

CO₂ Storage Capacity Below Structural Spill Point in the Utsira Formation*

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Abstract

The CO₂ storage capacity in saline aquifers is highly dependent on the different trapping mechanisms that are available. The largest rock volumes are generally positioned either outside structural closures or below structural closures but deeper than the structural spill point.

We have studied time-lapse seismic and undertaken modeling to understand the trapping mechanisms below the structural spill point of the Utsira Formation in the Sleipner region, and have found that as much as 70% of the CO₂ is stored below the structural spill point. The study further shows that the CO₂ is divided into layers, most of which are less than 7-8 m thick.

The fraction of CO₂ in the uppermost layers is increasing with time. After the termination of the CO₂ injection (ca. 2020), there will be a flow of CO₂ from the deeper to the shallower layers, but a part of the CO₂ will remain in the lower layers due to capillary and residual trapping. The remaining amount depends on the extent of these trapping mechanisms, on the irreducible water saturation, and on the reservoir inhomogeneities.

Modeling demonstrates that storage capacity estimates are highly dependent on the calculation methods and parameters (as grid size). This study nevertheless shows that large amounts of CO₂ can be trapped below structural spill points even in relatively homogenous sandstones. We expect even more CO₂ trapping below spill points in less homogenous reservoir sequences.

CO₂ storage capacity below structural spill point in the Utsira Formation

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Outline

- Sleipner data
- Trapping mechanisms
- Modelling of CO₂ trapping

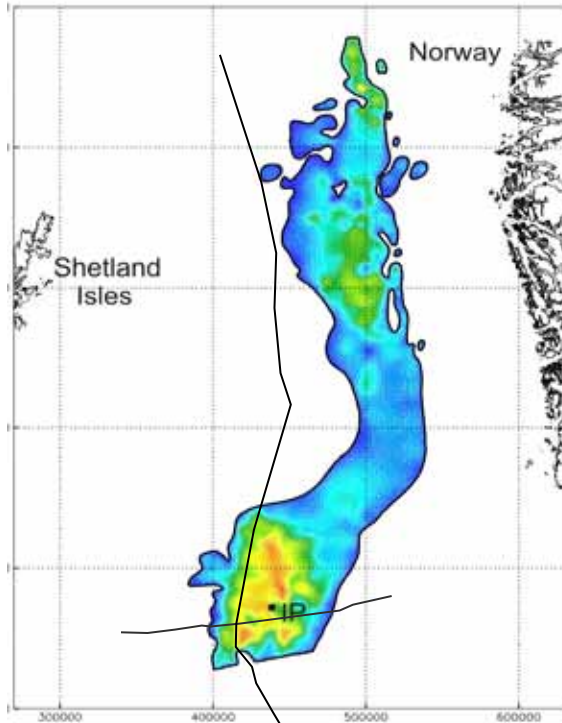
Storage capacity depends on

§ Economy (number of wells, etc.)

§ Injection strategy

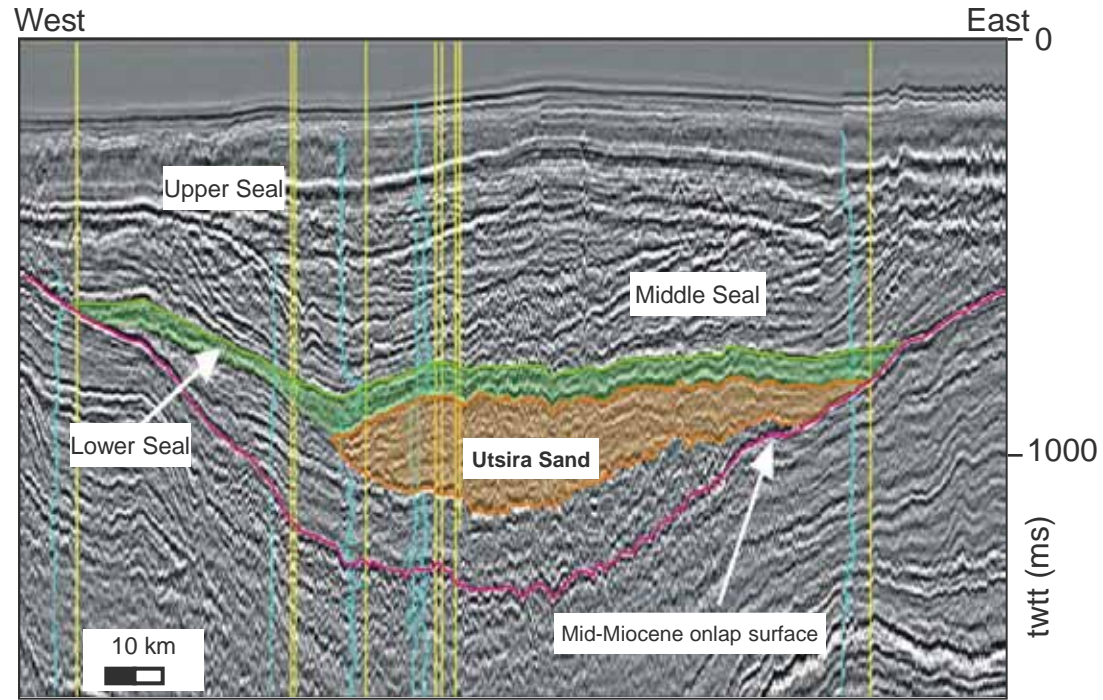
§ Risk acceptance

The Utsira Formation in the Sleipner area



Courtesy of BGS and GEUS

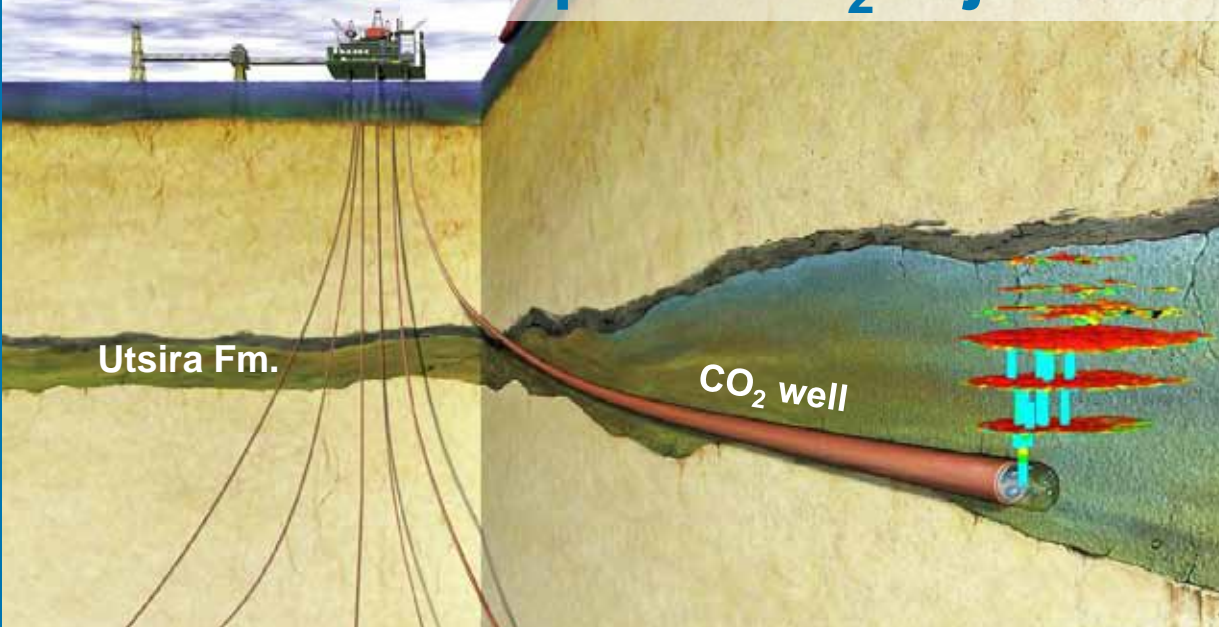
0.3 % of rock volume
within structural closures



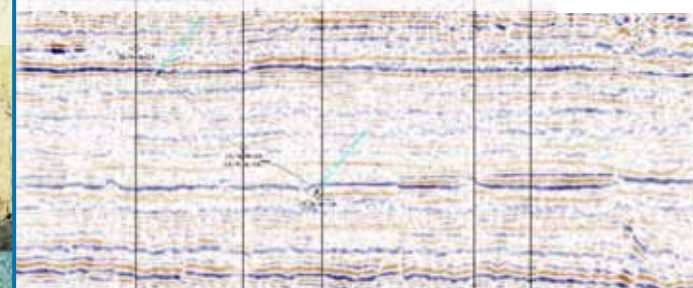
Loose sand, porosity: 35-40 %

K: 2D N/G 0.94 z=270 m

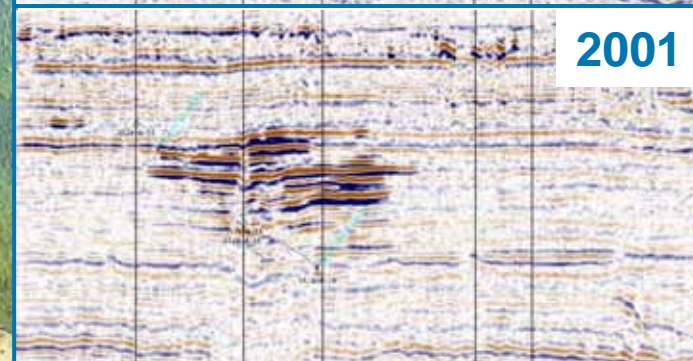
Sleipner CO₂ injection



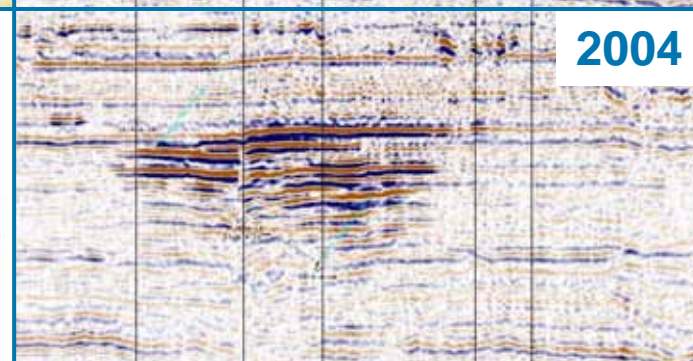
Time-lapse seismic data 1994



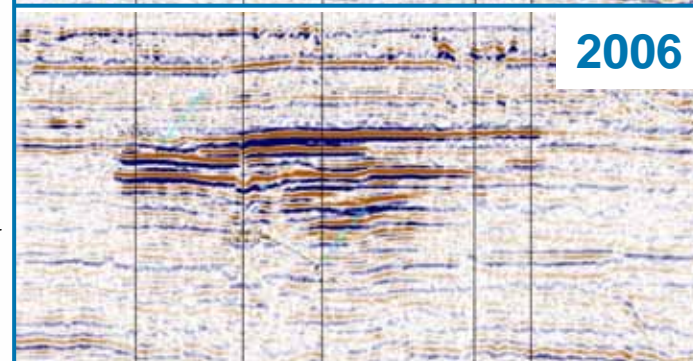
2001



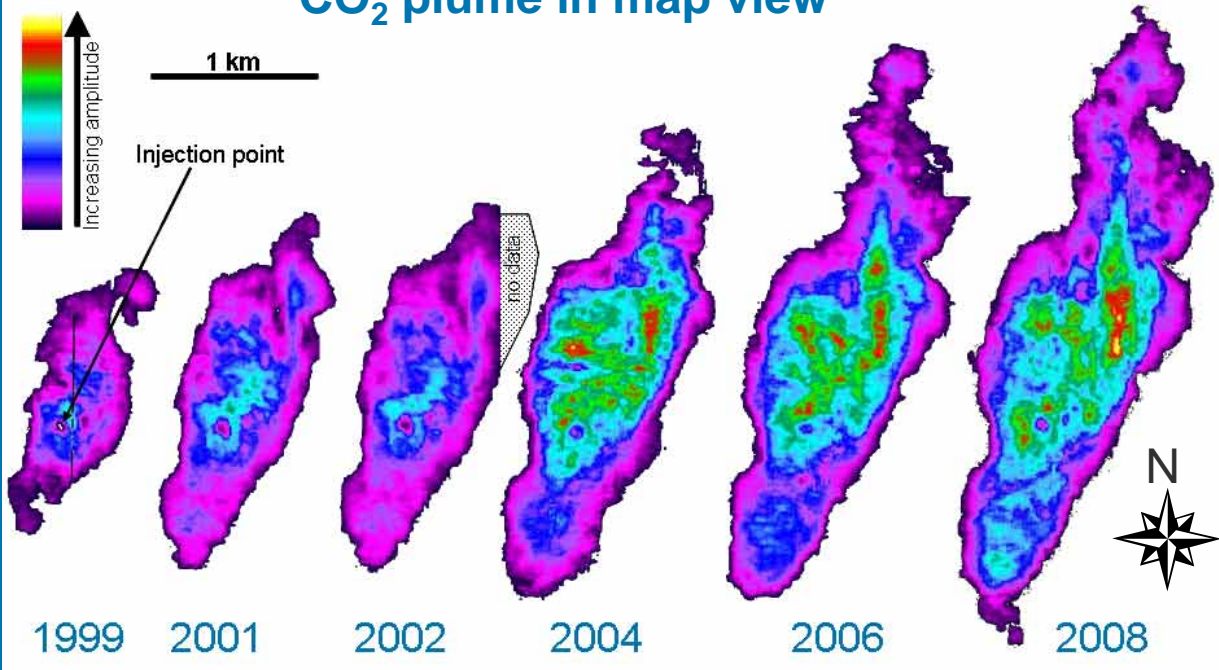
2004



2006



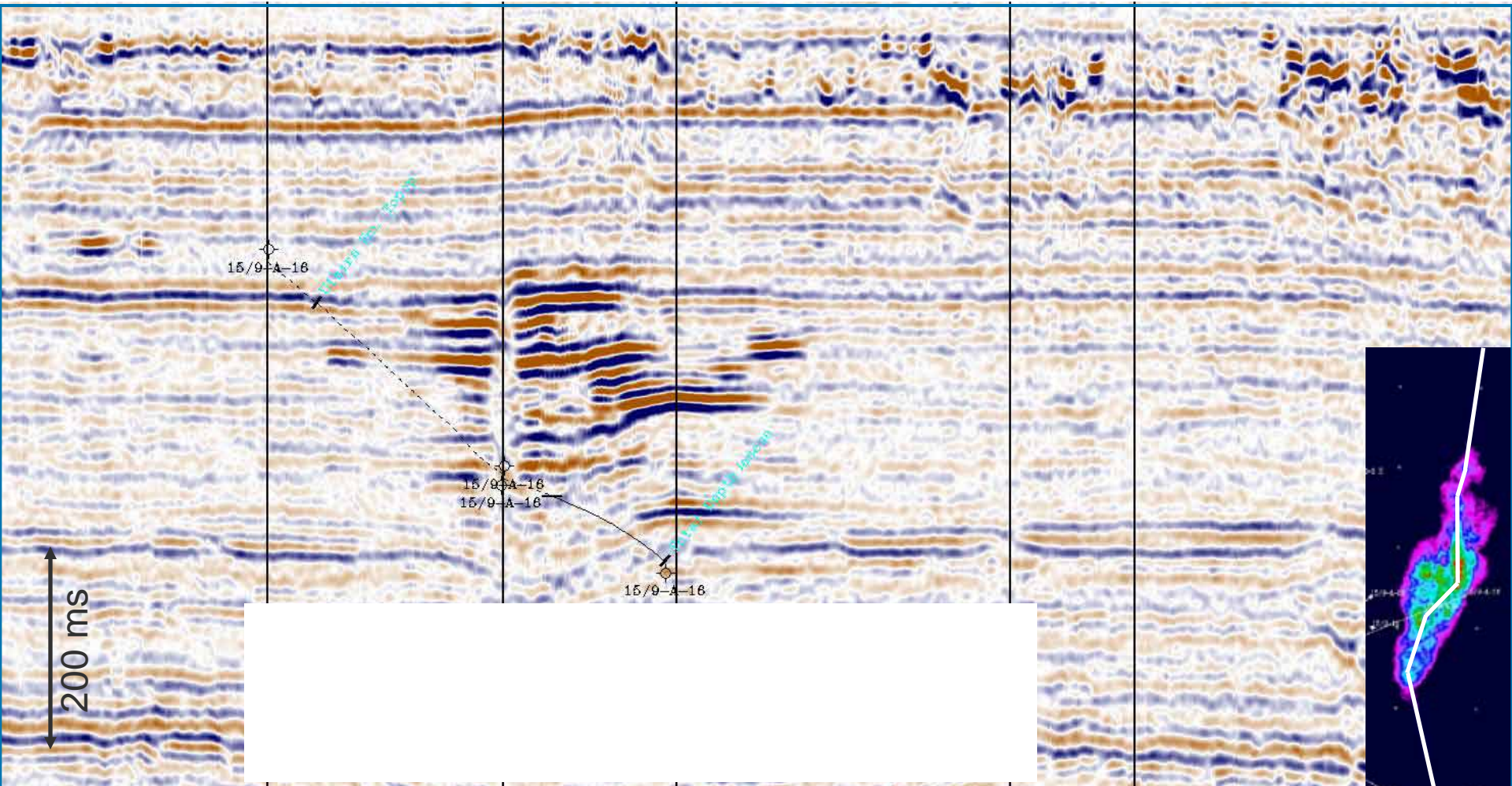
CO₂ plume in map view



Seismic image

1999

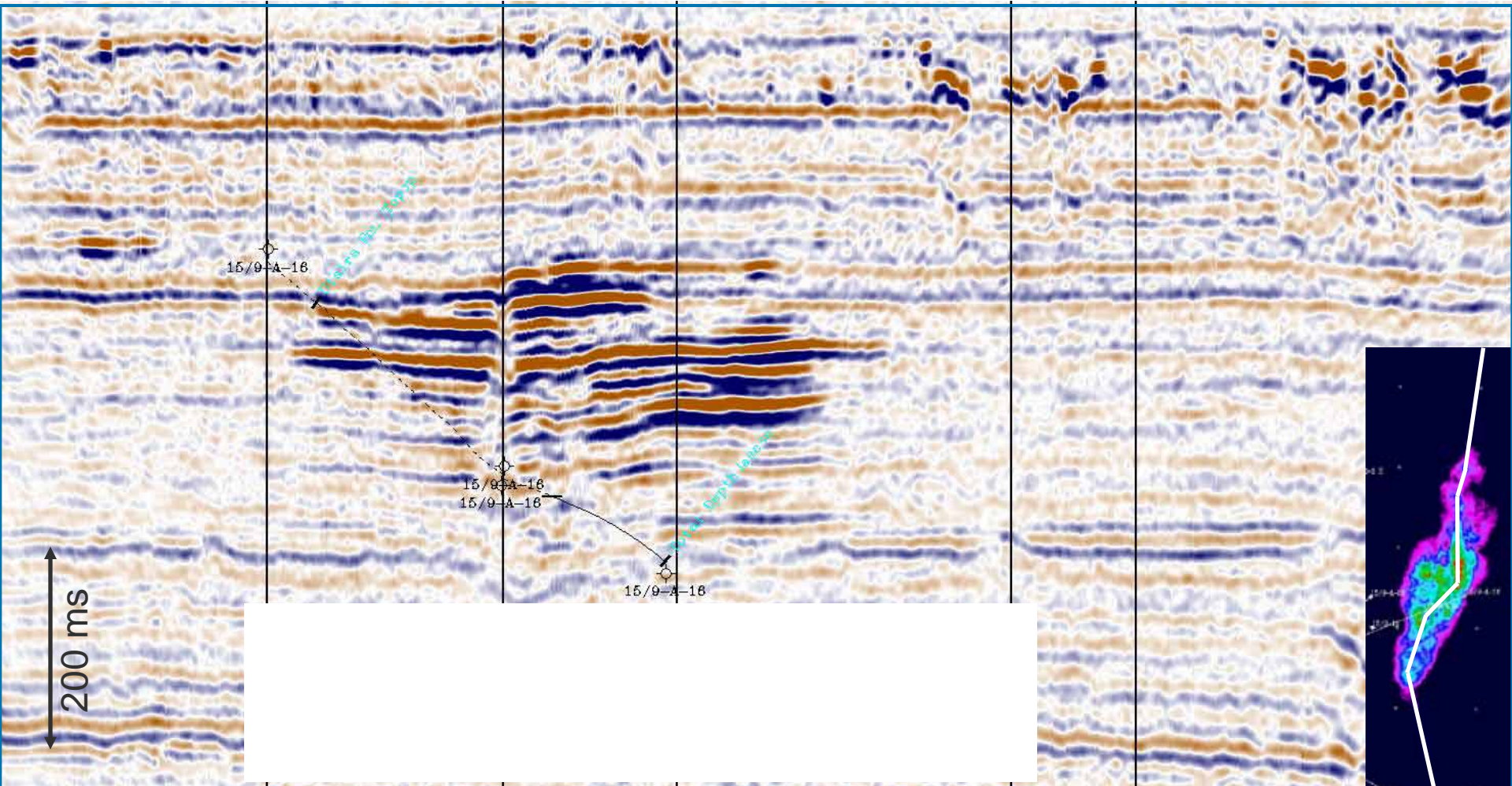
500m



Seismic image

2001

500m

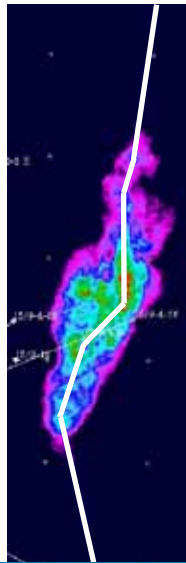
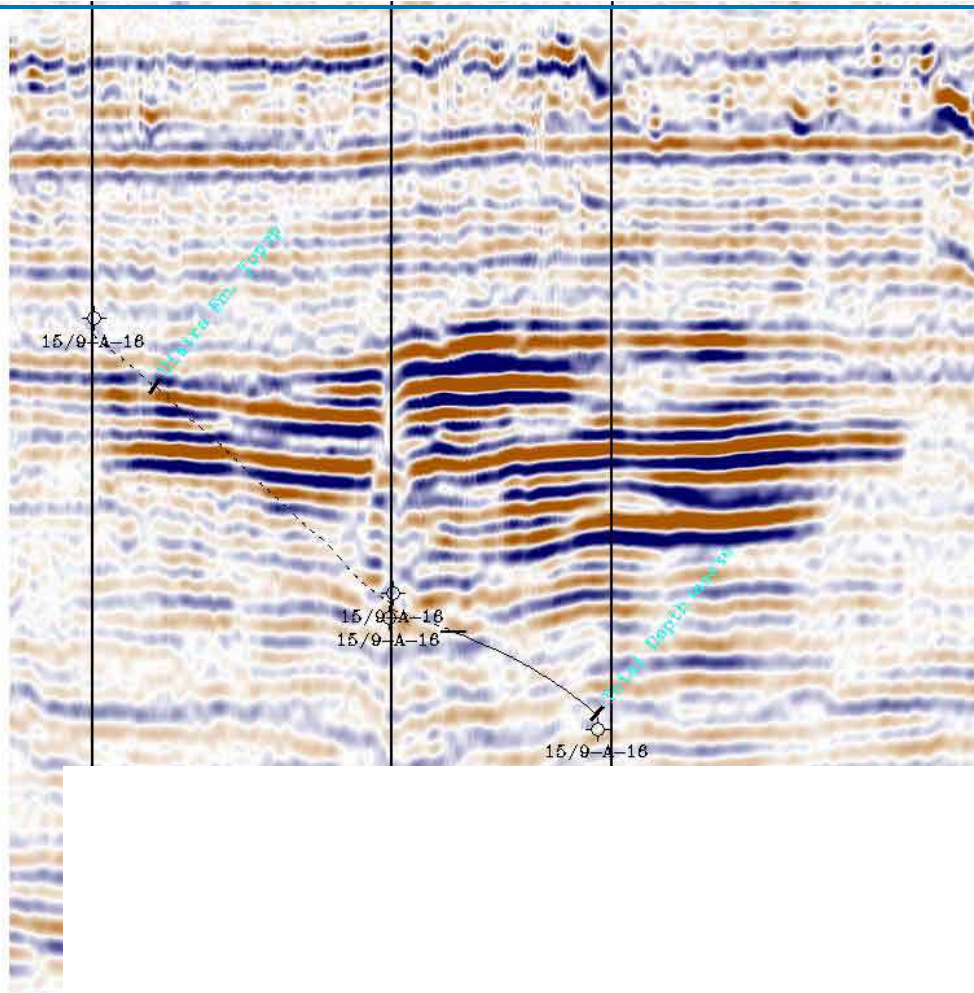


Seismic image

2002

500m

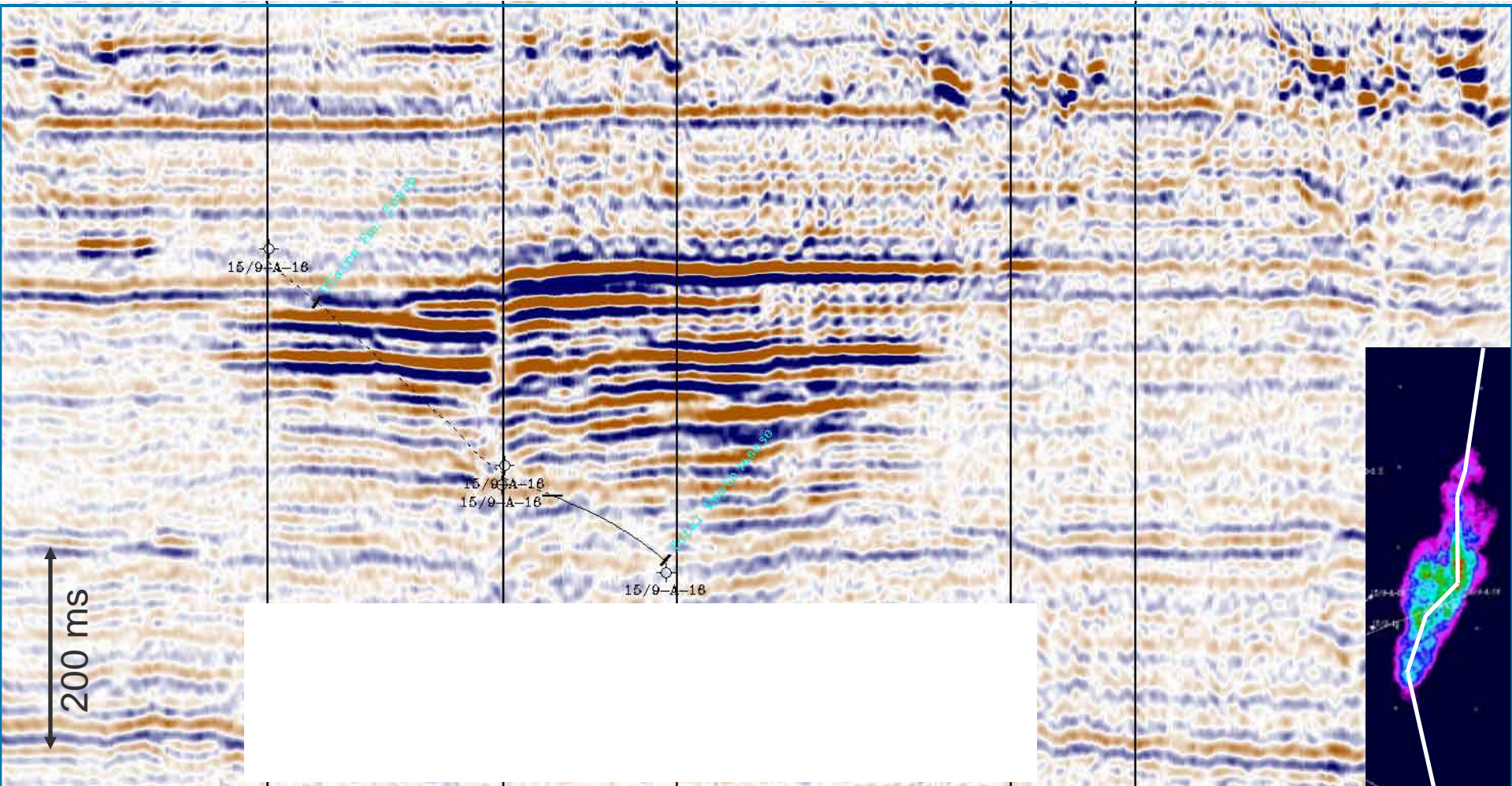
200 ms



Seismic image

2004

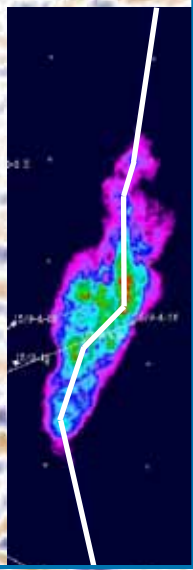
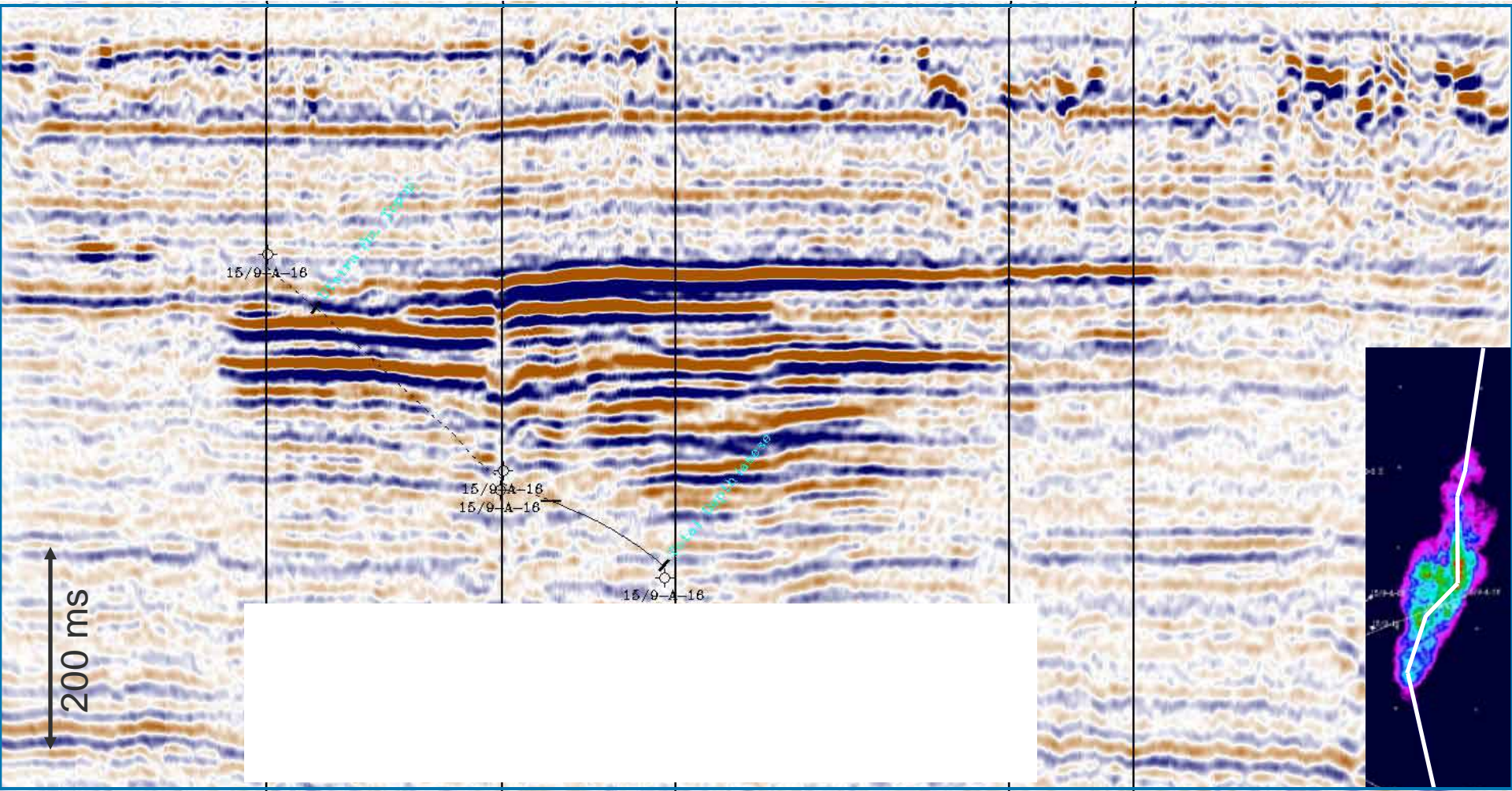
500m



Seismic image

2006

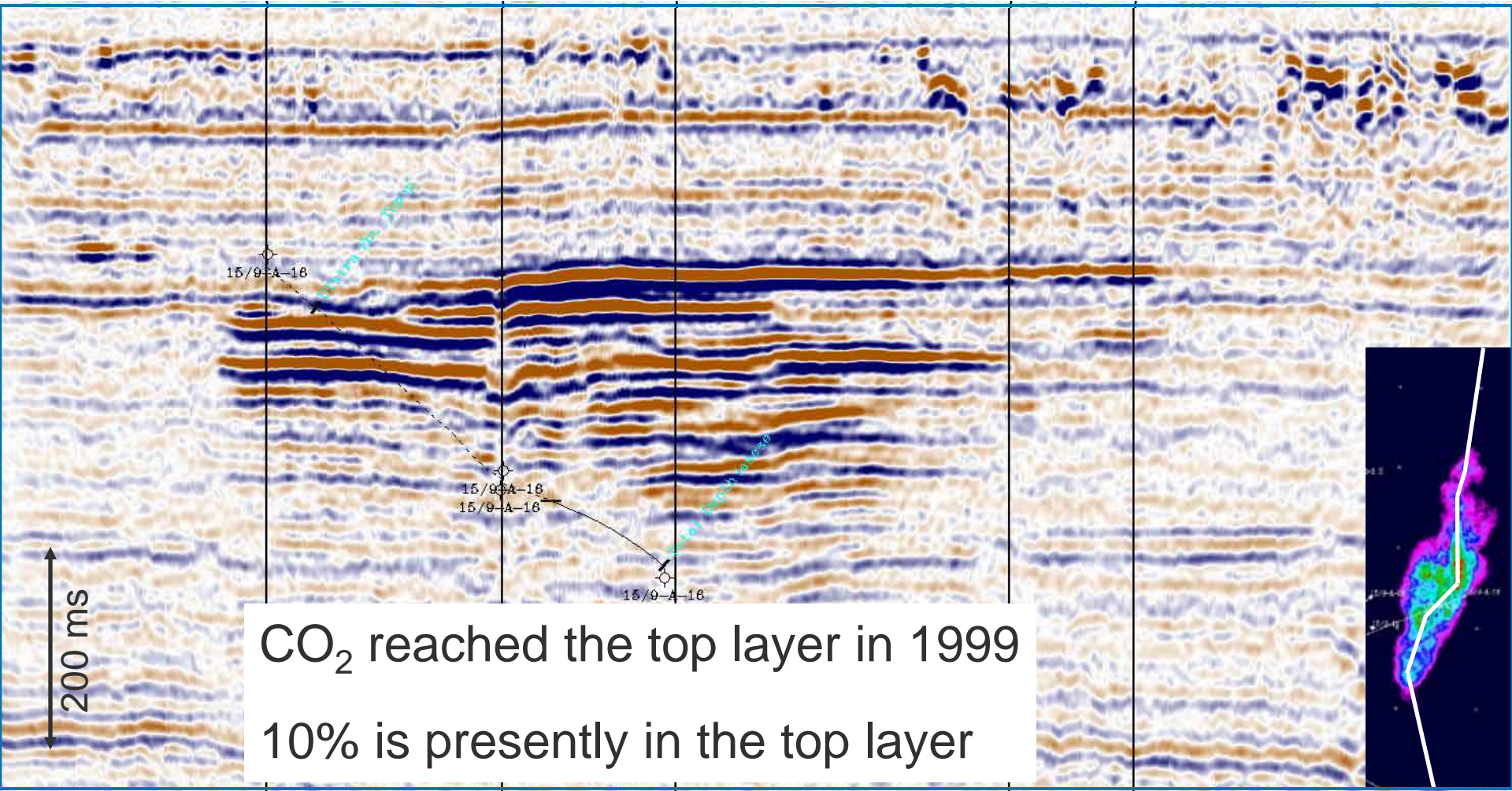
500m



Seismic image

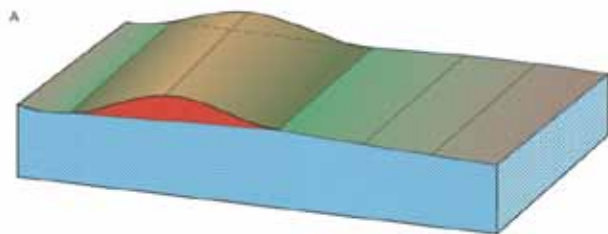
2006

500m

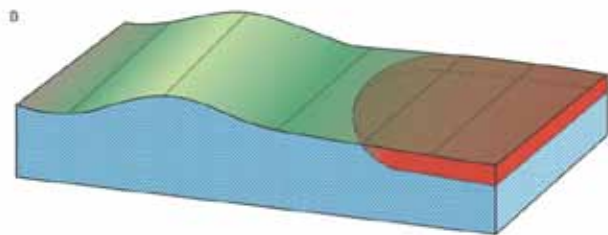


CO₂ reached the top layer in 1999
10% is presently in the top layer

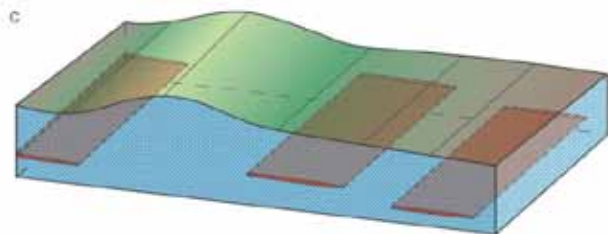
Where is the storage capacity?



Within mapped structures

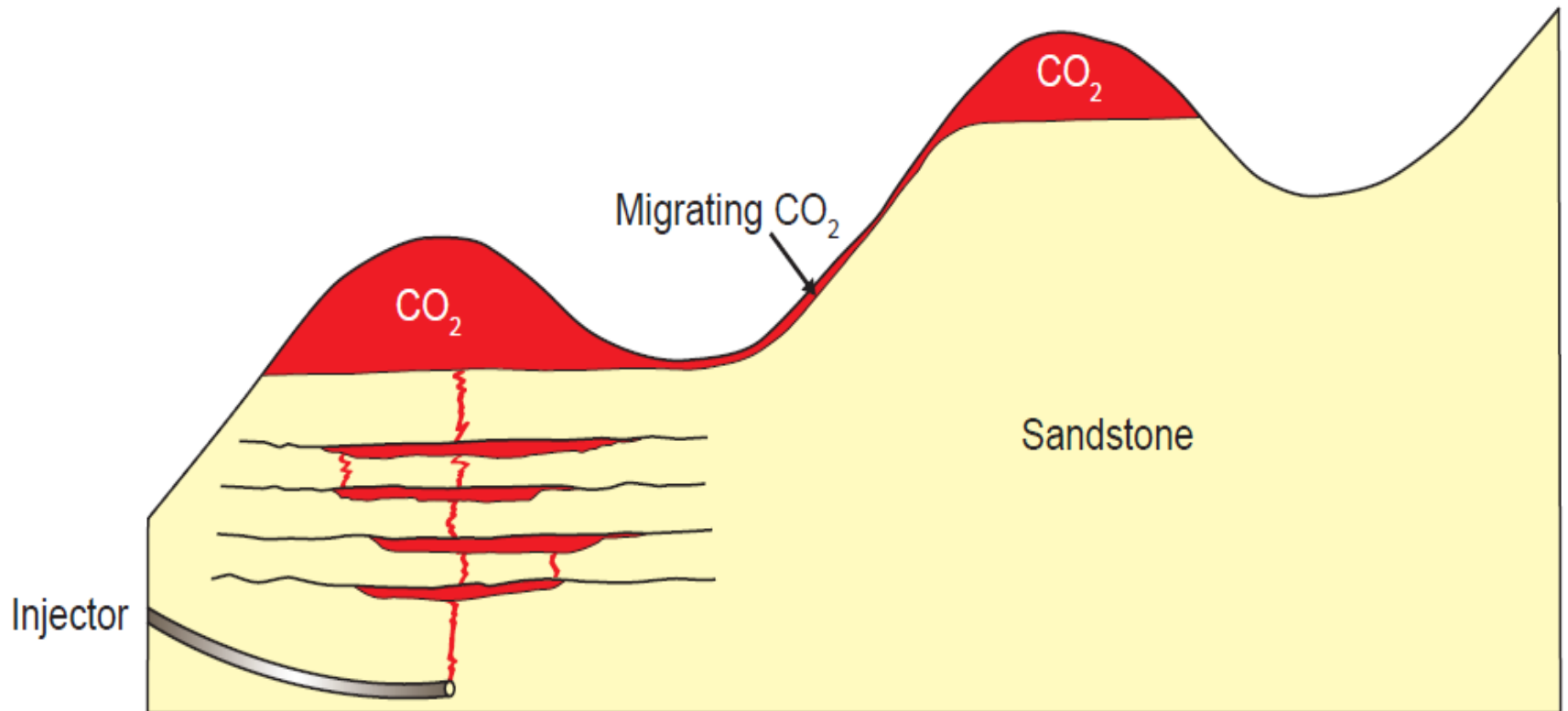


Along migration pathways -
various trapping mechanisms



Below unforeseen seals

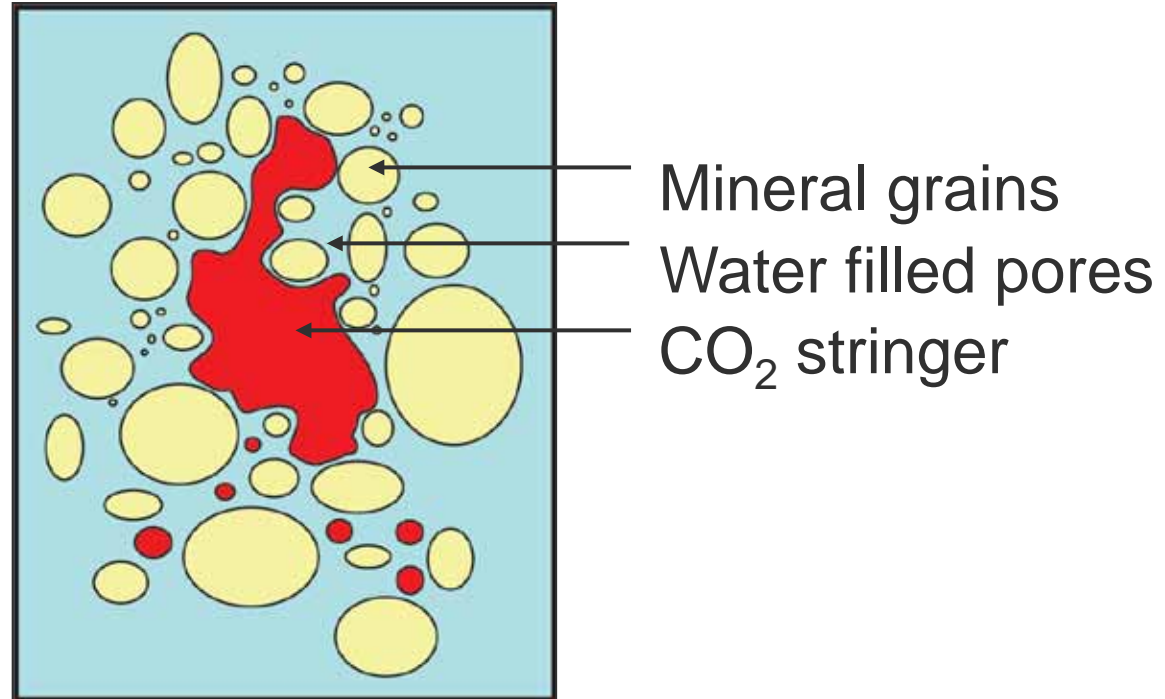
Limiting factor: filling of all structural closures + migration pathways



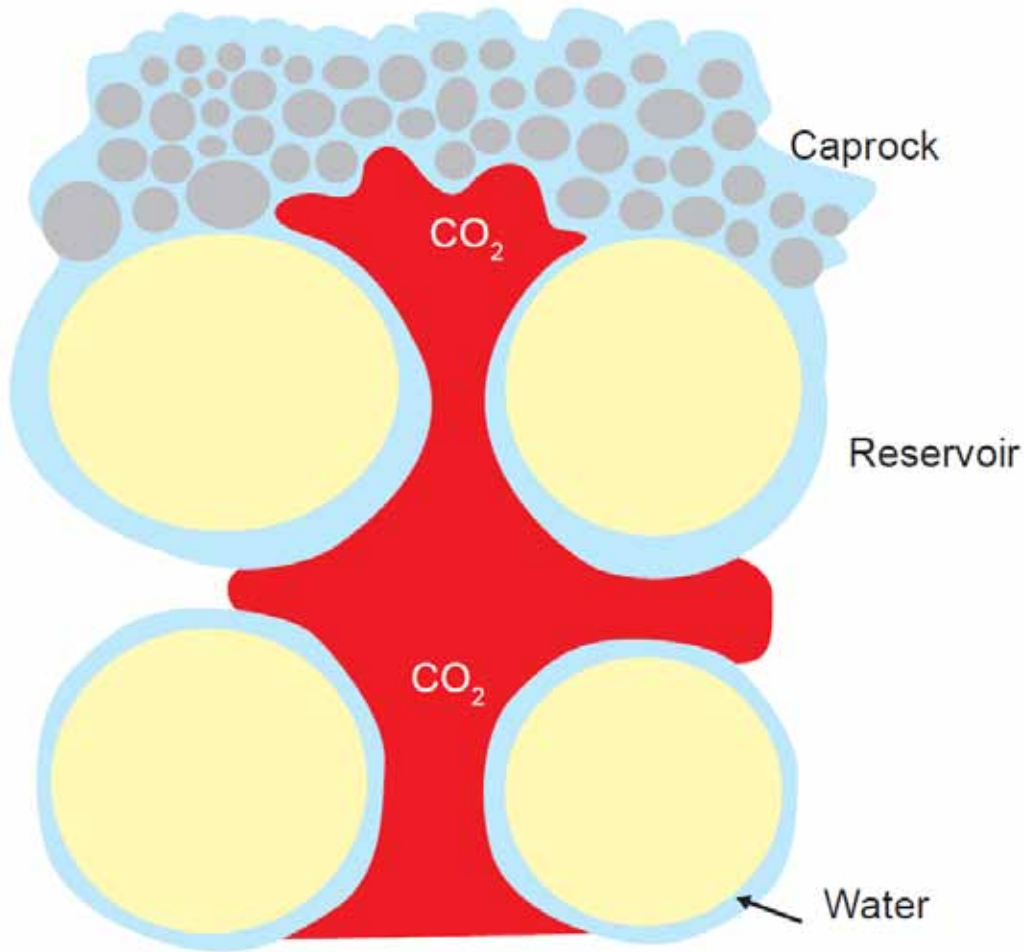
Structural trapping limits the storage potential



Residual trapping



Capillary trapping



Breakthrough when

$$P_c > P_{ce}$$

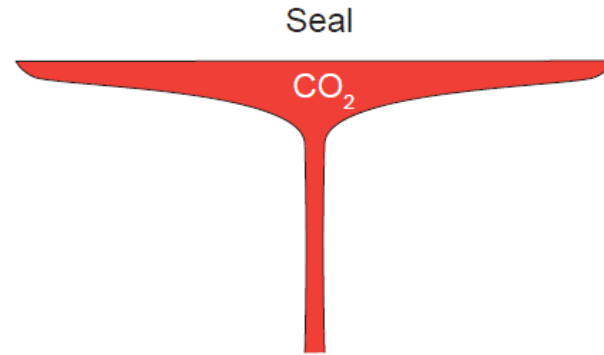
$$(r_w - r_{CO_2})gh > 2g/r$$

↑
column
height

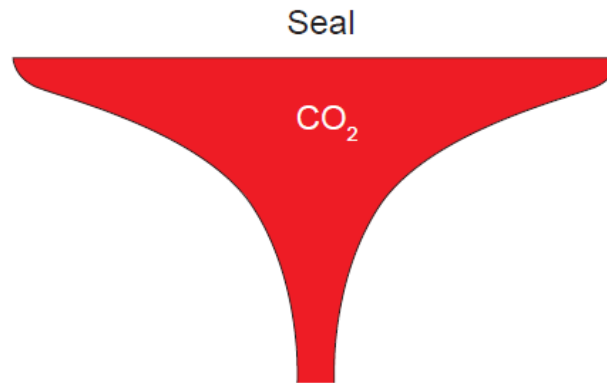
↑
pore
throat
radius

Depth of CO₂ – water contact

High perm. reservoir



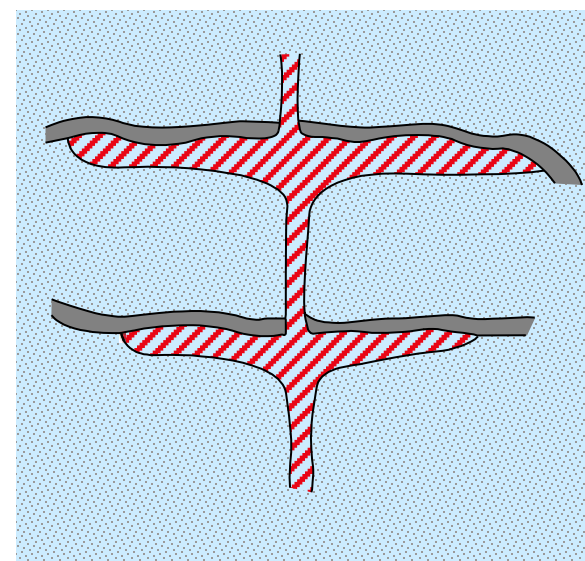
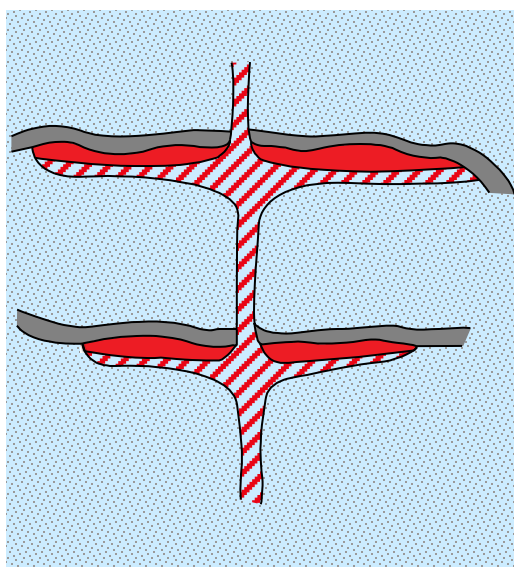
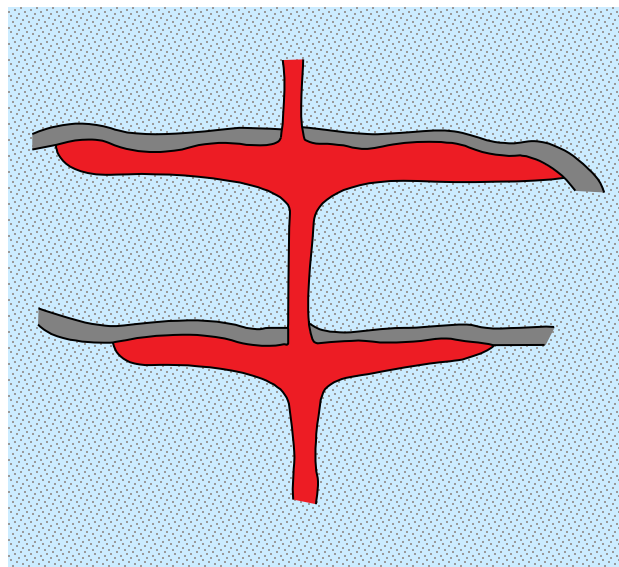
Lower perm reservoir



10m

1000m

CO₂ during and after injection



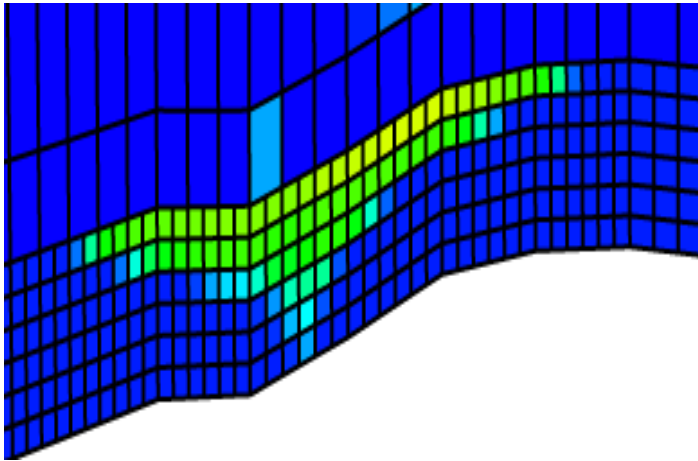
Modelling with little data



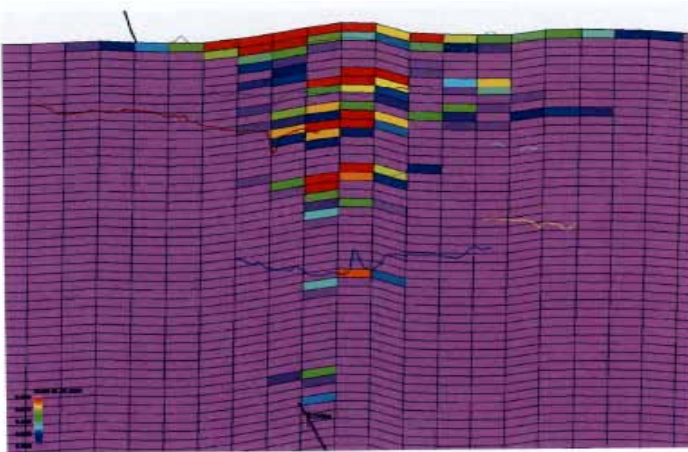
Modelling with little data



Numeric models depend on data availability



With little data



With more data

Different modelling approaches

Darcy Flow

- Time dependent
- Sloping CO₂ contact
- More radial CO₂ flow

- Long simulation time
- Coarse resolution

Invasion Percolation

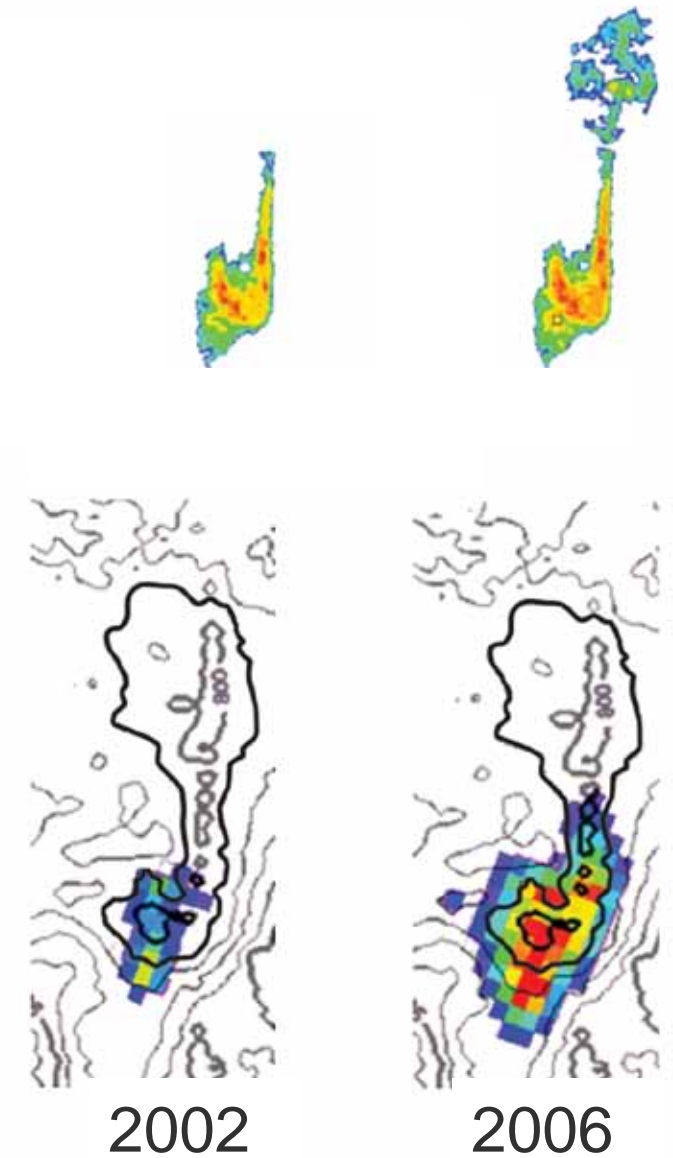
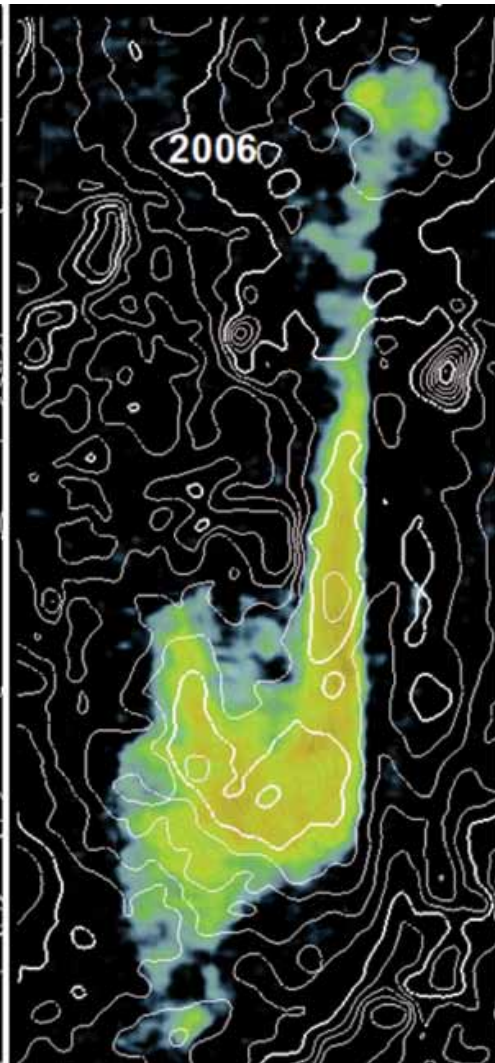
- Steady-state
- Flat fluid contact
- Flow follows topography

- Short simulation time
- Finer resolution

Modelling

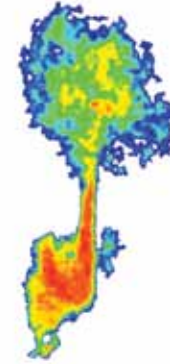
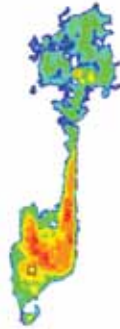
Invasion
Percolation

Darcy flow

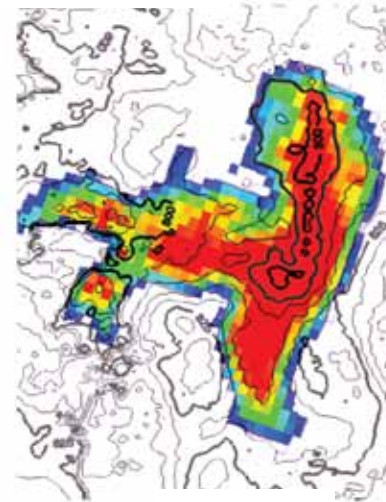
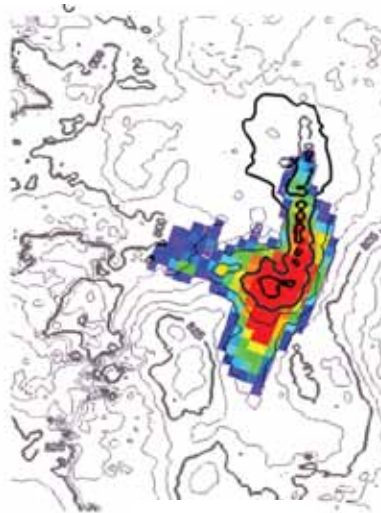


Future (predictions):

Invasion
percolation



Darcy flow



2012

2036

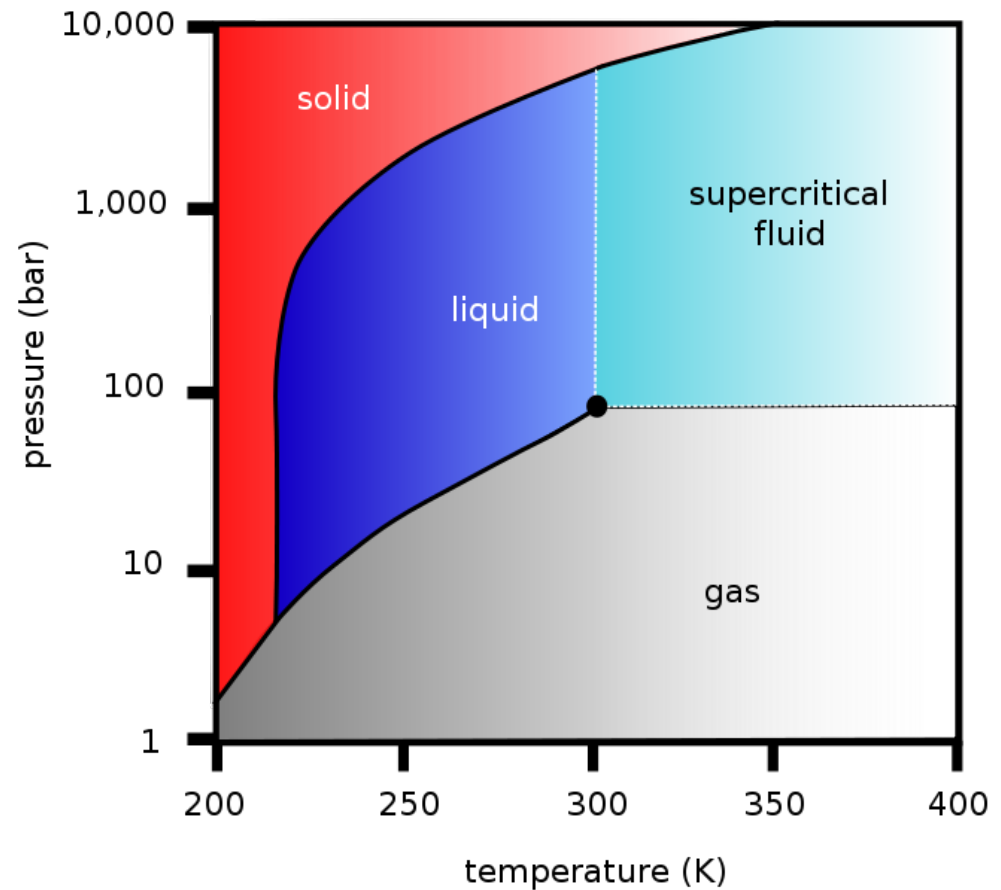
Differences due to:

Model formulations

Gridding

Parameters

CO₂ phase diagram



Darcy flow vs Invasion percolation (summarized)

- Differences:
 - Future flow directions
 - Storage capacity
- Implication: Model-dependent suggestions
 - Site selection
 - Overall CO₂ storage strategy

Conclusions

- A large part of the CO₂ storage potential of the Utsira Formation is outside structural closures
- CO₂ storage decisions here will be model-dependent
- The modelling results will be uncertain
 - Calibration to Sleipner data is essential
 - There is still a way to go
 -(to be continued)