CCS storage potential in Saline Aquifers

EBN Exploration Day, 17.11.2022

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ebn Energising the transition

Agenda

#	Topic	Presenter	Duration
1	Regional CCS Aquifer Screening, Introduction of EBN Project 2023	Petra Unverhaun EBN, CCUS	5 minutes
2	Investigating potential sites for saline formation CCS in the Netherlands Offshore	Prof. Harry Doust VU Amsterdam	15 minutes
3	Aquifer storage resources & rates; First insights from a conceptual portfolio analysis of aquifers	Thijs Huijskes EBN, CCUS	15 minutes
4	Q&A	all	5 minutes

Regional CCS Aquifer Screening, EBN Project 2023

Petra Unverhaun,
EBN

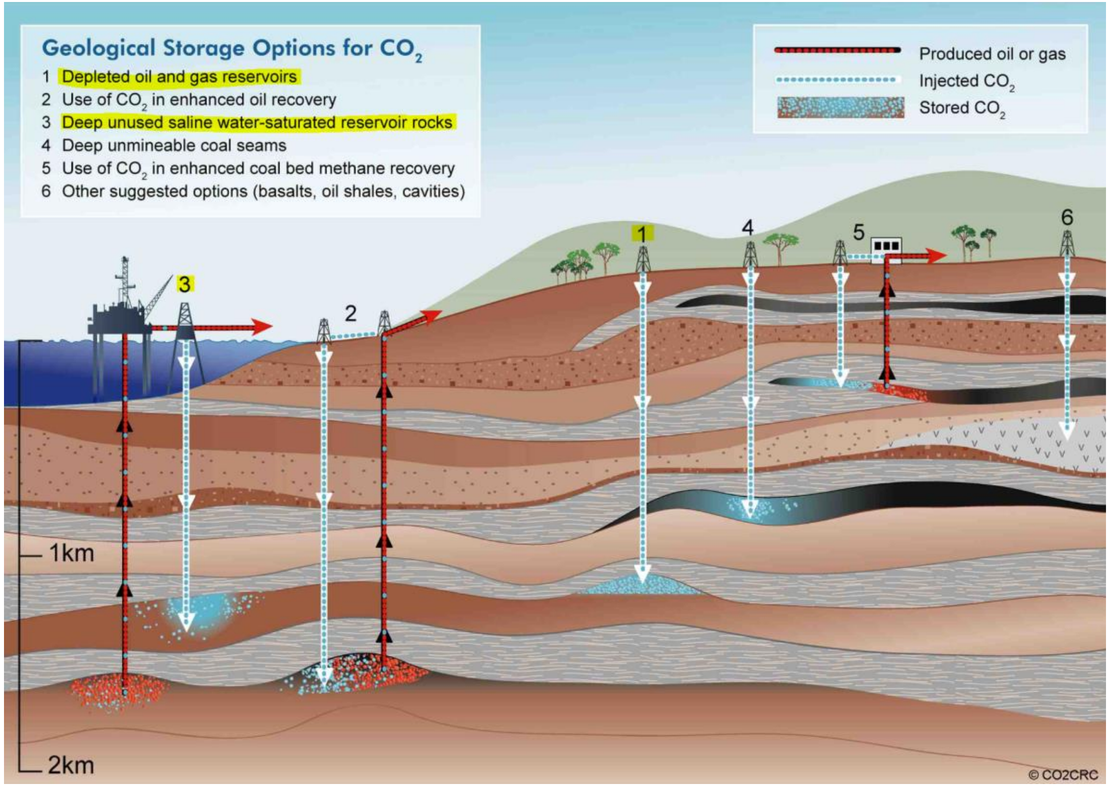
Introduction

Why Saline Aquifers for Carbon Capture and Storage?

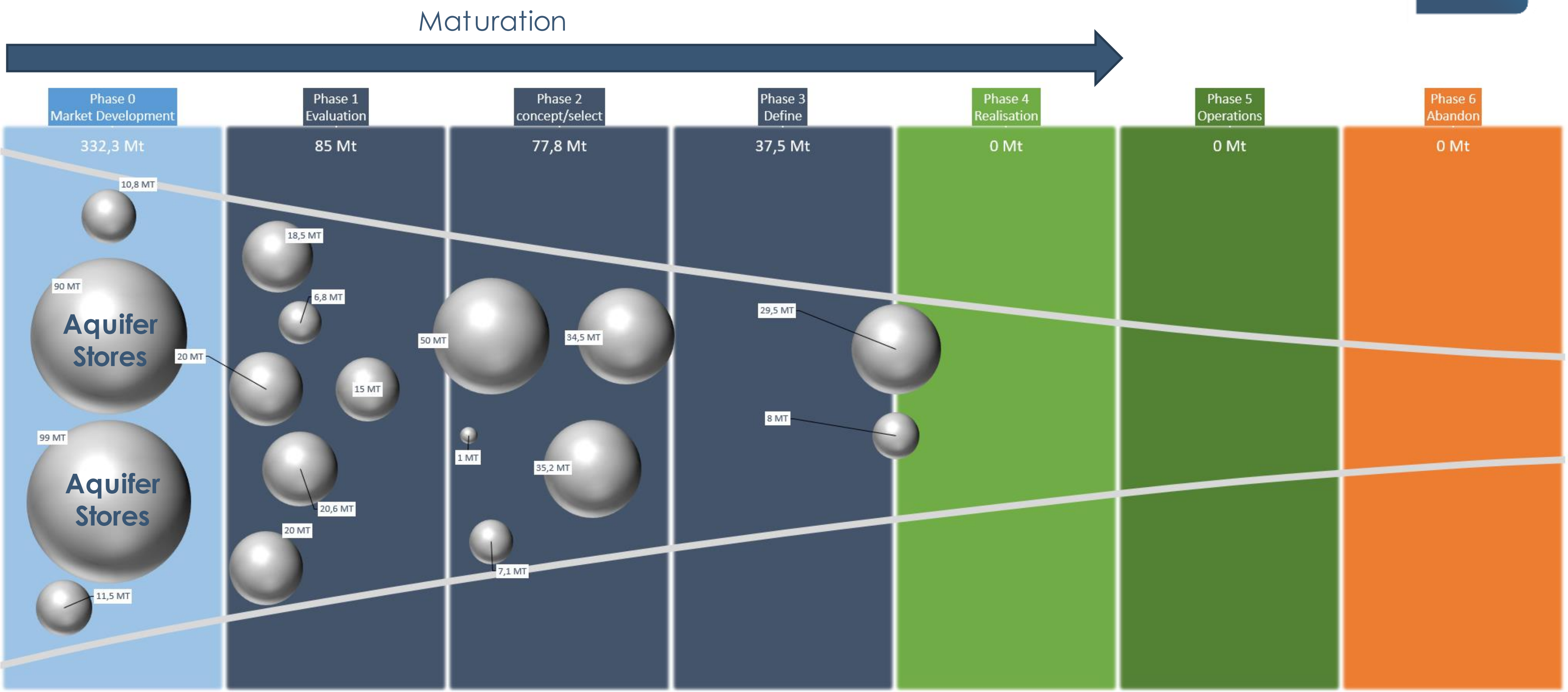
Carbon Capture and Storage (CCS) is regarded as a necessity to reach global greenhouse gas emissions targets.

Storage potential in depleted HC fields is bound and limited to structure.

- ❖ Saline Aquifers provide large storage potential.
- ❖ Many aquifers lie in hydrocarbon provinces → geology is known and close to existing infrastructure.
- ❖ Less wells than in depleted gas fields.
- ❖ Virgin pressure, beneficial CO2 phase behavior.



CCUS Stores Portfolio



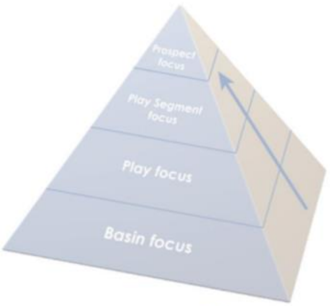
CCS Elements vs. O&G

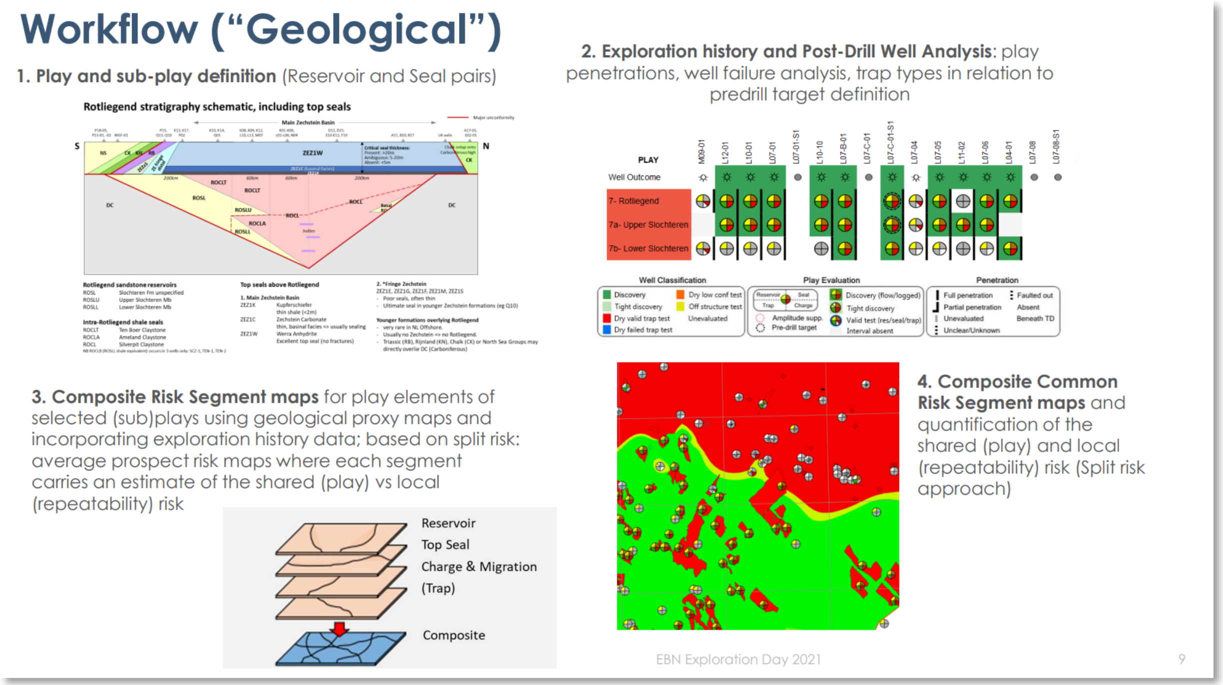
Usage of Exploration and Production Data

Oil & Gas risk element	CCS ELement	Driver	Data
Source Rock → Generation	Not relevant (as primary element)		
Reservoir → Migration	Injectivity	Reservoir presence and effectiveness (permeability, lithology), faults (transmissive vs. sealing) etc.	Well data, seismic interpretation (horizons, faults, attributes, inversion…), TD model, fault sealing potential, well information & Data (e.g. logs, pressure data, cores, cuttings), field data (e.g. production history), geomechanical data, drilling documentation, P&A reports, ROV inspection, CBL etc.
	Capacity / Storage Volume (connected aquifer)	Reservoir thickness and quality (poro/perm, NtG, heterogenity…), area, fault density and characteristics etc.	
Trap → Accumulation	Trap	Depending on type of store (depleted gas fields versus saline aquifers) etc.	
Seal → Preservation	Containment (geol.)	Top/side seal presence, composition, effectiveness, geomechanics, seismicity, geochemistry etc.	
	Containment (wells)	well conditions, density, integrity, P&A status etc.	
	Availability / licensing / public opinion / infrastructure / area strategy / stakeholders / monitoring / permitting etc.		

Application of Exploration Concepts

Using Play Based Exploration (PBE) approach





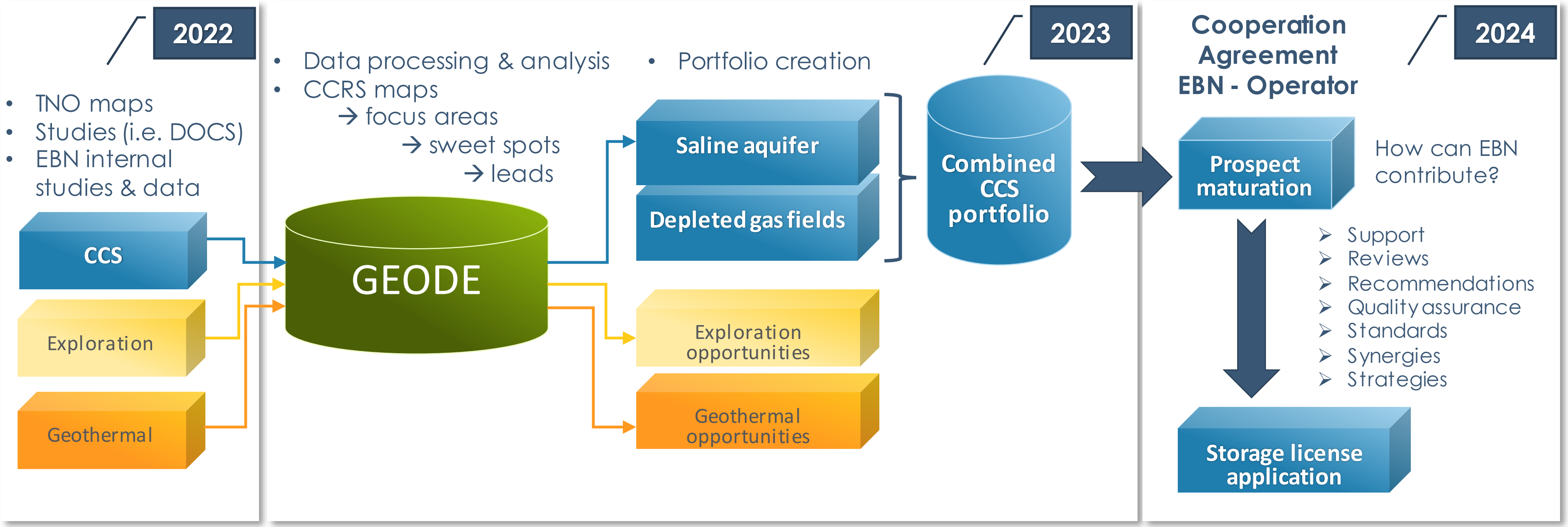
- Basic Principles from Exploration Play analysis can be used when screening for CCS storage potential.
- Skills and approaches are mostly the same in both, HC Exploration and CCUS.
- Idea: Utilize EBN platform GEODE for CCUS purposes.
- Benefit: Build on data that is available, qc'ed and used in Exploration, while incorporating EBN internal CCUS-specific experience and knowledge to maximize the results.

Outlook 2023: Regional Aquifer Screening Project

EBN Project

GOAL: Identify areas in NL offshore with

- sufficient reservoir and
- seal present
- at a depth that would enable
- CO_2 injection efficently, safely and economically feasible



Timeline

Regional Aquifer Screening Project 2022-23

Project Milestones:

2022 O	2022 N	2022 D	2023 J	2023 F	2023 M	2023 A	2023 M	2023 J	2023 J	2023 A	2023 S	2023 O	2023 N	2023 D
		Kick-off: Framing			QA: selection of focus areas		QA: selection of sweet spots			QA: selection of prospects		QA: risk and value drivers	QA: selection of opportunities	Final QA: Endorsement

Phase	Goal	Task
0	Project planning	
		Project setup, resource planning, processes, workflows
		Establish Geode GIS environment for Aquifer project
		Identify location of main data sources
		Inventory, compile data, Data Integration
I	A. Identify focus areas	
		Reservoir Presence
		Reservoir Effectiveness
		Containment Geology and Wells
		Structure
		Charge
		Compile CRS and CCRS maps
		Review / technical meeting
		Define focus areas for detailed prospect mapping
	B. Identify sweet spots	
		Containment Geology and Wells
		Reservoir quality
		Structure
		Review / technical meeting
		Define Sweet spots for detailed assessment
	C. Identify prospects	
		Reservoir Quality
		Connectivity Assessment
		Containment Geology and Wells
		Charge
		Review / technical meeting
		Define Prospects for volume and risk assessment
	D. Portfolio building	
		Volume assessment
		Uncertainty assessment
		Risk assessment
		Opportunity ranking for prospects > 2Mt
		Review / technical meeting
		Plug-in GEODE & Release
II	Detailed Assessment of selected Opportunities	

Investigating potential sites for saline formation CCS in the Netherlands Offshore

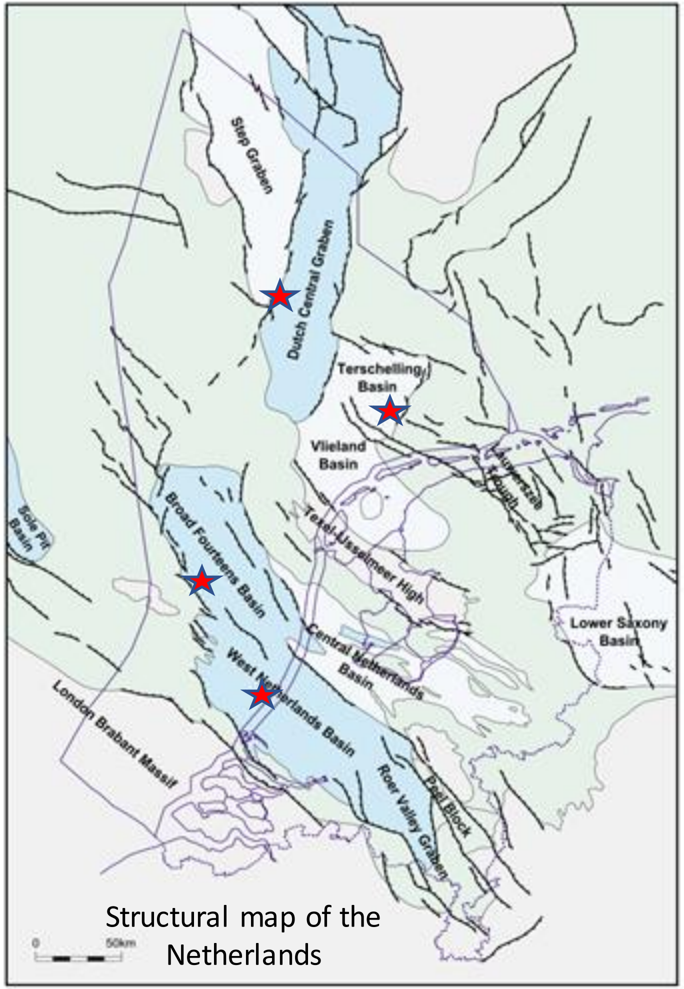
Prof. Harry Doust,
VU Amsterdam

DOCS
DEEP OFFSHORE CARBON STORAGE

VU VRIJE UNIVERSITEIT AMSTERDAM | Faculty of Science

ebn

DEEP OFFSHORE CARBON STORAGE



Structural map of the Netherlands

Inevitably, the volume potential in depleted oil or gas fields is limited, so at the VU in Amsterdam we have developed a programme to investigate whether larger storage sites might be present in the Dutch offshore *outside* depleting fields. We call this initiative DOCS and it is carried out by MSc students

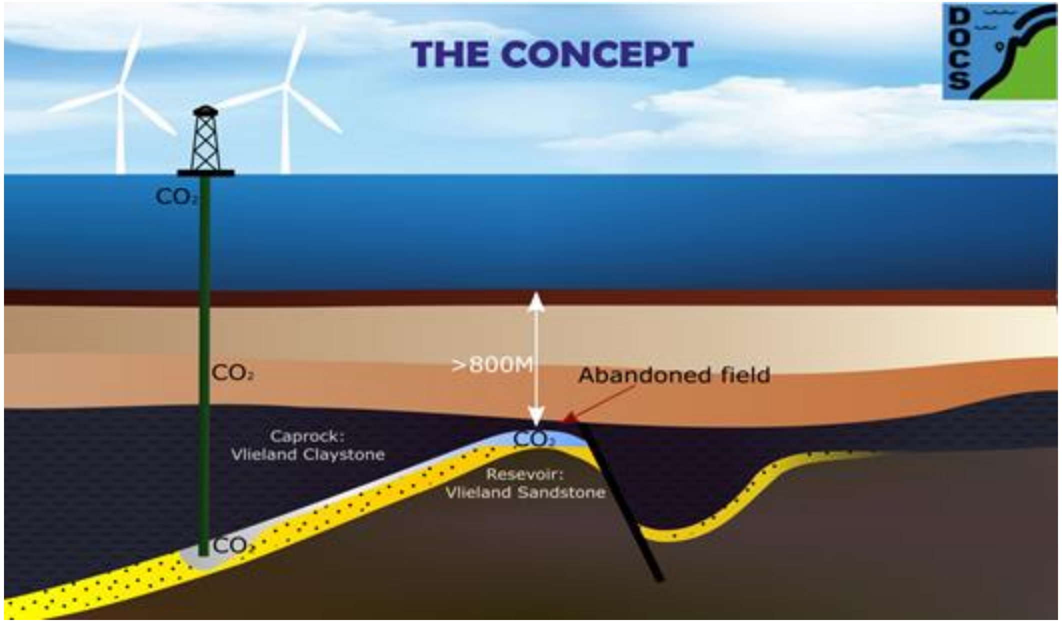
DOCS was initiated in 2019 and its objective are to

(i) investigate the potential for underground storage of greenhouse gas emissions in so-called 'saline formations' (in combination with or outside depleted oil and gas fields).

(ii) Enable students to develop the subsurface skills needed to prepare them contribute to the energy transition.

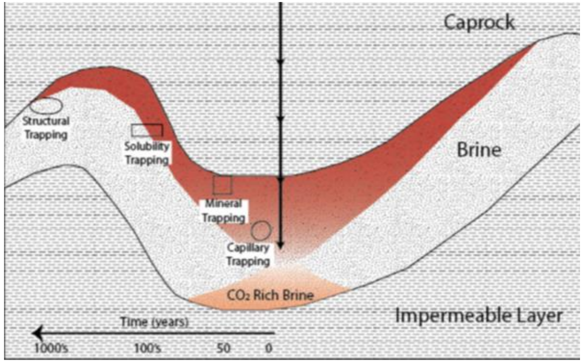
★ Sites under investigation so far

What is the concept?

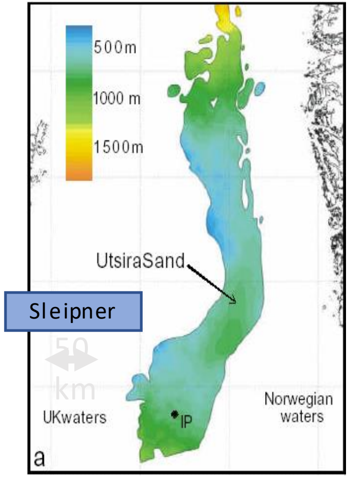


CO_2 in a supercritical state is transported offshore and injected into an identified storage formation (yellow) in structural depressions (synclines) rather than in depleted, deeper-lying oil or gas fields (red).

The plume of injected CO2 then migrates upwards within the formation before being trapped below impervious sealing rocks (dark blue).
As with depleted fields sequestration, no formation under consideration represents or is in contact with any fresh-water aquifer.



A couple of analogues:

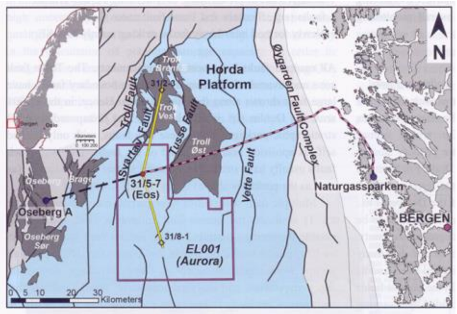


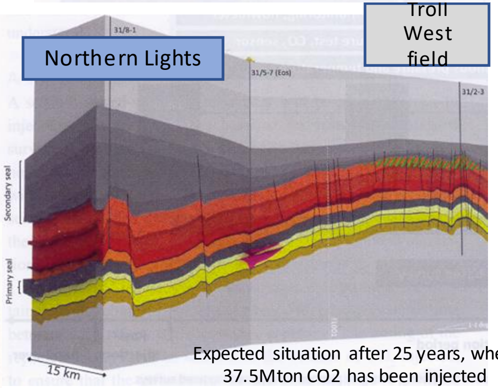
Sleipner: >17Mt of CO_2 has been injected into a saline formation the Utsira Sand at 1012m below sea level since 1996.

Formation: 30-40% porosity & 1-3D permeability, 250m thick stacked deep water fan lobes with thin shale interbeds (baffles to upward flow).

Northern Lights: Will host CO_2 in Early Jurassic sands downdip and below the Troll West gas field

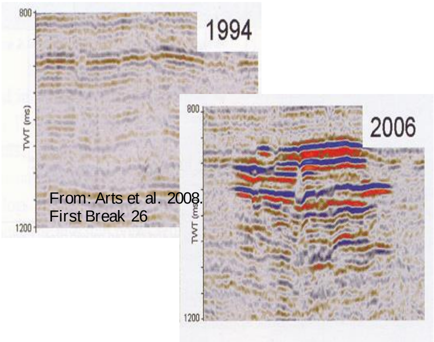
Gippsland Basin, SE Australia: Hybrid CCS - Proposed injection in basin center, plume to rise and eventually occupy depleted fields





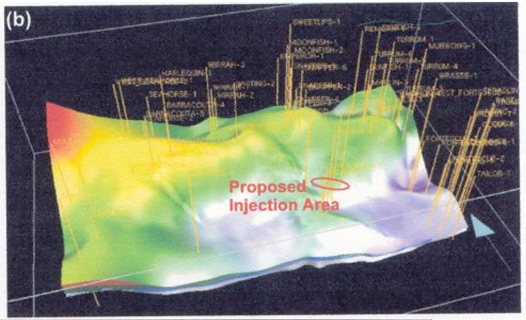
Expected situation after 25 years, when 37.5Mton CO_2 has been injected

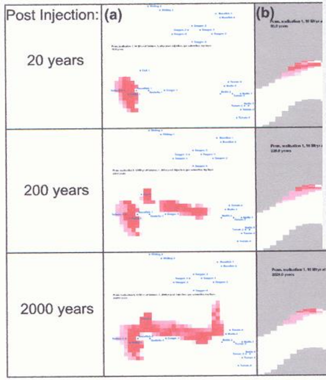
Utsira sand: 30-40% porosity & 1-3D permeability, 250m thick stacked deep water fan lobes with thin shale interbeds (baffles to upward flow).

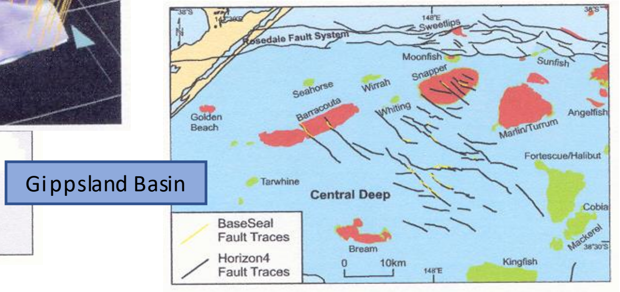


From: Arts et al. 2008. First Break 26

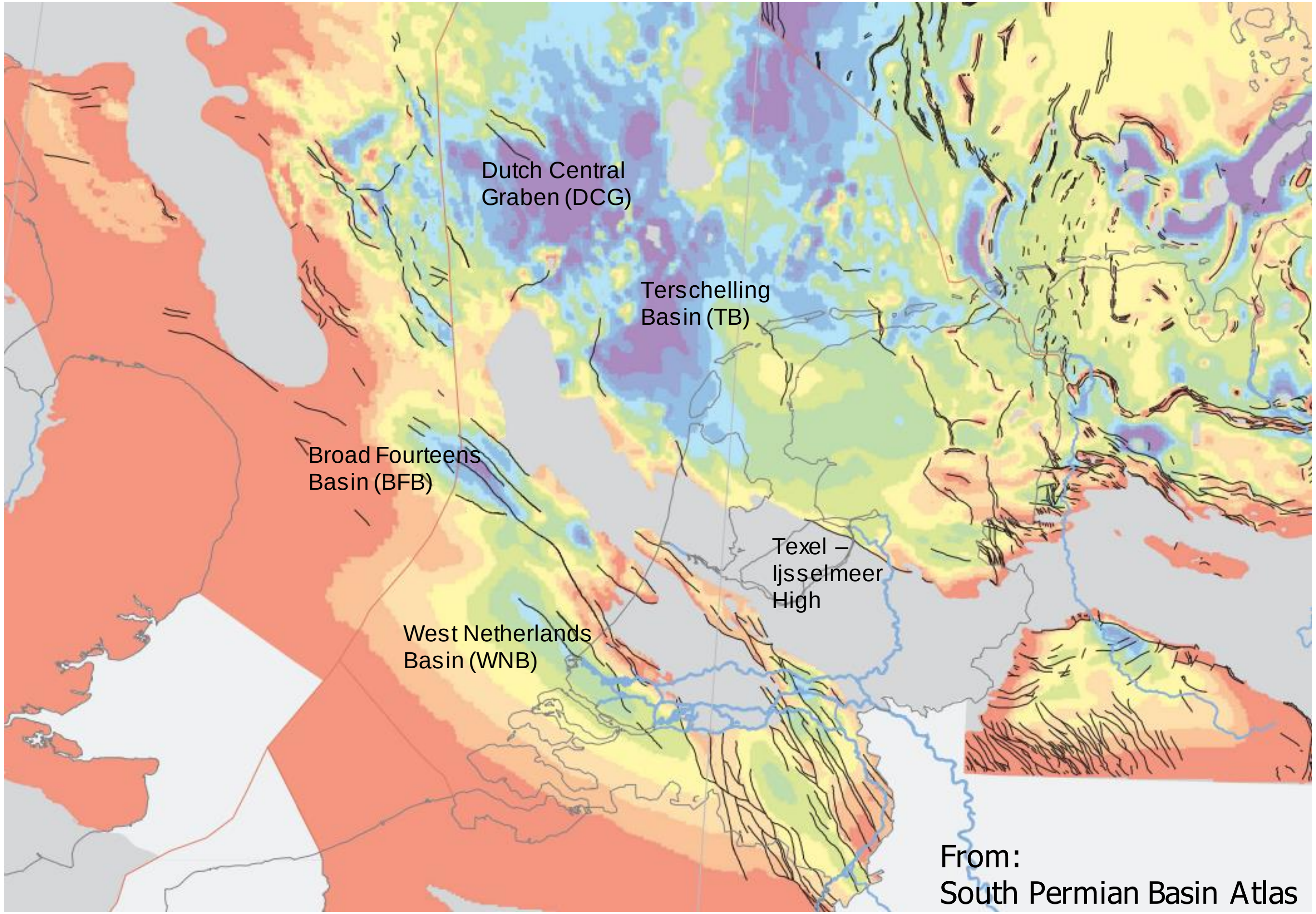
Seismic monitoring of CCS projects will involve major R&D in the coming years and will provide many employment opportunities



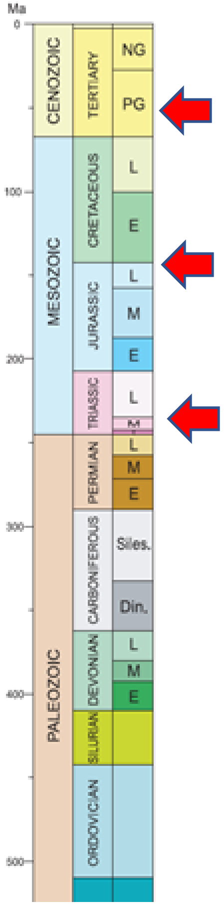




Base Cretaceous depth contours



From:
South Permian Basin Atlas



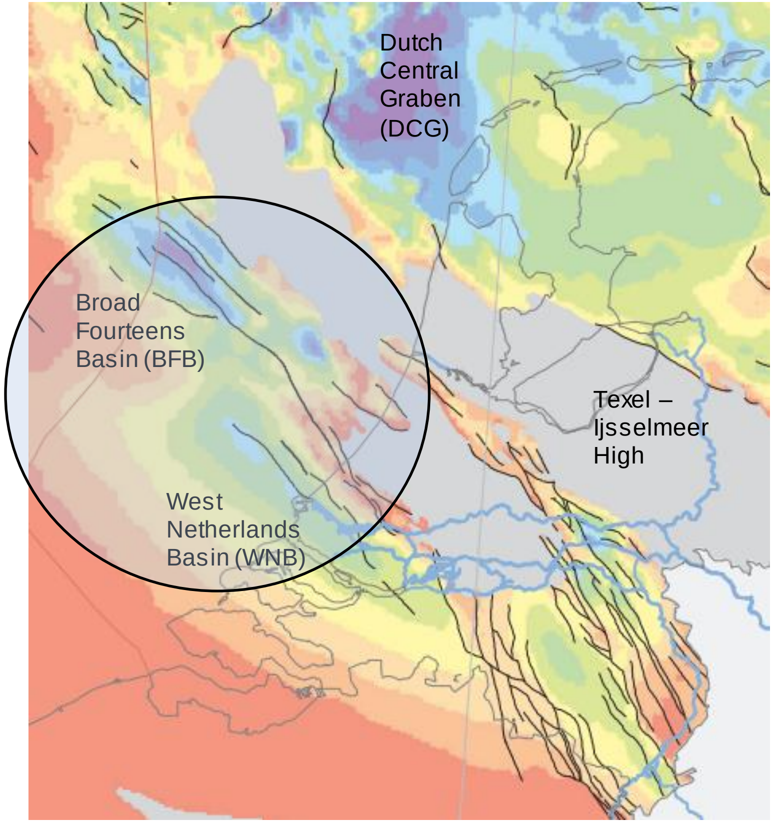
Brussels Sandstone WNB

Vlieland Sandstone BFB

Buntstandstein Group oh TB

Formations identified and being studied for possible storage

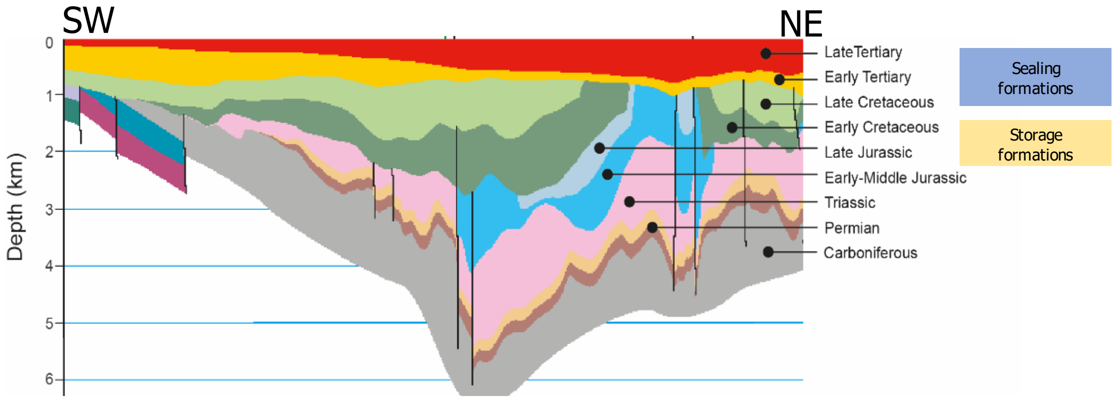
We started looking at the western offshore….



Current plans for CCS in depleted fields in the Netherlands. In the initial study area (in blue) we investigated the possible contribution of DOCS and its relevance to the Athos project. A feasibility study suggested that potentially attractive opportunities exist in the Broad Fourteens Basin.

The red outlines represent the projected storage locations in depleted gas fields.

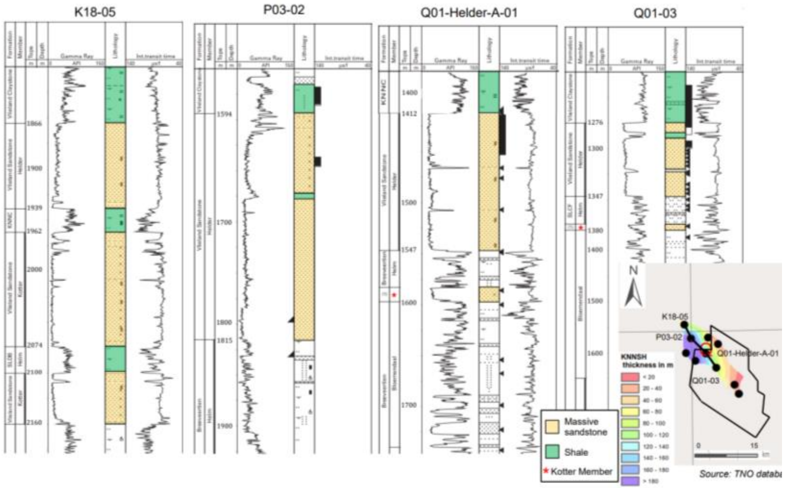
The western offshore: The Broad Fourteens Basin



Four 3D studies in in 2019-2020 identified promising structural geometries (synclinal depressions) in which formations with potentially adequate storage and sealing characteristics are developed

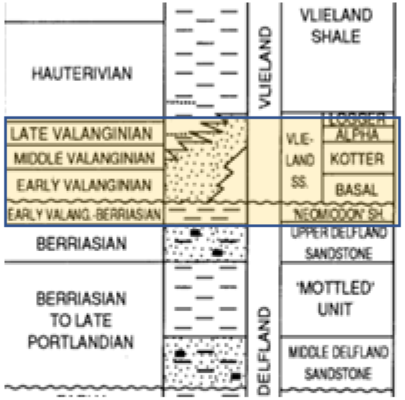
Storage volume in these structures could be very large, but requires confirmation with further study.

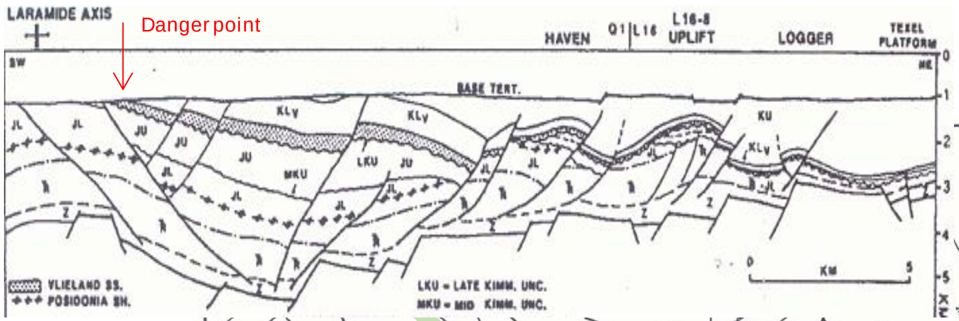
Preliminary evaluation suggests that a DOCS project proposal would need 6-7 years of preparation to be ready for implementation but could be matured within the coming decade.



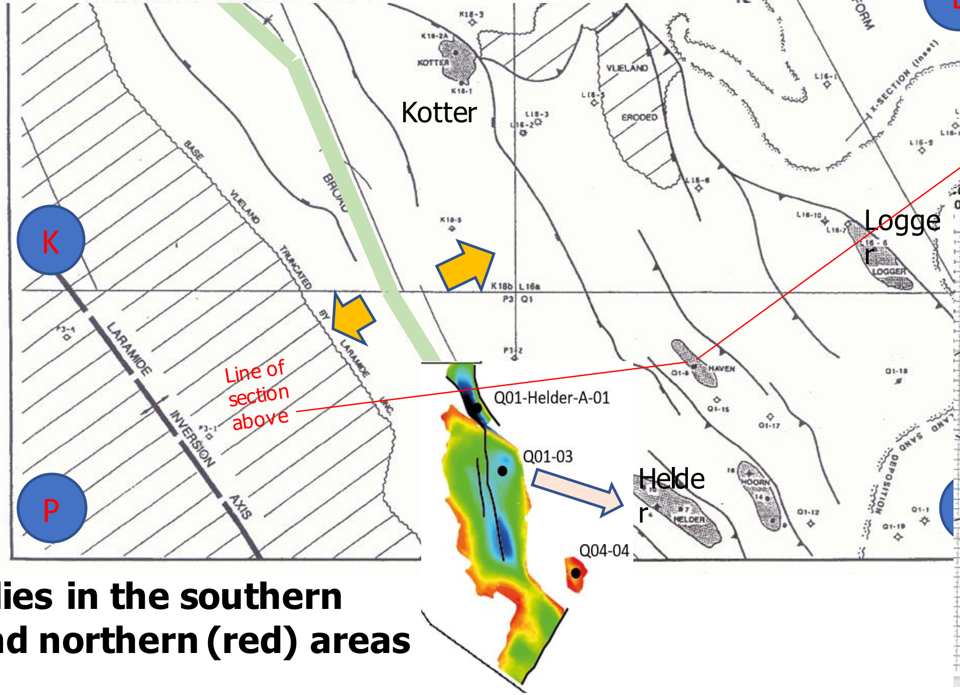
Attractive potential storage formation: Transgressive Lower Cretaceous Vlieland shoreface sand units overlain by Cretaceous marine claystone.

Opportunities also exist in the underlying Upper Jurassic Delfland Group

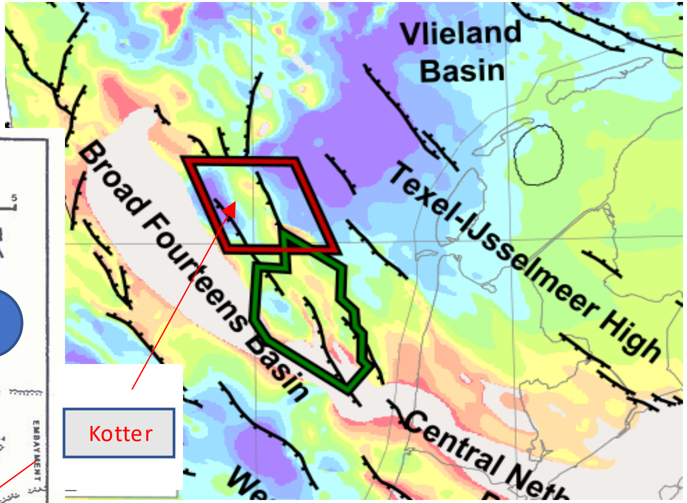


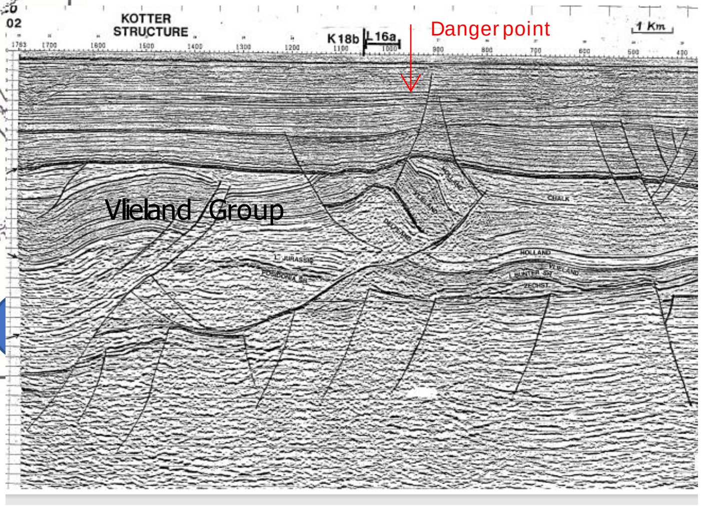


Northern sector (2021)

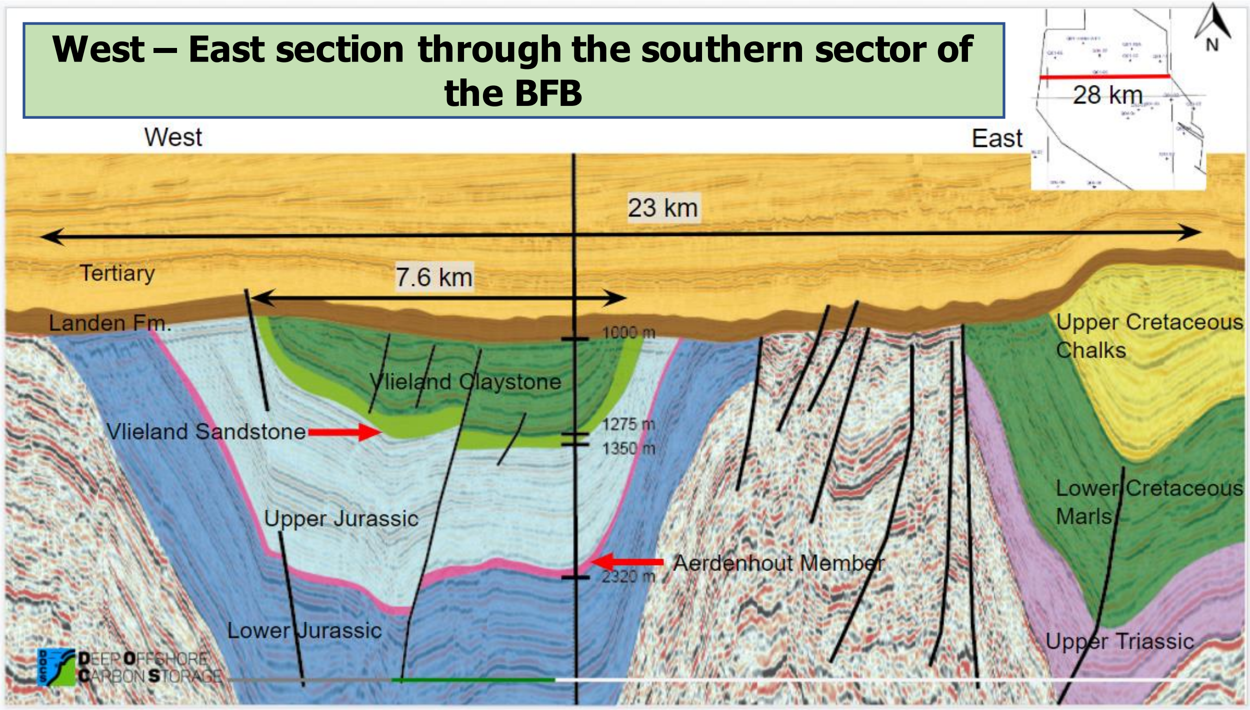


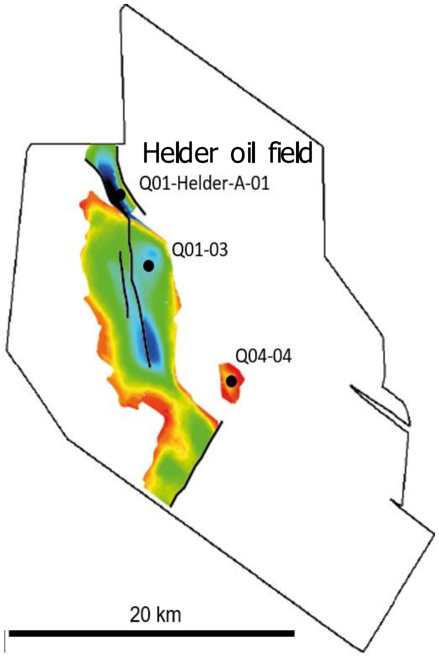
Southern sector (2019)



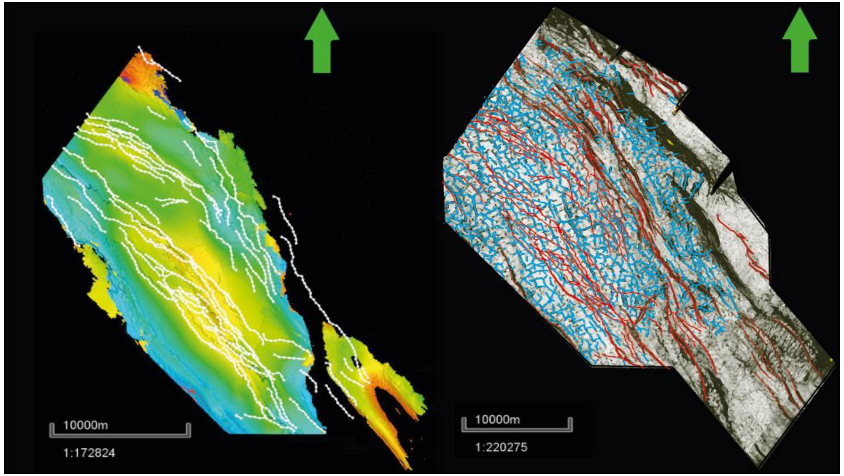


DOCS studies in the southern (green) and northern (red) areas of the BFB

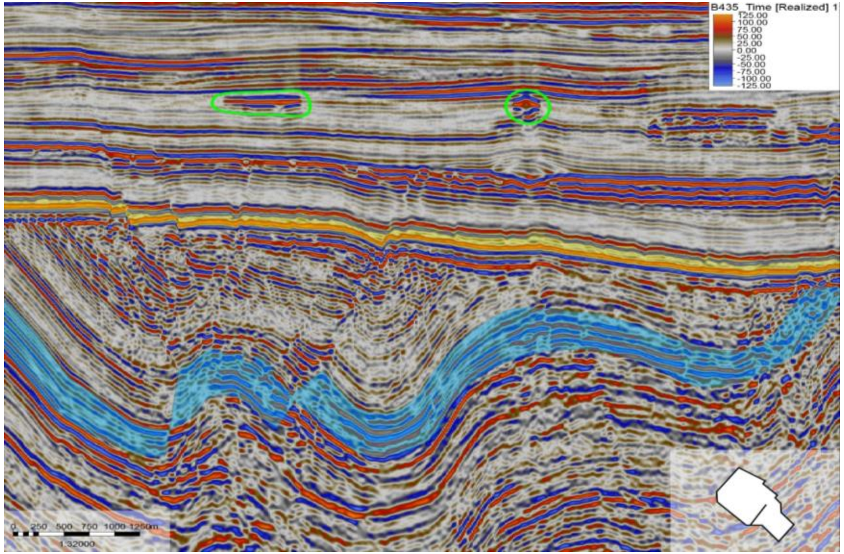




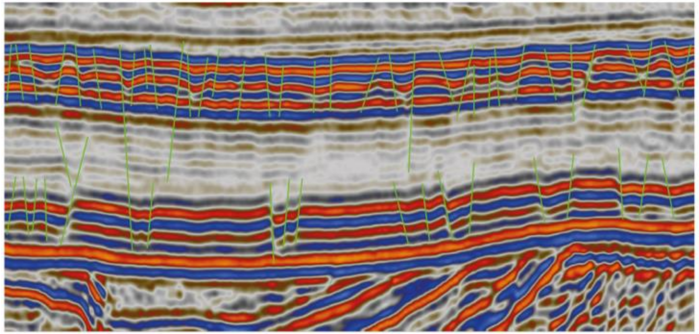
Here we interpreted the Vlieland Sandstone and Aerdenhout Member in a deep, narrow basin with between sharp inversions south of the Helder field. Adequate seals are present in the Upper Jurassic and Cretaceous, but large volume capacity requires a good seal at the base Tertiary (brown). This level appears to be faulted, so we looked at its sealing potential in detail…



Southern sector syncline. Above: Faults (white) in the Vlieland Sandstone (left), polygonal faulted horizons in the Lowermost Tertiary (right). Below: 2 levels of polygonal faults are present in the lowermost Tertiary seal formation.

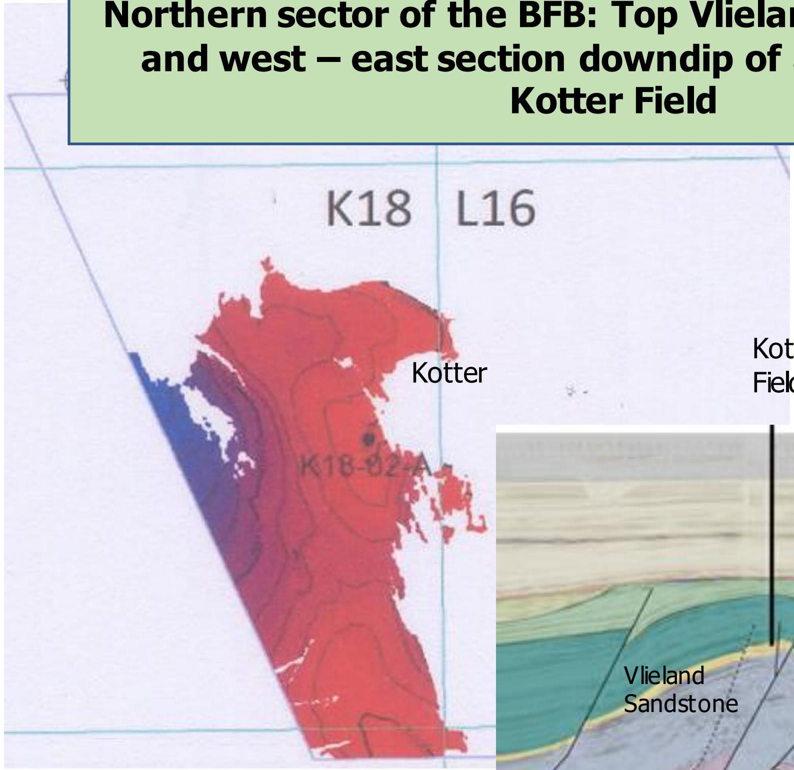


The Vlieland Claystone (blue) is cut by faults and is truncated (right) by the Lowermost Tertiary. The yellow horizon is affected by polygonal faults. Anomalies (green) may indicate gas leakage

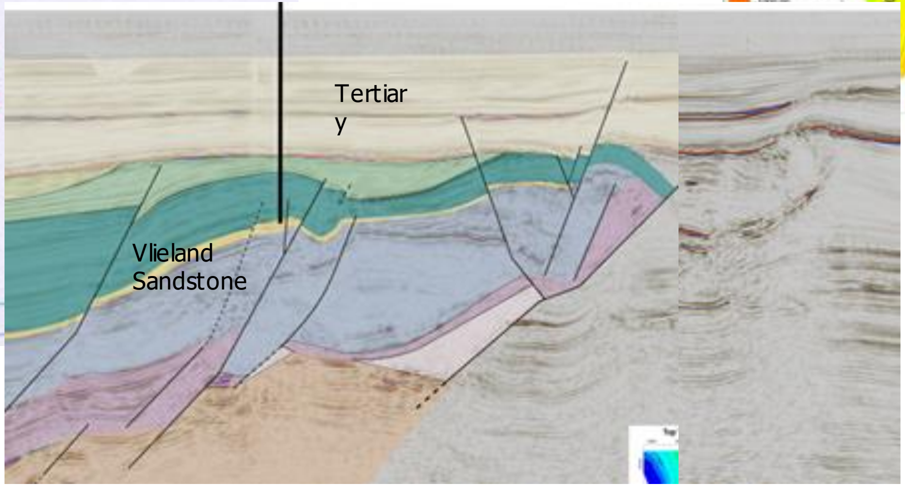


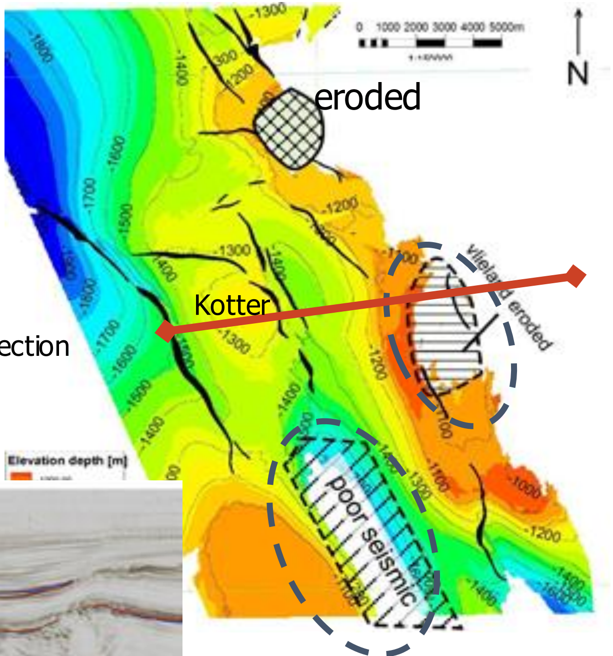
The results appear to be somewhat ambiguous. In phase II we shifted attention to the northern sector of the BFB near the Kotter Field, where also the Vlieland Sandstone is thicker

Northern sector of the BFB: Top Vlieland Sandstone map and west – east section downdip of and through the Kotter Field



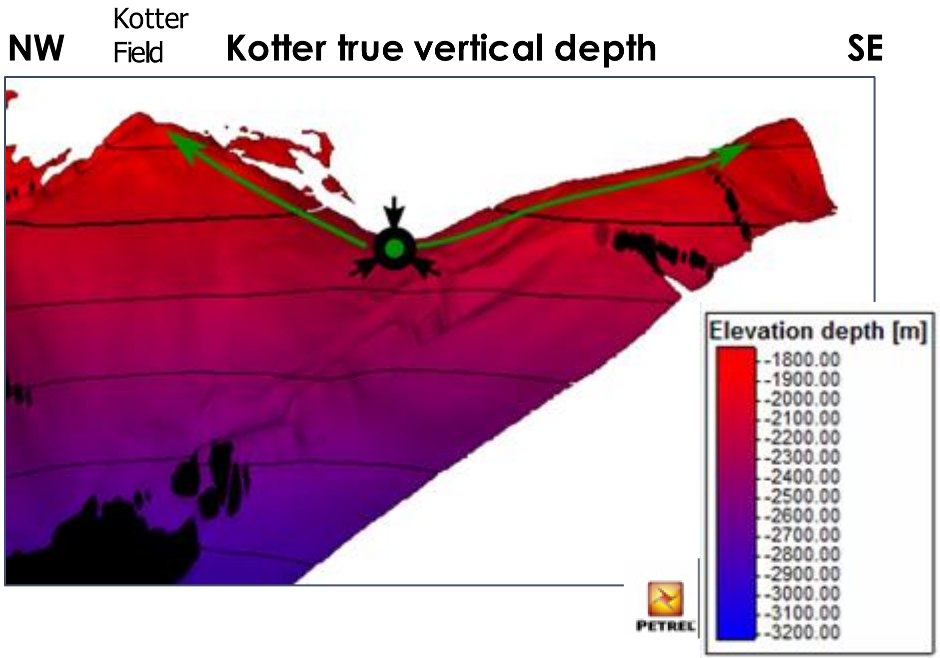
Top Vlieland Sandstone depth map showing deep syncline to the west

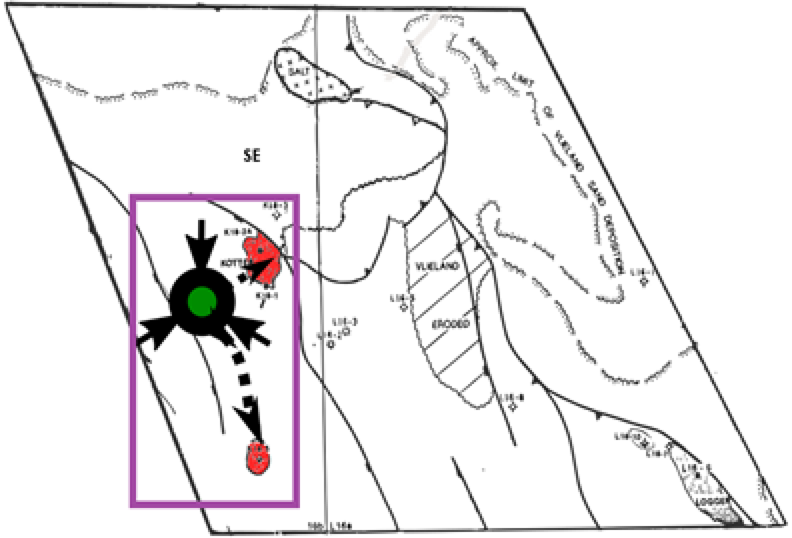




Regional map of top Vlieland Claystone seal. Note that the eastern anticline is truncated at base Tertiary

At the present stage of our investigations, the syncline downdip of the Kotter Field appears to provide the most promising location for saline Formation (SF) CCS. Thick, good quality reservoir is combined with a coherent, thick seal along a dipping flank that could provide hybrid SF and depleted field CCS in two directions

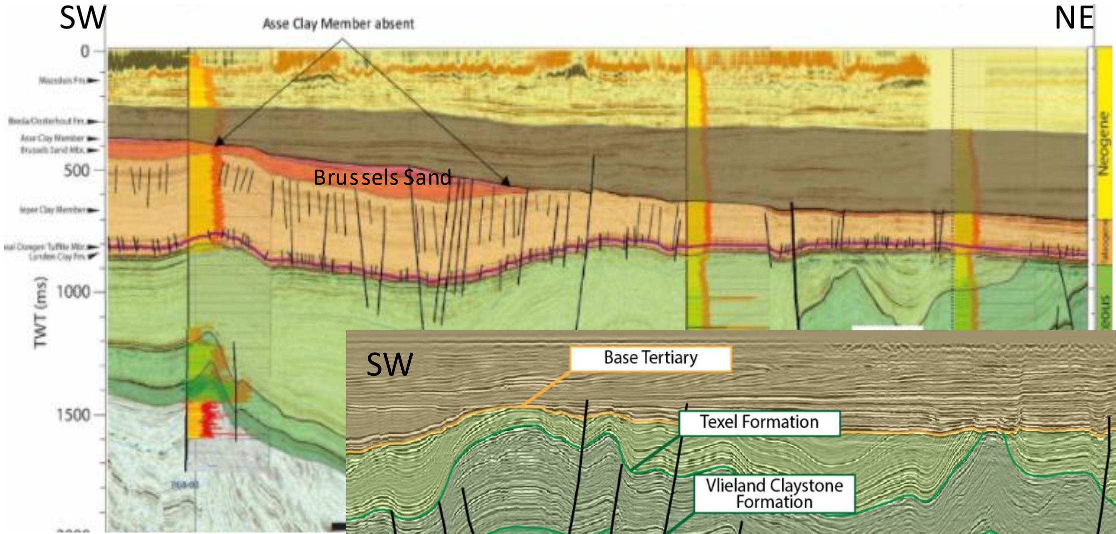




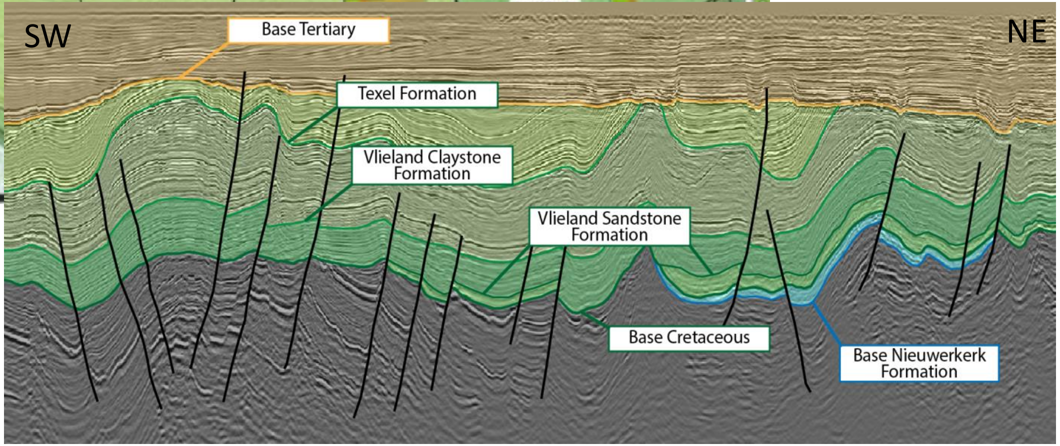
Edited after Goh, L.S. (1996)

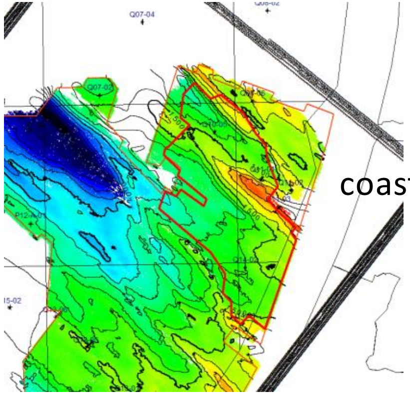
Possible injection concept

We have also looked at the West Netherlands Basin. We saw potential in the Lower Tertiary Brussels Sand and, closer to shore in the Vlieland and Nieuwerkerk formations. However, both have drawbacks....



The Brussels Sand lies less than 800m below Seabed

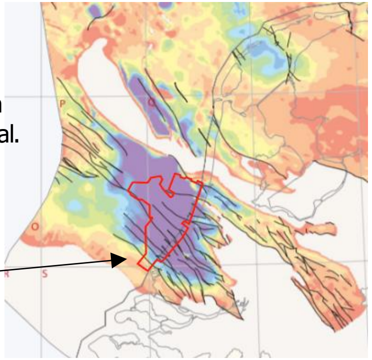




coast

The base Cretaceous map (left) shows that the sequence rises towards the coast

The Rijnland Group thickness map (right) shows the off- onshore structure VU MSc students have mapped part of the onshore WNB in connection with Geothermal potential.



In DOCS we are currently connecting the on- and offshore surveys and filling gaps to investigate the potential further

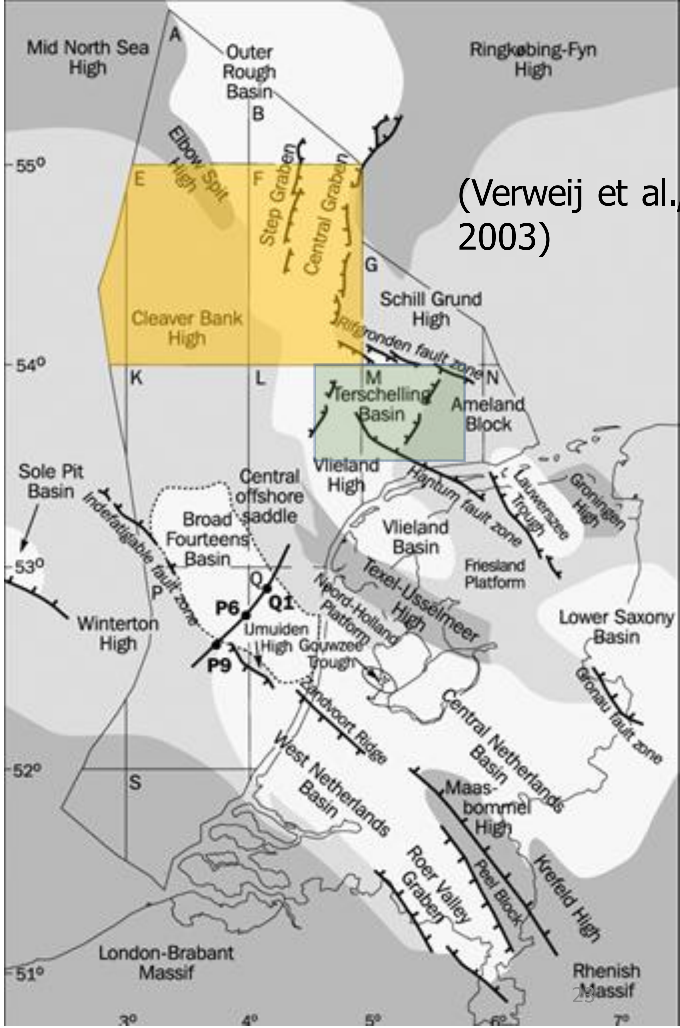
Recently we started reviews of the the Central and Step grabens and Terschelling Basin in the Northern Offshore

We carried out a scoping study in the **DEF** blocks using a play-based approach based on selection criteria to identify and evaluate ***CCI*** elements

- **Capacity**: Are potential porous reservoirs present at suitable depths?
- **Containment:** Is the sealing above potential for storage formations adequate?
- **Injectivity:** Do the storage formations identified have appropriate parameters for successful injection eg sufficient permeability?

The objective is to carry out detailed studies of promising areas.

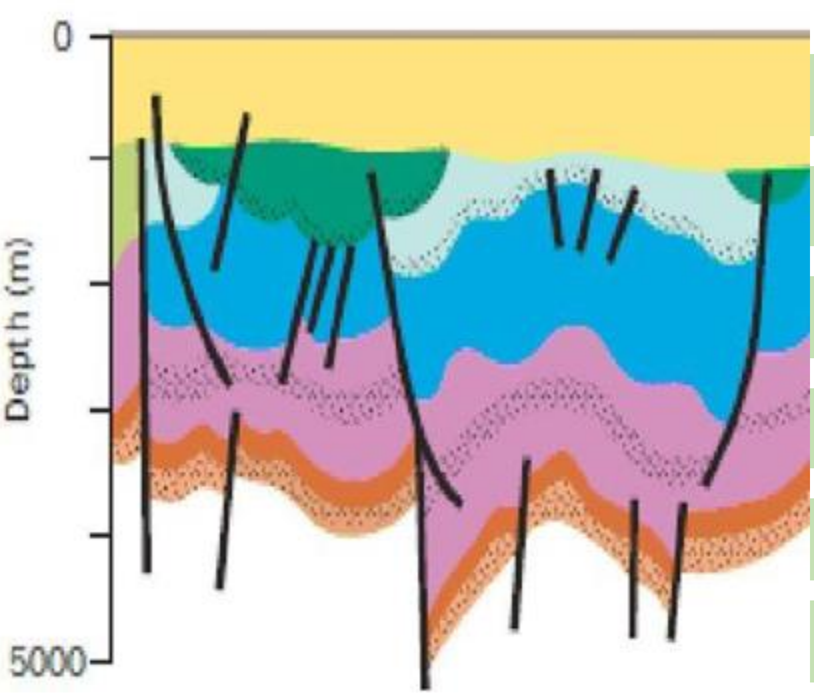
We have also commenced review of the Terschelling Basin



(Verweij et al., 2003)

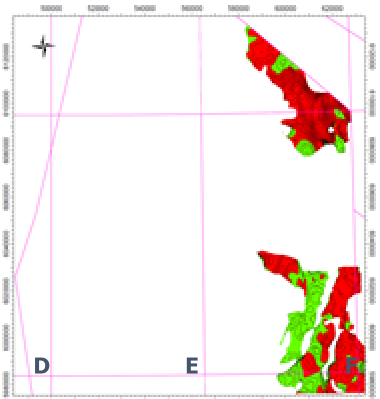
Selection criteria

		Positive indicators	Cautionary indicators
Storage Formation	**Depth**	1000 – 2500m	<800m, >2500m
	Net fm thickness	>50m	<20m
	Porosity	>20%	<10%
	Permeability	>300 mD	<100mD
Sealing Formation	**Lateral Continuity**	Uniform stratigraphy Small / no faults	Lateral variation, medium to large faults
	Net fm thickness	>100 mD	<20 mD
	Capillary Entry pressure	>C02 buoyancy force	~C02 buoyancy force

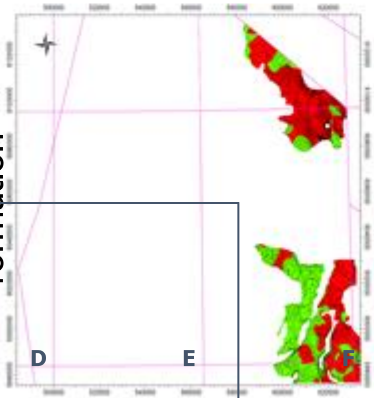


Play-based approach D,E,F blocks: method

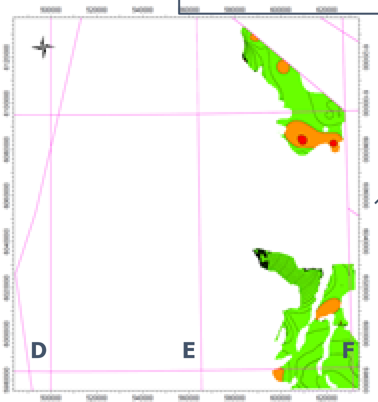
Base of formation



Top of formation

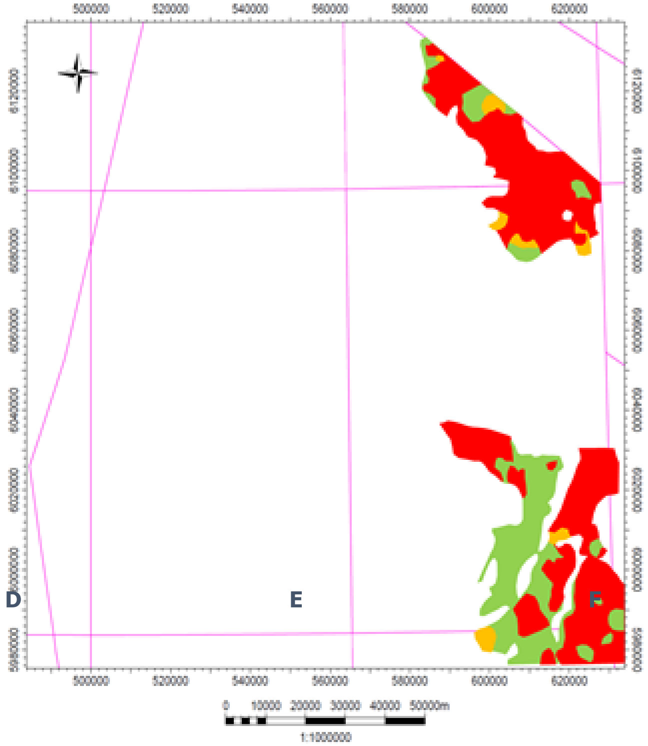


Thickness of formation



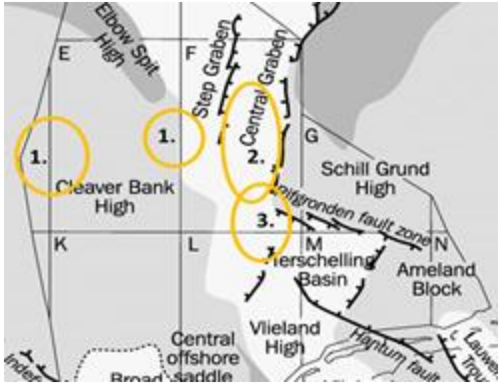
(red)	Poor conditions for CCS
(orange)	Moderate conditions for CCS
(green)	Good conditions for CCS

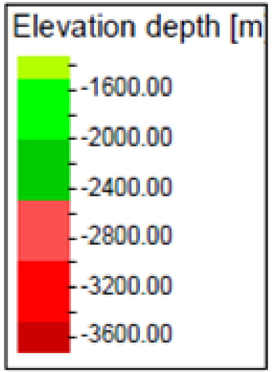
Example: Scruff Greensand Formation

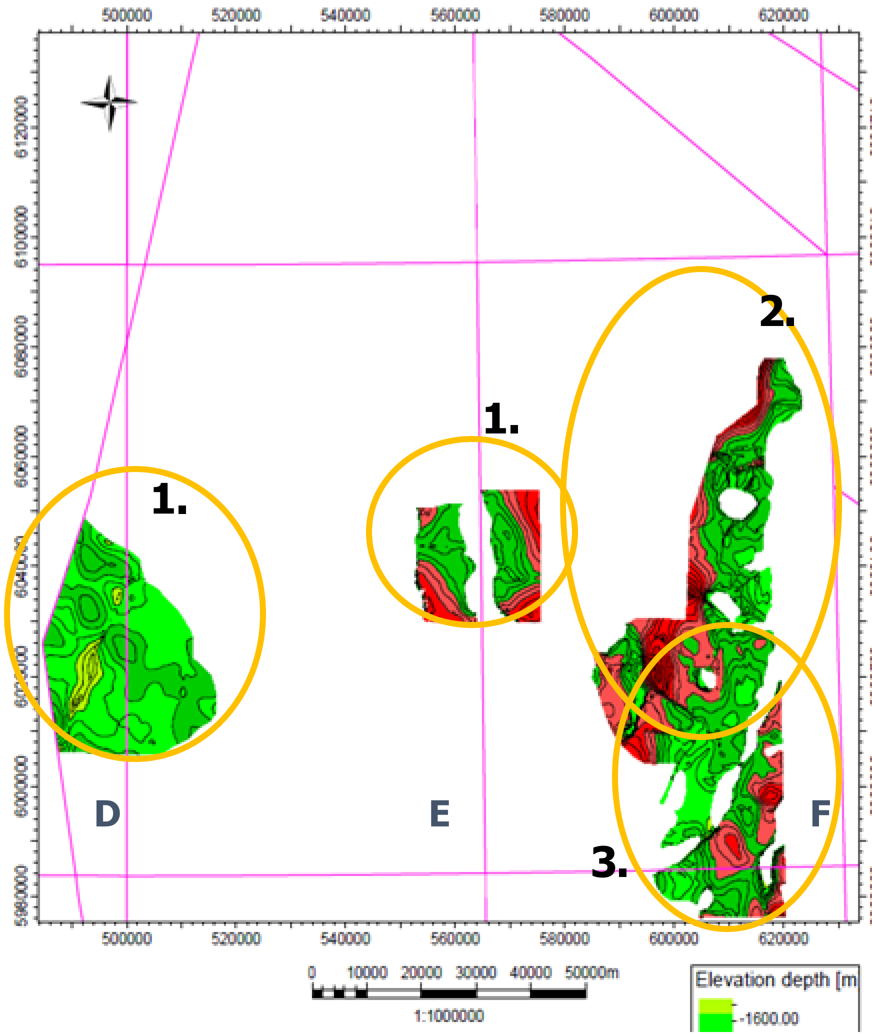


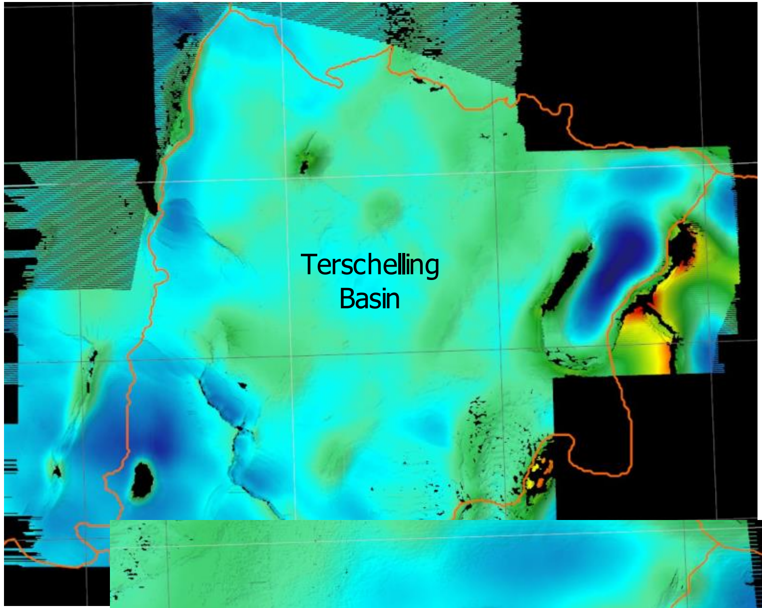
Potential Storage Formations identified

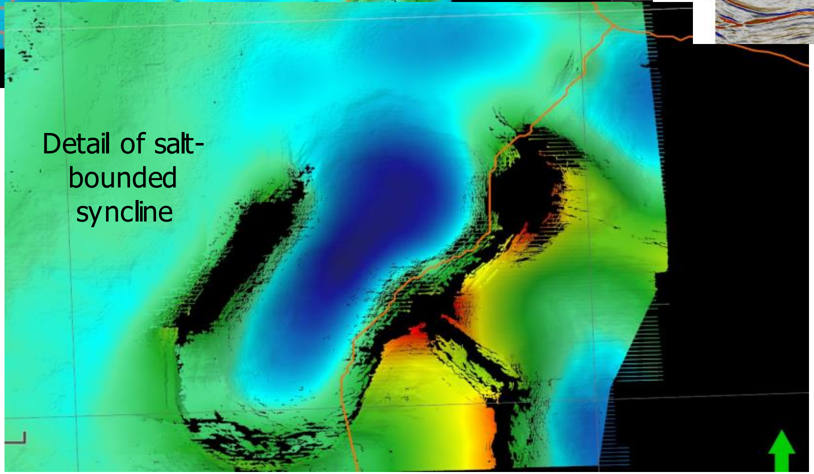
1. **Lower Volpriehausen Sandstone** (RBMVL Lower Germanic Trias Group)
2. **Lower Graben Formation** (SLCL, Schieland Group)
3. **Scruff Greensand Formation** (SGGS/SGGSP, Scruff Group)
4. **Ekofisk Formation** (CKEK, Chalk Group)

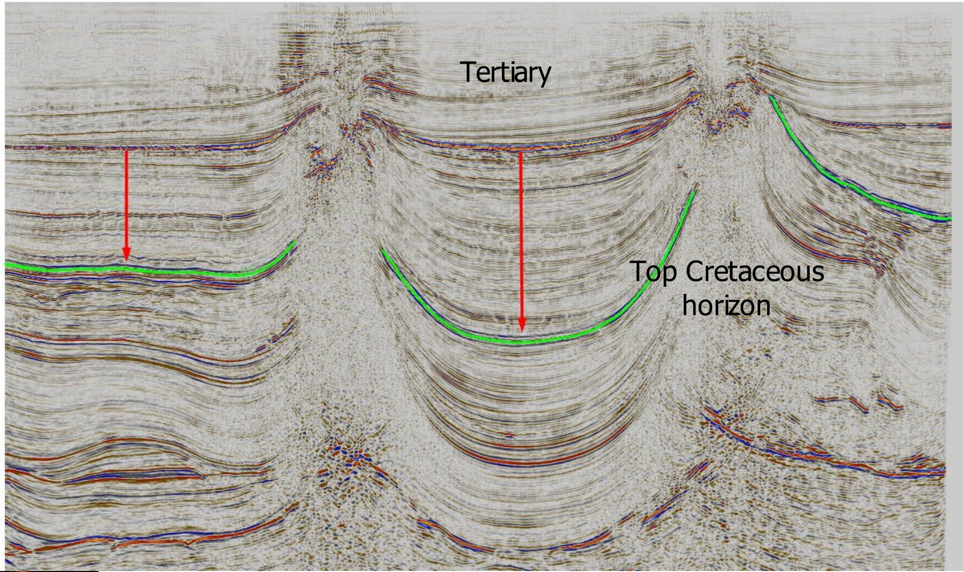












Terschelling Basin:

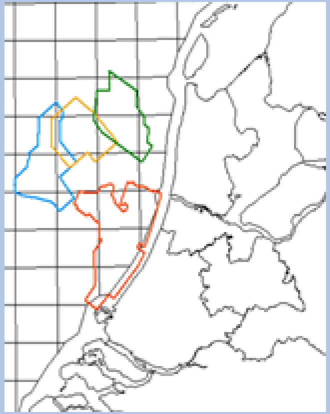
The basin has had little exploration and the geology is not well controlled. It combines attractive geometries with relatively shallow potential storage formations, however, particularly in the Triassic. It is also close to extensive infrastructure

Currently, we are looking at the possibility that sands may be present in the Lower Tertiary in salt-bounded synclines

2019 – 2022/3

DOCS 1	DOCS 2	DOCS 3	DOCS 4	DOCS 5
Students: Andre Bults, Michael Nolten, Alexandra Siebels, Jon Wierenga	Students: ★ Jasper Arendse, ★ Natalia Dovgelanoc, ★ Dirk Scholten	Students: ★ Jonathan Chin, ★ Bart Hijne, ★ Rosa Rijsdijk	Students: ★ Naomi v d Ameele, ★ Prosper Deitch, ★ Marion Kroon	Students: Hala Alwagdani, IVM student(s), Naomi v d Ameele — Tentative projects

DOCS 1



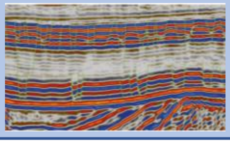
Reconnaissance mapping BFB and WNB

DOCS 2

★ **Economics of compression, transport & injection**

★ **Feasibility of DOCS to contribute to CCS in NL**

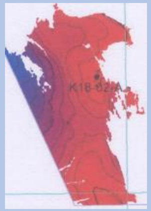
★ **BFB South - seal potential base Tertiary**



DOCS 3

★ **BFB North: seal potential Vlieland Clst**

★ **BFB North Kotter syncline hybrid CCS potential**

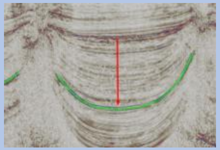


★ **Northern offshore scoping study DEF blocks**

DOCS 4

★ **WNB on-offshore mapping Nieuwerkerk Fm DOCS/Geothermal**

★ **Tertiary potential Terschelling Basin**



★ **Detail evaluation DEF selected areas**

DOCS 5

L. Triassic / U Cretaceous potential offshore

Risking Saline CCS using Ariane software

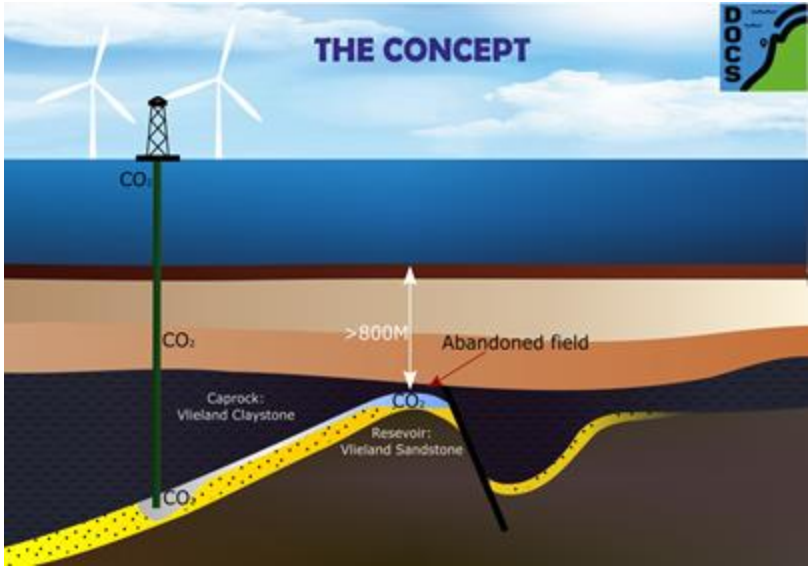
Monitoring experience active saline CCS projects

Review impact of CCS on society, economy & environment

Our target

Within the next decade:

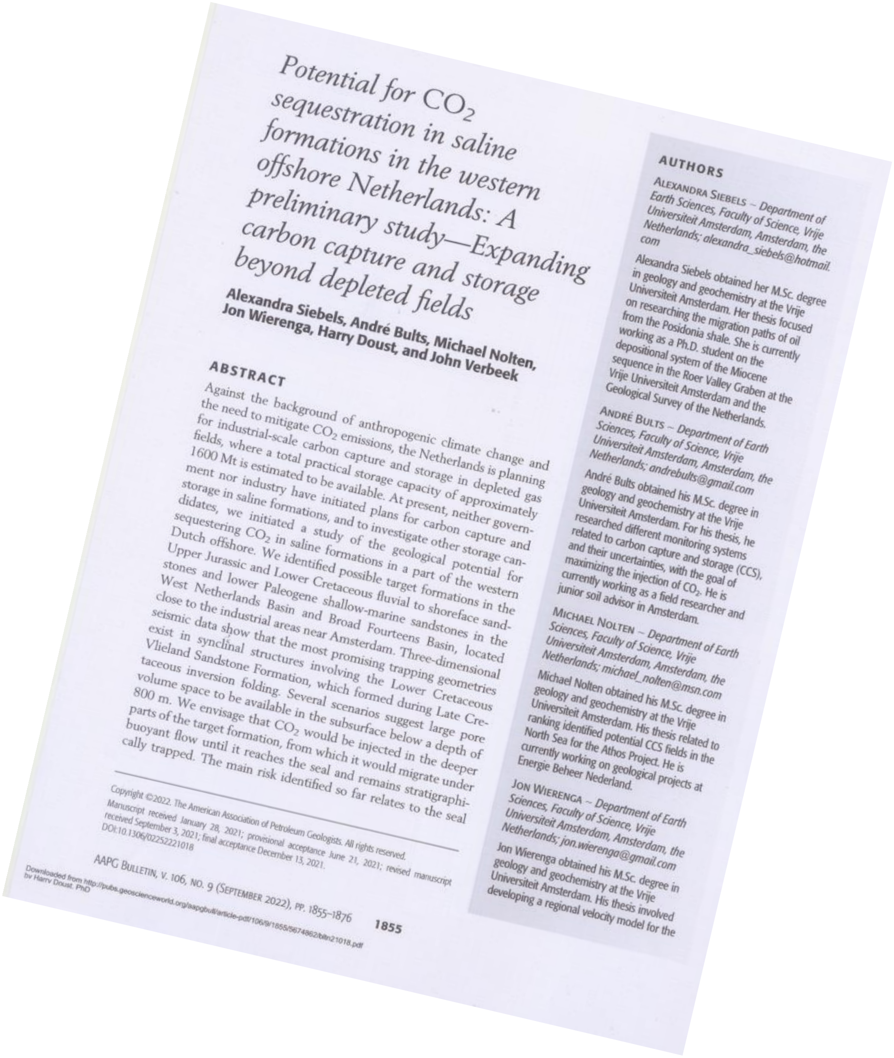
- Deep saline formation sequestration (DOCS) is incorporated in national plans as a realistic, cost-effective and safe destination for CCS in the Netherlands, contributing to the portfolio of options in the medium and longer term.
- At least one location for safe DOCS is fully evaluated and ready for ranking with other CCS options
- DOCS is a recognised and valued platform for training students with the subsurface and socio-economic knowledge and skills needed to efficiently plan and execute domestic or international CCS projects.



Watch this space!

With thanks to all the students…

Anouk Beniest, Harry Doust and John Verbeek



Potential for CO_2 sequestration in saline formations in the western offshore Netherlands: A preliminary study—Expanding carbon capture and storage beyond depleted fields

Alexandra Siebels, André Bults, Michael Nolten, Jon Wierenga, Harry Doust, and John Verbeek

ABSTRACT

Against the background of anthropogenic climate change and the need to mitigate CO_2 emissions, the Netherlands is planning for industrial-scale carbon capture and storage in depleted gas fields, where a total practical storage capacity of approximately 1600 Mt is estimated to be available. At present, neither government nor industry have initiated plans for carbon capture and storage in saline formations, and to investigate other storage candidates, we initiated a study of the geological potential for sequestering CO_2 in saline formations in a part of the western Dutch offshore. We identified possible target formations in the Upper Jurassic and Lower Cretaceous fluvial to shoreface sandstones and lower Paleogene shallow-marine sandstones in the West Netherlands Basin and Broad Fourteens Basin, located close to the industrial areas near Amsterdam. Three-dimensional seismic data show that the most promising trapping geometries exist in synclinal structures involving the Lower Cretaceous Vlieland Sandstone Formation, which formed during Late Cretaceous inversion folding. Several scenarios suggest large pore volume space to be available in the subsurface below a depth of 800 m. We envisage that CO_2 would be injected in the deeper parts of the target formation, from which it would migrate under buoyant flow until it reaches the seal and remains stratigraphically trapped. The main risk identified so far relates to the seal

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André Bults obtained his M.Sc. degree in geology and geochemistry at the Vrije Universiteit Amsterdam. For his thesis, he researched different monitoring systems related to carbon capture and storage (CCS), and their uncertainties, with the goal of maximizing the injection of CO_2. He is currently working as a field researcher and junior soil advisor in Amsterdam.

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Michael Nolten obtained his M.Sc. degree in geology and geochemistry at the Vrije Universiteit Amsterdam. His thesis related to ranking identified potential CCS fields in the North Sea for the Athos Project. He is currently working on geological projects at Energie Beheer Nederland.

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Jon Wierenga obtained his M.Sc. degree in geology and geochemistry at the Vrije Universiteit Amsterdam. His thesis involved developing a regional velocity model for the

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Aquifer storage resources & rates;
First insights from a conceptual portfolio analysis of aquifers

Thijs Huijskes, EBN

Aquifer Storage

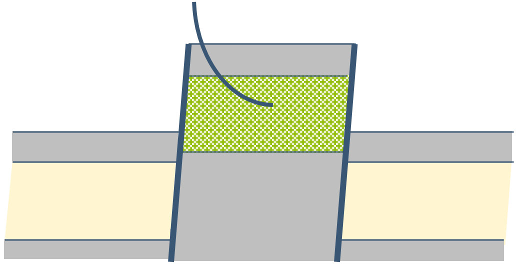
From play to lead & prospect characterization

What type of information is useful when going from Play to Lead identification?

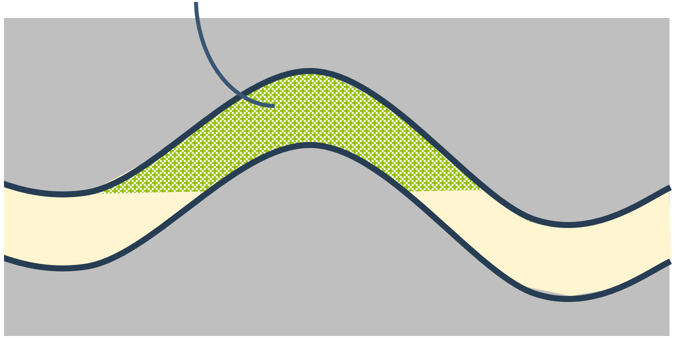
- Structural information
- Aquifer size & thickness
- Total compressibility
- Permeability (& thickness)
- Pressure limits (cap rock failure)
- Heterogeneity / depositional geology

Aquifer Storage

Storage types

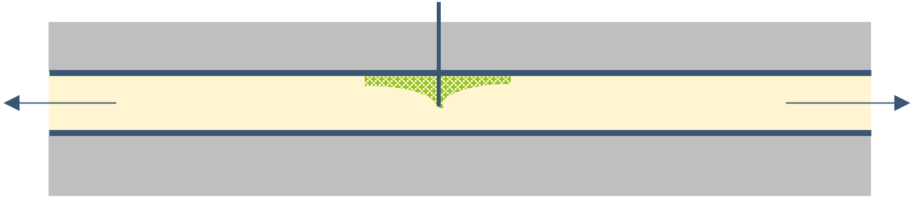


Closed Boundary (Ct)



Open Boundary (Ct + W, structure)

Infinite Aquifer (Ct + W)



Needed:

- **Compressibility very important**
- **Size of connected aquifer**

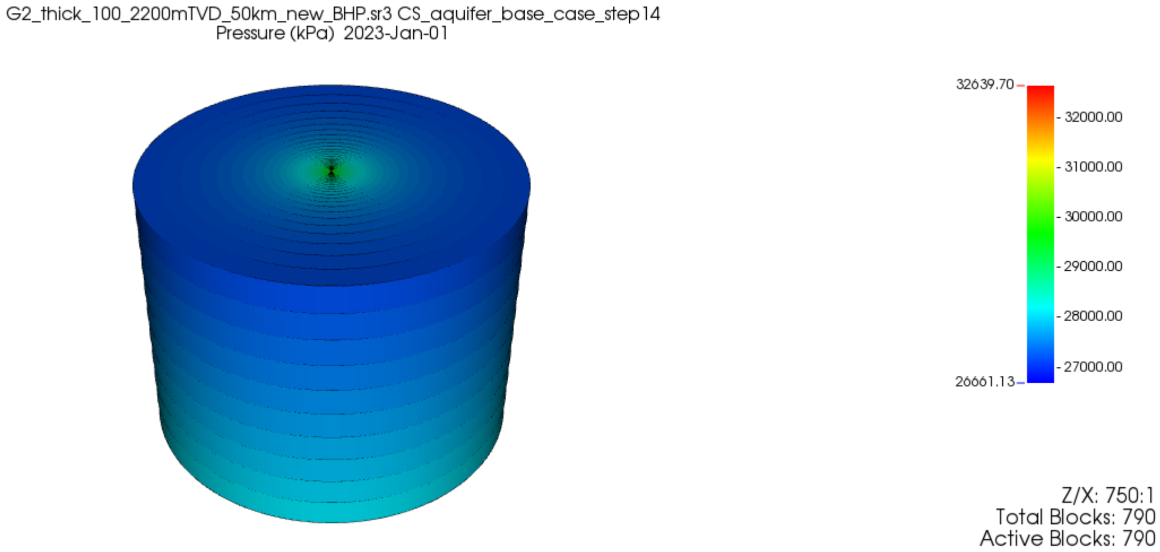
Aquifer Storage

Required reservoir characteristics for minimum volume and rates

Conceptual portfolio of reservoirs

Radial model, homogeneous, one vertical well

- Base case on size and kh
- Variations on: **k**, **h**, **size**, **por**, **depth**
- Bound by: **BHP** and **max rate**



Conceptual Modelling

Results

Learnings on storage volume potential

Learnings on rate potential

Conceptual Modelling

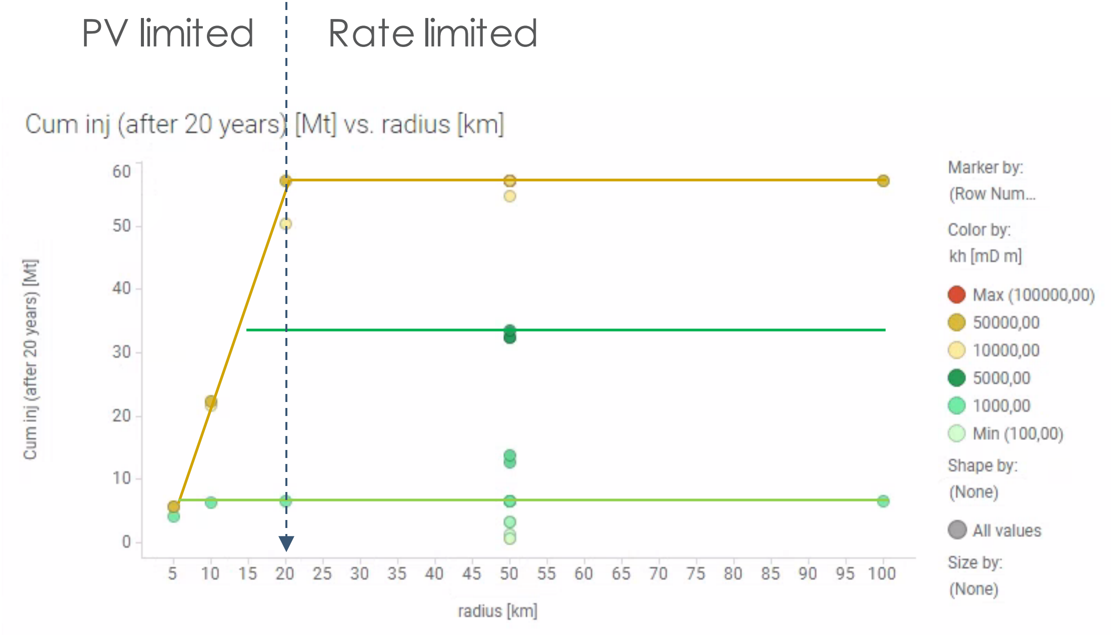
Learnings on storage volume

(injected after 20 years of injection)

- For R < 20 km (h = 100 m),
  M is bound by pore volume

- For R > 20 km
  M is bound by max rate

  (For high kh)



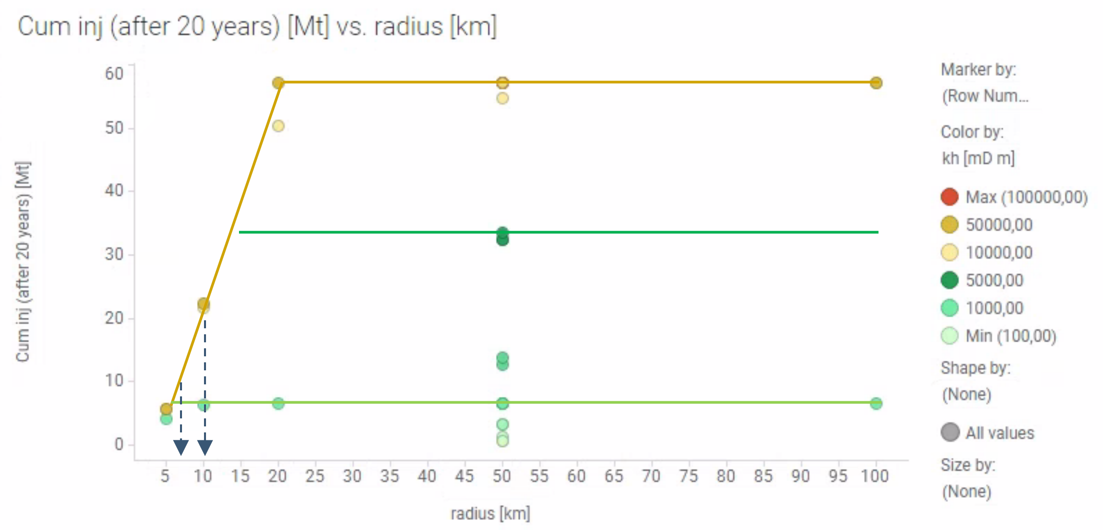
Conceptual Modelling

Learnings on storage volume

(injected after 20 years of injection)

What size should the connected PV be for a minimum storage volume?

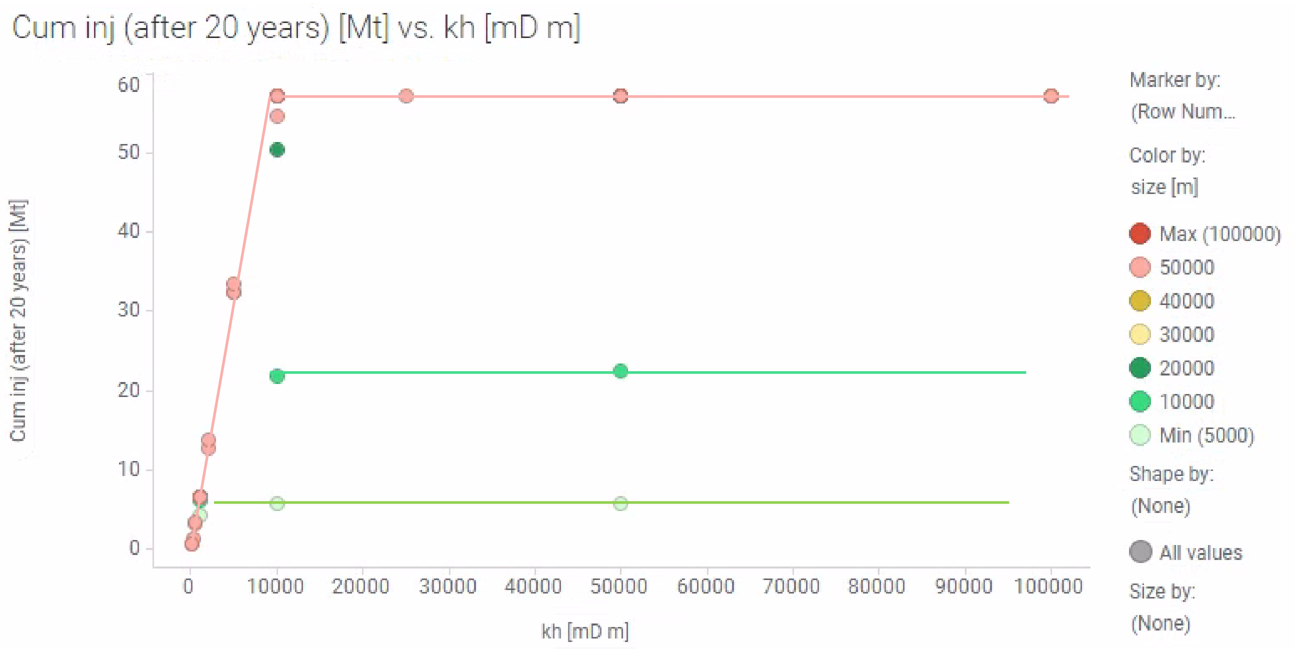
- For 10 Mt, one needs R > 7 km
- However, for 20 Mt, one needs R > 10 km (kh>5000 mDm)



Conceptual Modelling

Learnings on injection rates

What is the minimum kh required for decent rate? (20 yrs)



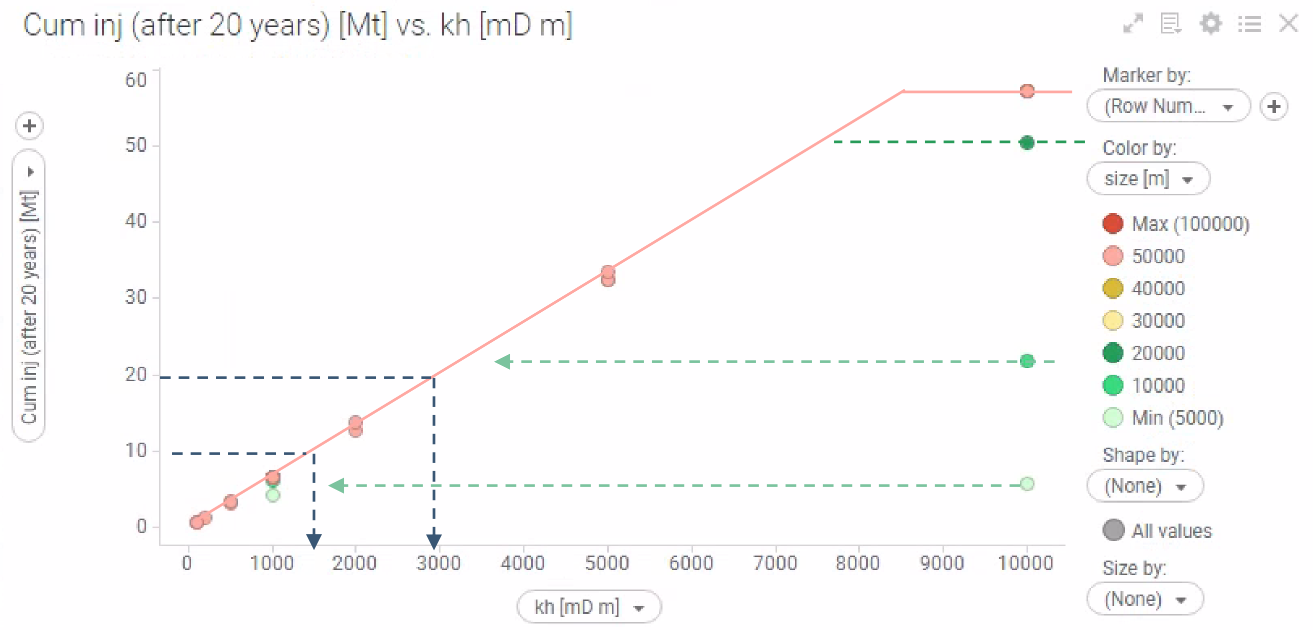
Conceptual Modelling

Learnings on injection rates

Minimum kh required for decent rate? (20 yrs)

At least 1500 mDm to reach ~ 0.5 Mt/y

And 3000 mDm for ~ 1 Mt/y



Conceptual Modelling

Preliminary conclusions

Conclusions for a 20 year project

Injection rates

For 0.5 Mt/y one needs at least 1500 mDm

For 1.0 Mt/y one needs at least 3000 mDm

Much higher kh than for gas reservoirs!

Resource estimation

For 10 Mt one needs a radius R > 7 km (kh > 1500 mDm)

For 20 Mt one needs a radius R > 10 km (kh > 5000 mDm)

Relatively large structures!

Much higher rates (and volumes) are possible but depend mostly on kh

Conceptual Modelling

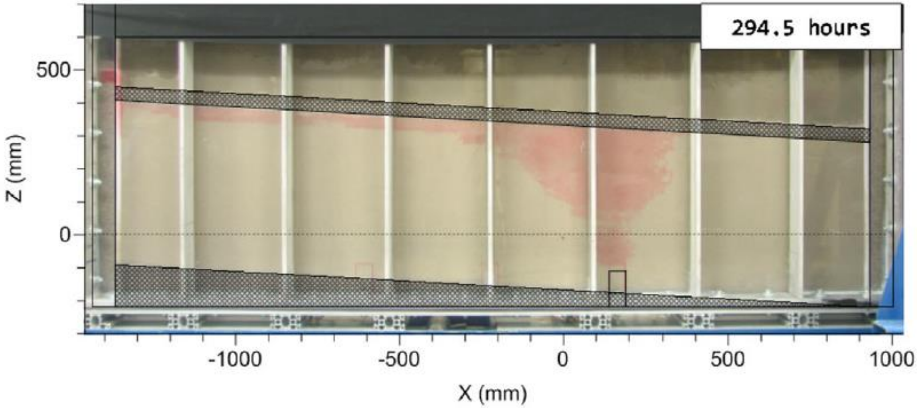
Discussion

- Sensitivity analysis on total compressibility
- Structural modelling
- Heterogeneous layering

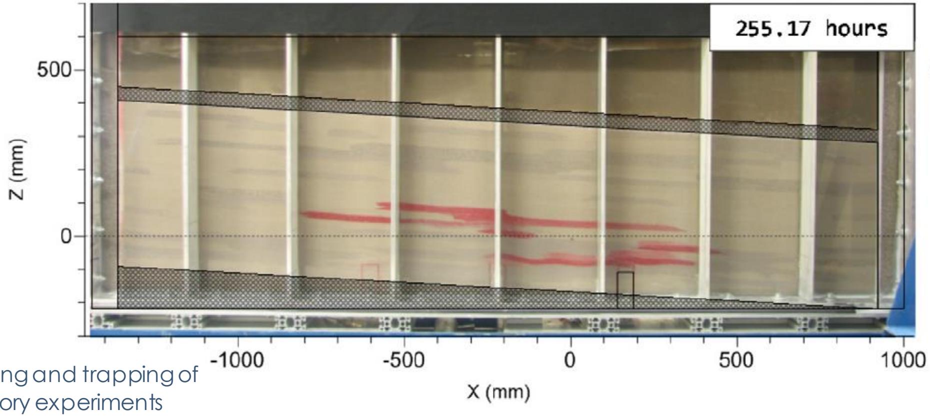
Aquifer Storage

Storage mechanisms

- Structural trapping (Buoyancy)
- Residual trapping (Capillary)
- Solution trapping (Dissolution)
- Mineral trapping (mineral precipitation)



Balance between buoyancy and capillary forces strongly driven by heterogeneity



<u>Knowledge of deposition and vertical heterogeneity very important for forecasting</u>

(Not so much for direct resource estimation, but for flow characterization and modeling of containment within structure)

Trevisan et al. (2016) Imaging and quantification of spreading and trapping of carbon dioxide in saline aquifers using meter-scale laboratory experiments

Thank you for your attention

ebn