

Reservoir modelling for the energy transition

Prof. Dr. Sebastian Geiger,
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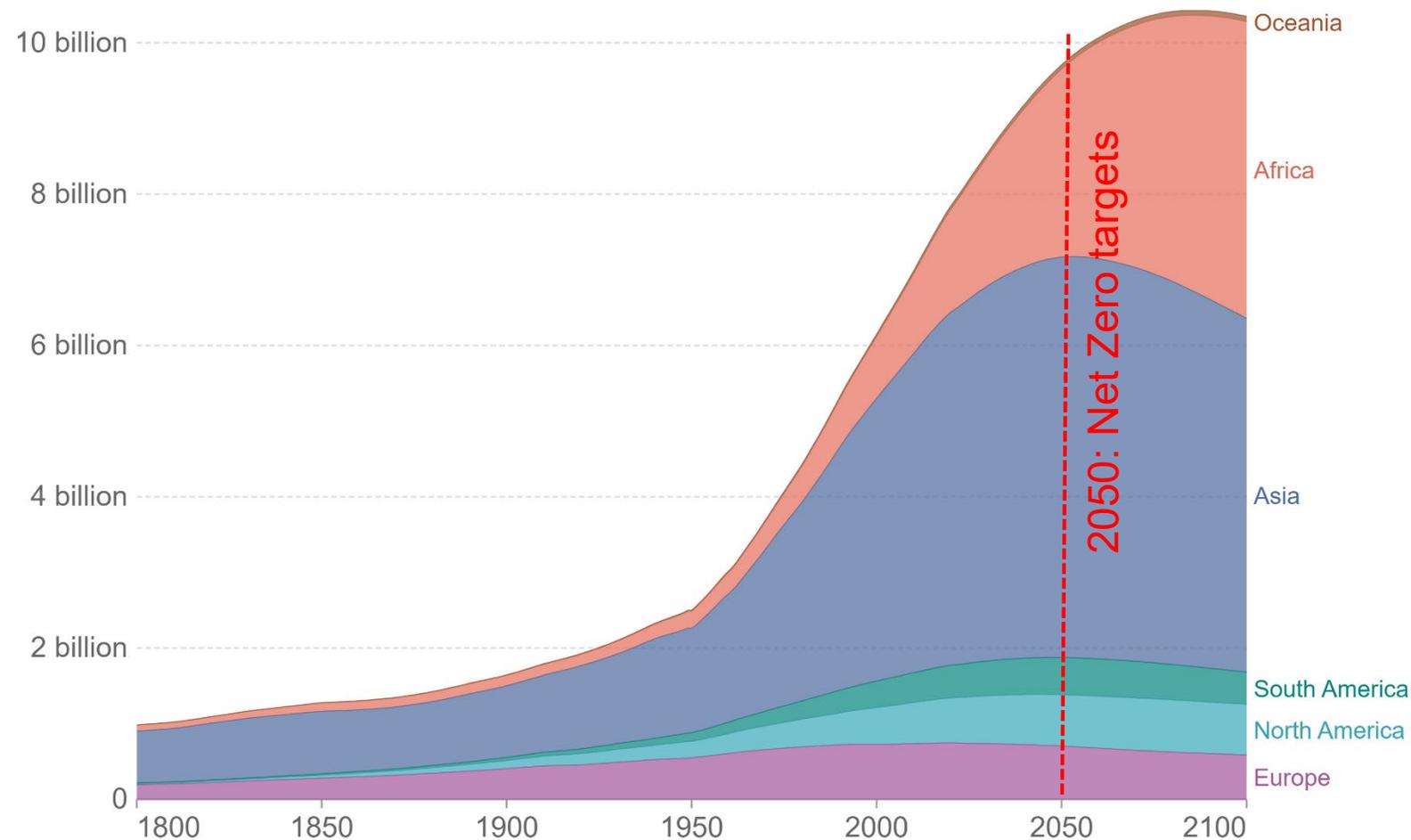


The context: Why the energy transition?

World population by region, including UN projections

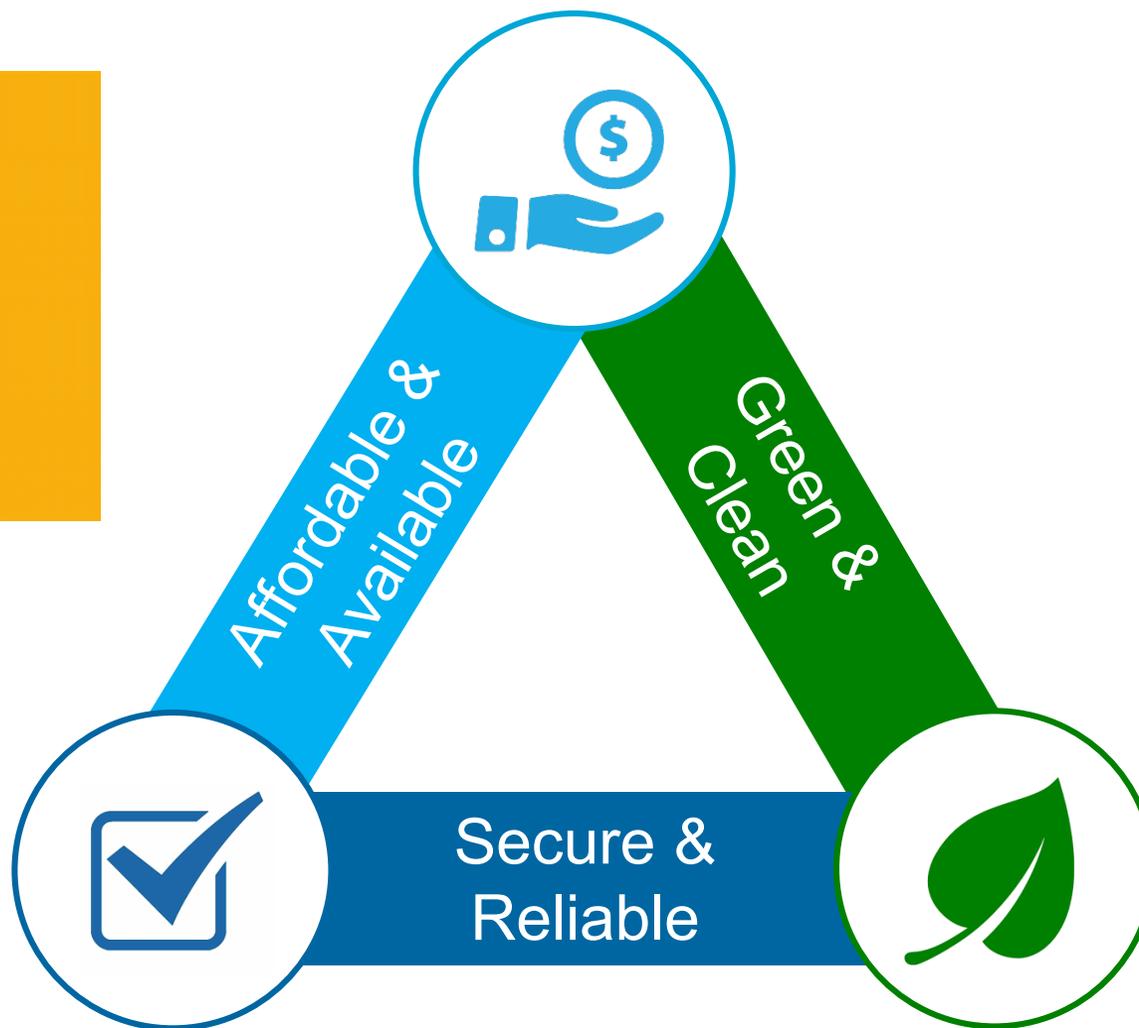
Future projections are based on the UN's medium-fertility scenario.

Our World
in Data



The energy trilemma

**7 AFFORDABLE AND
CLEAN ENERGY**

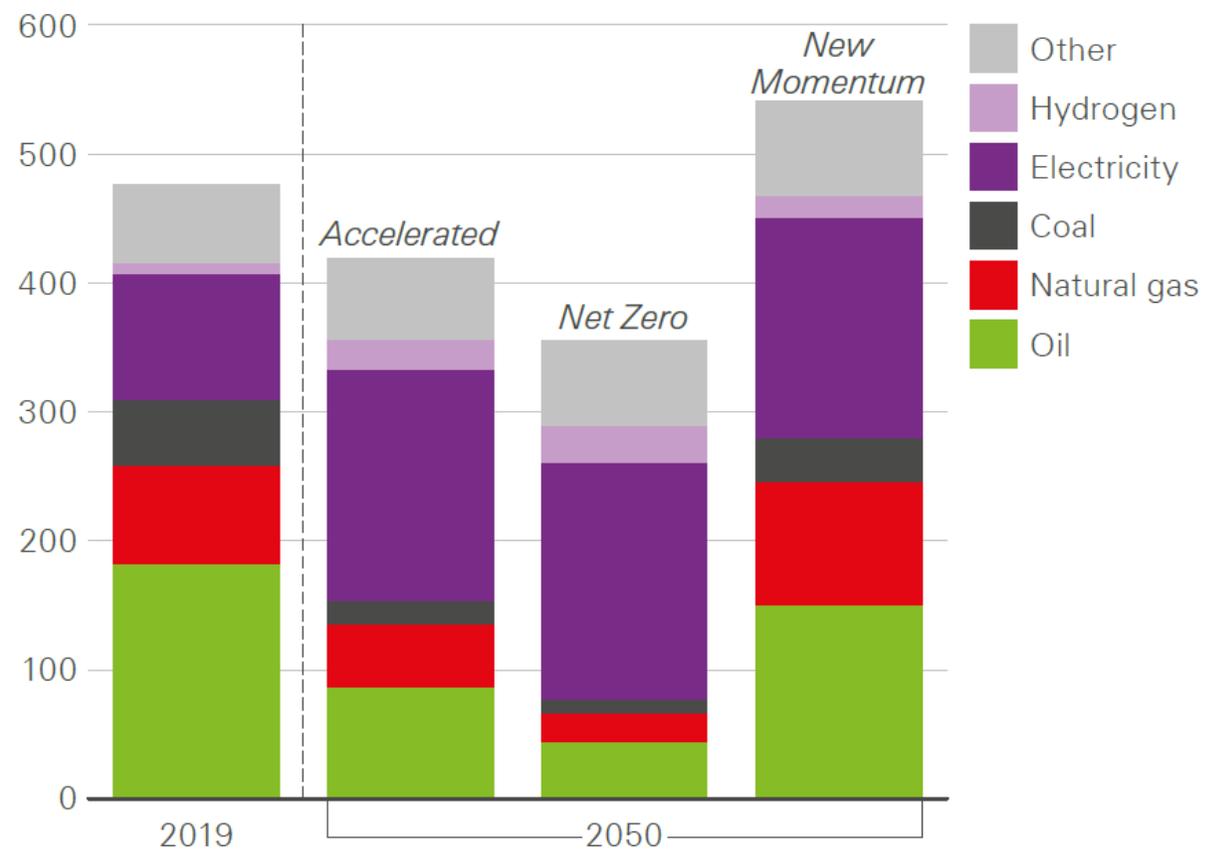


Global energy outlook



Fuel composition of final consumption

Energy demand, EJ

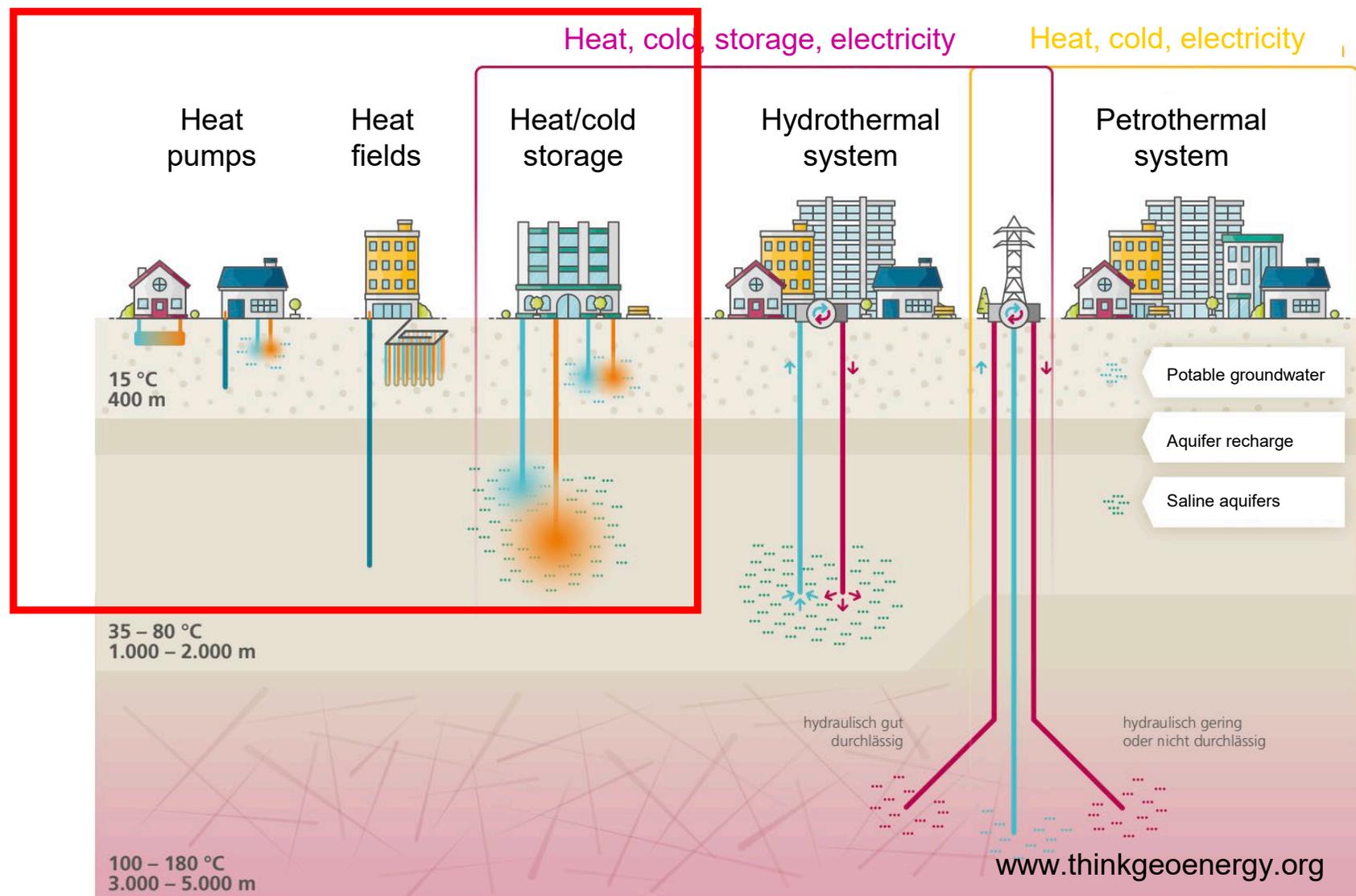


Changing just one fuel type

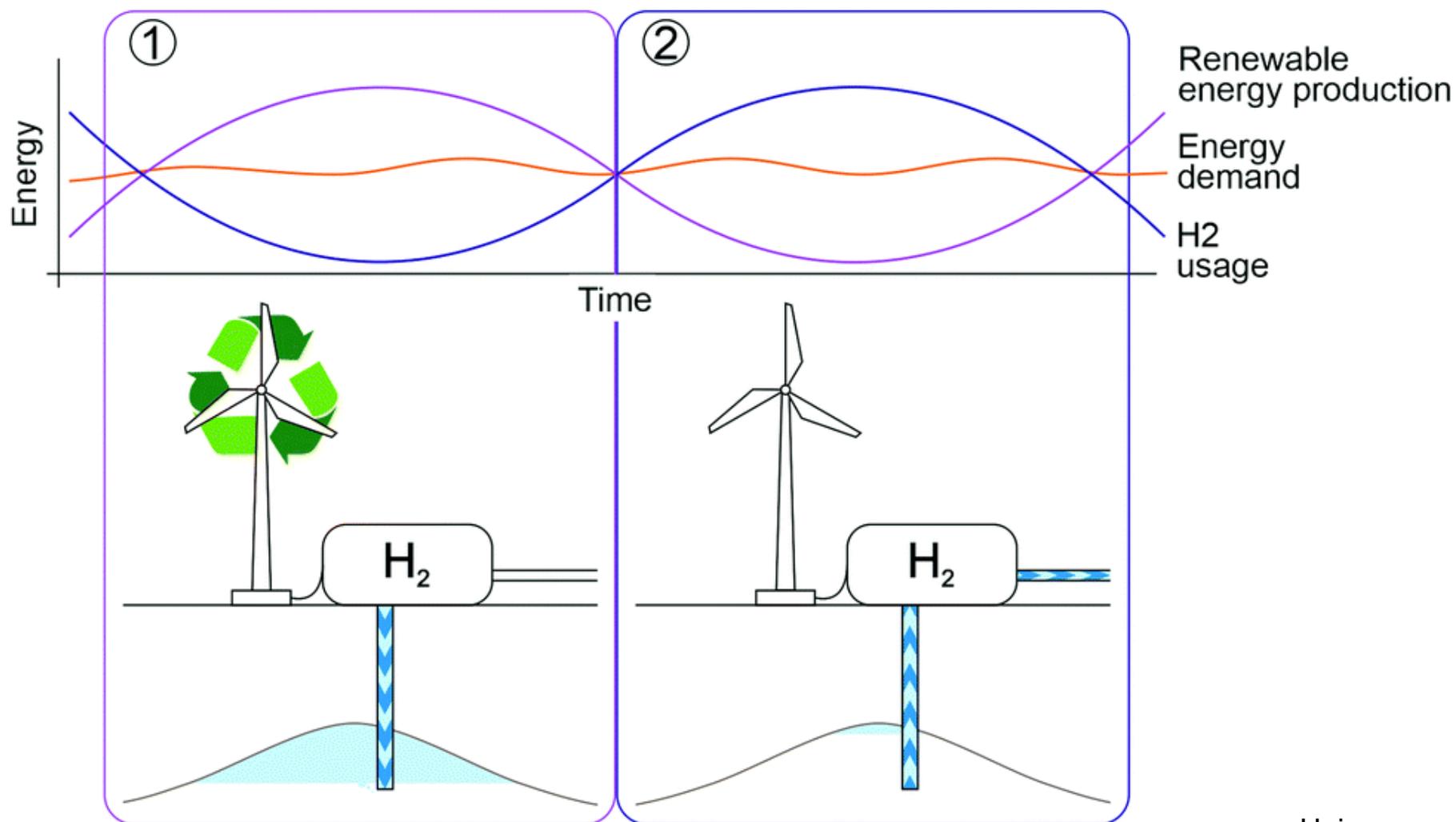
- Natural gas provides 1500 TWh on-demand energy in Europe, which is equivalent to
 - 20,000,000,000 of the latest Tesla batteries
 - 11,600,000 of the latest battery parks
 - 200 large-scale hydro-electric storage systems
- Unprecedented (human) costs and pressures on natural gas supply in Europe



Shallow and deep geothermal energy



Seasonal and short-term hydrogen storage



Carbon Capture, Utilisation, and Storage (CCUS)

www.europeanfiles.eu

Overview of existing and planned CCUS facilities

Norway

- 1. Sleipner CO₂ Storage*
- 2. Snøhvit CO₂ Storage*
- 3. Northern Lights*

Republic of Ireland

- 4. ERVIA

UK

- 5. Acorn*
- 6. Caledonia Clean Energy
- 7. H21 North of England*
- 8. Liverpool-Manchester Hydrogen Cluster
- 9. Net Zero Teesside*
- 10. Humber Zero Carbon Cluster*
- 11. Liverpool Bay Area CCS Project*

France

- 12. Lacq*
- 13. DMX Demonstration in Dunkirk*

Belgium

- 14. Leilac
- 15. Port of Antwerp*

Sweden

- 16. Preem CCS*

The Netherlands

- 17. Porthos (Port of Rotterdam)*
- 18. Athos (Ijmond)
- 19. Aramis (Den Helder)
- 20. Magnum (Eemshaven)*

Croatia

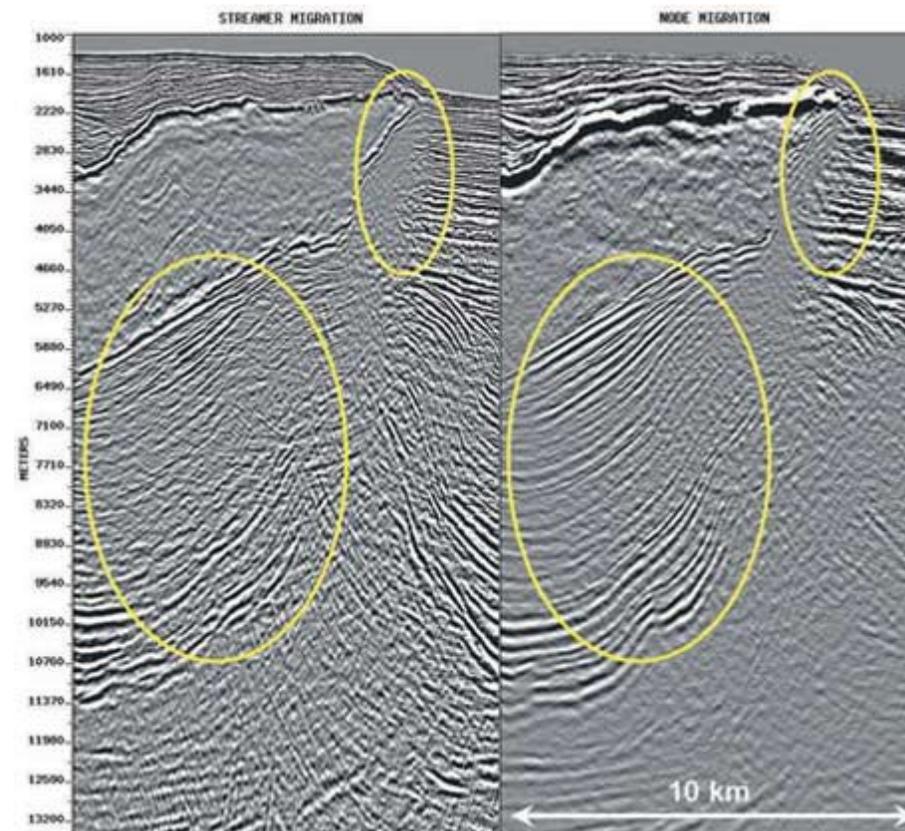
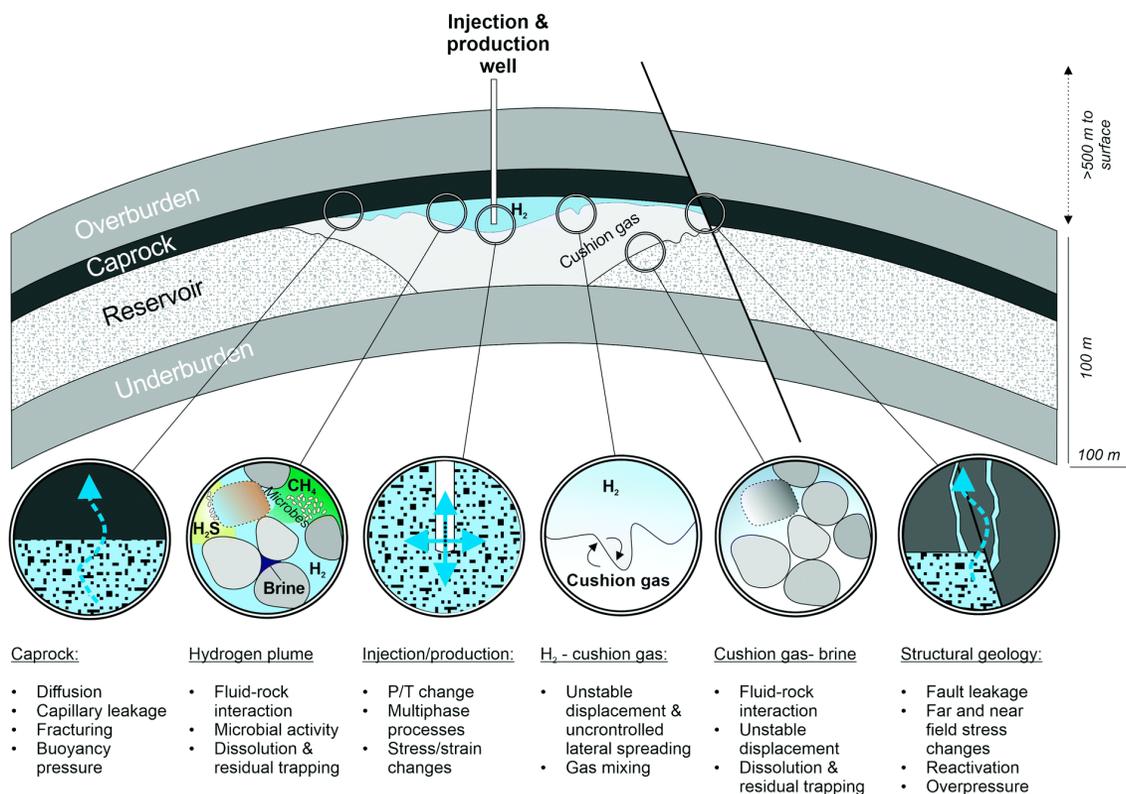
- 21. iCORD*
- 22. CO₂ EOR Project Croatia*
- 23. Bio-Refinery Project*

Italy

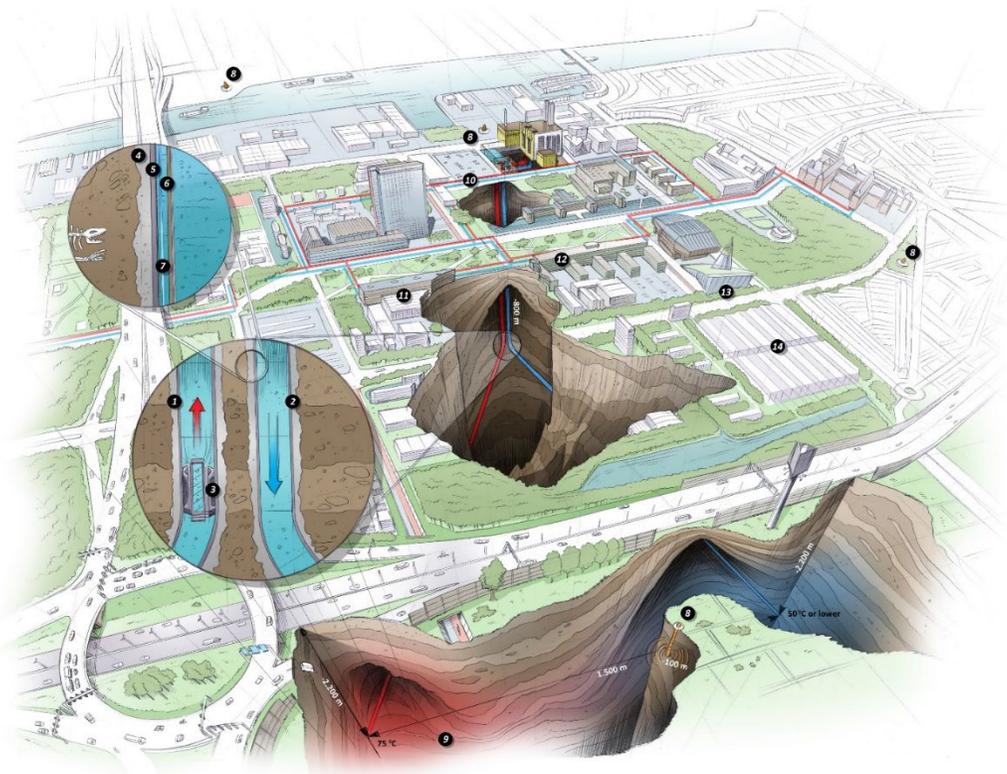
- 24. CCS Ravenna Hub*

* Project where IOGP members are involved
Projects listed in **bold** are in operation

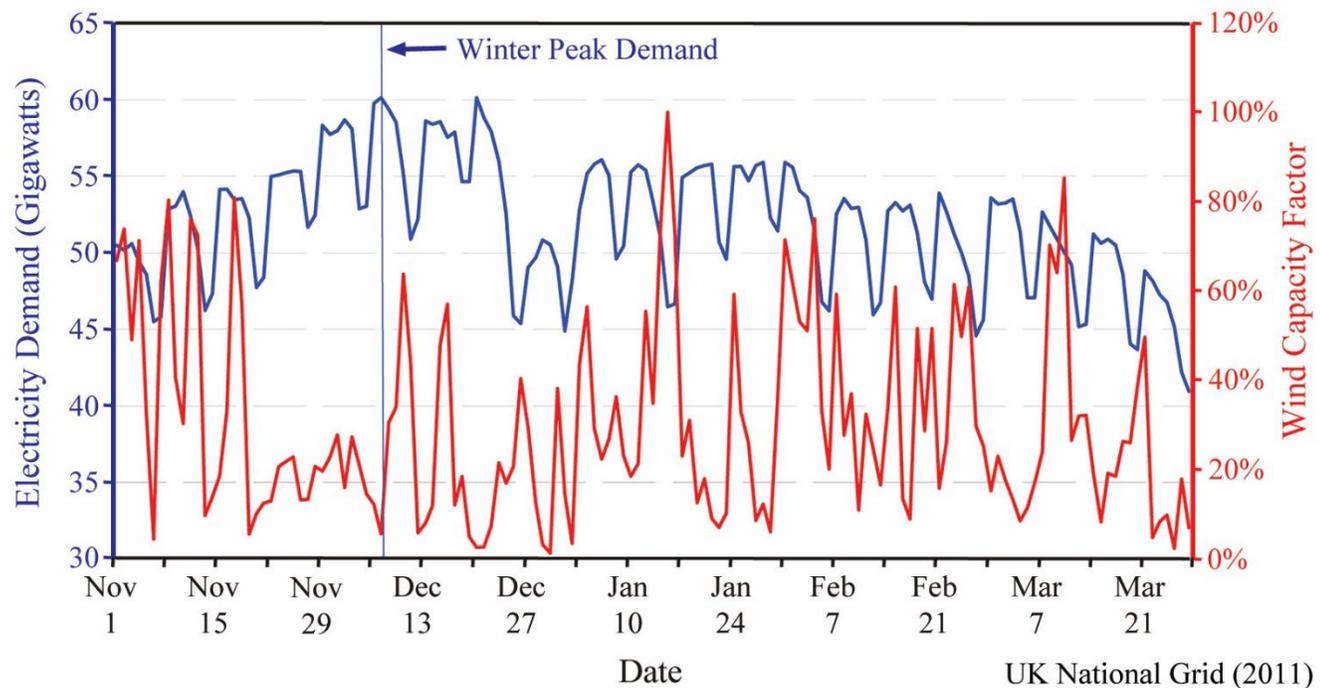
Complex physics and less data



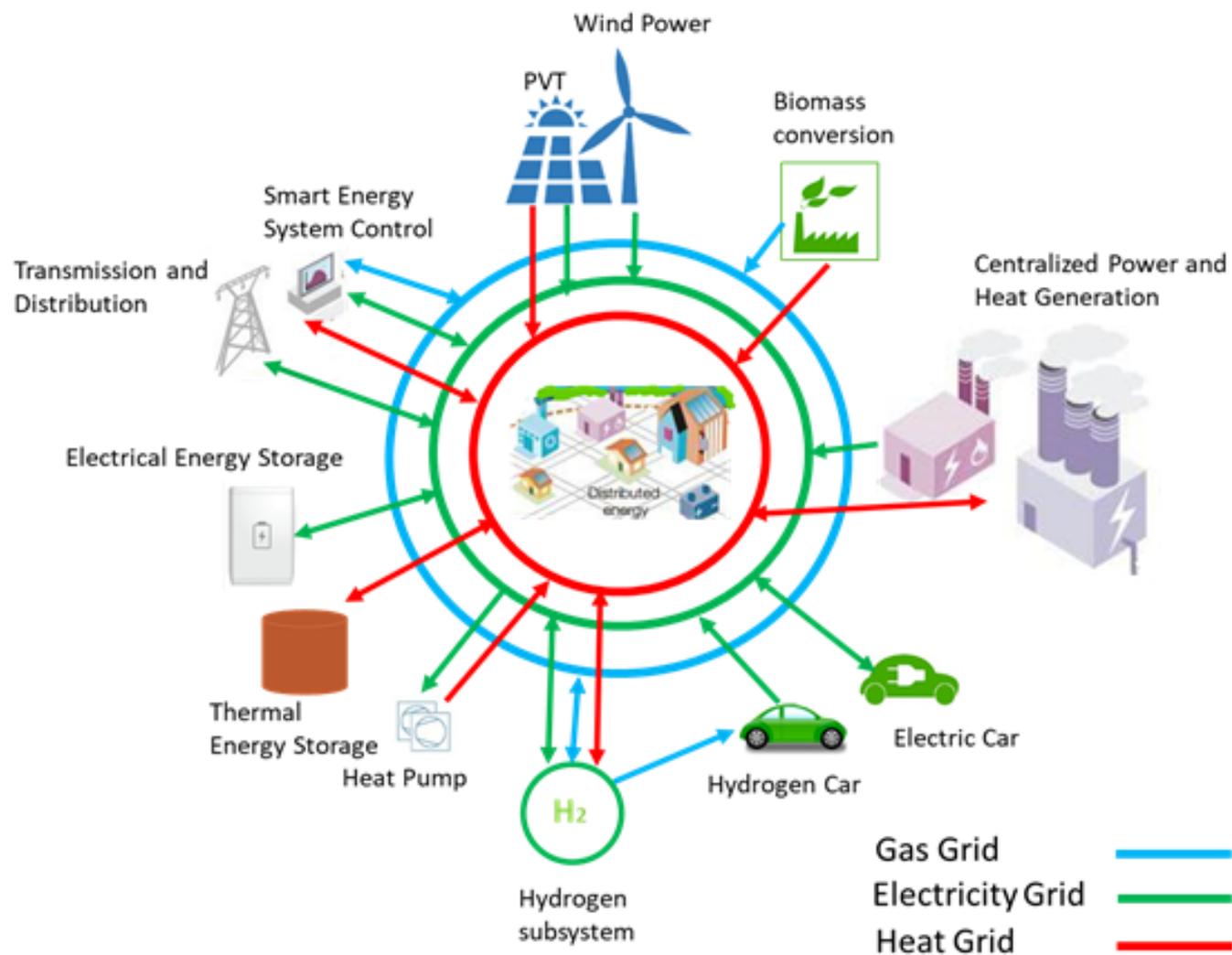
Proximity of location and intermittency of supply



UK Electricity Demand and Wind System Output Winter 2010-2011



Energy system integration



Engagement with society



But we are not on track

Indicators	Recent years	2050 ²²⁾	Off / On track	Required scaling factor (~X times)
Geothermal consumption	0.9 EJ ⁹⁾	4 EJ		4x
District heat generation - buildings	0.4 EJ ¹⁰⁾	7.3 EJ		Significant increase
CCS to abate emissions in industry	0.04 GtCO ₂ captured/yr ¹⁹⁾	3.4 GtCO ₂ captured/yr		Significant increase
BECCS and others to abate emissions in industry	0.001 (GtCO ₂ captured/yr) ²⁰⁾	5.0 GtCO ₂ captured/yr		Significant increase
Clean hydrogen production	0.8 Mt ^{16), 21)}	614 Mt		Significant increase
Investment needs for clean hydrogen infrastructure	0 ¹⁷⁾	116 USD billion/yr		Significant increase
Clean hydrogen consumption - industry	0 ¹⁸⁾	38 EJ		Significant increase

Geological reservoirs

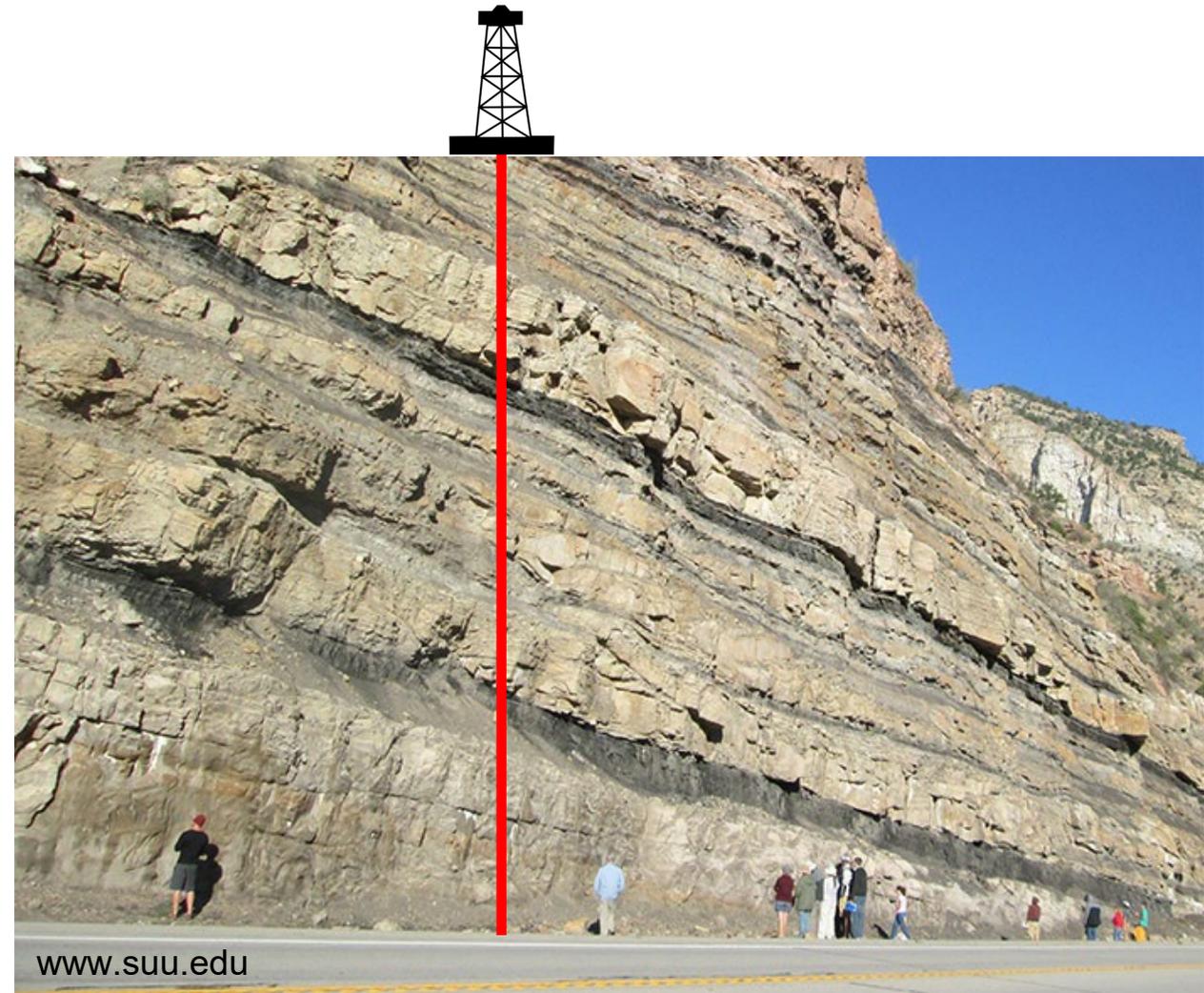
- Geological *heterogeneity* is the *key control* on *fluid flow* in a reservoir and influences engineering and management decisions

BUT

- Geological heterogeneity is *multi-scale*
- Geological heterogeneity is *complex*
- Heterogeneity is sparsely sampled and inherently *uncertain*

SOLUTION

- *Build the reservoir model*



Problems with uncertainty

- We perceive uncertainty in a biased way
- We tend to be overconfident when estimating ranges
- Biases in data and/or our estimates lead to narrowed ranges of uncertainty
- Many reservoir models do not capture uncertainties properly
- **Missing out on key uncertainties can lead to dramatic consequences**



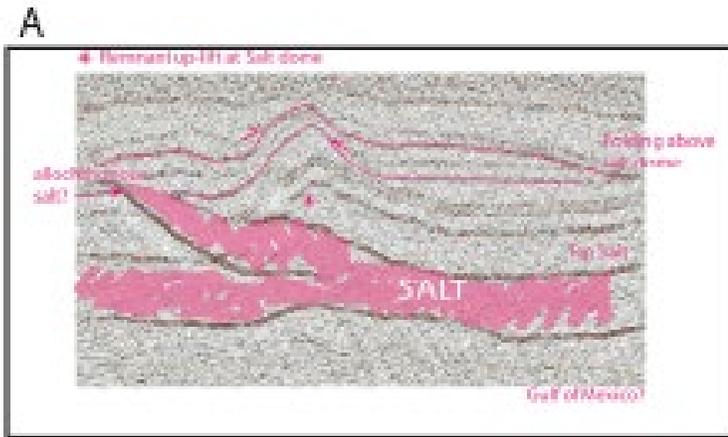
A classical example of uncertainty and bias

How would you interpret this section?

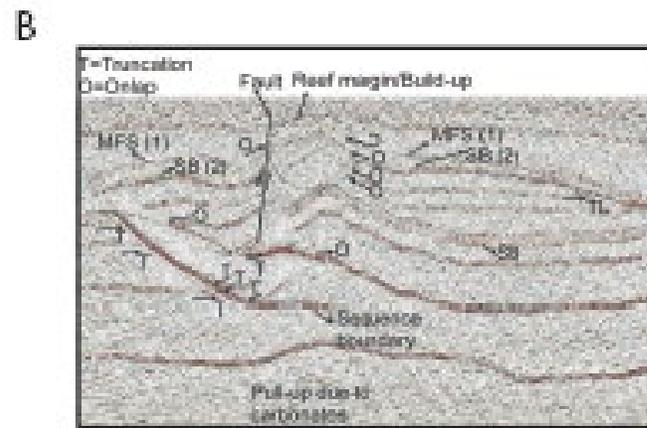
Midland Valley 



Different geological concepts due to different experiences



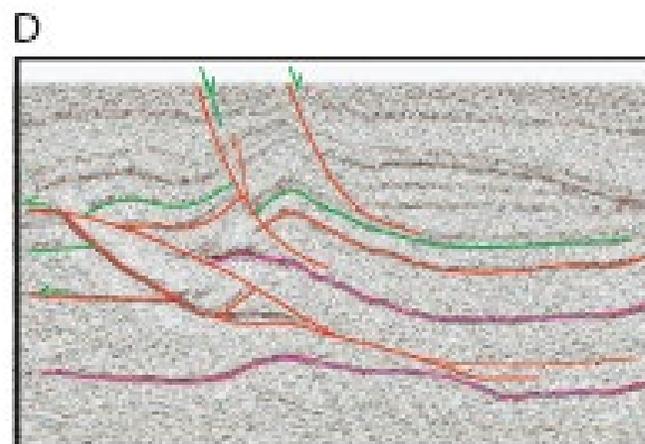
Student - PhD salt tectonics



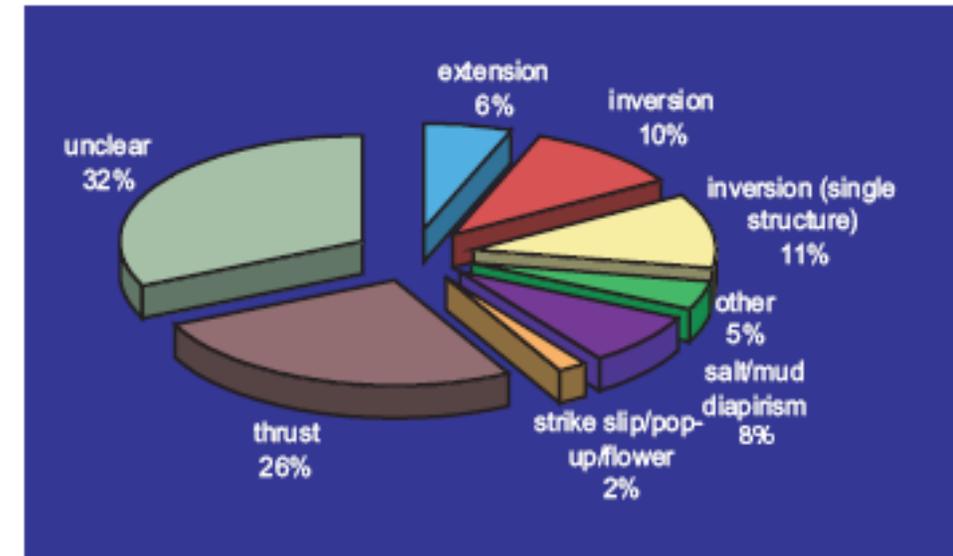
Student - MSc sequence stratigraphy



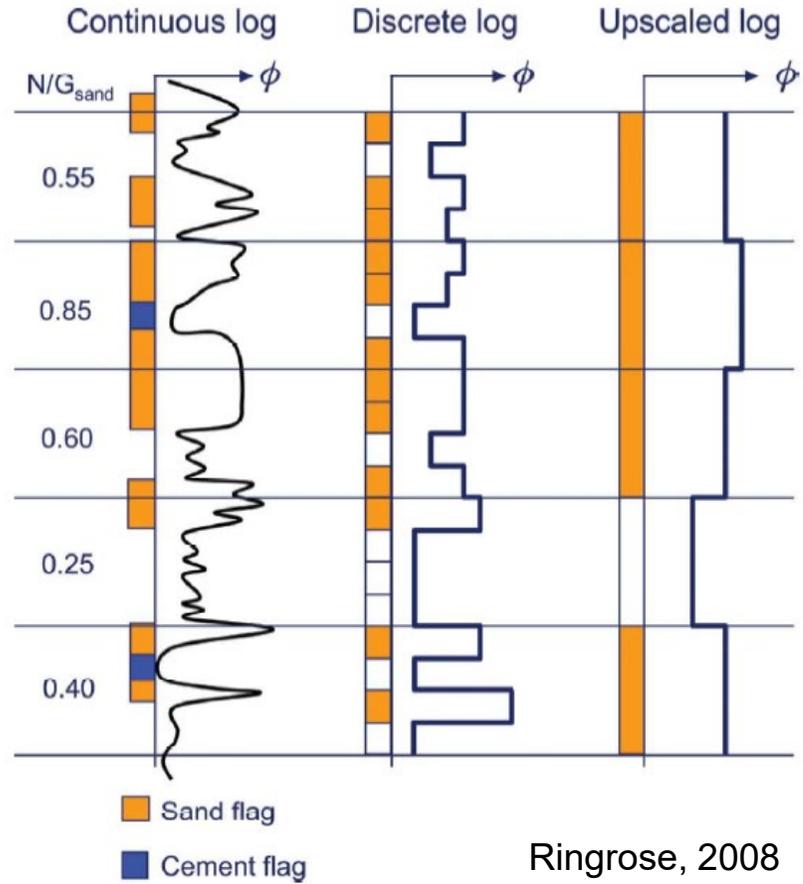
+15 yrs - thrust expertise



+15 yrs - extensional expertise

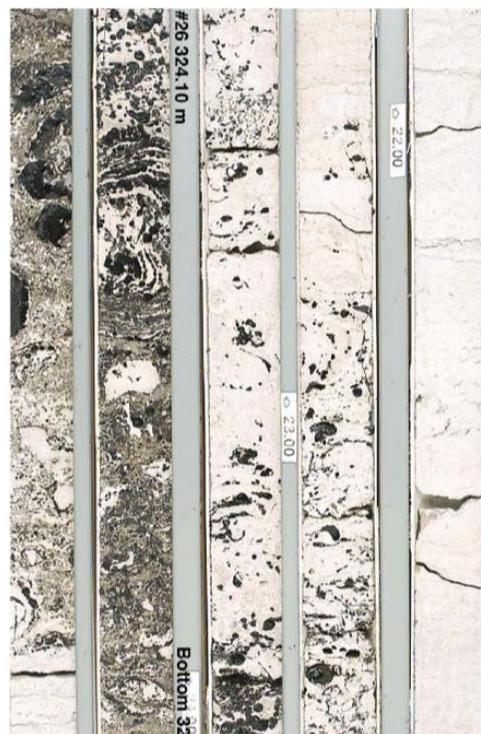
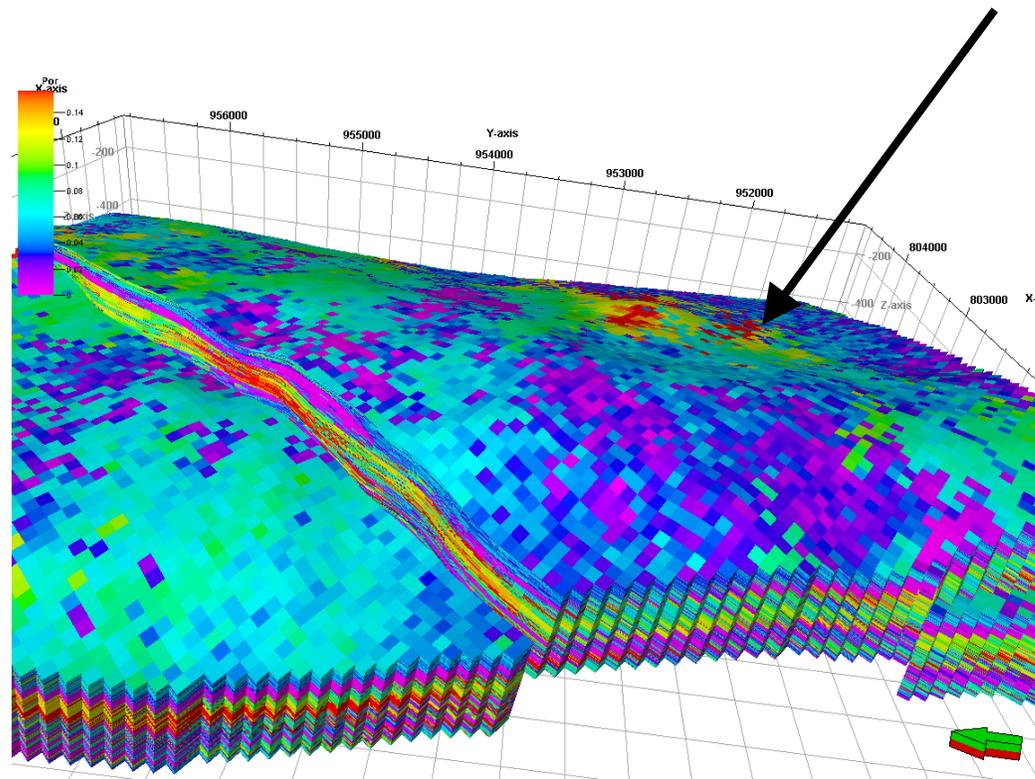


Even the “hard data” in a model is uncertain (and biased)



A real reservoir model

A single grid block of
100 x 100 x 2 m contains
~ 5,000 t fluid and ~ 50,000 t rock
All with uniform properties

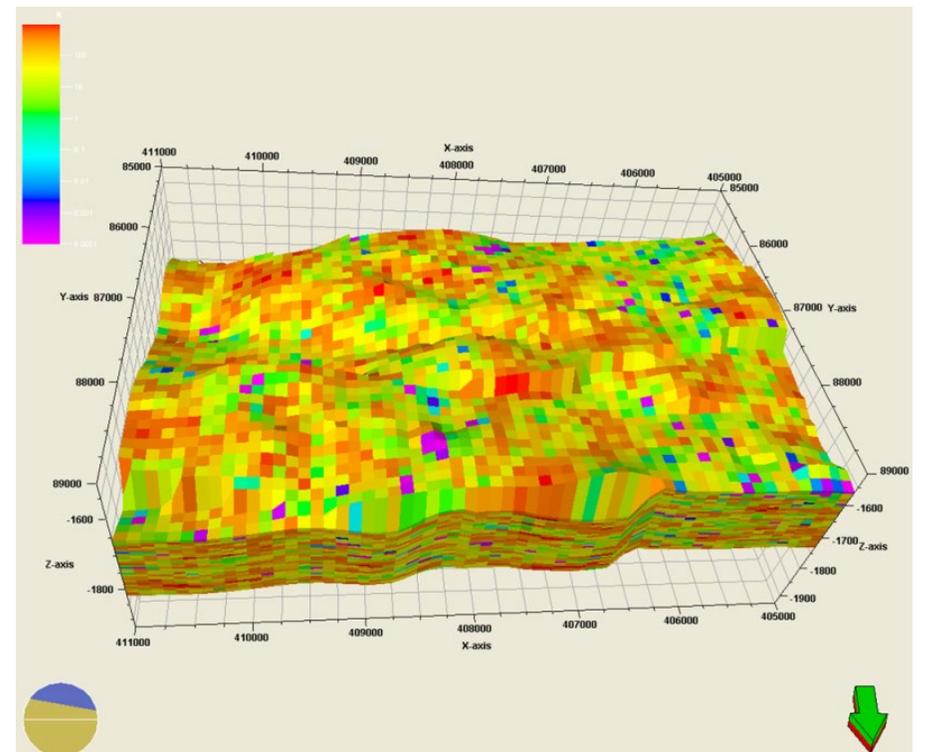
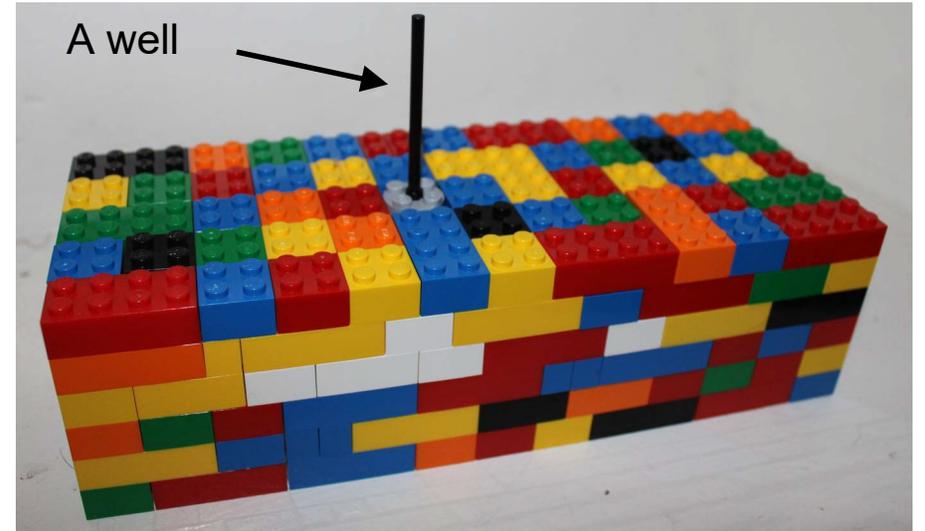


Several km

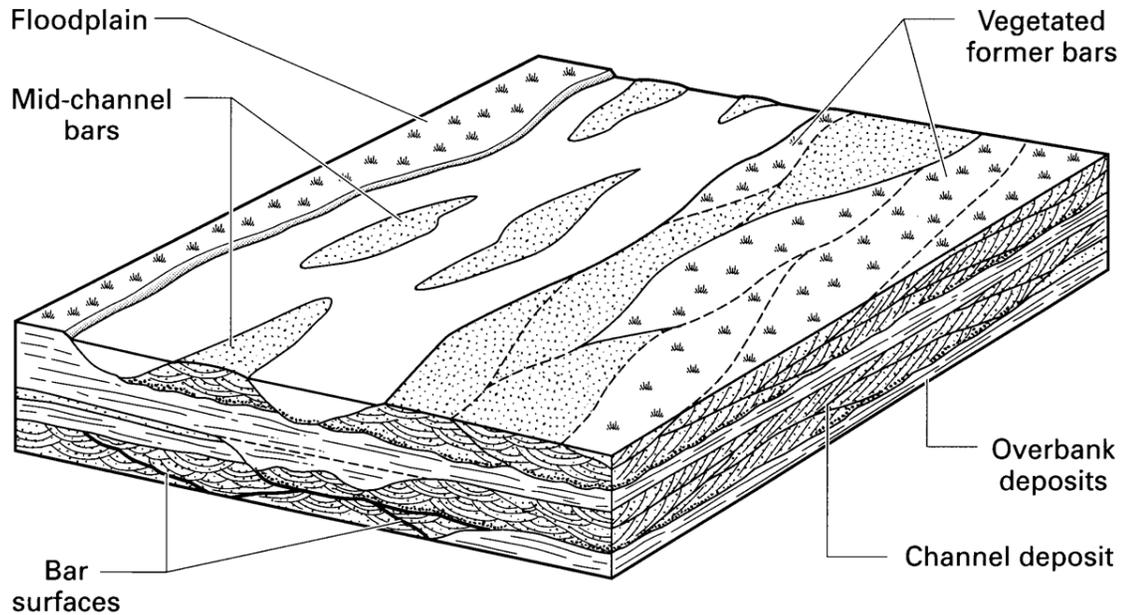


Reservoir modelling often is...

- a slow and inefficient exercise in compromise
- requiring us to lock in concepts early and hence limits exploration of different model scenarios
- a poor representation of a reservoir system
- emphasising “matching” vs. “learning”
- underestimating uncertainty
- creating big models that are precisely wrong
- often resulting in two things we don't understand
 - the reservoir and the model



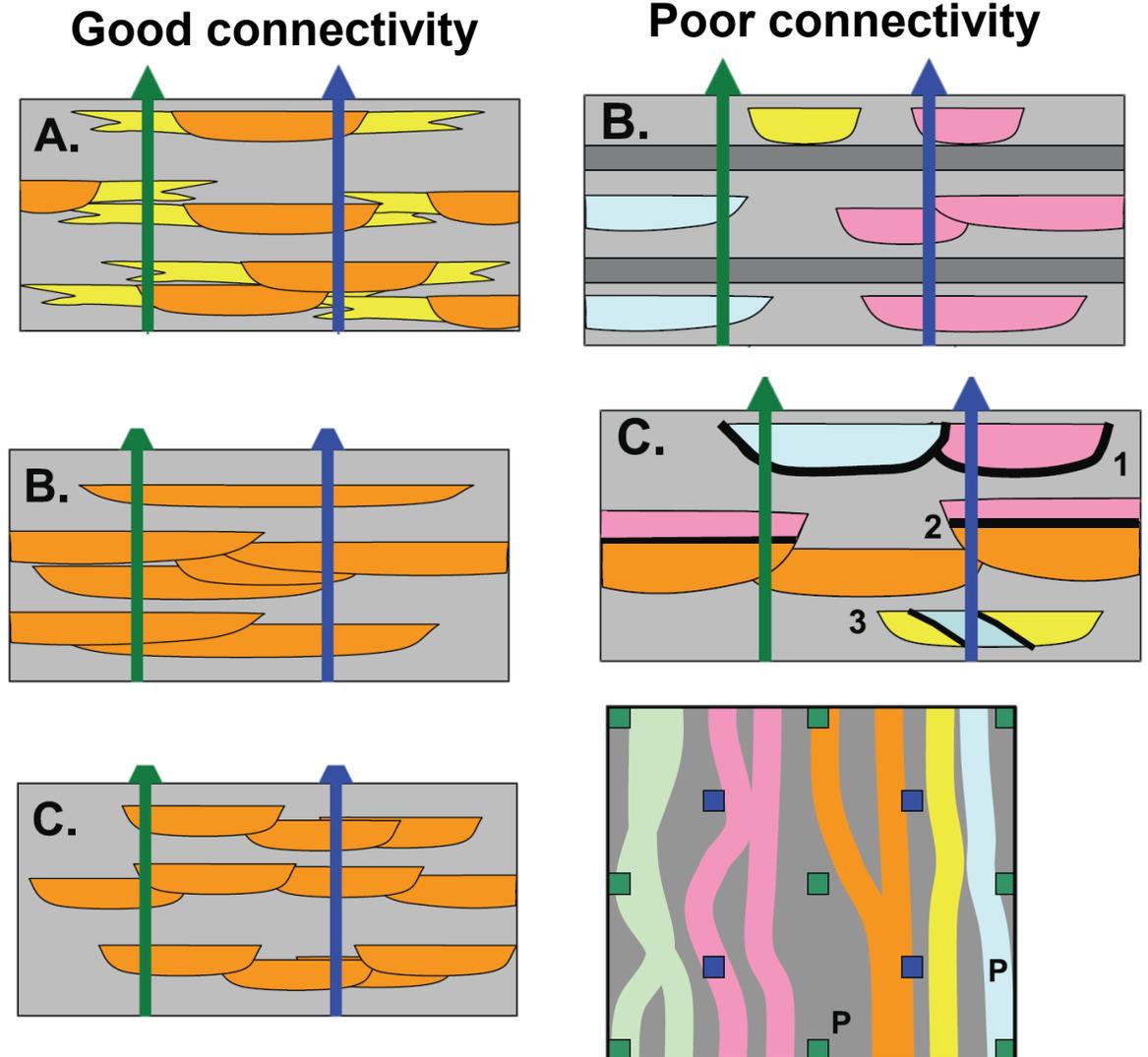
If you can't draw it, don't model it



- If you can draw your geological concept then you understand what you are trying to build
- If your model looks nothing like what you drew then it's probably wrong
- Another geological concept means another (possibly very different) model

Capture heterogeneity and connectivity

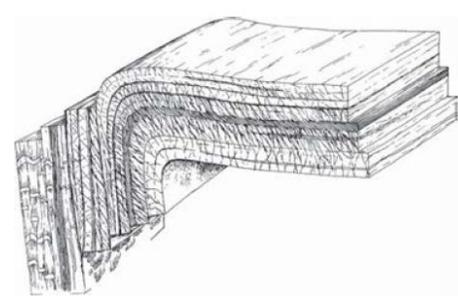
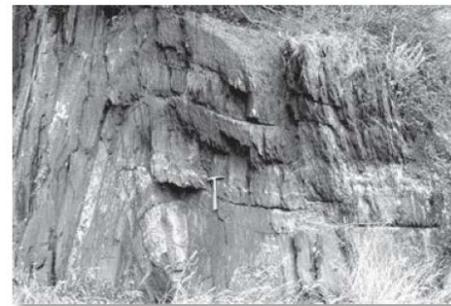
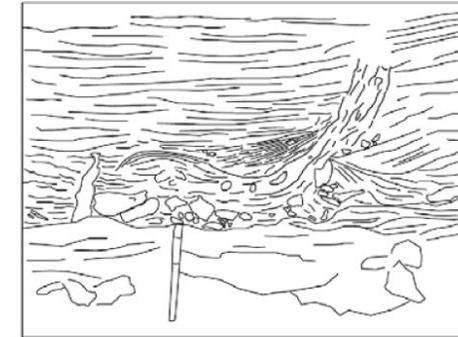
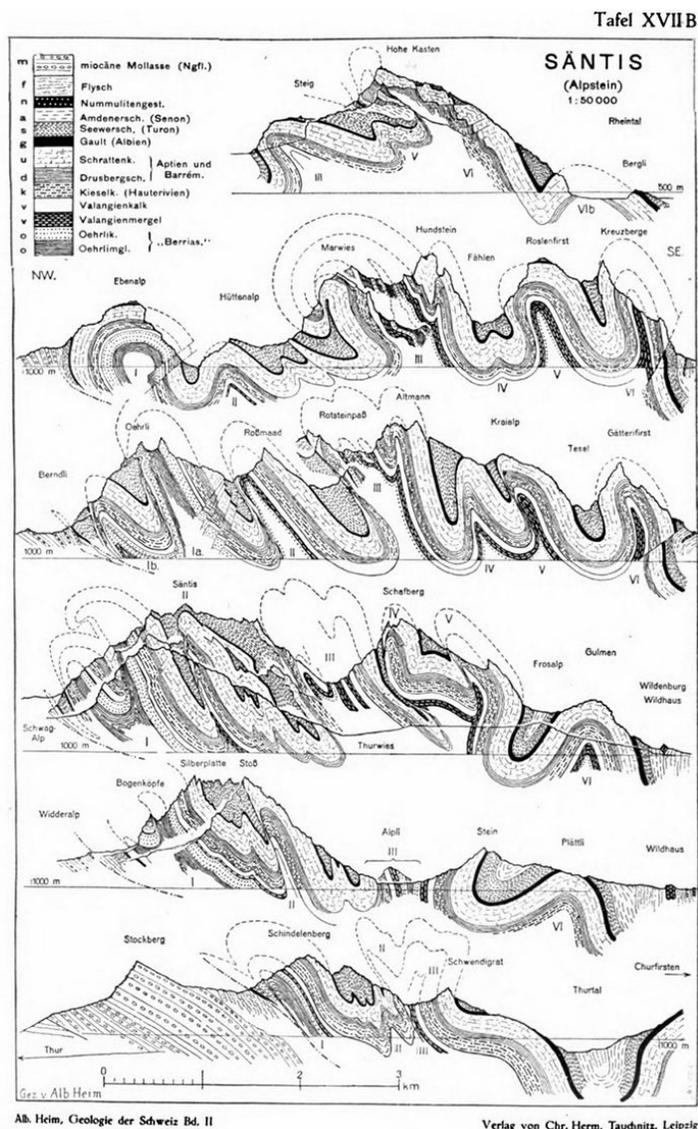
- **Magnitude** of heterogeneity
- **Scale** of heterogeneity
- **Degree** of connectivity
- **Complexity** of flow paths

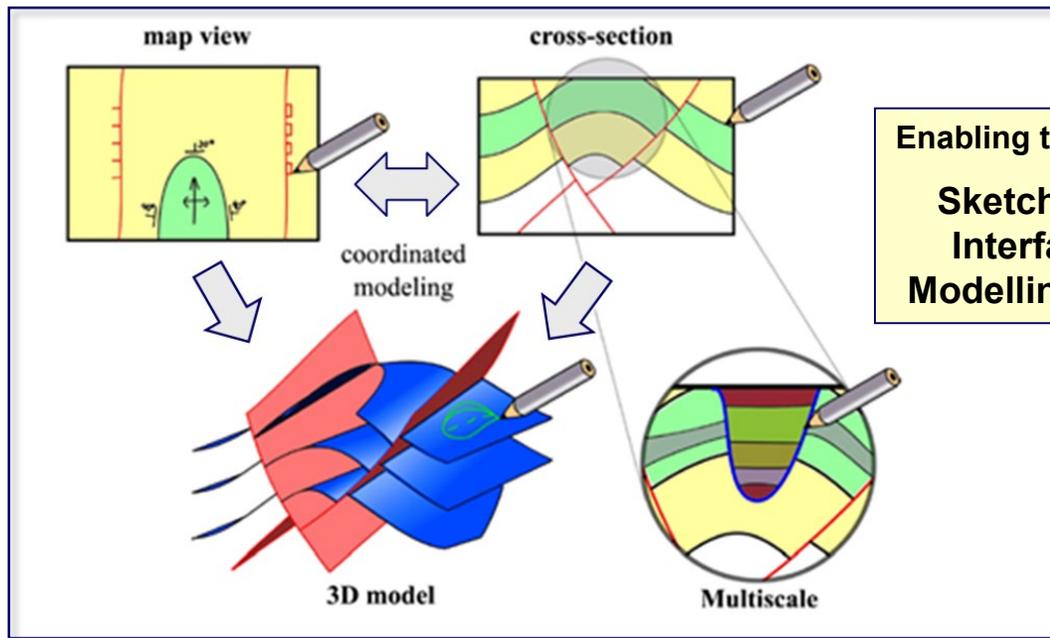


Larue and Hovadik, 2006

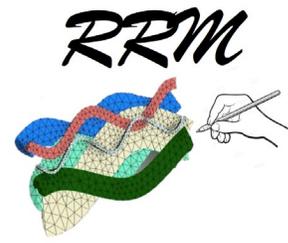
Prototype reservoir models from geological sketches

Hypothesis: Is it possible to create reservoir model prototypes interactively, rapidly and intuitively to analyse how geology influences reservoir flow at multiple scales?

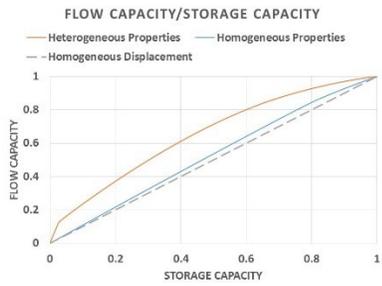
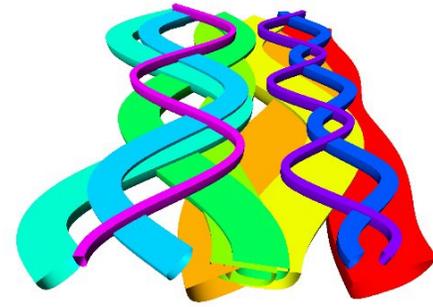
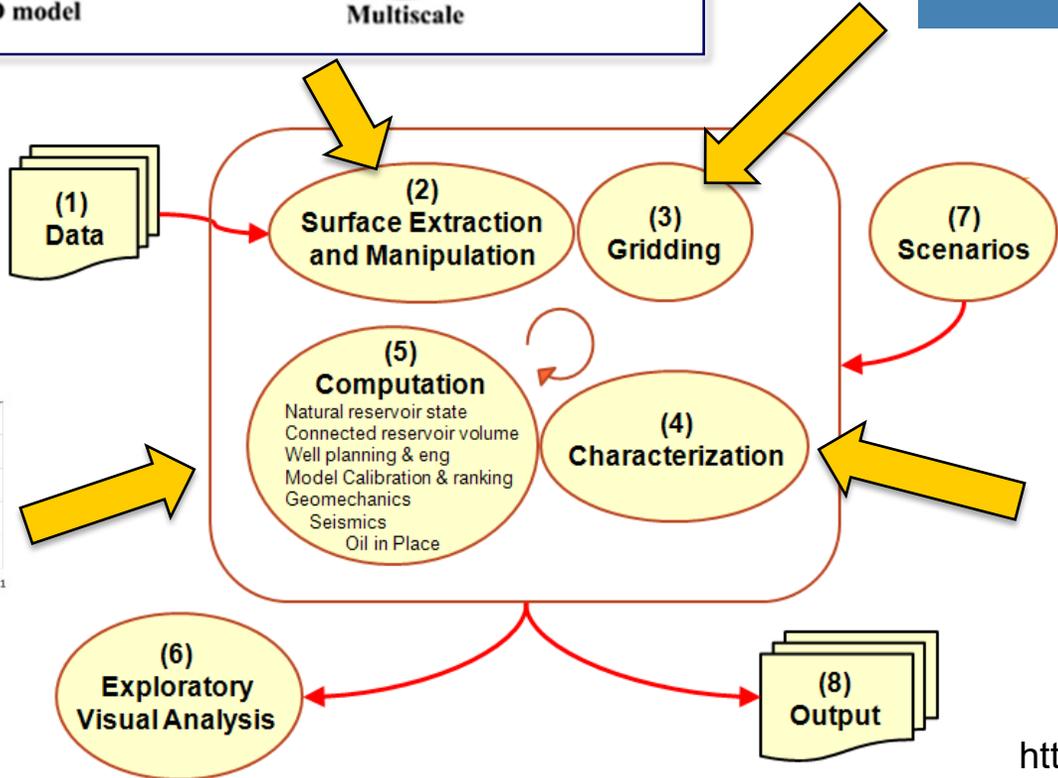
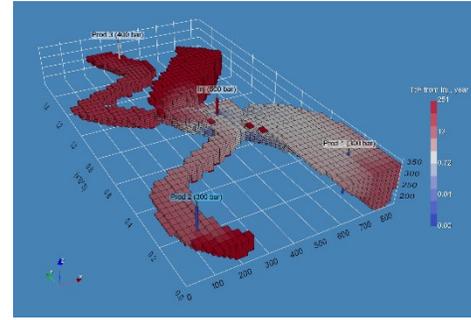




Enabling technology:
**Sketch-based
 Interfaces &
 Modelling (SBIM)**



RRM Workflow



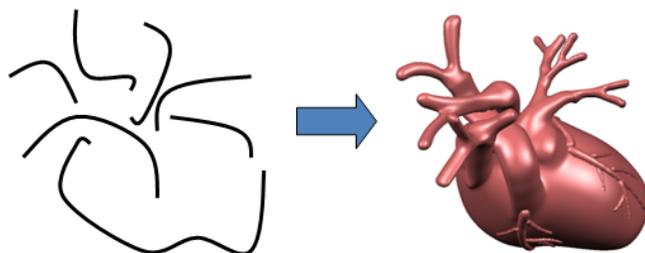
**Flow approximation,
 diagnostics**

Enabling technology: SBIM

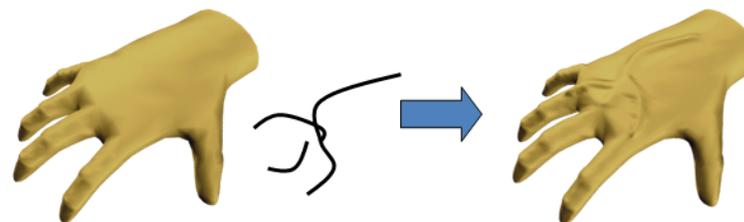
Approximation + Storyboarding + Fast



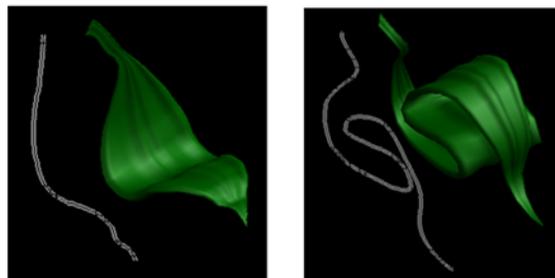
Overall Form



Shape Augmentation



Conceptual / Operator Marking

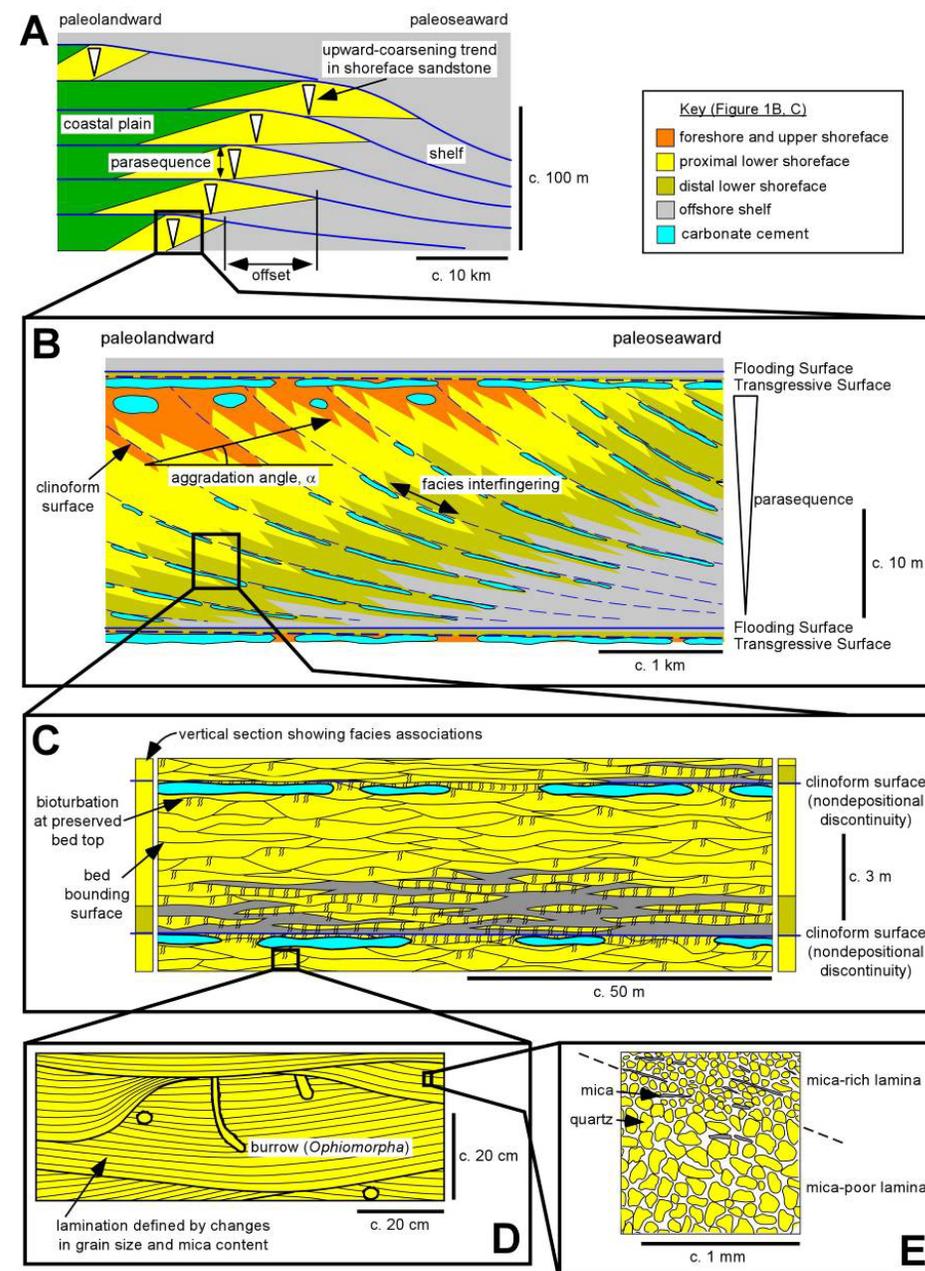


- **Content creation**
(Walt Disney, Electronic Arts)
- **Car industry** (FIAT)
- **Technical, Medical & Science Illustrators**
- **Botany**
- **Medicine**
- **Oil & Gas Industry** → RRM

Surface-based modelling and SBIM

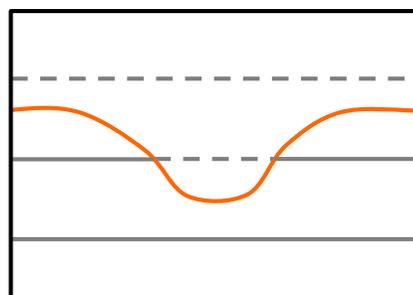
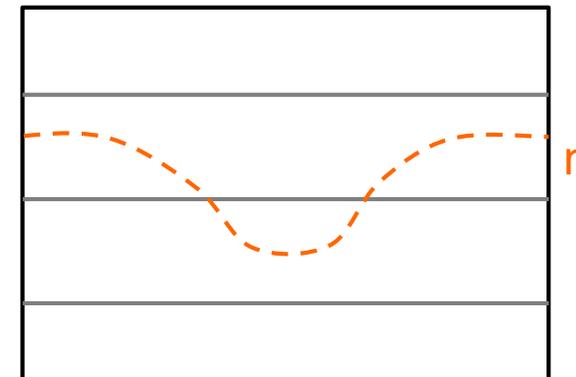
- Geological heterogeneity is modelled as one or more discrete rock volumes bounded by surfaces (“geological domains”)
- Hierarchy of surfaces (faults, stratigraphy, facies, diagenetic bodies...)
- Transport (petrophysical) properties within geological domains are constant
- Equivalent to a grid-based approach but petrophysical properties are constant within geologically meaningful domains

Jackson et al., 2013 and Hampson et al., 2018

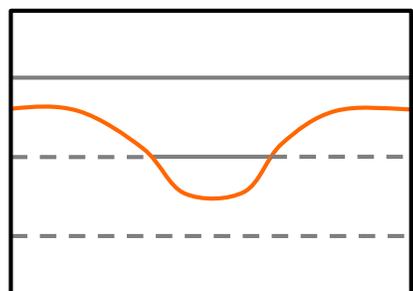
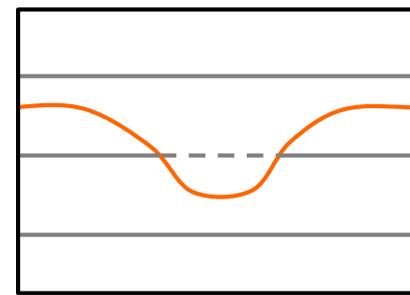
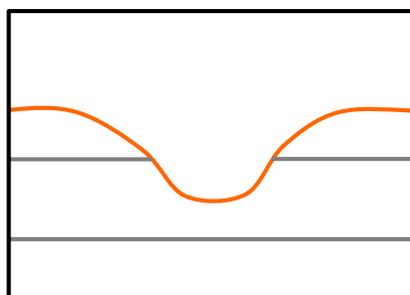


Stratigraphic rules for surface interactions

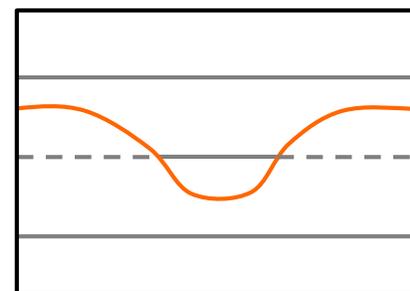
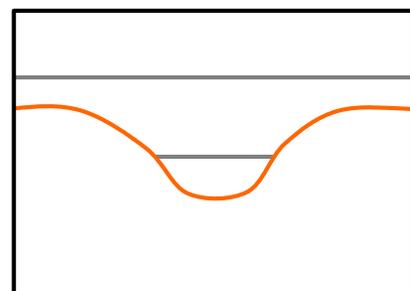
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4. Remove below intersect



Remove Above

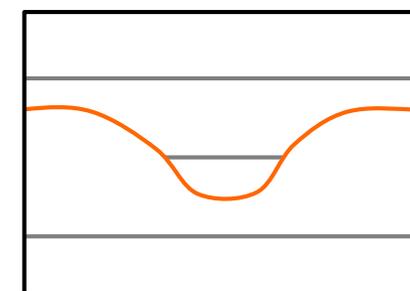
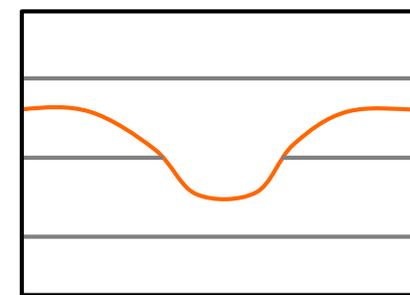


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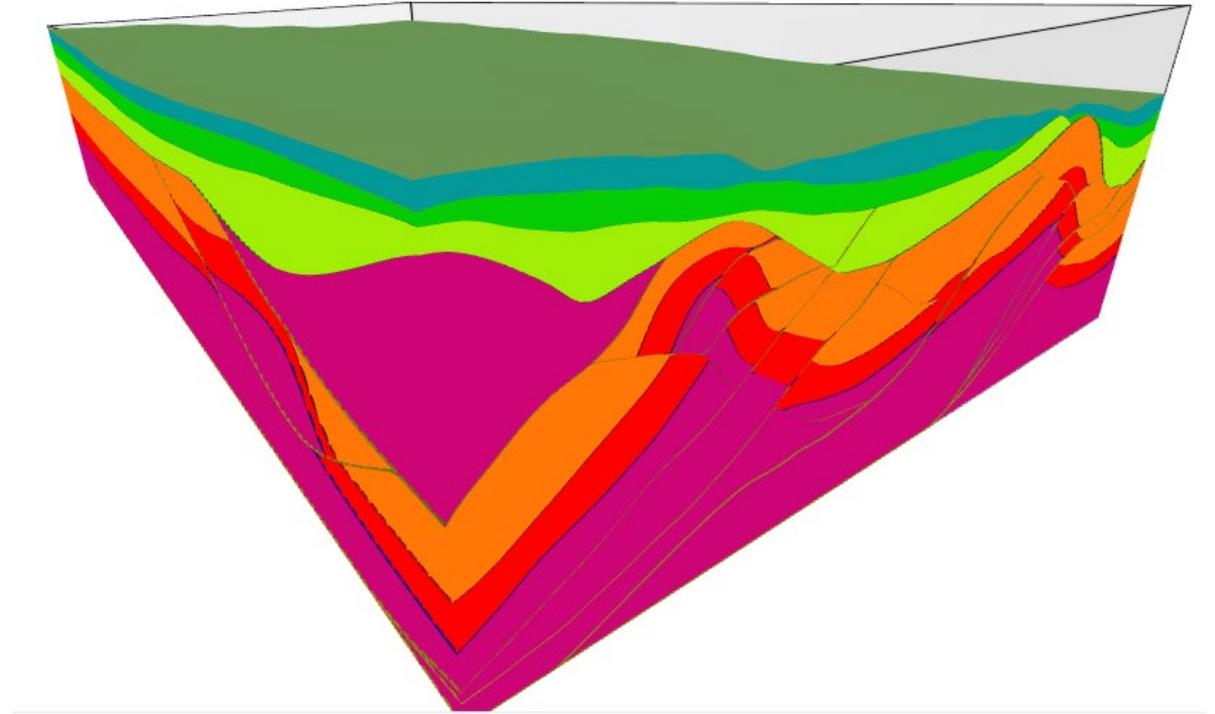
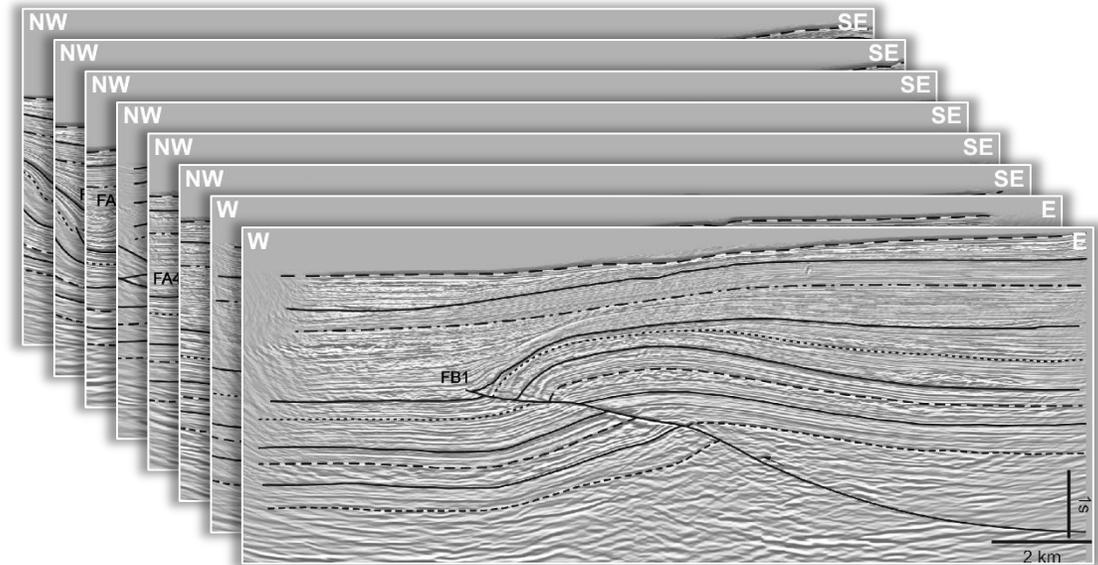
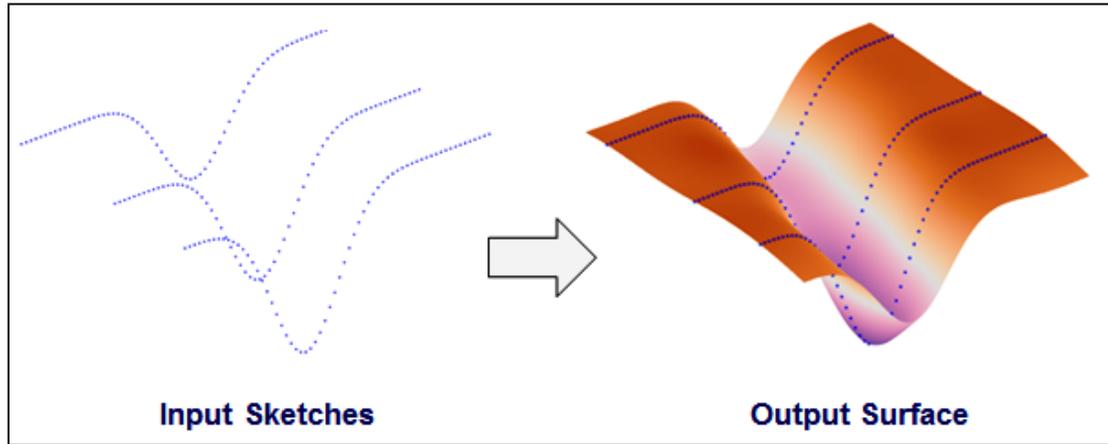


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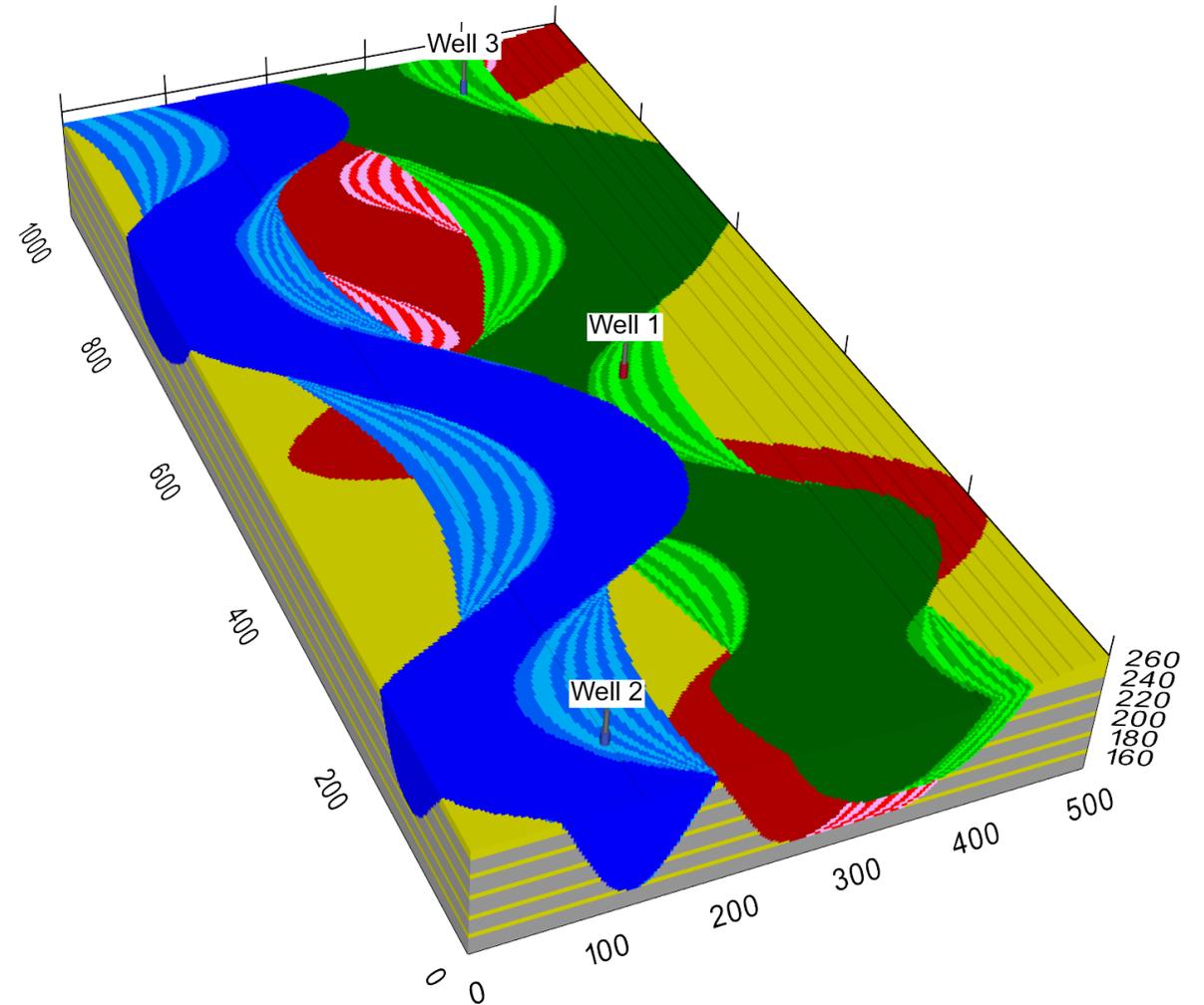
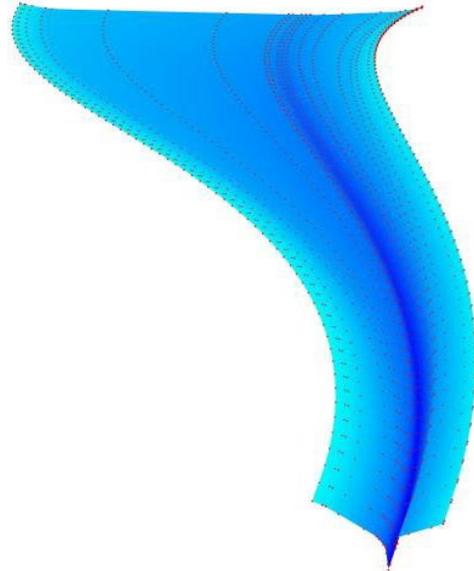
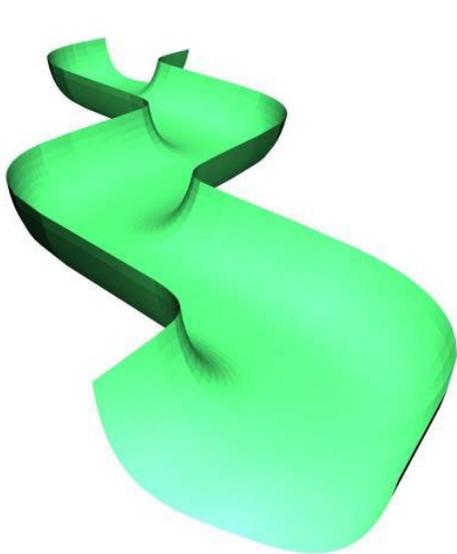
Remove Below Intersect



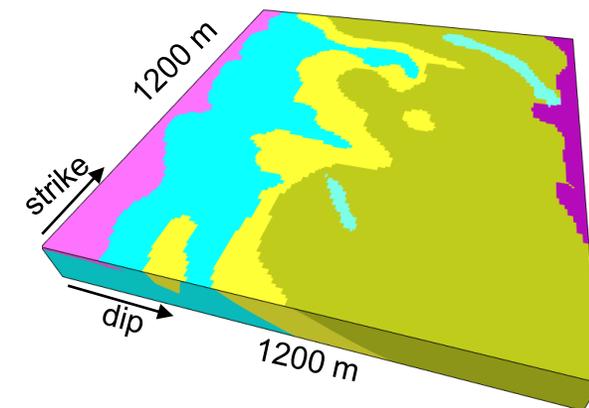
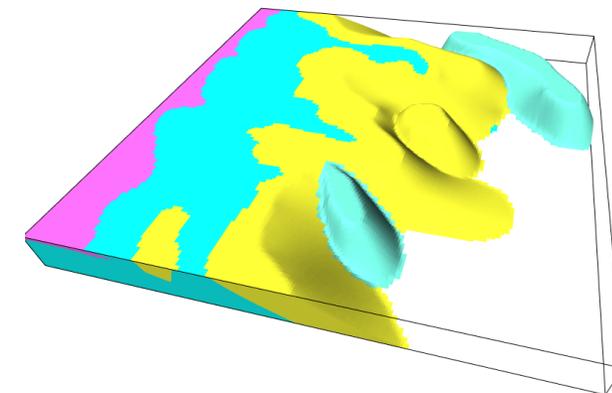
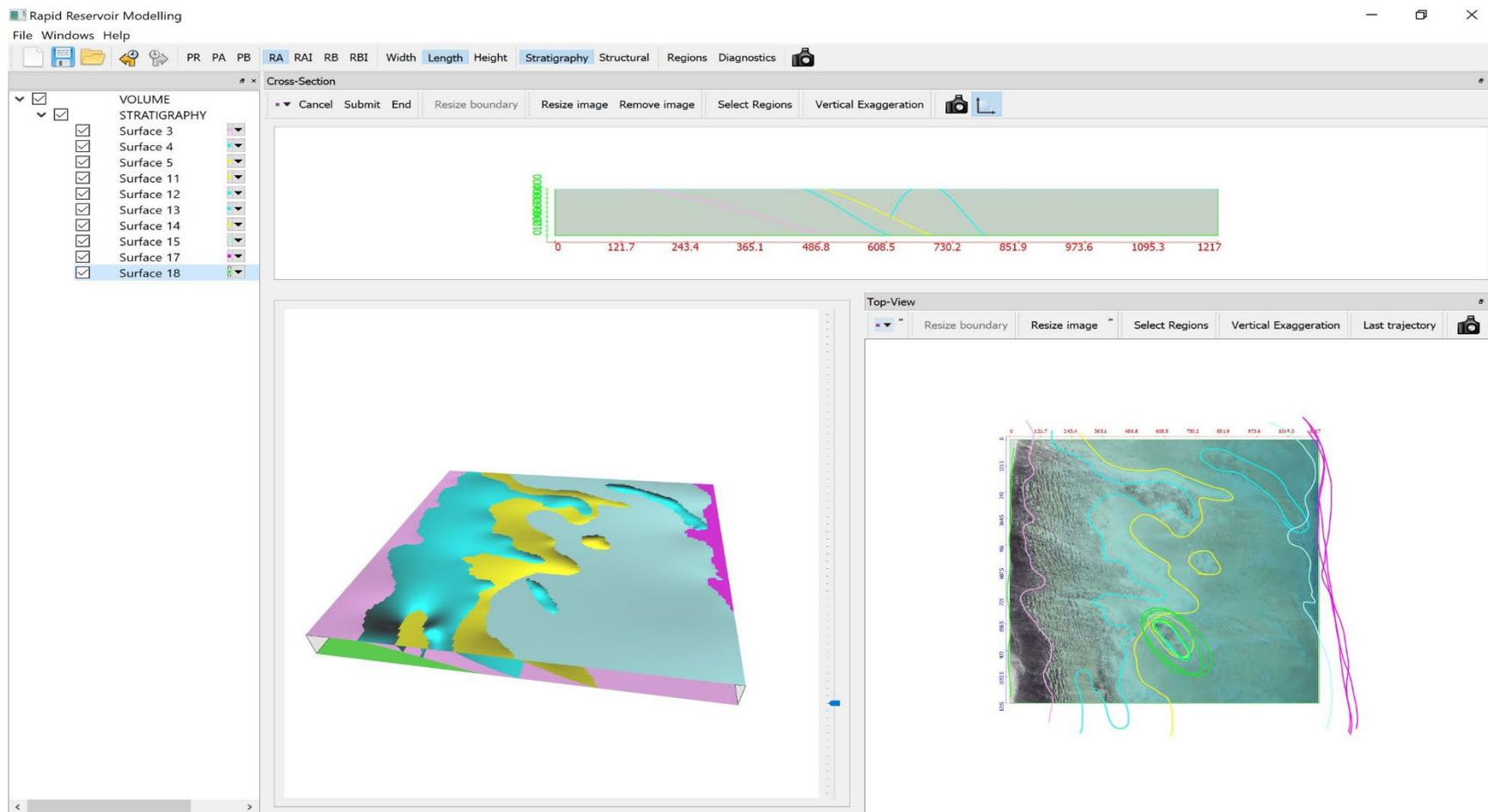
From 2D to 3D: Interpolating between cross-sections



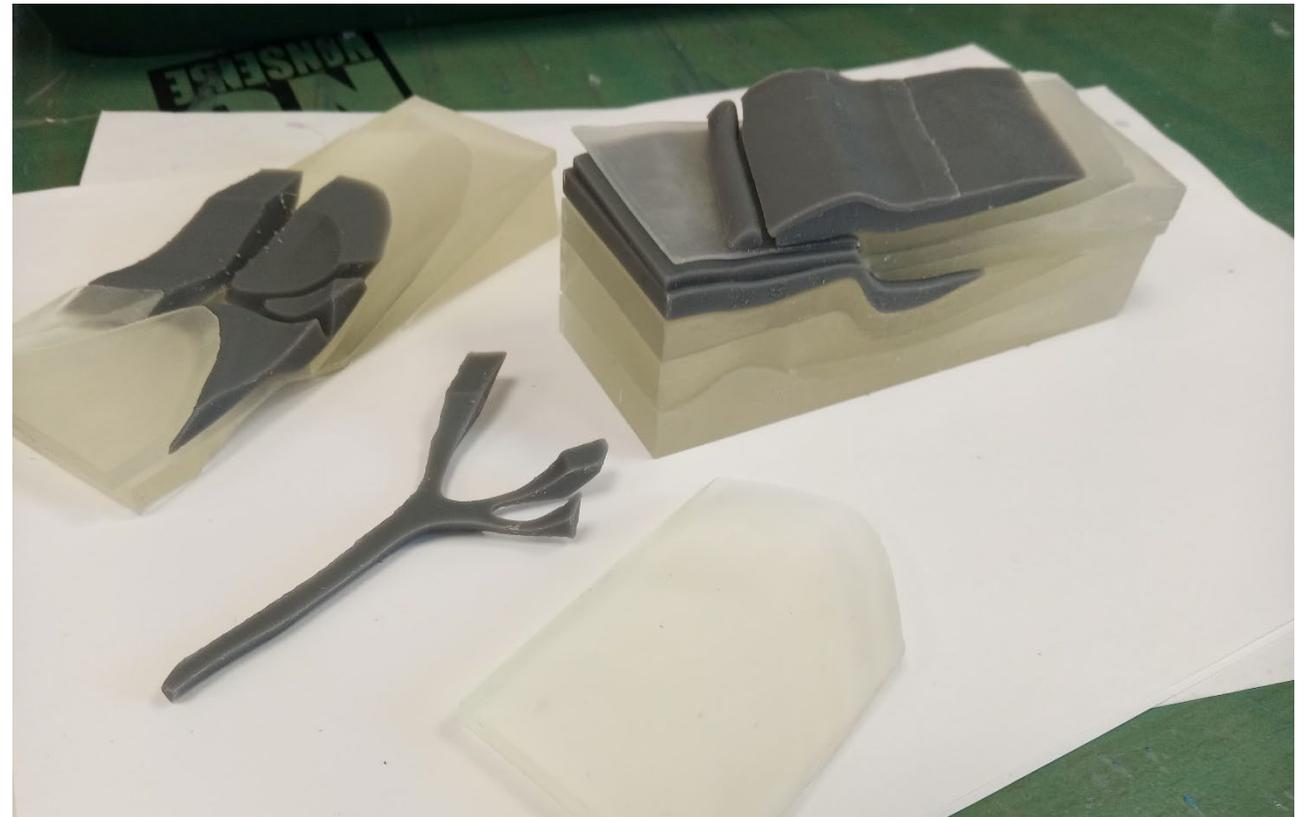
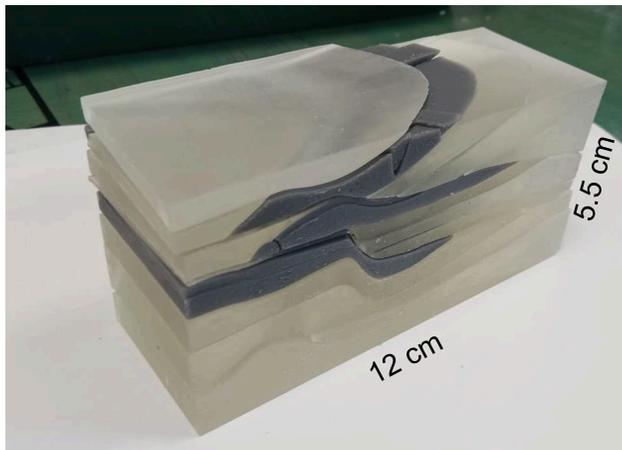
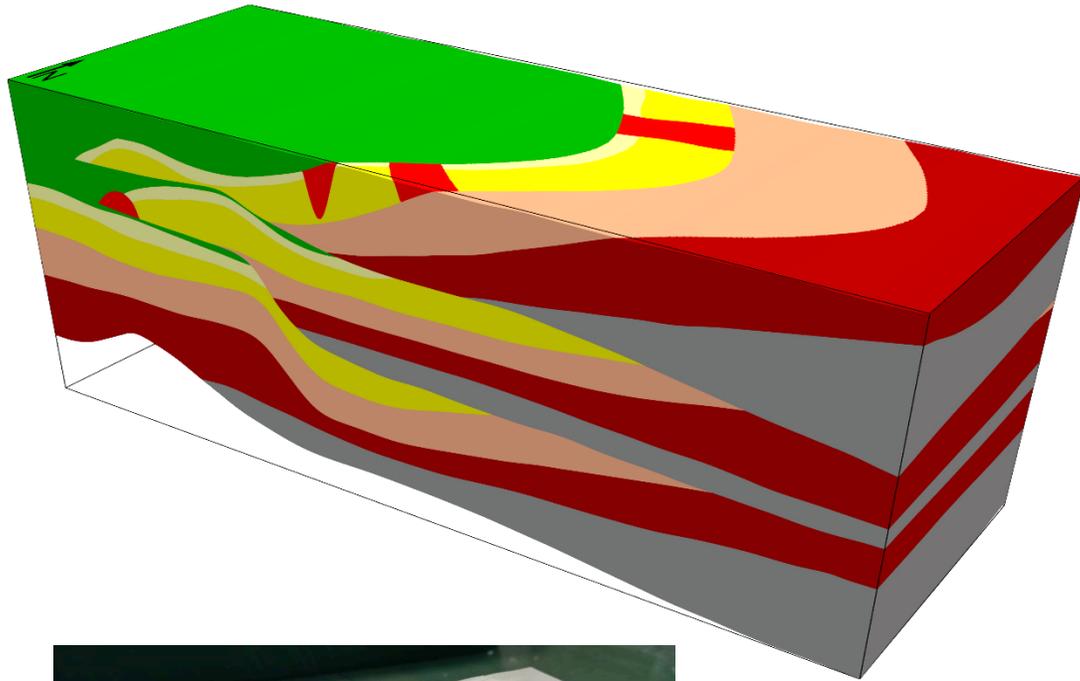
From 2D to 3D: Extrusion along paths



From 2D to 3D: Contour lines

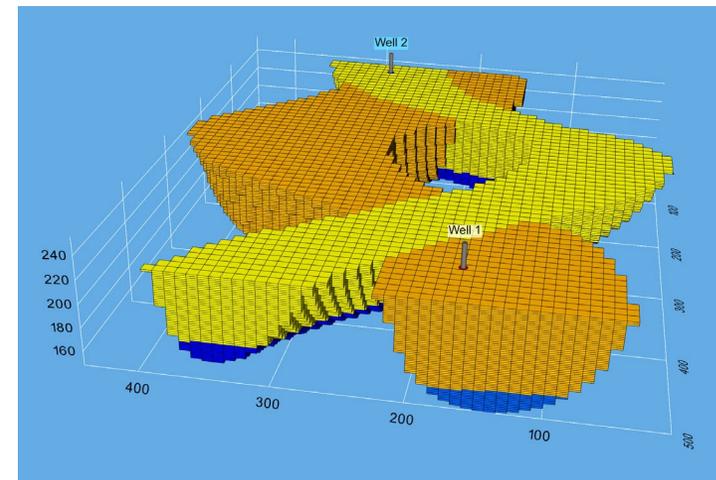
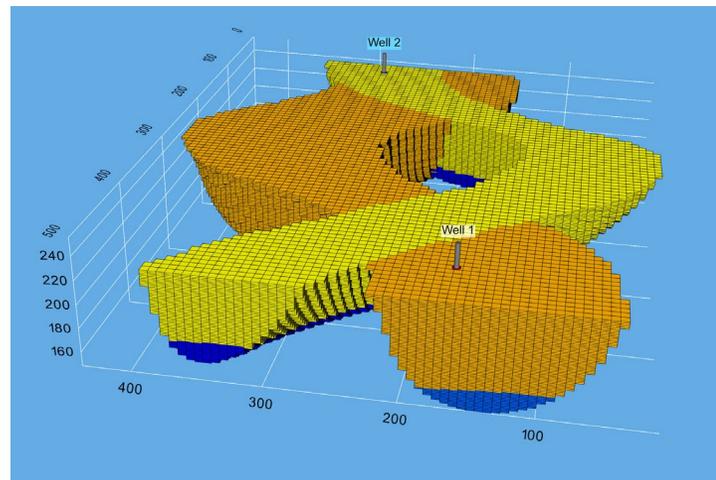
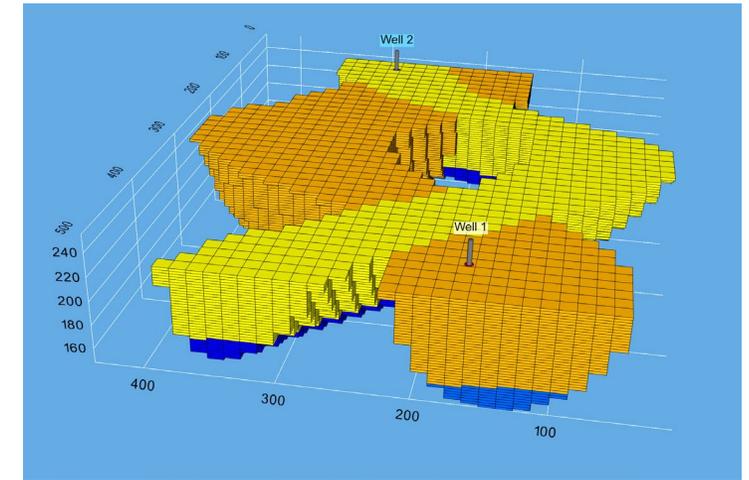
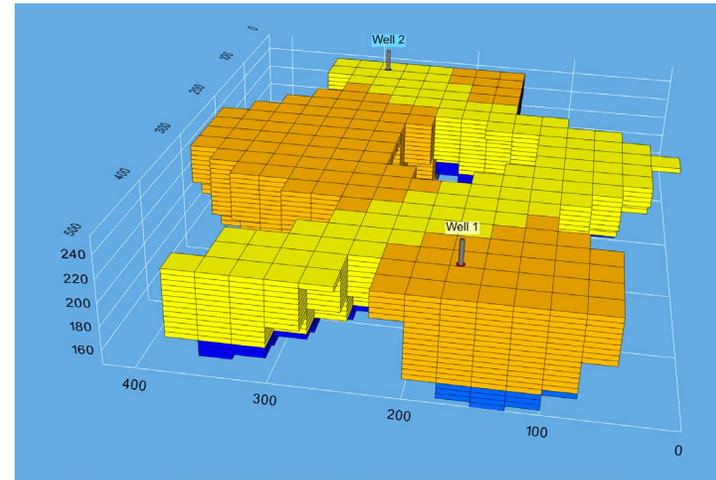
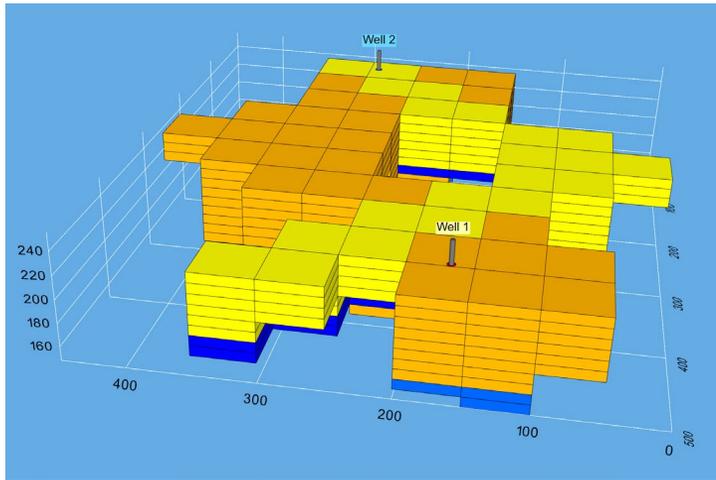


NB: Exploring reservoir models through 3D printing



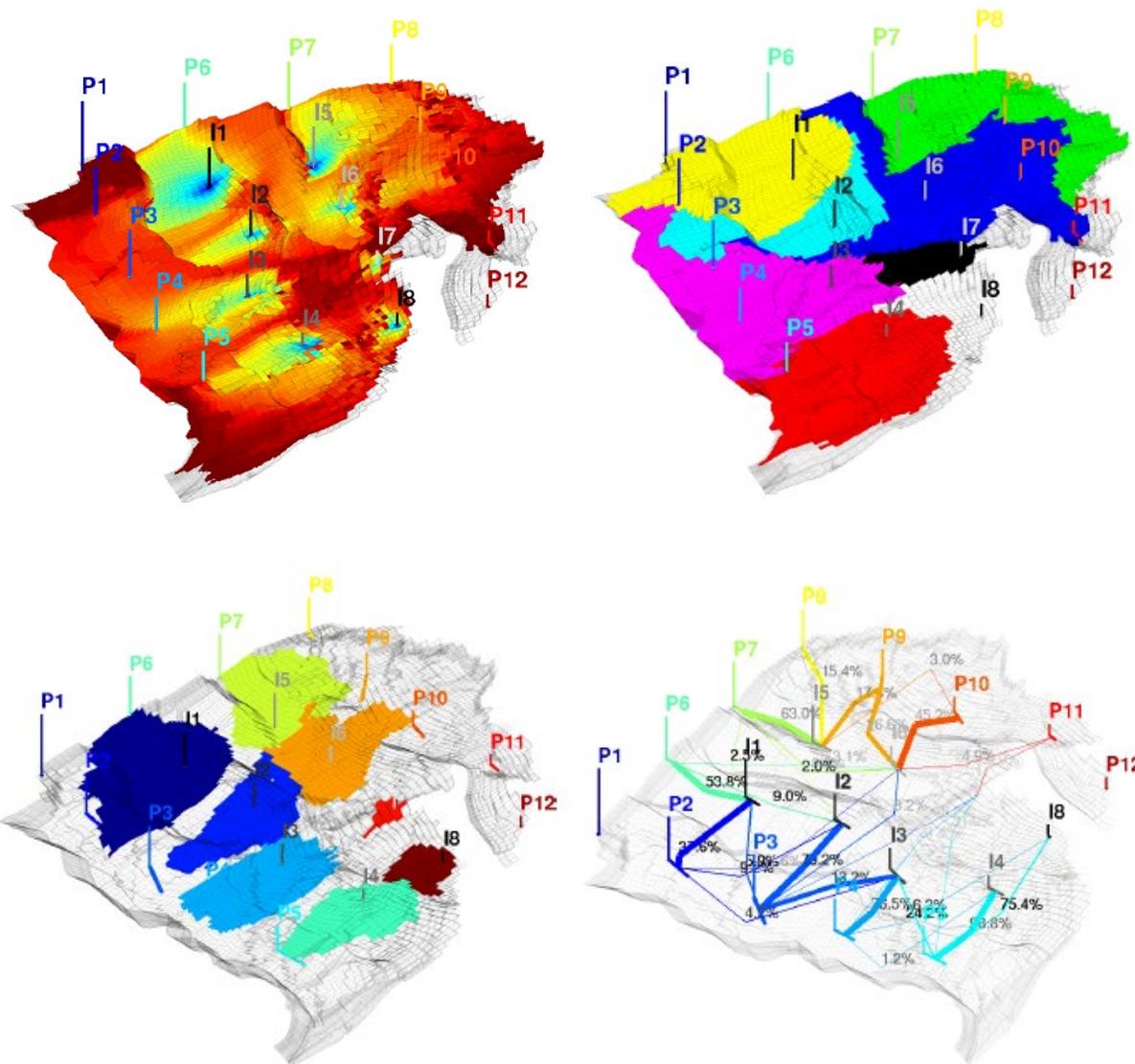
Model printed by PhD student Alex Patsoukis at Heriot-Watt University

Grids are generated on demand

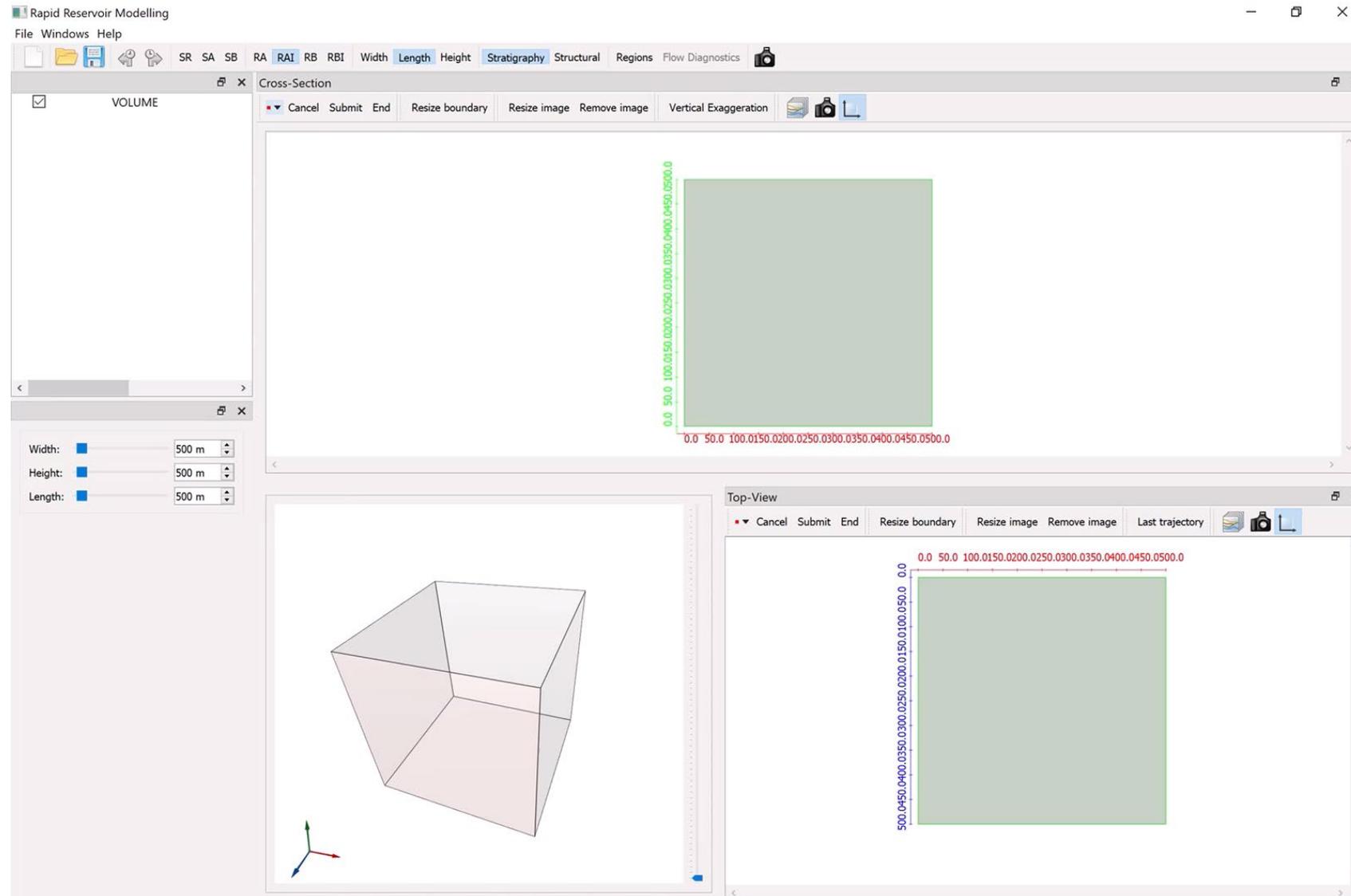


Approximating reservoir dynamics with flow diagnostics

- Provides information
 - Reservoir pressure
 - Time-of-flight
 - Reservoir partitioning
 - Well allocation factors
 - Sweep efficiency
 - Dynamic heterogeneity
- Very fast (order of seconds)
 - Based on steady-state approximations

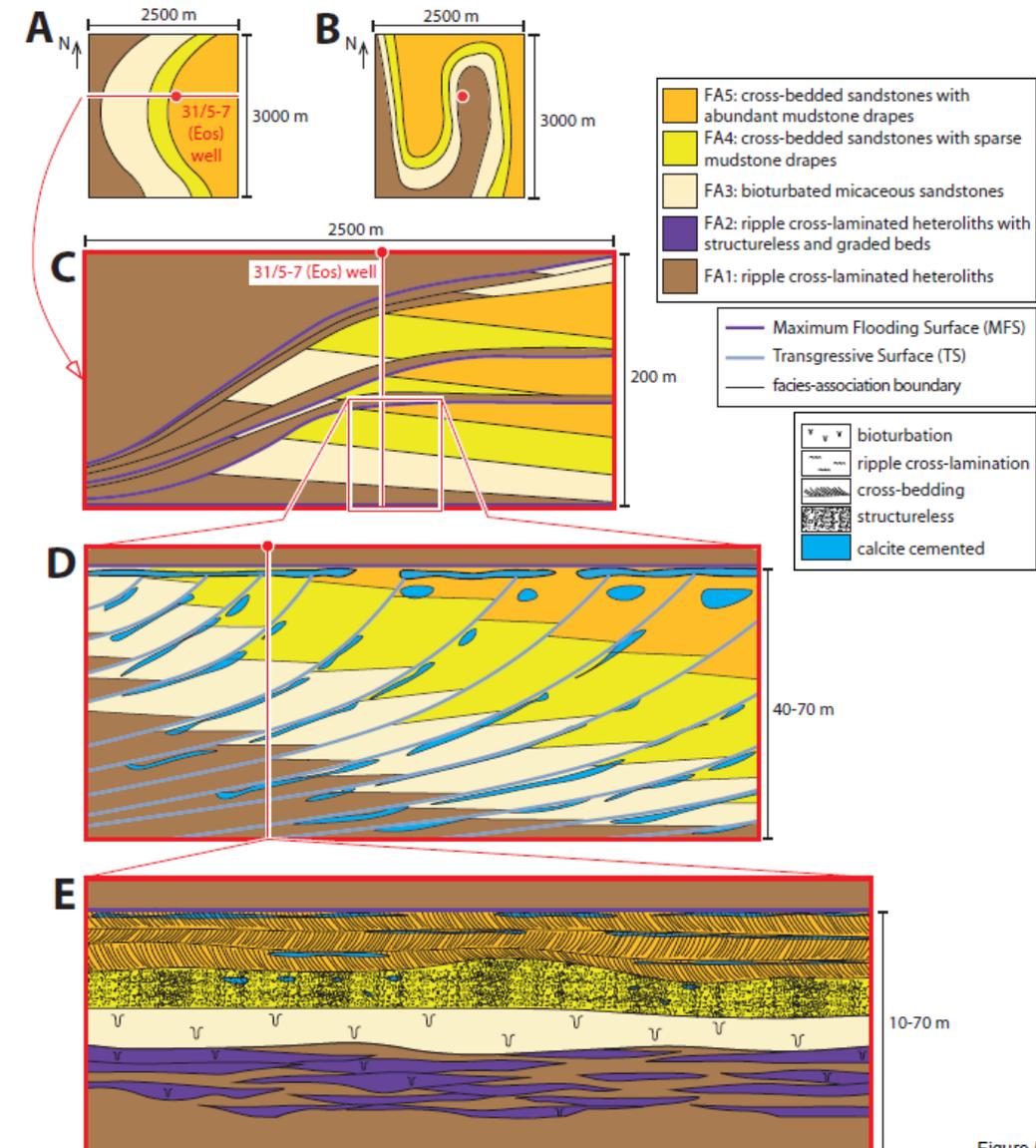


A real-time RRM example



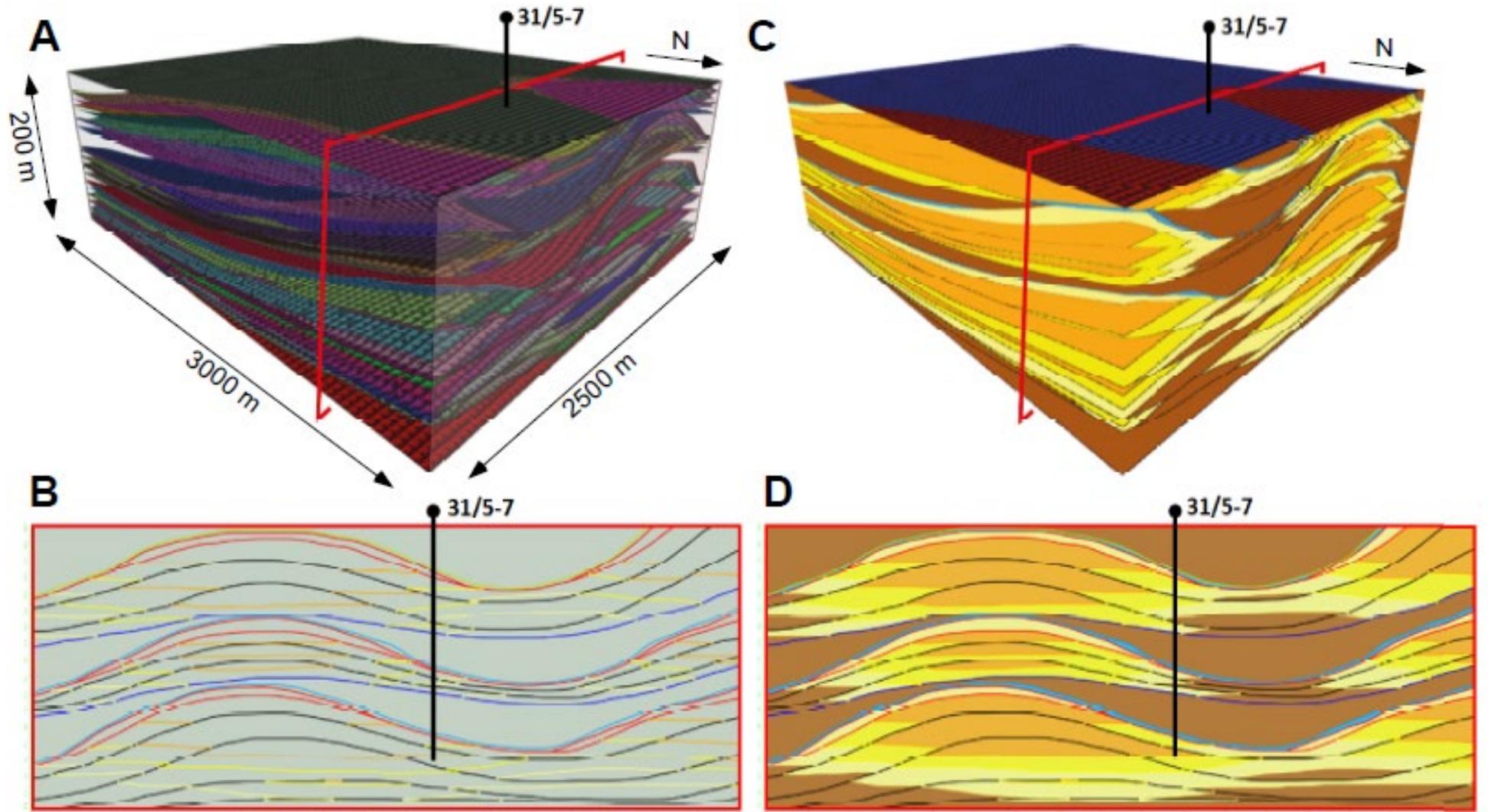
RRM for the Northern Lights CCS Project

- Central CO₂ storage hub for Europe
- Shallow marine Johansen Formation
- Test impact of multi-scale sedimentary heterogeneities on storage and approximate CO₂ plume migration
- Experimental design with 32 reservoir models
- Flow diagnostics to assess pore volumes for storage and PV injected at breakthrough for each model and different well locations
- Entire work done in a few weeks



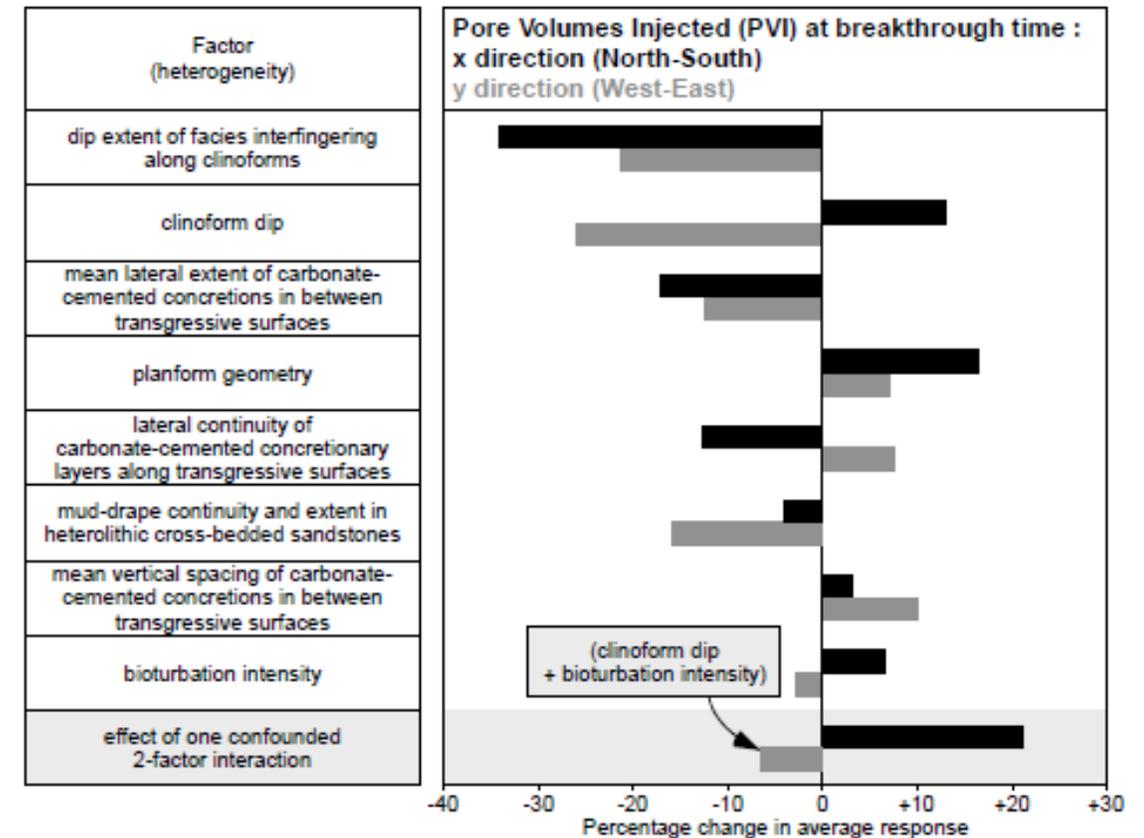
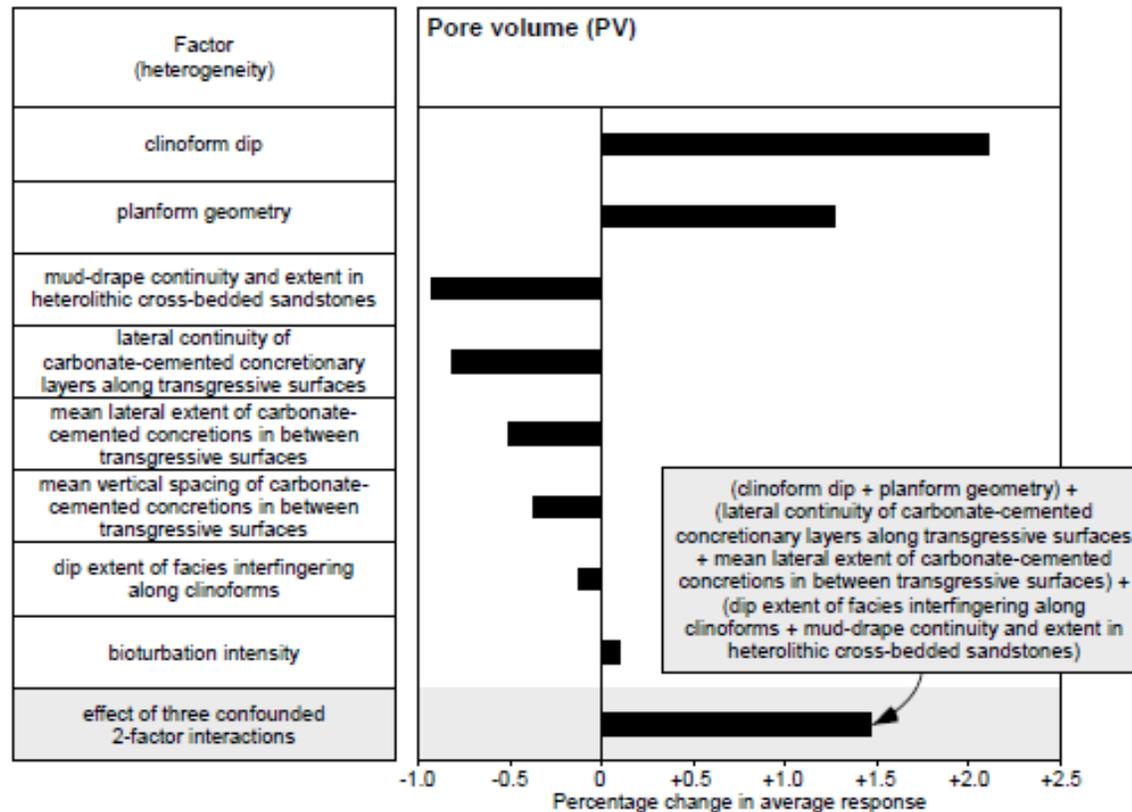
Example models

Jackson et al., 2022



Initial sensitivity analysis and screening

Jackson et al., 2022



Summary

- The energy transition is accelerating and geoscience will play an important role
- We need to ensure that geological uncertainties are properly considered and integrated with reservoir engineering decisions
- Subsurface modelling outcomes will influence large-scale energy system integration
- Shift from being initially precisely wrong to being approximately right first, then proceed



Thank you for your attention

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