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A silhouette of an offshore oil rig stands in the middle of a vast, calm blue ocean under a clear sky. The rig is reflected in the water.

ATLAS OF DEEP SUBSURFACE RESOURCES IN THE NETHERLANDS

Rotliegend update

16 November 2023 – Dutch Exploration Day

Rotliegend Play



- Presented by: Marloes Kortekaas
- Team: Renaud Bouroullec, Stefan Peeters, Marianne van Unen (TNO)
Daan den Hartog Jager, Merel Swart, Edward Wiarda, Marloes Kortekaas (EBN-BUG)
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- Source rock input: IGI PSA NL study, Susanne Nelskamp (TNO)
- GIS support: Merel Swart, Sabine Korevaar, Daan Petri (EBN)
- Reviewers: Kees Geel, Clemens Visser

AGENDA



Introduction

- GEODE project goal and deliverables

Rotliegend play evaluation

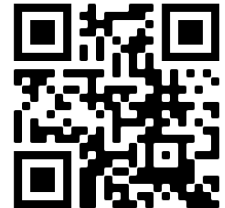
- Updated stratigraphic framework
- HC exploration onshore
- Saline aquifer CCS offshore

What's next?

- Plan for 2024

GEODE in a nutshell

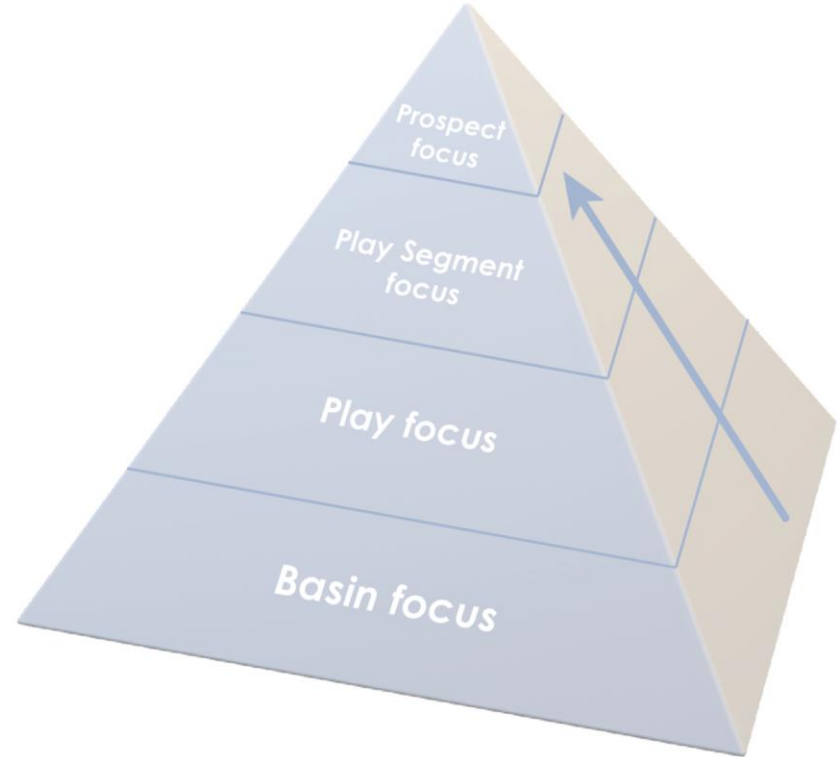
- Joint project of EBN B.V. and TNO to create an atlas of subsurface resources in the Netherlands.
- Easily accessible web-based GIS environment where **play-based exploration data** is presented for the main hydrocarbons plays in the Netherlands and for **saline aquifer CCS** in the Dutch offshore.
- Results of this project are made available to the public free of charge.
- Online since November 2021, yearly updates and added play evaluations.



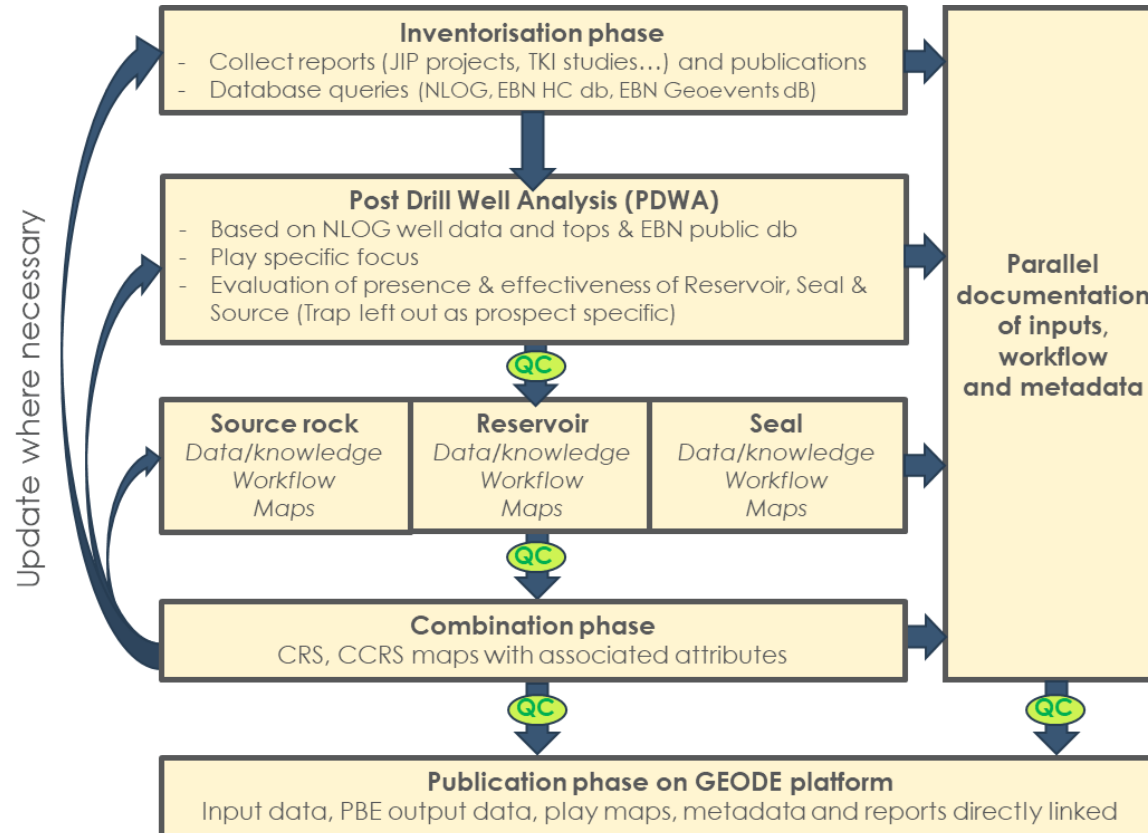
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GEODE approach

- A Play Based Exploration (PBE) approach is used to create many subsurface datasets including common risk segment (CRS) maps.
- Historical data is transformed into mappable information and provides an indication of the most prospective areas for HC exploration and sweet spots for saline aquifer CCS.
- Player software (from GIS-PAX) is used to perform play analyses.
- Results also as layered PDF (annotated play map)



Workflow per play



GEODE Project goals 2023



- **New Scope:**
 - Onshore for E&P
 - Saline aquifer CCS Offshore
- More regional datasets available
- **Plays updated during 2023:**
 - Petroleum System NL
 - Rotliegend
 - Triassic
 - Lower Cretaceous (ongoing)



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GEODE Rotliegend project 2023

Onshore included E&P, Offshore Saline Aquifer CCS

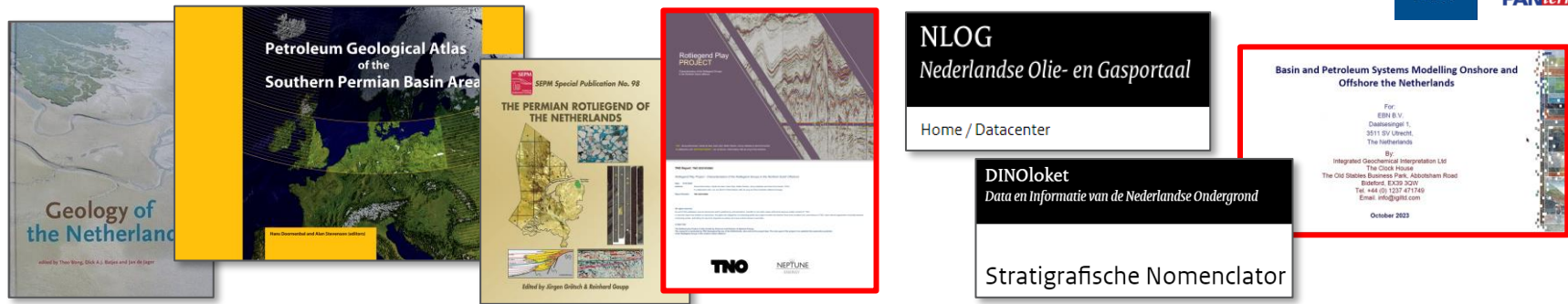


New Scope:

- Additional deliverables (e.g. perm, N/G, Kh, qualitative storage capacity, injectivity, pressure)

New data:

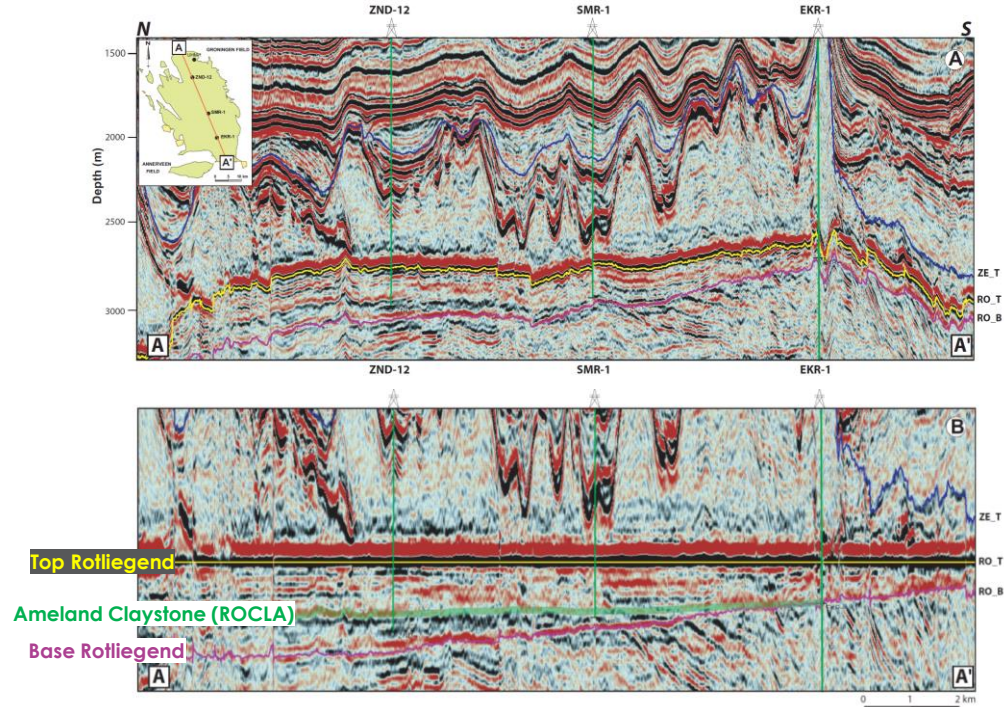
- EBN- and TNO-studies including newly released material
- New reservoir property data (ThermoGIS data 2021, SCAN data, EBN machine learning)
- Special thanks to NAM, Neptune and Panterra for making studies and datasets public



Rotliegend onlap – evidence in the South:



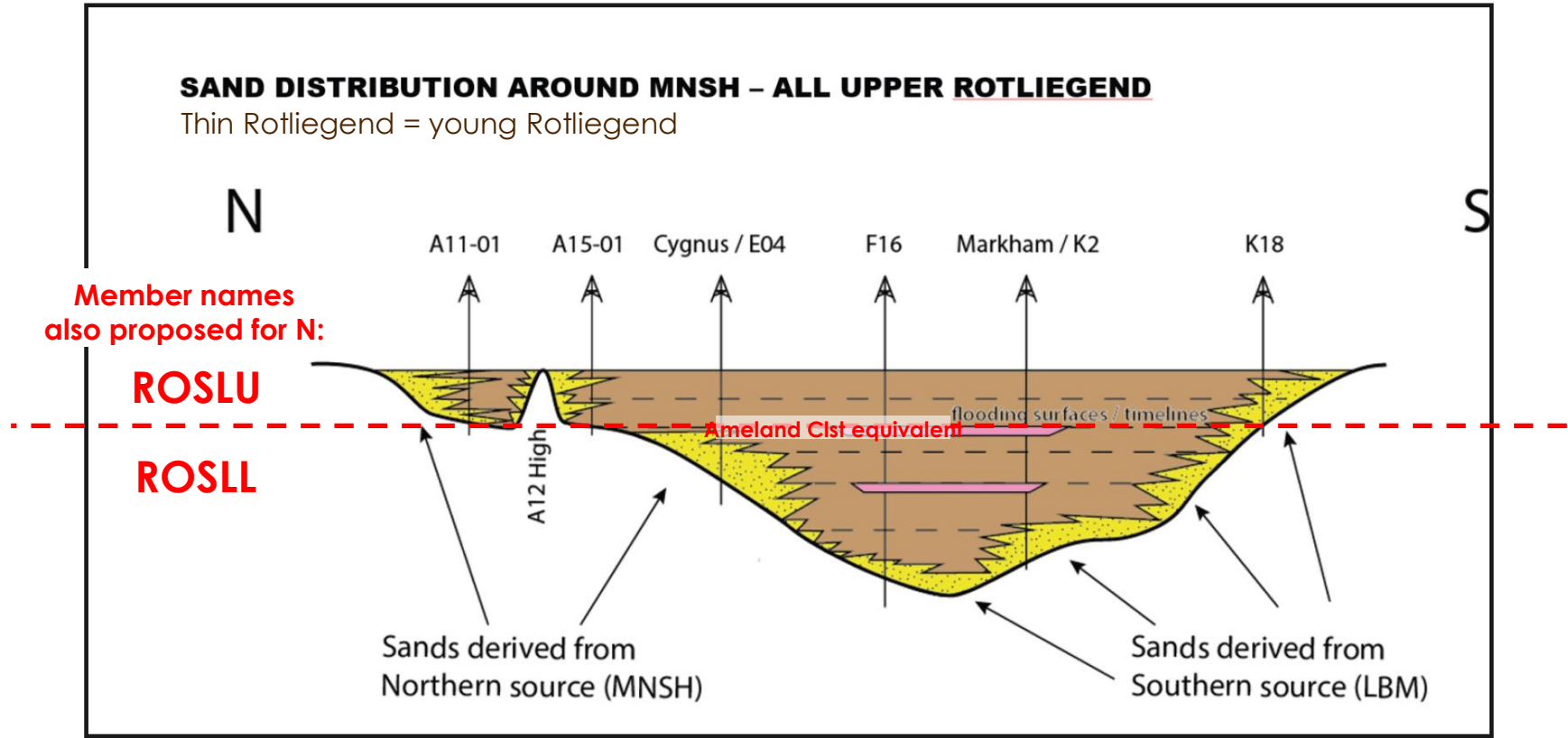
- Rotliegend basin fill with onlap against pre-existing higher areas is well documented from the southern side of the Southern Permian Basin.
- Example: Groningen field



Groningen line flattened: vert exagg. 6.4x

Onlap model in North

In recently released TNO-Neptune study



Rotliegend reservoir – seal summary GEODE 2021 (superseded)



GEODE

← Main Zechstein Basin →

P18-05,
P13-01, -02 WGF-01

P15, K13, K17,
Q13, Q10 P02

K10, K14,
Q01

K08, K09, K12,
L10, L13, M07

K01-K06,
L01-L06, N04

D12, D15,
E10-E12, F10

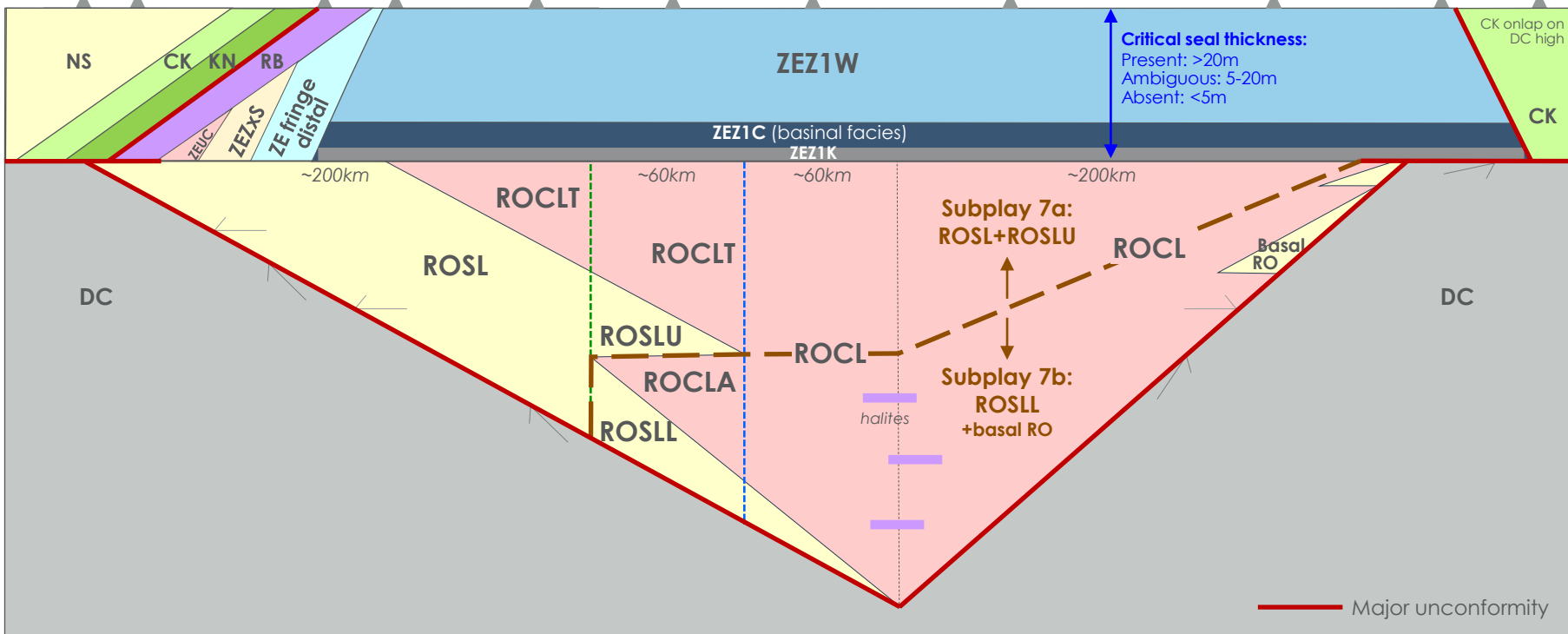
A11, B10, B17

UK wells

A17-01,
E02-01

S

N



Rotliegend reservoir – seal summary - GEODE 2023



GEODE

U. Rotliegend
pinchout line S

~ROSL
pinchout line S

ROCLA
pinchout line

ROSLU
shaleout line

~ROSL
pinchout line N

U. Rotliegend
pinchout line N

Main Zechstein Basin

P18-03,
P13-01, 02 WGF-01

P15, K13, K17,
Q13, Q10 P02

K10, K14,
Q01

K08, K09, K12,
L10, L13, M07

K01-K06,
L01-L06, N04

D12, D15,
E10-E12, F10
(Cygnus)

B17

A11, B10

A05

A17-01,
E02-01

NS

CK KN

RB

ZE1C

ZE1XS

ZE fringe, distal

ZE1W

ZE1C (basinal facies)
ZE1K

CK onlap on
DC high

N

Critical seal thickness:
Present: >20m
Ambiguous: 5-20m
Absent: <5m

~200km

ROCLT

ROCLT

ROCL

Subplay 7a:
ROSL+ROSLU

ROSLU
N equivalent

extrusive

Igneous
rocks XX

In- and
extrusive

DC

ROSL

ROSLU

ROCL

ROSL
N equivalent

In- and
extrusive

DC

ROCLA

ROSL

Subplay 7b:
ROSL

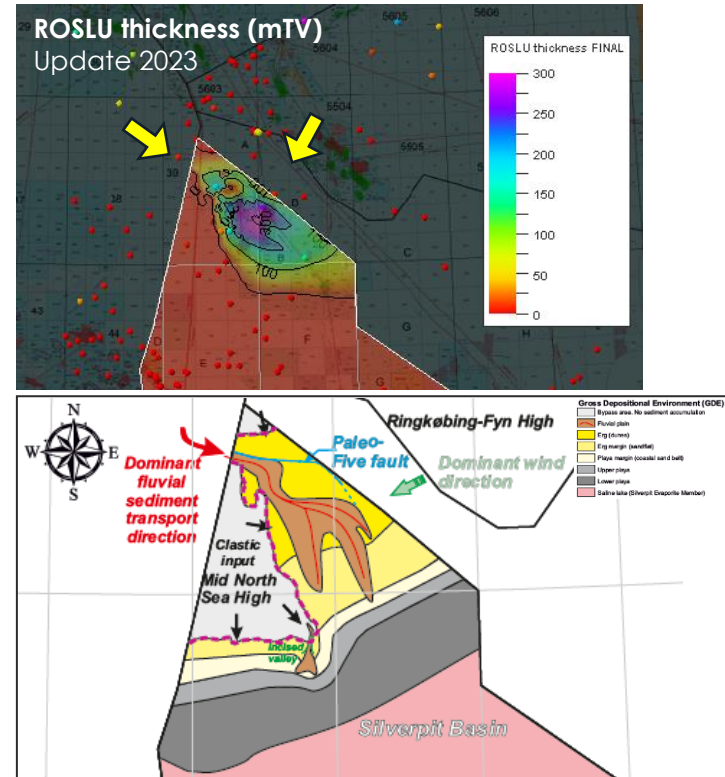
Major unconformity

S

Impact Rotliegend update

Northern offshore: more Upper Slochteren sandstones

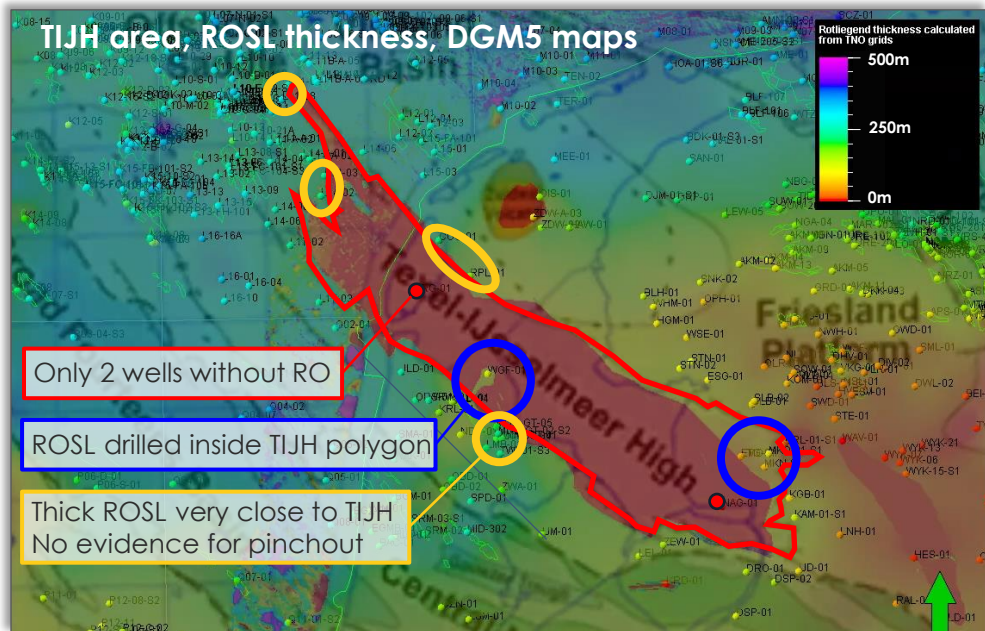
- Onlap Rotliegend applied
- Reclassification of Rotliegend sst in northern offshore to ROSLU
- Updated correlations and new thickness maps, showing the extent of ROSLU derived from the north



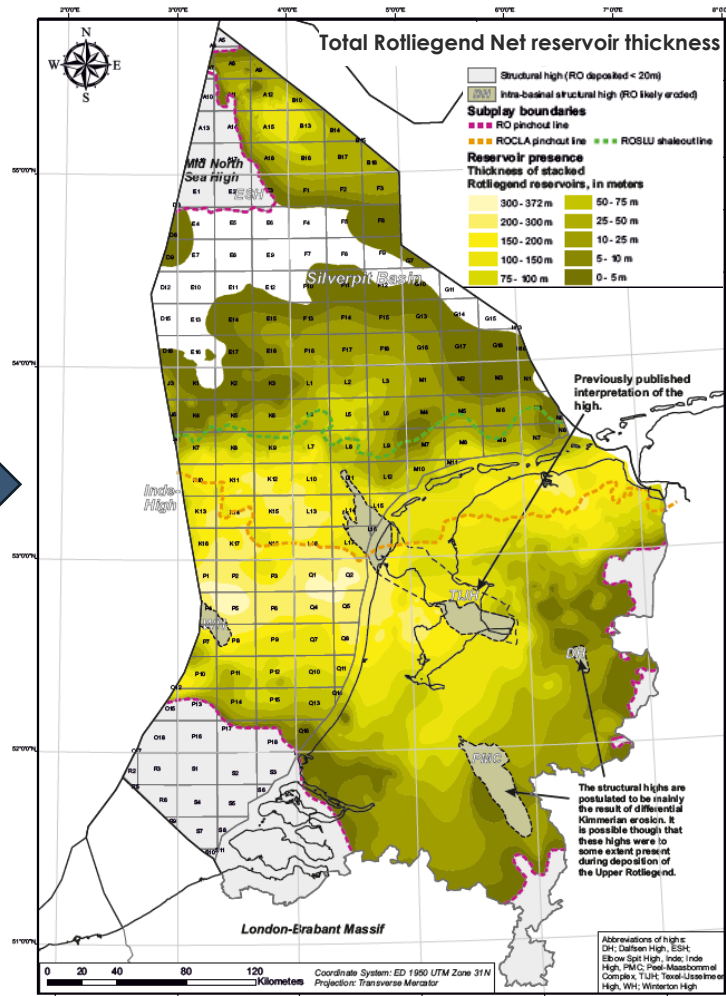
ROSLU paleogeographical map

GEODE 2023: structural elements

Texel-IJsselmeer High



TIJH did not exist during RO deposition.

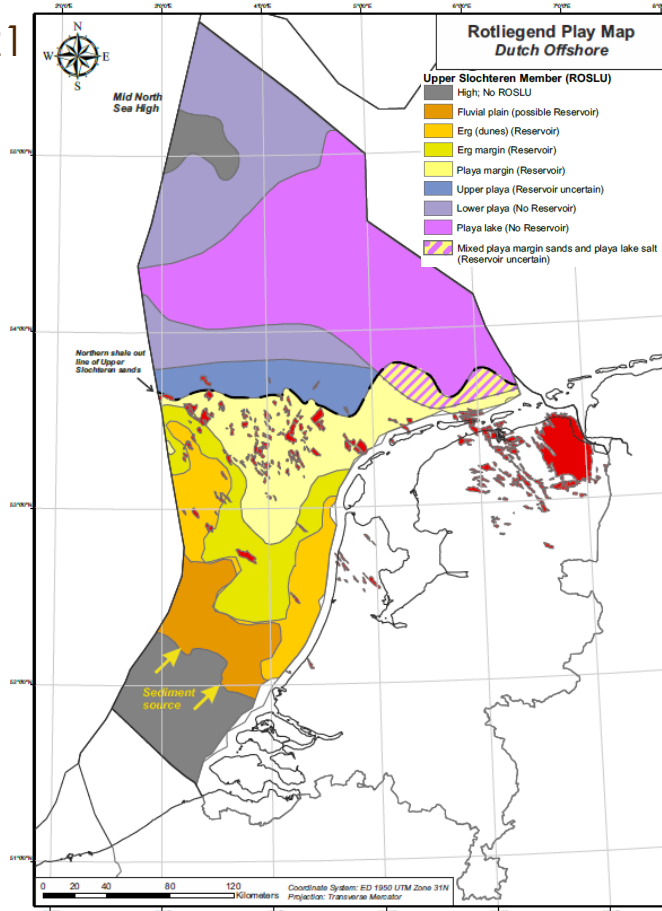


Annotated play map – example ROSLU paleogeographic map

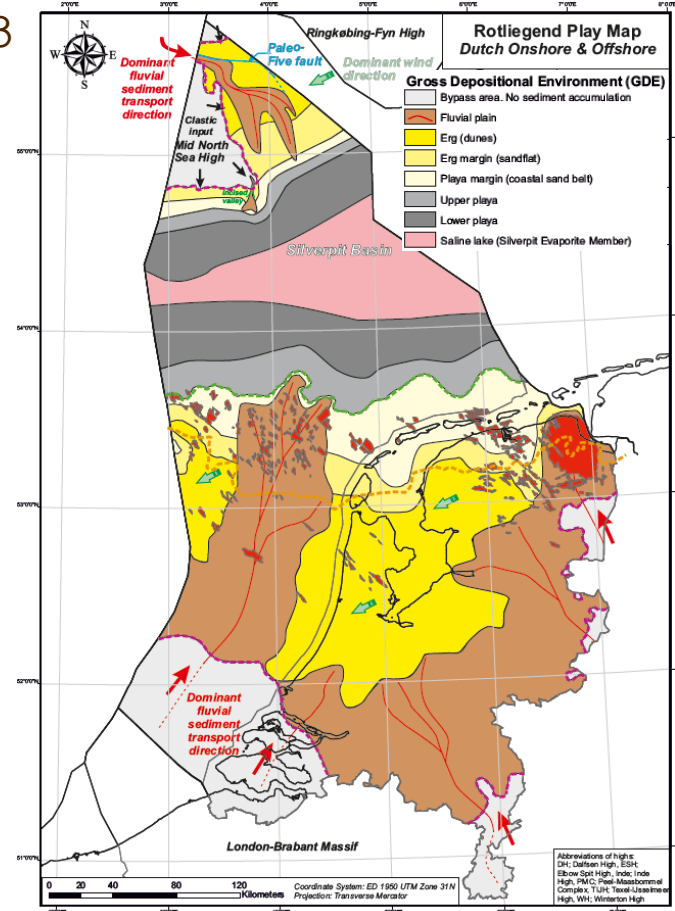


GEODE

2021



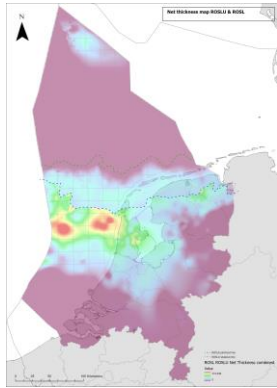
2023



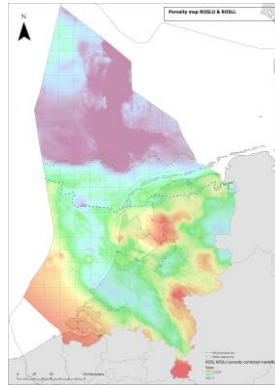
Final Risk map - Upper Slochteren example

Stacking of play element risk maps for HC exploration

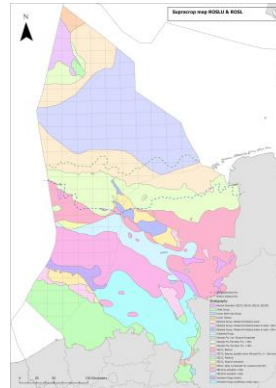
input



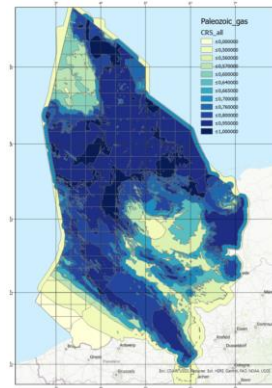
Thickness



Porosity

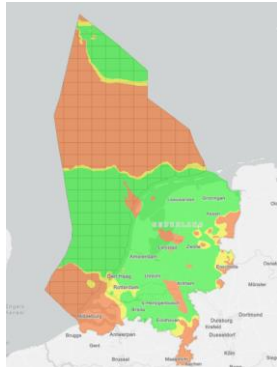


Supracrop map

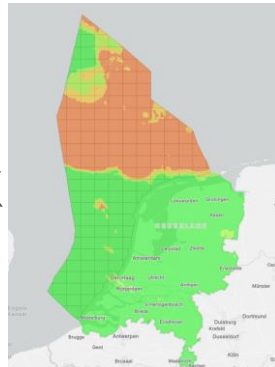


Paleozoic Charge

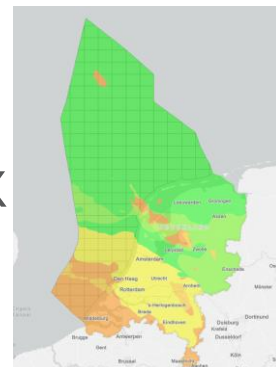
Play element risk maps



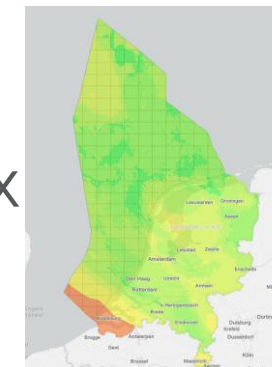
Reservoir Presence



Reservoir Effectiveness



Seal



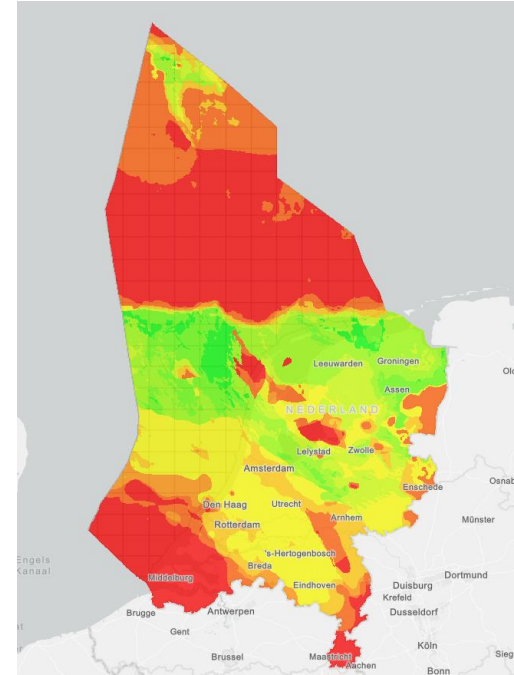
Paleozoic Charge

X

X

X

=



CCRS (Play chance)

Introduction Saline Aquifer CO₂ storage

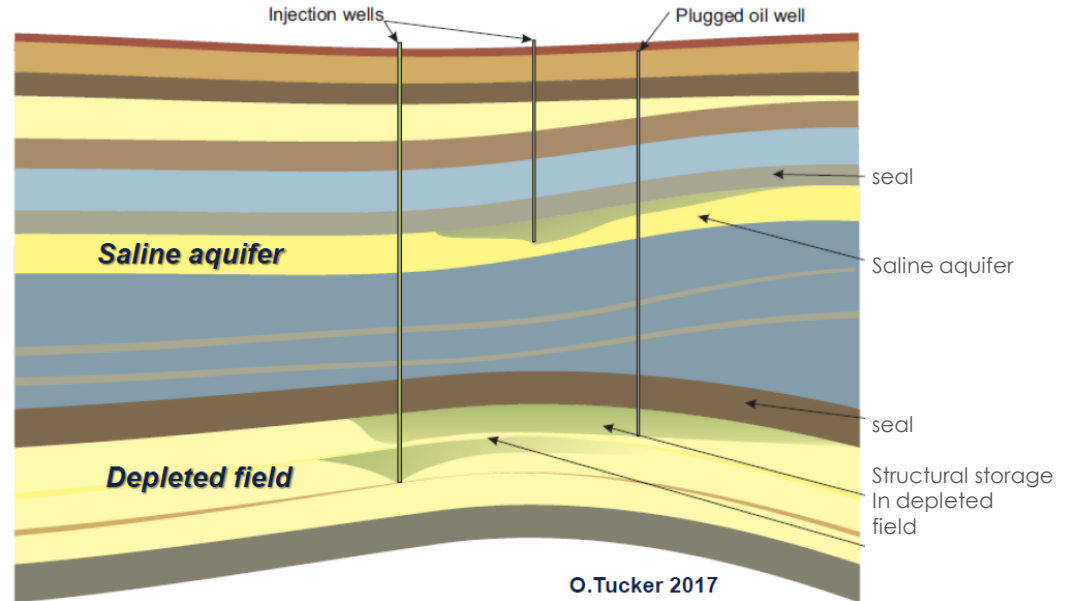
Why Saline Aquifers for Carbon Capture and Storage?

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.

Screening of CCS opportunities focuses on the following subsurface drivers:

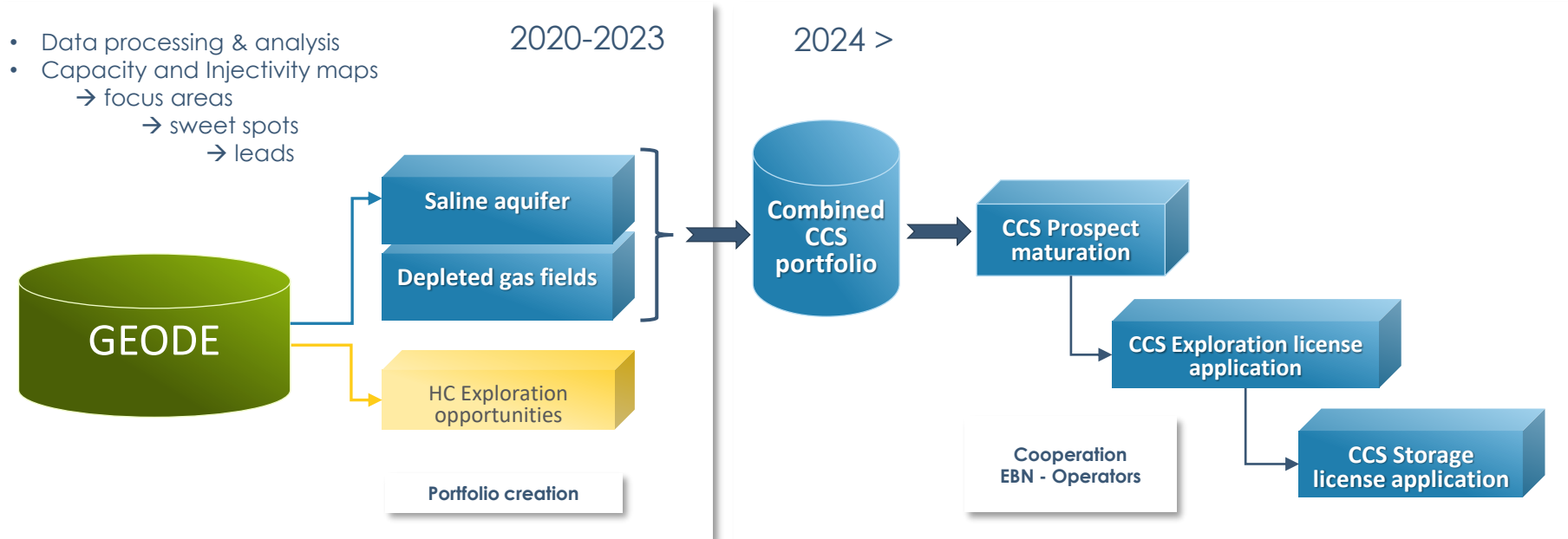
- Capacity
- Injectivity
- Containment



Regional saline aquifer CCS Screening

GEODE 2023:

- Regional screening for sweetspots for saline aquifer CCS
- Identify sufficient reservoir and seal present in NL offshore



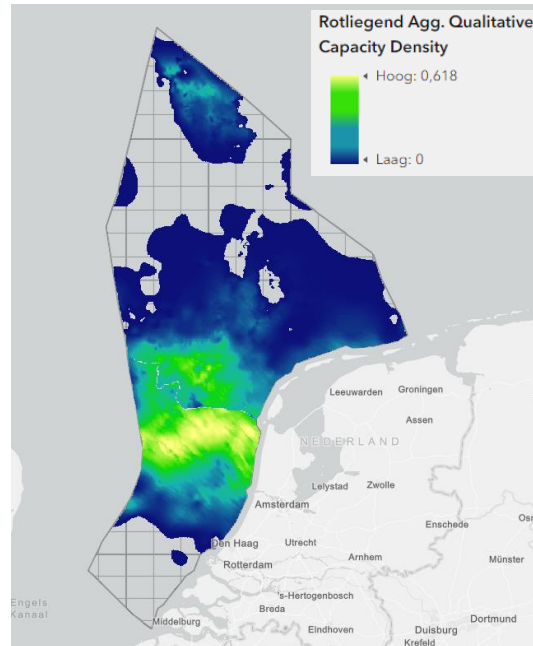
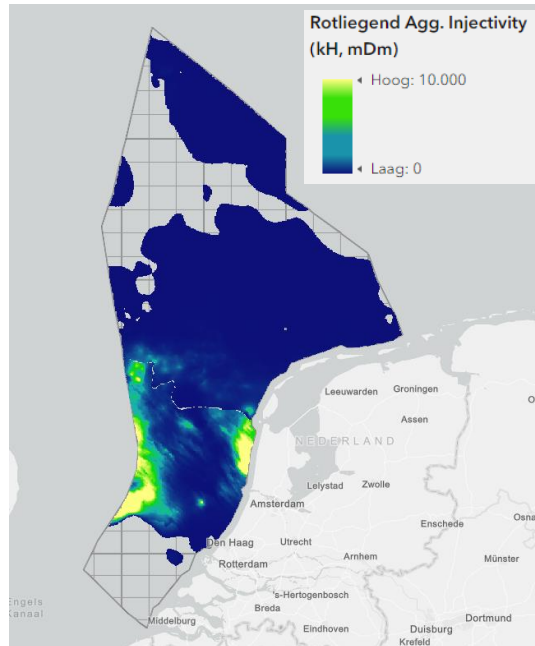
Drivers for saline aquifer CCS screening

Based on Hydrocarbon E&P Data



HC Risk element	HC Drivers	CCS Driver
Charge	Source Rock (presence/expulsion)	Not relevant for CCS
	Migration	
Reservoir	Presence	Capacity
	Effectiveness	Injectivity
Seal	Lithology/ thickness top seal	Geological containment
		Well containment (prospect level)
Trap – not part of GEODE Prospect Specific!	Faults / Timing	Depleted HC field (proven trap!) Closed aquifer system Open aquifer systems (no trap)

Rotliegend saline aquifer CCS potential



Injectivity regional screening:

- Reservoir thickness
- Reservoir permeability

Capacity regional screening:

- Pore volume (reservoir thickness and porosity)
- Rock and fluid properties (density, compressibility)
- Pressure space (fracture gradient – safe margin – hydrostatic gradient)

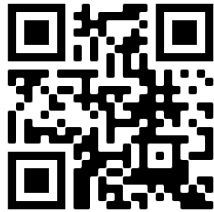
GEODE selected plays for the Netherlands

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	Offshore E&P	Onshore E&P	CCS offshore	
1 CENOZOIC - SHALLOW GAS	✓			
2 UPPER CRETACEOUS - CHALK	✓	✓	✓	2025
3 LOWER CRETACEOUS	✓	✓	✓	2024 – Q1
4 JURASSIC	✓	✓	✓	Stratigraphic pre-study in 2024
5 TRIASSIC	✓	✓	✓	
6 ZECHSTEIN	✓	✓	✓	2024
7 ROTLIEGEND	✓	✓	✓	
8 CARBONIFEROUS	✓			
9 SOURCE ROCKS	✓	✓		NEW Petroleum System Analysis NL 9 SR intervals!

Thanks for your attention



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BACK-UP SLIDES

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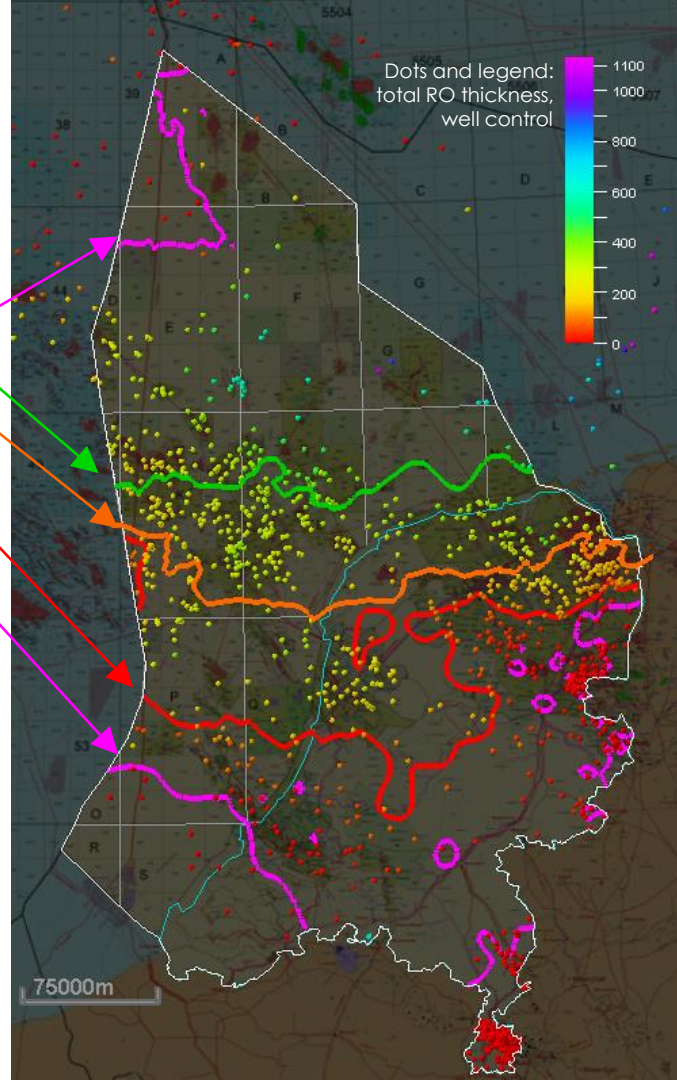
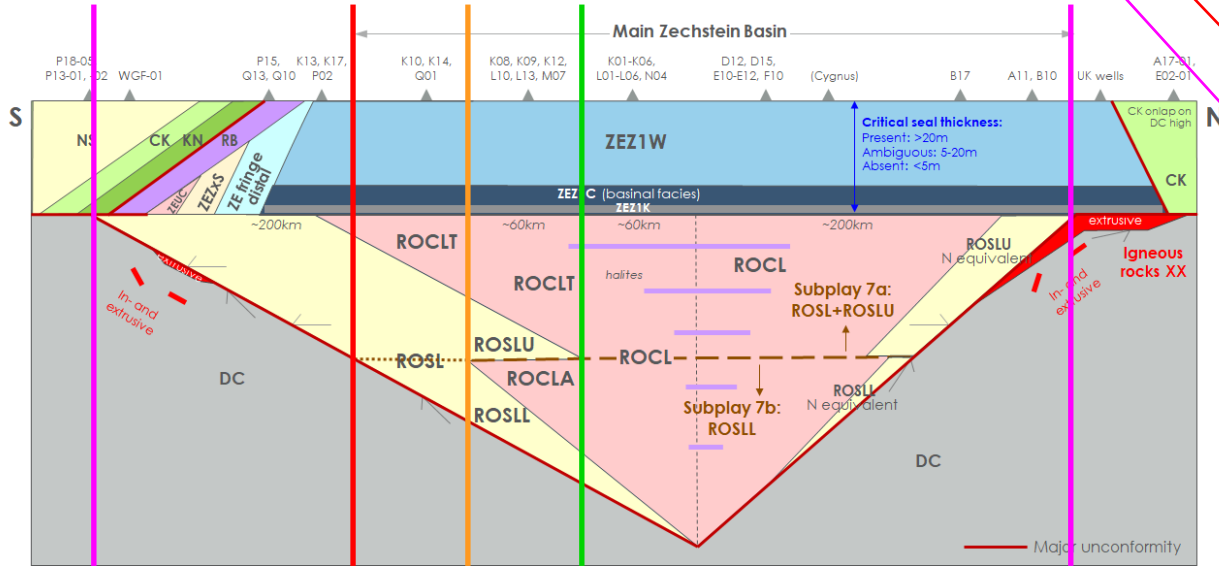
Key member boundary lines

Upper Slochteren Sst (ROSLU) shaleout S=>N

Ameland Clst (ROCLA) pinchout N=>S

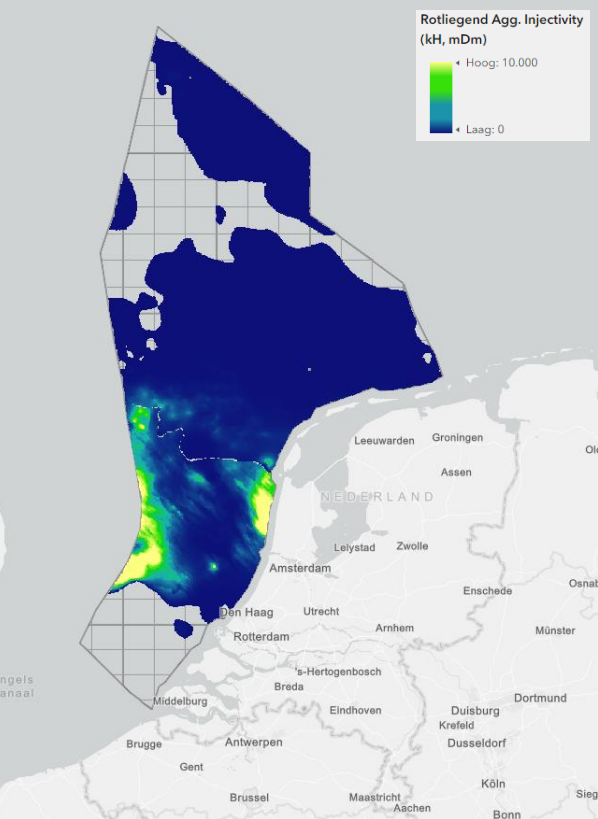
Likely Lower Slochteren Sst (ROSL) pinchout N=>S

Upper Slochteren Sst (ROSLU) pinchout (both S and N)
= Upper Rotliegend (RO) pinchout

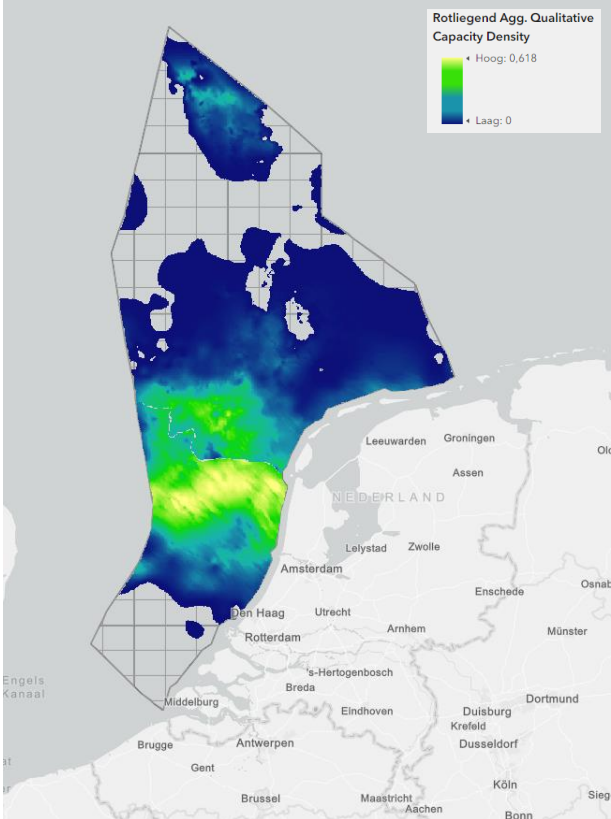


Rotliegend CO2 saline aquifer storage potential

Injectivity (Kh)



Qualitative Capacity Density



Qual. Cap. Density * Injectivity

