

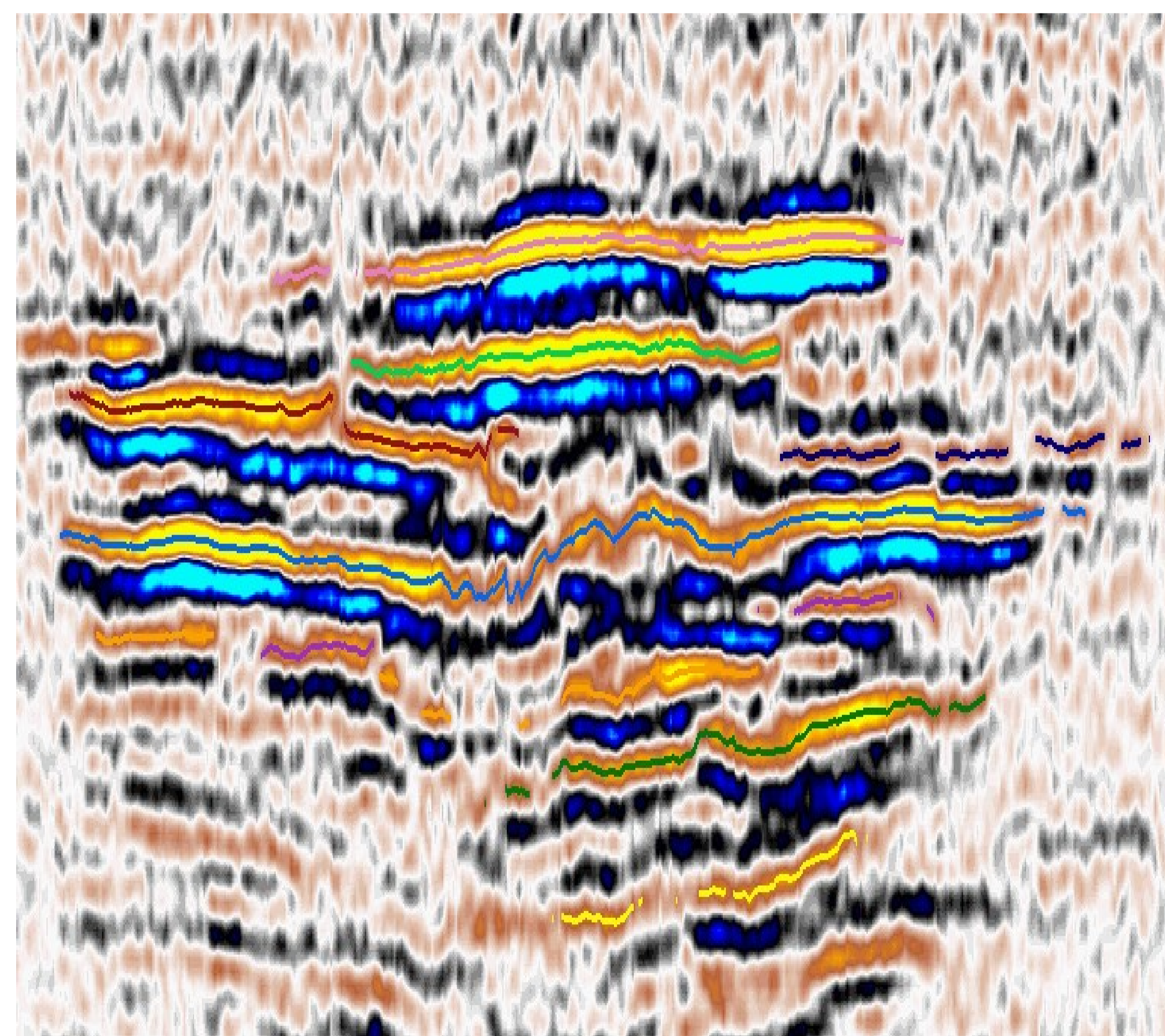
Modelling of CO₂ injection and seismic data analysis in the Utsira formation

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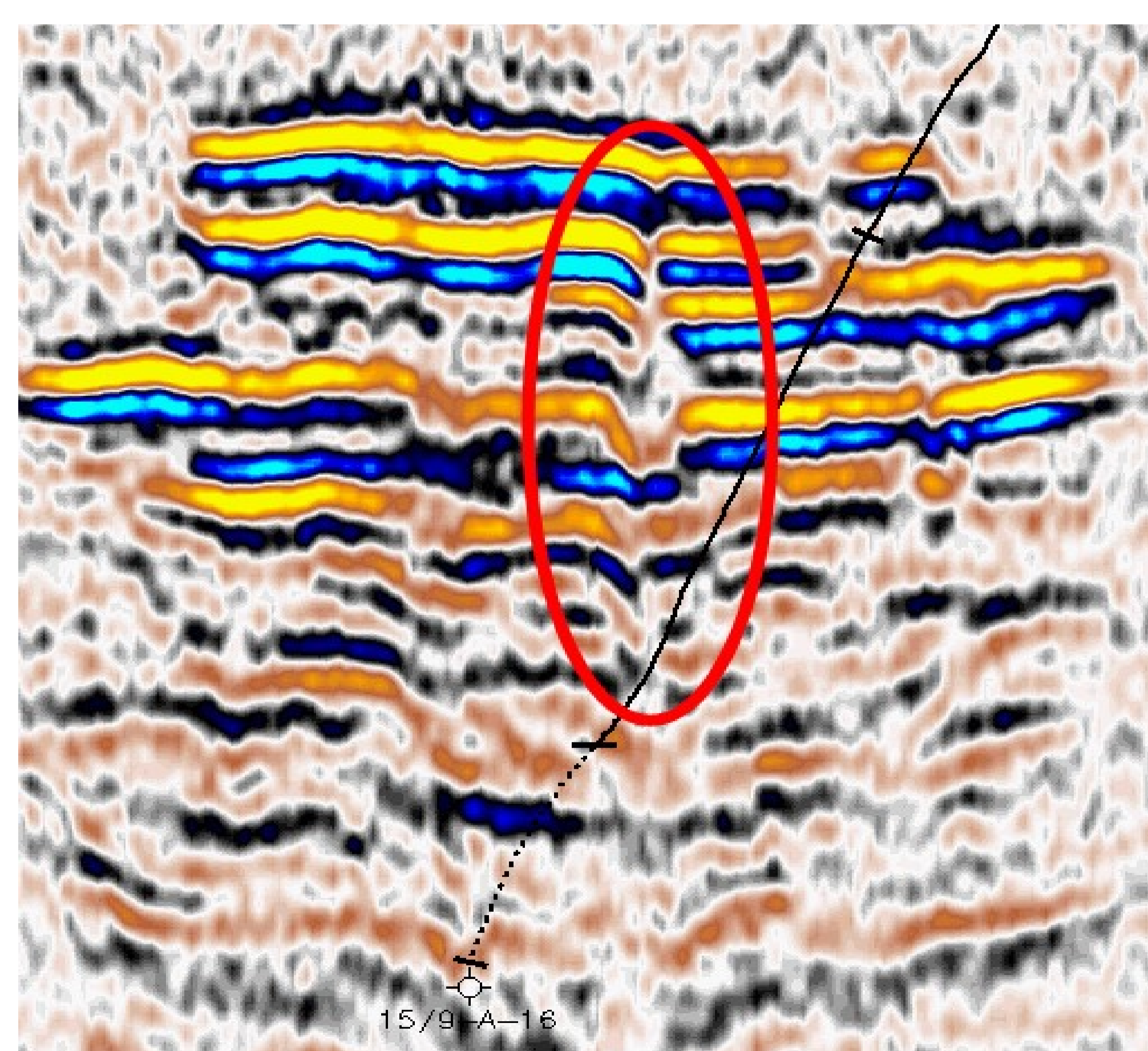
*: StatoilHydro ASA, **: The Permedia Research Group Inc.

Sleipner CO₂

- Produced CO₂ is injected into the Utsira formation
- Injection rate of 0.9 Mtonn since 1996
- Monitoring of the CO₂ is done with seismics as the injected CO₂ gives a strong time lapse response
- Monitoring has shown that the CO₂ is partly trapped under 9 barriers that have been interpreted from well logs as shale baffles.



The seismics shows a number of high amplitude events. These have been interpreted as 9 shale horizons which hinders the vertical flow of CO₂



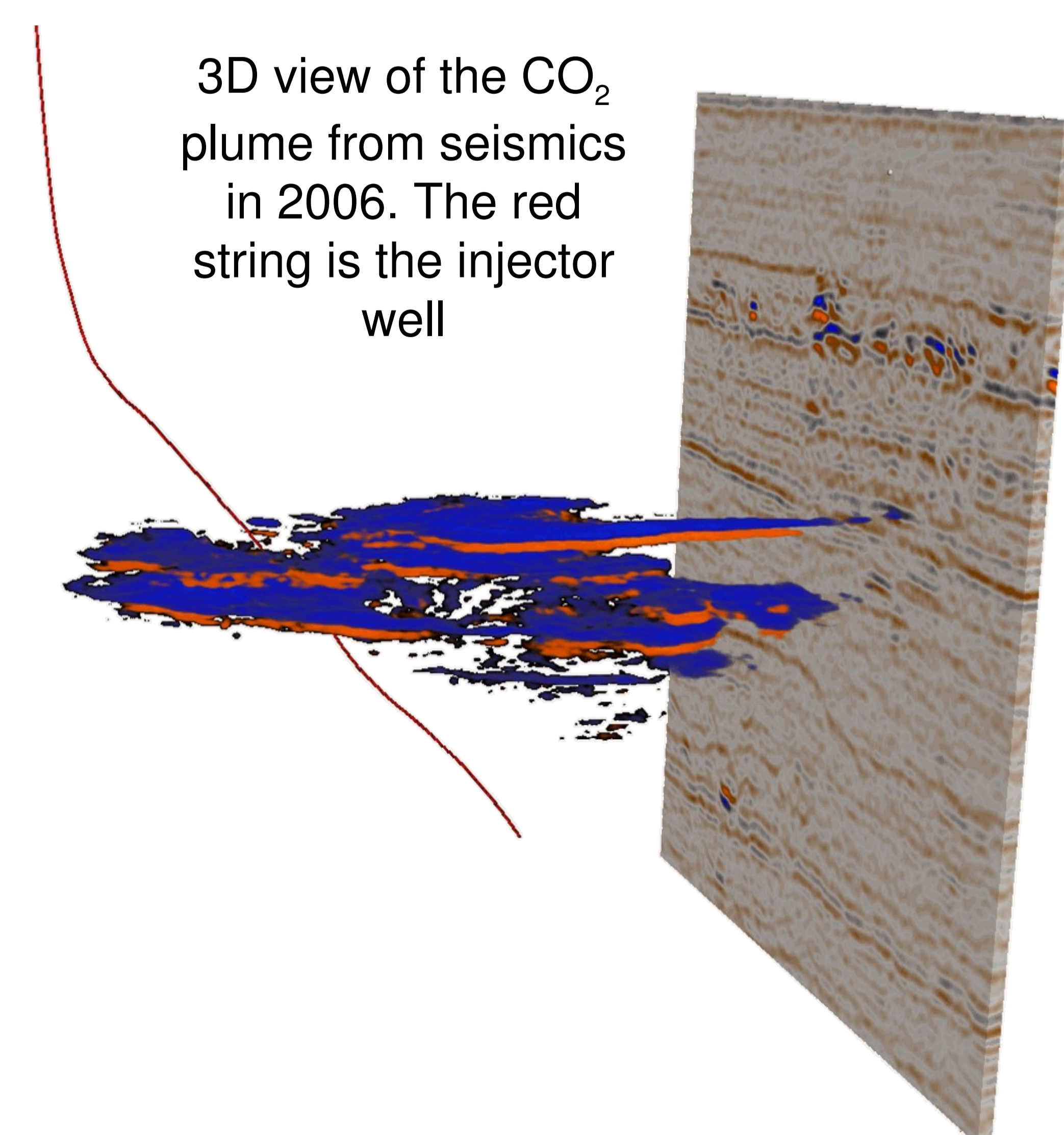
A remarkable feature in the Sleipner CO₂ seismics is the plume chimney. In the figure above, the chimney is seen as a vertical stack of broken reflectors associated with a sharp pulldown of the high amplitude event. The chimney almost directly overlies the injection point and is assumed to be a significant flow path for the CO₂. It was probably formed by the injection process. The black line is the injector well bore.

Why model flow of injected CO₂?

- Support in time critical decisions:
 - Seismic planning
 - 4D shadow zone
- Storage capacity in mapped area:
 - Can injection be increased and by how much?
 - Well recompletion
 - Well planning
- Knowledge base:
 - New storage site evaluation
 - Storage under spilling point
- **NOT** just a model that replicates seismic

Approach to flow modelling

- Select two different approaches for the CO₂ flow: Without capillary trapping (Darcy flow) and with such trapping (Invasion Percolation)
- Build the two models in 3D
- Calibrate models to 2006 data
- Examine fit to intermediate data
- Forecast storage capacity within mapped structural closure



Results and implications

• Observations

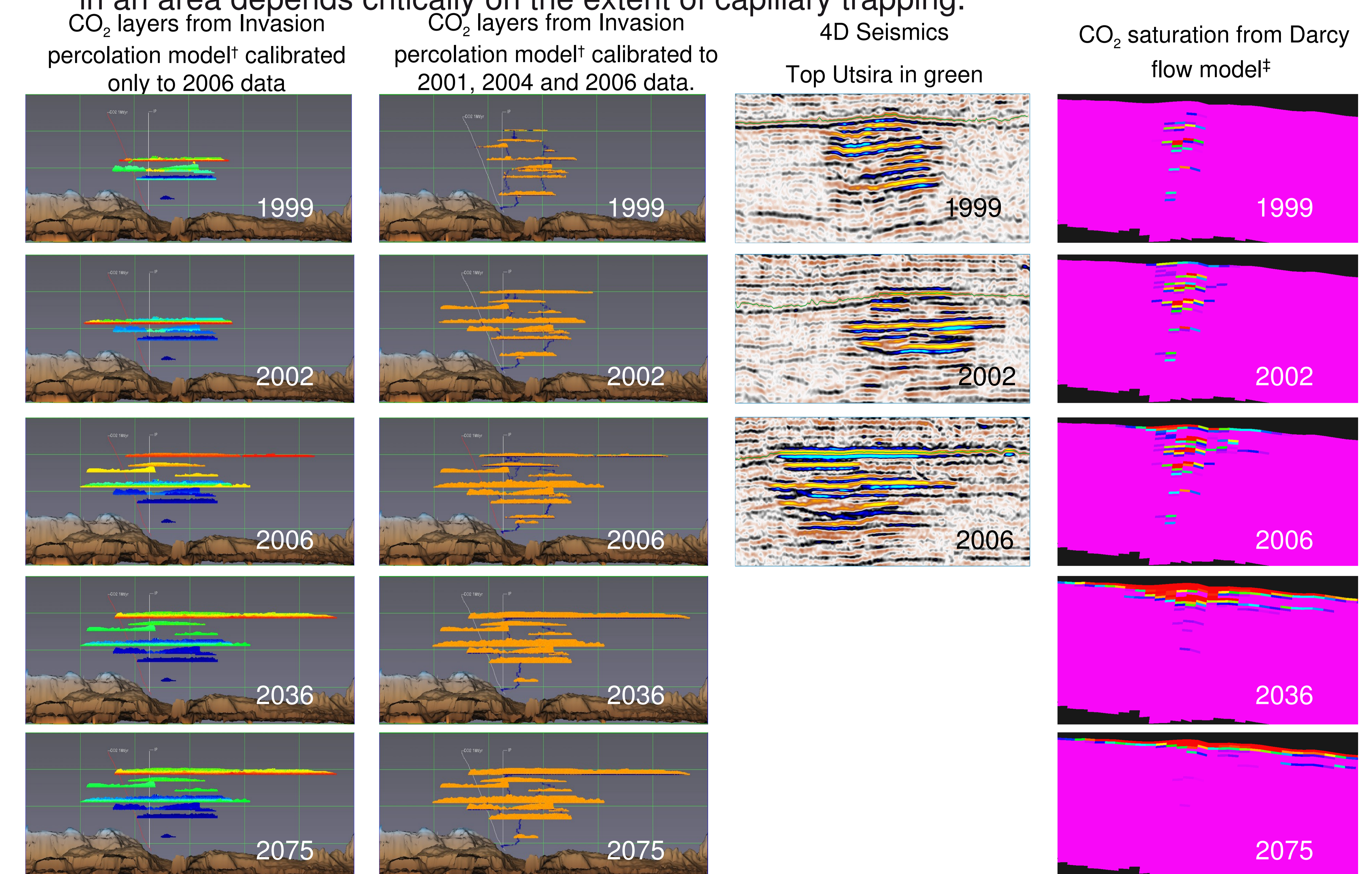
- Both models that have been calibrated to match the 2006 data replicate the data reasonably well, although both the Invasion Percolation modelling and Darcy modelling underestimates the early influx to the top layer. The Invasion Percolation model calibrated to the 2001, 2004 and 2006 data with different capillary entry pressures matches very well to the influx at the top layer in 1999 and 2002.
- Both models suggest that an increasingly larger portion of the CO₂ will be accumulated in the top layer.
- The Darcy modelling suggests that all movable CO₂ will move towards the top layer with time after the CO₂ injection has stopped, whereas the Invasion Percolation modelling suggests that no CO₂ movement will take place after injection has stopped.

• Interpretations

- The difference between the modelled filling histories documents the importance of increased understanding of the mechanisms that control the fluid flow. Such mechanisms include capillary trapping, vertical flowpath presence and flowpath alterations that result from the CO₂ injection. Modelling of increased CO₂ flow in the chimney with time is expected to improve the match between modelling results and the observations from the different seismic vintages.
- The different predictions after injection has ceased result from the role of capillary trapping, which is included in the Invasion Percolation modelling but not in the Darcy flow modelling.

• Implications

- The importance of capillary trapping of CO₂ needs to be verified, as the storage capacity in an area depends critically on the extent of capillary trapping.



† Percolation model made by Permedia Research group Inc

‡ Darcy model made by StatoilHydro, Sleipner reserve replacement team