Structural Uncertainty: Why it matters to Carbon Storage

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Midland Valley Exploration

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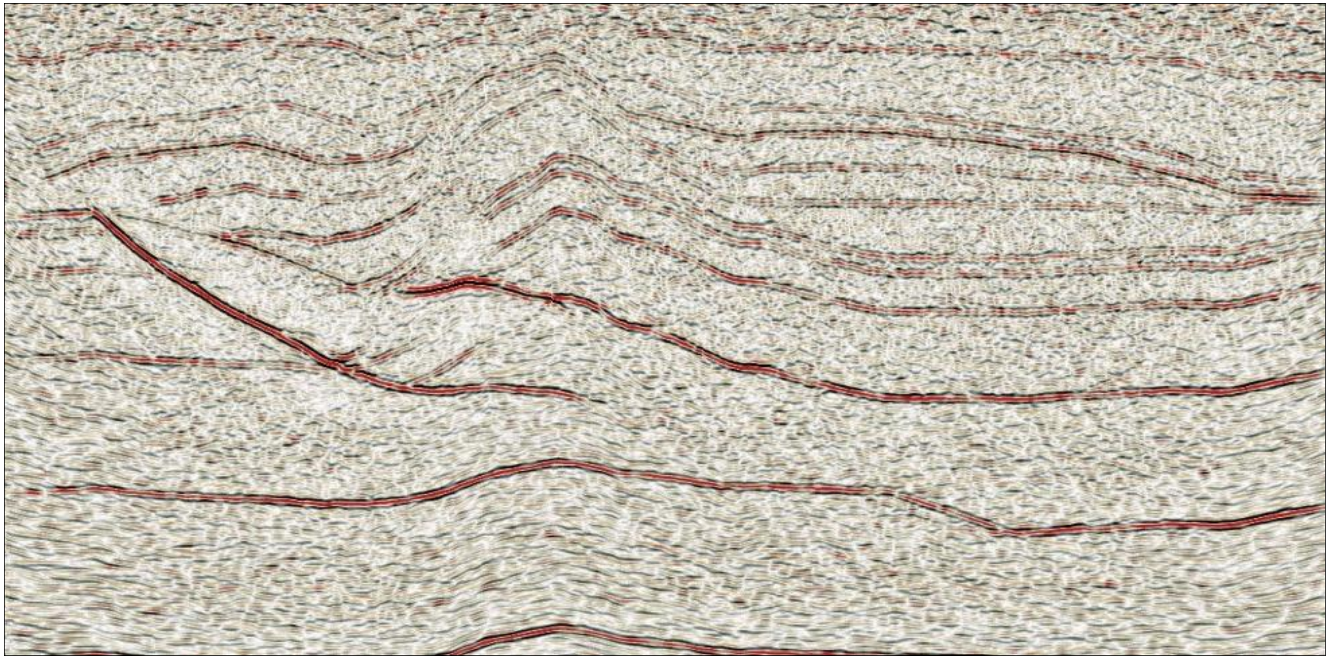
Aim

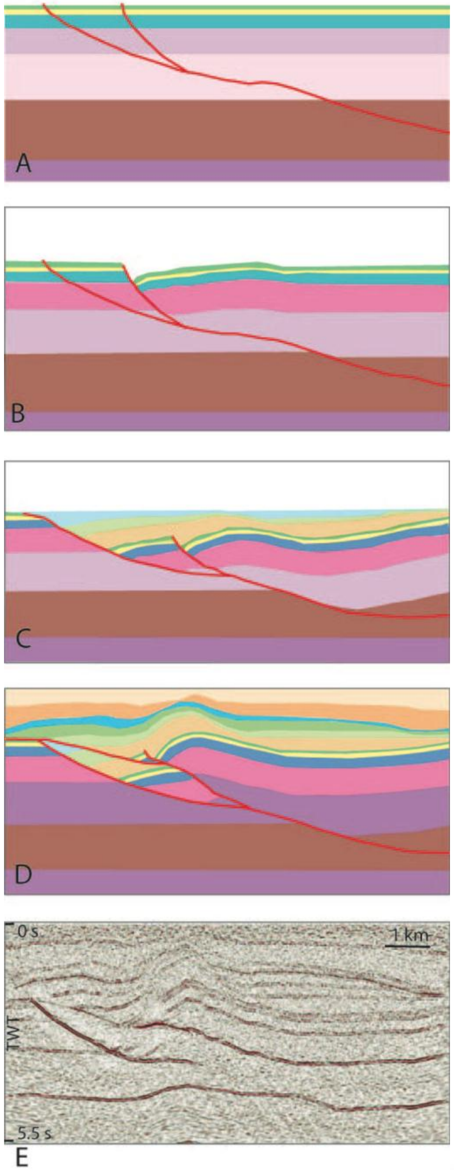
An overview of uncertainty in structural interpretations – research with the University of Glasgow.

How to use structural modelling techniques that enable an assessment of the validity of geological interpretations and therefore lead to models with reduced uncertainty.

Show that a ***dynamic understanding*** rather than a static geological model is useful in predicting fractures and their connectivity thus affecting CO_2 migration pathways in the subsurface.

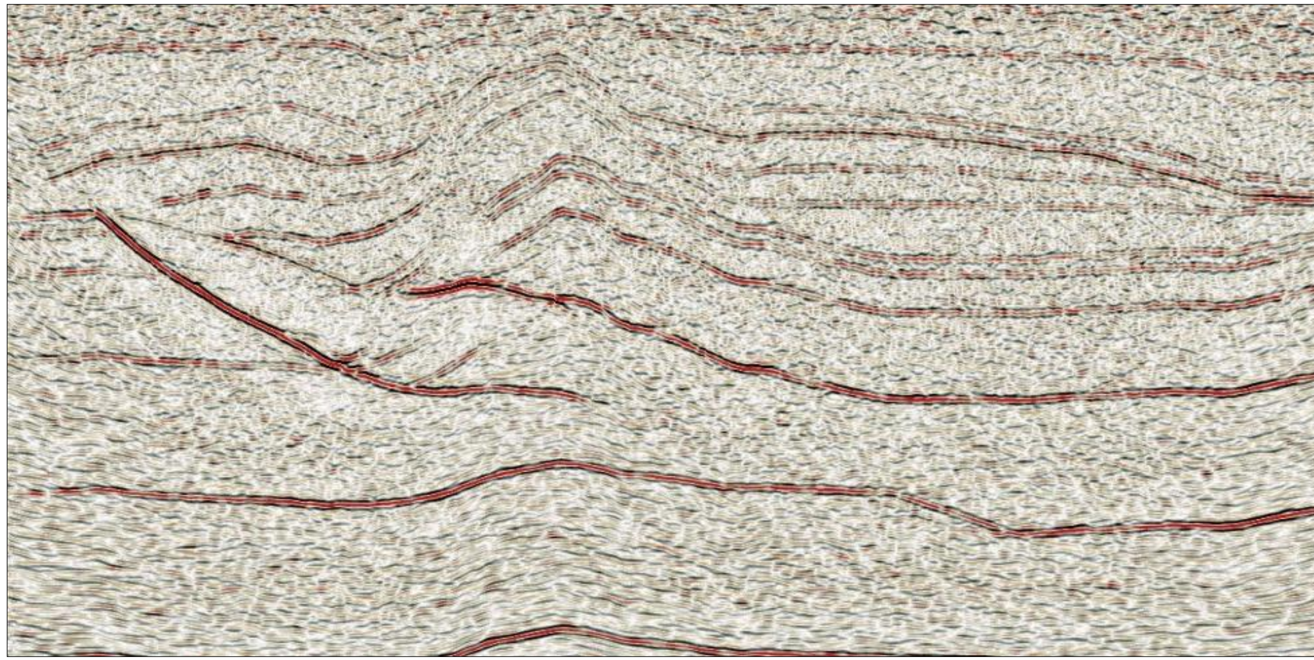
Why conduct Structural Modelling?





The Odin Project

412 Geoscientists – 1 dataset



How many different interpretations?

Bond et al. (2007)

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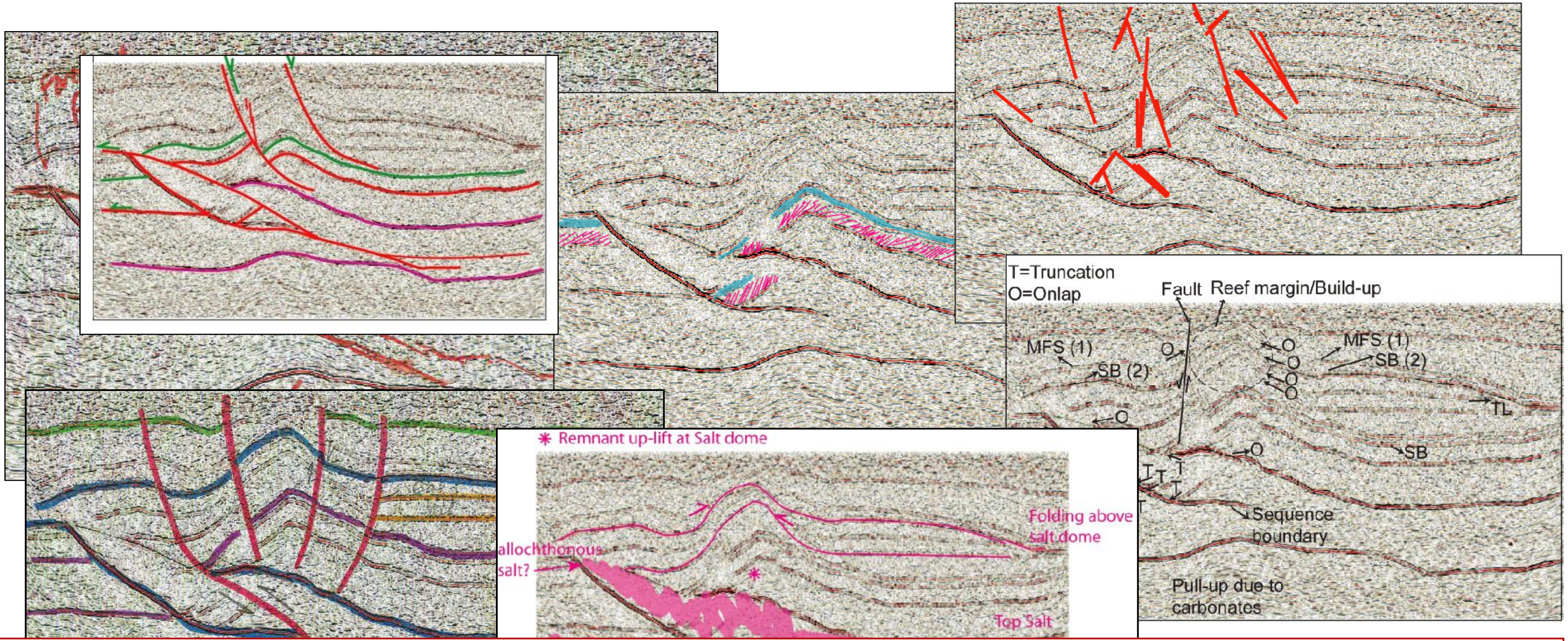
Concept Uncertainty



Only **21%** of respondents identified the original / correct tectonic setting (inversion)

If an interpretation is invalid all further analysis will be incorrect.

Bond et al. (2007)

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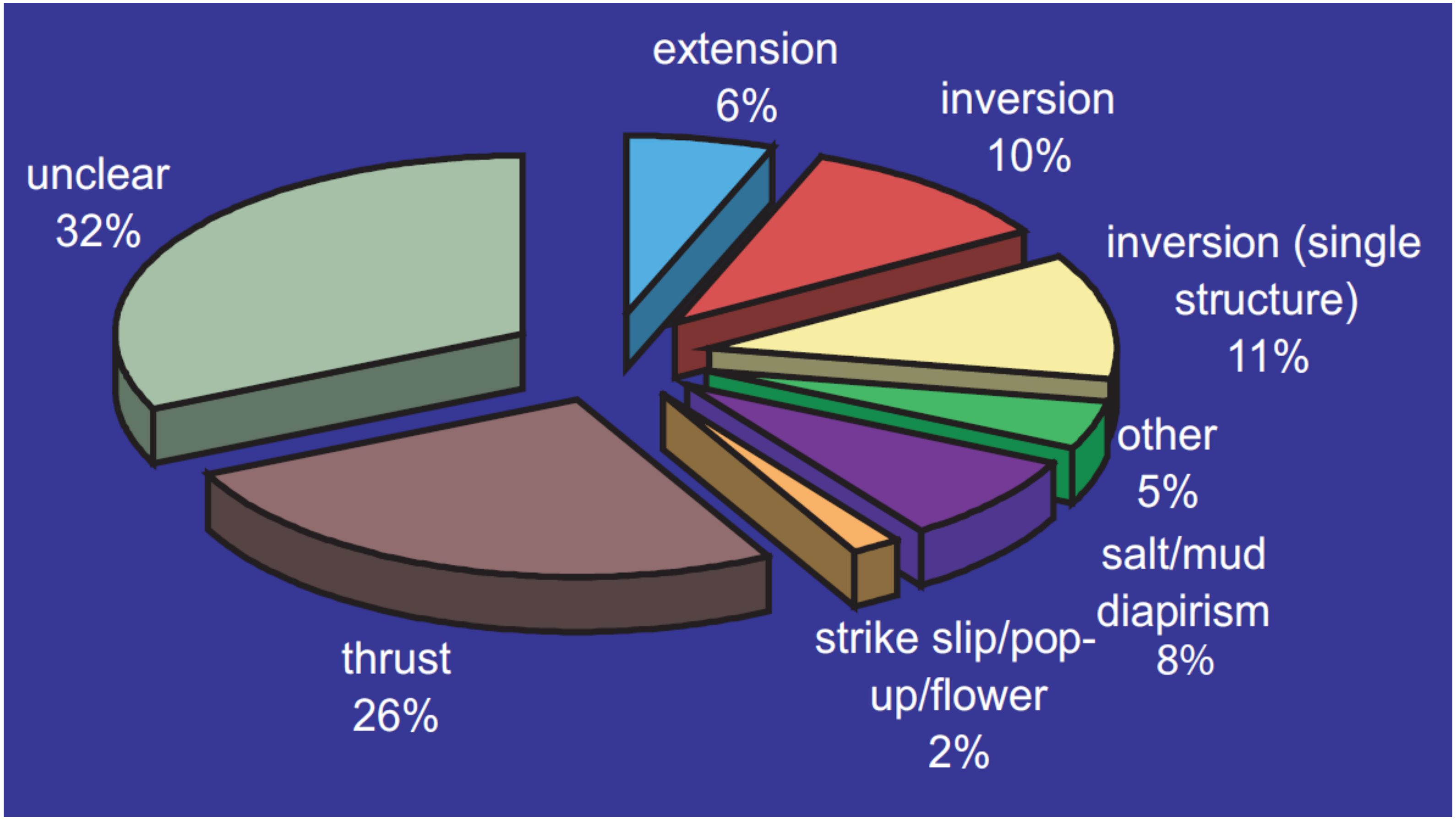

Bond et al. (2007)

No. of techniques	No. of geoscientists	% with modelled answer
4	2	100
3	31	52
2	202	25
1	176	13

The more interpretational techniques used the better the success rate

Bond et al. (2007)

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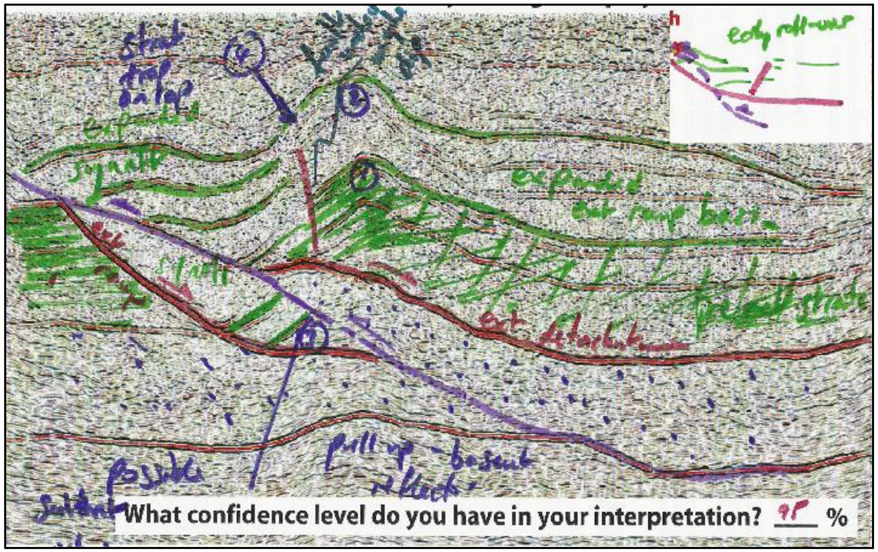
Only 28 people showed evidence of evolutionary thought processes



Those that thought in the 4th dimension produced a correct answer

Interpretation type	No. of people	% of people
Inversion	26	92.86
Thrust	1	3.57
Extension	1	3.57

Bond et al. (2007)

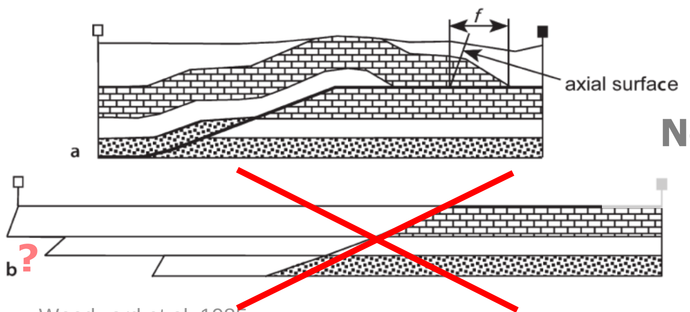
Structural restoration

The restoration is a fundamental test of the validity of the interpretation. If a section is not restorable, it is geologically not possible.

In areas of sparse data, multiple **valid** structural models can exist! No unique solution to a structural problem.

The restoration technique helps to

- Validate structural interpretation
- Determine structural evolution
- Make predictions about structures that are not imaged

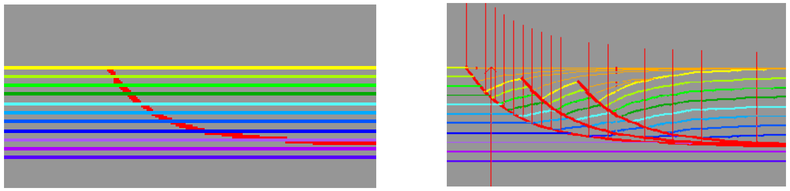


Woodward et al. 1985

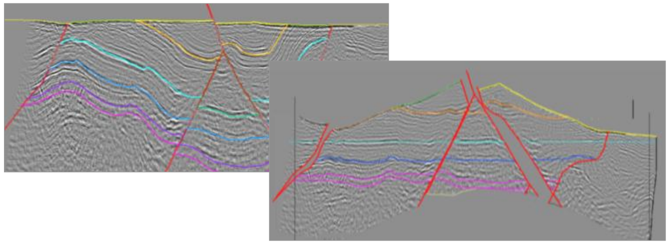
Not a valid model

Three main structural validation methods

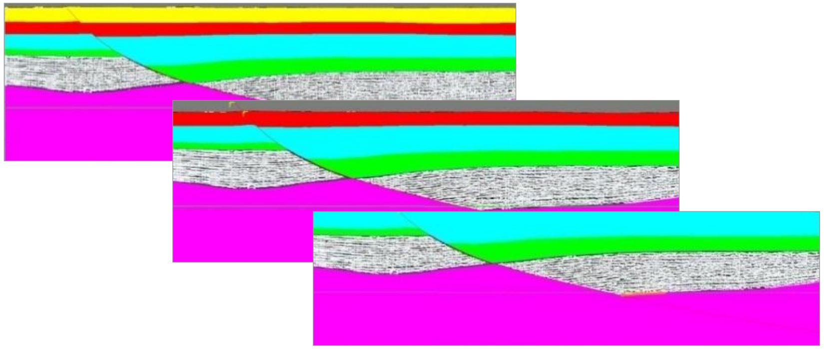
1. Forward modeling. First pass quick analysis. Set up model with thicknesses measured from the section. Try to test ideas how the section got to the present state.



2. Block restoration. First pass quick analysis. Unfolding and fitting faulted blocks together. Two stages: deformed stage and undeformed stage. Does not show intermediate steps.



3. Sequential restoration. Shows the intermediate stages between fully deformed and fully restored. Provides insights into the structural evolution and is a more rigorous test.



Balancing

Interpretation

↓

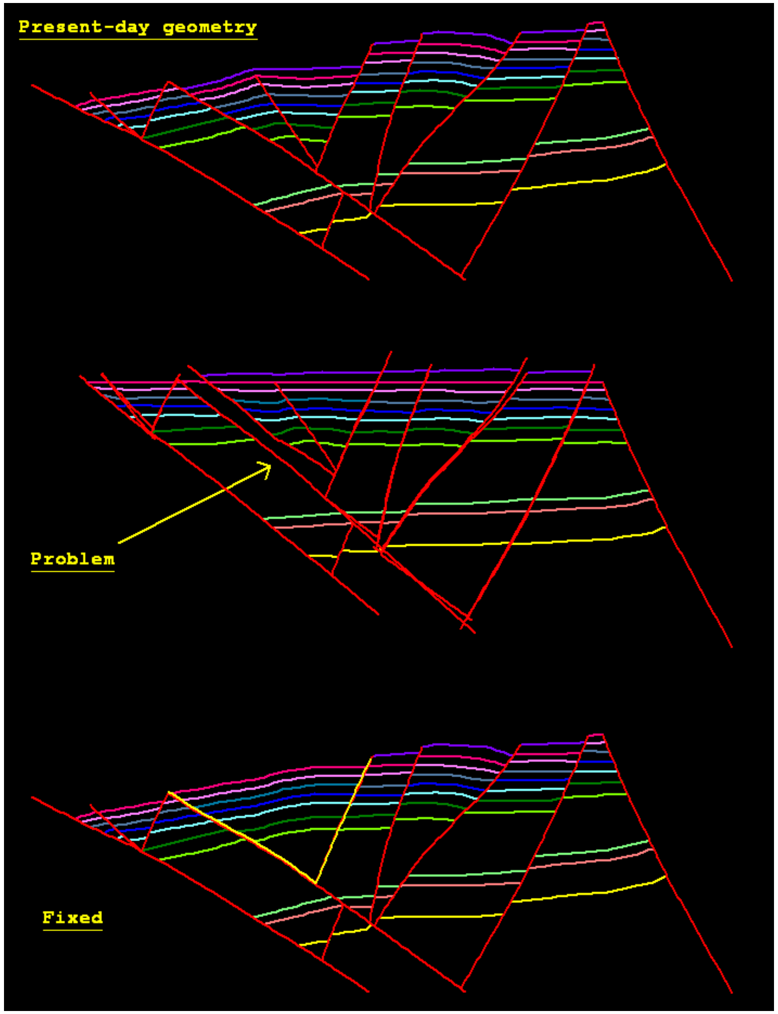
Block translation and unfolding

Line-length balance?

Re-interpretation

↓

One valid model



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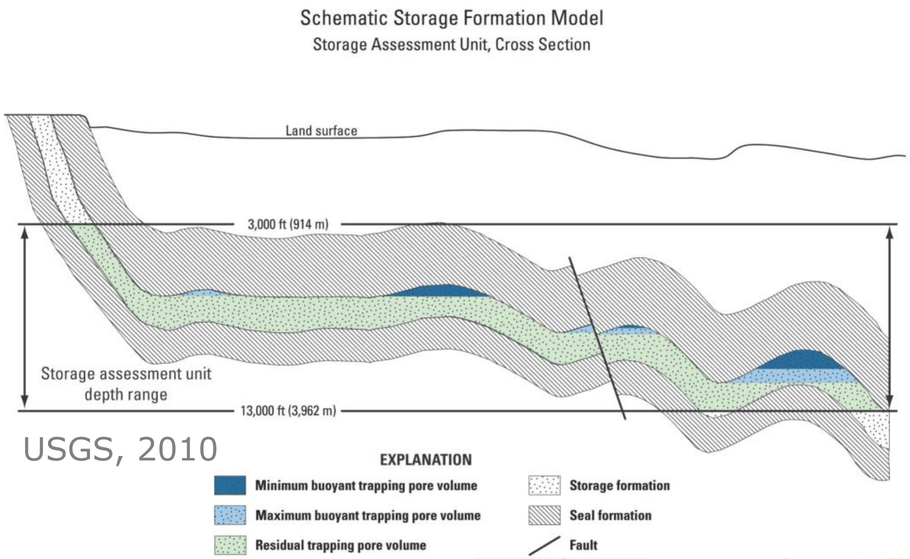
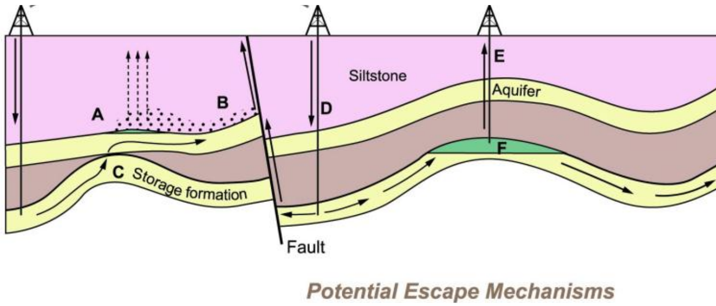
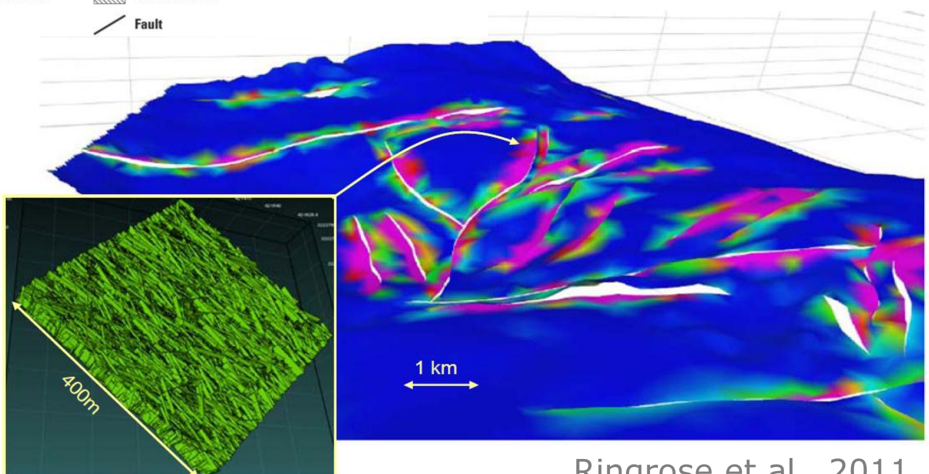
Capacity, Containment, Injectivity



USGS, 2010



IPCC, 2005



Ringrose et al., 2011

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Best Practice Workflow

Establish Structural Geological History

- Evolutionary thought

Validation and Testing

- Is it restorable – does it balance?

Fracture 'Recipe'

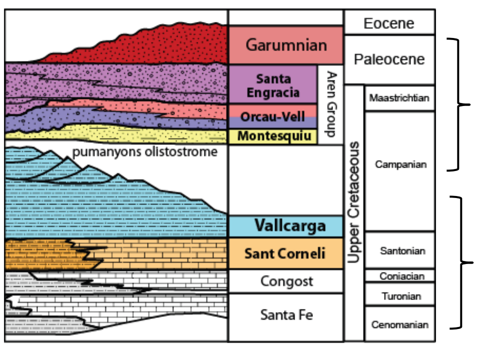
- Relate model to known relationships between deformation and fractures

Fracture Modelling

- Calculate reservoir properties and their effects on CO_2 migration pathways

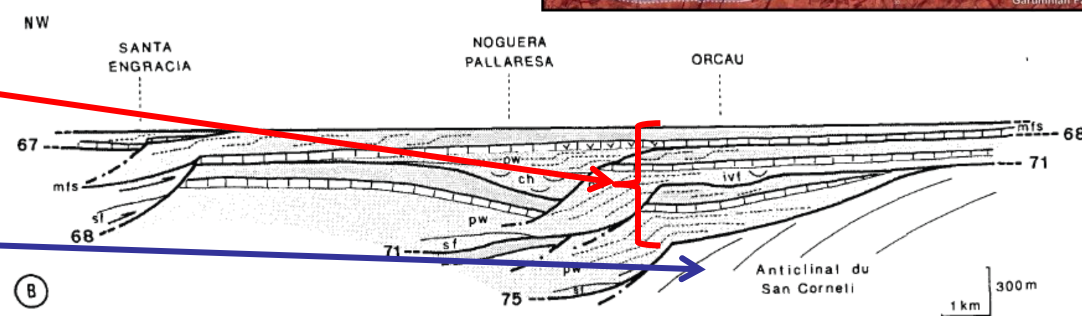
Case Study – Sant Cornelli Anticline

Structural Geological History



Growth

Pre – growth



Bond et al., 2010

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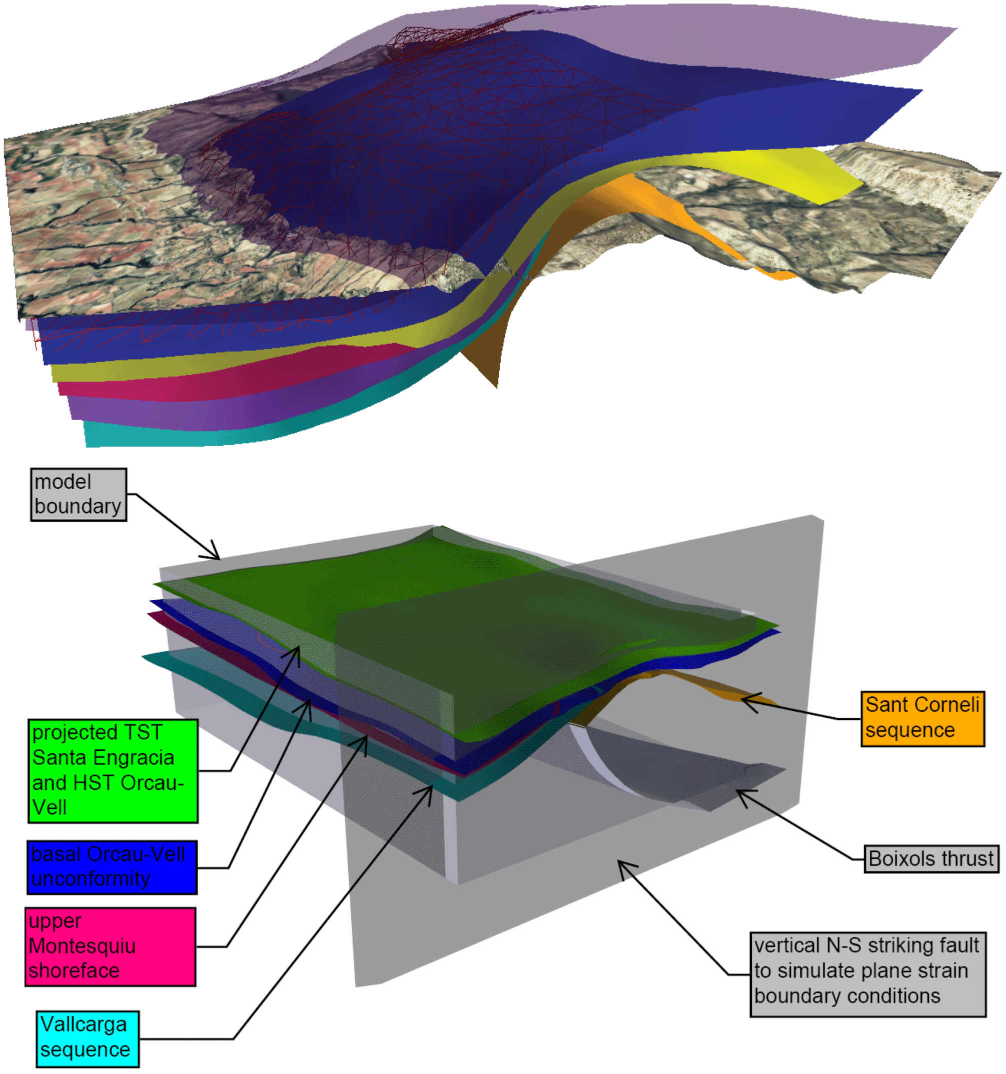
Validation and Testing

Static 3D model of the present day geometry was created

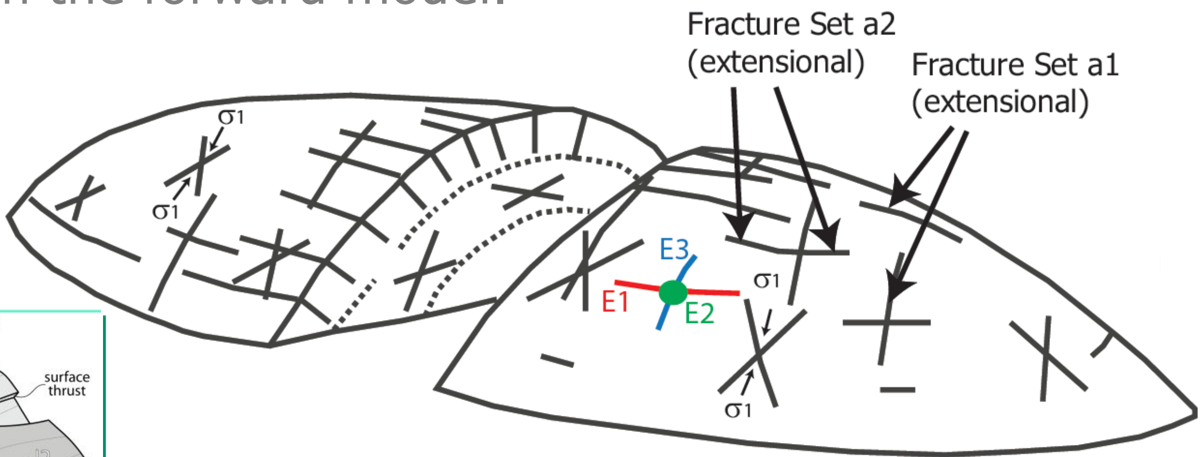
The 3D model was restored in sequential time steps to validate the geometries created in the model from the field data



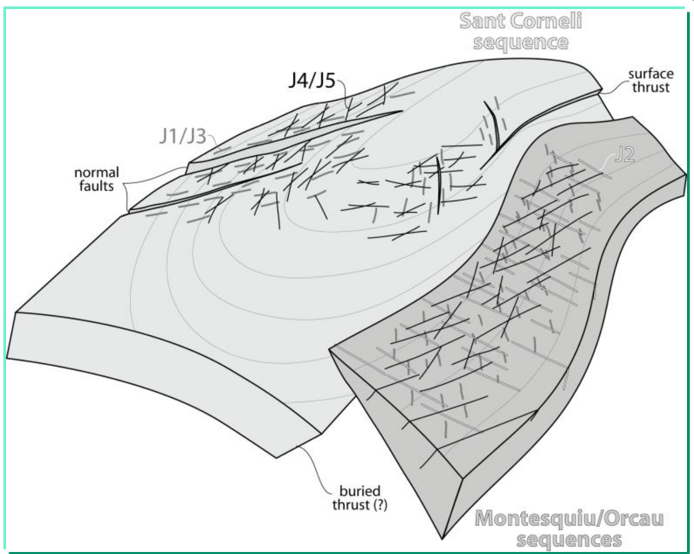
Shackleton et al., 2011

Fracture "Recipe"

The fracture orientations chosen are based on a theoretical understanding of fracture formation during folding, with the fracture intensity determined by the strain predicted in the forward model.



Adapted from Price and Cosgrove, 1990



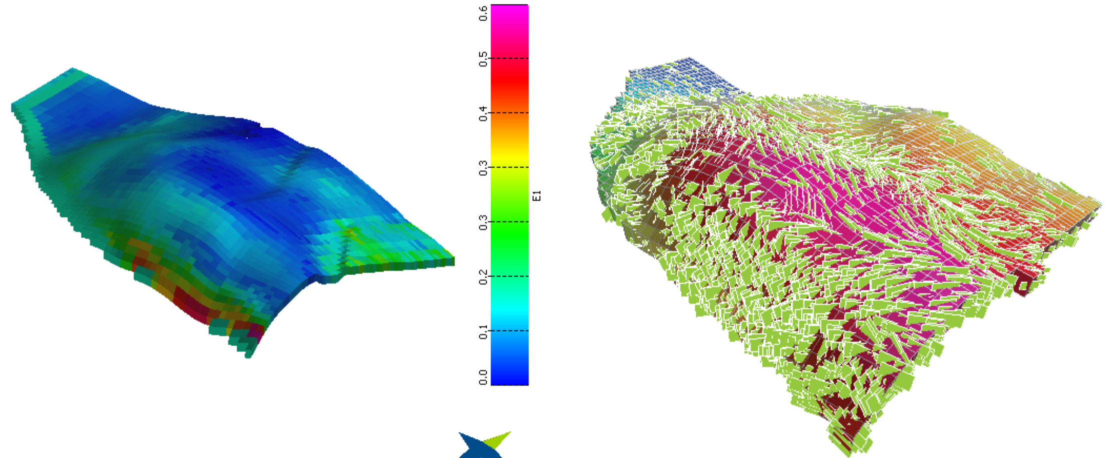
In addition fractures and joints of different generations and orientations, were measured in the field and placed in sets based on a conceptual model of formation during folding.

Shackleton et al., 2011

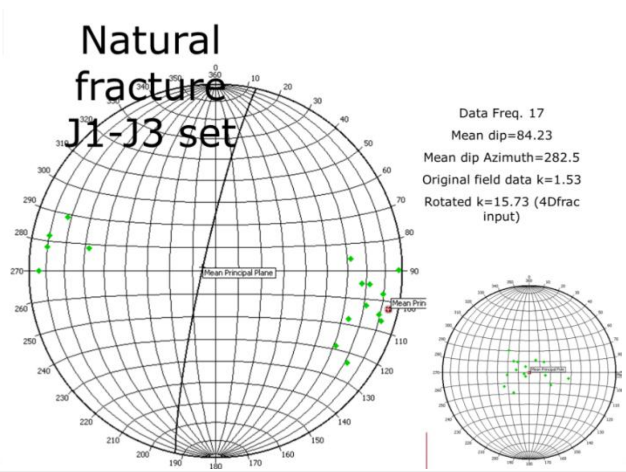
the structural geology experts

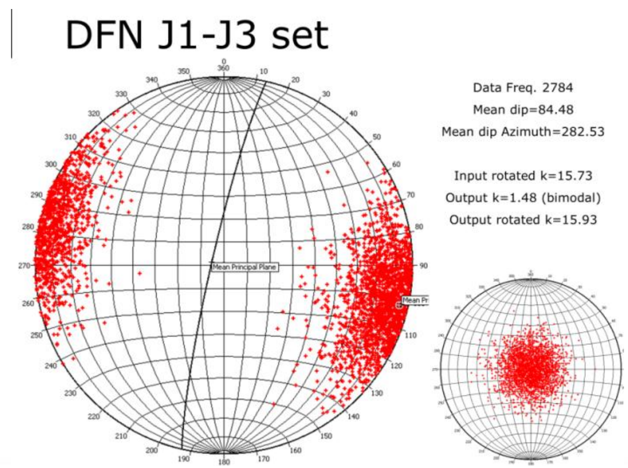
Fracture Modelling and Validation

Fractures modelled based on strain predicted by a forward model. Orientations and intensities from fracture recipe. Predicted fractures can then be compared against the fractures mapped in the field and scaled appropriately.



Bond et al., 2010, Shackleton et al., 2011





Gibbs et al., 2010

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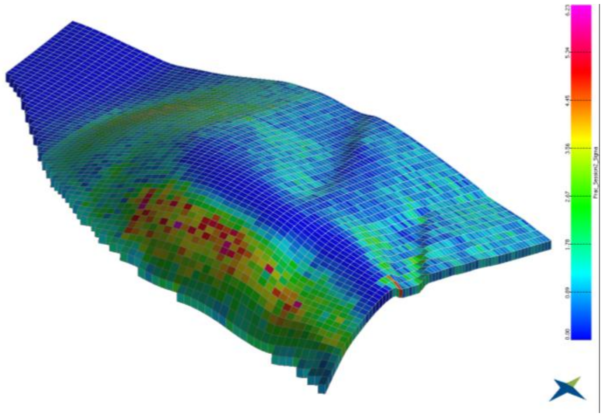
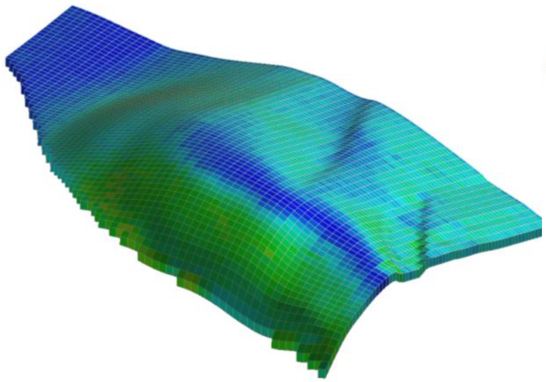
Reservoir Properties

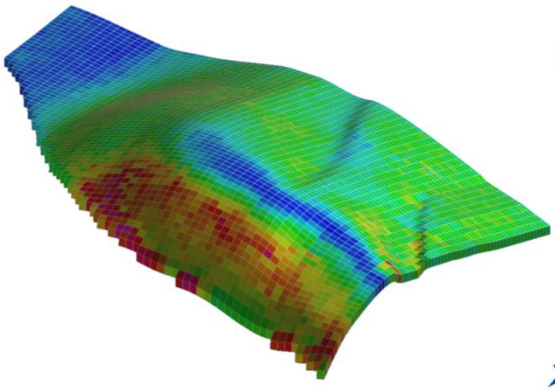
The P32 (fracture area per unit volume), sigma, permeability, and porosity are calculated from the modelled fracture set. In total eight separate fracture sets were modelled and scenario analyses carried out on fracture set interaction and relative dominance.



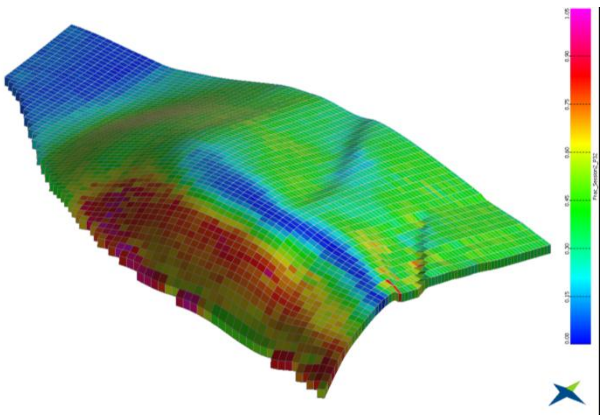
Sigma factor



Porosity (%)



Permeability (D)



P32

Bond et al., 2010

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Conclusions

Geological data inherently under-constrained and uncertain

Even when data is good, interpretational bias can be significant, evolutionary thought can reduce the bias

Structural modelling allows an assessment of geological interpretations and can provide valid scenarios and therefore can significantly reduce uncertainty in site characterisation for CCS projects

Prediction of fractures to assess connectivity, permeability etc. and potential CO_2 pathways

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Zoe Shipton[1] and Clare Bond[2] at the University of Glasgow for their work on the Odin project (now at: [1]University of Strathclyde, [2]University of Aberdeen)

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