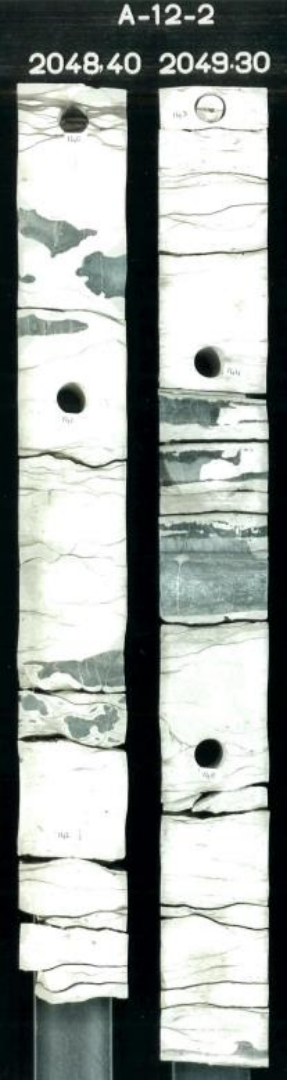
ATLAS TO EXPLORE HYDROCARBON OPPORTUNITIES IN THE DUTCH OFFSHORE

UPPER CRETACEOUS PLAY



Upper Cretaceous Play

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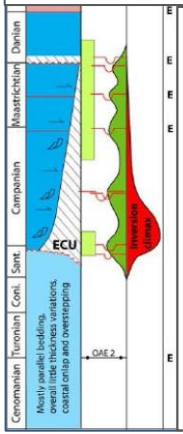
TNO ebn Energising the transition

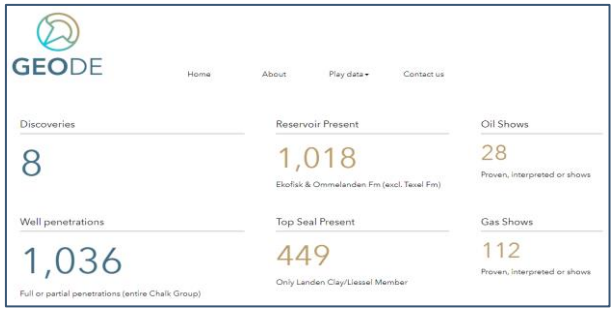
The Chalk Play Definitions

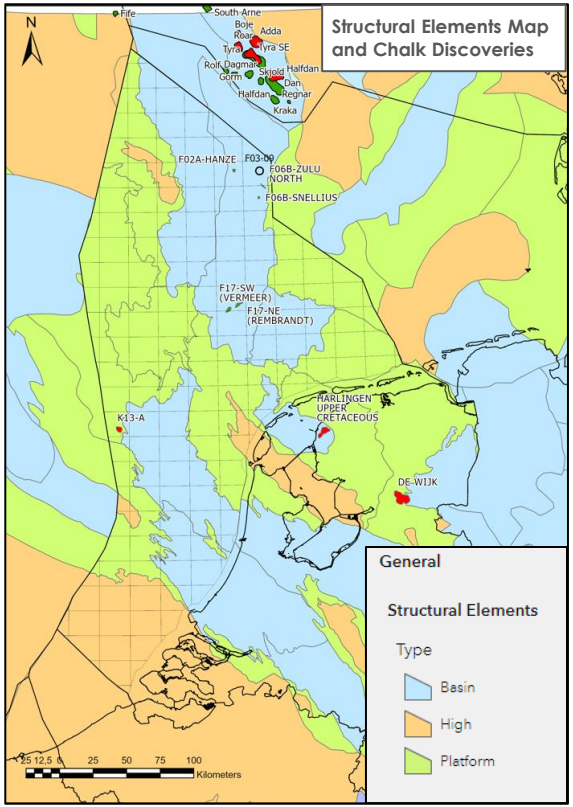
Limited success in the Netherlands

North Sea Group	Liessel Mbr.	Seal
Chalk Group	Ekofisk Fm.	Reservoir
	Ommelanden Fm.	
	Texel Fm.	Seal?



Modified from 2018 van Buchem et al.



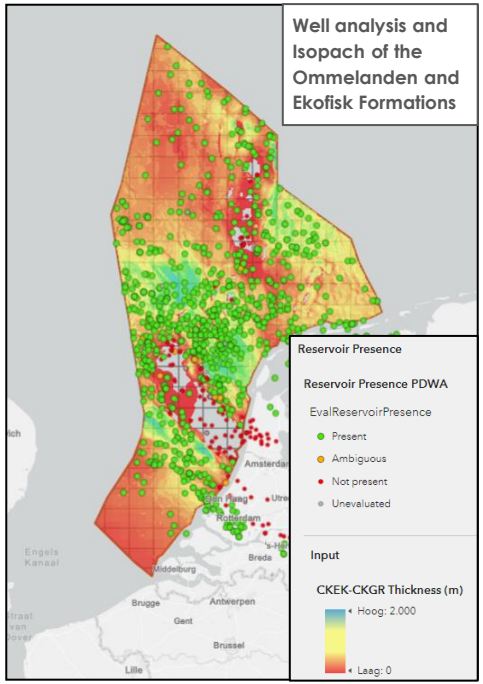


Source: 2012 Kombrink et al. and 2010 Doornenbal & Stevenson

- The reservoir seal pair is the Ekofisk/Ommelanden and the Liessel Member (the former Landen Clay Member).
- The main charge is coming from the Carboniferous coals, Posidonia and the Middle Graben Formation.
- The Chalk has been divided in two plays:
  - Oil Play (based on the Hanze Field and multiple discoveries)
  - Gas Play (based on the Harlingen Field)

Reservoir Presence and Risking Workflow

Thickness map CKEK + CKGR



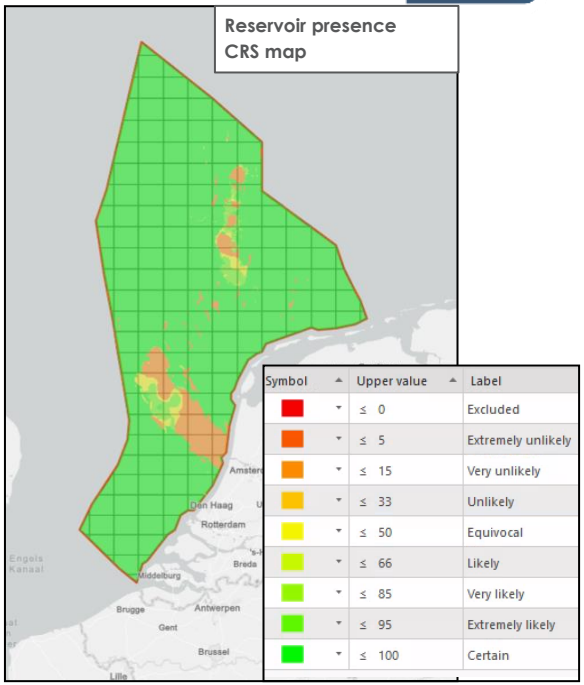
Input data map

&

Chalk play type	Reservoir Presence component	POS	Comments
Oil play + gas play	CKEK + CKGR Thickness	%	
	Absent [= 0 m]	10	Uncertainty due to local variation and inaccuracies in mapping boundaries
	Ambiguous [0 – 5 m]	50	Uncertainty due to local thickness variation
	Present [>5 m]	100	continuous, thick chalk interval present.

Note: All risking tables are available in Geode for the Chalk Play

& Boundaries and risk weigthing



Resulting in a Common Risk Segment (CRS) map

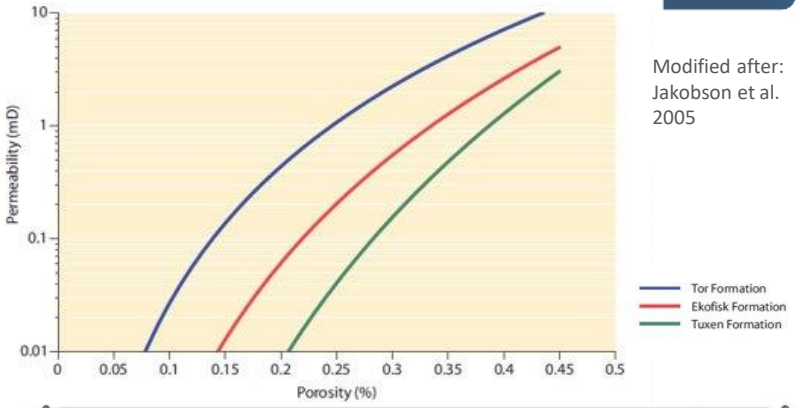
Reservoir Effectiveness for the Chalk

Approach to determine reservoir effectiveness

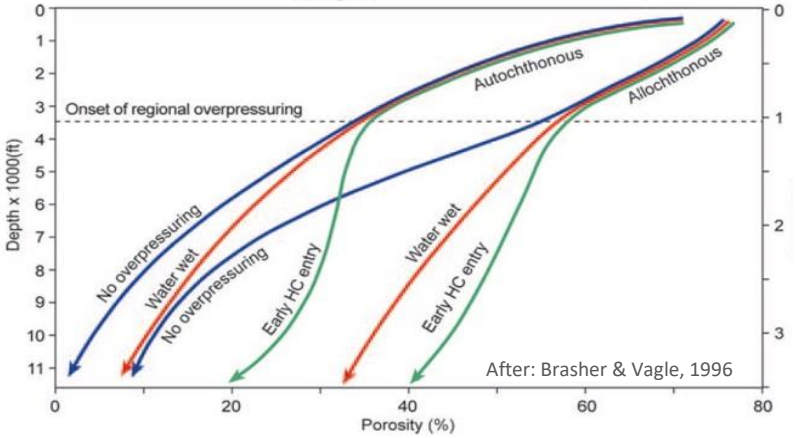
- The Chalk has typical high porosity (25-35%) and low permeability (0-5 mD)

- Reservoir effectiveness is determined by:
  - Burial depth
  - Overpressure
  - Early Charge
  - Autochthonous/Allochthonous facies
  - Natural fracture networks

- For Reservoir effectiveness mapping:
  - Early charge was lumped under charge
  - Autochthonous/Allochthonous facies used to determine min and max ranges reservoirs are still effective in Burial depth. (Can be further worked on prospect scale)

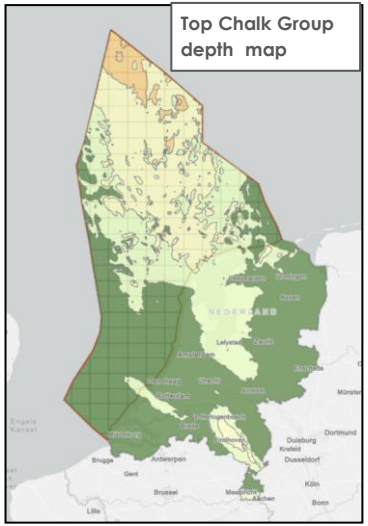


Modified after: Jakobson et al. 2005



Reservoir effectiveness For the Oil Play

Data input maps and resulting CRS map



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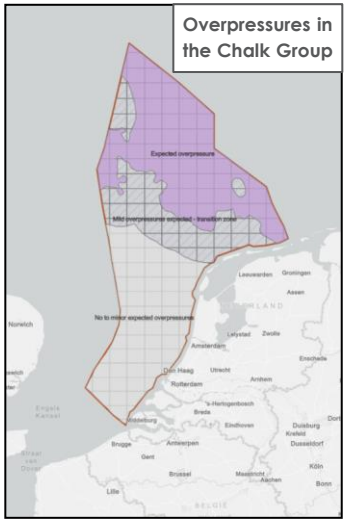

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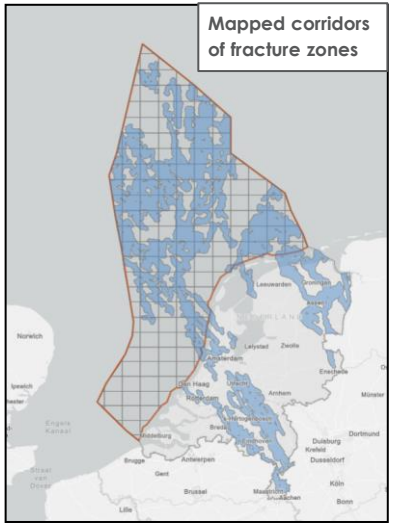
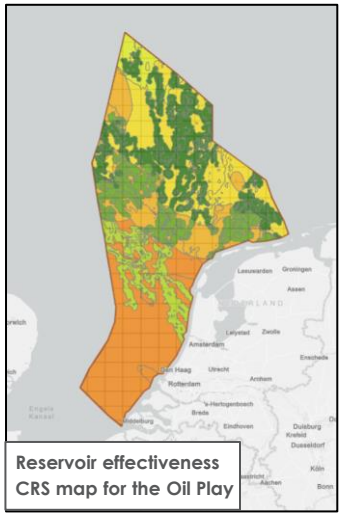


+ Risking =



Top Chalk Group depth map with colour display high lightening the selected boundaries

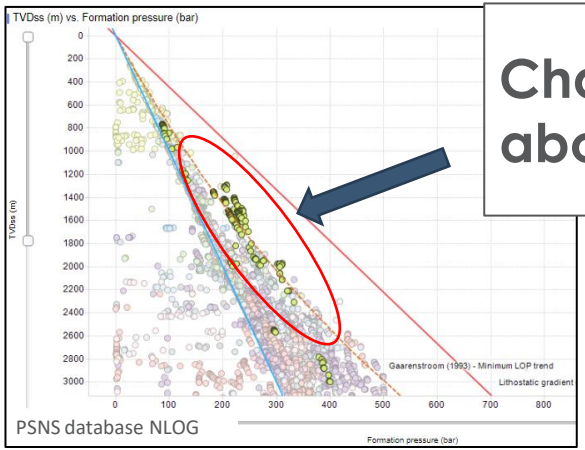
Overpressure mapping using Velmod4b and calibration with the SNS pressure database

Mapped fracture systems using slope analysis of maps calibrated with discoveries

Reservoir effectiveness CRS map for the Oil Play

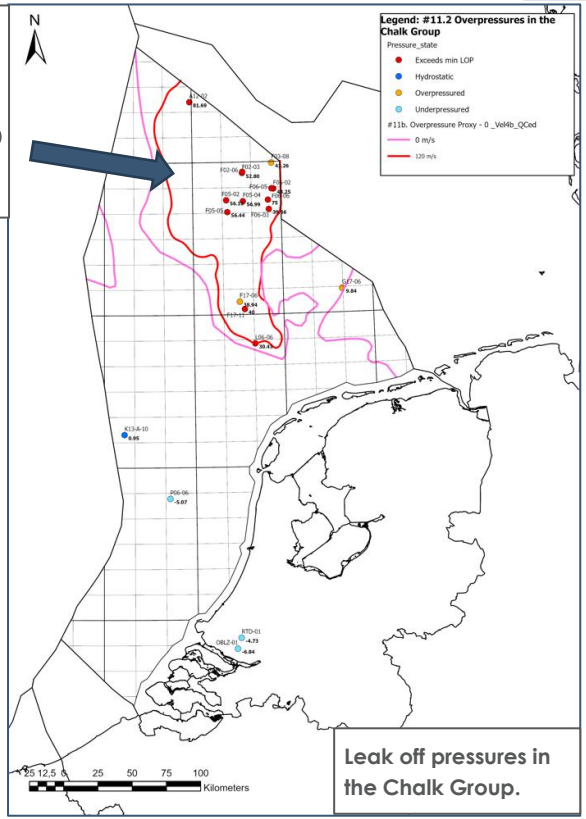
Seal Effectiveness and Leak Off Pressures

High overpressures reduces the sealing capacity



Chalk pressures above the minimum LOP

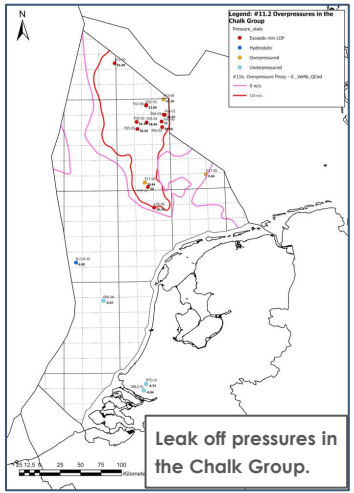
- A large group of Chalk pressures is close or above the minimum Leak Of Pressure (LOP)
- This creates a "leaky" seal system, where gas and condensate is leaking into the overburden and oil is only partially retained
- In such a system underfilled traps (downside) but also the presence of protected traps (upside) can be expected



Leak off pressures in the Chalk Group.

Seal Effectiveness Gas Play

Data input maps and resulting CRS map



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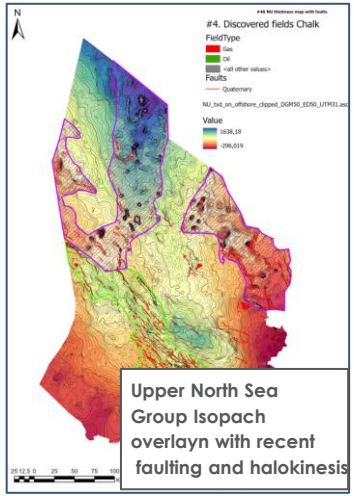

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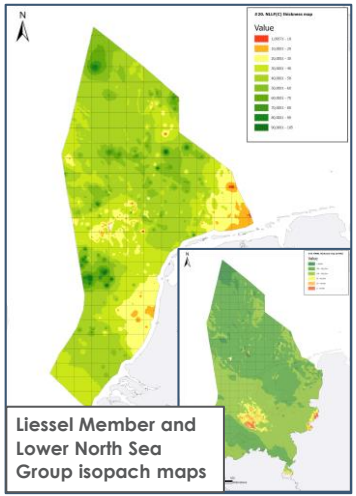
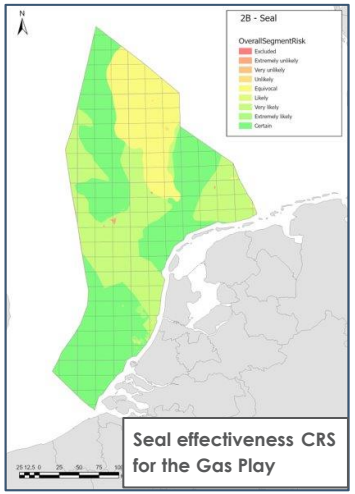


+ Risking =



Overpressure map highlighting the area where the LOP exceeds the fracture gradient

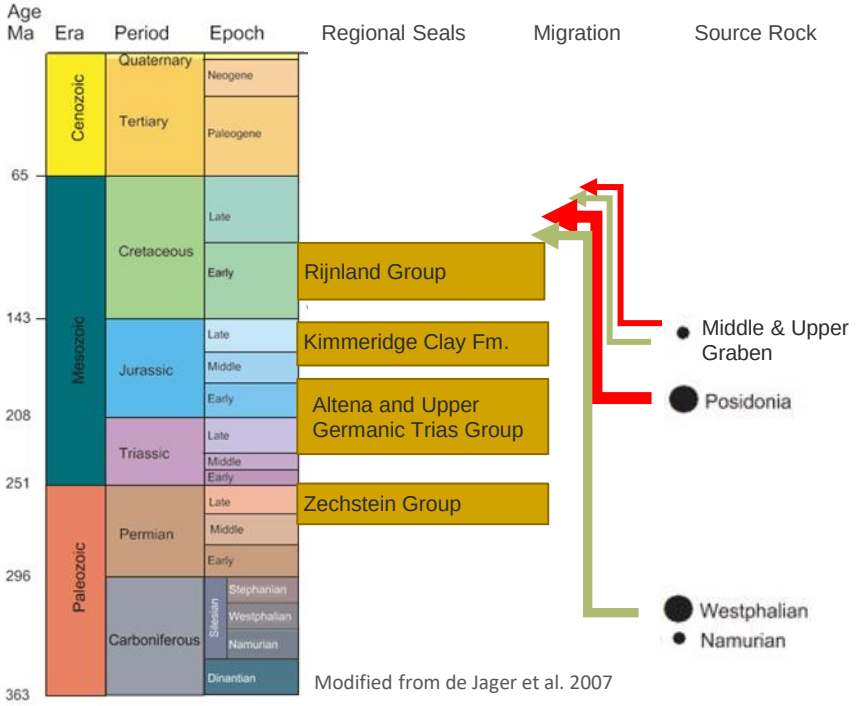
Fault density maps are based on Neogene faulting and recent (Miocene - Holocene) halokinesis

Thickness maps and well data of the Liesel Member and the Lower North Sea Group were used as input

Seal effectiveness CRS map for the Gas Play

Charge and Migration model

Multiple marine clays and halite seals are present, hampering migration

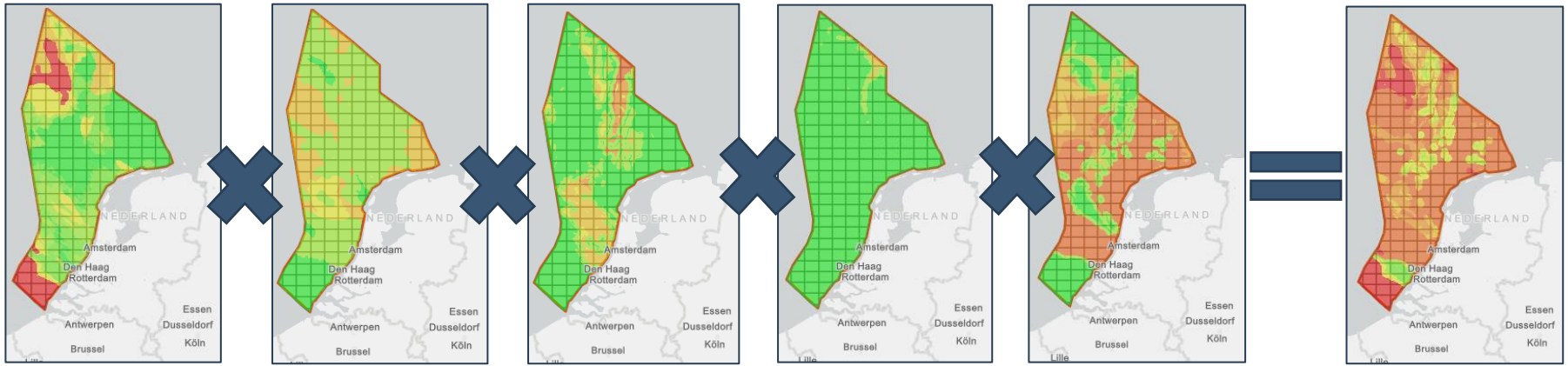


Modified from de Jager et al. 2007

- 4 large regional seals are being recognised in the offshore stratigraphy
- Besides the well known Posidonia and Carboniferous source rocks the Middle Graben formation has also been included as an oil and gas source rock

Vertical migration DC to CK for the Gas Play

Multiple sealing formations limit the change of gas reaching a chalk structure



Carboniferous **Charge CRS**

Zechstein Gp. **Migration CRS** (including large faults and sills)

U. Triassic Gp. and Altena Gp. **Migration CRS**

Kimmeridge Clay Fm. **Migration CRS**

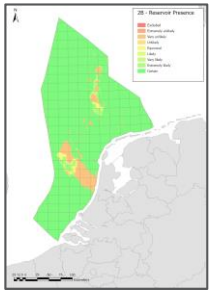
Rijnland Gp. **Migration CRS**

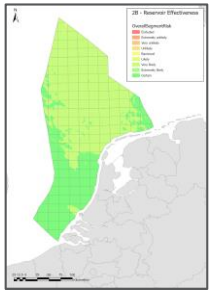
Carboniferous Gas **Charge & Migration CRS**

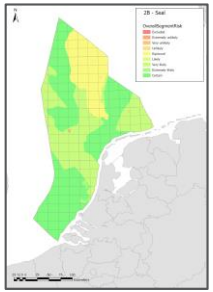
- Note that especially the Rijnland Group is a large barrier for migration into the Chalk Group
- Total gas charge might be a bit better as some gas is expected to come from the Middle Graben Formation

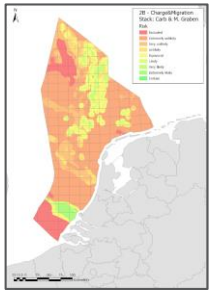
CCRS calculation

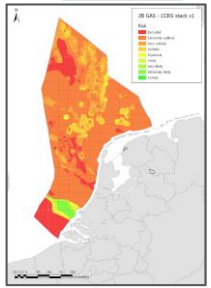
Chalk Gas Play "Stack"


Reservoir presence

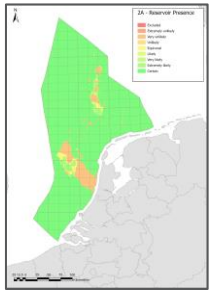

Reservoir Effectiveness

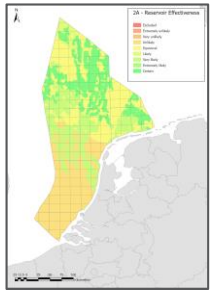

Seal Effectiveness

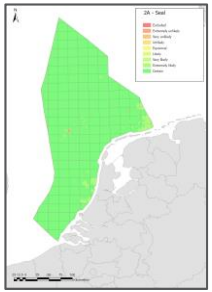

Charge & migration

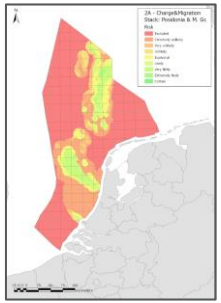

Combined Common Risk Segment (CCSR) map

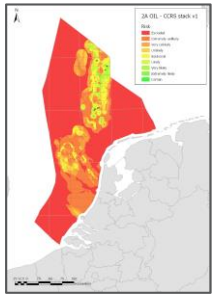
Chalk Oil Play "Stack"


Reservoir presence


Reservoir Effectiveness


Seal Effectiveness

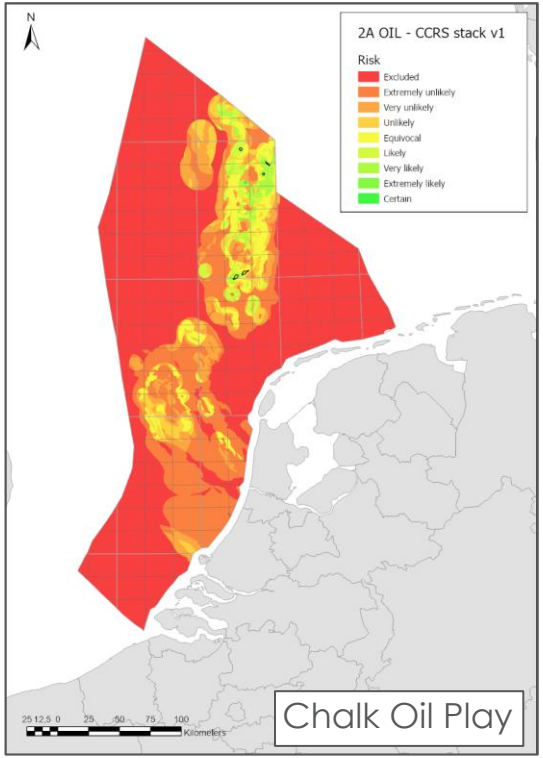

Charge & migration


Combined Common Risk Segment (CCSR) map

- Note that especially charge & migration are the limiting play element in the Chalk Group

CCRS Maps for both the Oil and Gas Play

Where are the prospective areas?

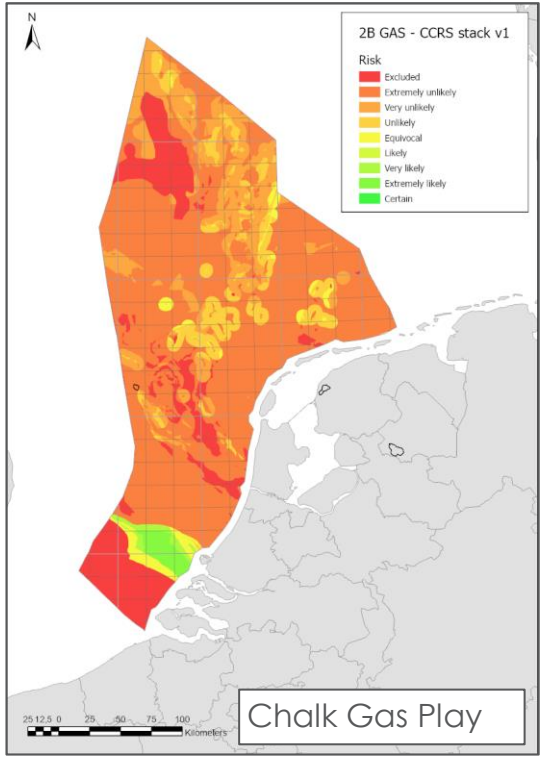


Chalk Oil Play

- All oil discoveries plot in the green segments in the Central Graben area.
- The Central Graben is most prospective
- Some possibility of succes exists in the Broad Fourteen Basin
- In other areas there is no known oil charge taking place, basically excluding these segments

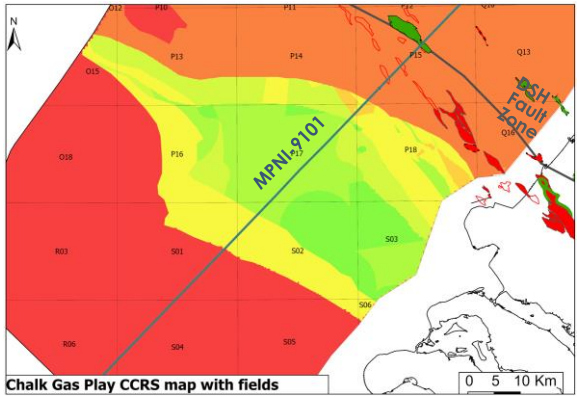
Chalk Gas Play

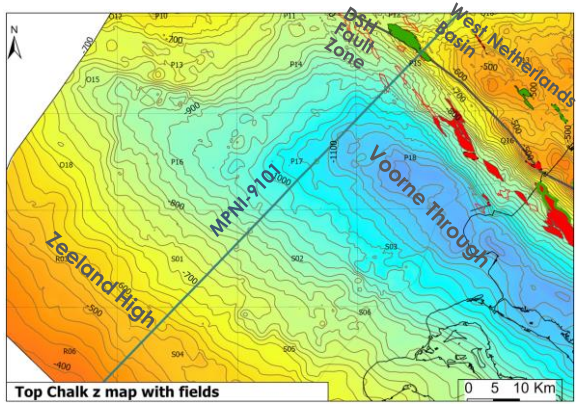
- There is still a large area with a small possibility of finding gas (like the K13A discovery).
- Unexpected outcome is the sweetspot around the Voorne Graben

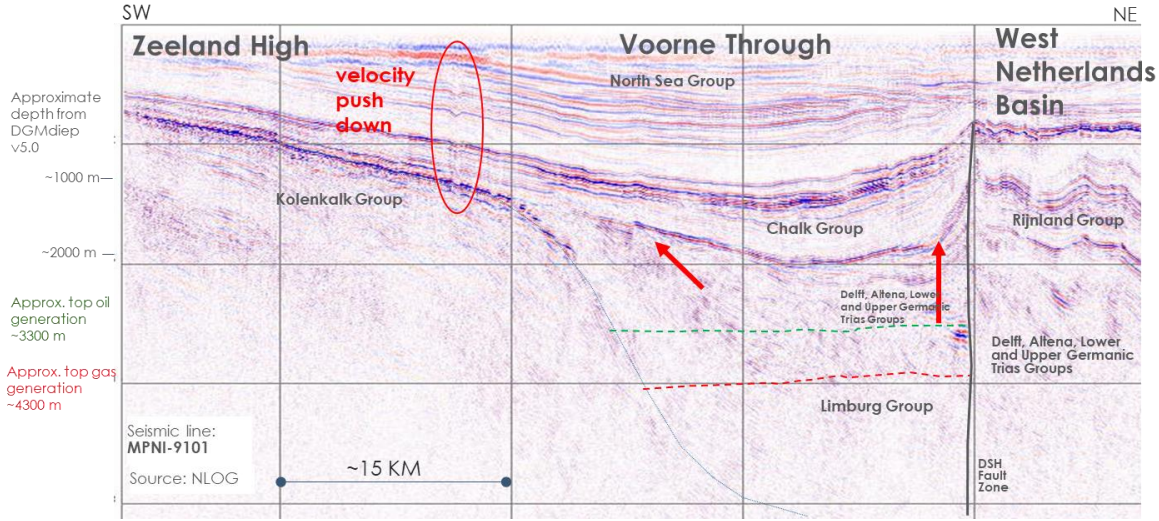


Regional seismic line MPNI-9101

Direct connection between the Limburg and the Chalk Gp





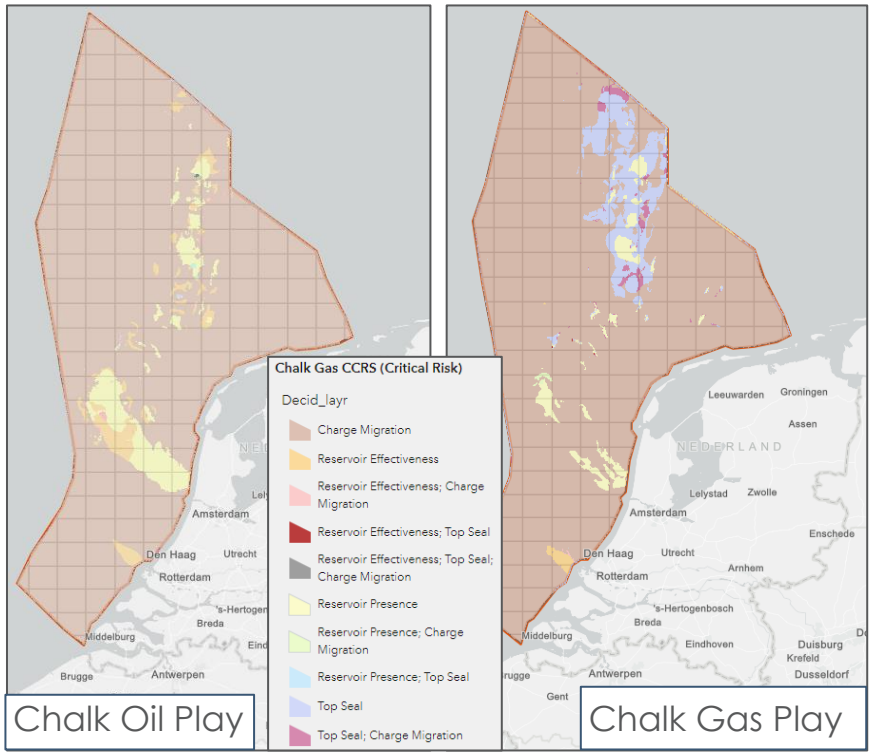


- Mature Carboniferous is directly charging into the Chalk Group
- Velocity push down indirect indicator of gas presence
- But.. limited structuration offshore, although maps are a bit rough.
- Pinch out structures of the Dongen sands above the Chalk Group on the Zeeland High? Is there more structuration onshore?

Conclusions on the Chalk Play

- Key succes factor for exploration in the Chalk Oil and Gas plays is access to Charge and Migration
- The high overpressures in the Central Graben creates a "leaky" petroleum system with limited oil column heights and a protected trap system
- The main prospective area for oil is in the Central Graben with some local possibilities of succes in the Broad Fourteen Basin
- Over nearly the whole Dutch Offshore there is a small change of finding gas in the Chalk
- The main prospective area for gas is the sweetspot around the Voorne Graben, although a lack of structuration might hamper further discoveries

Weakest Element Maps for the Chalk plays



Reservoir Effectiveness for the Chalk

Approach to determine reservoir effectiveness

- **The Chalk has typical high porosity (25-35%) and low permeability (0-5 mD)**
- **Three factors were used for reservoir effectiveness mapping (after Brasher & Vagle, 1996):**
  - Porosity / permeability by burial depth
  - Porosity / permeability preservation by overpressure
  - Natural fractures network to enhance permeability (for the oil play)
- **For other factors:**
  - Early charge was lumped under charge
  - Allochthonous / autochthonous facies used to determine ranges (see figure)
- **Best/worst case scenarios are used to determine the depth ranges for oil and gas**

Determining Reservoir effectiveness boundaries for oil and gas