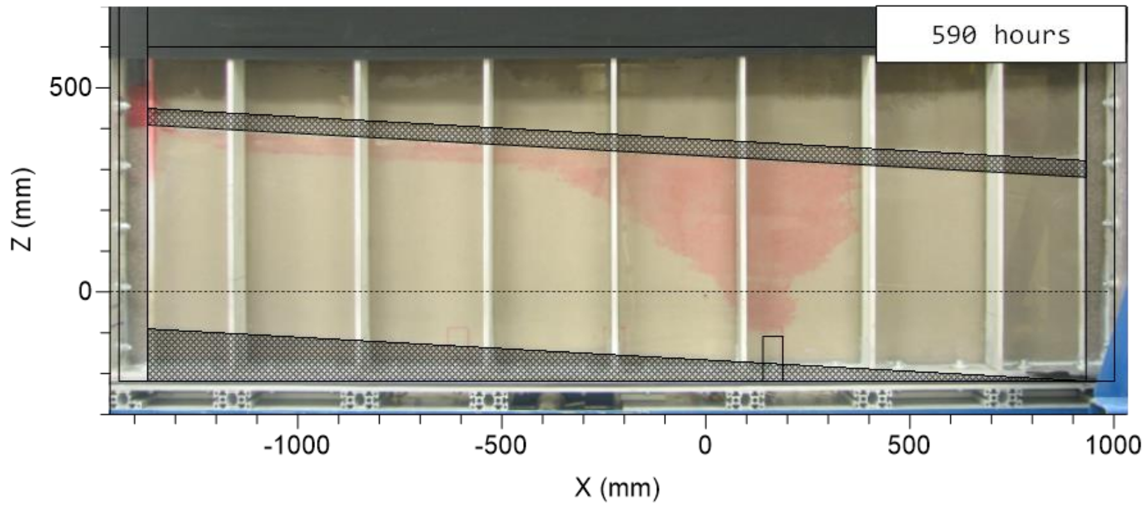
Decreased storativity

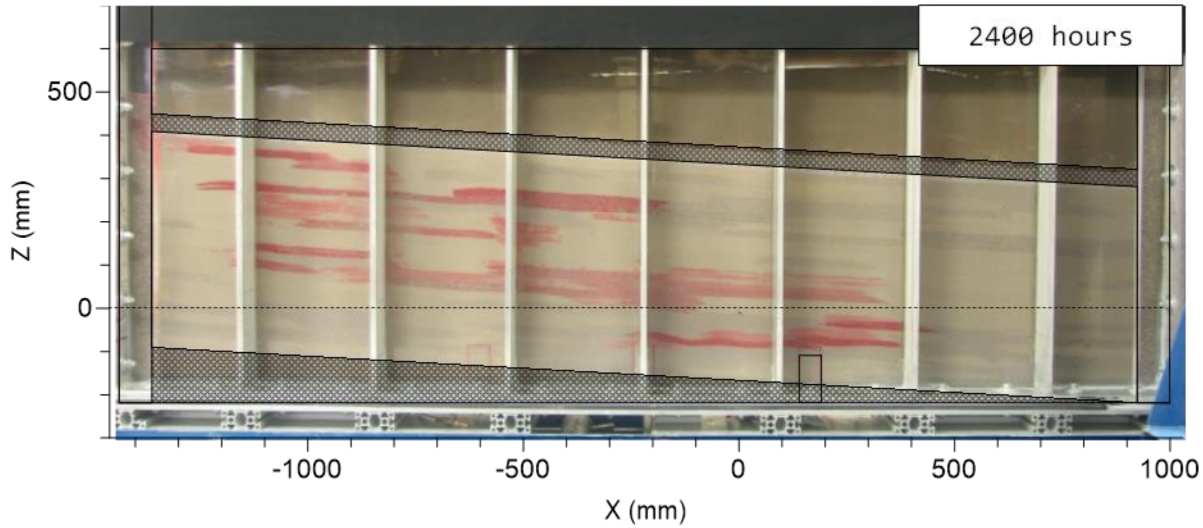
Increased capillary trapping

Increased need to understand the small-scale

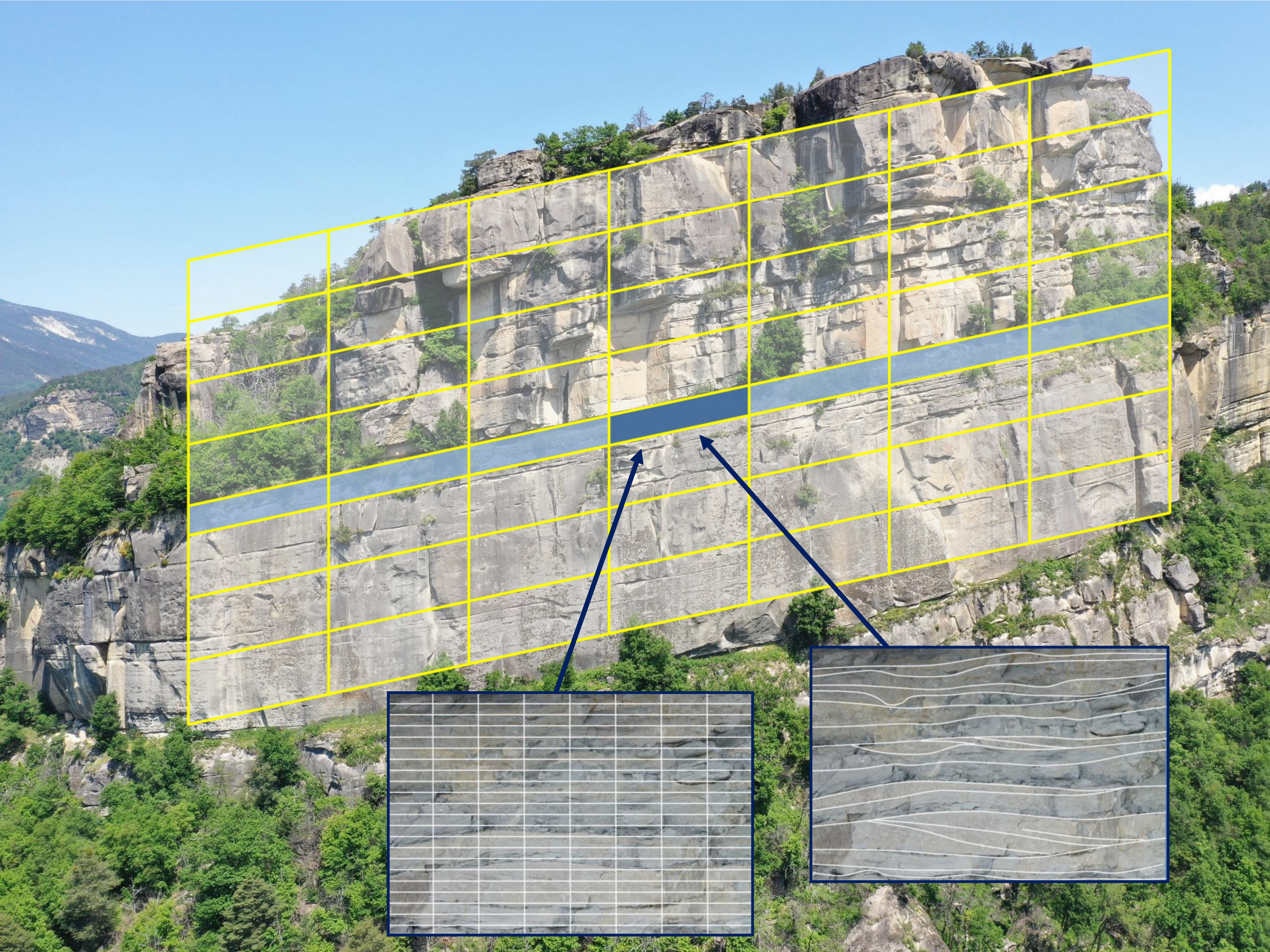


Other types of models ….



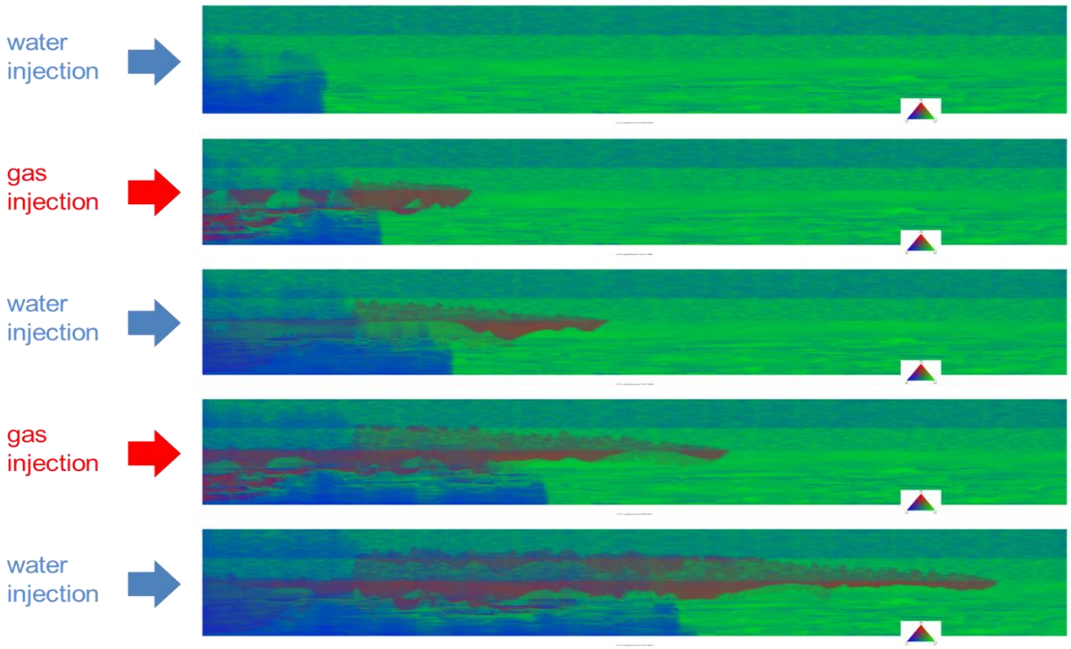


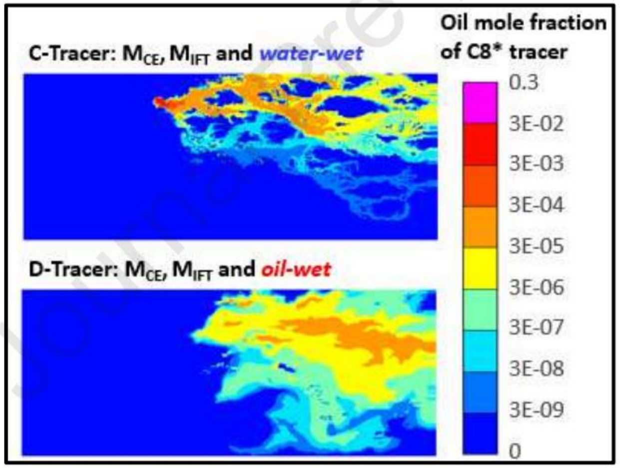

TRACS



Truth models – REVs - restoring lost heterogeneity

When the really small-scale matters (effective properties, capillary effects)

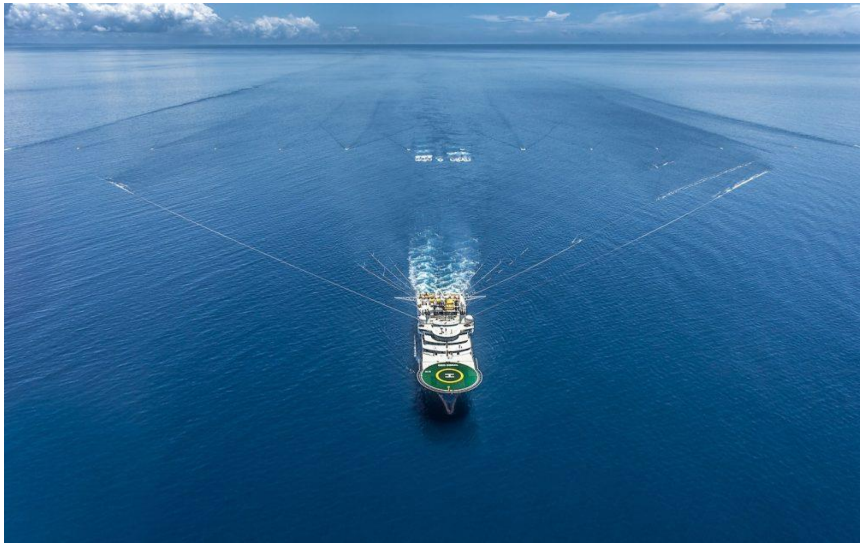




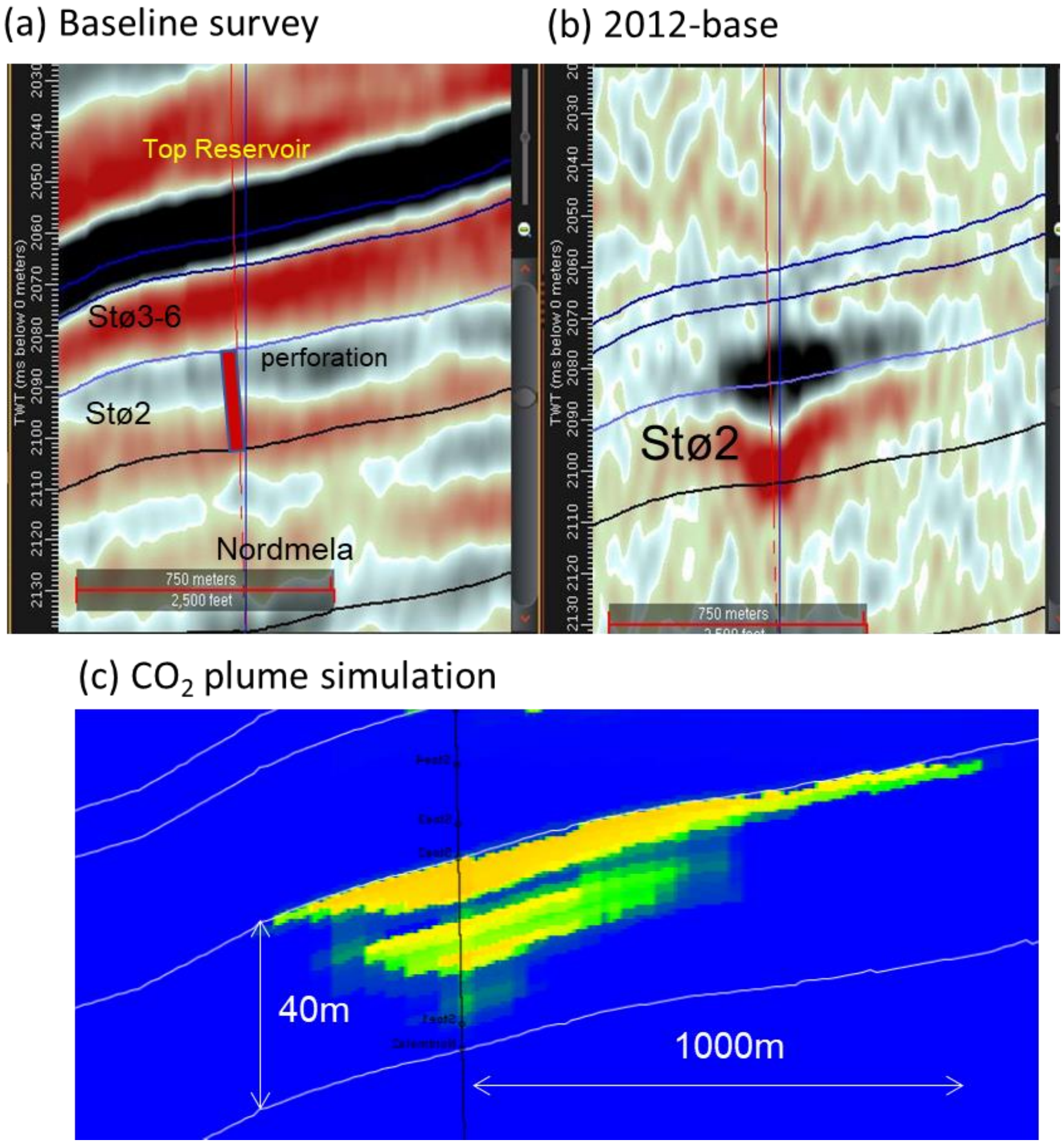
Models for Production vs. Storage

MONITORING

Job for life

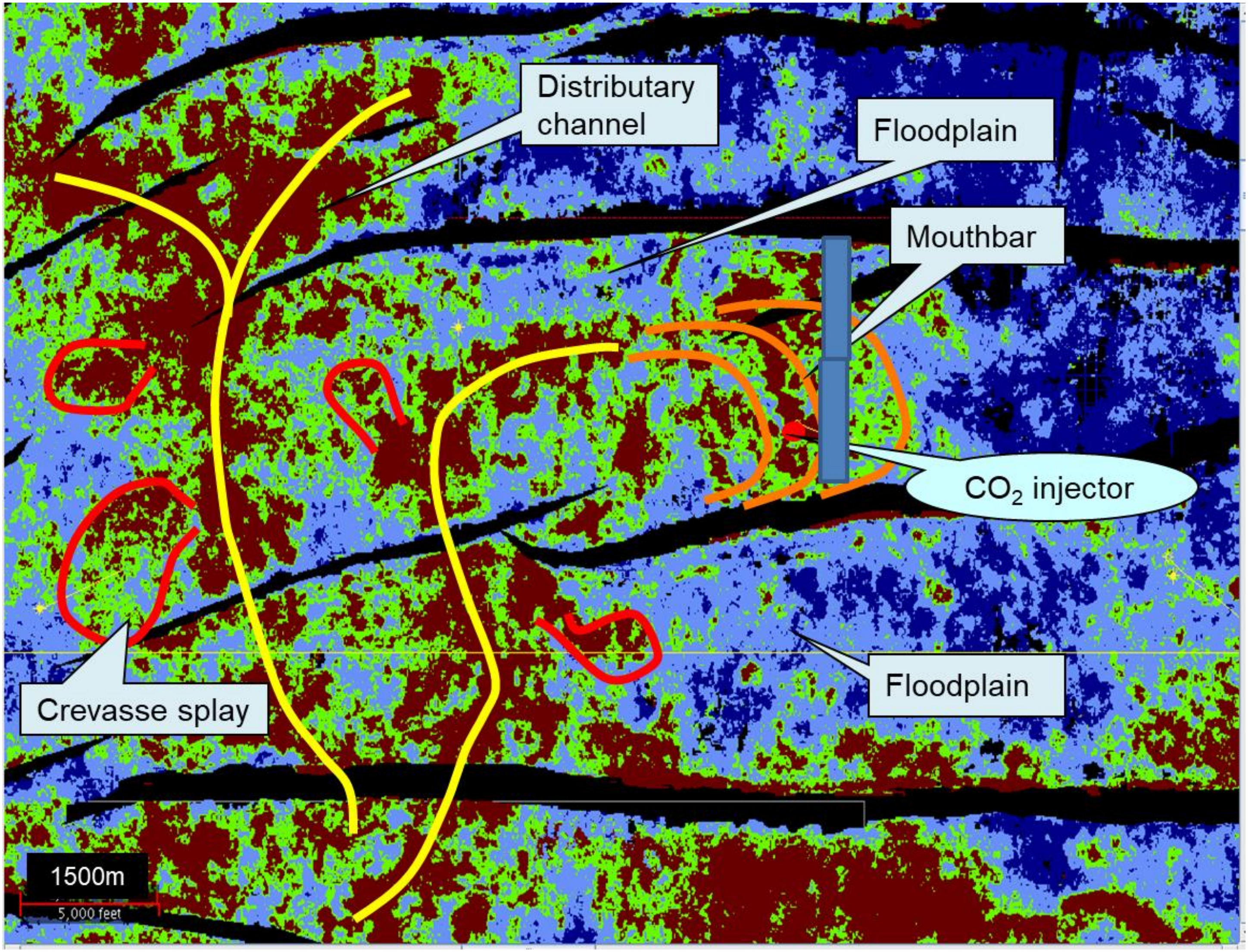


Monitoring

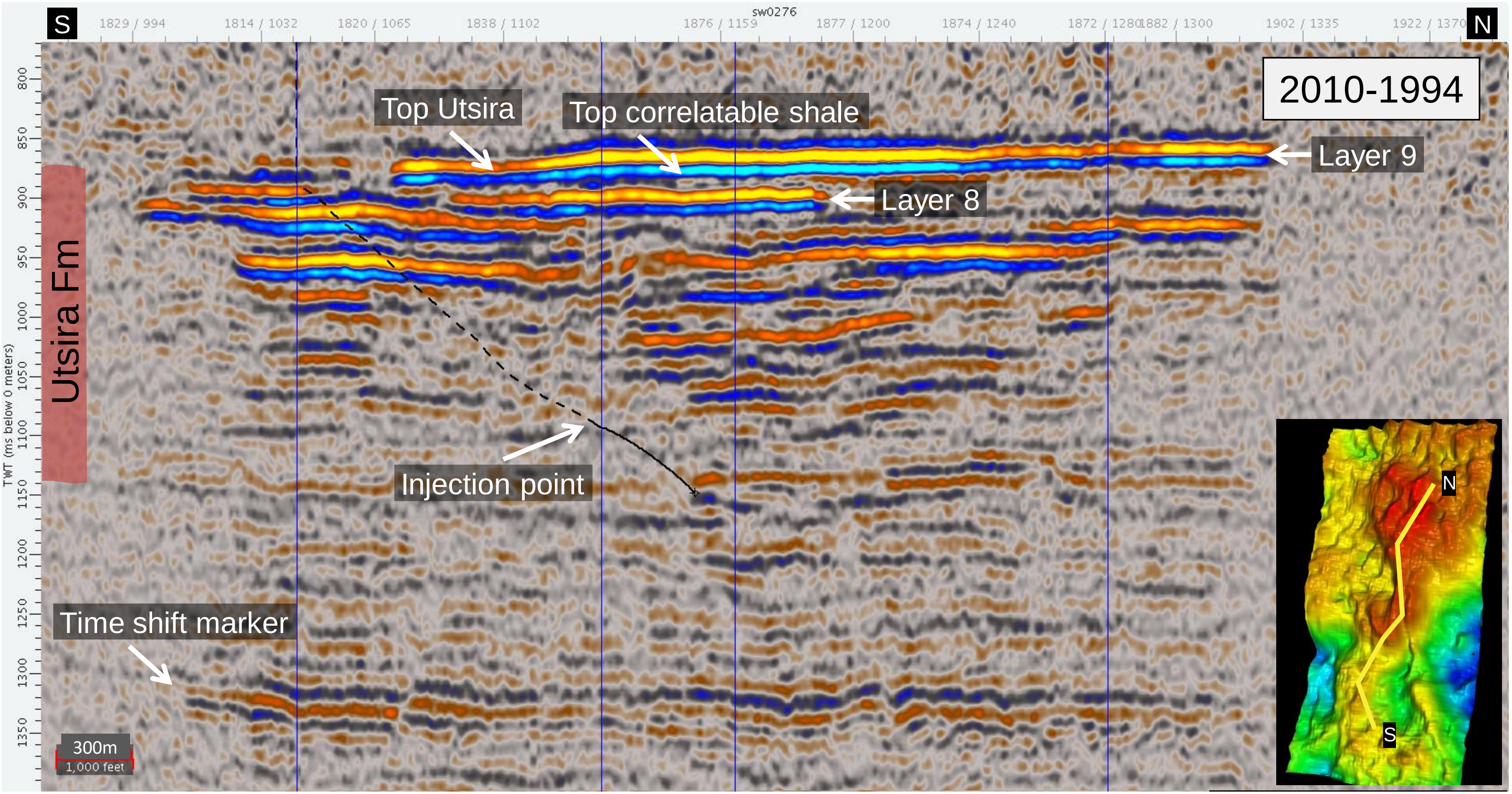


(a) Baseline survey
(b) 2012-base
Top Reservoir
Stø3-6
perforation
Stø2
Nordmela
750 meters
2,500 feet
TWT (ms below 0 meters)
Stø2
750 meters
(c) CO_2 plume simulation
40m
1000m

Monitoring

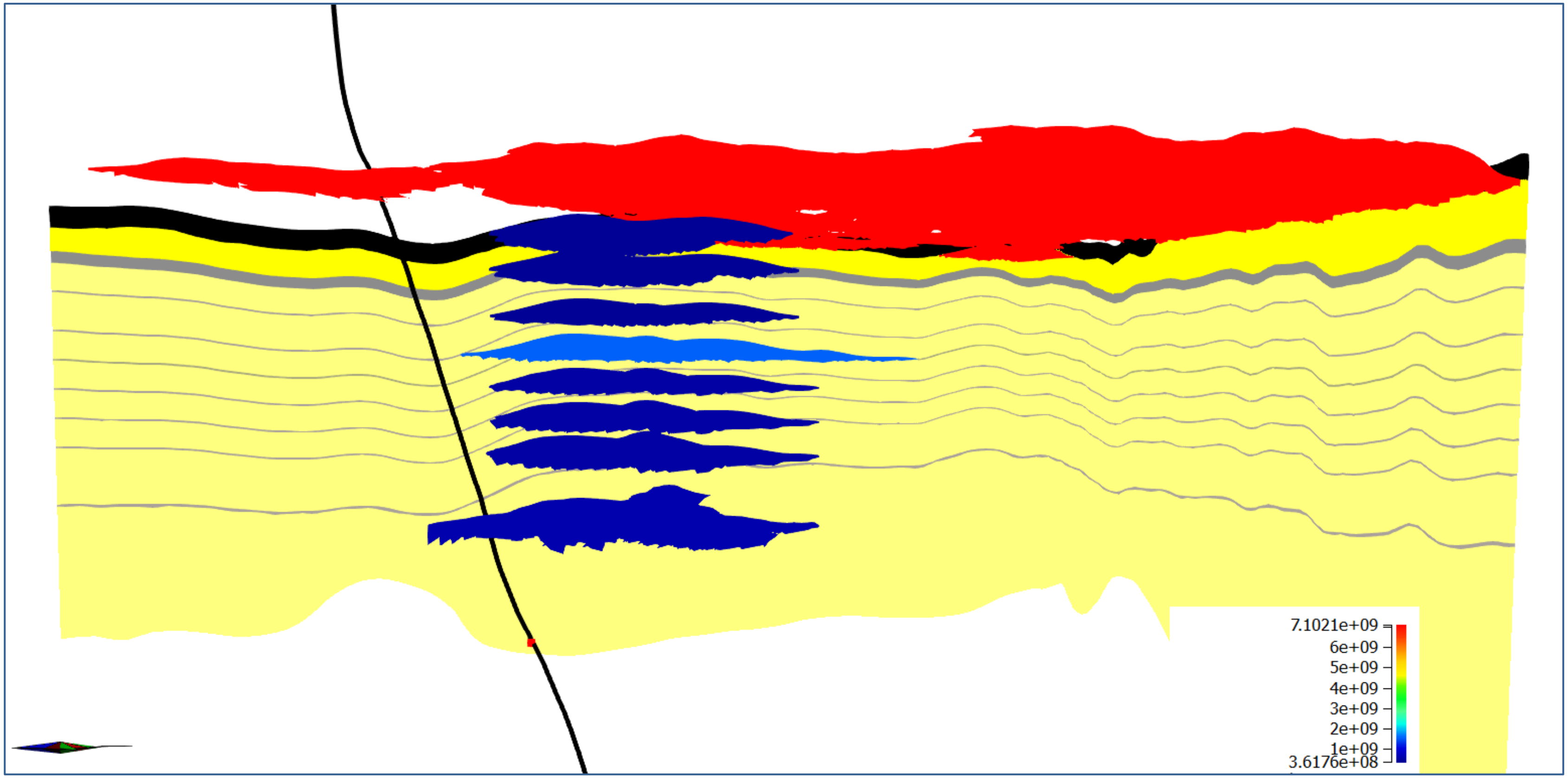

Distributary channel
Floodplain
Mouthbar
CO_2 injector
Floodplain
Crevasse splay
1500m
5,000 feet

Monitoring



S
N
sw0276
1829 / 994
1814 / 1032
1820 / 1065
1838 / 1102
1876 / 1159
1877 / 1200
1874 / 1240
1872 / 1280
1882 / 1300
1902 / 1335
1922 / 1370
2010-1994
Top Utsira
Top correlatable shale
Layer 9
Layer 8
Utsira Fm
Injection point
Time shift marker
TWT (ms below 0 meters)
300m
1,000 feet
N
S

Monitoring



Models for Production vs. Storage

COMMUNICATION

Nuclear

Nuclear


Nuclear power?
No Thanks


ATOOM KRACHT?
NEE MERCI
NUCLEAIRE?
NENI VALET
KODOLENERGIJA?
ATOMINĖS JĖGOS ?
AČIŪ NEREIKIA

Nuclear

EU CCS Directive (EC 2009; annex 1):

"Sufficient data shall be accumulated to construct a volumetric and three-dimensional static (3-D)-earth model for the storage site and storage complex, including the caprock, and the surrounding area, including the hydraulically connected areas"

'Leakage' =

" ... any release of CO_2 from the storage complex'

'Significant irregularity' =

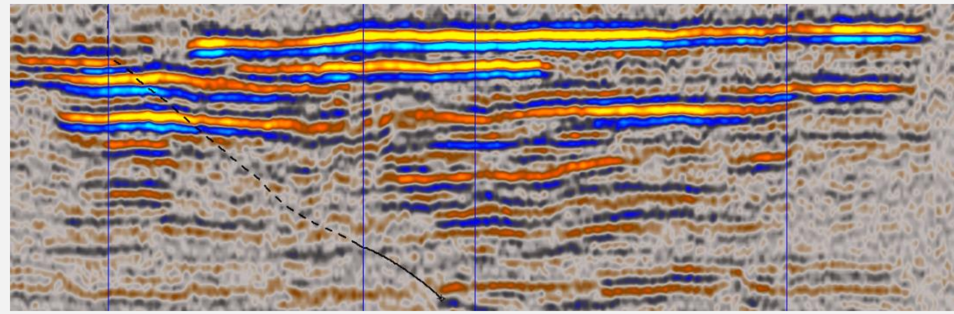
" … any irregularity in the injection or storage operations or in the condition of the storage complex itself, which implies the risk of a leakage or risk to the environment or human health.'

HC Production vs. CO_2 injection and storage

Production	CCS
Model the field	We need the whole storage complex
Focus geomechanics on reservoir & caprock	Geomechanics also required for over- and under-burden
We approximate the small-scale and simplify physics	We need to capture capillary effects and fine heterogeneity (small models)
We can be isothermal	Super-critical fluids! We shouldn't be isothermal
Aquifer sometimes important (but can be simplified)	Aquifer always important (and multi-scale effects apply)
Balance of forces: "viscous forces dominate" in water injection – can often get away with simplification	Balance of forces: viscous during injection, gravity post-injection, capillary before and after for trapping
Multi-decade simulations	Multi-millennia simulations
Multi-decade monitoring	Multi-millennia monitoring

And for us modellers …..

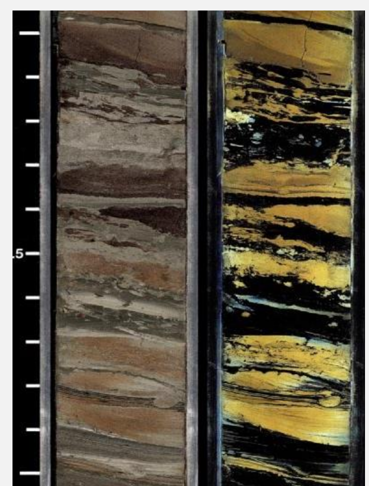
We need the whole storage complex (large models) – long term geophysics



Get a geomechanical friend, ideally with sidebur(de)ns

The fluids are sensitive to a wide range of length scales (Flora plus)

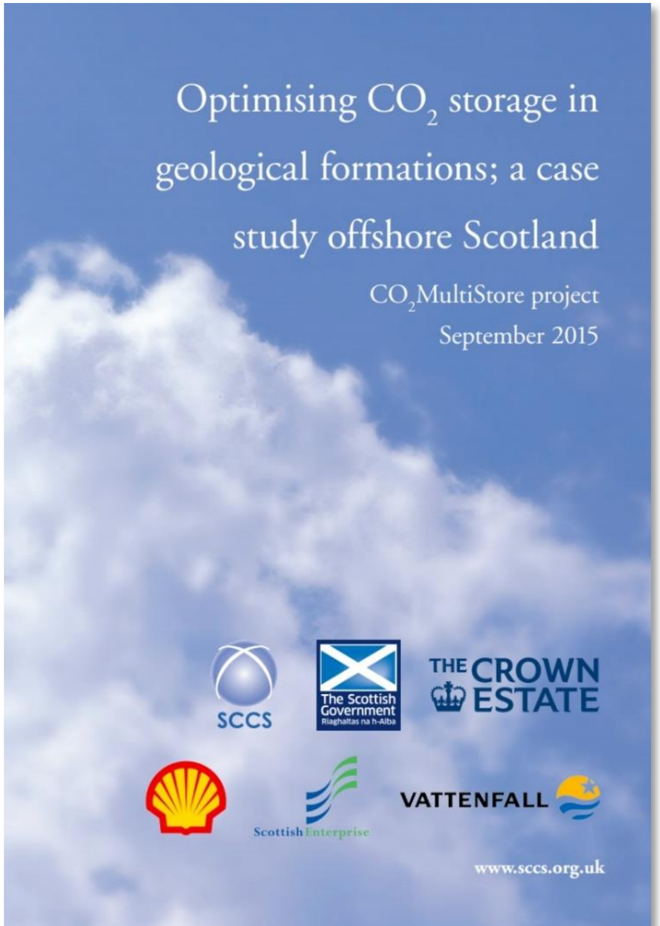
Critical permeability contrast	3 orders	2 orders	1 order		1/2 order ?	
Fluid fill	dry gas	wet gas	light oil	heavy oil	aquifer	residual gas
Production mechanism	depletion (no aquifer)	depletion (with aquifer)	water injection	gas/steam injection	CO_2 injection	



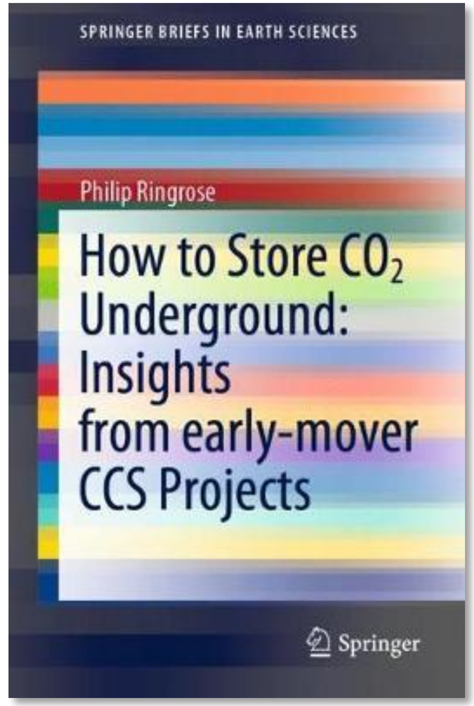
We are sensitive fine-scale heterogeneity – and it's on our side; embrace the REV

Models for production vs. storage

Handy references



www.sccs.org.uk
Lots of useful links on their website
CCS published material



Phil's 2020 brief on the Equinor project experiences – notes from the people who are actually doing this

Our res mod design text – 2nd edition 2021, rewritten for the energy transition with a chapter on modelling for storage