



November 21<sup>st</sup>, 2024

9<sup>th</sup> Dutch Exploration Day

**TNO** innovation  
for life

ebn

# Return to the Zechstein Play

## Unlocking its potential for wider energy applications

Aart-Peter van den Berg van Saparoea

# GEODE Zechstein 2024



## Contributors:

### TNO:

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### QA/QC panel:

- Jo Garland (Cambridge Carbonates)
- Bastiaan Jaarsma (EBN)
- Heijn van Gent (SodM)
- Allard van der Molen (Nobian)



# Content



Introduction to the GEODE platform

Zechstein play

Zechstein CO<sub>2</sub> storage potential

Zechstein hydrogen storage potential

ZE2C exploration potential

# GEODE in a nutshell



- Joint project of EBN and TNO to create an atlas of subsurface resources in the Netherlands.
- Easily accessible web-based GIS environment where **play-based exploration data and knowledge** is presented for:
  - the main **hydrocarbon** plays in NL
  - saline aquifer **CO<sub>2</sub> Storage** in the Dutch offshore
  - **H<sub>2</sub> storage** in Zechstein salt in NL
- Results of this project are made available to the public free of charge.
- Online since November 2021, yearly updates and added plays evaluations.

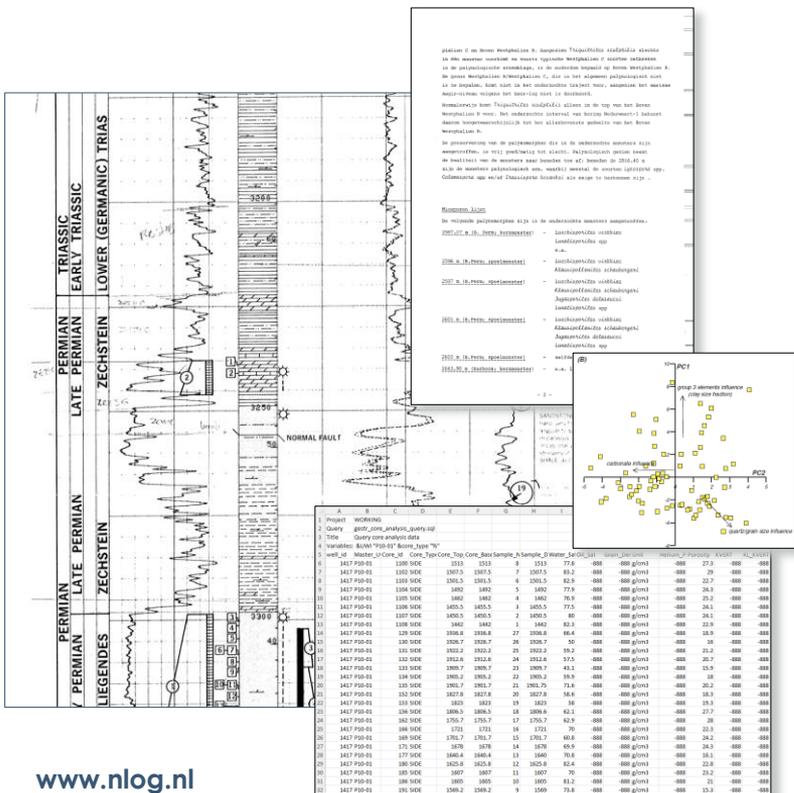


# From data to accessible knowledge

> 500 integrated datasets and interpretations



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**Reservoir screening information**  
> 280 datasets/maps

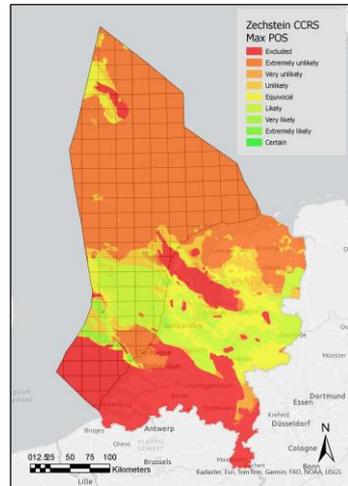
**Seal assessment information**  
> 120 datasets/maps

**Fault information**  
> 20 datasets/maps

**Country wide basin model**  
> 80 datasets/maps



## Zechstein CCRS map



**Risk/chance maps**  
> 150 maps

# Zechstein play

2024 update



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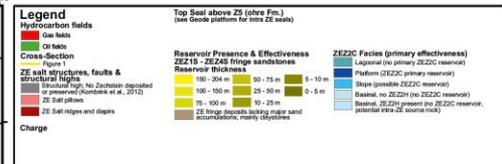
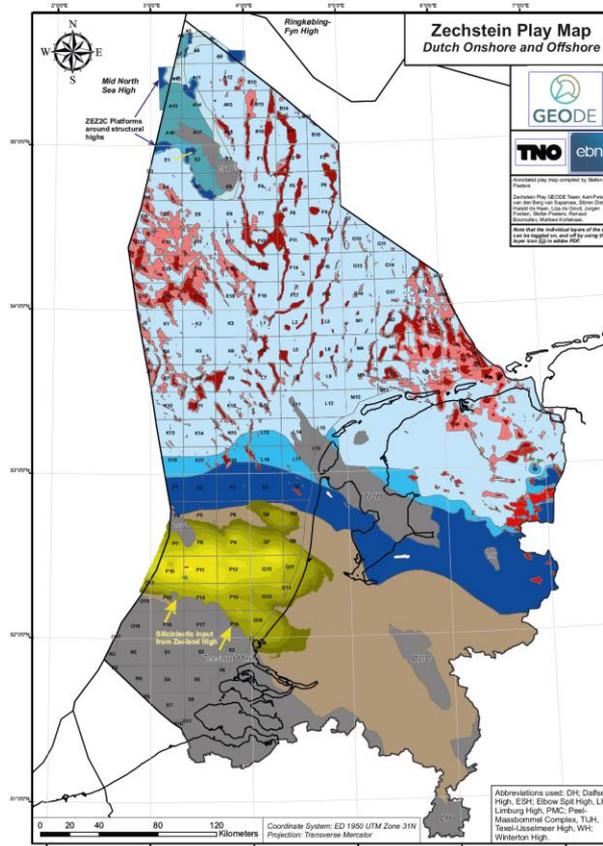
## Sub-plays:

- Zechstein Fringe Sandstones
- Zechstein 2 carbonates
- Zechstein 3 carbonates
- Evaporites

## New maps:

- Reservoir quality
- CO<sub>2</sub>-storage
- H<sub>2</sub>-storage
- Onshore

Zechstein annotated play map

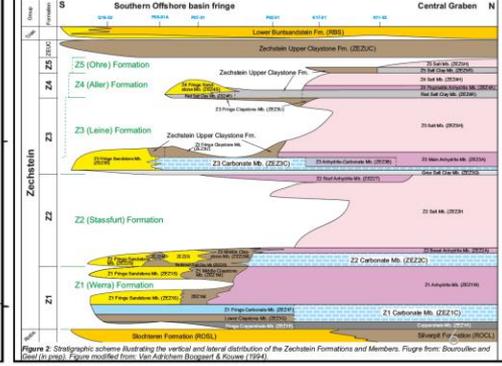


**Zechstein Play**

The Zechstein Group is a succession of Upper Permian evaporites, carbonates and siliciclastic formations that were deposited in the Southern Permian Basin. The Zechstein Group was deposited into 4 cycles under warm and arid conditions (Gela, 2007; Paturo, et al., 2017; Grant et al., 2016). Each Zechstein cycle is characterized by an initial transgression and highland, represented by carbonate deposition, followed by a phase of regression during which vast amounts of halite were deposited in the central parts of the basin (Gela, 2007; Meiss, and Conrath, halokinetic lobes formed the typical salt pillow, salt diapir and salt walls that today make the Zechstein instantly recognizable on seismic data. Towards the paleo basin margins of the Southern Permian Basin, the Zechstein is thinner and mainly consists of fringe deposits, including carbonate platforms, anhydrites and locally siliciclastics. The most significant reservoirs are found within these fringe deposits around the basin margins and include: The Zechstein Fringe Sandstones (ZE18, ZE20, ZE23, ZE24S), as well as the platform and possibly slope deposits of the Z2 Carbonate (ZE20ZC; see also cross section 1), and Z3 Carbonate (ZE23C). An additional potential Zechstein reservoir occur in some places but formed by fractured Zechstein caprock above salt structures, as is the case for the G1-G4 in field. Located exposures during the Mid Permian tectonic event resulted in meteoric dissolution of some carbonates, adding potential secondary dissolution porosity (bruggy rock/dissolution breccia). Quantifying reservoir properties for carbonates is challenging (especially on a regional scale), but more qualitative information on carbonate reservoir properties is given on the Geode Platform. For the reservoir properties of the siliciclastic fringe sandstones, quantitative information is on the Geode Platform.

The most important seals for the ZE20ZC and ZE23C carbonates are into ZE anhydrites and halites (see figure 2). In most areas these intra-ZE seals are thicker than 20 m and form an effective seal. In some areas, the intra-ZE seals are absent. There, the overlying siliciclastic seals of the Barrier Shales and the Visland shales often form an effective seal. Note that relatively small areas around the Elbow Spill High and just north of the Zeland High likely lack a working seal.

Charge could potentially occur in large parts of the offshore. Charge risks are greatest on the Zeland High and around the Elbow Spill High. It is noted that only areas are shown on the map where carboniferous (Palaeozoic) oil- and gas-bearing basins facies of the Hauptdolomit could potentially also function as a source rock (e.g. Paturo et al., 2017). Although this is not proven in the Dutch offshore, it might create additional source rock potential for the Zechstein play. References can be found here.



# CO<sub>2</sub> Storage in Saline Aquifers

## Zechstein Fringe Sandstones

Assumption: closed aquifer

Deliverables:

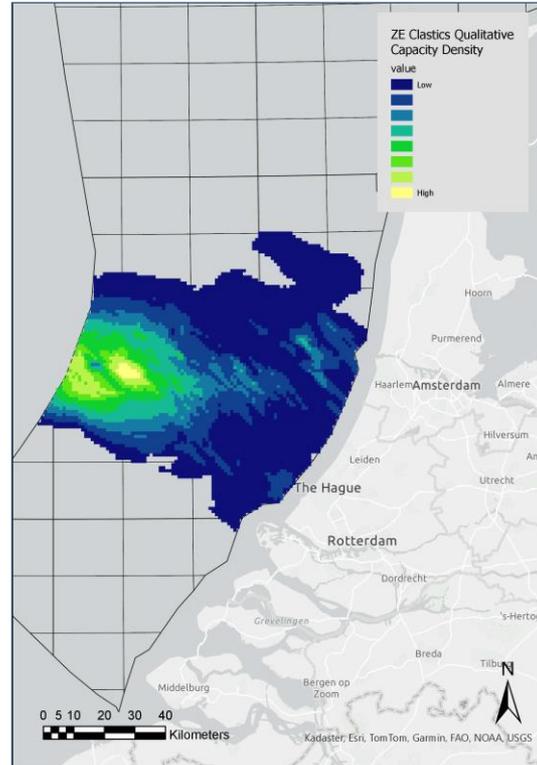
- Capacity Density (Mt/km<sup>2</sup>)
- Permeability \* Thickness (kh as proxy for injectivity)

Input:

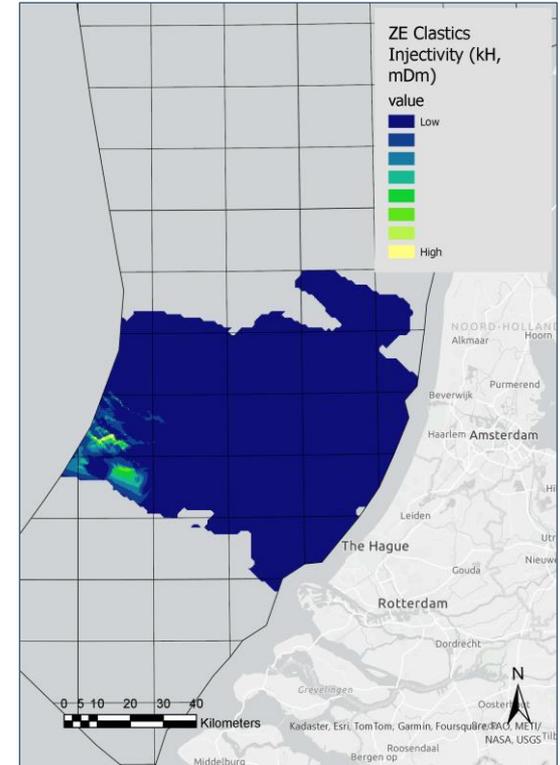
- Pore Space Height (Thickness \* Porosity)
- Pressure Space
- Compressibility of the system (Rock + Water)
- Density CO<sub>2</sub>

[www.geodeatlas.nl/pages/play-6-zechstein](http://www.geodeatlas.nl/pages/play-6-zechstein)

### Qualitative Capacity Density



### Injectivity





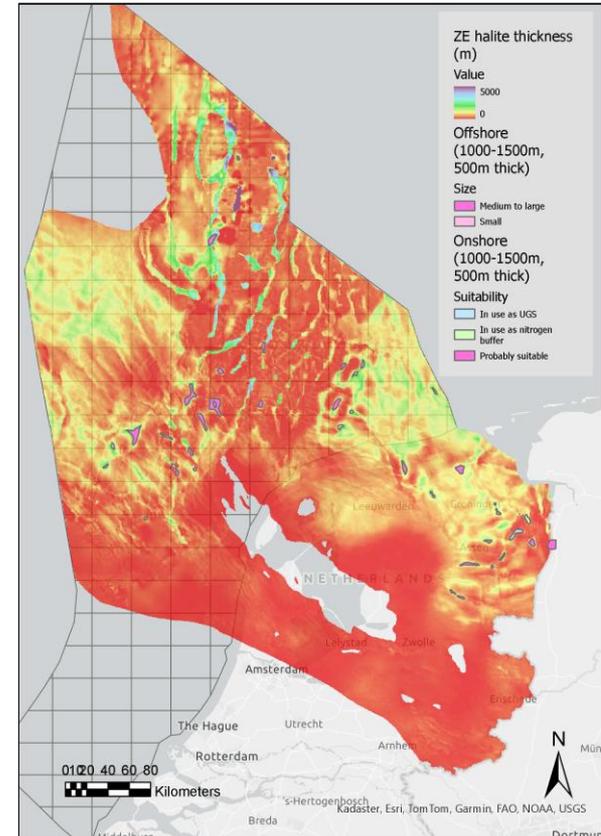
# Underground H<sub>2</sub> Storage in Salt Diapirs

## Salt must be present:

- below 1000 m TVDSS for sufficient storage capacity (max pressure)
- above 1500 m TVDSS to prevent cavern convergence (due to salt creep)

[www.geodeatlas.nl/pages/play-6-zechstein](http://www.geodeatlas.nl/pages/play-6-zechstein)

## Zechstein halite thickness





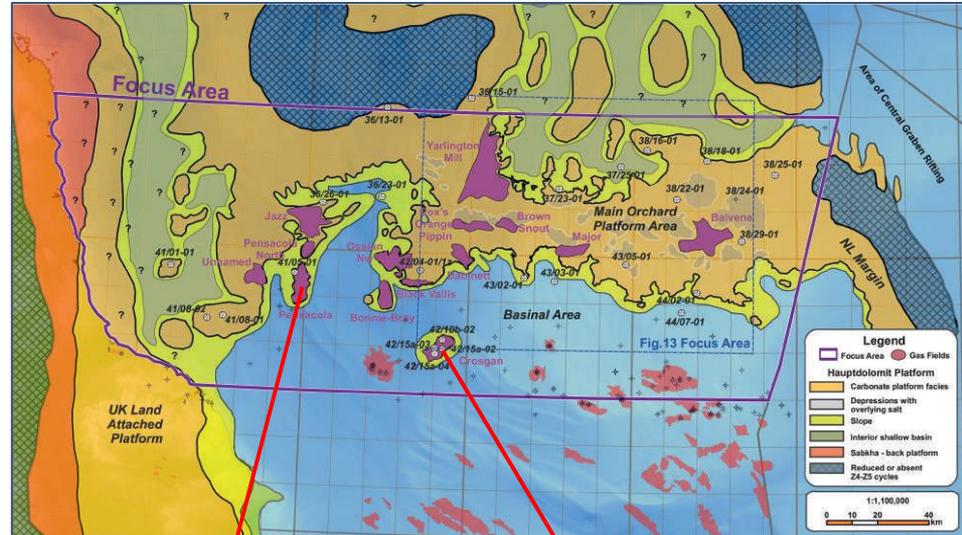
# Exploration for Natural Gas



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## ZEZ2C sub-play

- Zechstein 2 carbonate play in the UK
- Carbonate platforms along the Mid North Sea High
- Recent exploration successes



**Pensacola**  
8.4 BCM  
recoverable

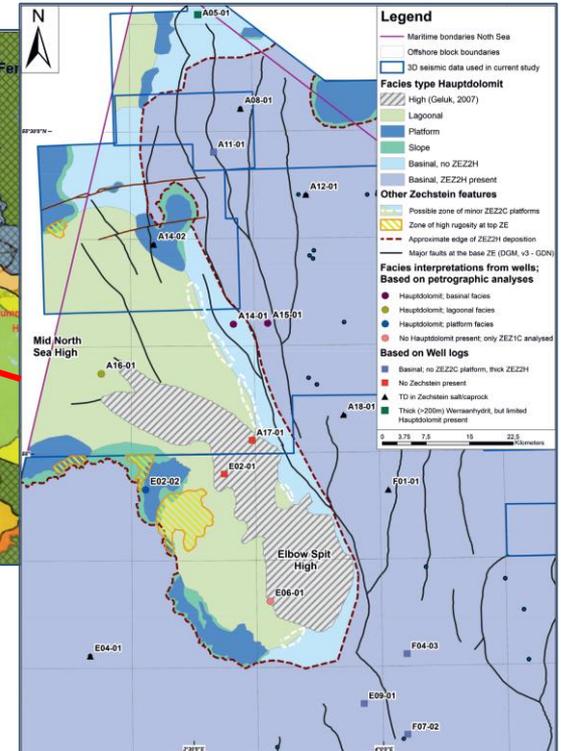
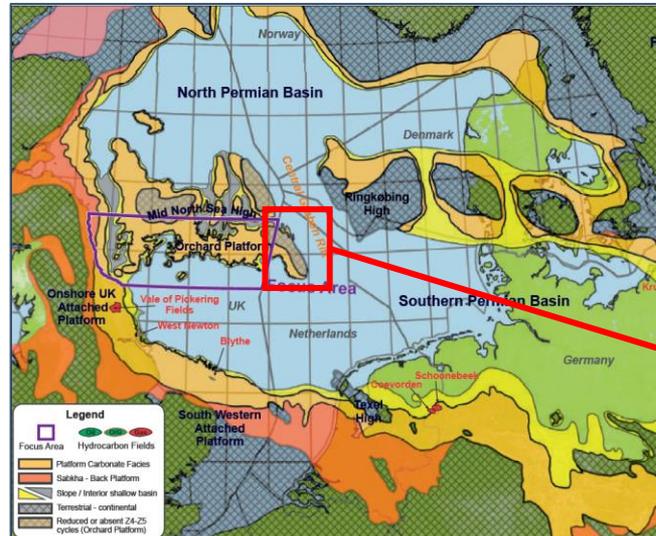
**Crosgan**

2023 Browning Stamp - Zechstein Z2 Hauptdolomite in UK Mid North Sea High

# Exploration for Natural Gas

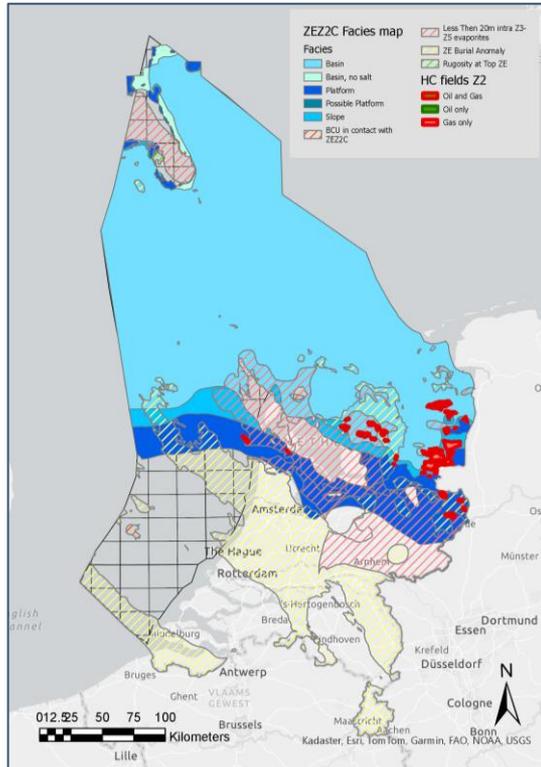
## ZEZ2C sub-play

- Play extends into northern Dutch offshore around the Elbow Spit High
- Area mapped in detail in TNO ZEPHYR study

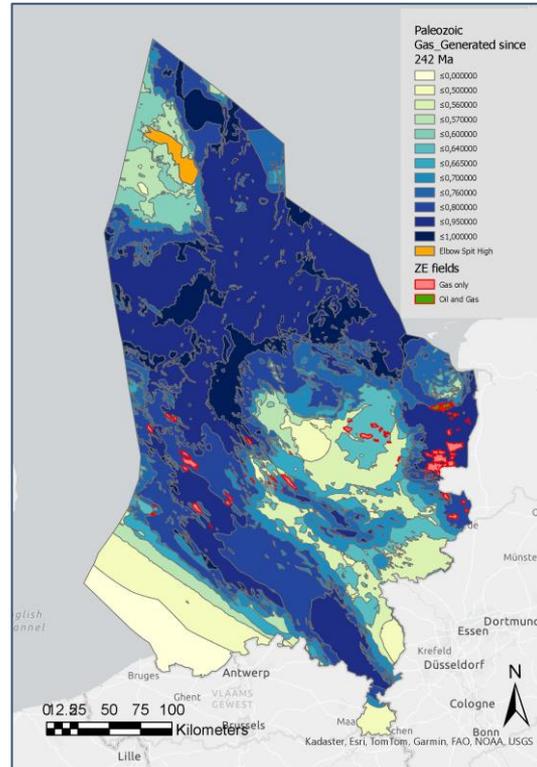


# Exploration for Natural Gas ZEZ2C sub-play

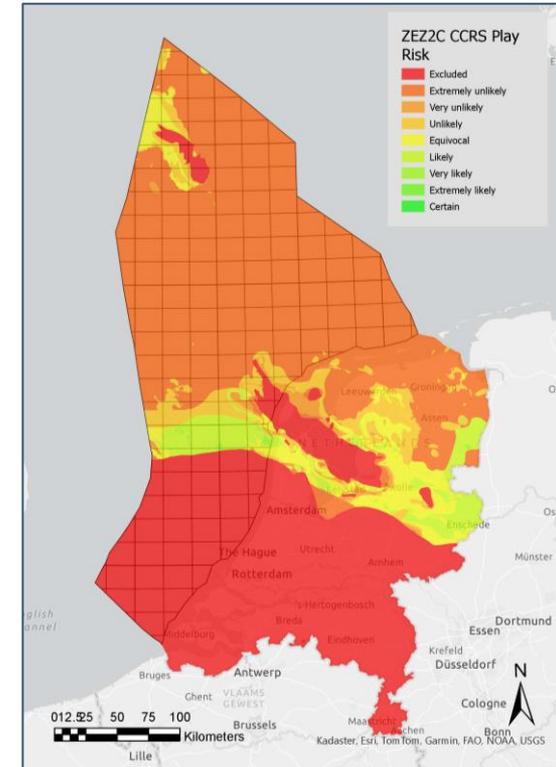
## ZEZ2C facies map



## Paleozoic gas generated since 242 Ma



## ZEZ2C CCRS map





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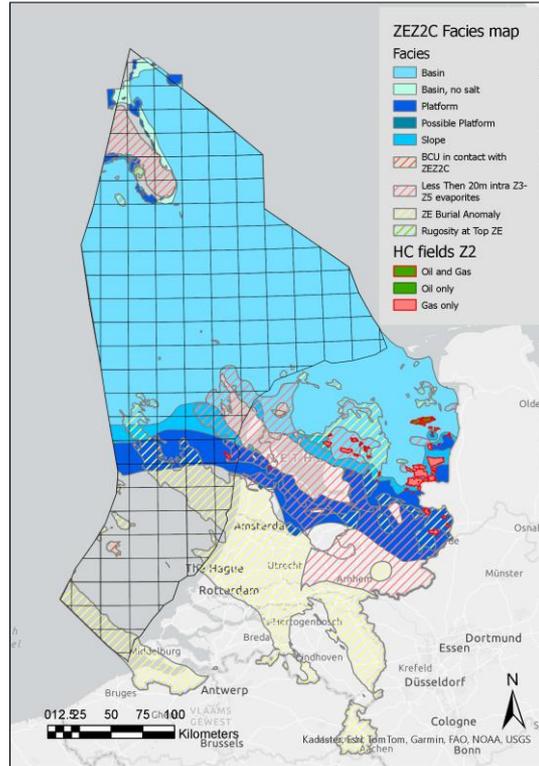
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**TNO**

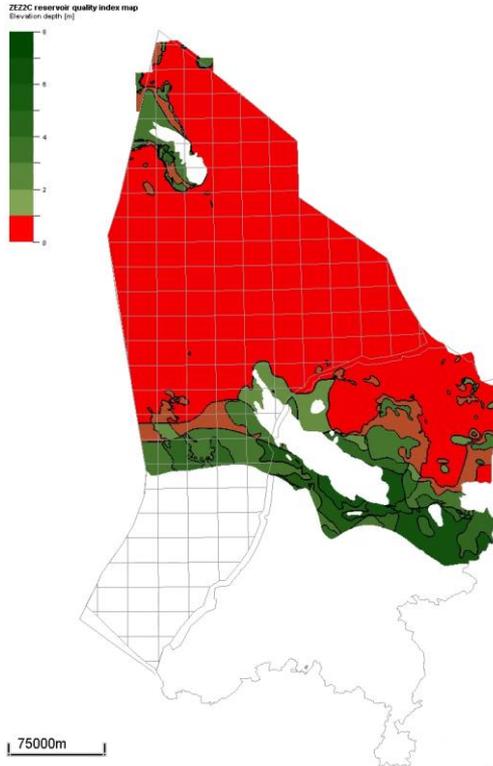
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# Zechstein carbonates

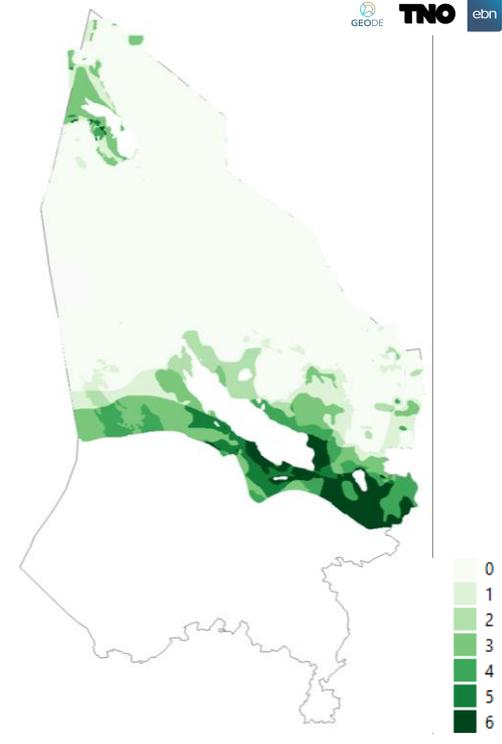
## Reservoir-quality index map



Facies map



Quality index map

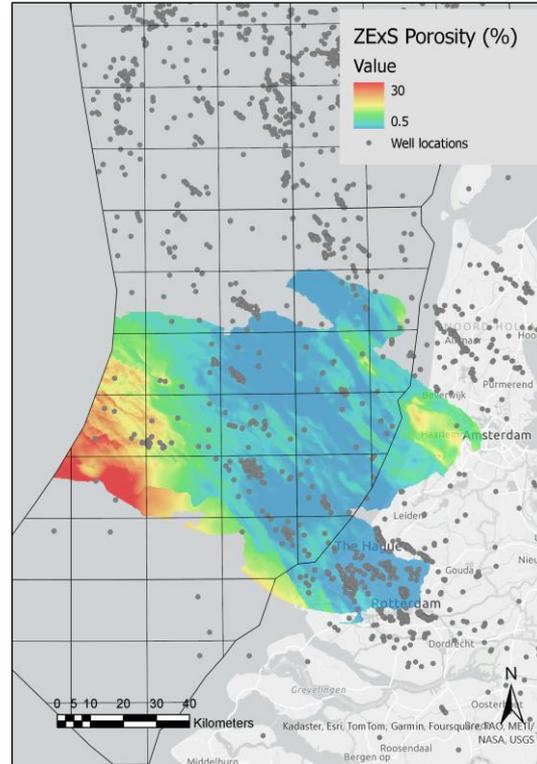


CRS input map

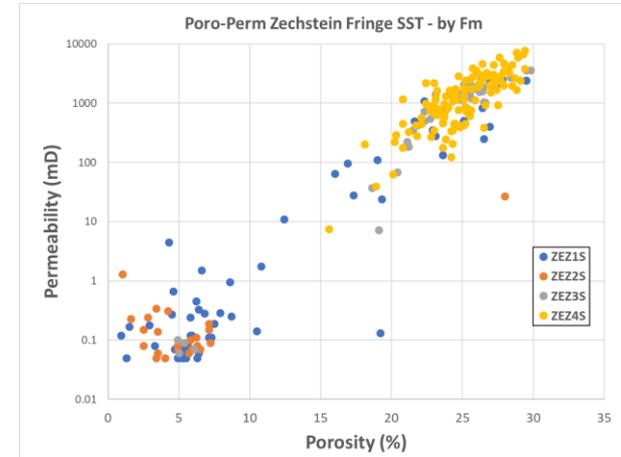
# CO<sub>2</sub> Storage in Saline Aquifers

## Zechstein Fringe Sandstones

- Sparse well data
- Deep burial in basin center
- ThermoGIS workflow



[www.geodeatlas.nl/pages/play-6-zechstein](http://www.geodeatlas.nl/pages/play-6-zechstein)



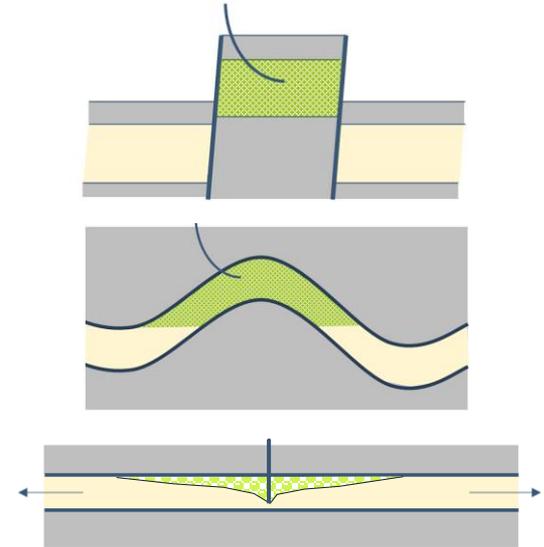
# How to calculate Capacity Density?

$$Q = A \cdot D \cdot \Phi \cdot \rho_{\text{CO}_2} \cdot E_{\text{st}}$$

A= Area aquifer, D=thickness of good reservoir rocks,  $\Phi$ =porosity,  $\rho_{\text{CO}_2}$  density of  $\text{CO}_2$ ,  $E_{\text{st}}$  = storage efficiency (<1)

(best practice for the storage of  $\text{CO}_2$  in saline aquifers SACS and  $\text{CO}_2$ STORE projects 2007)

- Is the aquifer Open, Semi-Closed or Closed
- **Closed** aquifer: Pressure constrained
- **Open** aquifer: Pressure can dissipate. Pore volume constrained
  
- **Closed aquifer:**
- $Q = A \cdot D \cdot \Phi \cdot (C_r + C_w) \cdot \Delta P \cdot \rho_{\text{CO}_2}$
  
- **Regional** versus **local** storage efficiency  
Calculating local storage efficiency requires *dynamic modelling*



# Storage Volume Calculation Closed Aquifer

$$Q = A \cdot D \cdot \Phi \cdot (C_r + C_w) \cdot \Delta P \cdot \rho_{CO_2}$$

Q= Storage Capacity

A: Area from GEODE maps

D: Thickness from Geode maps

$\Phi$ : Porosity from Geode maps

$C_r$ : Rock Compressibility

constant =  $9.1E-5$  (1/bar)

$C_w$ : Water Compressibility

constant =  $3.2E-5$  (1/bar)

$\Delta P$ : Pressure Space

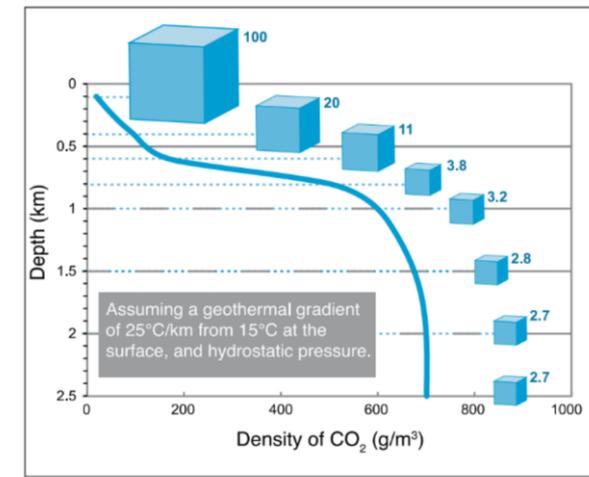
constant =  $0.035$  bar/m

$\rho_{CO_2}$ : Density  $CO_2$

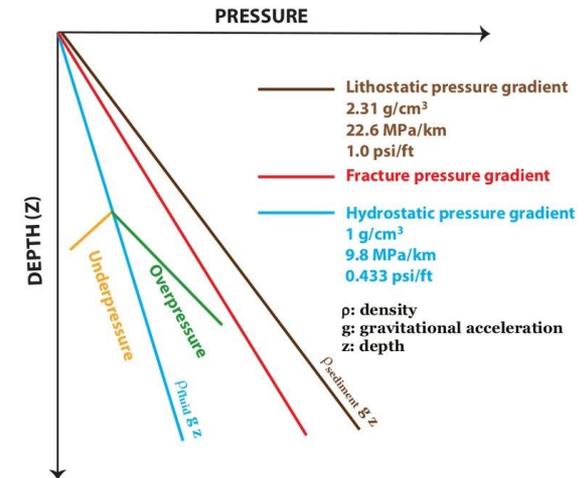
constant =  $700$  kg/m<sup>3</sup>

Storage Efficiency Factor  
 GEODE ( $E_{st}$ ) =  $(C_r + C_w) \cdot \Delta P$

Depth (m)	Efficiency Factor	$E_{st}$ (%)
1000	0.004	0.43
1500	0.006	0.65
2000	0.009	0.86
2500	0.011	1.08
3000	0.013	1.29
3500	0.015	1.51
4000	0.017	1.72



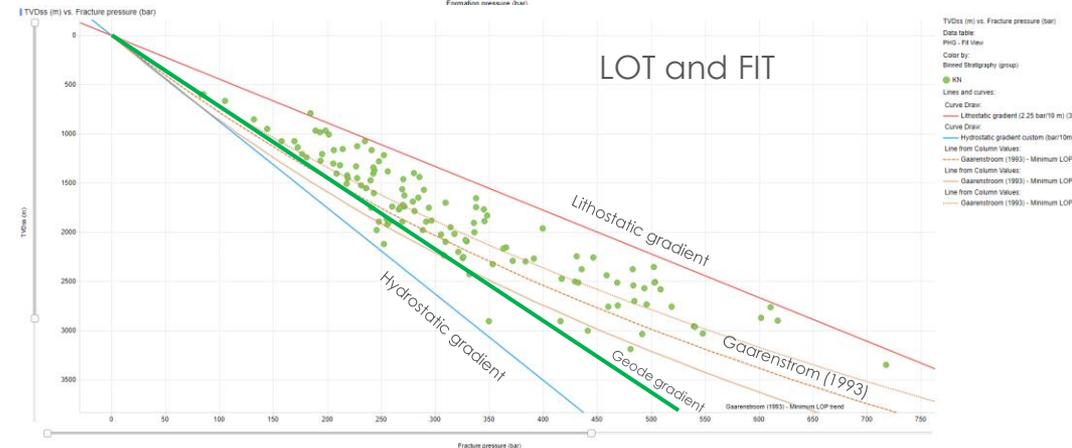
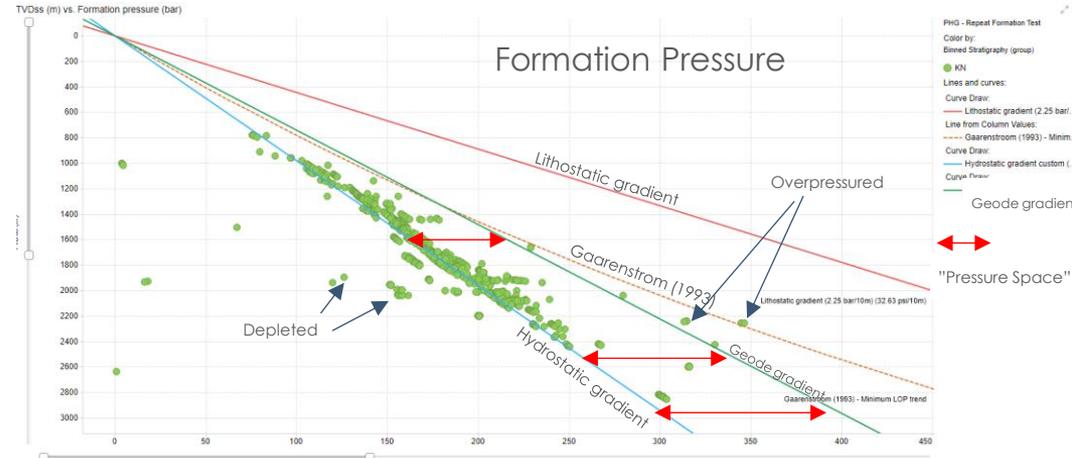
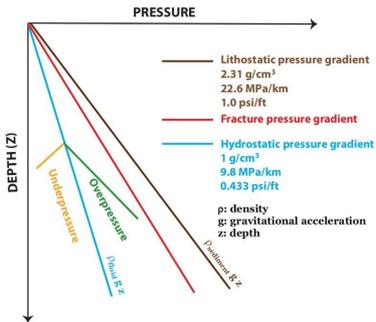
Depth vs density for  $CO_2$ . At depths greater than 800 m, ).



# “Pressure Space” from SNS pressure database (NLOG)



- CO2 storage will increase the formation pressure
- Stay below pressures that may cause leakage or seismicity
- Indication of fracture gradient from Leak-Off tests (LOT) and Formation Integrity Tests (FIT)
- Geode Pressure Space between hydrostatic and 1.035 bar/10m
- Overpressure reduces Pressure



# CO<sub>2</sub> Storage in Saline Aquifers

## Deliverables

1. Capacity Density Zechstein Fringe Sandstones
2. Kh Zechstein Fringe sandstones (as proxy for injectivity)
3. Capacity Density x Kh Fringe Sandstone (sweet spots for CCS)
4. Hydrocarbon shows
5. Overpressure maps
6. Faults, legacy wells, Seal quality



# Underground Hydrogen Storage in Salt Diapirs

## Deliverables

1. Depth (Top and Base Salt map)
2. Thickness
3. Salt structure shapes
4. Temperature
5. Pressure
6. Stress field
7. Faults
8. Salt heterogeneity
9. Factsheets per salt body



# Exploration for Natural Gas

## Key deliverables

- Thickness
- **Porosity/permeability Fringe Sandstones**
- **Reservoir quality maps ZE2 & ZE3 Carbonates**
- GDE maps
- Post-drill Well Analysis
- **CRS and CCRS maps**





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