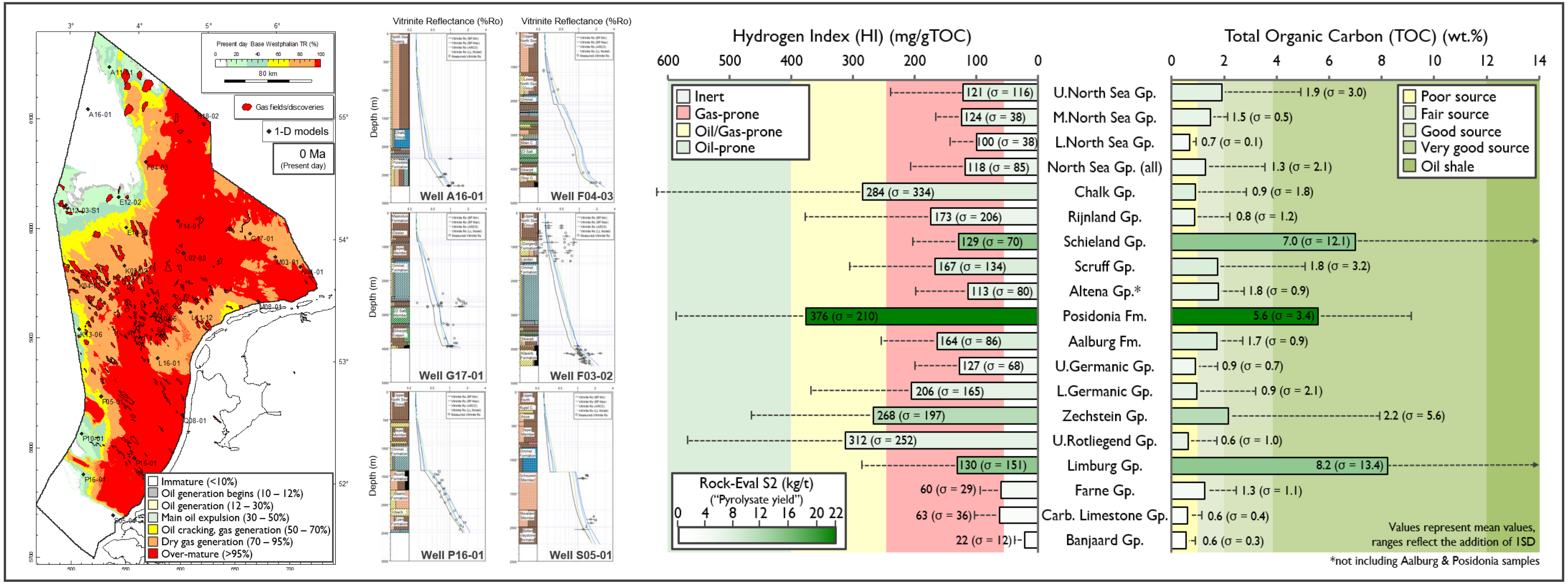
Regional petroleum systems modelling in the Dutch offshore

A "hot" topic of conversation



David Gardiner[1], Linda Janssen[2],

Tiago Cunha[1] & Kees van Ojik[2]

[1]IGI Ltd.
[2]EBN B.V.

Presentation courtesy of:

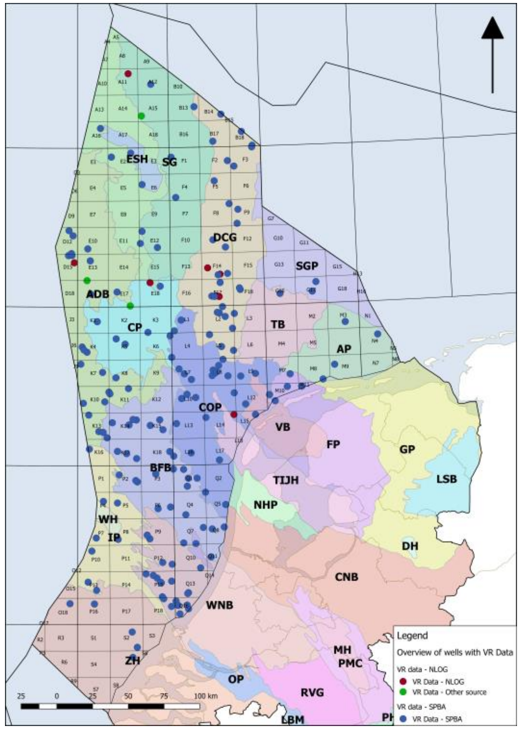
2019 Dutch Exploration Day
Wednesday 20th November

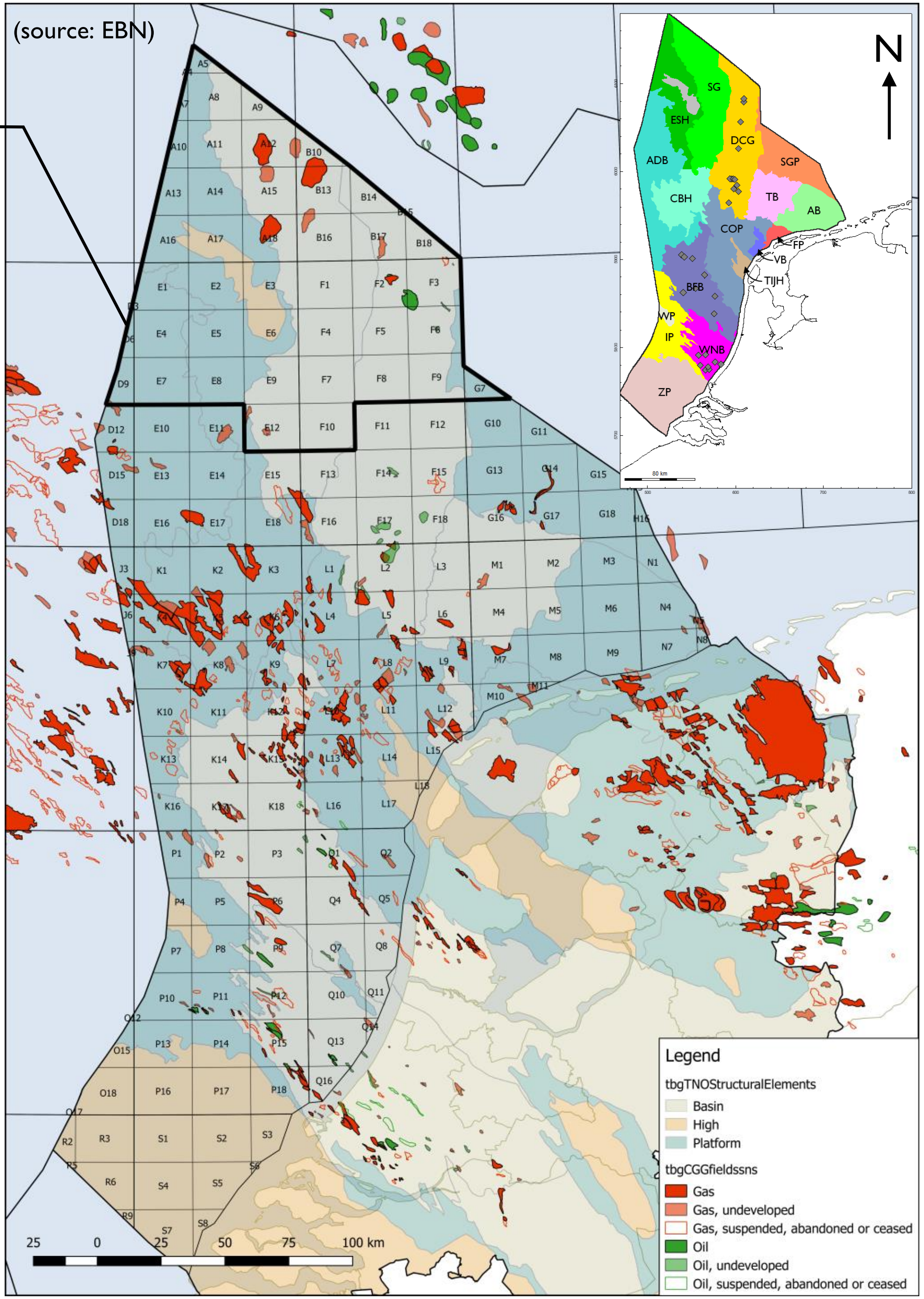
Overview

What will we cover?

- Overview of petroleum systems
- Source rock richness & kerogen type
- Maturity calibration – getting an eye into the past
- Integrated 3-D petroleum systems model
- Summary

The 57,000 km^2 AOI of the entire Dutch offshore. Note: the distribution of gas fields





Petroleum System

Summary of existing knowledge

Source rocks

Jurassic: Kimmeridge Clay Fm., **Posidonia**, Aalburg Fm., Sleen Fm.

Carboniferous: **Westphalian coal**, Namurian shales, Visean coals

Reservoirs

Cretaceous: Chalk Gp., Lower Cretaceous turbidites, Vlieland sand

Jurassic: **Upper & Lower Graben Fms**., Kimmeridgian sands

Triassic: Bundandstein sandstone

Permian: Zechstein Gp. (e.g. Z3 carbonates), **Upper Rotliegend Gp.**

Carboniferous: Tubbergen Sandstone

Stratigraphic seals

Cenozoic: Paleogene muds

Cretaceous: Chalk Gp., **Lower Cretaceous shales**

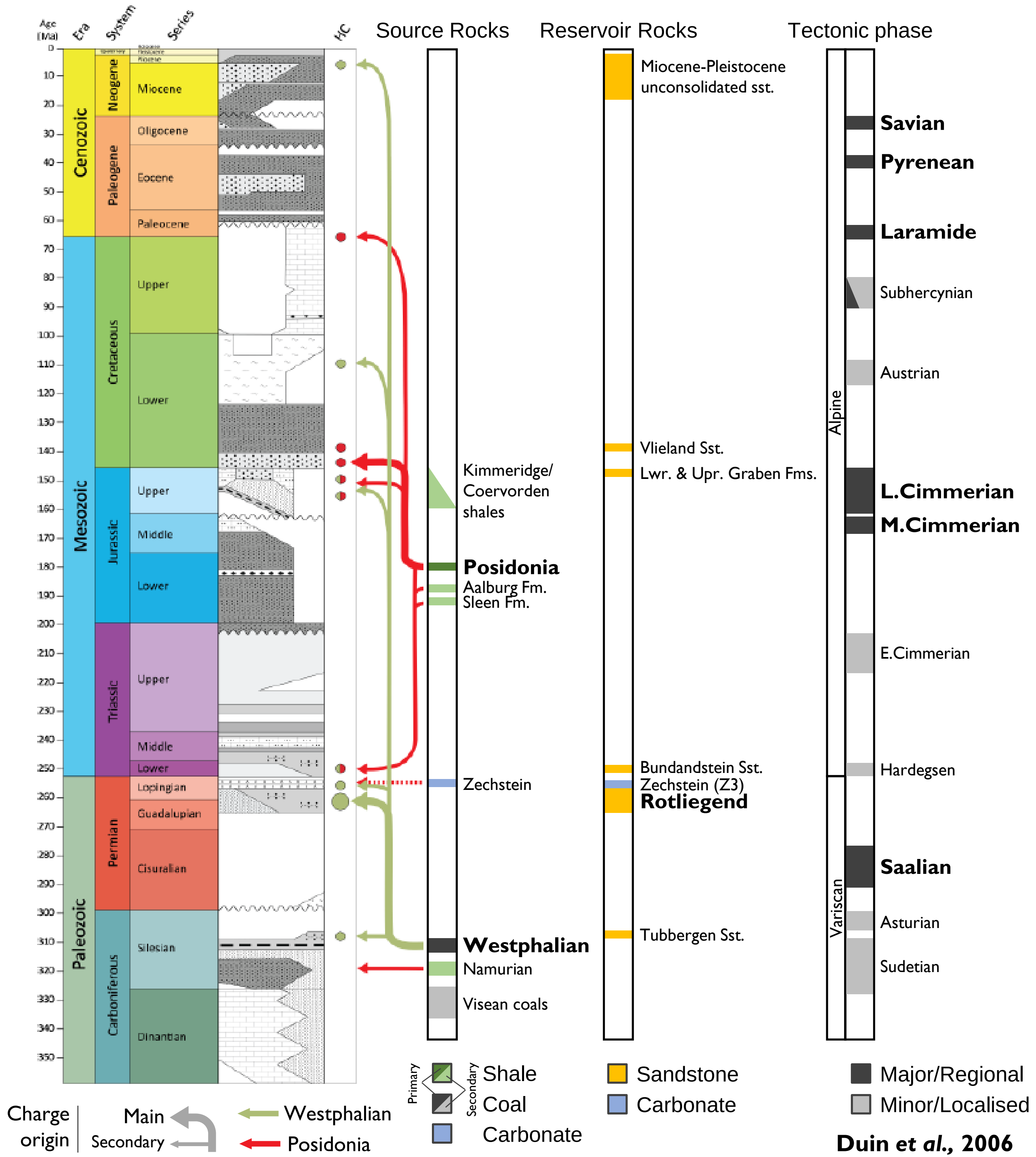
Jurassic: Kimmeridge Clay Fm.

Permian: **Zechstein Gp. evaporites**

Two main petroleum systems:

1) Paleozoic (Westphalian → Rotliegend)
2) Mesozoic (Posidonia → Lwr./Upr. Graben Fms.)

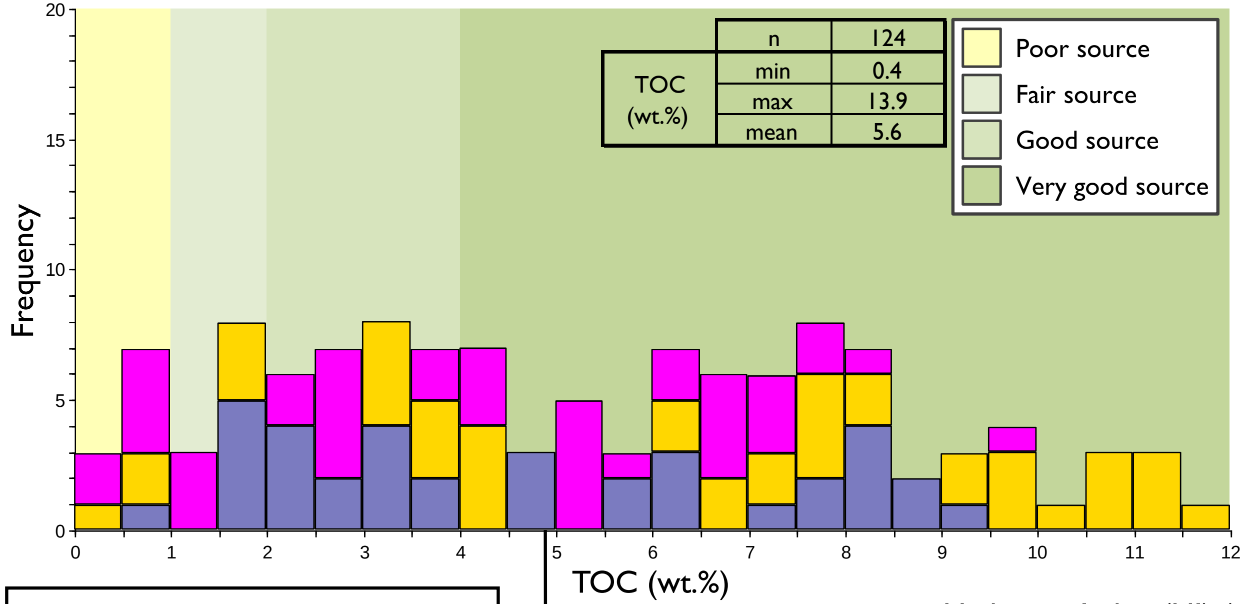
Major erosive unconformities



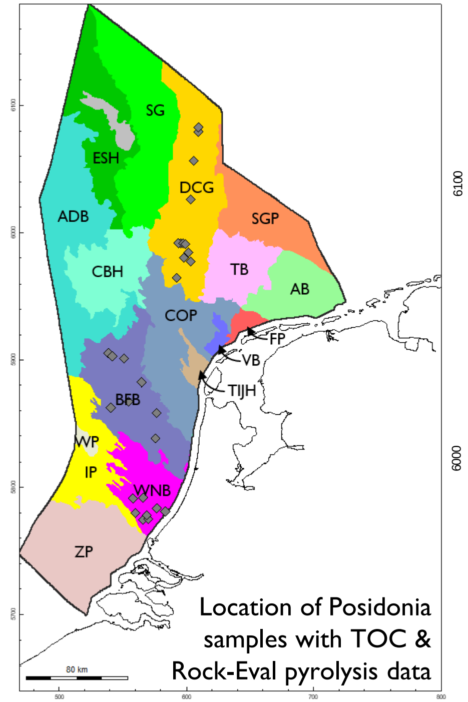
Duin et al., 2006

Posidonia Shale

Source rock summary

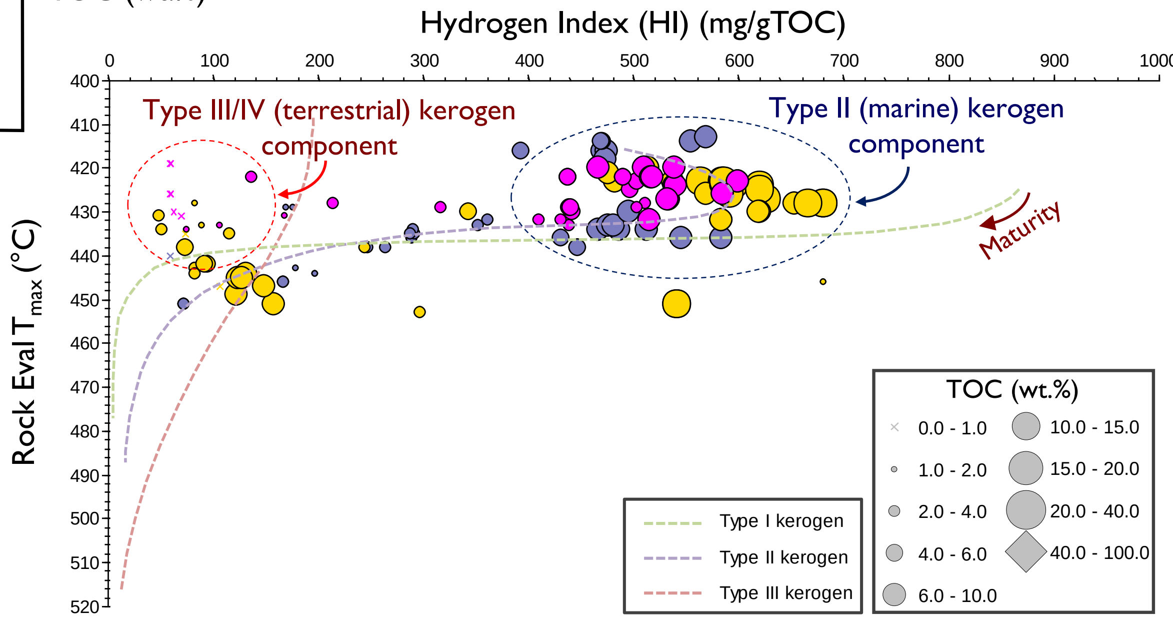


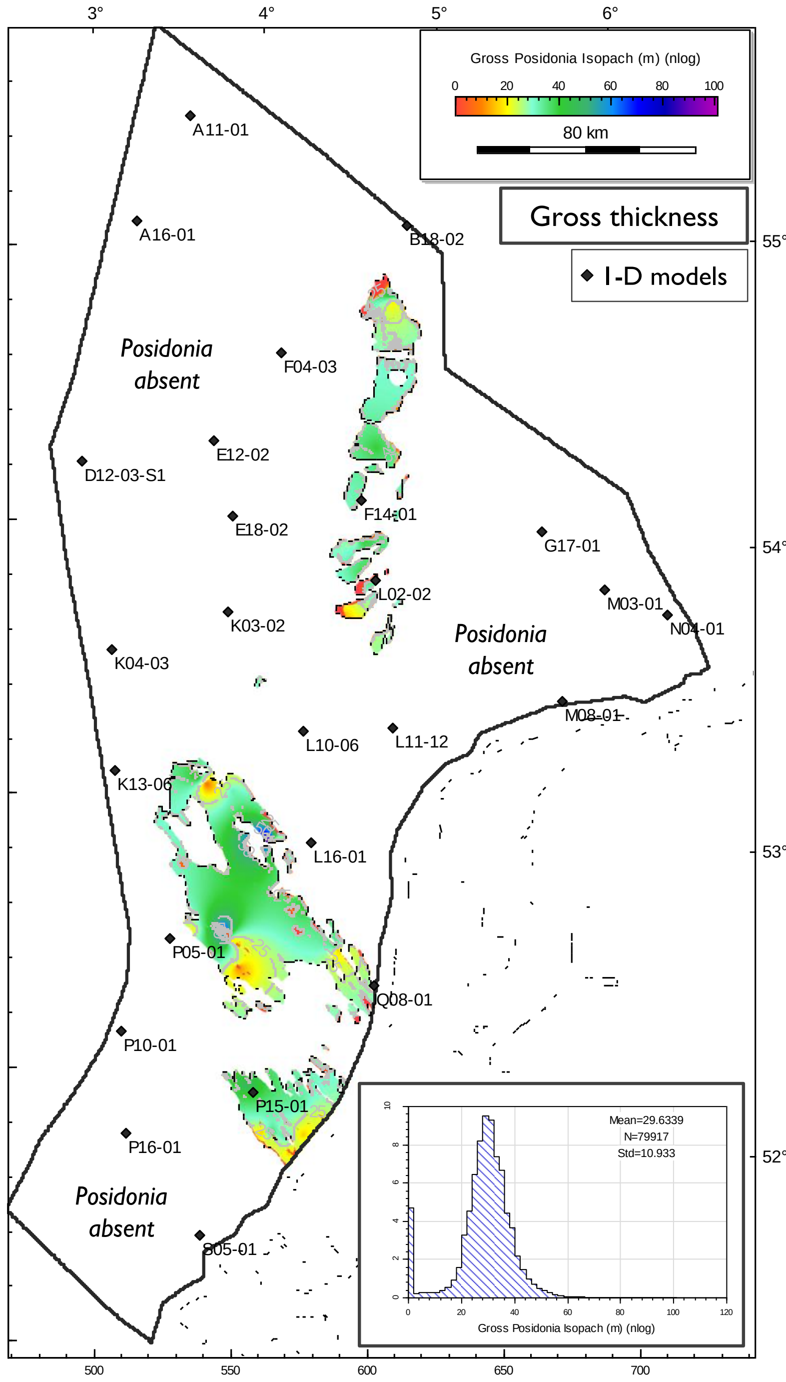
TOC (wt.%)		
	n	124
	min	0.4
	max	13.9
	mean	5.6



Bi-modal distribution, relative homogeneity and mean TOC of 5.6 wt.% typical of world-class source rock

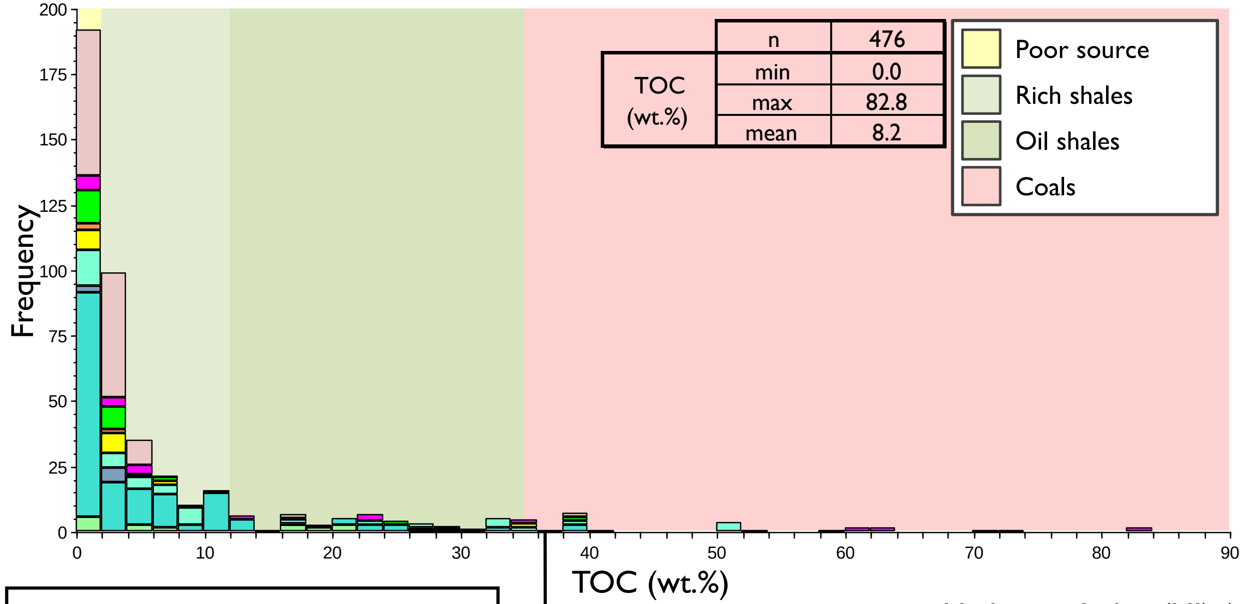
The Posidonia shale is thin and only locally present, but highly organic-rich and oil-prone

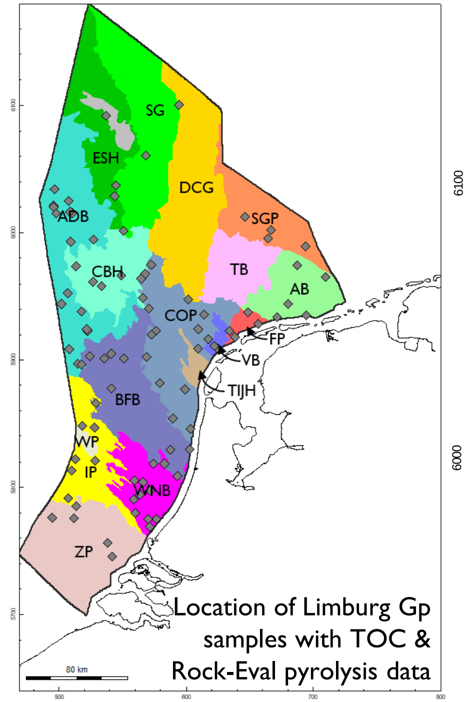




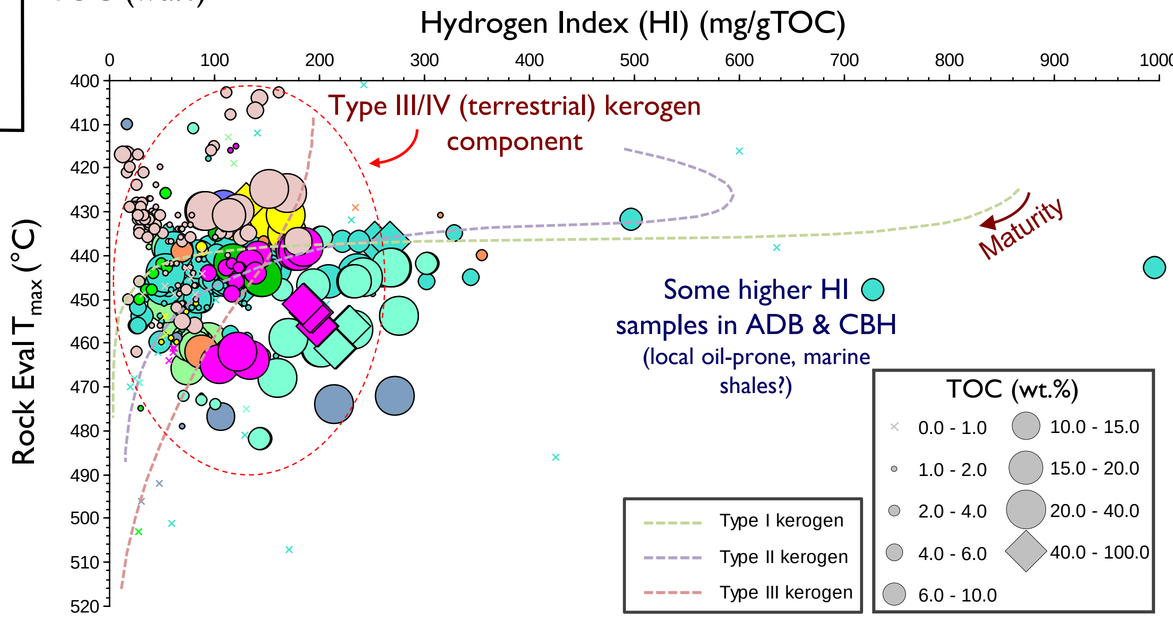
Westphalian coals (Limburg Gp)

Source rock summary

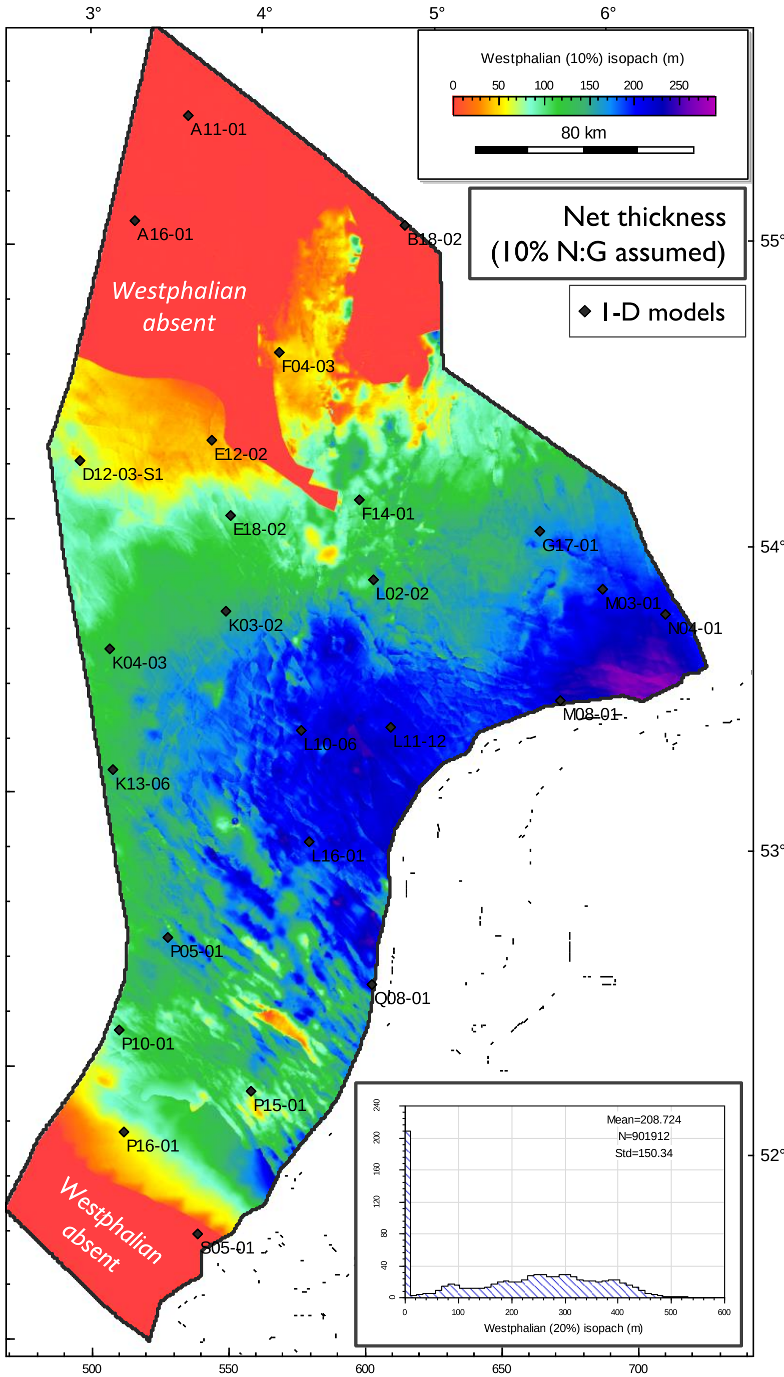




Highly heterogeneous clastic system with coals (regionally) and organic-rich shales (locally in ADB & CBH)

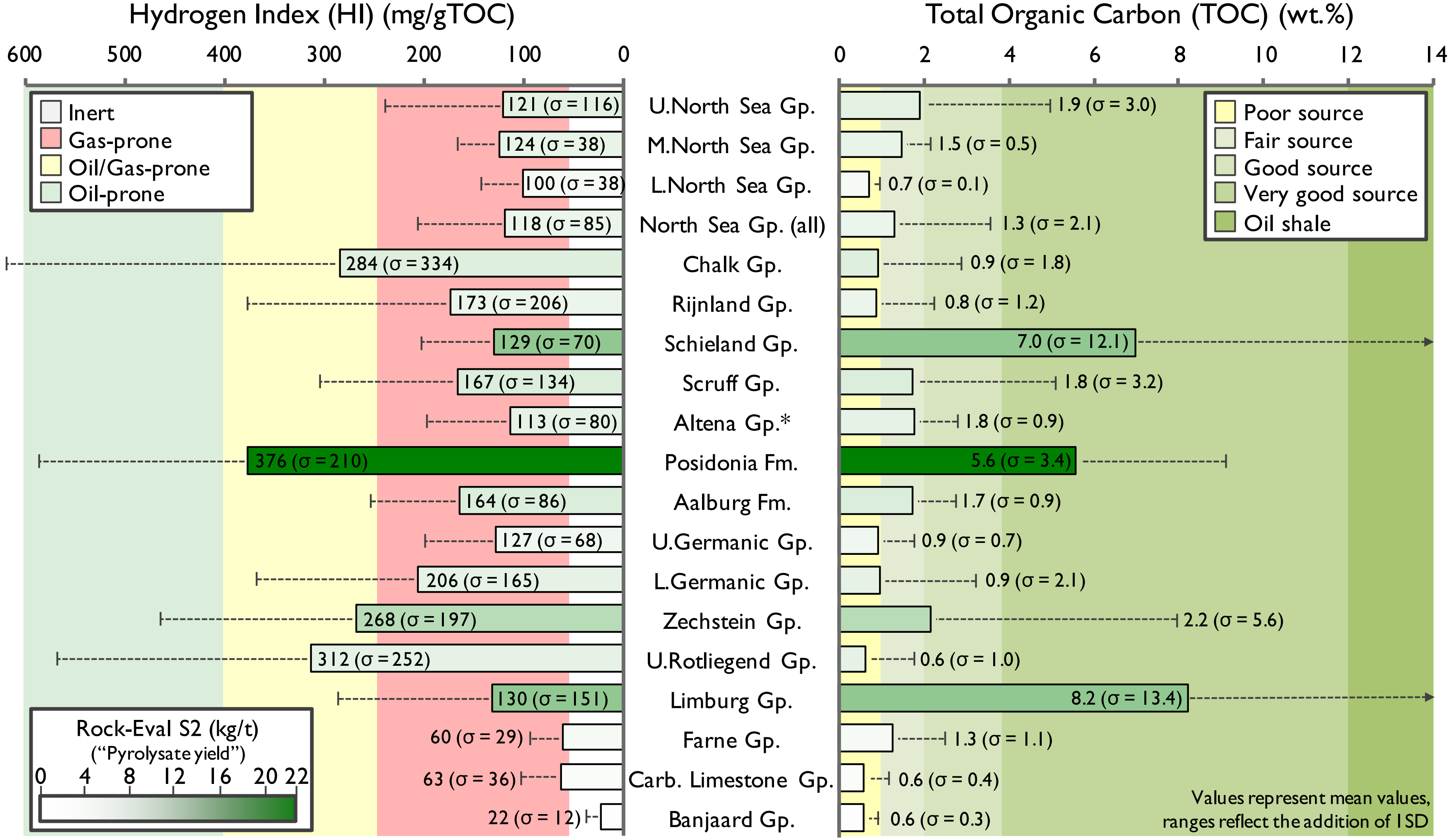


The Westphalian is thick and regionally extensive, with mainly gas-prone, terrestrial kerogen



Summary of source rocks offshore

Tornado plot

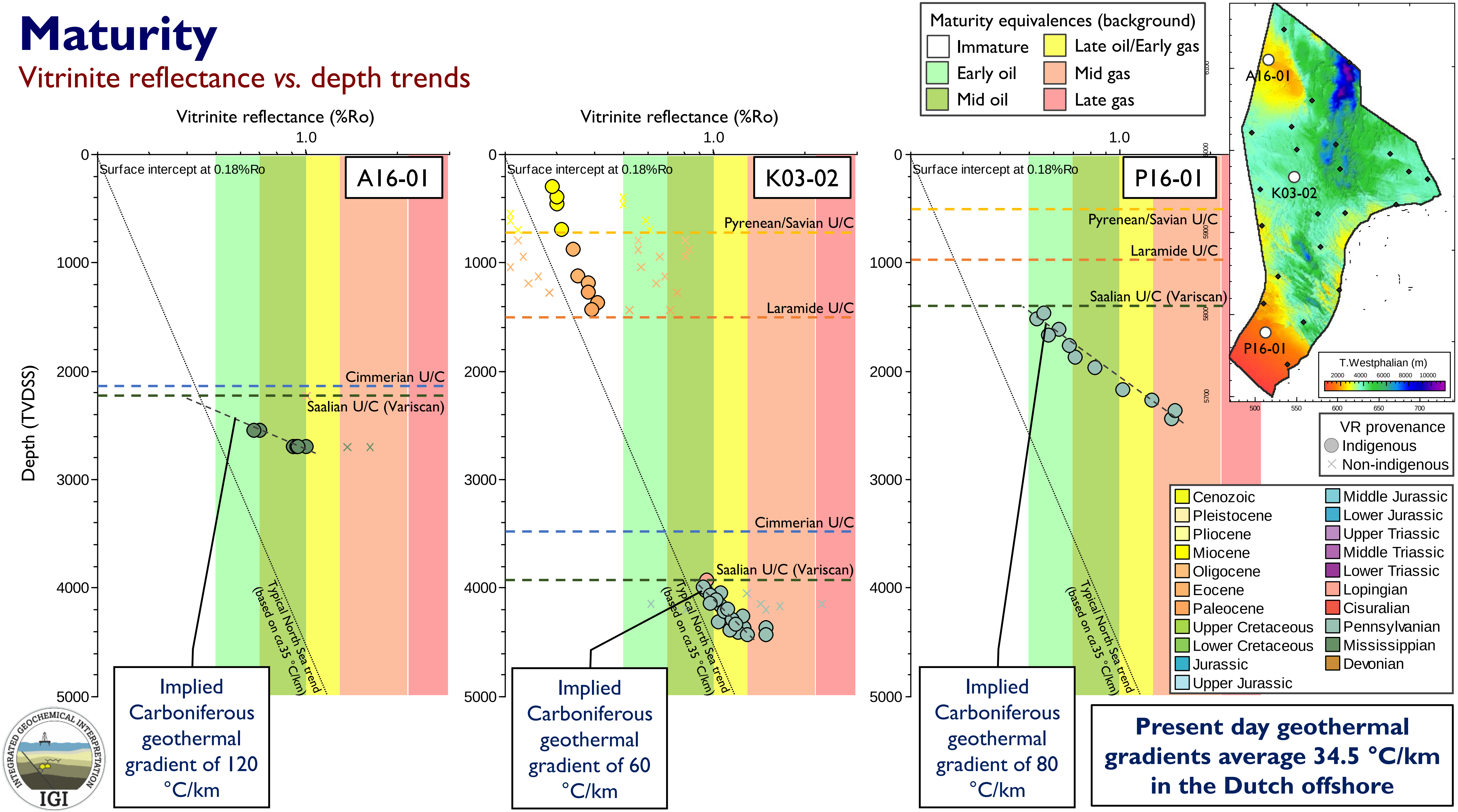


*not including Aalburg & Posidonia samples

The Toarcian Posidonia shales and Pennsylvanian Limburg Gp. coals represent the best source rocks in the Dutch offshore, although localized potential exists in other units (e.g. Zechstein, Kupferschiefer & Lwr. Cretaceous shales of the Schieland Gp.)

Maturity

Vitrinite reflectance *vs.* depth trends

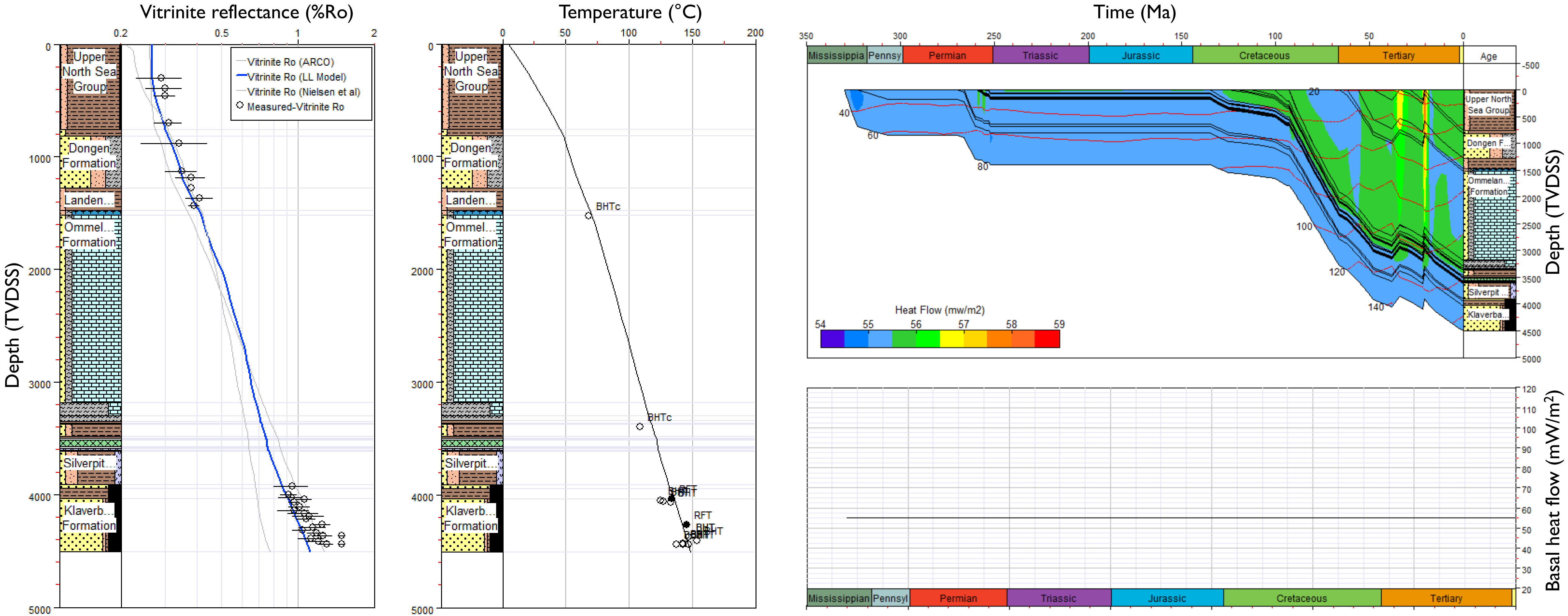


Present day geothermal gradients average 34.5 °C/km in the Dutch offshore

Maturity

Vitrinite reflectance *vs.* depth trends

Scenario 1: Constant Basal HF through time, no Saalian/Cimmerian erosion



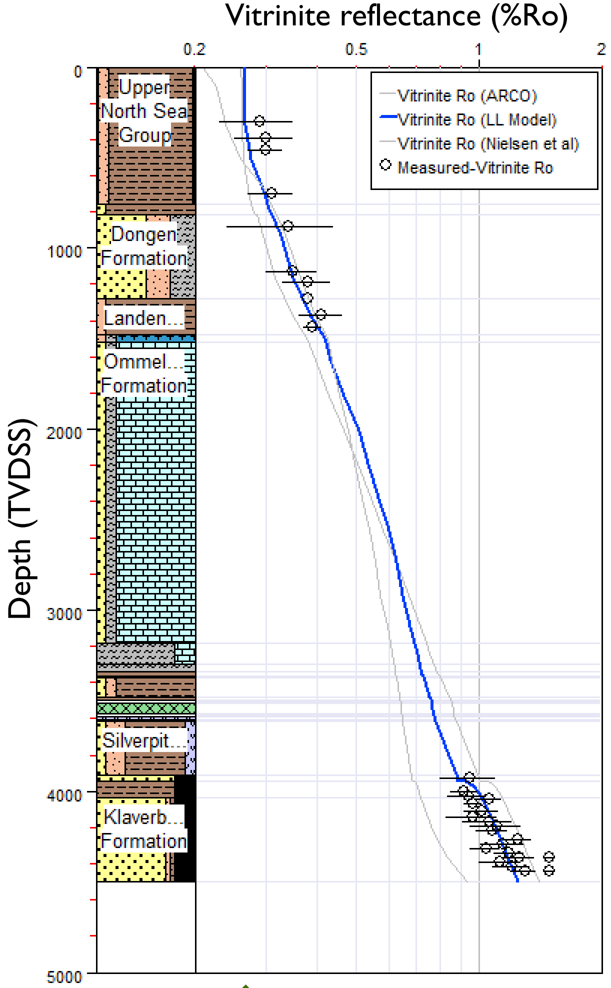
- Good calibration to temperature, poor to vitrinite reflectance
- ❌ Geologically unrealistic (no erosion at unconformities and constant HF)
- ❌ Paleozoic maturity gradient not captured

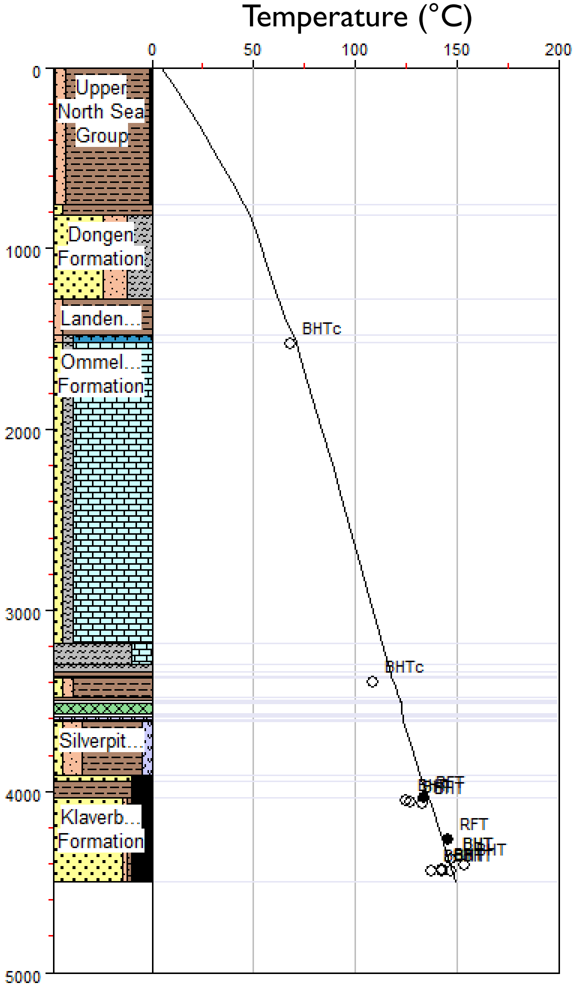
Present geothermal gradient:	33.0 °C/km
Present day surface heat flow:	56.0 mW/m^2
Peak palaeo basal heat flow:	56.0 mW/m^2 (constant)

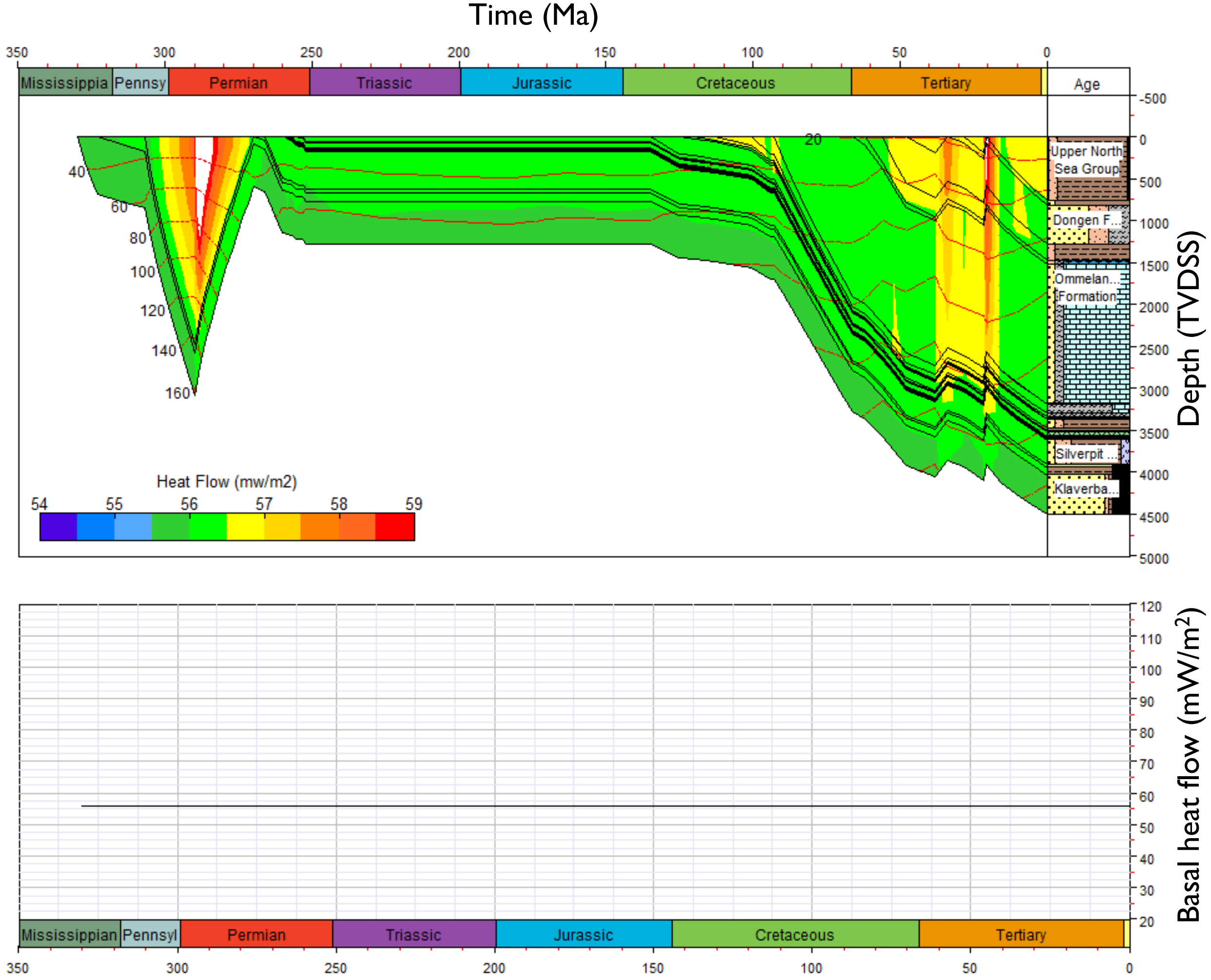
Maturity

Vitrinite reflectance *vs.* depth trends

Scenario 2: Constant Basal HF through time with 2,500 m Saalian erosion







- ✔ Good calibration to temperature, mod. to vitrinite reflectance
- ✘ Geologically unrealistic, Saalian U/C erosion too large
- ✘ Paleozoic maturity gradient not captured

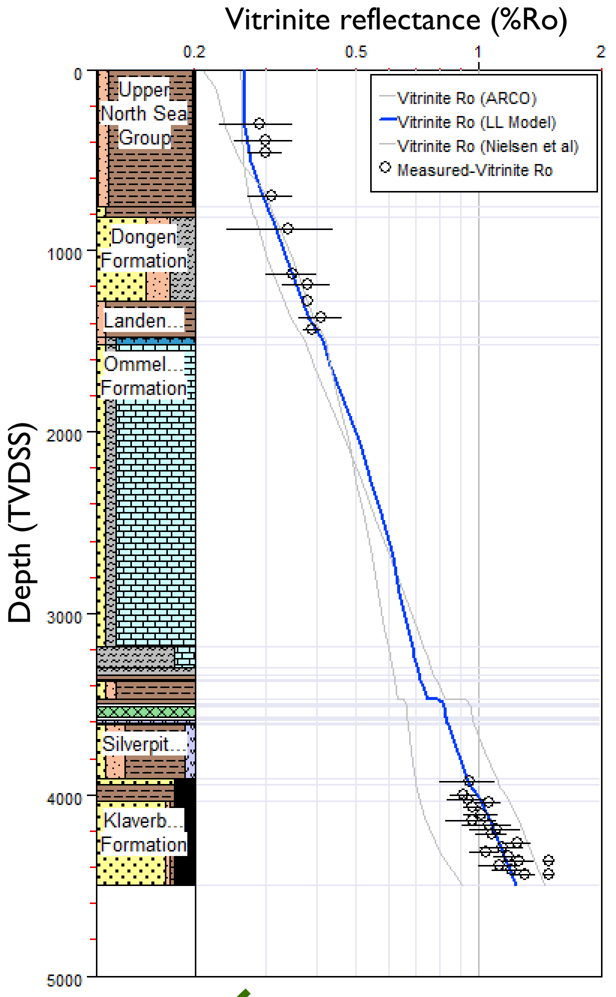
Present geothermal gradient:	33.0 °C/km
Present day surface heat flow:	56.0 mW/m^2
Peak palaeo basal heat flow:	56.0 mW/m^2 (constant)

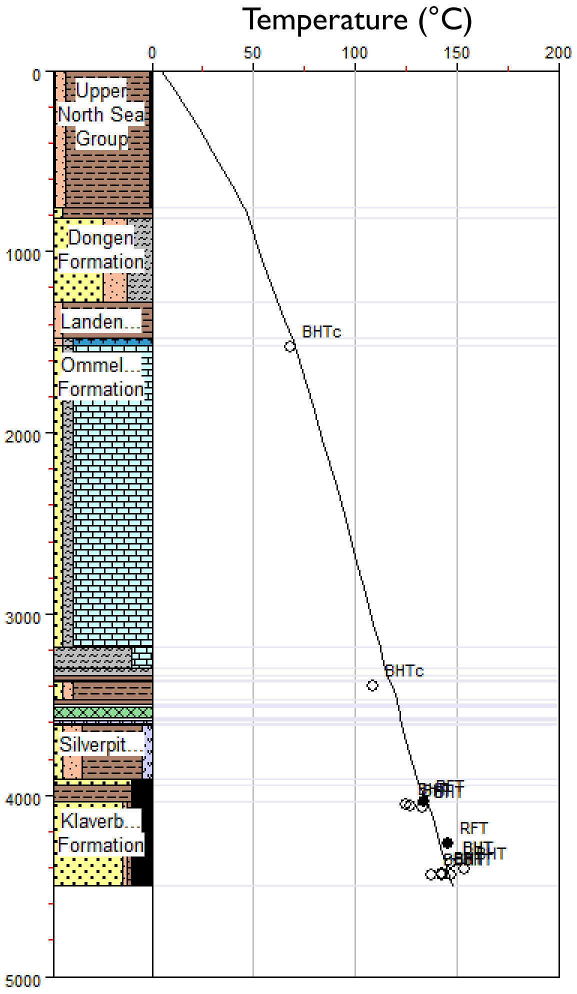
INTEGRATED GEOCHEMICAL INTERPRETATION
IGI

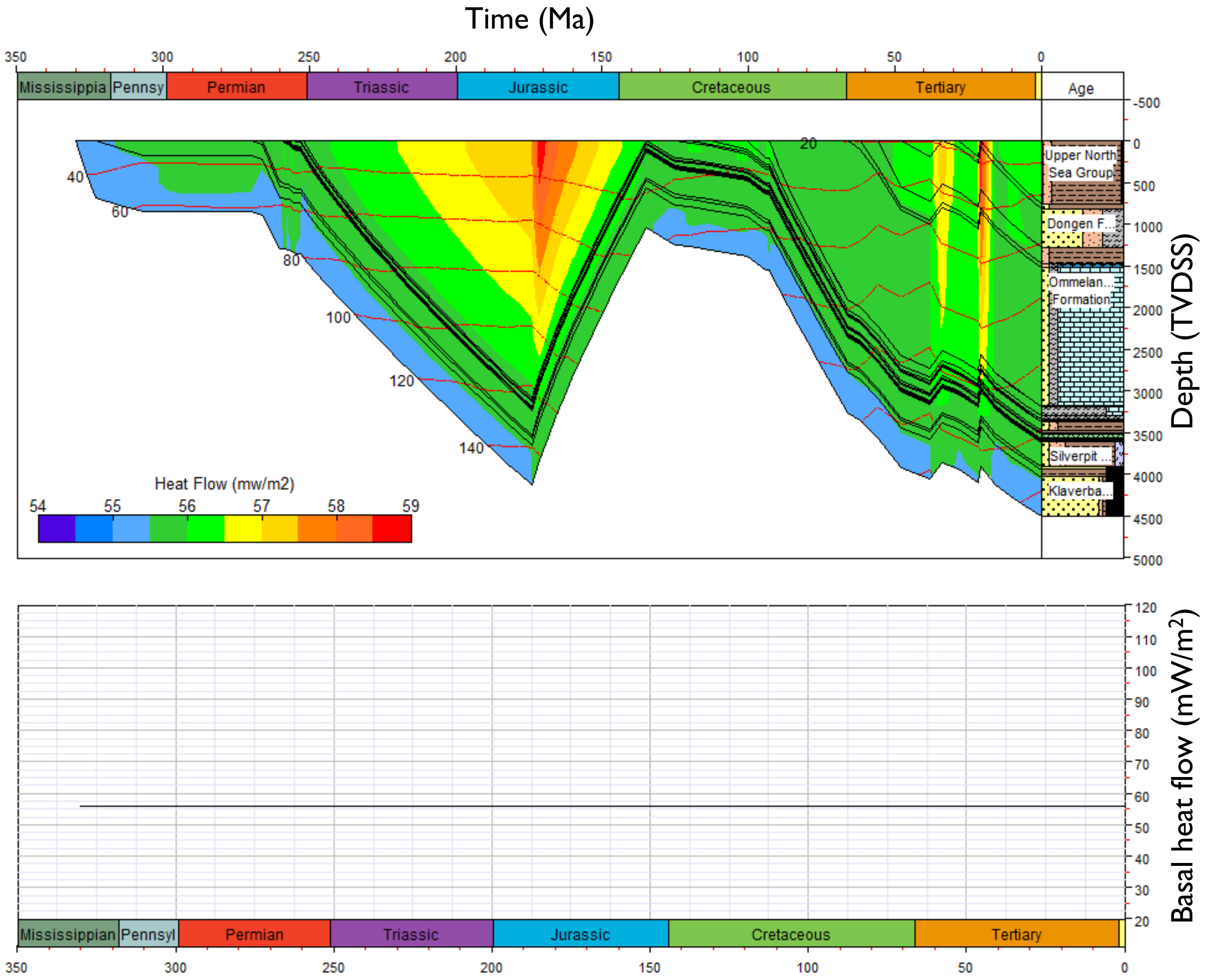
Maturity

Vitrinite reflectance *vs.* depth trends

Scenario 3: Constant Basal HF through time with 3,100 m Cimmerian erosion







- ✓ Good calibration to temperature, mod. to vitrinite reflectance
- ✗ Geologically unrealistic, Cimmerian U/C erosion too large
- ✗ Paleozoic maturity gradient not captured

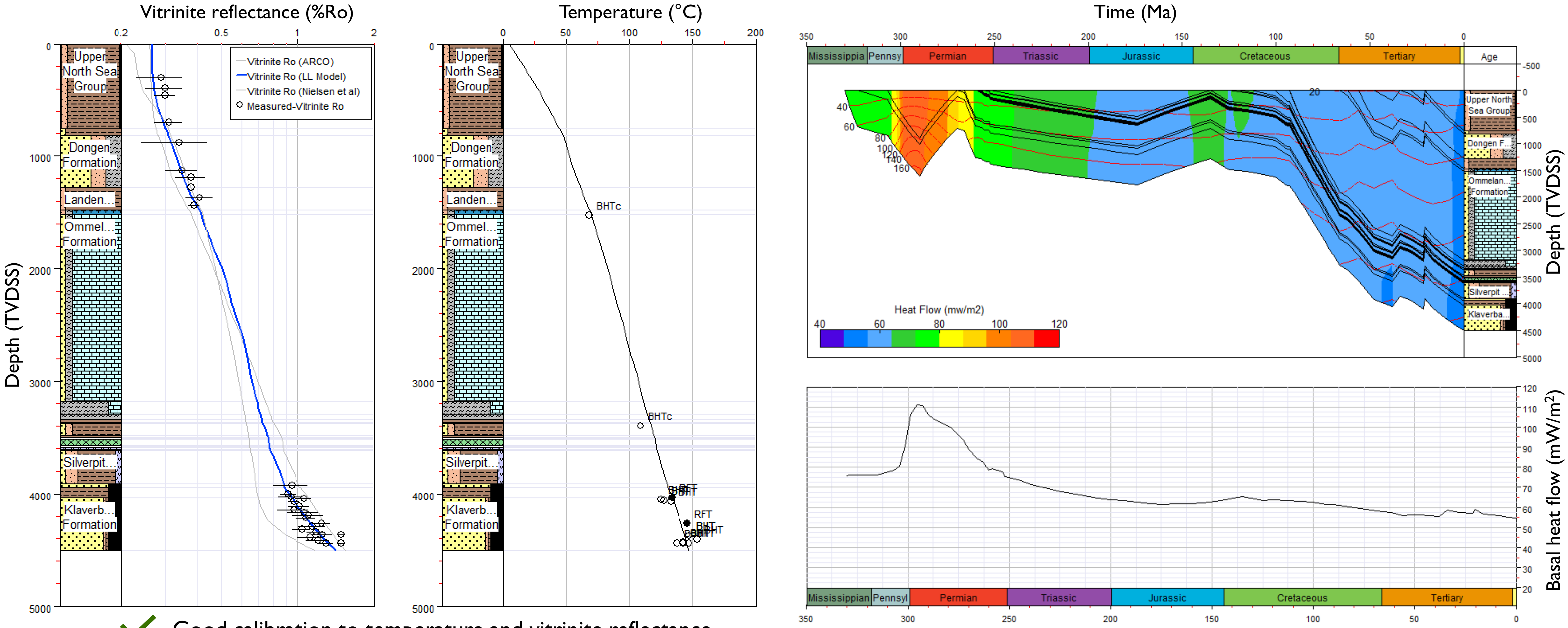
Present geothermal gradient:	33.0 °C/km
Present day surface heat flow:	56.0 mW/m^2
Peak palaeo basal heat flow:	56.0 mW/m^2 (constant)

INTEGRATED GEOCHEMICAL INTERPRETATION
IGI

Maturity

Vitrinite reflectance *vs.* depth trends

Scenario 4: High Permo-Carboniferous heat flow and moderate erosion



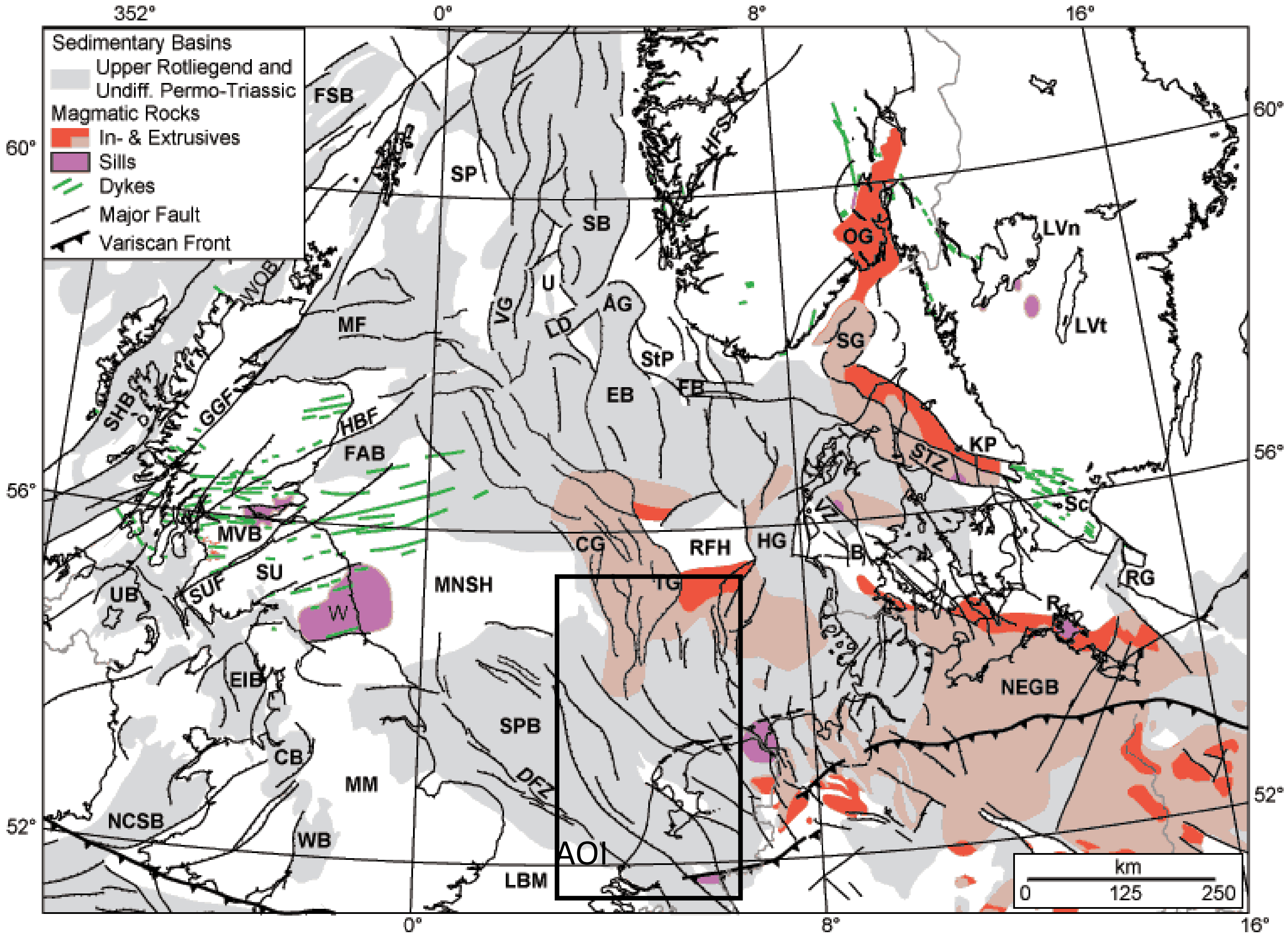
- ✔ Good calibration to temperature and vitrinite reflectance
- ✔ Includes erosion at both Cimmerian (500 m) and Saalian (900 m) U/C
- ✔ Only moderate erosion magnitudes required
- – High palaeo-heat flow required (mantle plume?)

Present geothermal gradient:	32.8 °C/km
Present day surface heat flow:	55.8 mW/m^2
Peak palaeo basal heat flow:	111 mW/m^2 (295 Ma)

Palaeozoic Heat "Pulse"

Mantle plume, adiabatic melting or rift development?

Overview of the distribution of late Carboniferous to early Permian igneous material in the North Sea from Heeremans et al. (2004)



Between the uppermost Carboniferous and early Permian, widespread igneous activity is observed throughout the southern North Sea, including the Dutch offshore and southern Norway. Calc-alkaline to tholeiitic intrusions have been radiometrically dated to ca.300 – 280 Ma (Wilson et al., 2004).

Melting was probably induced by local decompression and thinning of lithosphere in response to regional stretching north of the Variscan front, although the PREMA affinity implies that involvement of a mantle plume cannot be discarded (van Bergen & Sissingh, 2007).

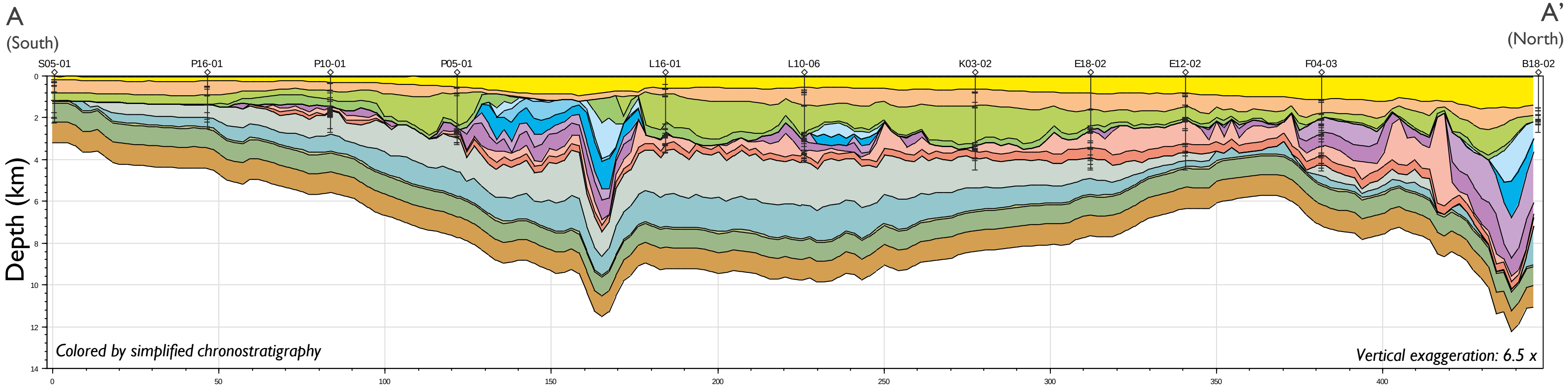
Although a mantle plume has been inferred in some studies (e.g. Bonté et al., 2019), several aspects are not fully consistent:

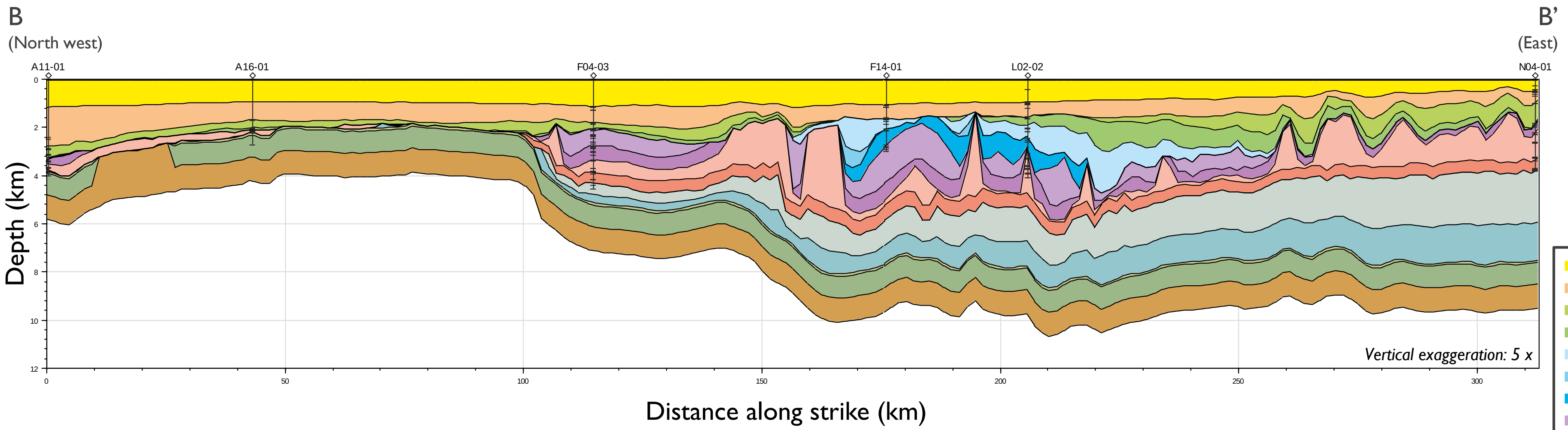
- The lack of a clear, age-progressive volcanic track
- Pre-magmatic subsidence and not uplift
- The absence of a large igneous province
- Low to moderate values of $^3He/^4He$

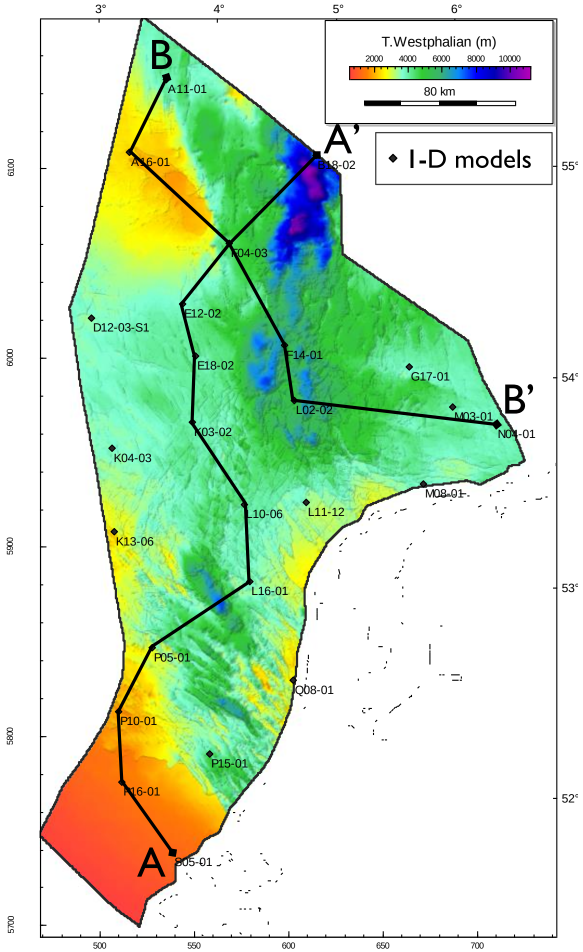
INTEGRATED GEOCHEMICAL INTERPRETATION IGI

Grid-based 3-D Model

Structural construction in Trinity T3







- Bathymetry Offshore (m)
- Base Upper North Sea
- Base North Sea Super Gp
- Base Chalk Gp
- Base Rijnland Gp
- Base Schieland Gp
- Base Posidonia Fm/Top Aalburg
- Base Altena Gp
- Base Upper Germanic Trias Gp
- Base Low er Germanic Trias Gp
- Base Zechstein Gp
- Saalian U/C (Top Westphalian)
- T.Westphalian (m)
- Base Westphalian (T.Namurian) (m)
- Base Namurian
- Base Elleboog Fm
- Base Dinantian

3-D basin model constructed using 19 depth maps (mainly sourced from DGM-deep V3 Offshore, from nlog) across the AOI and thermally-calibrated to 25 1-D models. No halokinesis has been included on this regional-scale but should be included on the local

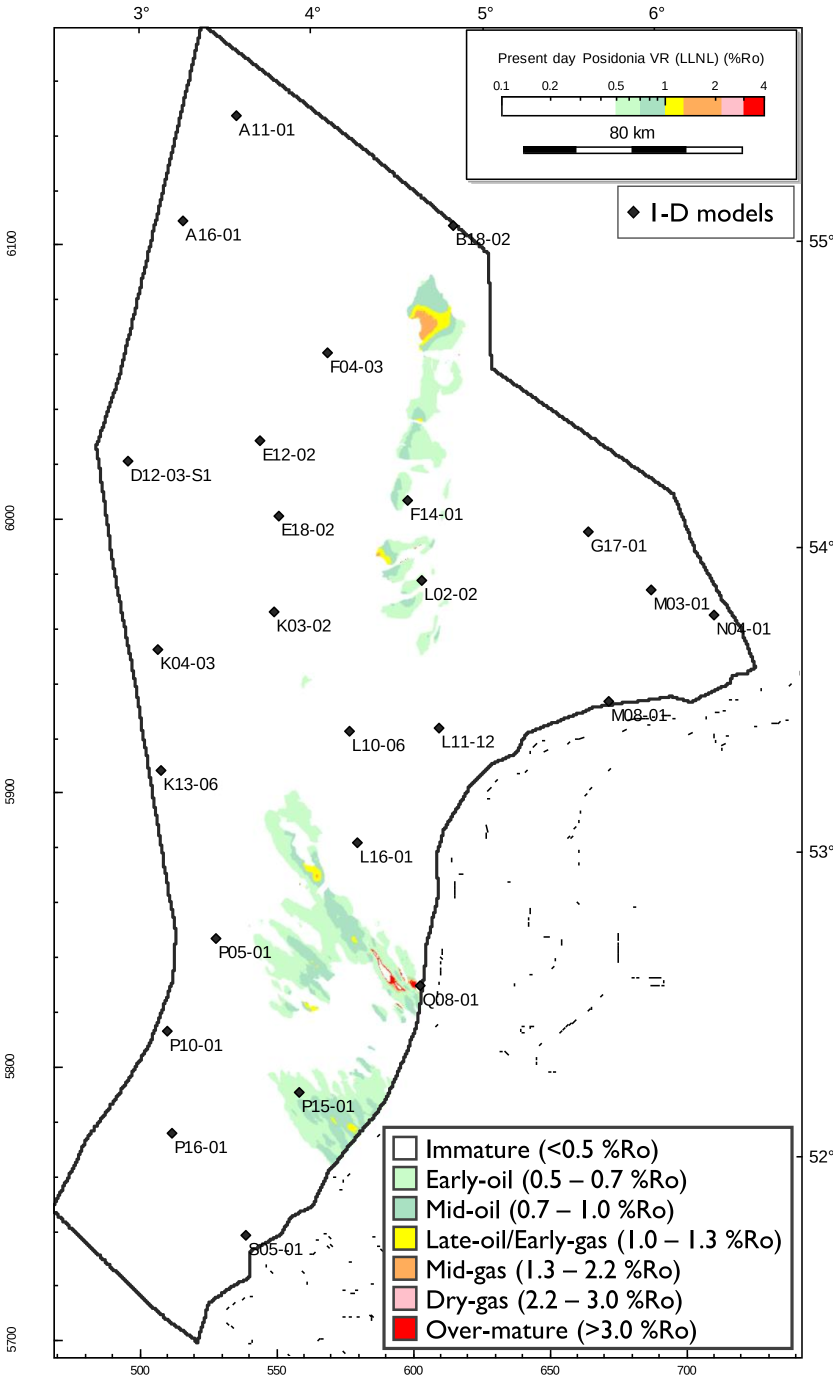
Posidonia Shale

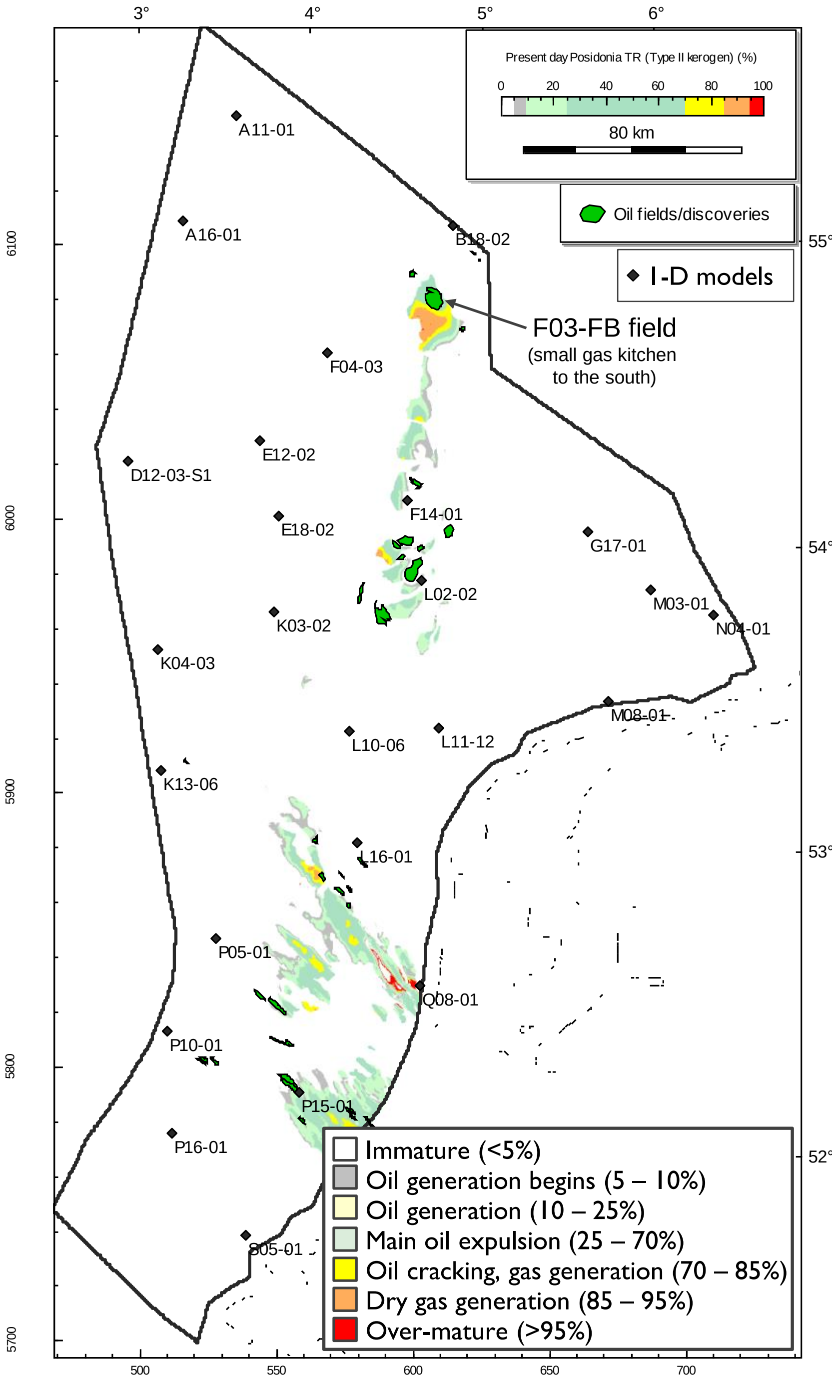
Maturity (VR & Transformation Ratio)

The Posidonia shale, where present/preserved, is predicted to be mature for hydrocarbon generation at present.

There is an excellent agreement between the known oil fields/discoveries and the oil-mature Posidonia, strongly suggesting a Lower Jurassic marine shale is the predominant source of most of these oil accumulations.

Exploration targeting oil should focus on charge originating from the identified kitchen fairway, unless an alternative oil-prone source rock is present. This may be possible on a local scale, e.g. Zechstein carbonates or Lower Cretaceous shales (where mature).





Based on Type II kerogen

Top Westphalian

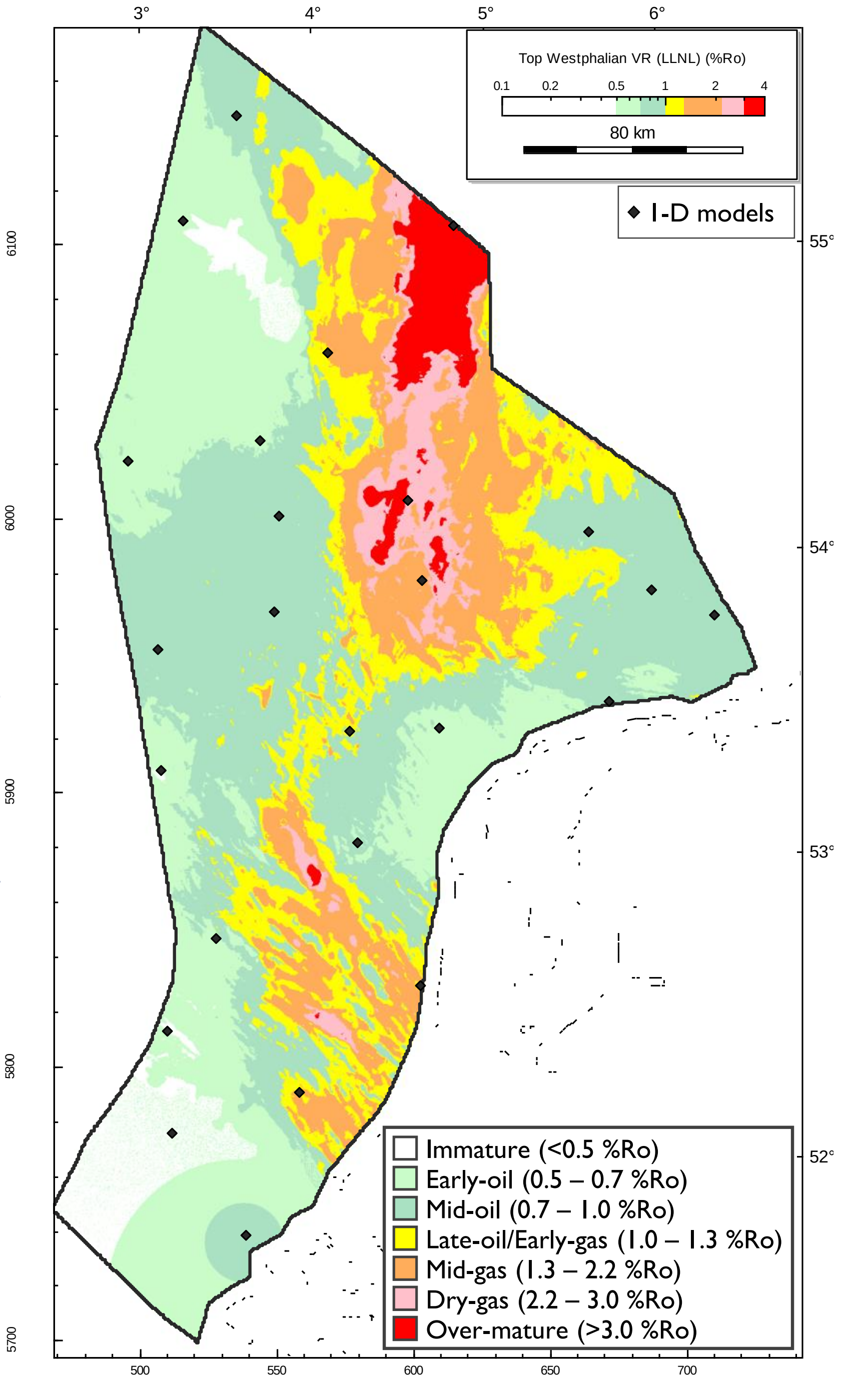
Maturity (VR & Transformation Ratio)

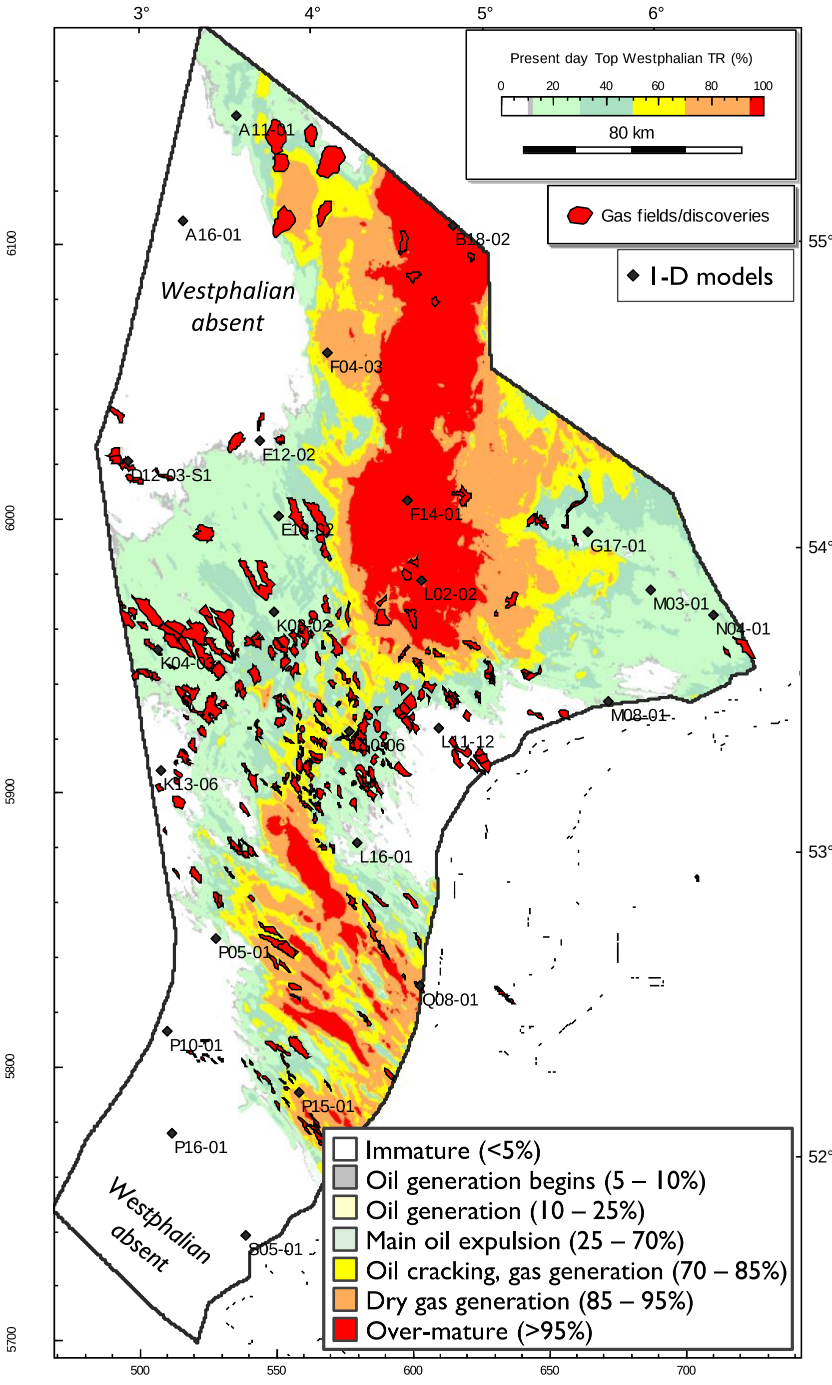
The maturity of the upper Westphalian is not consistent with the distribution of the known gas fields in large areas of the Dutch offshore,, namely the Anglo-Dutch Basin, Cleaver Bank High and Central Offshore Platform, as well as onshore.

The exceptions are the gas-mature kitchens areas in the Dutch Central Graben, Broad Fourteens Basin and West Netherlands Basin, based on the Transformation Ratio.

However, the Westphalian is very thick in some areas, notably in the east of the AOI (e.g. Ameland Block & Terschilling Basin), and so it is likely that a significantly higher maturity is found near its base.

Alternatively, much higher amounts of Alpine erosion could be envisaged, to explain the widespread generation of dry-gas.





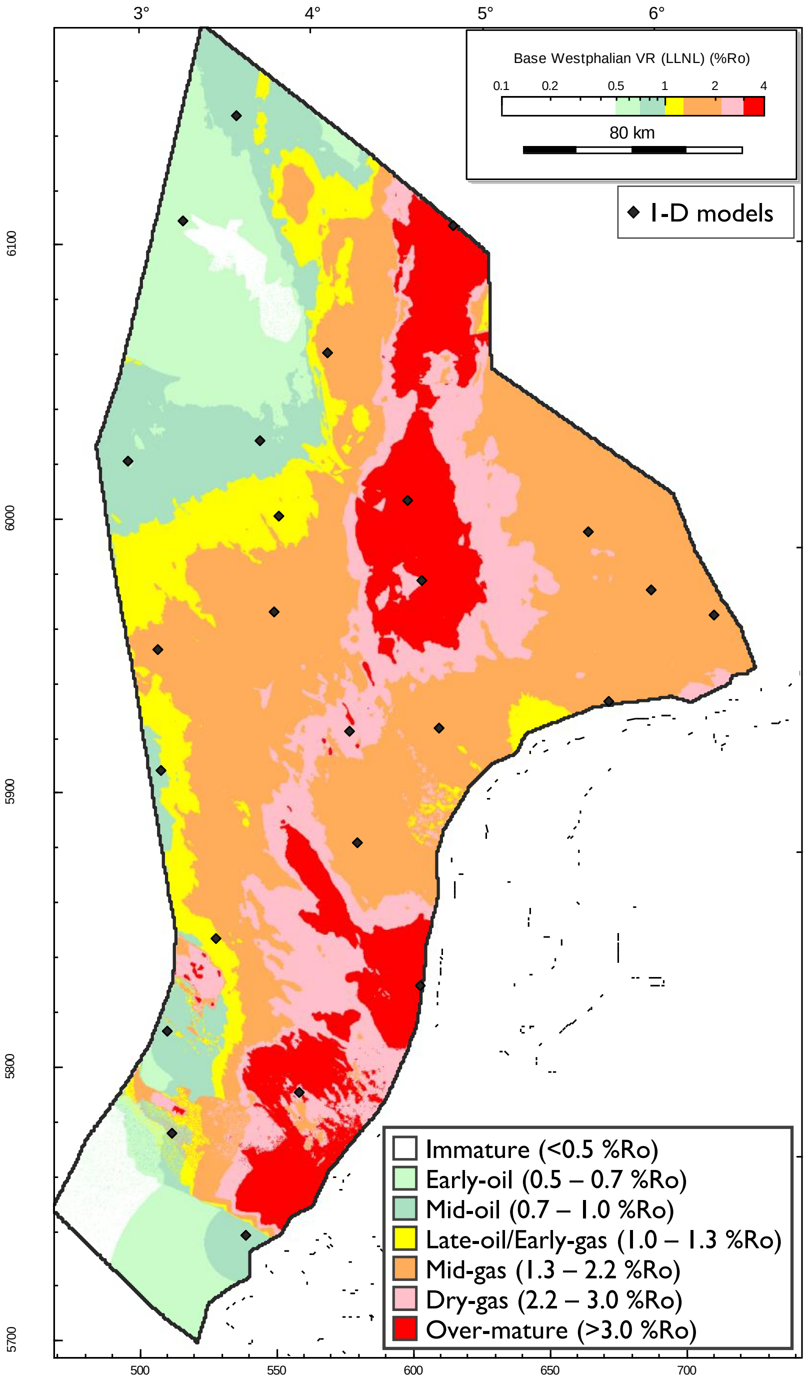
Based on Type III kerogen

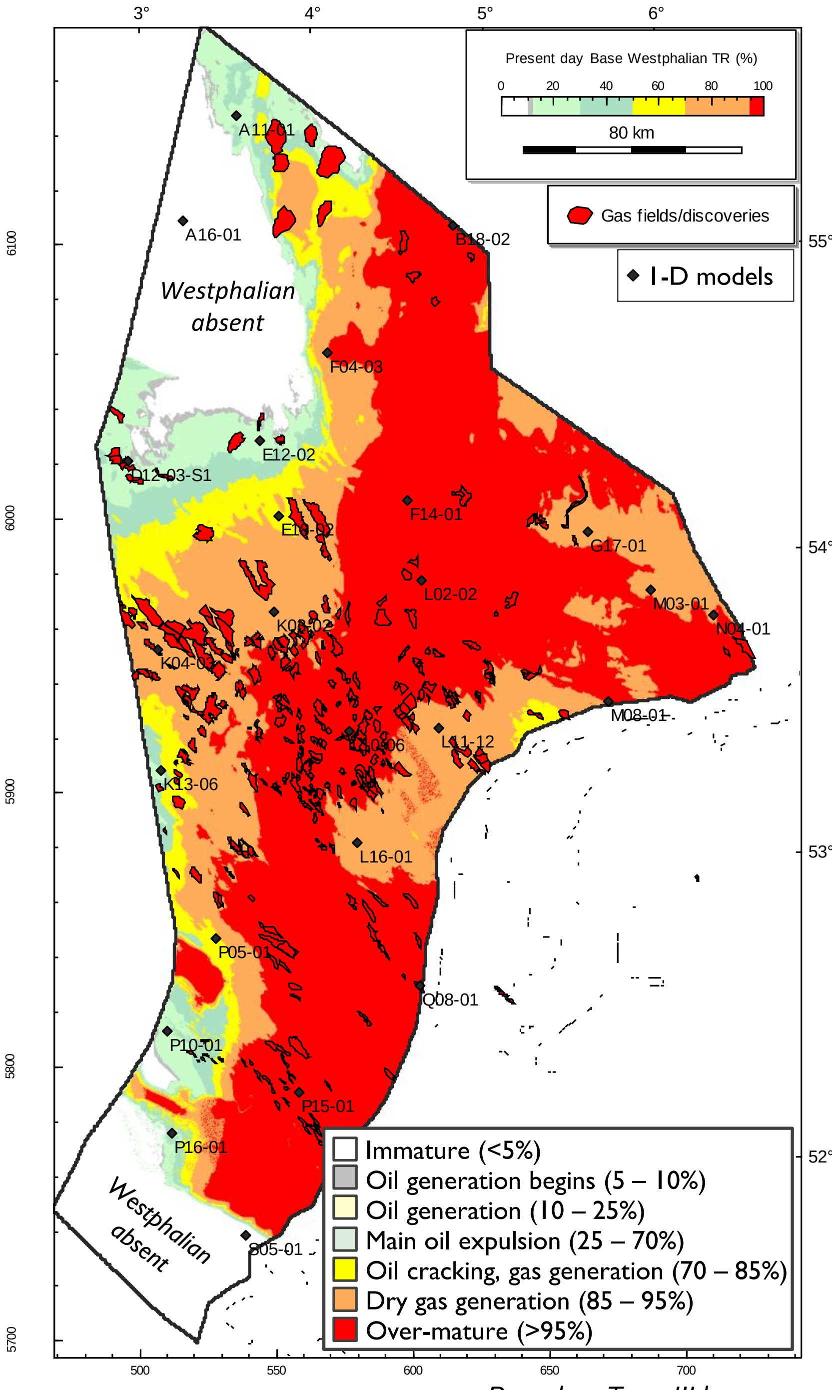
Base Westphalian

Maturity (VR & Transformation Ratio)

The Base Westphalian represents the highest maturity while also providing a proxy for the maturity of the underlying top Namurian source rock section.

The maps show a good correlation between the dry-gas generation window (and above) with the distribution of gas fields/discoveries.





Based on Type III kerogen

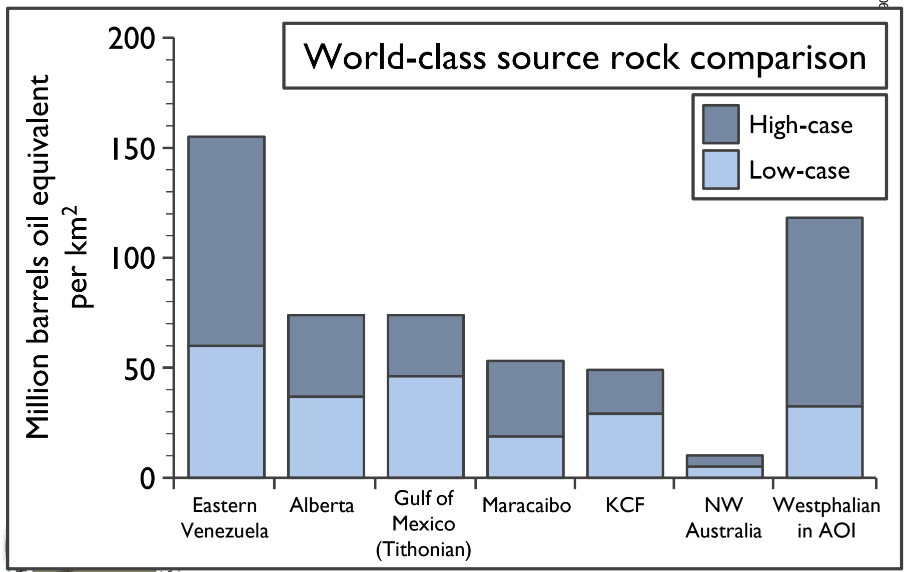
Base Westphalian

Gas Expulsion

Gas expulsion is a function of source quality (TOC & kerogen type), thickness (assumed 10% N:G) and maturity.

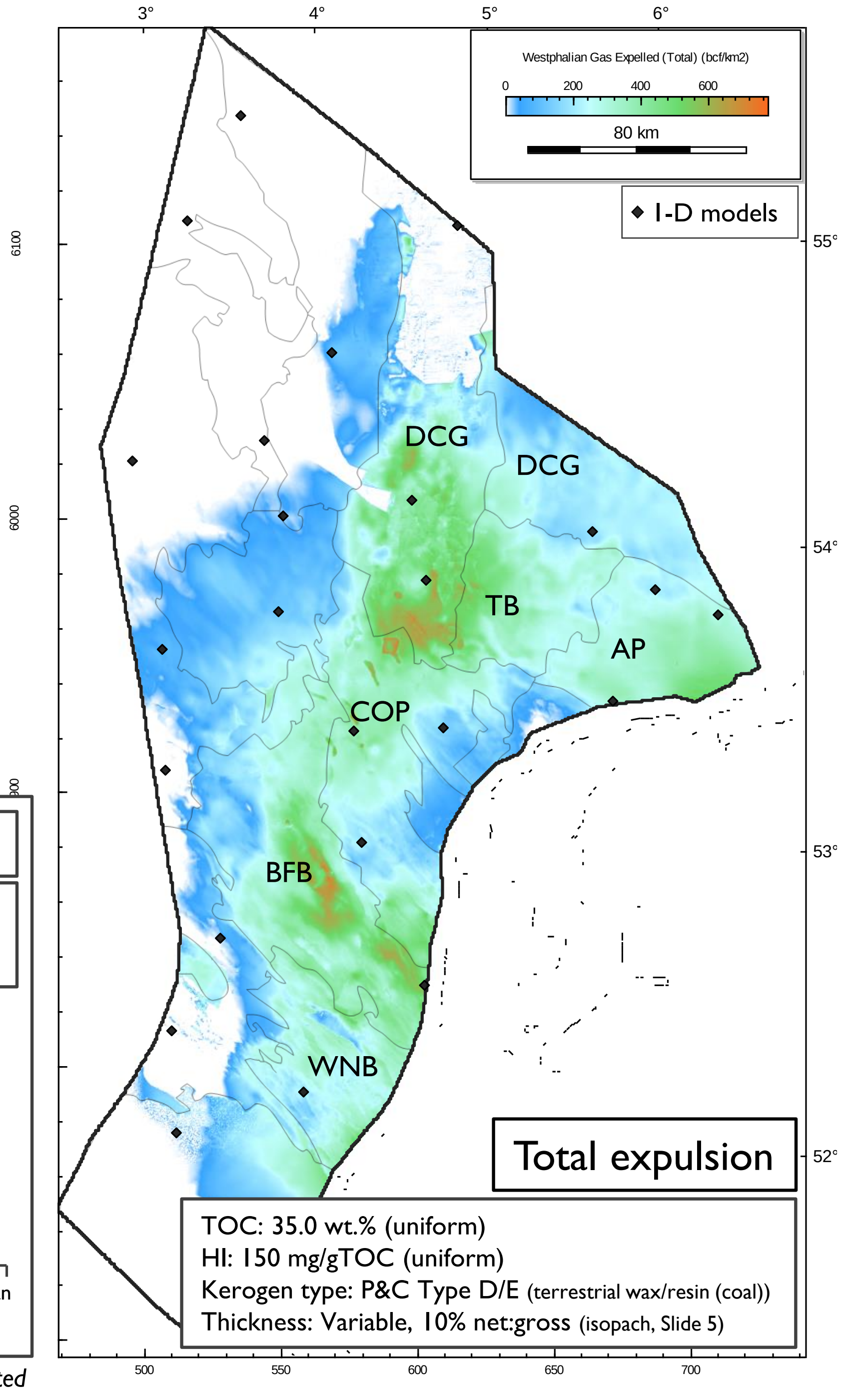
Here we demonstrate that most gas expulsion has occurred in the BFB, DCG, COP & WNB, with a strong correlation to known gas fields and discoveries.

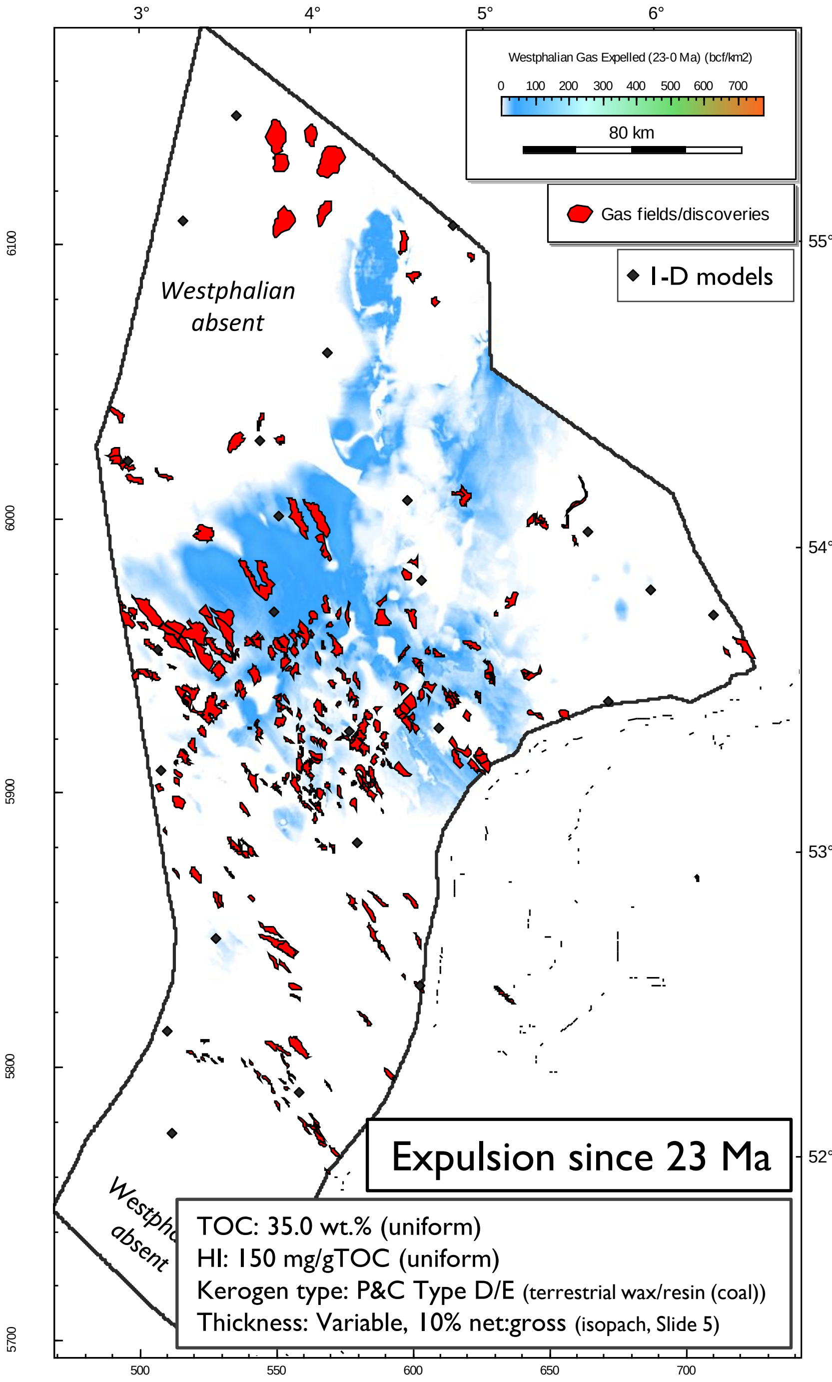
Geologically-recent gas expulsion, since the Miocene, also correlates to most fields and predicts gas expulsion in the Ameland Block & Terschilling Basin areas.



From Zhiyong He

High-case = maximum value predicted
Low-case = mean of predicted data





Based on Type III kerogen

Conclusions

Regional petroleum systems modelling in the Dutch offshore

A geochemical database containing >10,000 samples has been constructed, containing high-level Rock-Eval and vitrinite reflectance data. Our interpretation suggests the primary source rocks are the Toarcian Posidonia shales & Pennsylvanian Westphalian coals.

Multiple erosion events across the Dutch offshore makes interpretation difficult, as VR (and AFTA) data are often overprinted by subsequent burial. Our best-fit model is broadly consistent with previous authors which suggest Saalian erosion was limited to 2,000 m (most likely *ca.* 500 – 1,000 m), while erosion at the Cimmerian unconformities is also limited to < 1,000 m of erosion.

Mantle upwelling (plume emplacement), associated with magma underplating and/or igneous intrusions contemporaneous of a transitional tectonic regime (compressive-to-wrenching) resulted in very high palaeo-heat flow (up to 140 mW/m^2) during the uppermost Carboniferous to lower Permian (300 – 280 Ma).

The predicted regions of Posidonia source rock maturity and oil expulsion correlate well with known oil fields/discoveries.

Westphalian source rock maturity, in particular in its lower section, also correlates well with the distribution of known gas fields/discoveries, and abundant gas expulsion is predicted, continuing into the Miocene and possibly to the present day.

The model presented here also predicts significant gas expulsion in the Ameland Block & Terschilling Basin, where relatively few discoveries have been made to date. This may be of consideration for future exploration.

Thank you for listening

Presentation courtesy of: