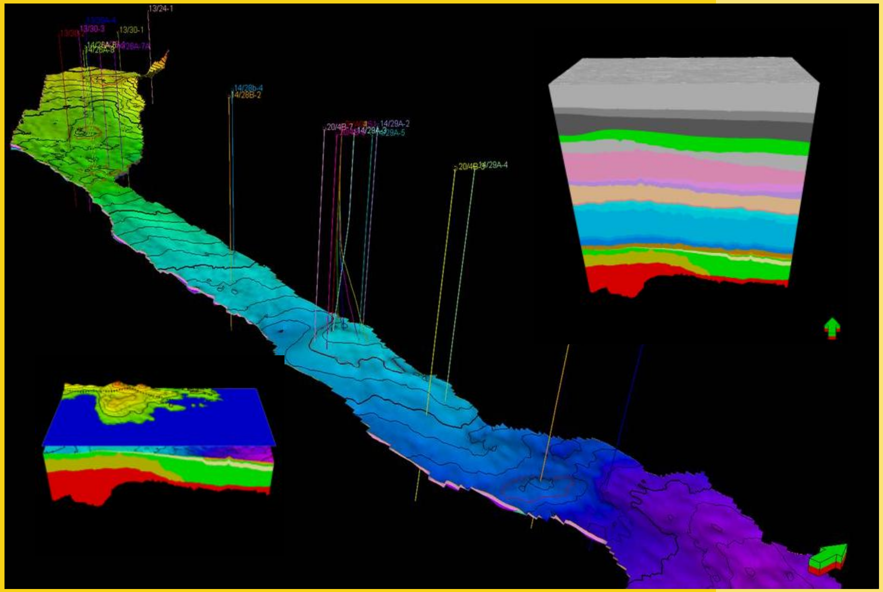
Migration from the primary store
- a cross network challenge -



IEA GHG

2nd Joint Network Meeting

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Santa Fe, New Mexico

Max Prins
Shell Global Solutions International

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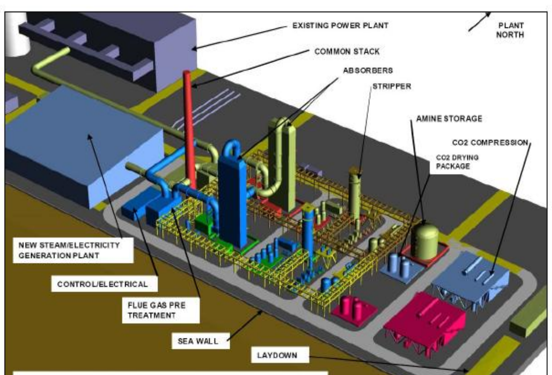
Problem statement

- How do we determine if we can detect migration from the primary store?
  - Where is it likely to occur – via what flow paths?
  - When can it occur?
  - At what rates can it occur?
  - What volumes can we detect?

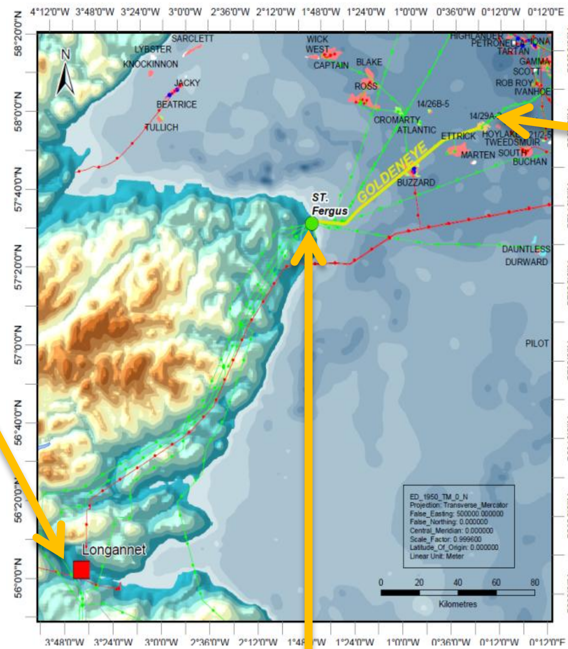
This work was done as part of the Longannet to Goldeneye Project

CO_2 extracted from flue gas at Scottish Power's 2.4 GW coal-fired Longannet Power Station

Carbon capture technology provided by Aker Clean Carbon, already tested on site with mobile pilot plant

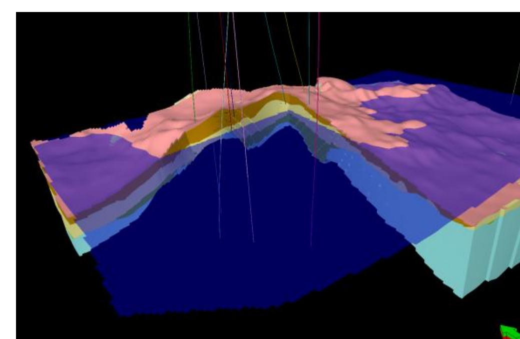


CO_2 piped to St Fergus Gas Terminal using existing National Grid gas pipeline

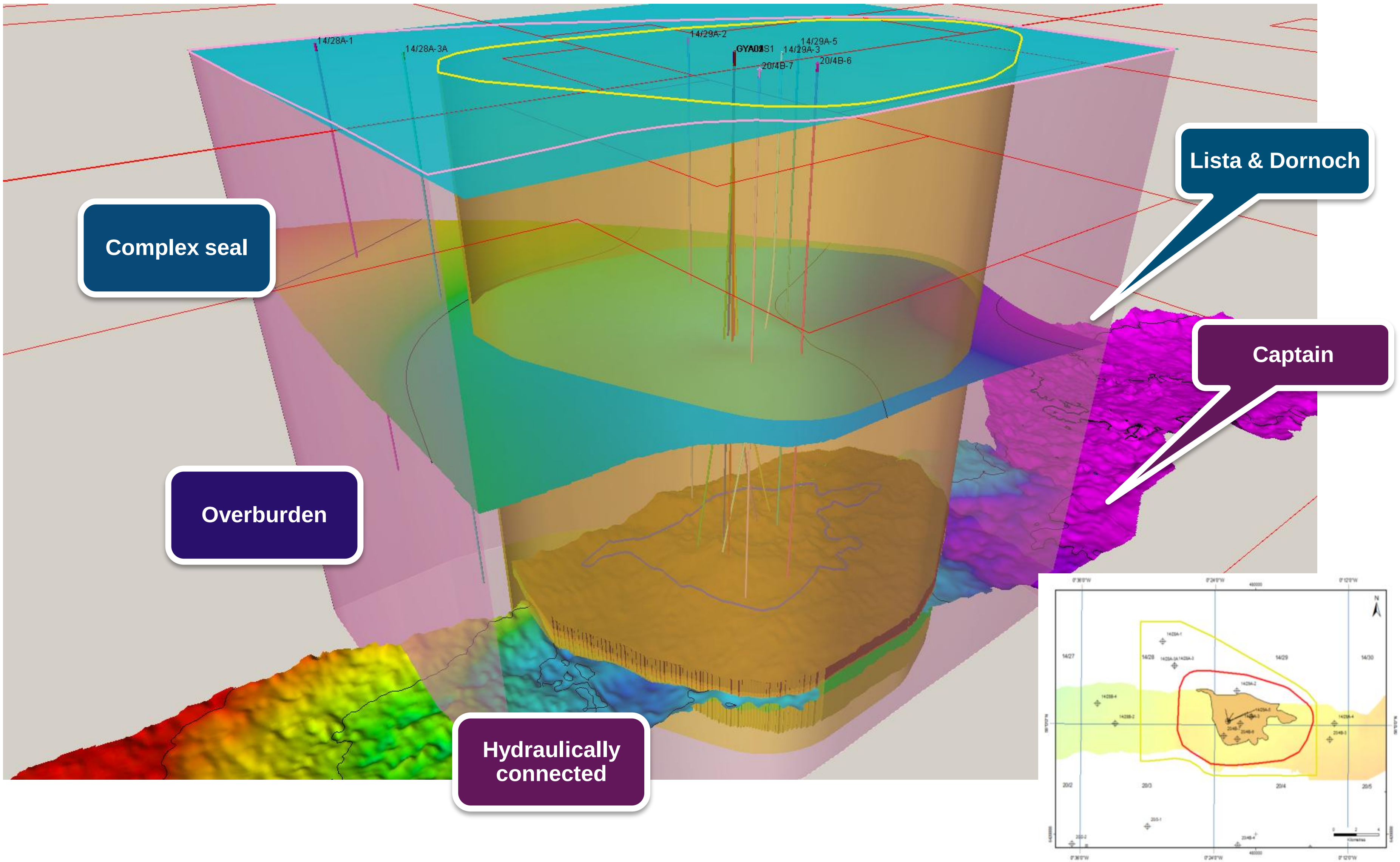


CO_2 transported to Goldeneye field using existing101 km offshore pipeline

20 Mt CO_2 stored in the depleted Goldeneye gas reservoir, injecting via existing platform wells

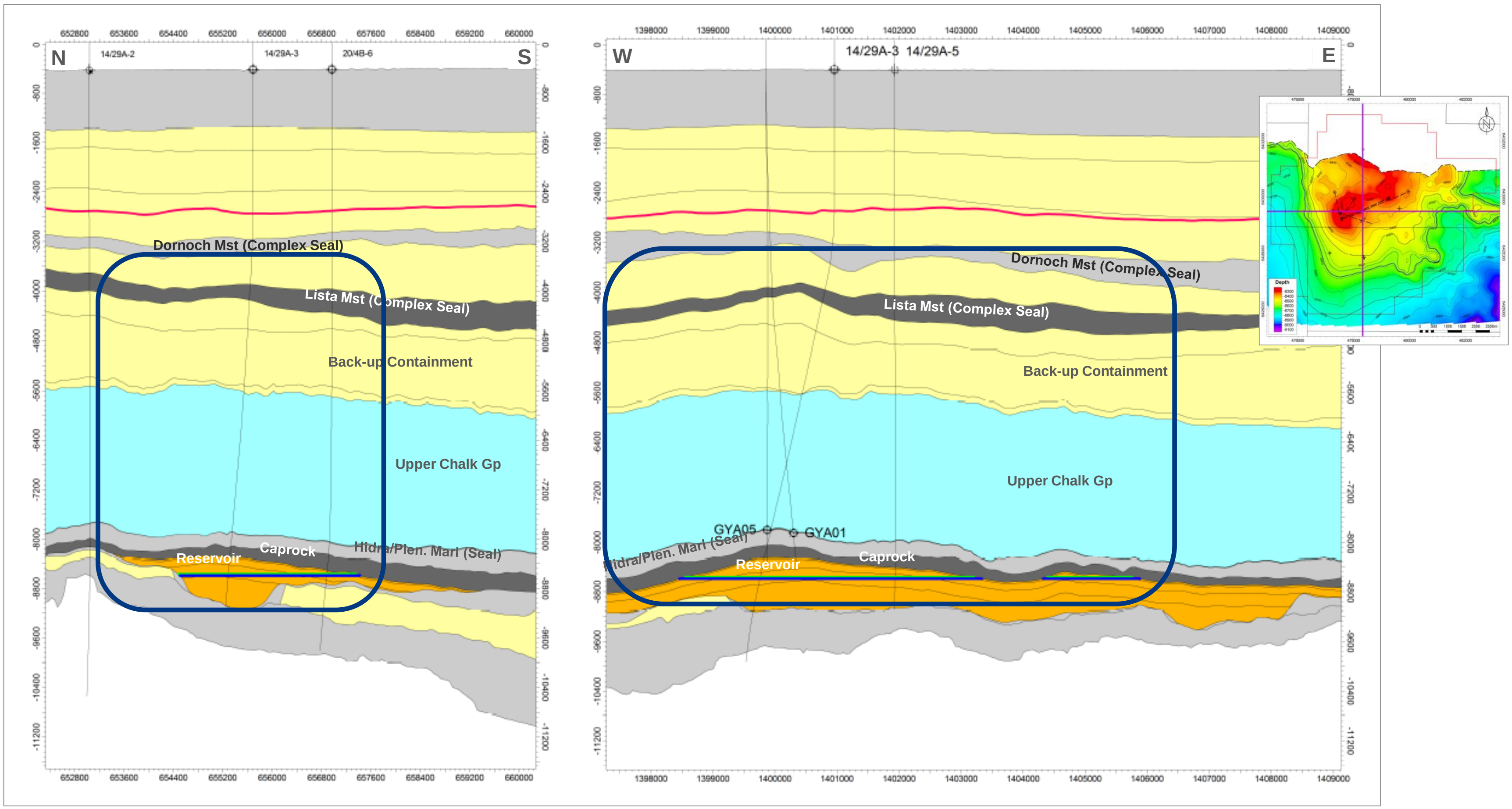


Storage complex



210 mD, S_{gtrap} 25%, 1500 tonnes/day injection.

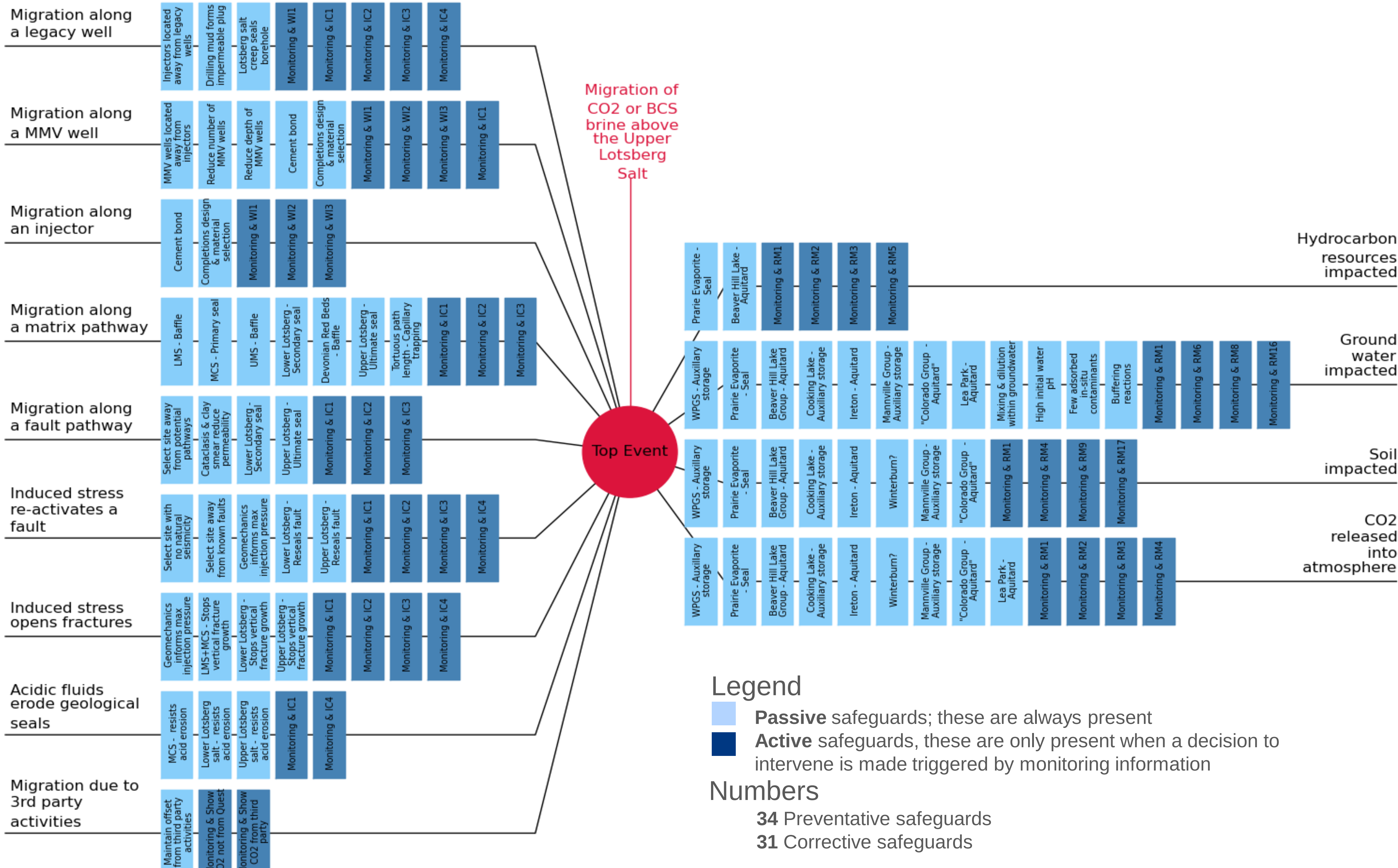
Cross section of store and complex



Risk assessment

Where is it likely to occur – via what flow paths?

A full bow-tie analysis was performed to identify and assess containment risk



Legend

Passive safeguards; these are always present

Active safeguards, these are only present when a decision to intervene is made triggered by monitoring information

Numbers

34 Preventative safeguards

31 Corrective safeguards

Bow tie results lead to identification of threats and potential migration paths

Threats

Acidic fluids react with minerals ...
- And perforate primary seal
- In fault / fracture cement making them conductive
- In reservoir weakening the formation and causing failure
- In the fault / fracture cement allowing fault to reactivate

Diffusion
- Pure diffusion of CO_2 through primary seal (Rodby)

Stress of injection
- Fault opening or formation of new open fault in seal
- Fracture opening or formation of new open fractures in primary seal

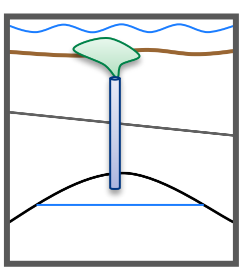
Existing faults
- Existing faults crossing primary seal (migration in complex)
- Faults / features crossing 1st & 2nd seals (migration from complex)

Lateral migration
- Lateral migration along the Captain fairway beyond the storage complex.

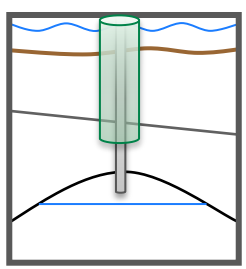
Abandoned wells
- Flow up abandoned E&A wellbores to near surface
- Abandoned injection wells create leak path

Injection wells
- Injection well tubing leak to
- Behind production casing cross flow

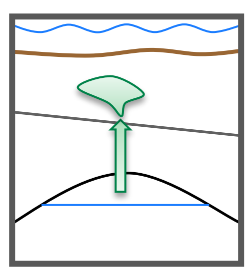
❶ CO_2 leakage through Plugged and Abandoned Wells



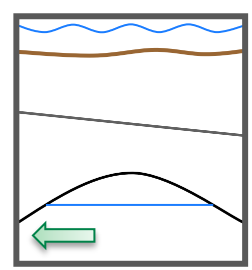
❷ CO_2 leakage through injectors



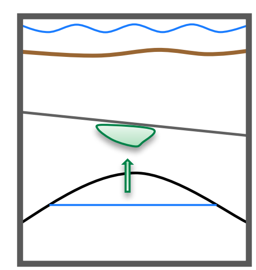
❸ CO_2 leakage through faults/fractures



❹ CO_2 leakage laterally to Captain Fairway Aquifer



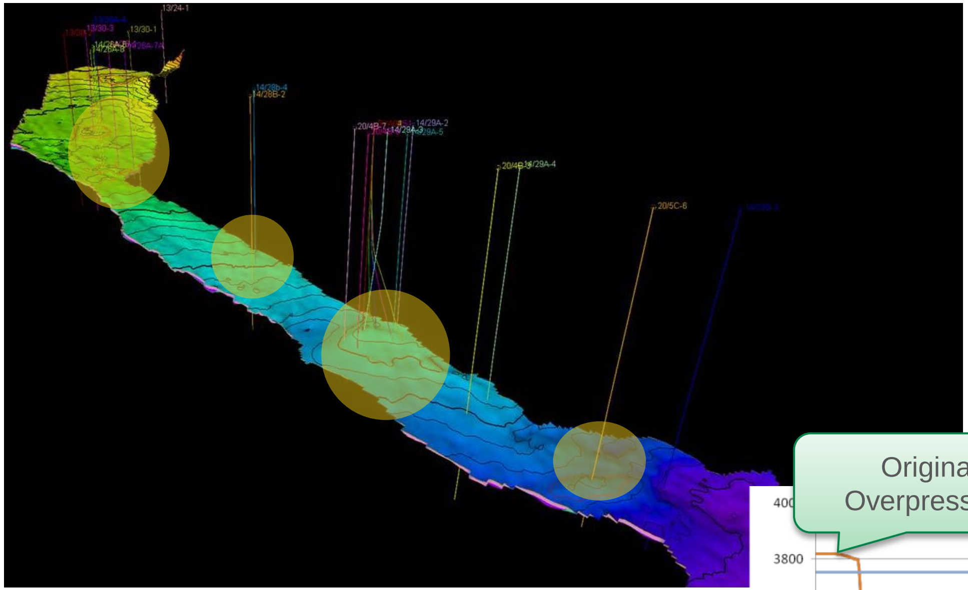
❺ CO_2 leakage to Mey Sandstone via caprock or wells

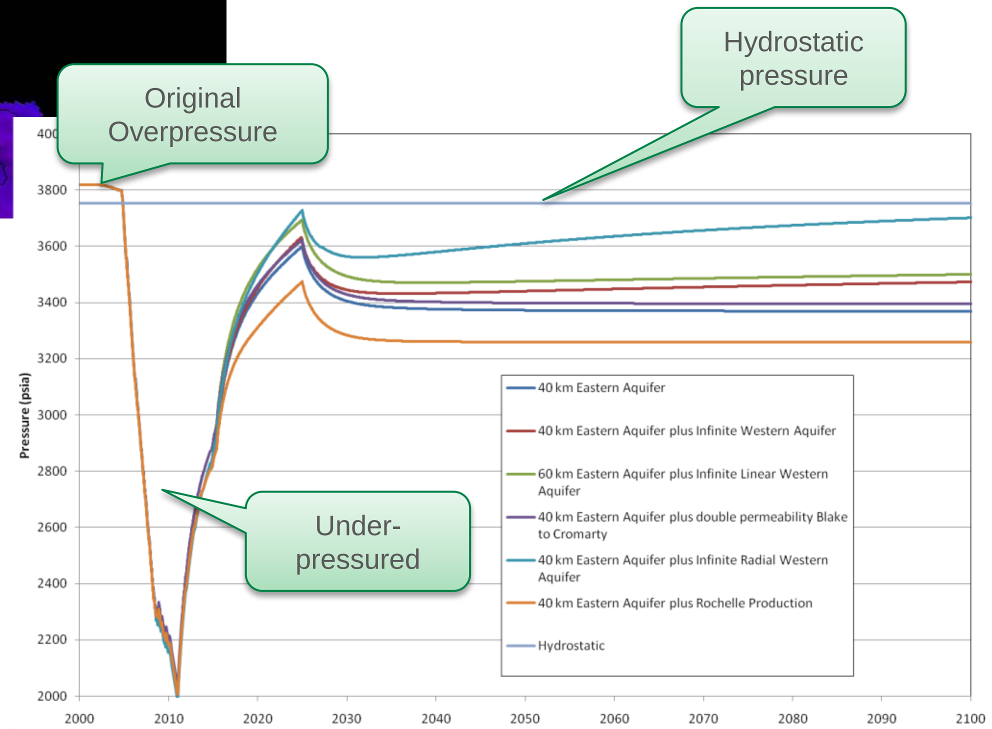


Timing of migration

When do the conditions to drive migration occur?

During the injection of CO_2 the field is sub-hydrostatic in all but two cases until the end of injection



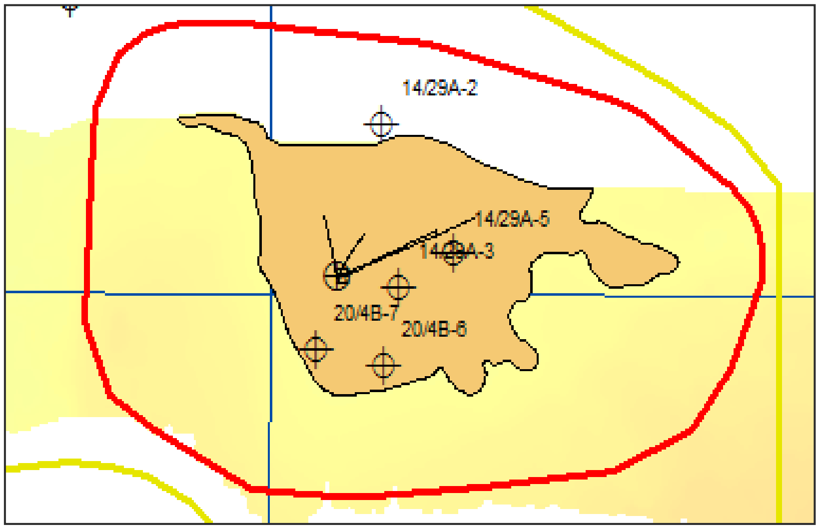


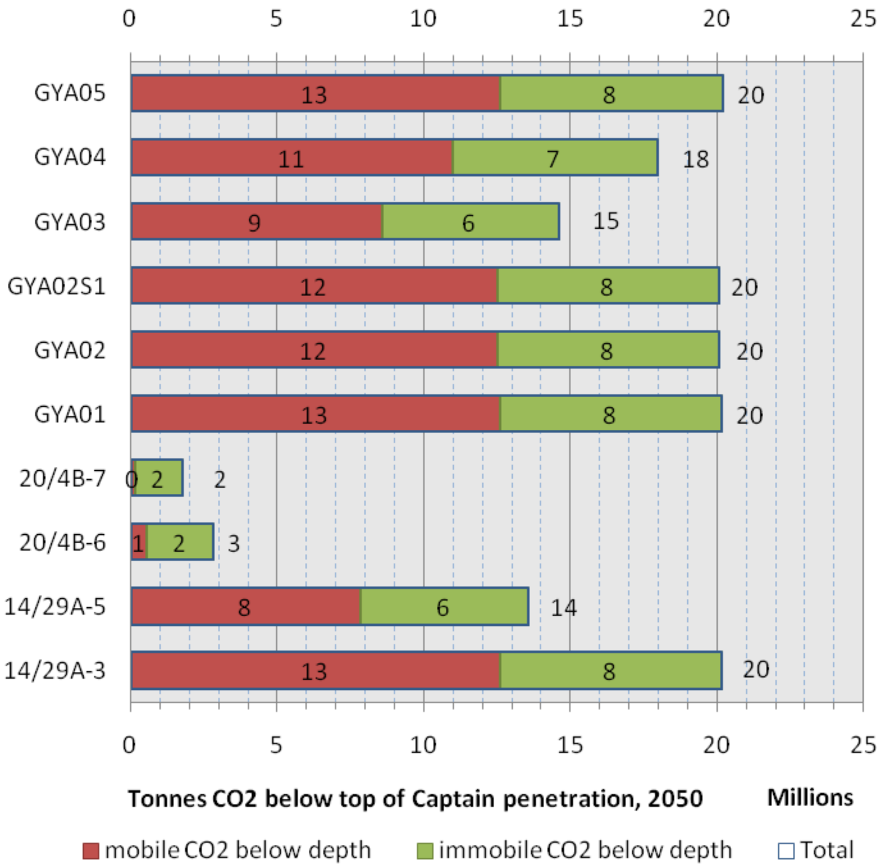
- Regional modelling of hydraulically connected volumes and other fields.

Maximum volume

What is the volume at risk

Take each well and calculate the mobile CO_2



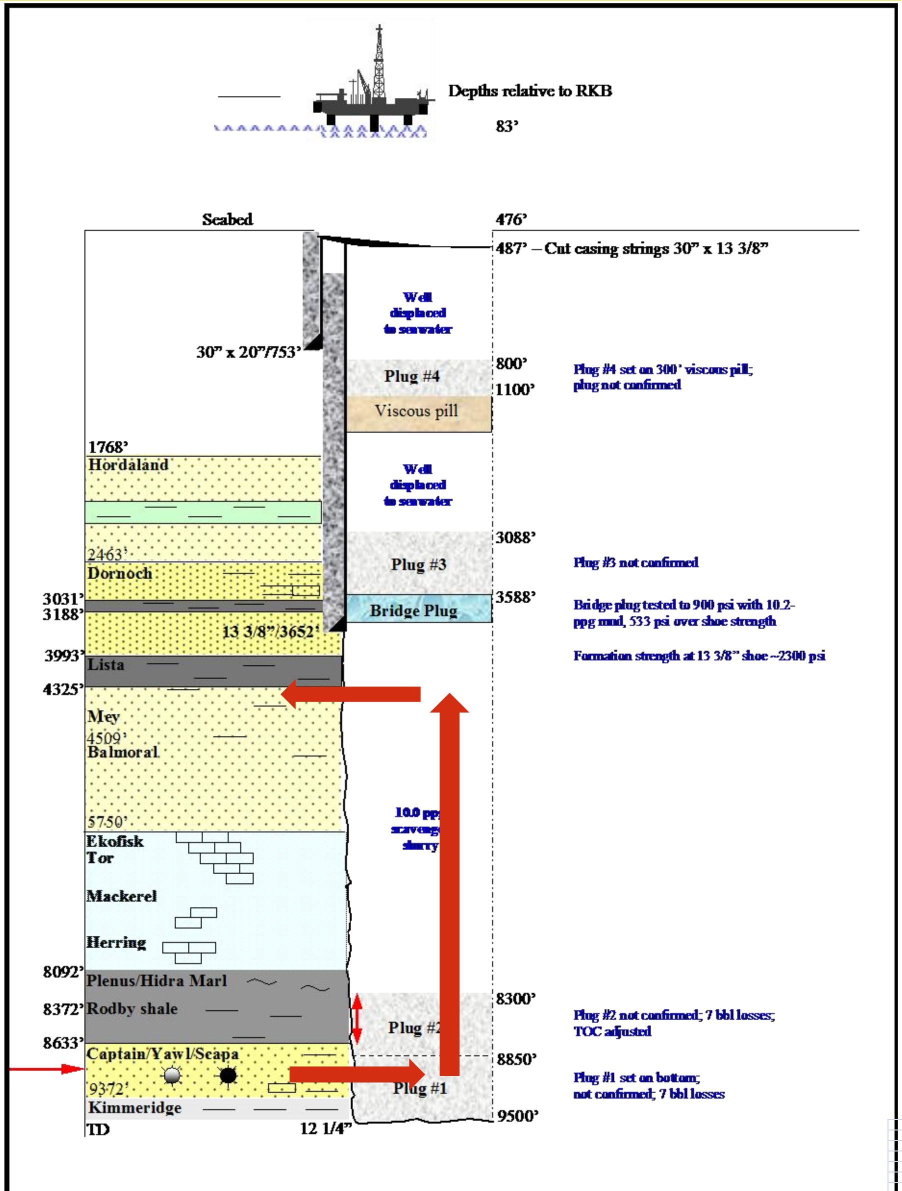


- Figure shows the volume at risk below each well within the store after the system has reached gravity equilibrium in 2050 after injection of 20Mt.
- The chart separates CO_2 into mobile and immobile CO_2.

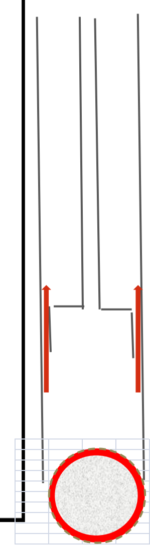
Rate of migration

What are the likely rates for a leak up a well

13Mt can migrate, but at what rate (if re-pressured)?



- Significant modelling required looking at realistic micro annulus scenarios
- Constrained by cement plug tests and experiments
- Rates
  - 1500 Tones per day. Total CO_2 migration is 10Mt. This represent a total failure of all barriers.
  - 100 tonnes/d based on cement shrinkage factor of 0.7%.
  - Most realistic leak rate 2.1 tonnes/d

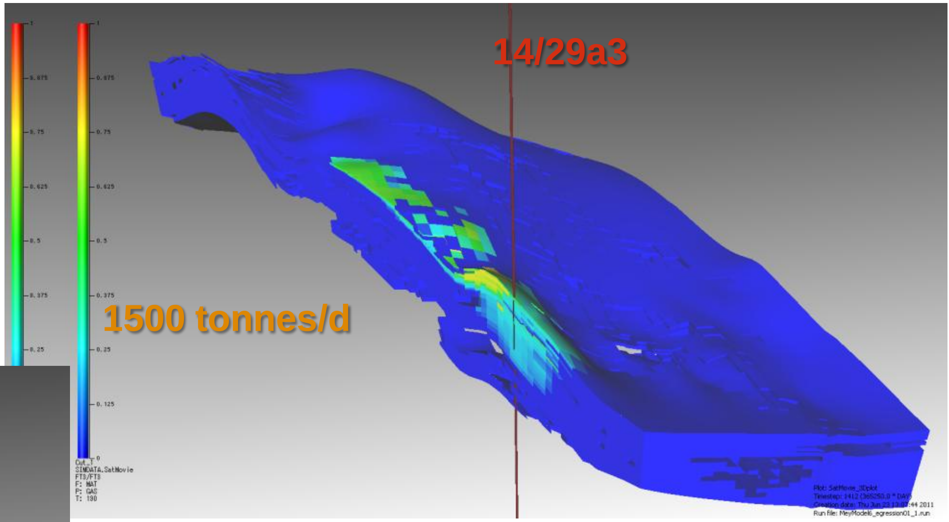


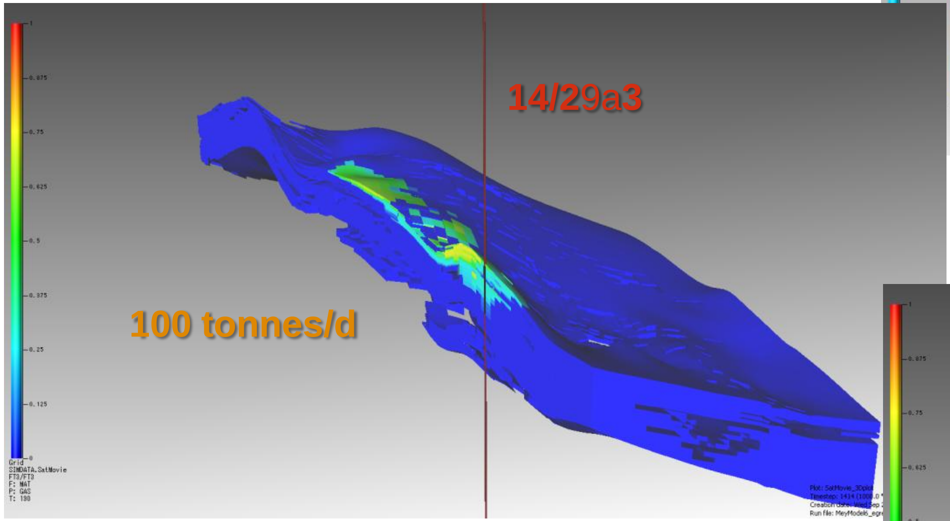
Detection

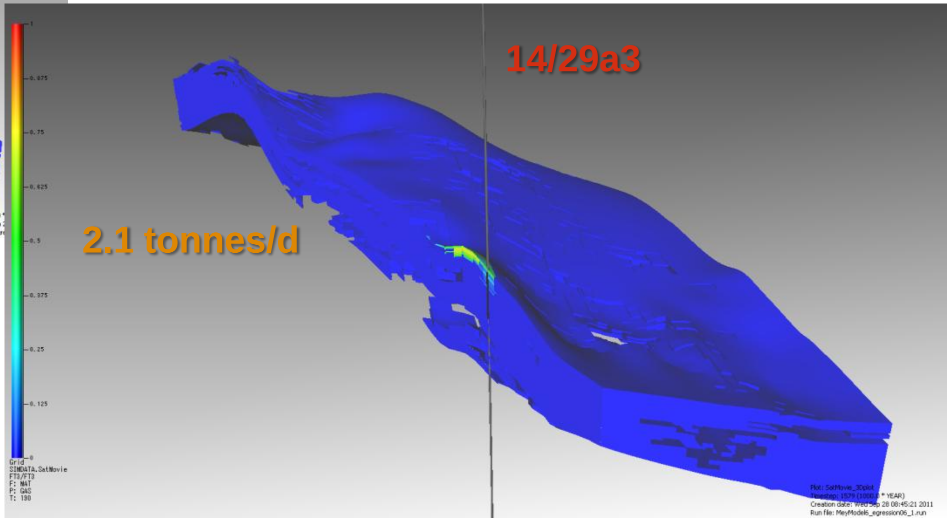
What volumes can we detect?

Multiple simulations of the secondary store were created with different cross flow rates

- 1000 year migration





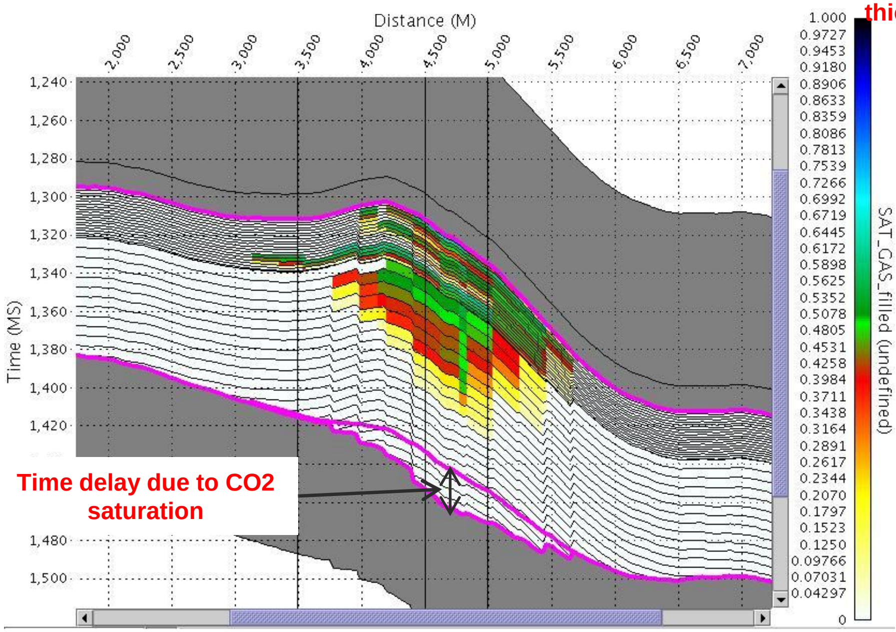


Synthetic 4D seismic was generated

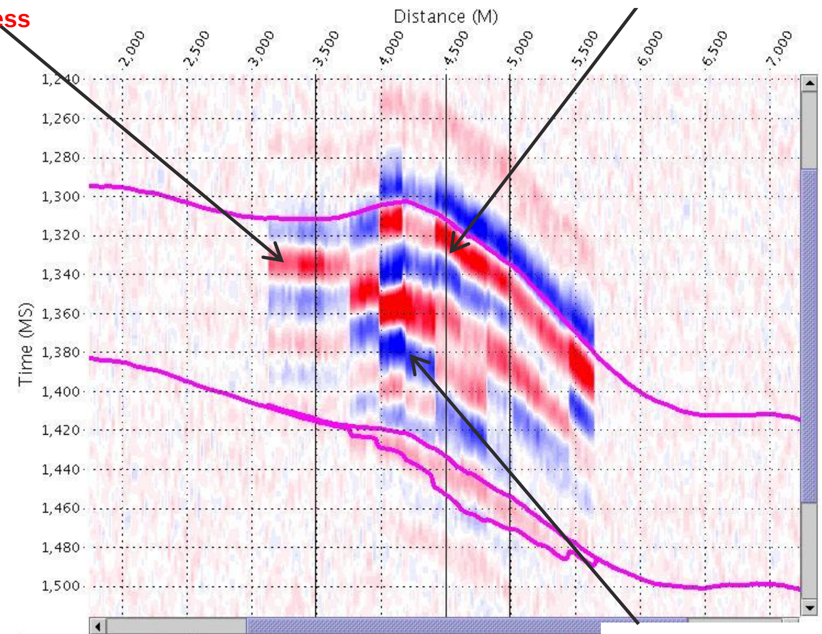
Strong CO2 softening signal at top reservoir

Dim amplitudes corresponding to low saturation and thickness

Saturation CO_2 plume



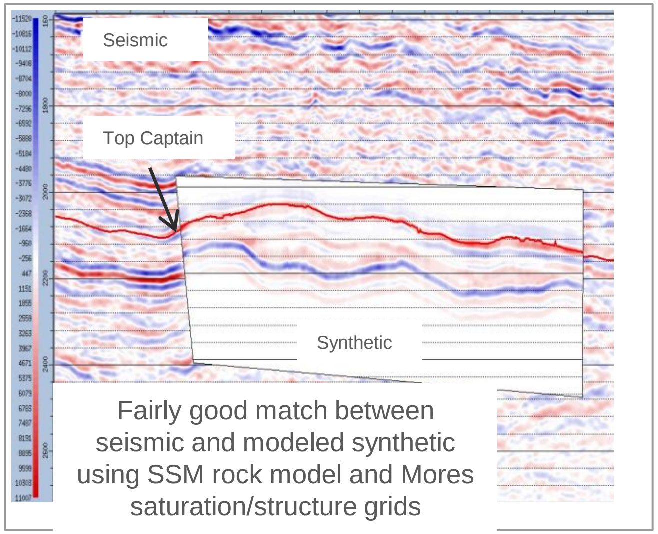
RMS amplitude response CO_2 plume



Strong CO2 signal at base saturation

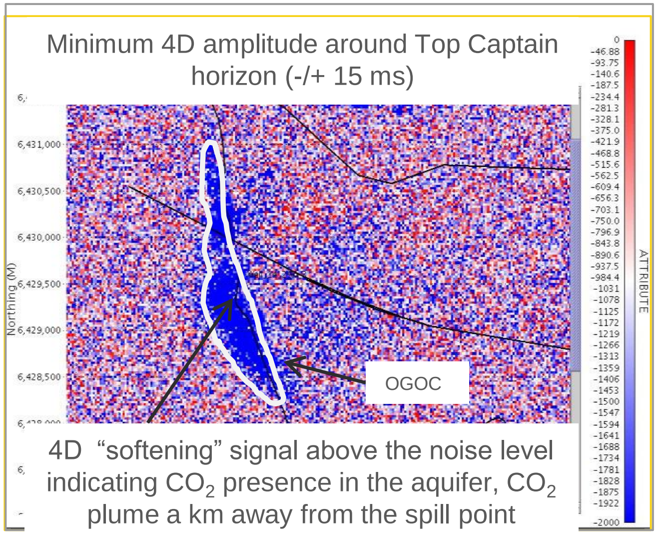
This was also done for lateral migration from the store

- Synthetic seismic at Captain level
- Can see CO2 in lateral aquifer even when noise superimposed



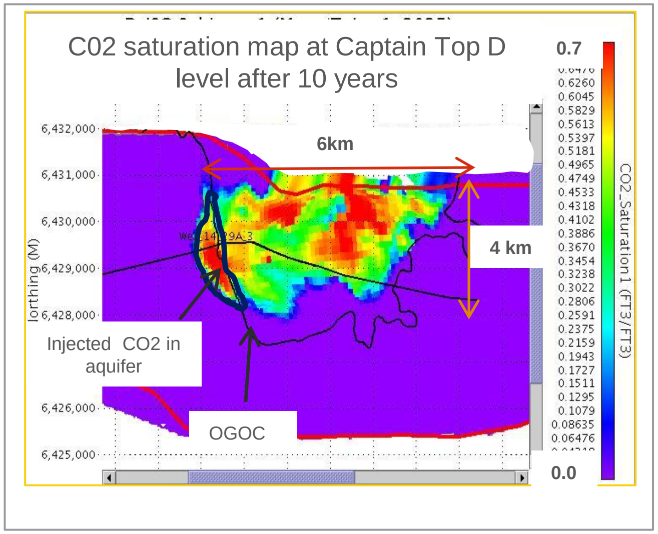
Fairly good match between seismic and modeled synthetic using SSM rock model and Mores saturation/structure grids

Minimum 4D amplitude around Top Captain horizon (-/+ 15 ms)

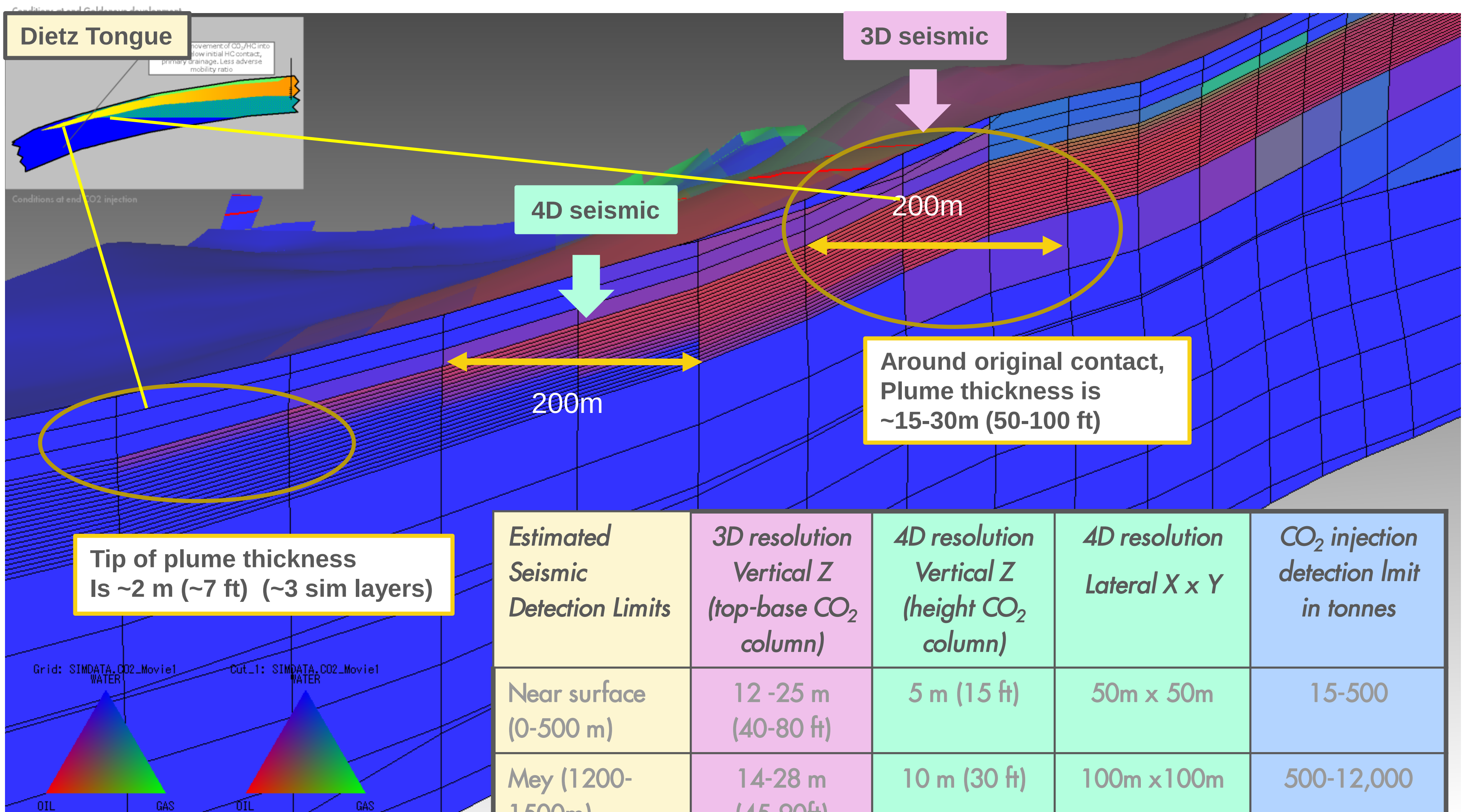


4D "softening" signal above the noise level indicating CO_2 presence in the aquifer, CO_2 plume a km away from the spill point

C02 saturation map at Captain Top D level after 10 years



Captain CO_2 plume tip at end injection – Detectability



Estimated Seismic Detection Limits	*3D resolution Vertical Z (top-base CO_2 column)*	*4D resolution Vertical Z (height CO_2 column)*	*4D resolution Lateral X x Y*	*CO_2 injection detection lmit in tonnes*
Near surface (0-500 m)	12 -25 m (40-80 ft)	5 m (15 ft)	50m x 50m	15-500
Mey (1200-1500m)	14-28 m (45-90ft)	10 m (30 ft)	100m x100m	500-12,000
Reservoir (2500-2750m)	17-36 m (55-120ft)	13 m (50 ft)	200m x 200m	3,000-30,000

Conclusion

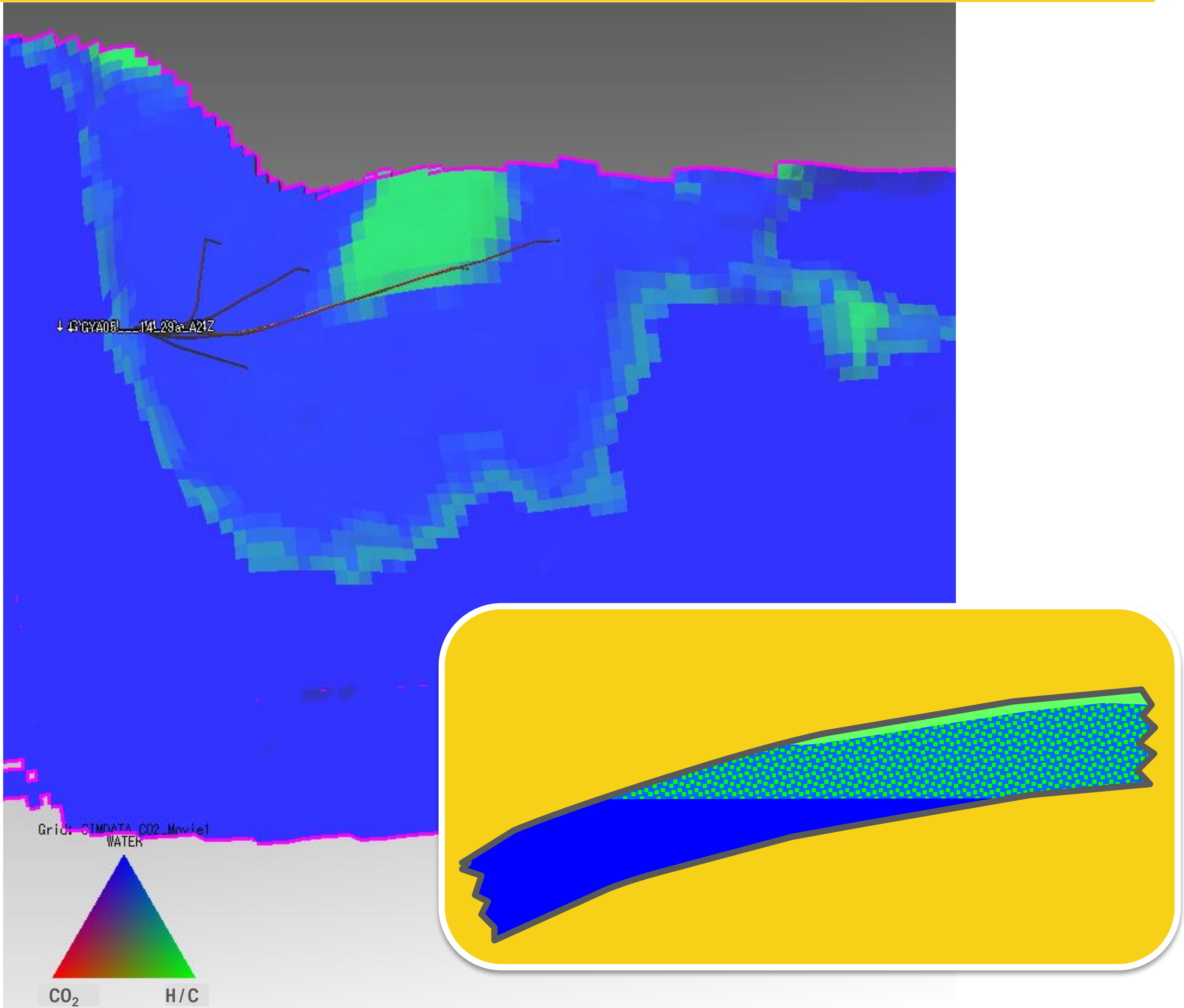
- Even in this simple example we have seen integrated network approach:
  - Risk assessment
  - Wells
  - Modelling
  - Monitoring
  - Environmental
- All working together to show that potential migration can be detected.
- Some areas for improving understanding – input for tomorrow R&D sessions: migration though overburden, migration up microannuli in wells, quantitative measurement of CO_2 migration.

Many thanks to the team:

- Over 30 staff who worked for 9 months to deliver this as part of a larger team who spent 70,000 hours on this end to end project
- Message to governments and organisations – 90/10 rule

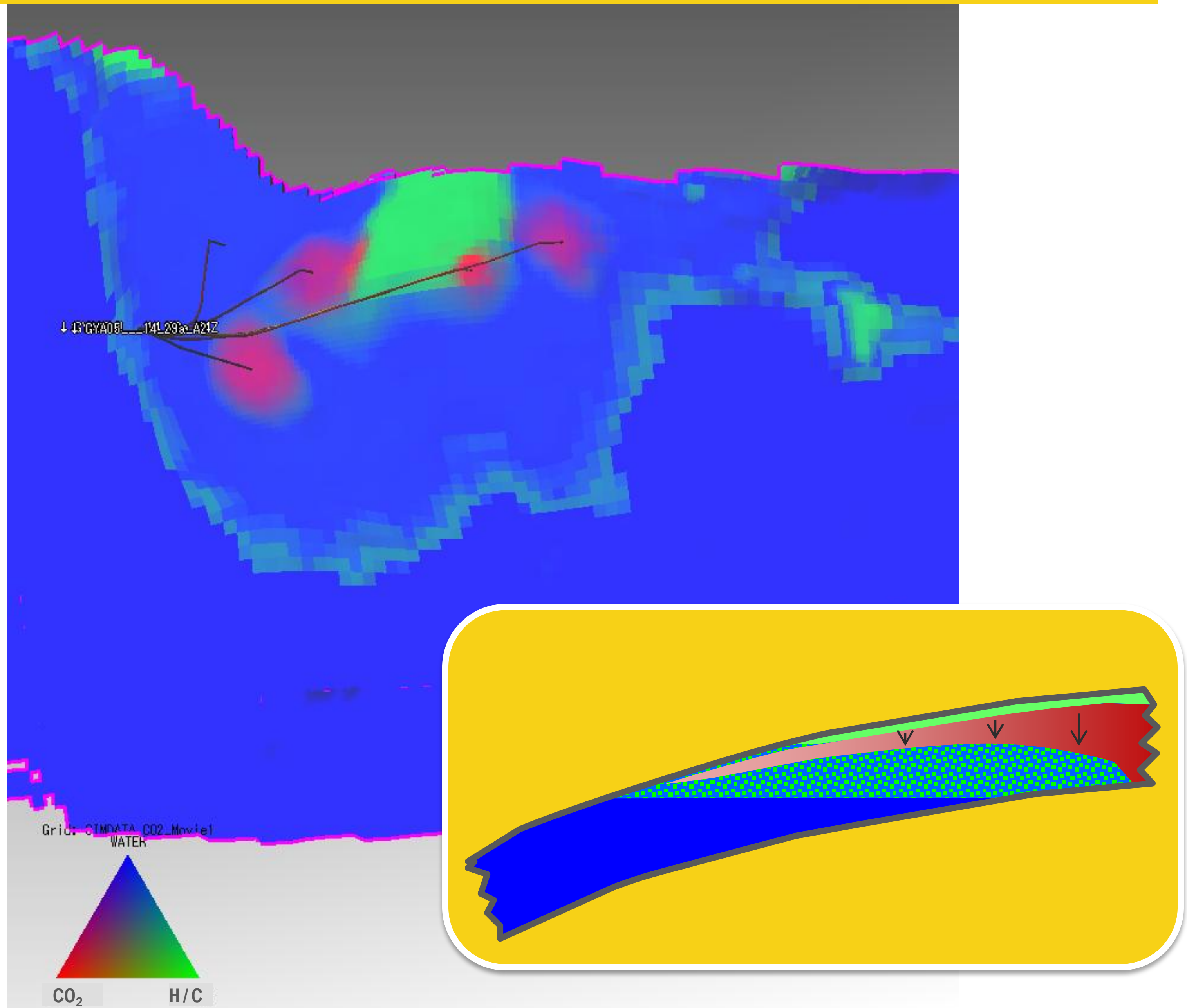
Goldeneye full field model: some water invaded

Year 0



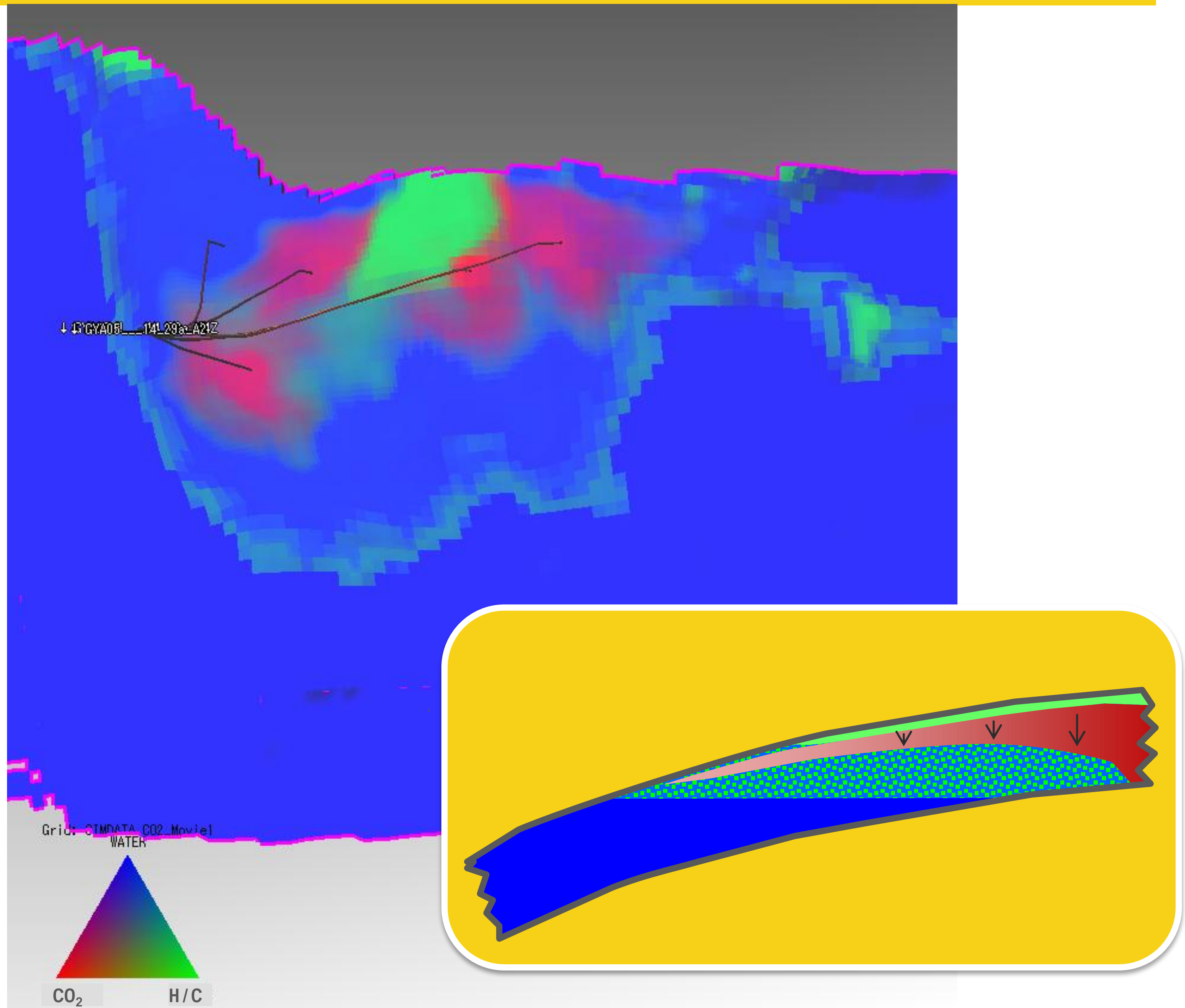
CO_2 injected at existing well locations

Year +2



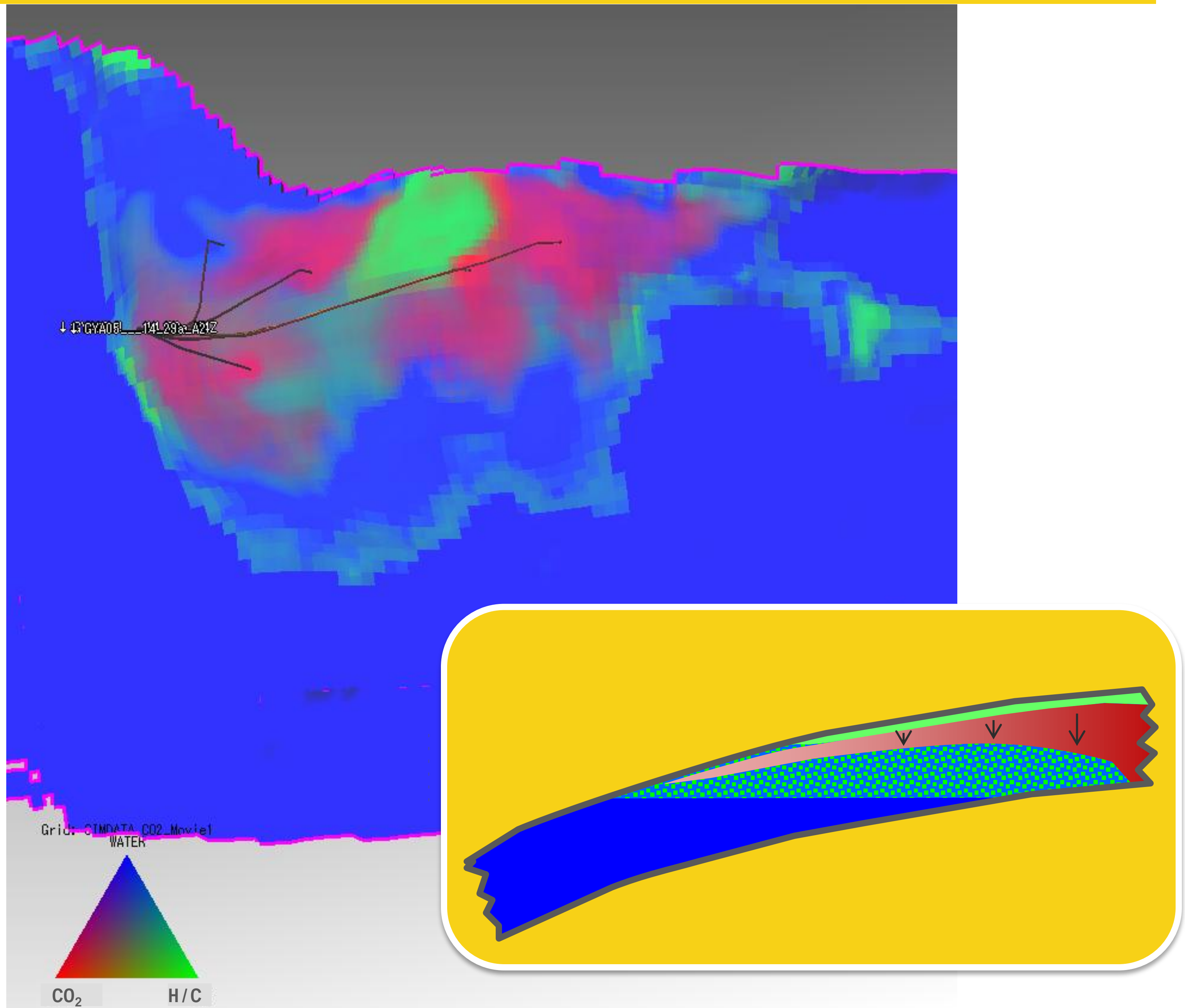
CO_2 displaces water and mixes with remaining gas

Year +4



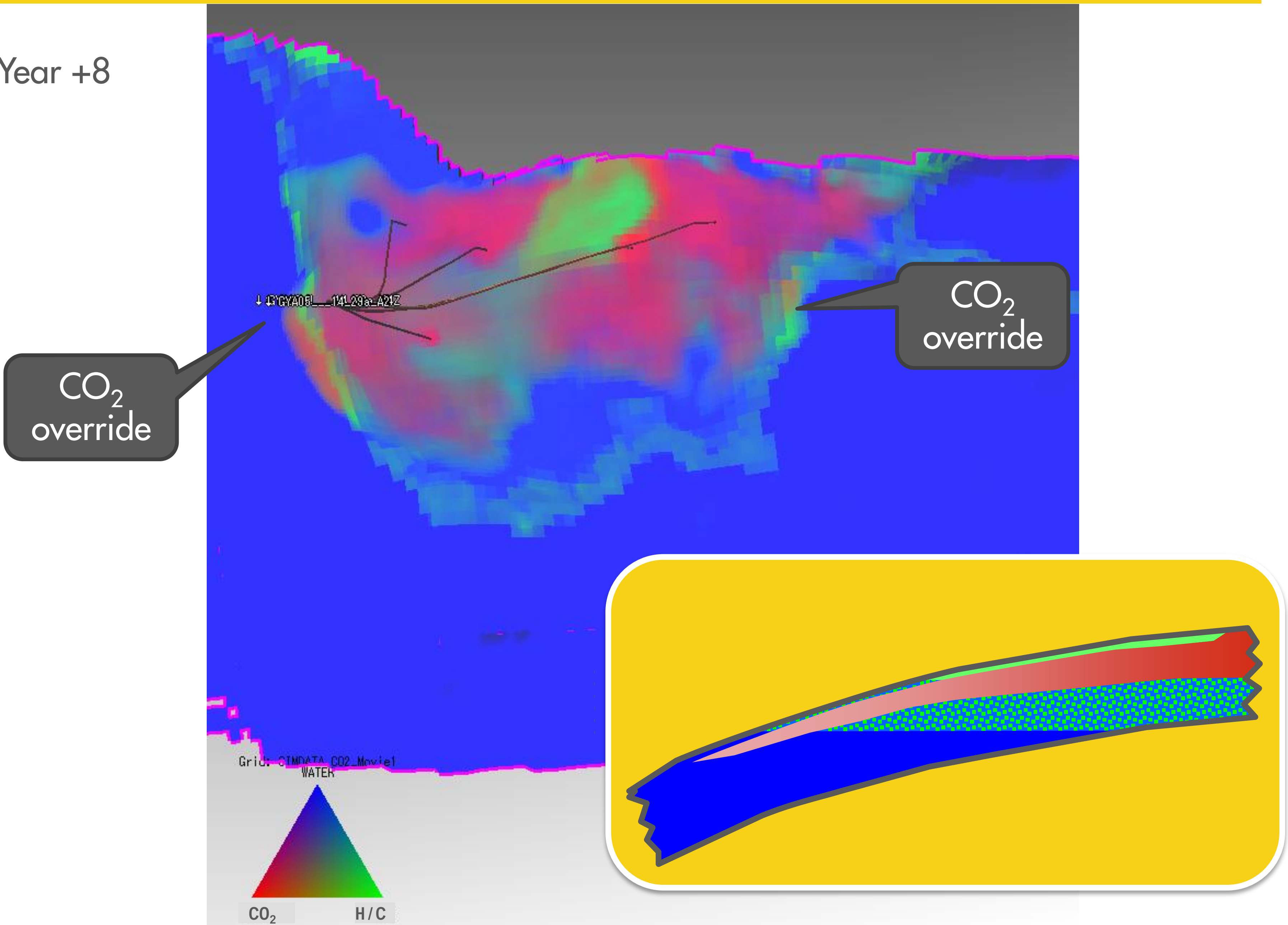
CO_2 filling the original structure

Year +6



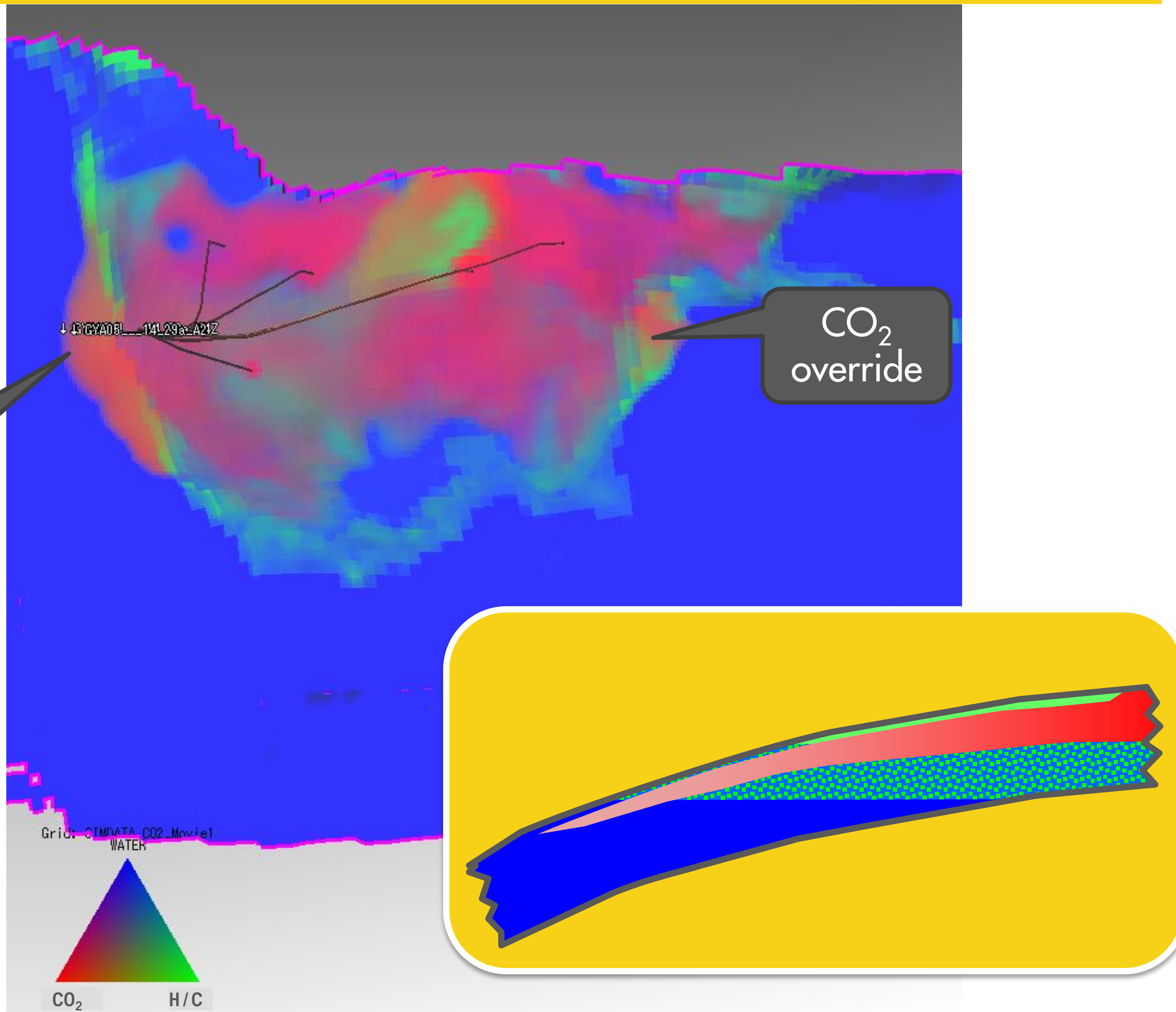
CO_2 driven below original contacts by force of injection

Year +8



CO_2 maximum extent at end of injection

Year +10



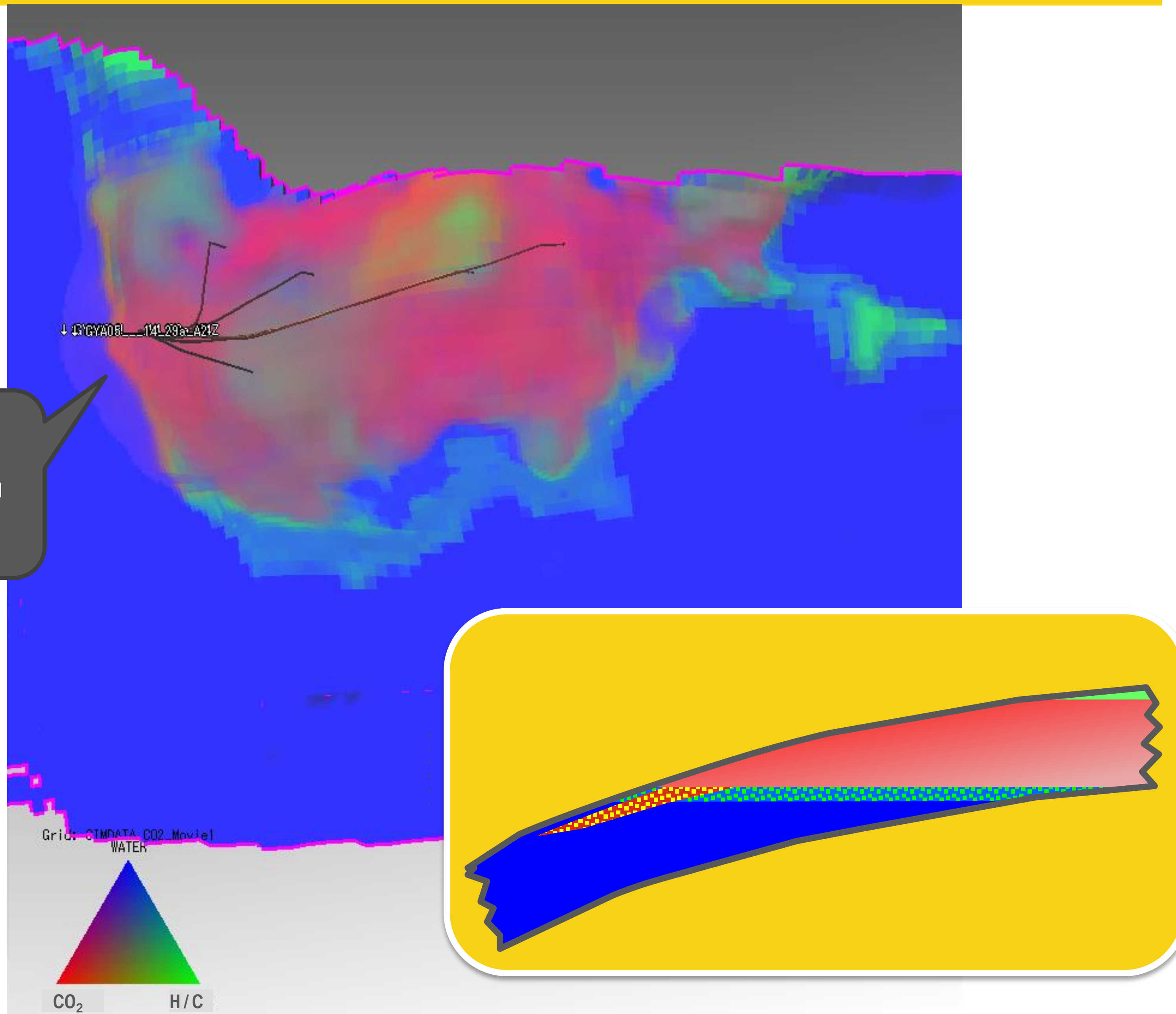
CO_2 override

CO_2 override

CO_2 moves back into gas leg driven by buoyancy

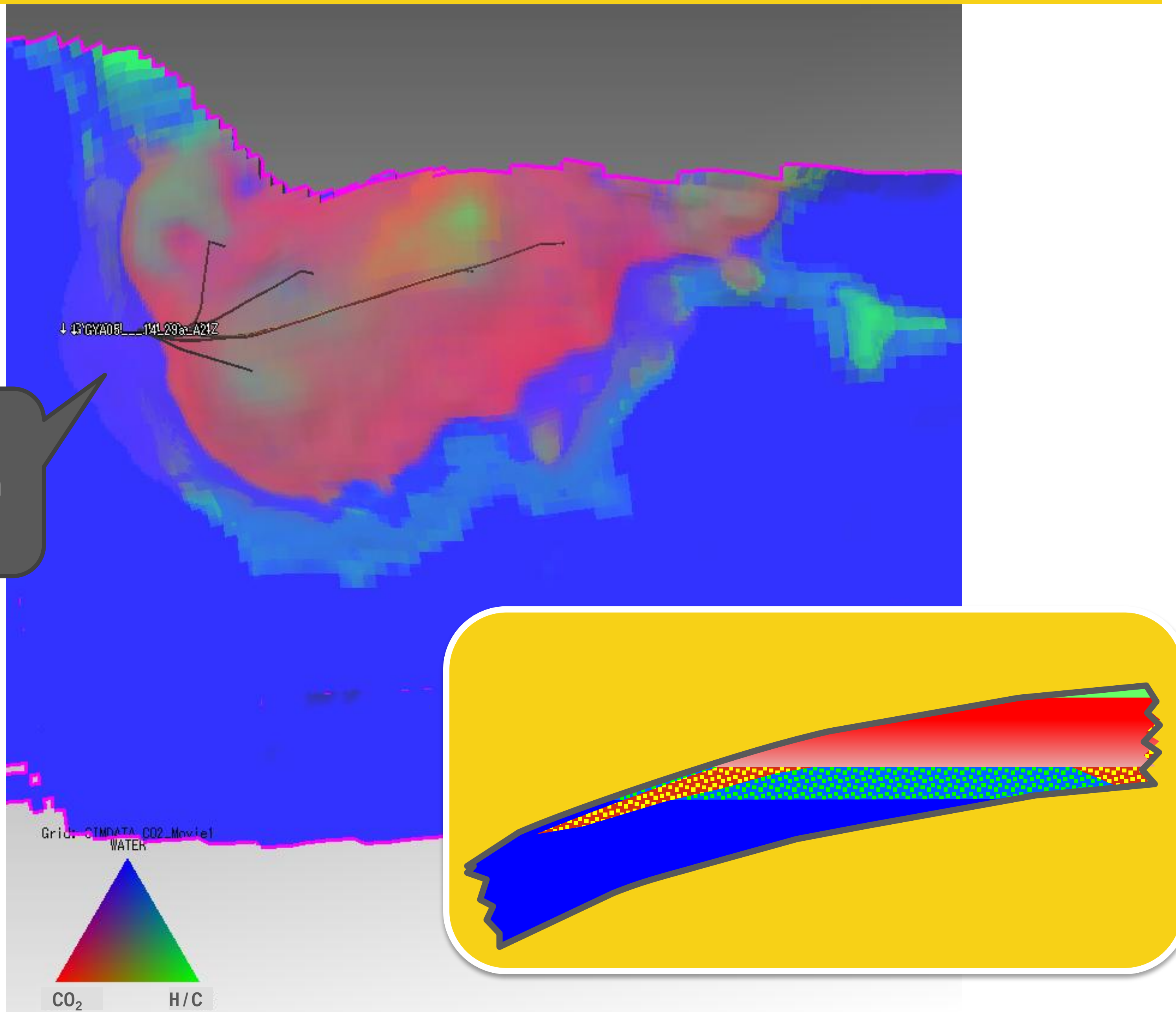
Year +20

Capillary trapping in water leg



Trapping is structural with capillary and dissolution

Year +50



Capillary trapping in water leg