Solid Bitumen in Shales: Facies and Maturity Effects on Microstructures*

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Abstract

Solid bitumen is in the focus of recent research work on shale oil/gas plays as it might lower effective gas permeabilities due to the occlusion of pore throats, but also provide important hydrocarbon storage space and form migration pathways if a porous network of oil-wet pores is present. However, despite its significance for the quality of a shale reservoir, ambiguities about the various definitions of (solid) bitumen in organic geochemistry and petrography, as well as regarding the actual onset of compositional and microstructural transformations during thermal maturation and accompanying hydrocarbon generation, exist. In an attempt to visualize different solid bitumen types and transformation stages over a broad maturity range (0.5-2.7% R_o) in shales of varying primary kerogen composition, we reviewed optical and scanning electron microscopy data of shales with a Cambrian to Triassic age with emphasis on the petrographic characteristics of solid bitumen.

We were able to identify in-situ pre-oil solid bitumen as well as migrated post-oil solid bitumen at various maturity stages. We found solid bitumen to be surprisingly mobile already at marginal to early oil window maturity, arguing for significant influence of primary migration. Onset of porosity development in solid bitumen differs considerably between predominantly oil-prone (e.g. alginite) and gas-prone (vitrinite-rich) kerogen compositions; furthermore, solid bitumen (pyrobitumen at advanced maturity) in rocks with a terrestrially-dominated facies seems to be considerably less mobile compared to pre- and post-oil solid bitumen in oil-prone rocks. In most samples, several solid bitumen populations with varying reflectance were observed, complicating its use as a petrographic maturity indicator. Microstructural features such as irregularly distributed spongy porosity or detrital and authigenic mineral inclusions in the sub-micrometre scale were found to have a great influence on texture and reflectivity in lower-resolution optical microscopy. The formation of authigenic minerals (quartz, various carbonate phases, magnetite in Cambrian samples) was observed frequently in post-oil solid bitumen of oil-prone rocks; this points to a close genetic relationship between transformation products formed during hydrocarbon generation (e.g. acetate, carbon dioxide and methane) and the dissolution and precipitation of minerals during diagenesis.

Solid bitumen in shales:
Facies and maturity effects on microstructures

Misch, D., Klaver, J., Gross, D., Liu, B., Sachsenhofer, R.F., Schmatz, J., Urai, J.L.

AAPG ACE San Antonio - 2019/21/05

Der Wissenschaftsfonds.

Outline

- **Cambrian:** Arthur Creek Fm., Australia
- **Ordovician/Silurian:** Graptolite Shale, Lithuania
- **Upper Visean:** Rudov Beds, Ukraine
- **Upper Jurassic**: Mandal Fm., Norway
- **Triassic:** Yanchang Fm., China

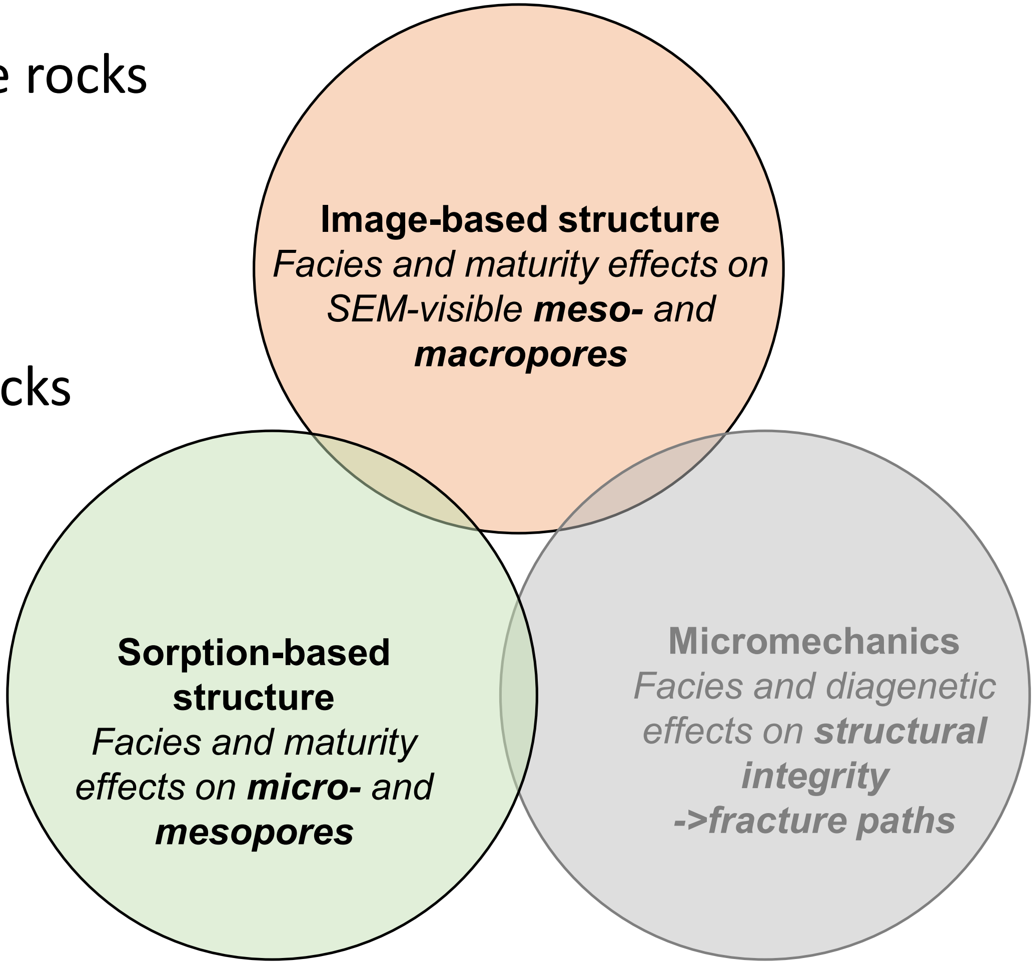
source rocks

- **Miocene**: Vienna Basin, Austria

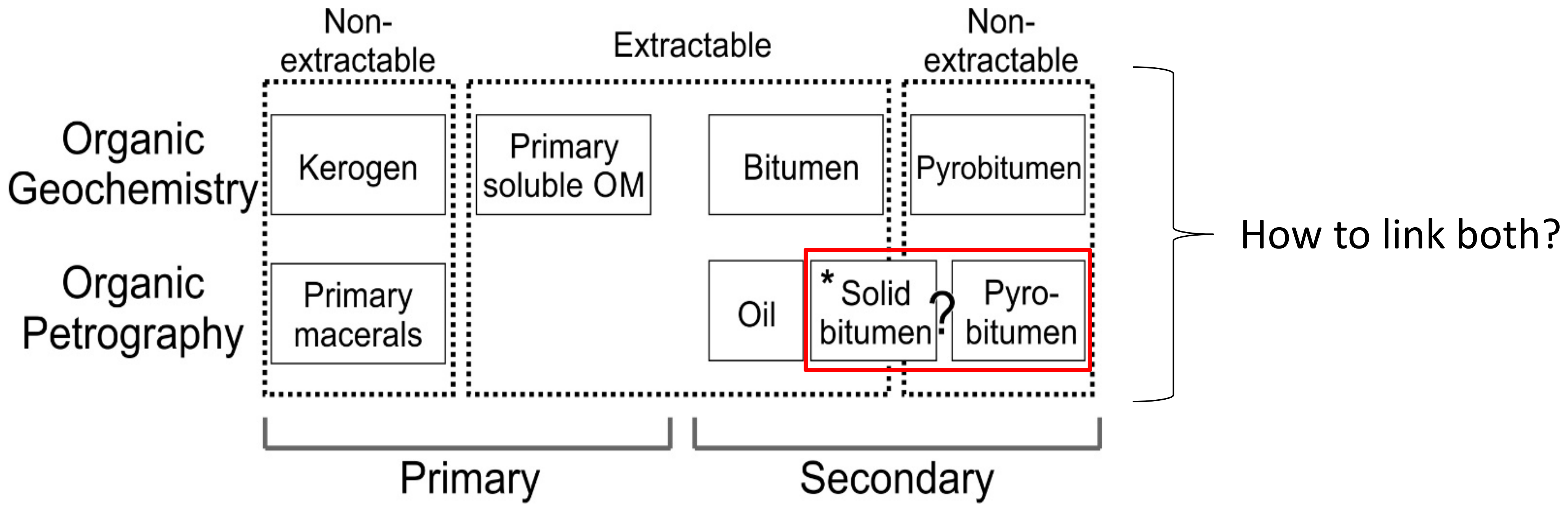
cap rocks

Data sources:

-> Comparative optical and scanning electron microscopy
-> Bulk geochemistry & source rock extracts
-> Gas adsorption
-> Mercury intrusion porosimetry

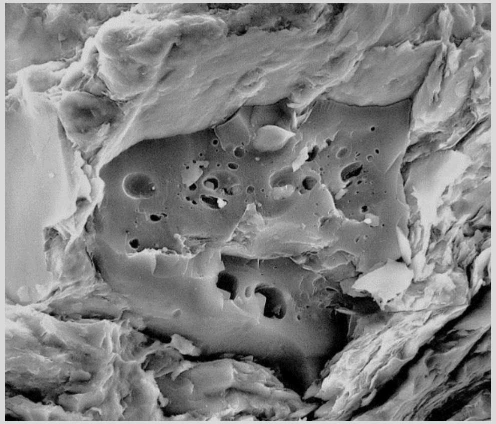


Solid bitumen in shale reservoirs

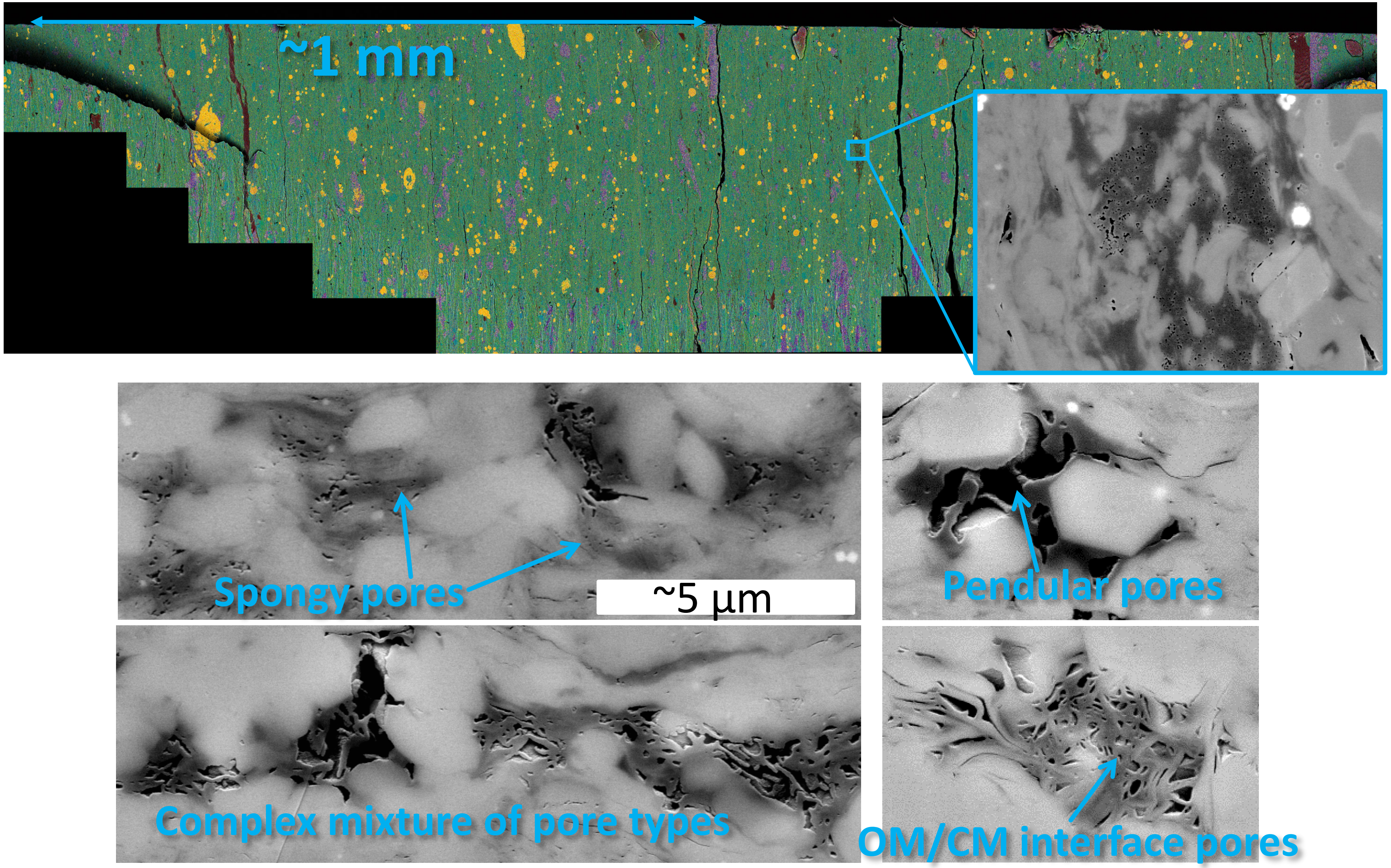


→**<u>Solid bitumen</u> plays an integral role for:**

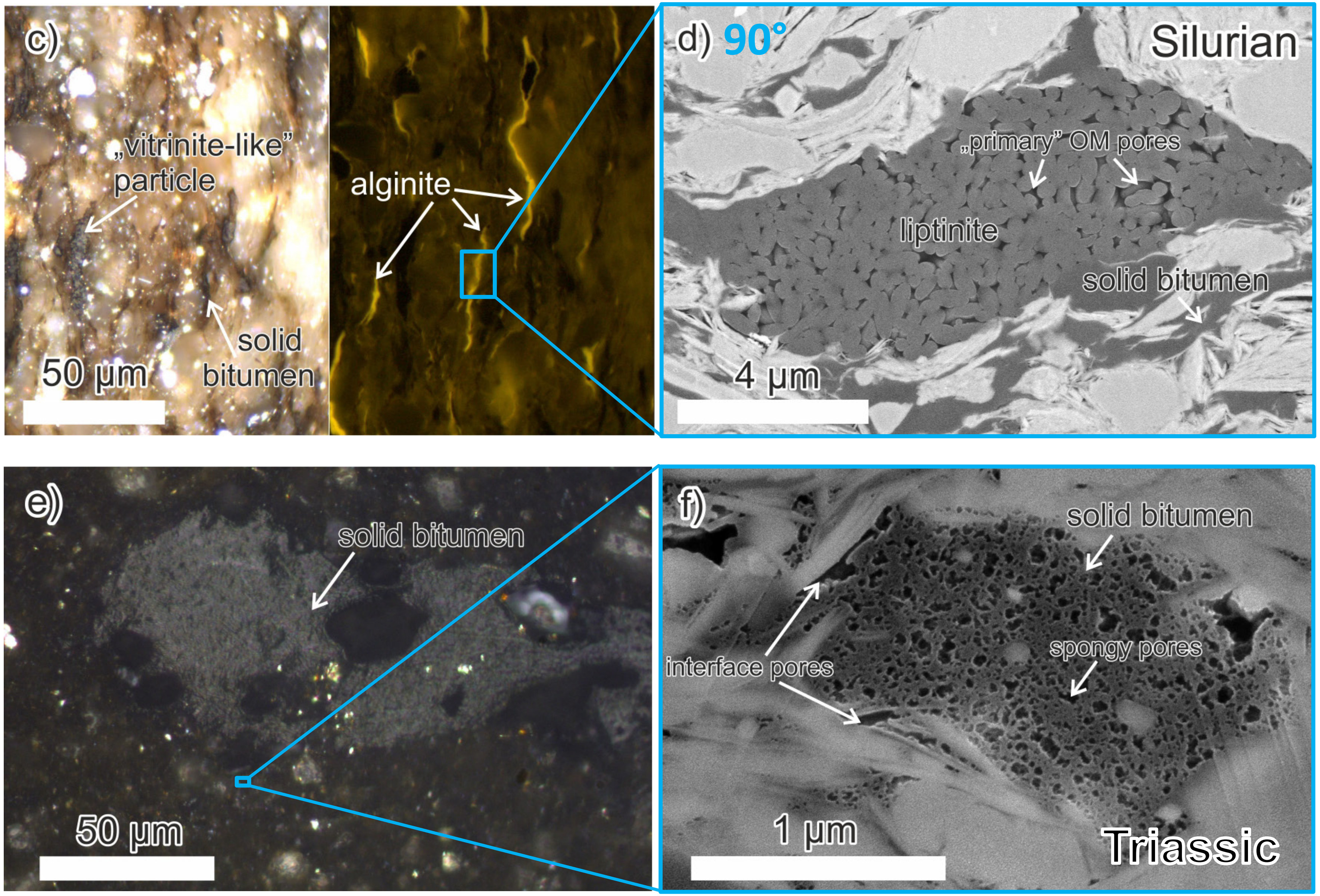
- Maturity evaluation
- Mineral authigenesis
- Porosity evolution
- HC storage and expulsion



Visualize organic matter textures: BIB-SEM



How to identify solid bitumen in the SEM?

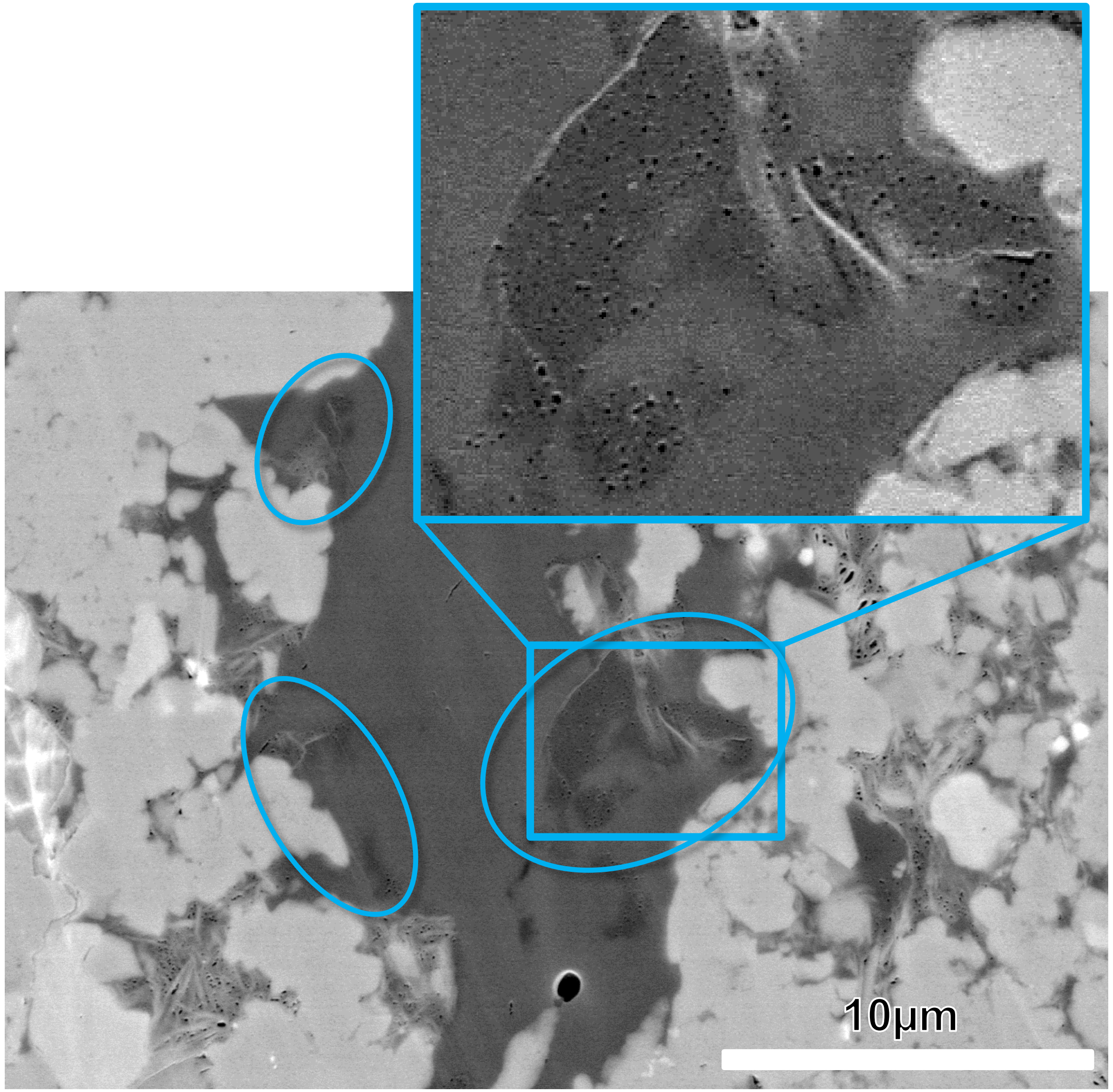


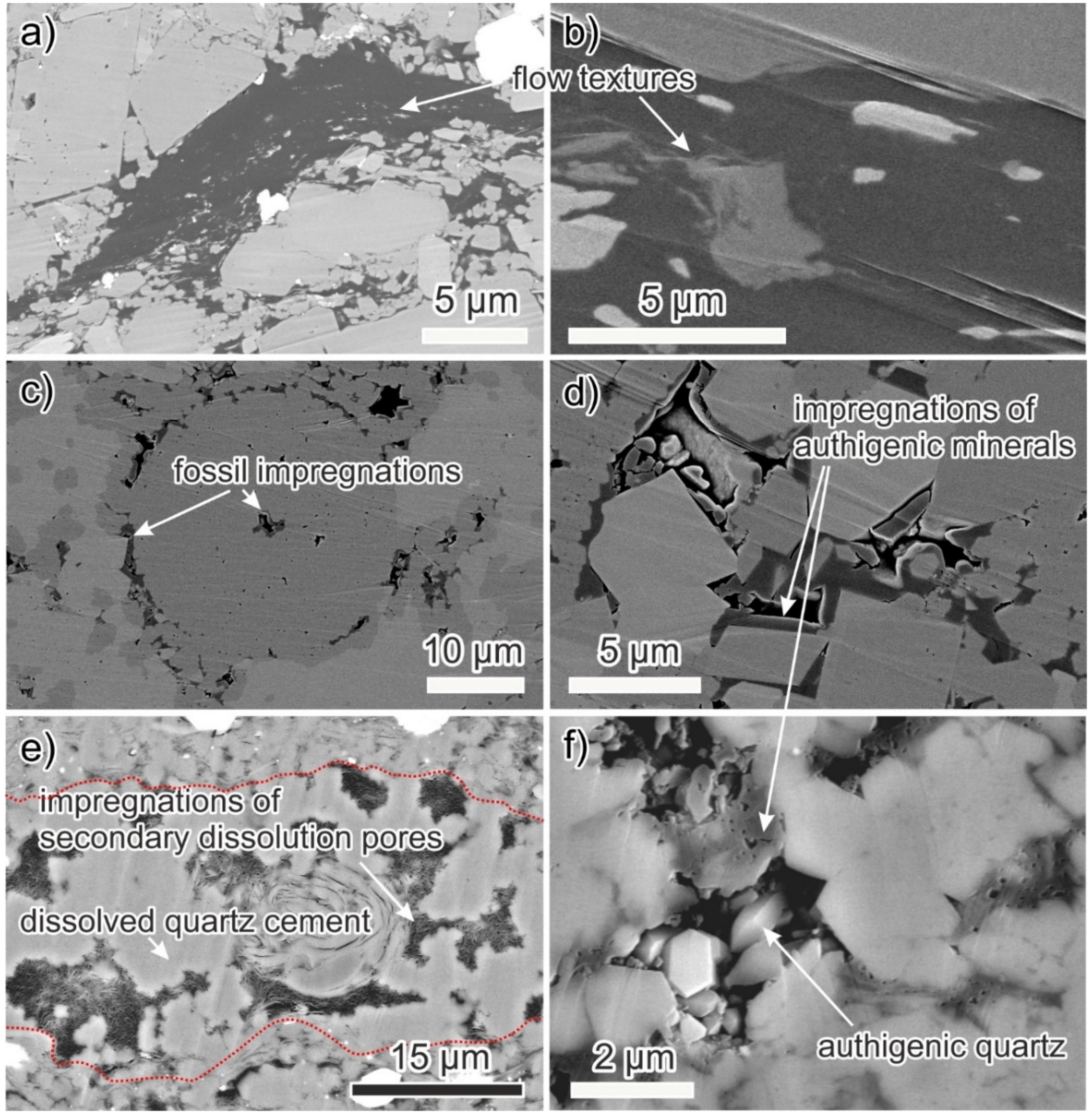
Solid bitumen: remobilized vs. in-situ

In-situ

hardly distinguishable!

Remobilized



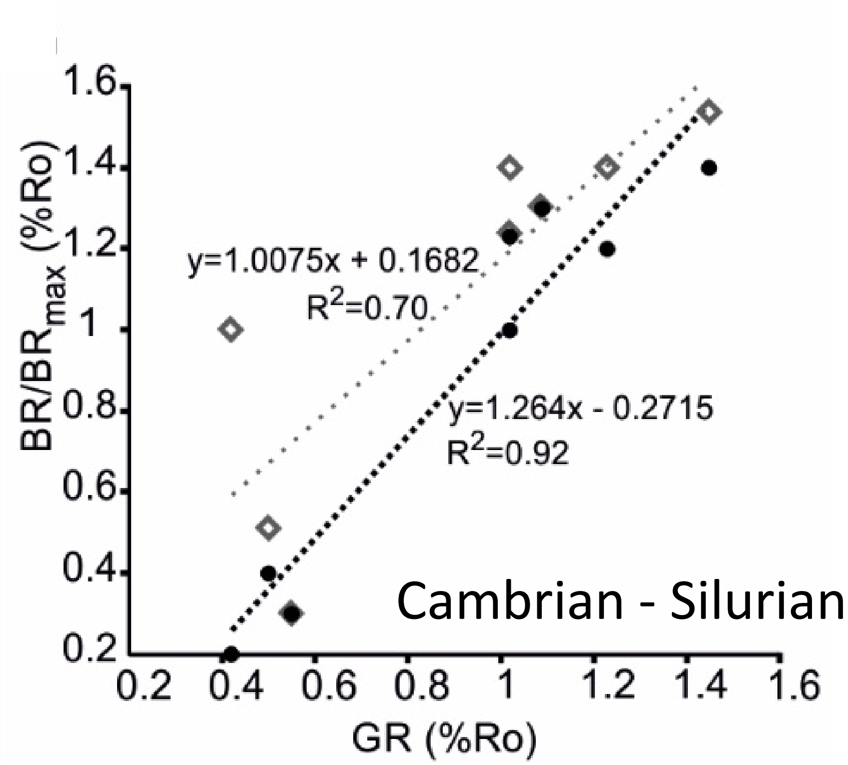


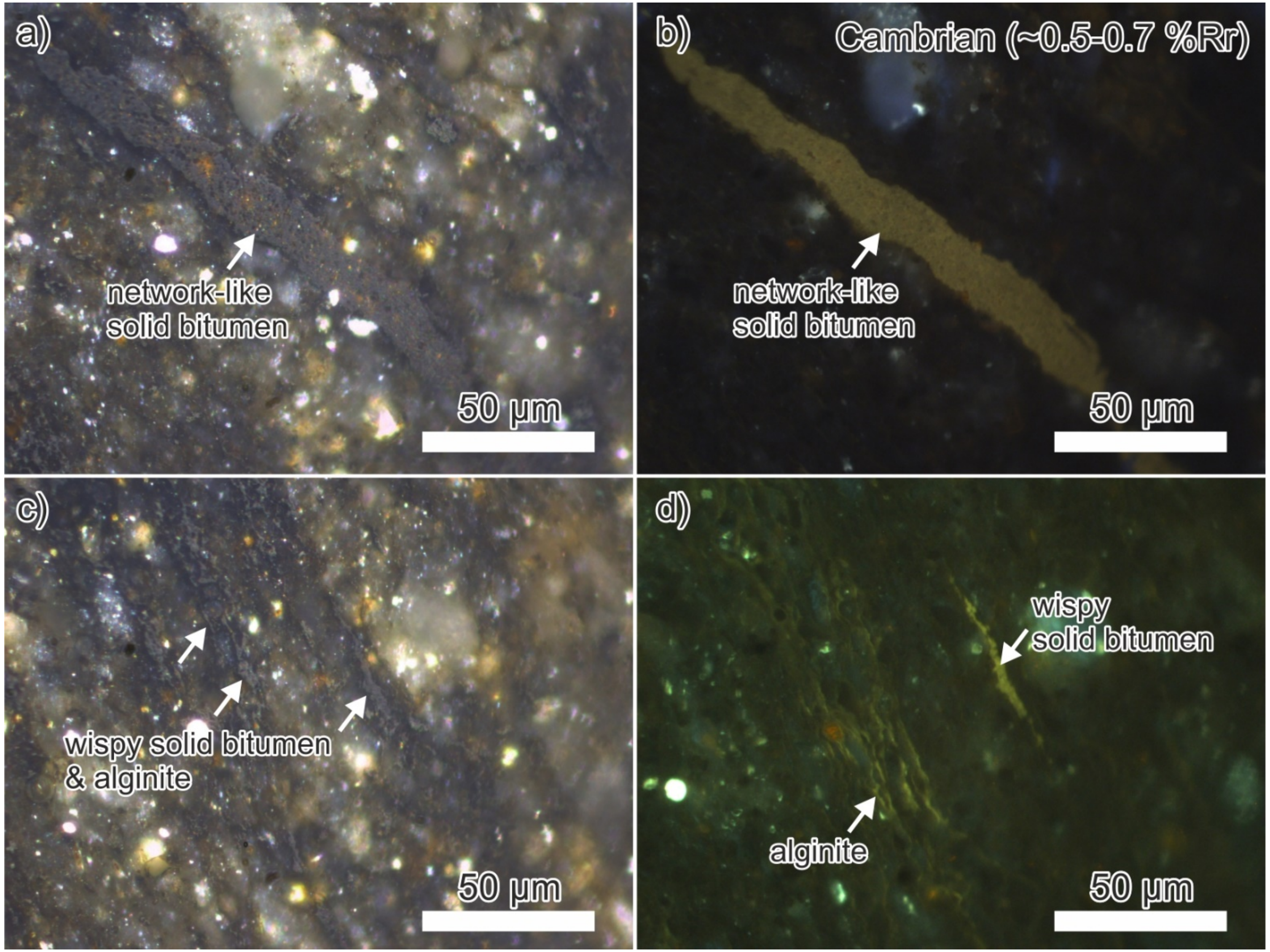
Solid bitumen: remobilized vs. in-situ

Fluorescence populations at early oil window:

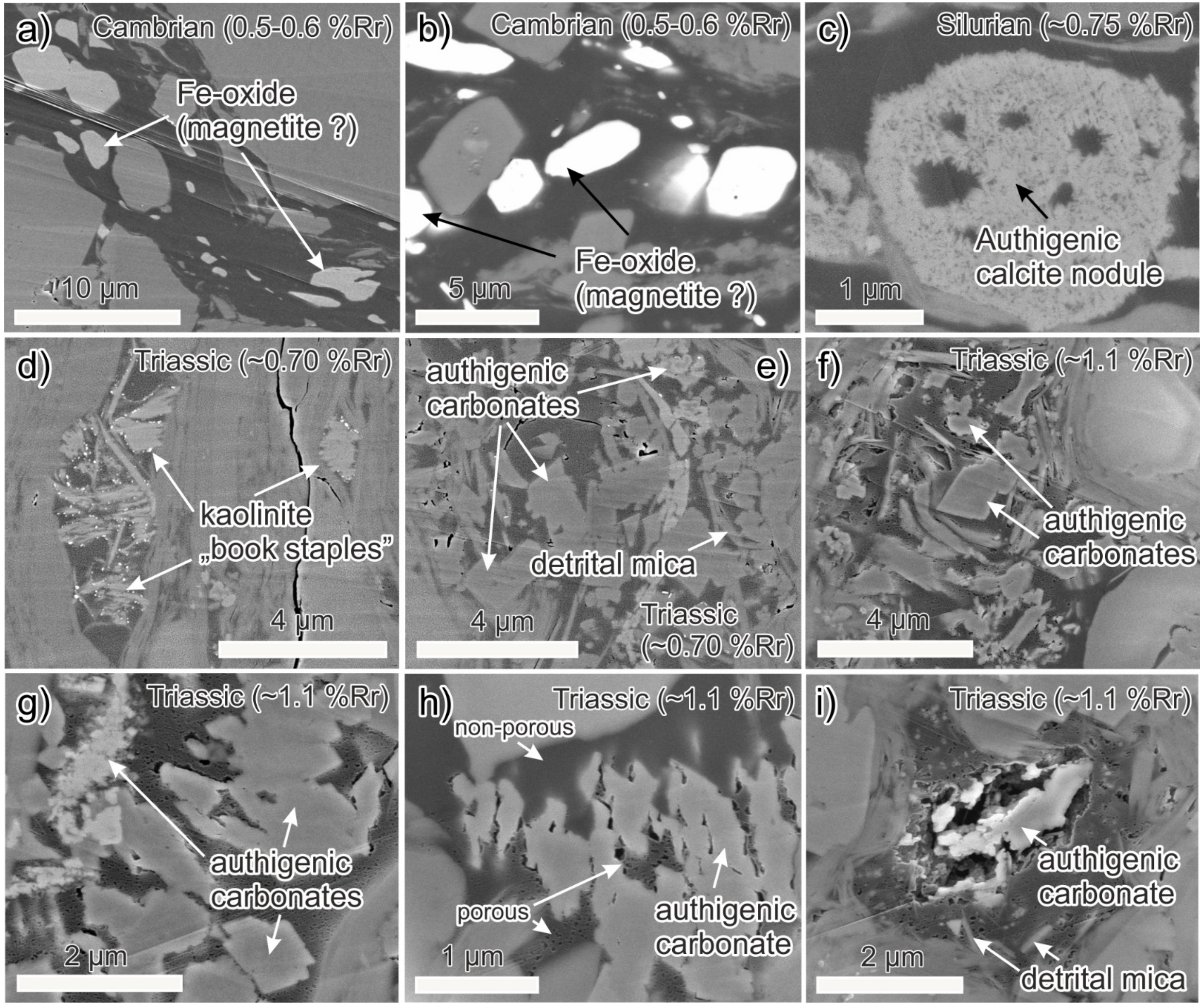
-> Wispy SB along alginites

-> Network SB in microfractures



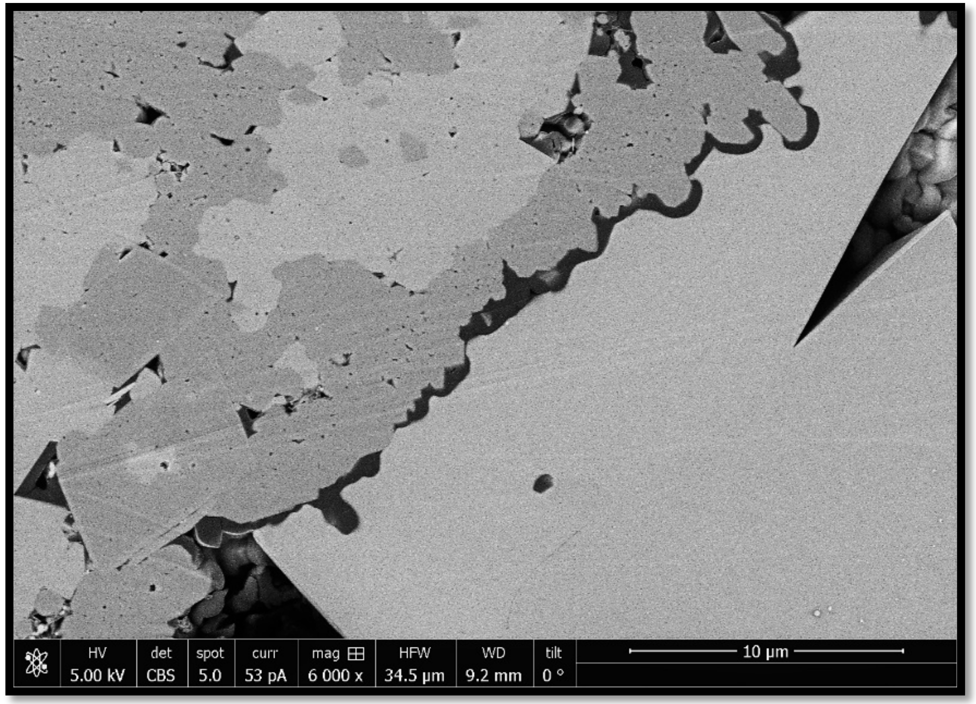


Mineral authigenesis



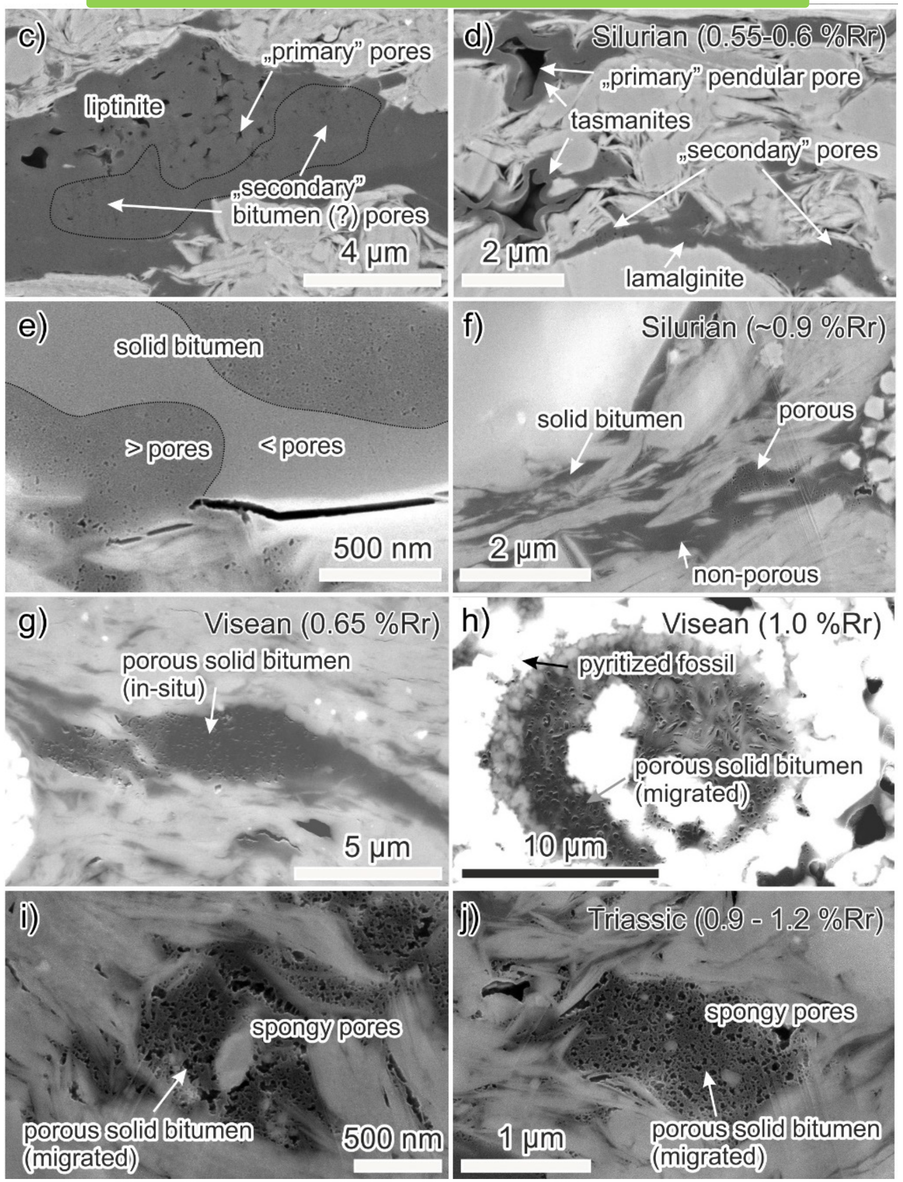
Two phase-fluid

(oil/SB – water)

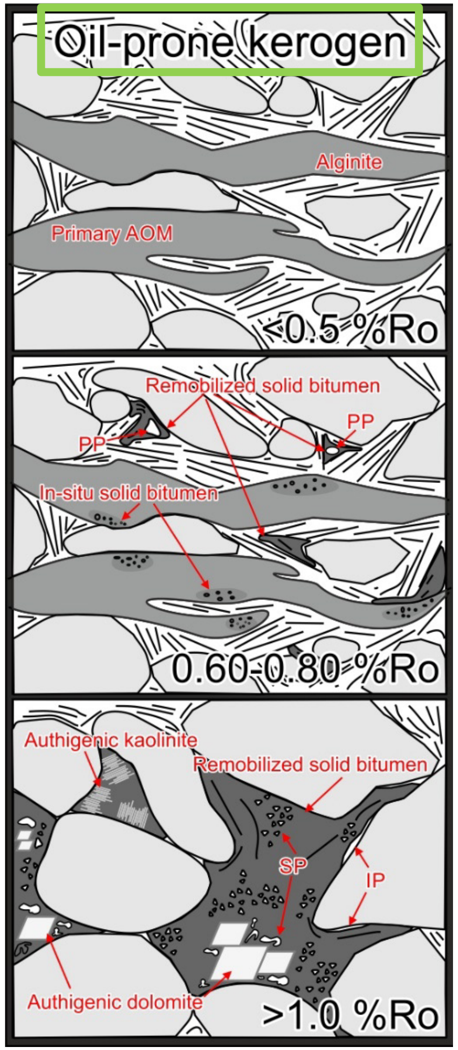


Solid bitumen porosity - organofacies

Oil-prone (Silurian – Triassic)



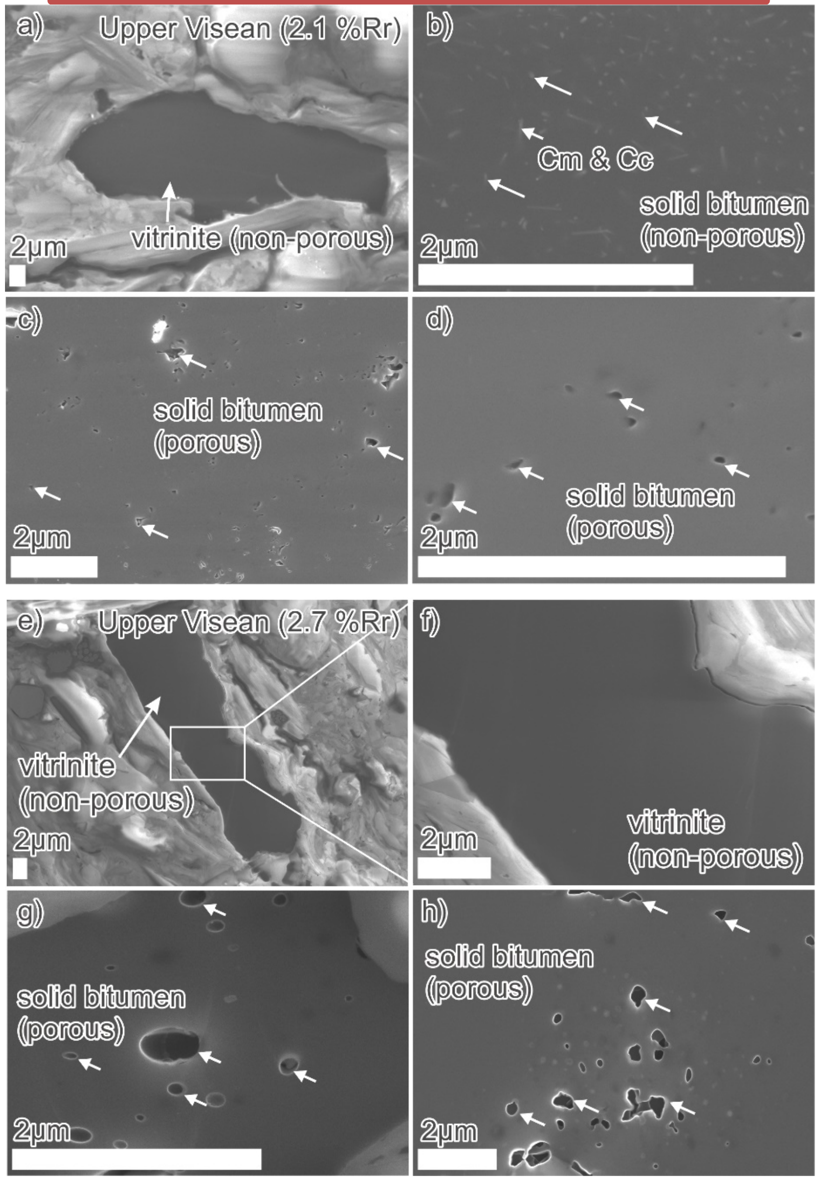
reactivity/mobility ↑

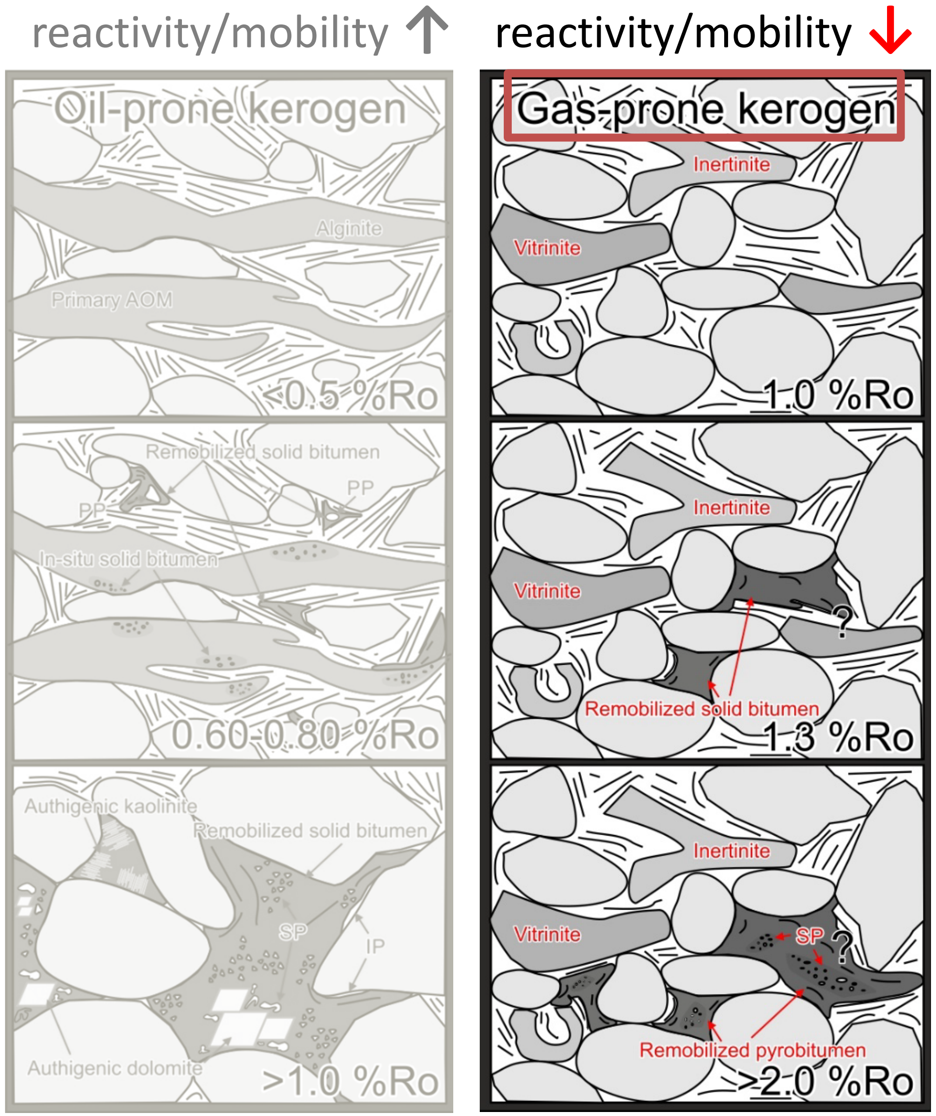


(~70 samples in total)

Solid bitumen porosity - organofacies

Gas-prone (Upper Visean)

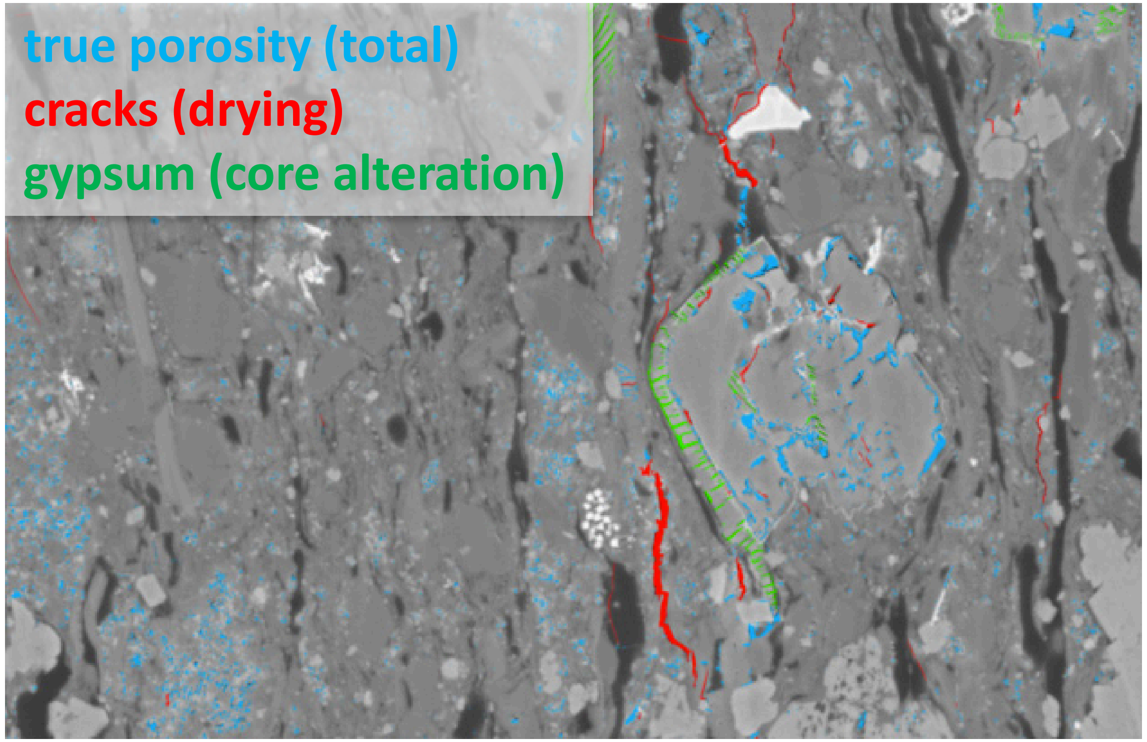




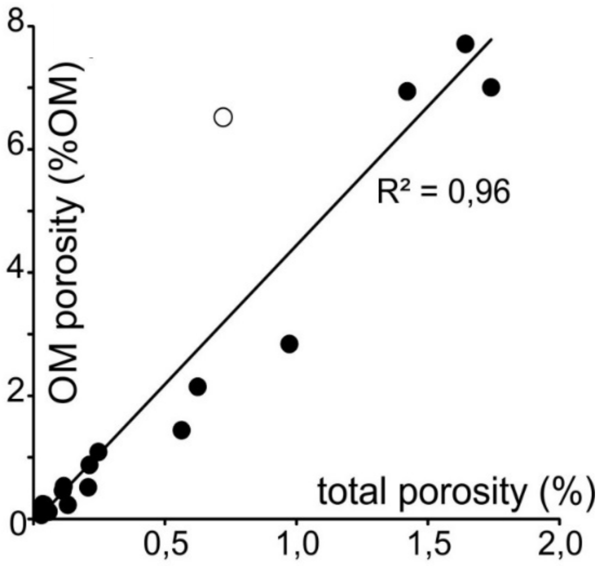
(~70 samples in total)

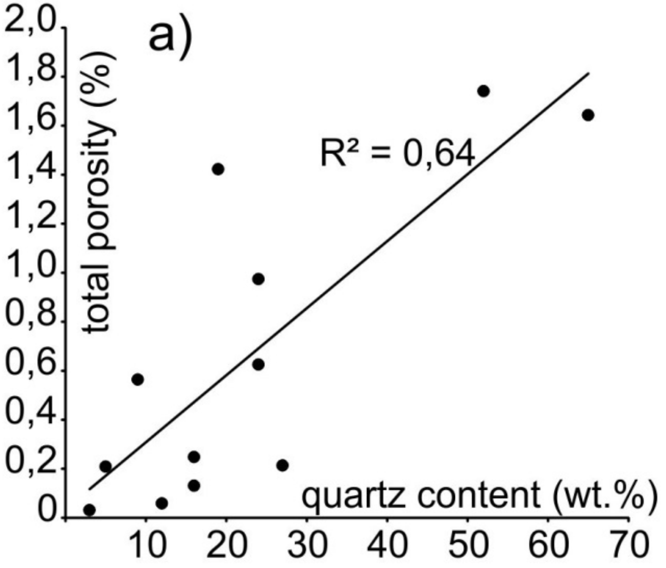
Quantification: total vs. OM-hosted porosity

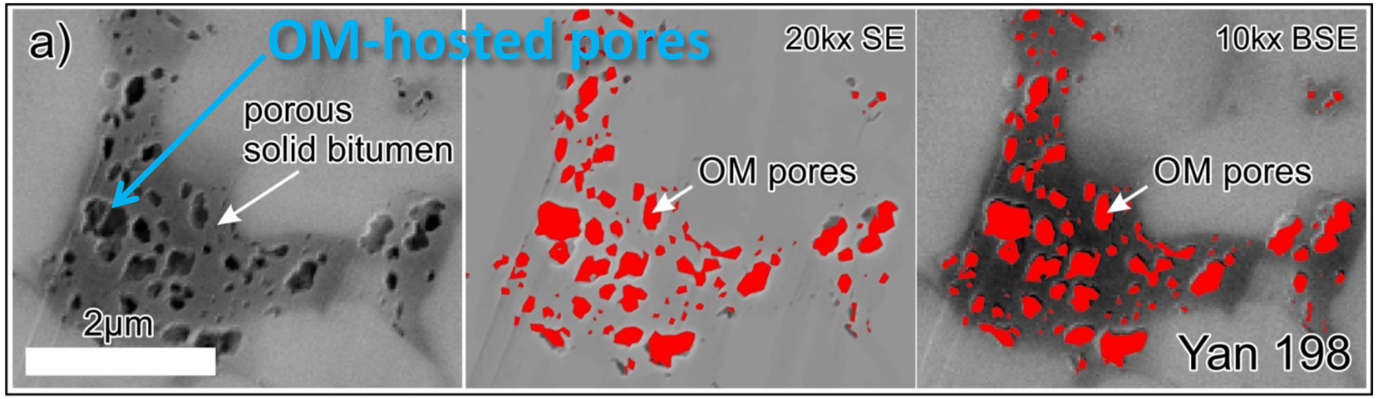
<u>BIB-SEM</u>: Segmentation of pores on representative areas



Upper Visean (17 samples)



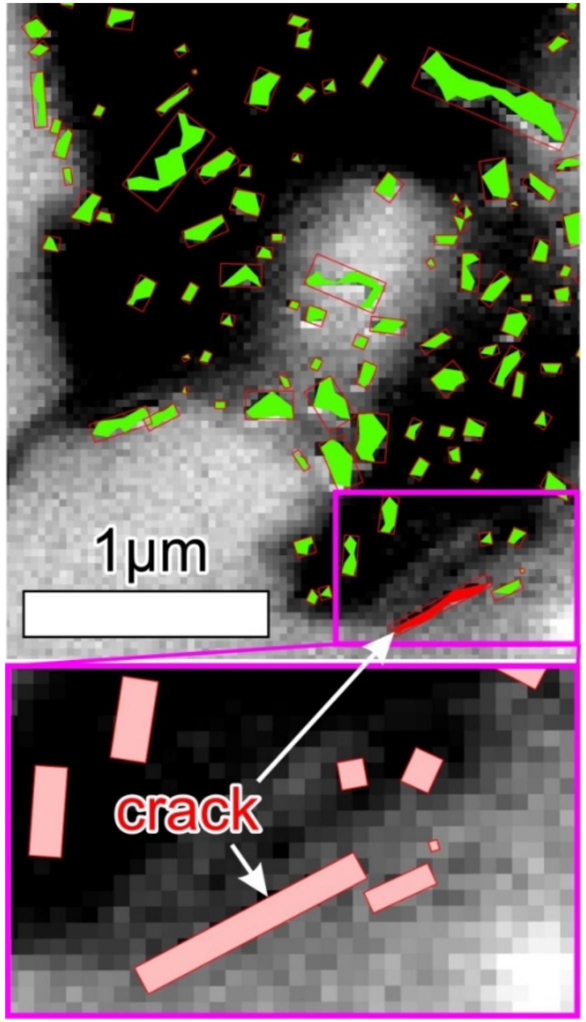


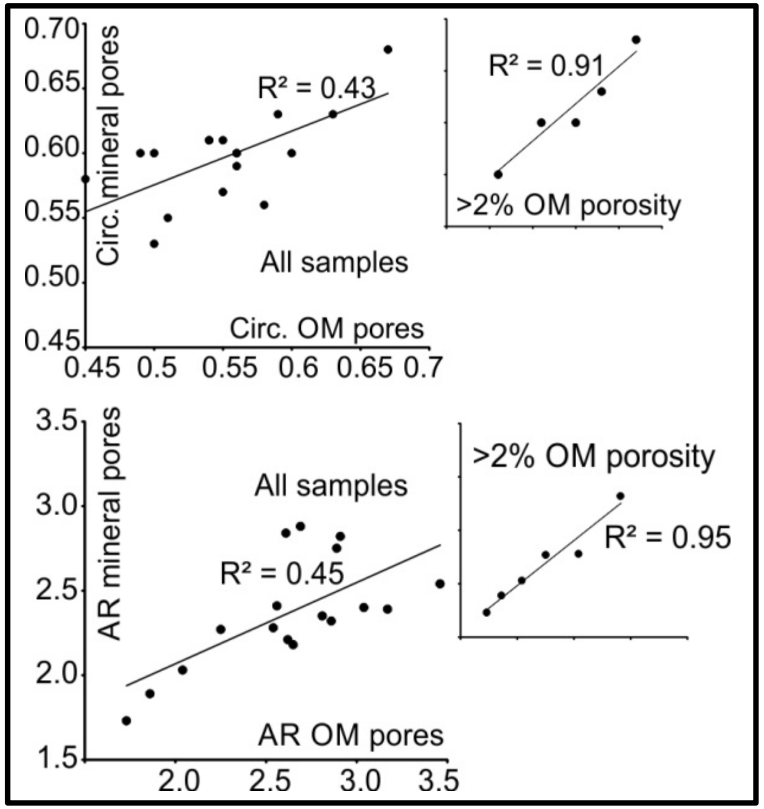


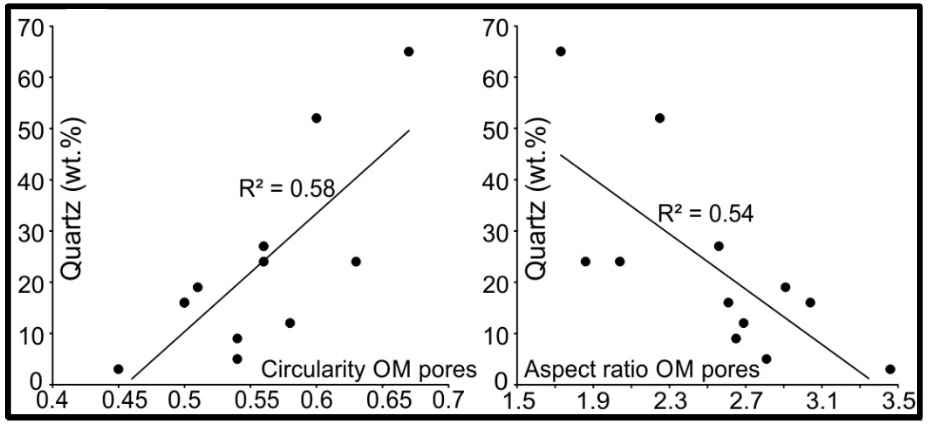
-> Correlation of ϕ_{total} vs. ϕ_{OM}

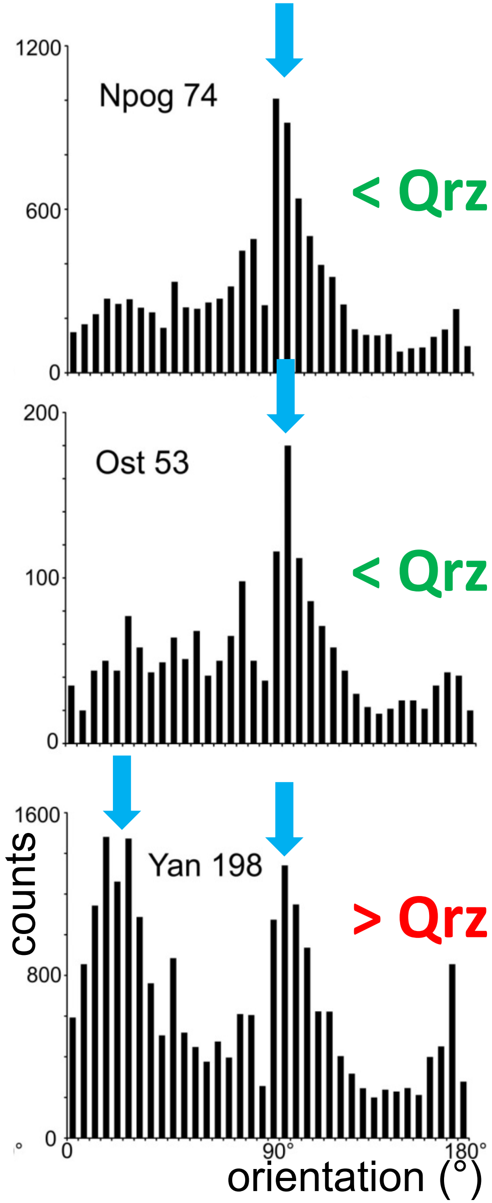
-> Weak correlation ϕ_{total} vs. wt% quartz

Influence of compaction on pores?

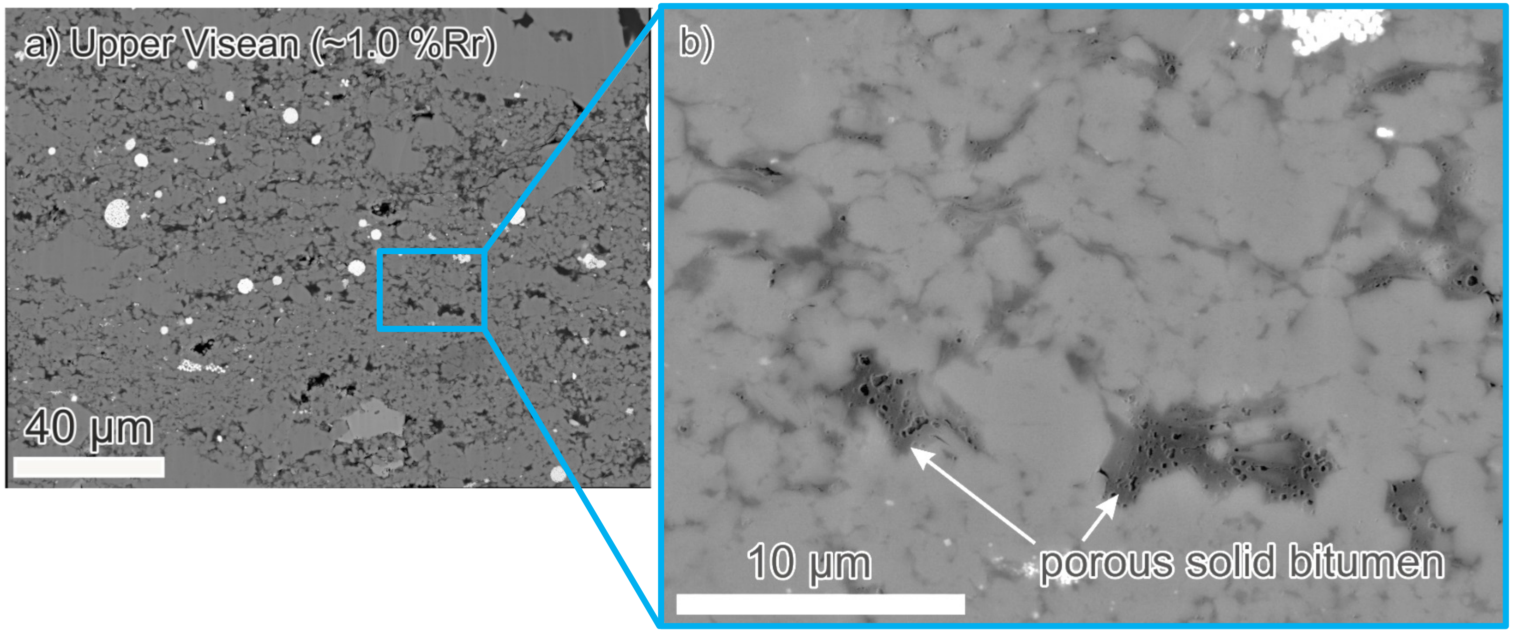






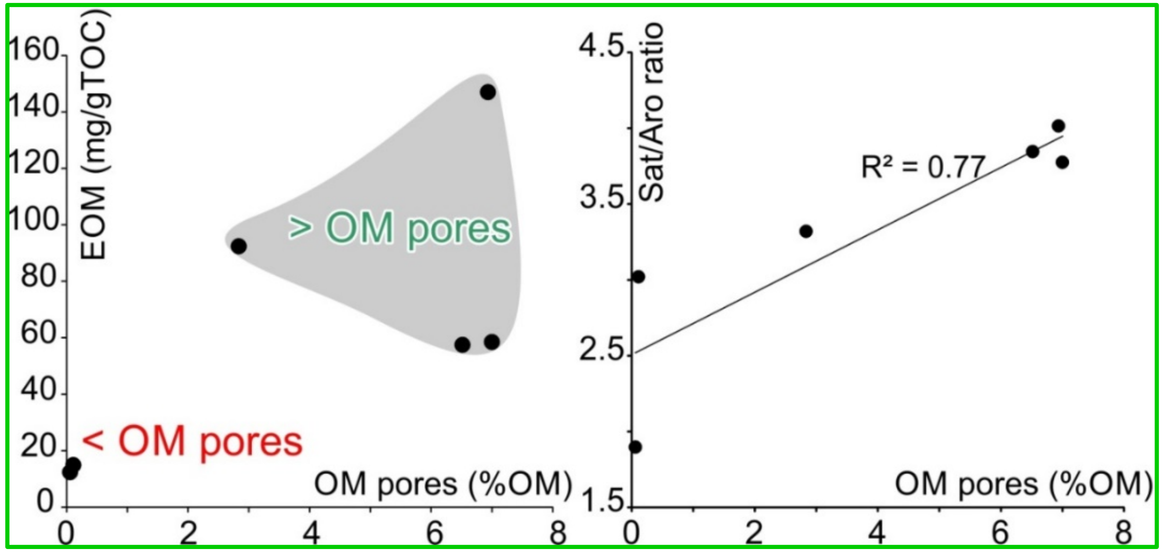


Hydrocarbon retention/expulsion



Often connected, porous networks

Extracts at equal maturity (1.0-1.1 %Ro VR)

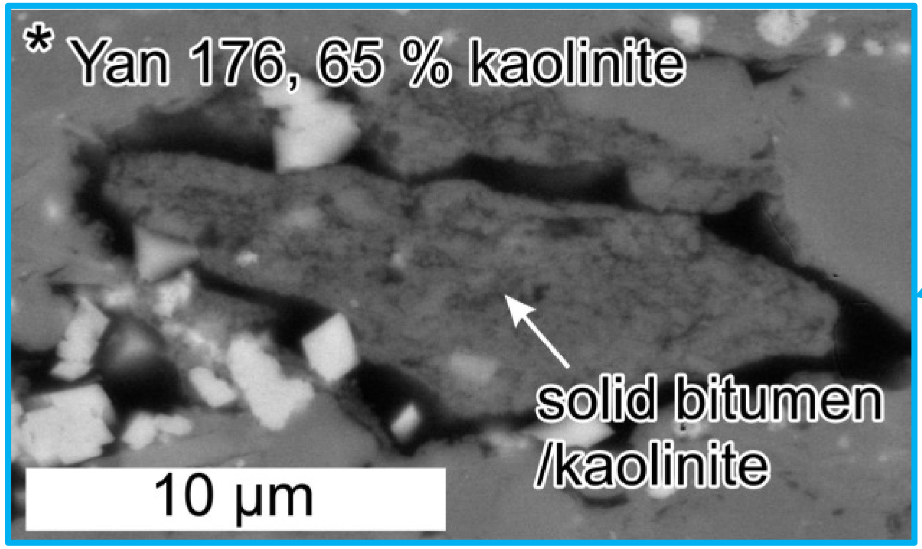


<u>Source rock extracts:</u>

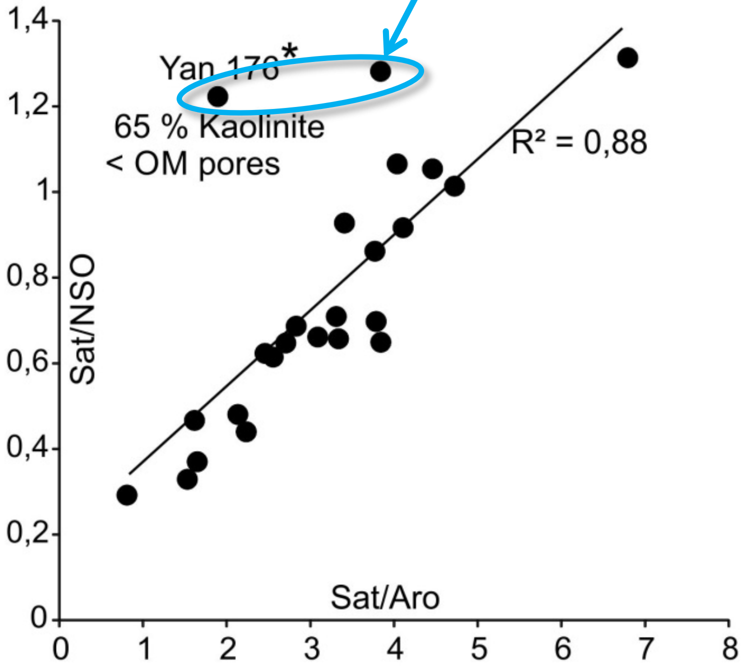
Composition suggests that solid bitumen pores are filled with a lighter HC phase

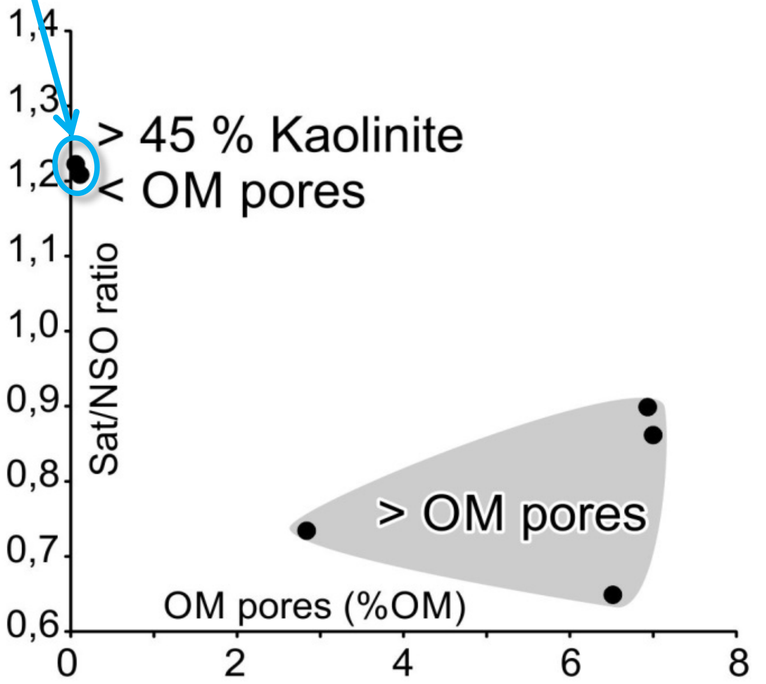
↑ OM-pores → ↑EOM & Sat/Aro

Hydrocarbon retention/expulsion



Selective retention of NSOs by kaolinite (?)





Hydrocarbon retention/expulsion

Upper Jurassic Mandal Fm. (Norway)

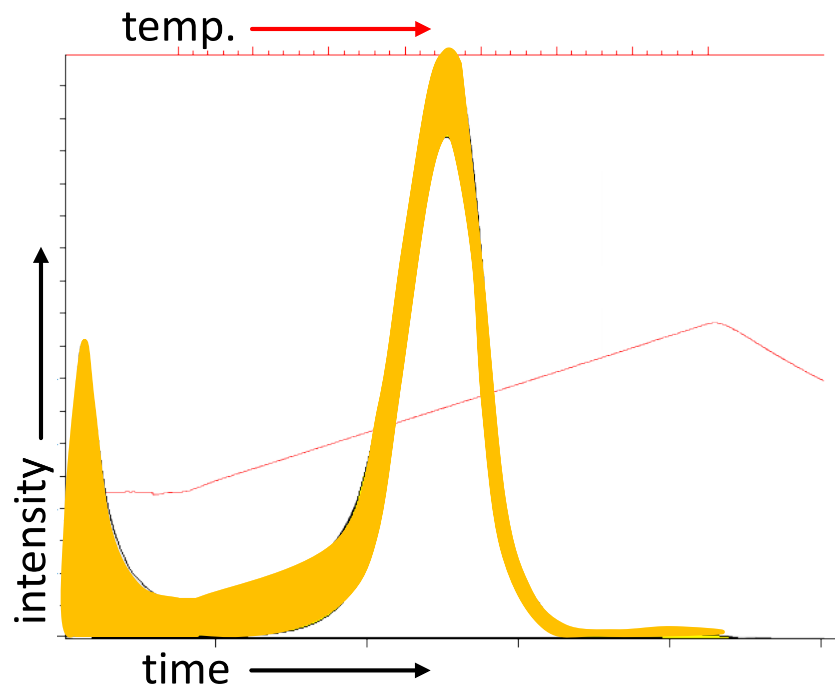
Petroleum Quality (PQ): $S1/S1+S2_{bitumen}$

Mixed type II/III kerogen

Total Petroleum: $S1+\mathbf{S2}_{\mathbf{bitumen}}$

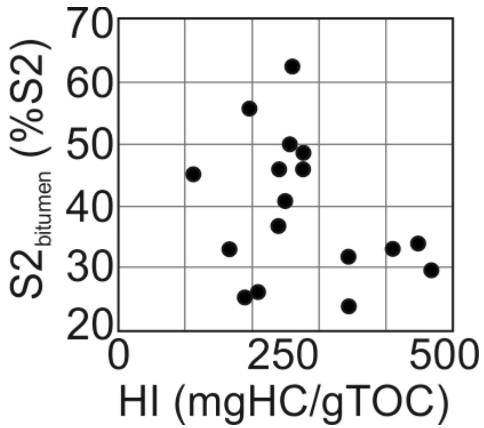
-> 30-60% of S2 peak extractable @ 430-450°C Tmax!

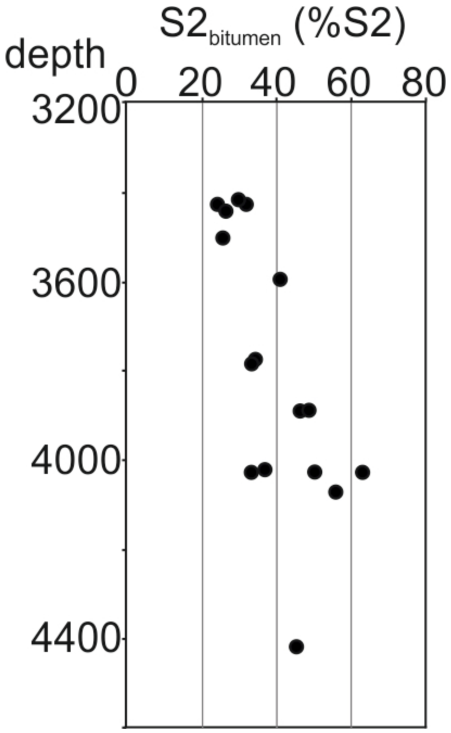
-> Important information on hydrocarbon storage and expulsion efficiency



Ziegs et al., 2017

No correlation!



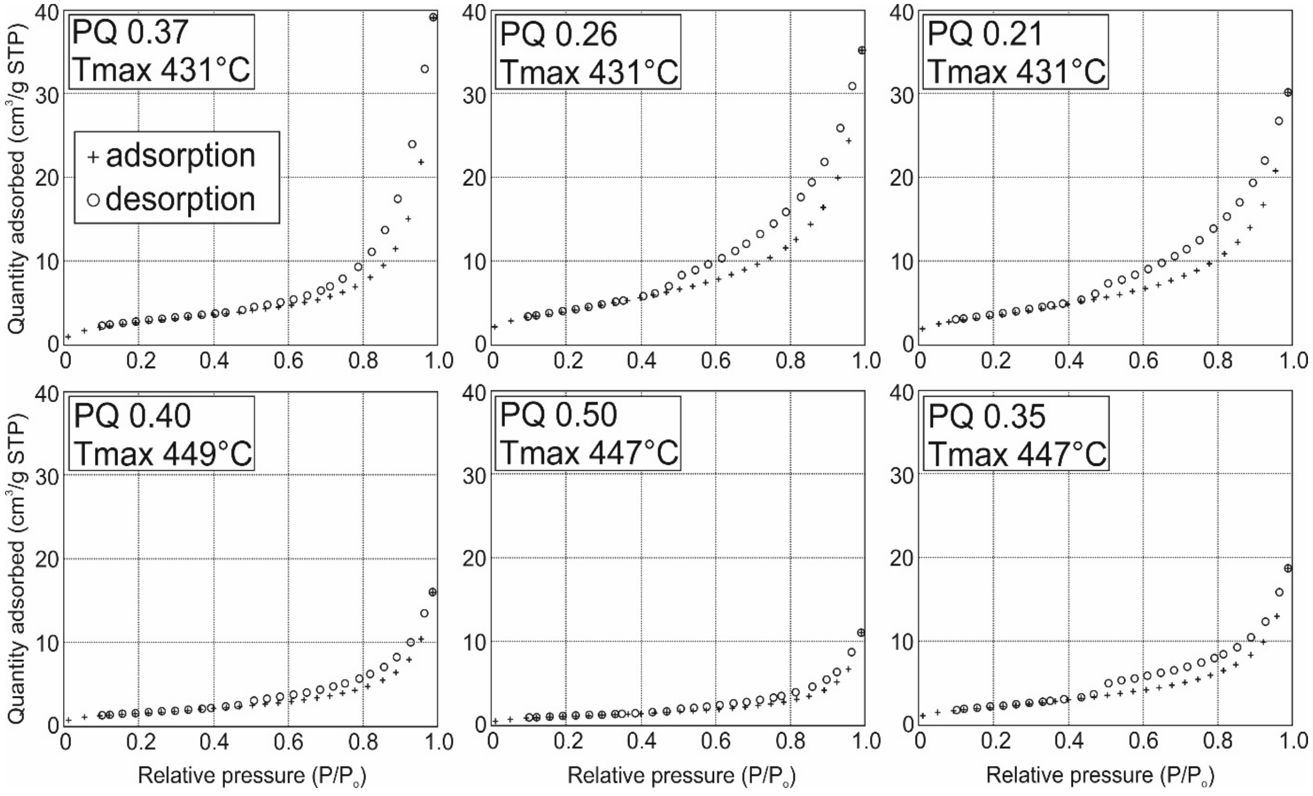


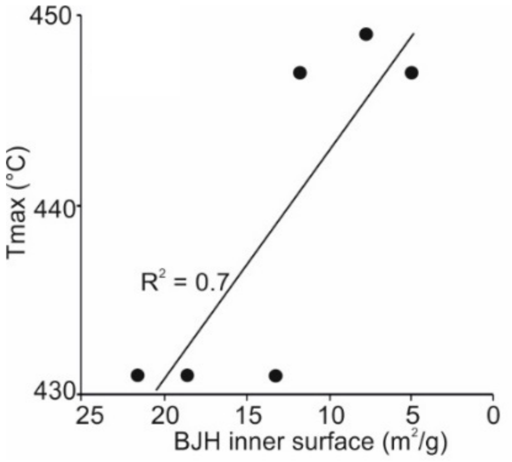
Hydrocarbon retention/expulsion

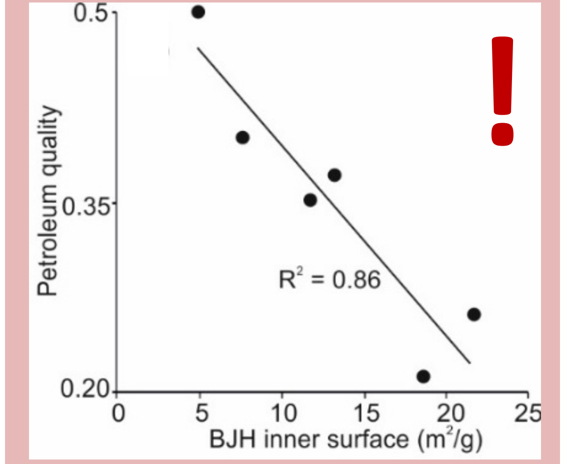
Upper Jurassic Mandal Fm. (Norway)

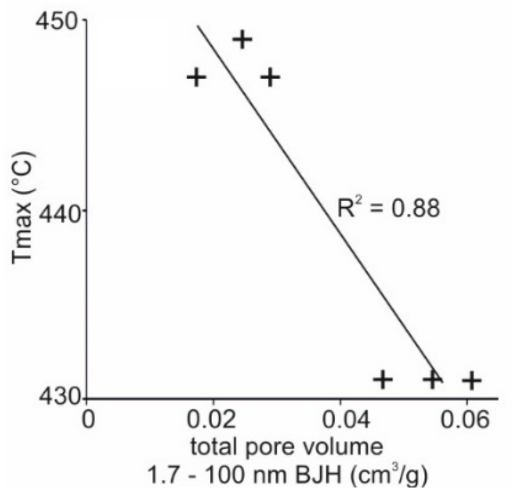
Petroleum Quality (PQ): $S1/S1+S2_{bitumen}$

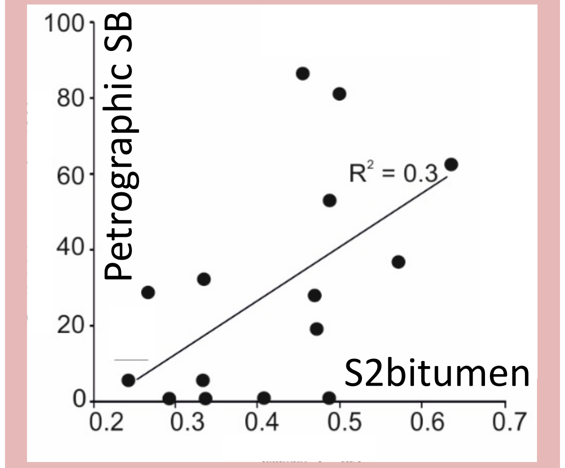
Nitrogen adsorption isotherms











Hydrocarbon retention/expulsion

MONTAN UNIVERSITÄT

Sorption capacity ↓

!

SEM-visible SB porosity ↑

Low PQ → **High** PQ

Upper Jurassic

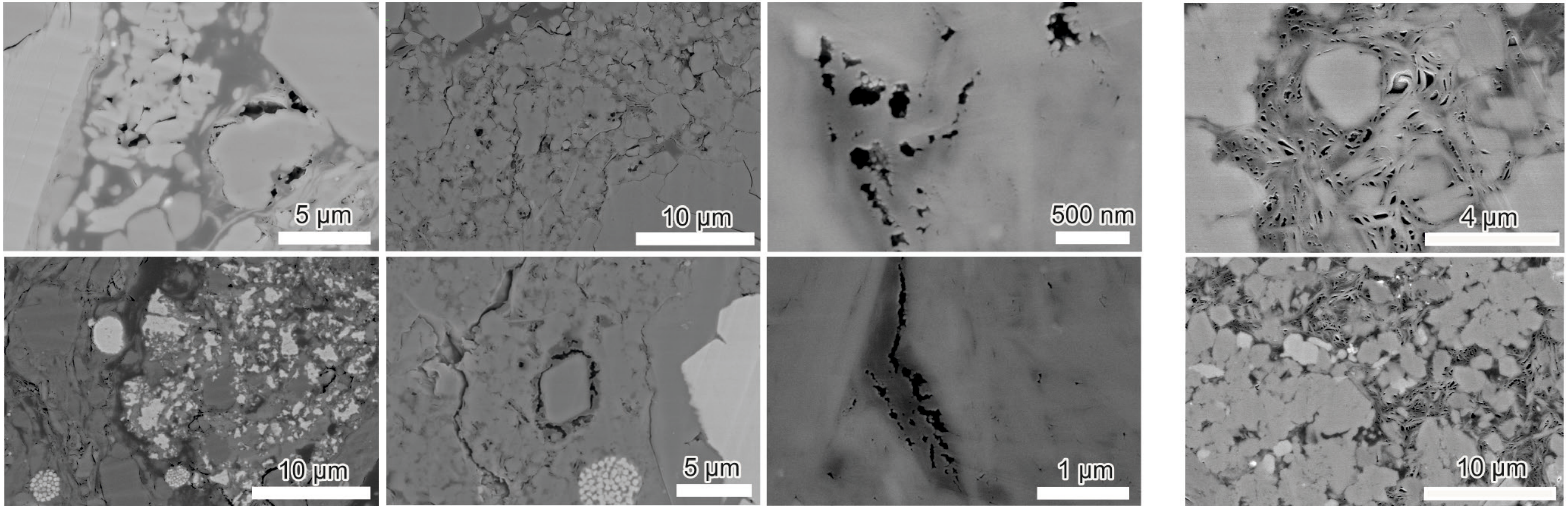
Upper Visean

431°C; PQ 0.21
32 %$S2_{bit}$; total oil 6.03

436°C; PQ 0.37
49 %$S2_{bit}$; total oil 17.50

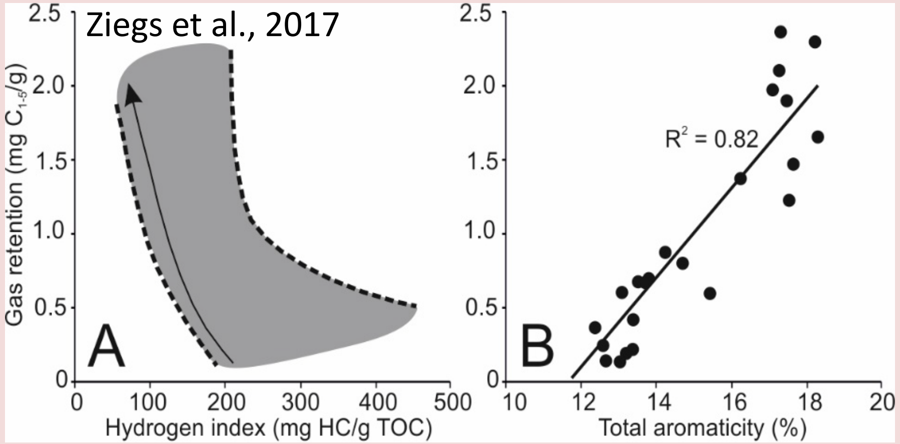
449°C; PQ 0.4
50 %$S2_{bit}$; total oil 9.51

463°C; PQ 0.69
11 %$S2_{bit}$; total oil 1.9 mg/g

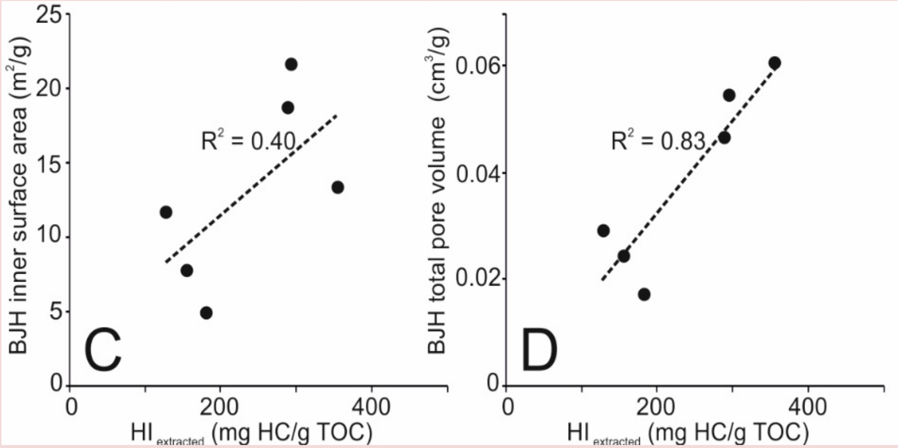


Hydrocarbon retention/expulsion

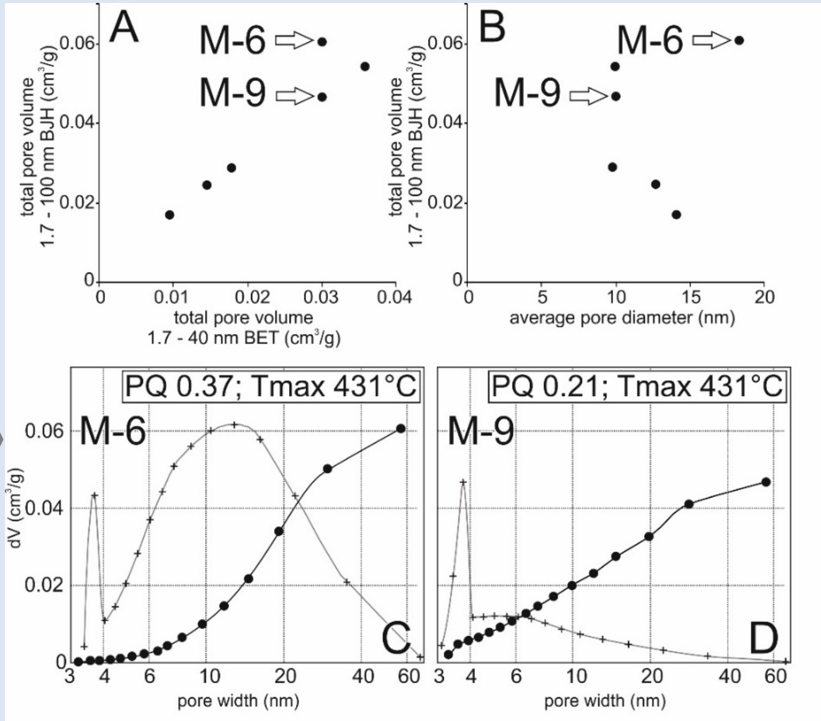
Microporosity (< 2nm) dominated by $S2_{bitumen}$:

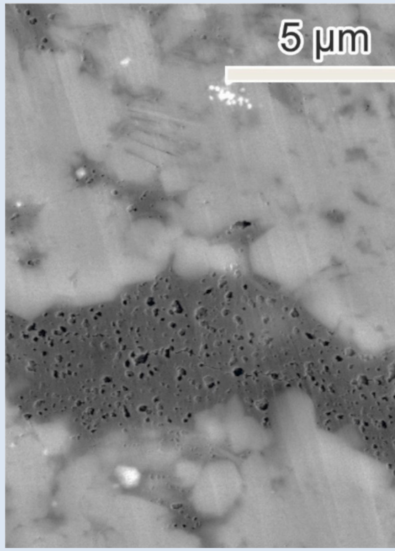


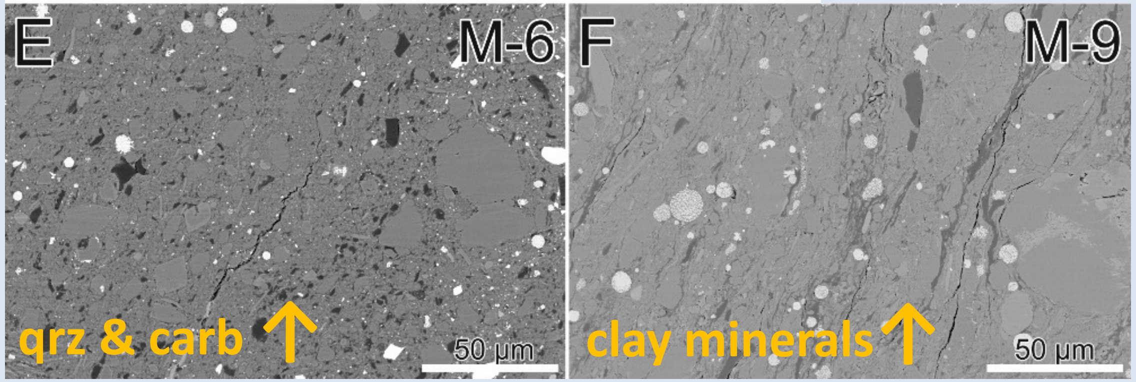
Organofacies & Maturity



Meso- & macroporosity (2-200 nm) controlled by clay (mineralogy) & „SEM-porous“ solid bitumen:



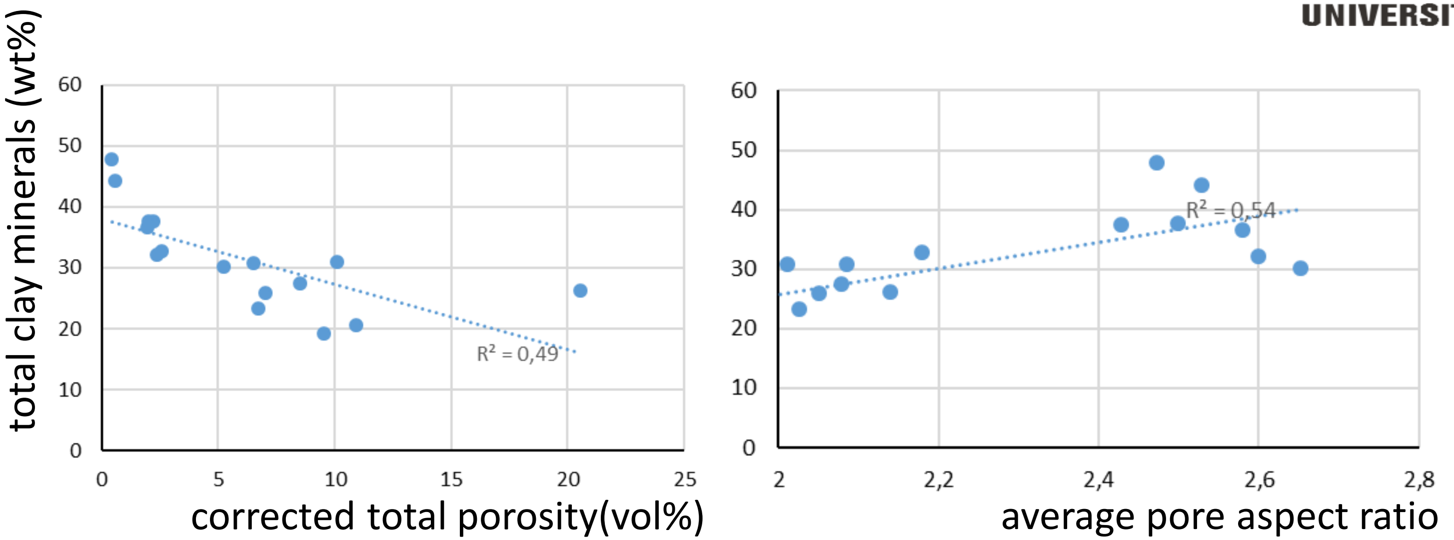




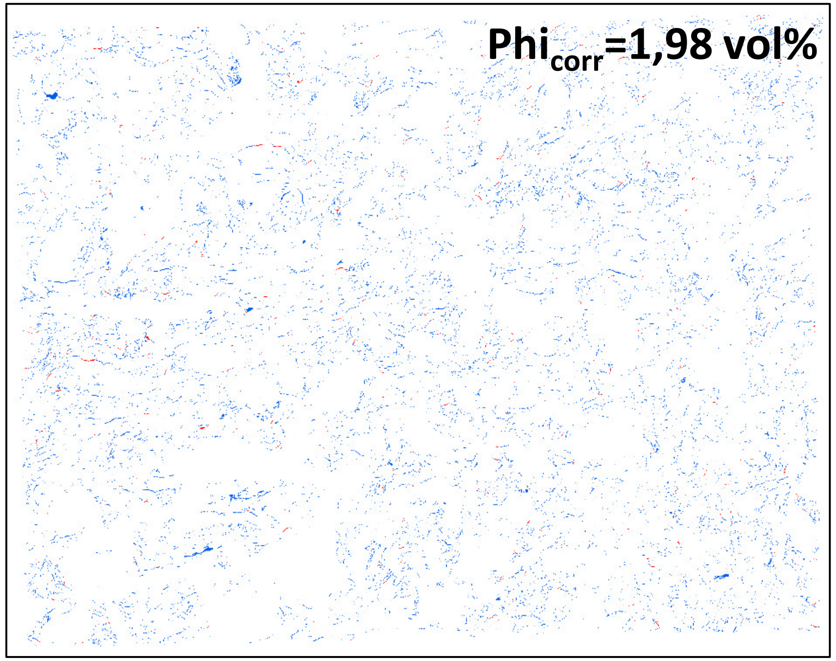
Cap rock integrity: BIB-SEM

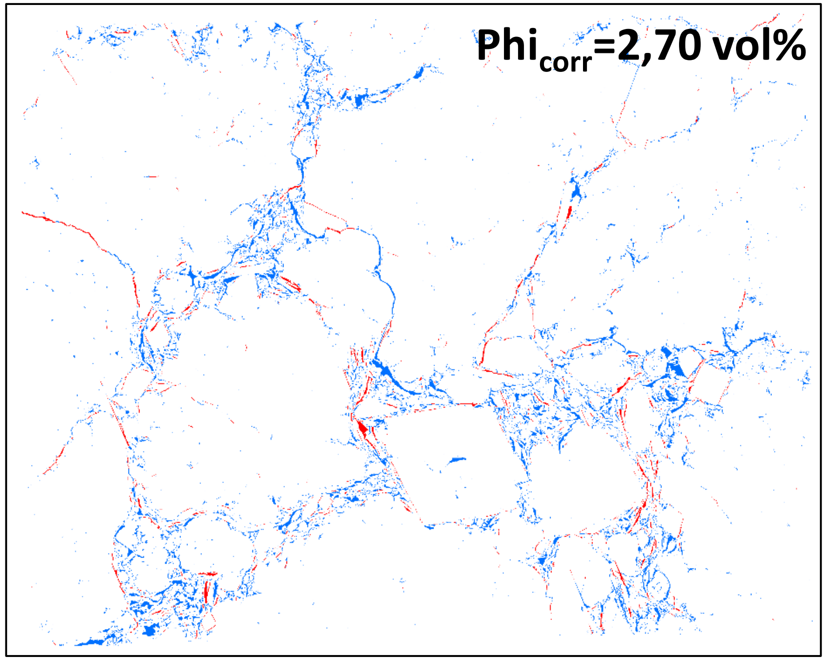
Miocene cap rocks (Vienna Basin)

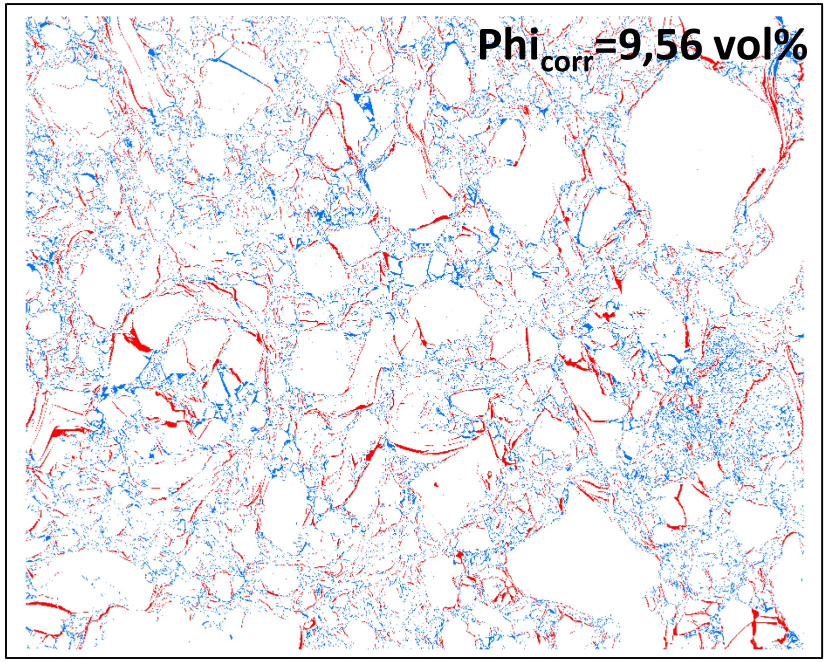
- Pore size distributions
- **Geometry (Area, Perimeter, AR, Circ)**



BIB-SEM study to investigate flow paths



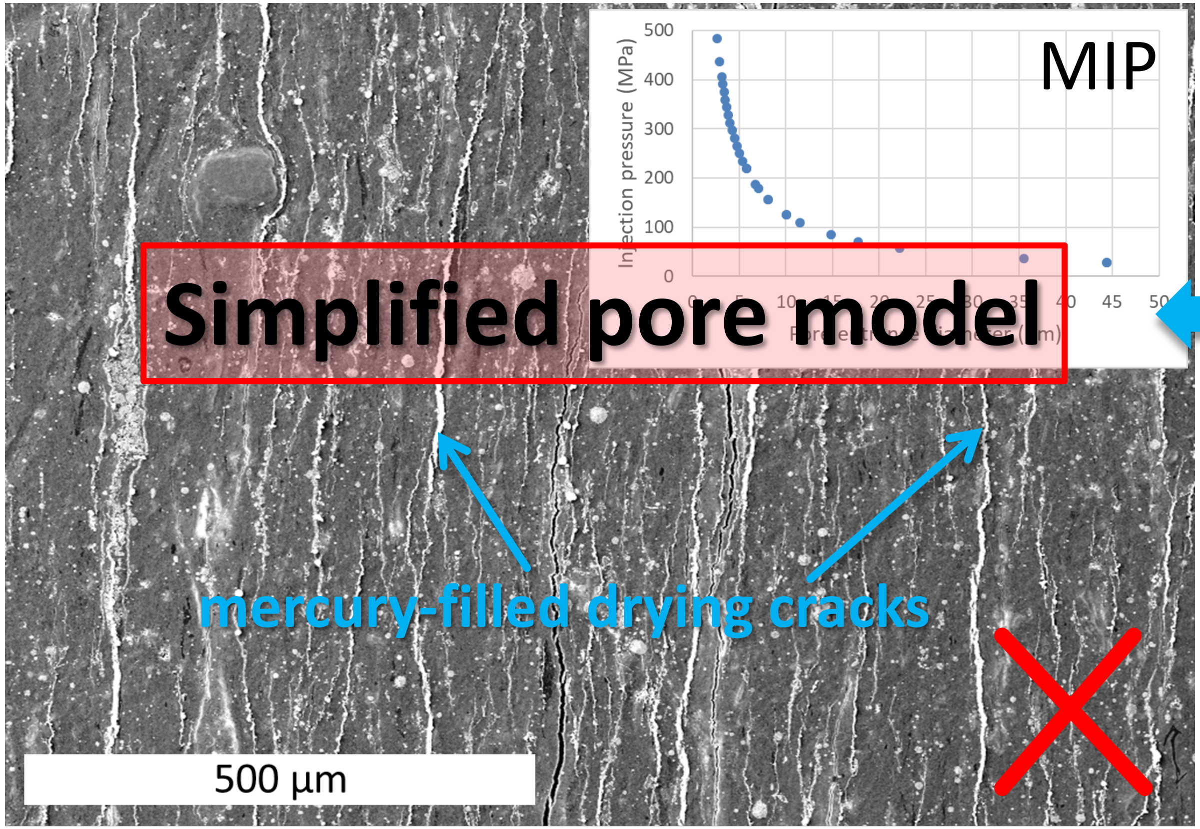


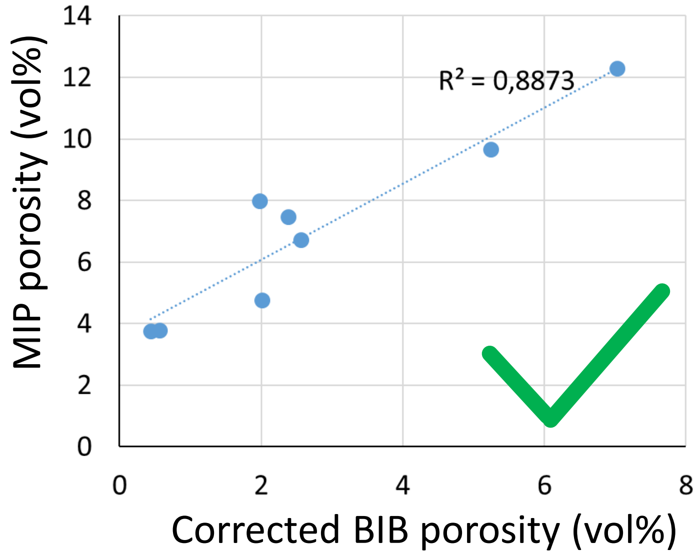


Cap rock integrity: MIP vs. BIB porosity

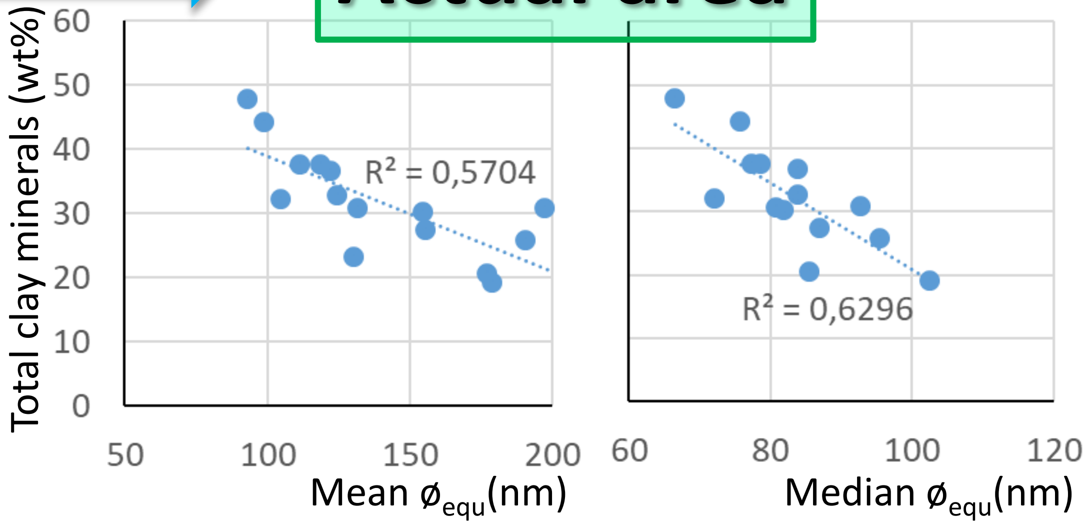
Miocene cap rocks (Vienna Basin)

-> **Validation** of petrophysical methods
(e.g., **M**ercury **I**ntrusion **P**orosity - MIP)





Actual area



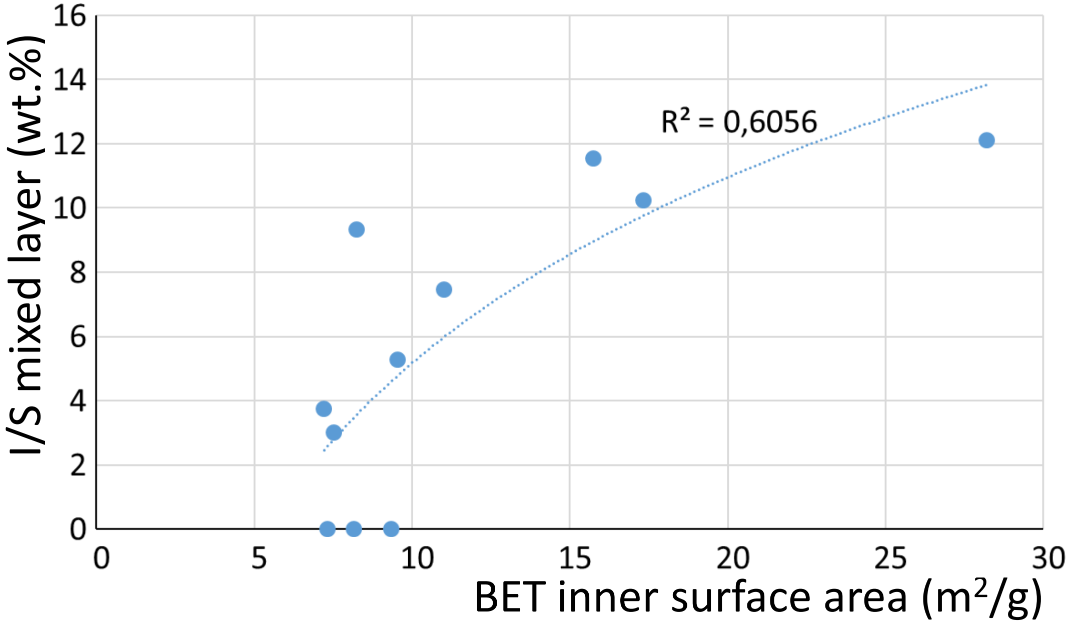
Cap rock integrity: sorption

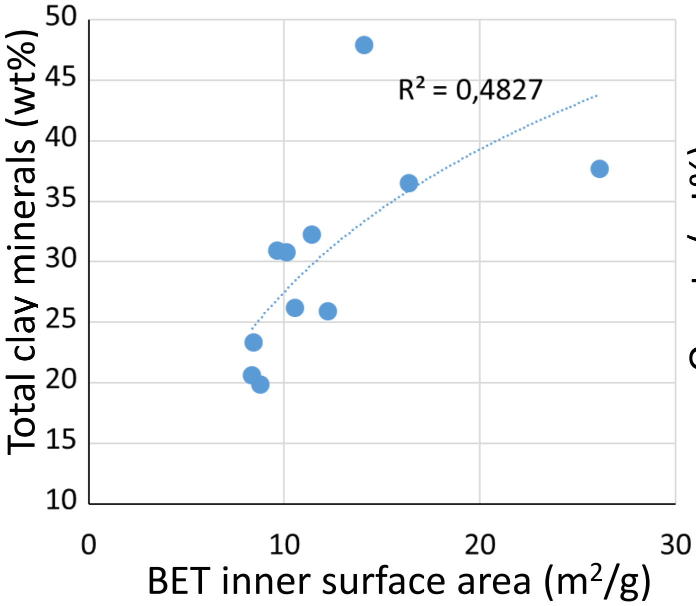
Miocene cap rocks (Vienna Basin)

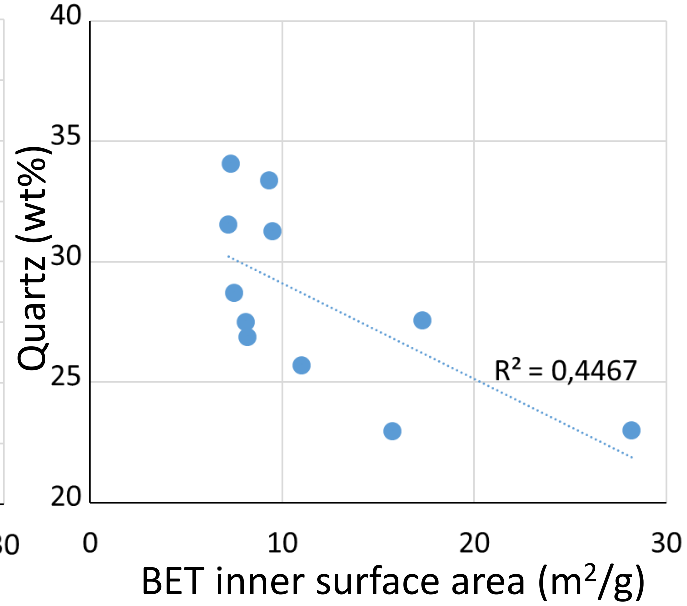
Nitrogen adsorption isotherms

-> Trends are also observed in **matrix mesopores (BET: 2-40 nm)**

-> Influence on **gas retention?**







Summary & Outlook

- Comprehensive understanding of **depositional and diagenetic influences on storage/expulsion**

- Input for **mechanical and transport modelling** of experimentally inaccessible material properties