Structural Diagenesis in an Upper Carboniferous Tight Gas Sandstones Reservoir Analog*

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Abstract

The effective exploration of unconventional hydrocarbon reservoirs such as tight gas sandstones is getting more important as conventional hydrocarbon reservoirs are becoming increasingly scarce. Gas from tight gas reservoirs has been successfully produced in the Lower Saxony Basin, Germany, for more than four decades but only contributes with a minor amount to the overall gas production. Unconventional reserves however are vast and could significantly support the supply with domestic gas in Central Europe over the next decades, if reservoir quality predictions as well as production technologies can be improved. We integrate quantitative data from a reservoir outcrop analogue and contribute to the understanding of the effect of structural diagenesis, which in turn may contribute to an enhancement of recovery factors of tight gas sandstone reservoirs in the region. We demonstrated that the Piesberg quarry near Osnabrueck, northwest Germany acts as a suitable reservoir outcrop analogue to Upper Carboniferous tight gas fields of the Lower Saxony Basin in terms of size, facies, structural inventory and diagenesis. This study focuses on the multi-scale reservoir heterogeneity exposed in the Piesberg quarry, comprising fluvial sandstone cycles of Pennsylvanian age. The main porosity is secondary and resulted mostly from carbonate leaching and limited dissolution of feldspar. Porosity variations are both stratigraphically and structurally controlled. Primary pore space was occluded by the development of a pseudomatrix resulting in low porosities (<10%) and very low permeabilities (<0.01 mD). Lateral and vertical variations of reservoir properties within depositional facies and stratigraphic cycles are well documented in high-resolution wall panels displaying porosity and permeability distributions. Structurally controlled matrix porosities increase up to five orders of magnitude (up to 25%) in fault corridors. Fractures and fault planes are quartz-cemented around faults,

indicating localized mass transport and may be associated with the structural and diagenetic evolution of the Upper Carboniferous of the Piesberg area. Within this R&D project, a predictive model for the carbonate cement distribution and related porosity-permeability variations in Upper Carboniferous sandstones will be established. Reservoir quality is structurally and stratigraphically controlled, which might lead to new well placements close to faults. This may change future tight gas exploration.

Reference Cited

Adriasola Muñoz, Y., R. Littke, and M.R. Brix, 2007, Fluid systems and basin evolution of the western Lower Saxony Basin, Germany: Geofluids, v. 7, p. 335-355.

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AAPG ICE 2014

Unconventional Resources: Tight Sand Plays

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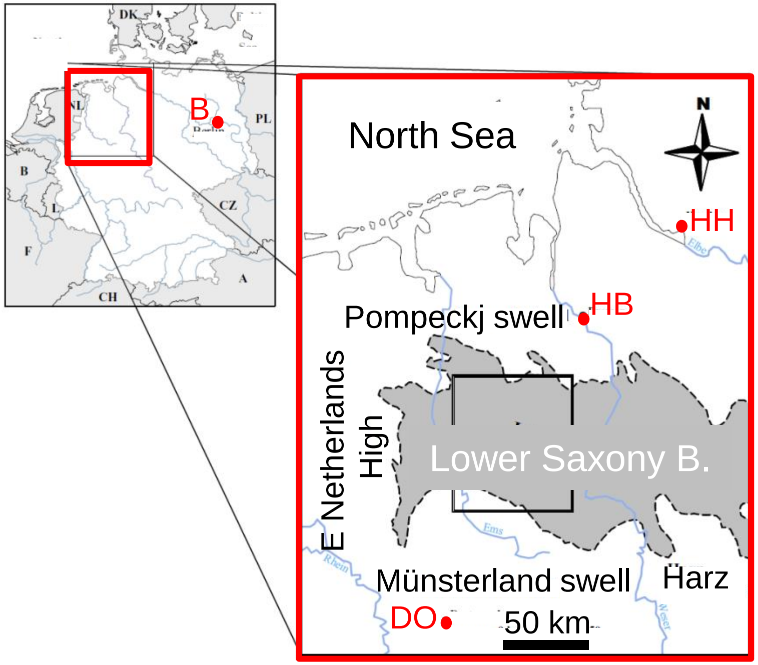
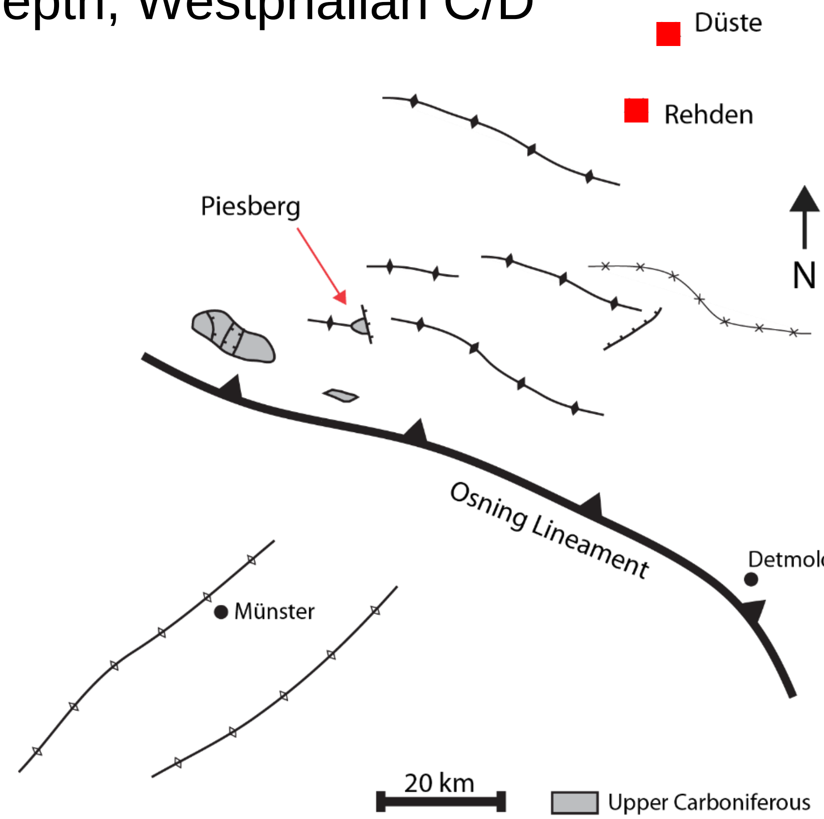
Location outcrop analog vs. wells

- **Piesberg outcrop analog**: surface, Westphalian C/D (Pennsylvanian)
- **Düste tight gas field**: ~ 4 km depth, Westphalian C - Stephanian (Pennsylvanian)
- **Rehden tight gas field:** ~ 2 km depth, Westphalian C/D (Pennsylvanian)



after Adriasola Muñoz 2007



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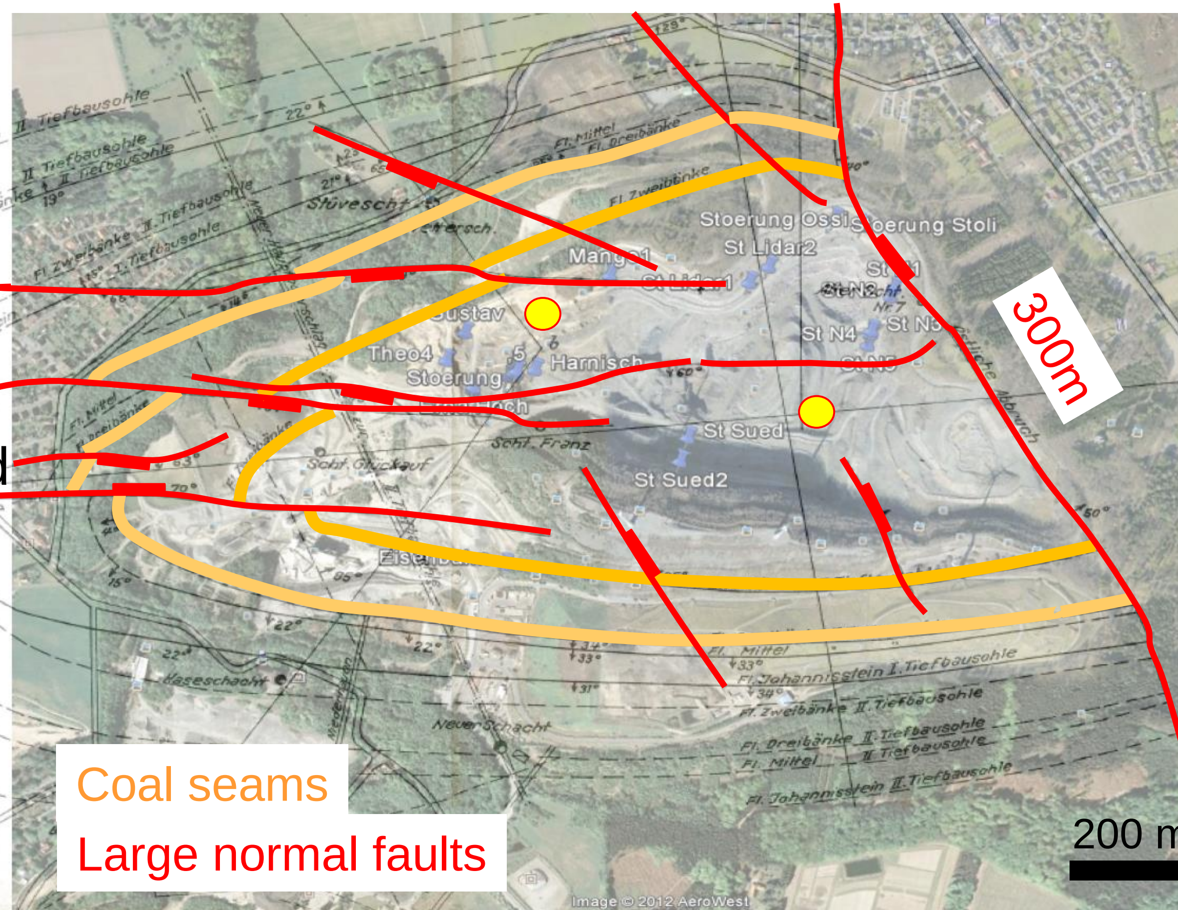
The Piesberg as reservoir analog

- Similar stratigraphy
- Similar fault strikes
- Similar scale
- Large “seismic-scale” faults
- Unique, large & deep quarry
- Size that 2 wells would fit in one quarry



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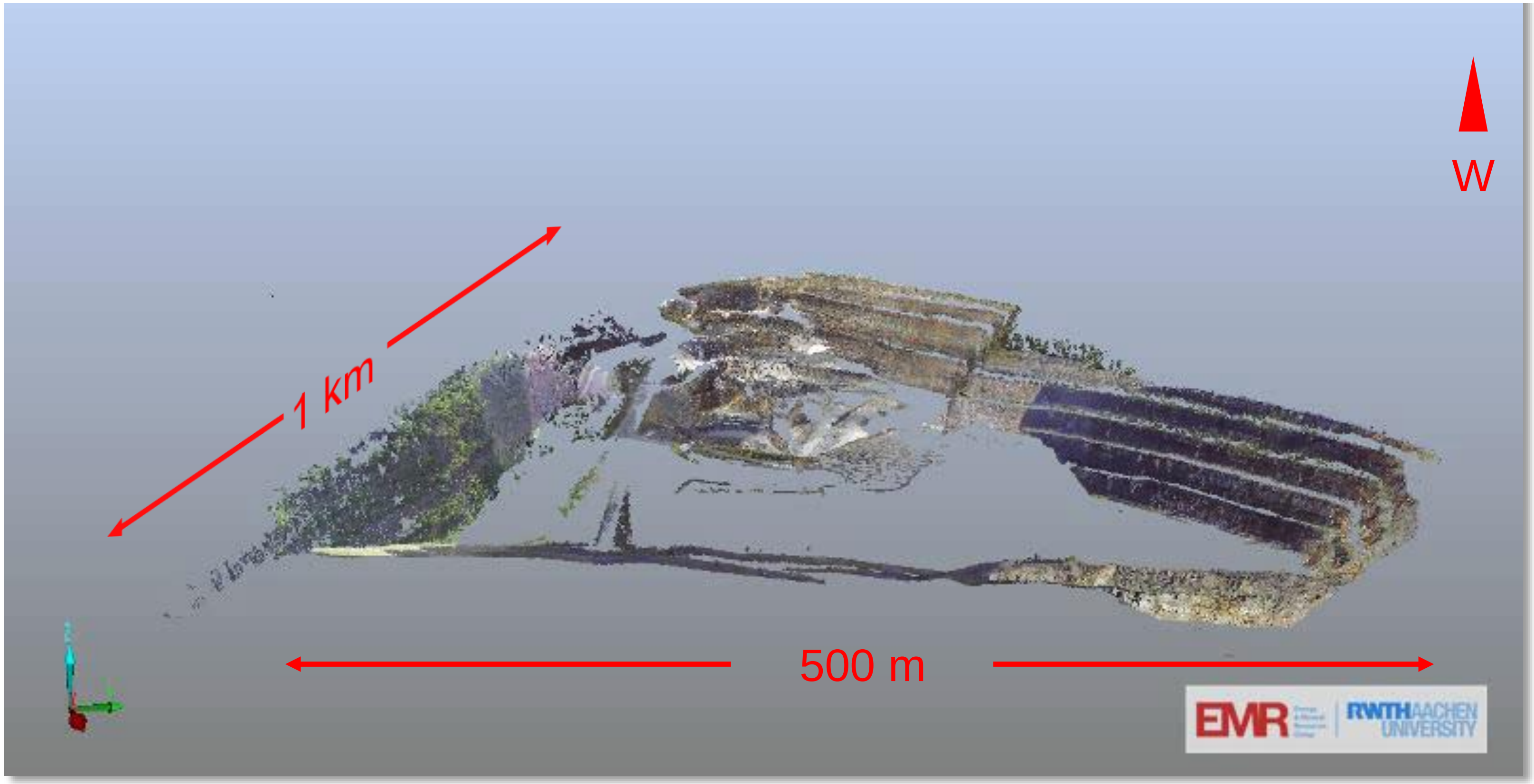
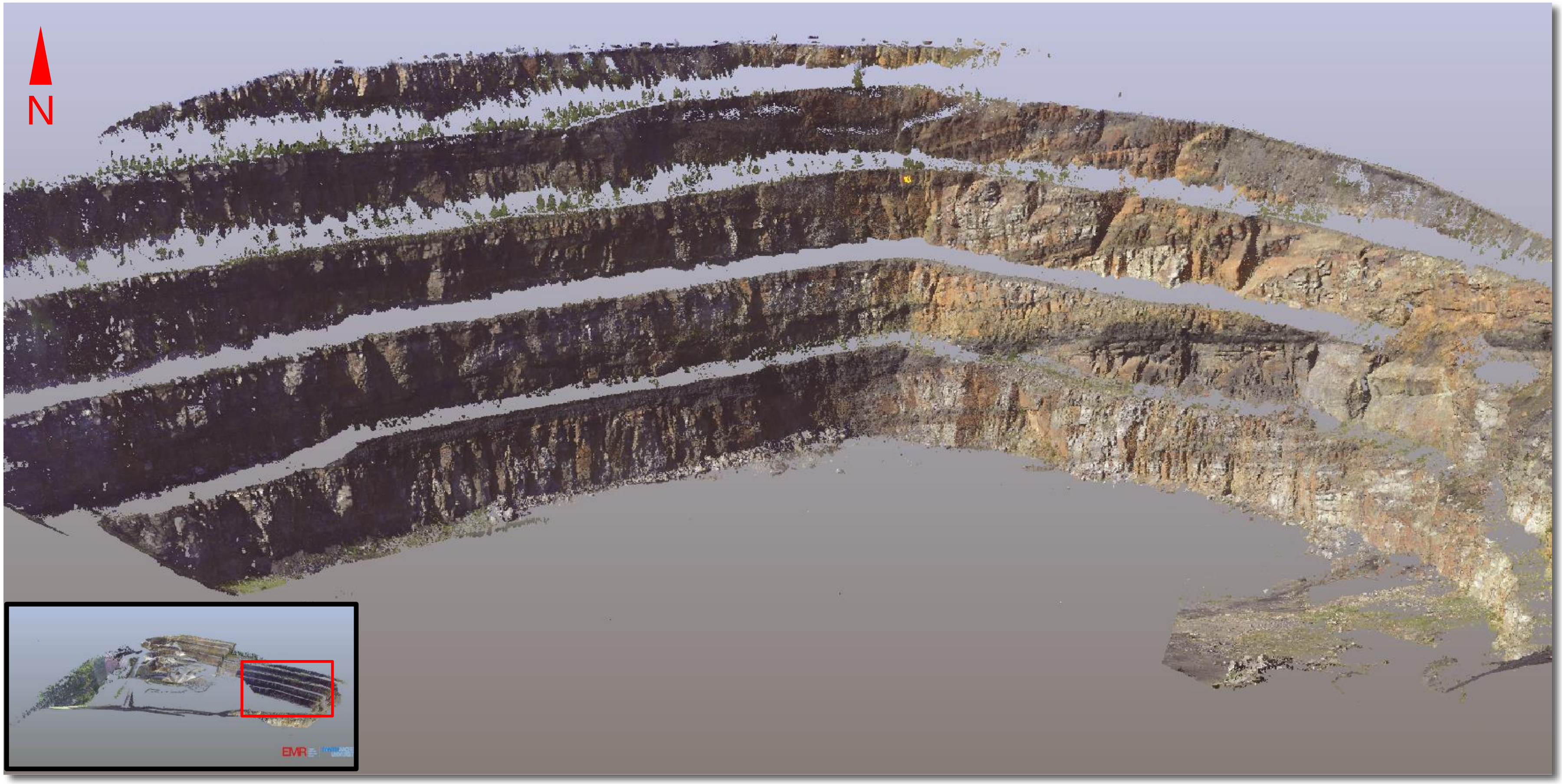
Take the outcrop home

- Terrestrial Laser scanning
- Geo-referenced 3D model → high resolution reservoir model



Fracture network analysis

- NW of quarry, lowermost stratigraphic position
- Color-coded main fracture orientations



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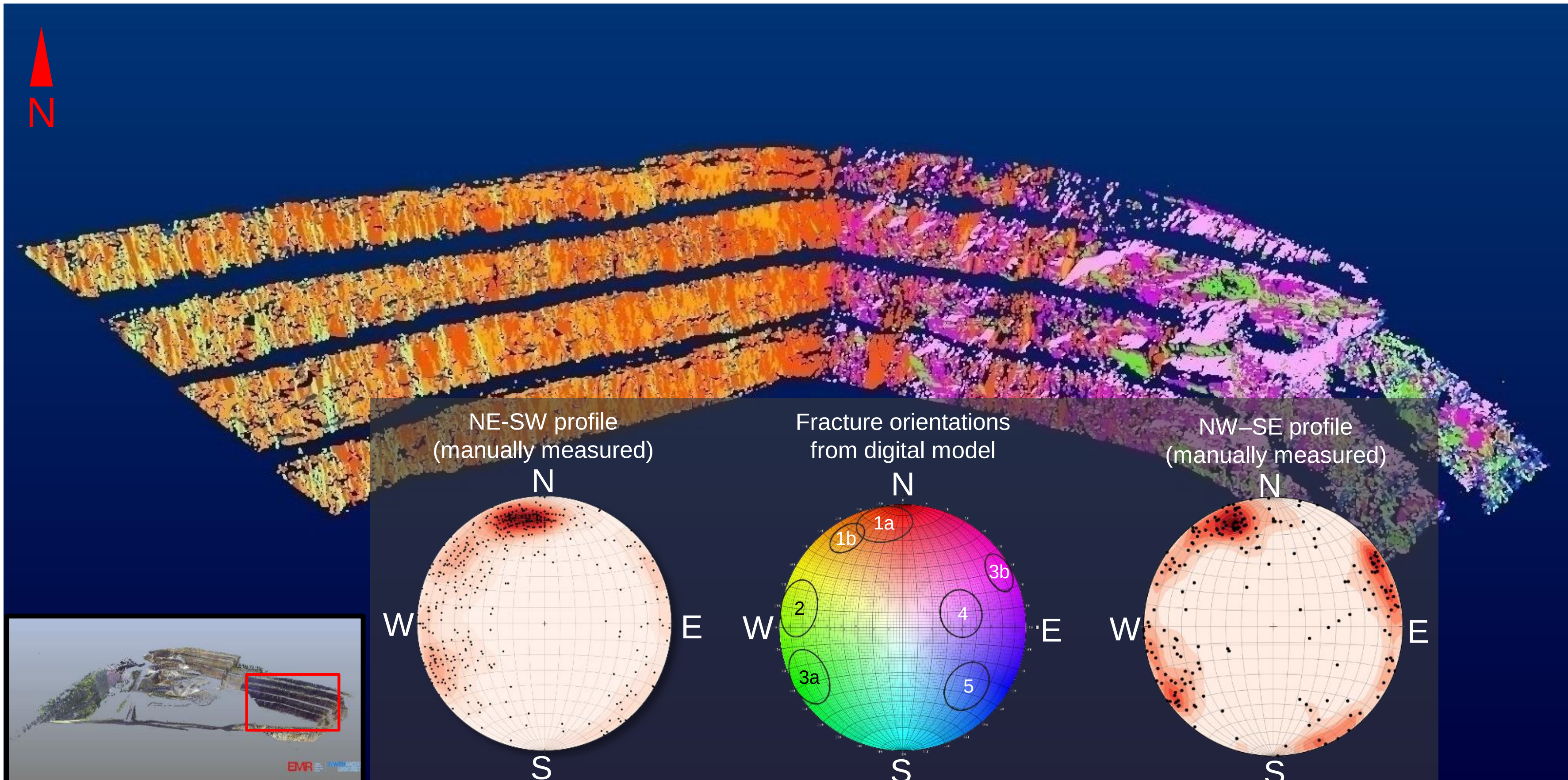

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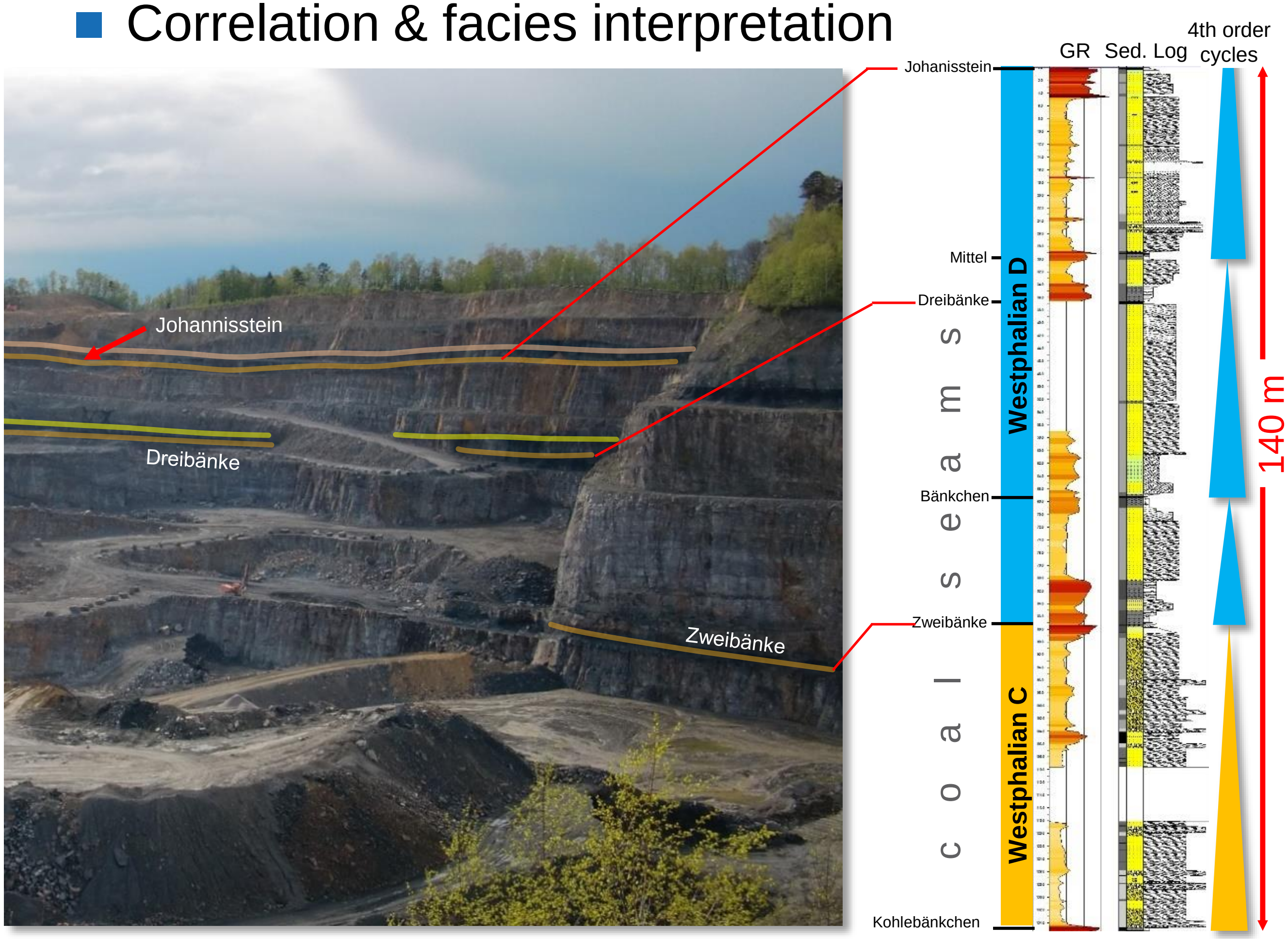
Gamma Ray assisted lithology log

- Piesberg exposes 4 fourth-order fluvial fining-upward cycles
- Correlation & facies interpretation



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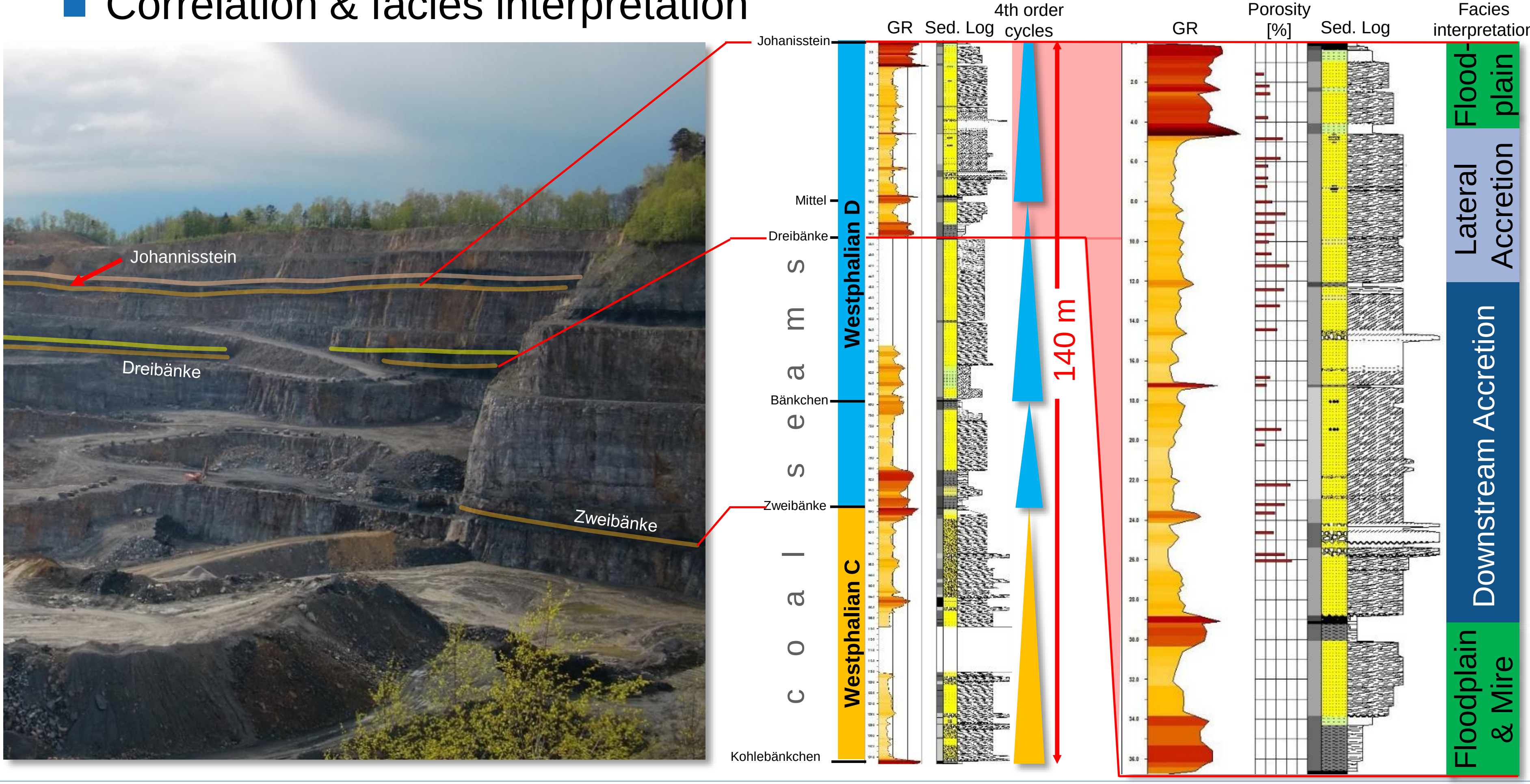

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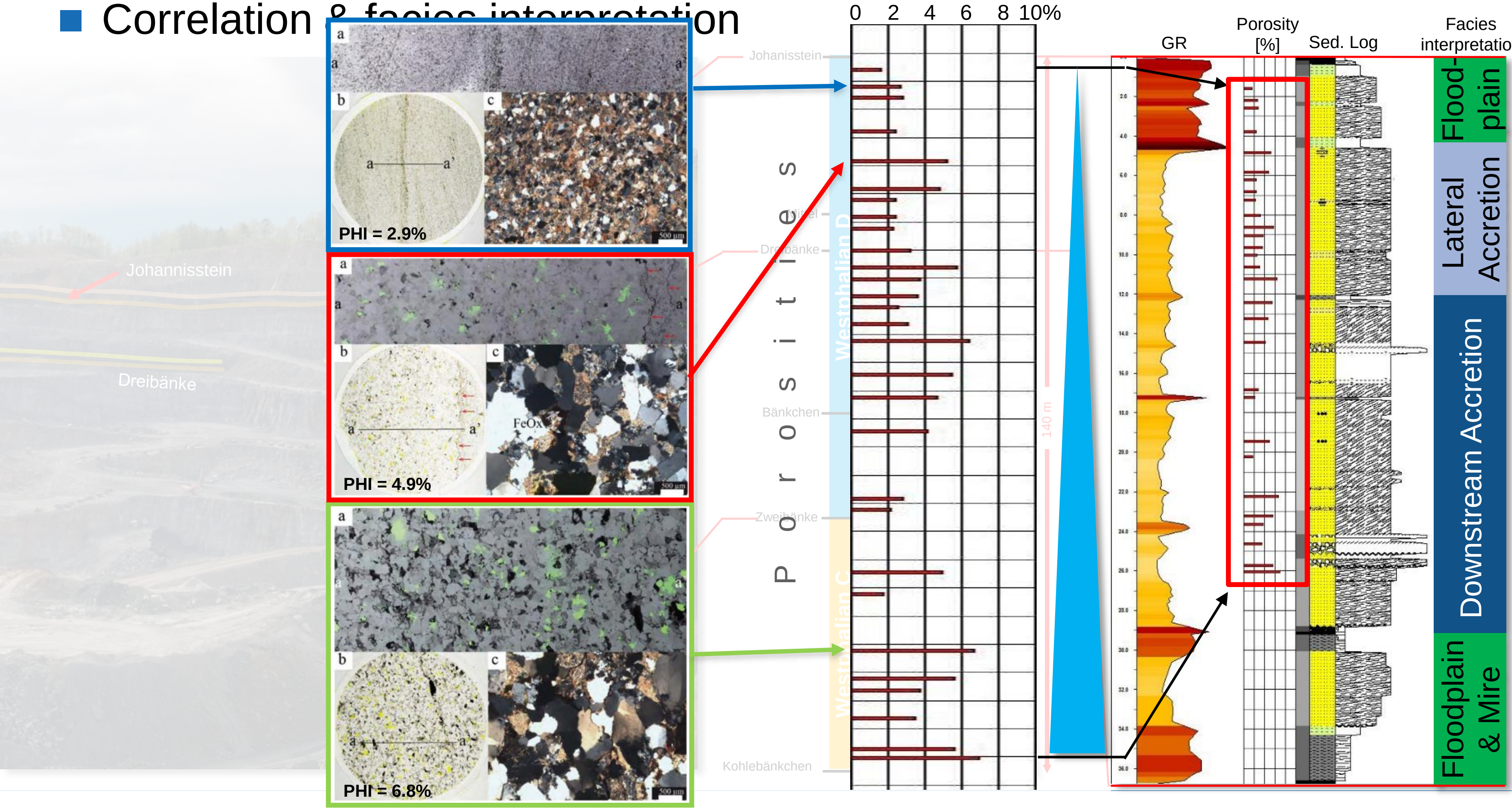

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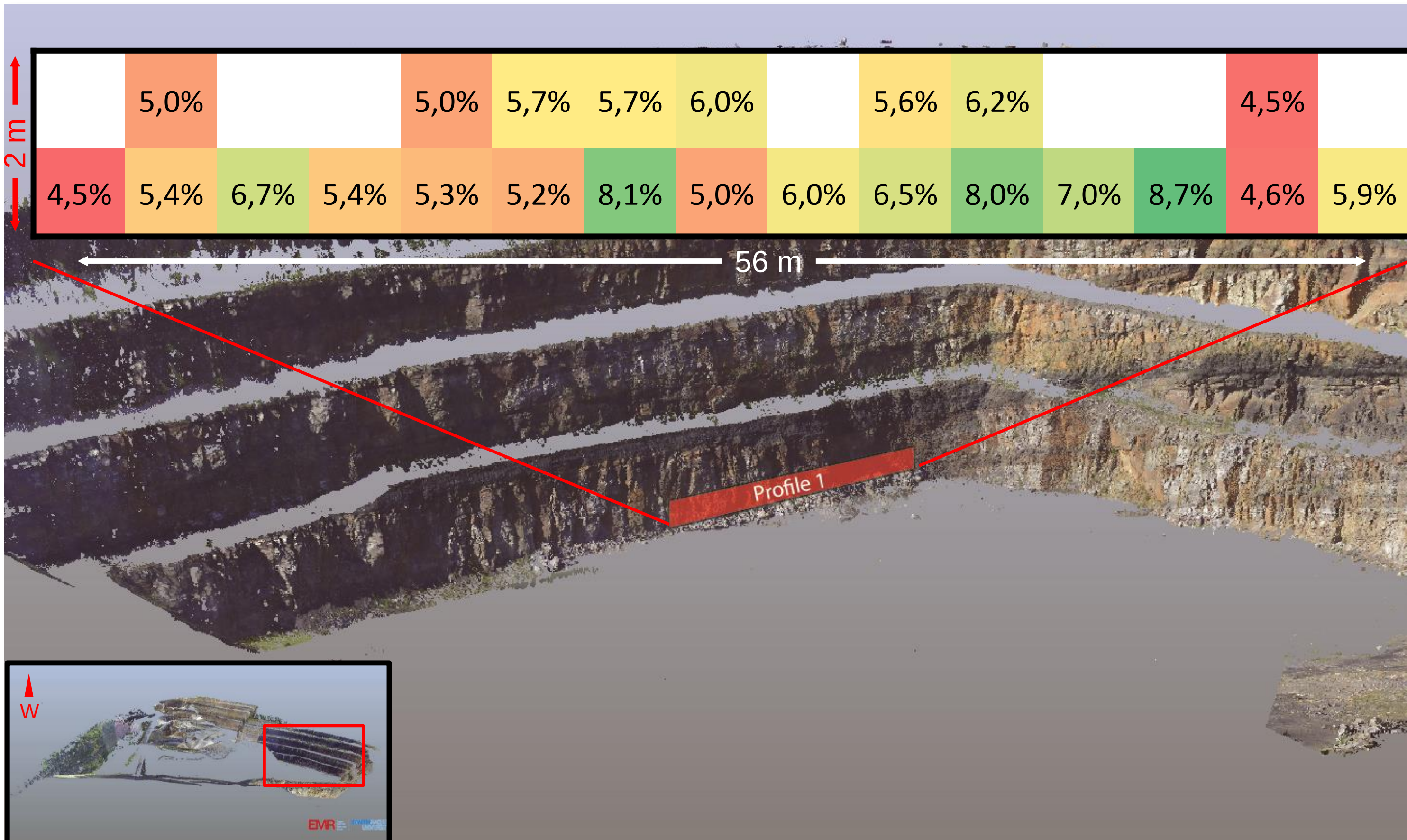
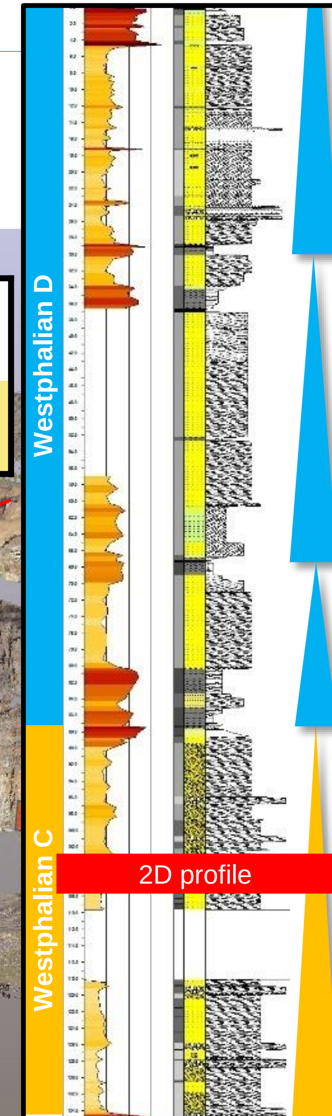
Lateral 2D porosity profile

- Average He-plug porosity: ~ 6%, no significant lateral variations on meter scale within a single fluvial sandbody



	5,0%			5,0%	5,7%	5,7%	6,0%		5,6%	6,2%			4,5%	
4,5%	5,4%	6,7%	5,4%	5,3%	5,2%	8,1%	5,0%	6,0%	6,5%	8,0%	7,0%	8,7%	4,6%	5,9%



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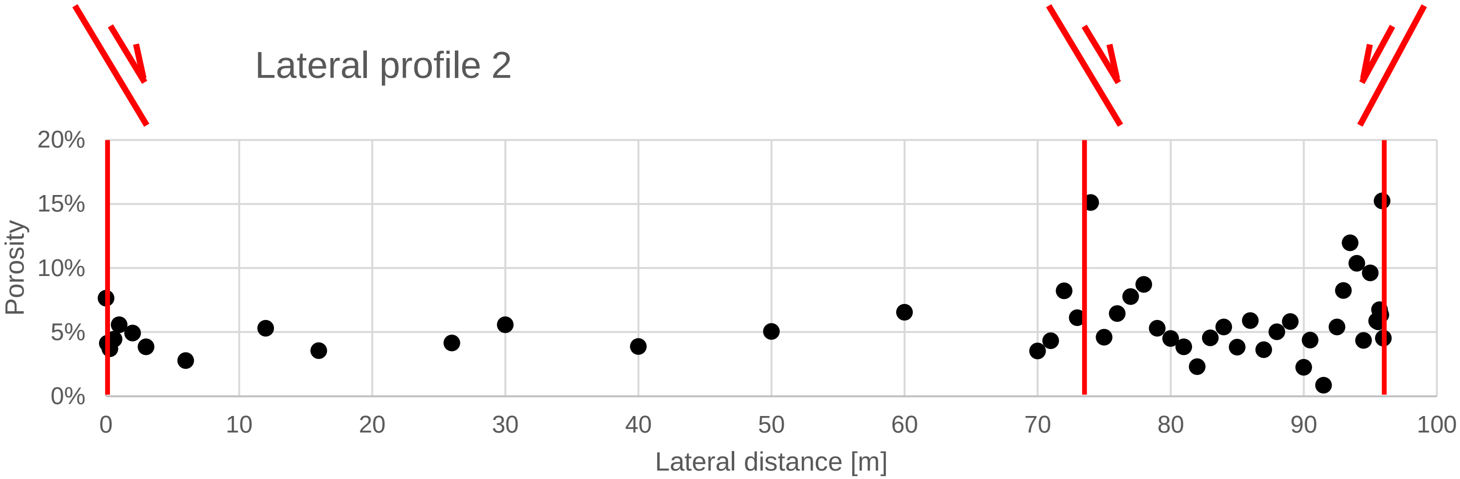
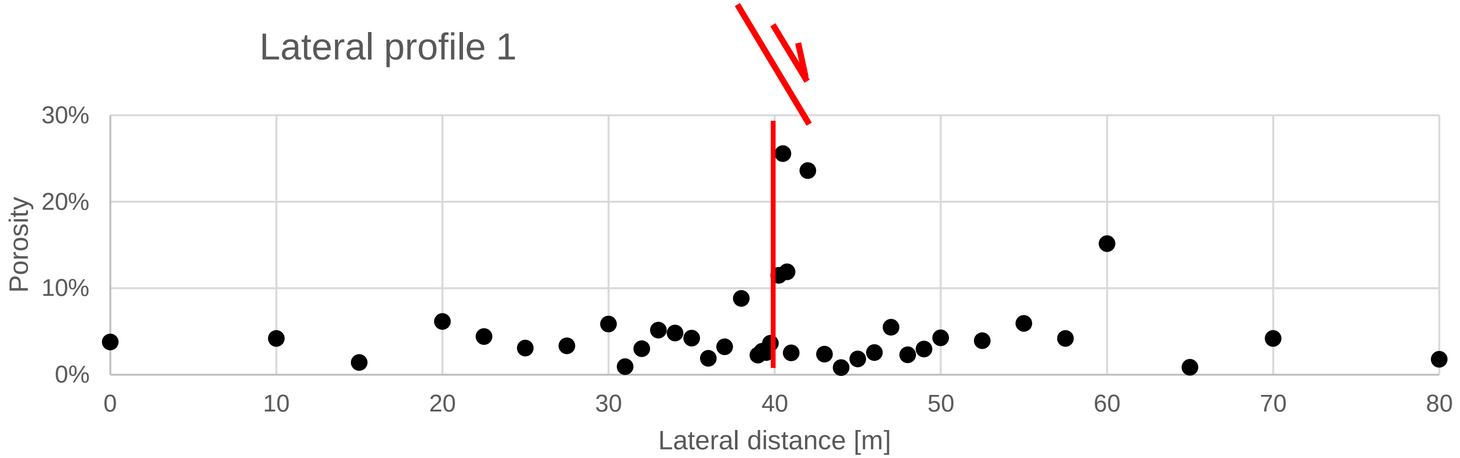
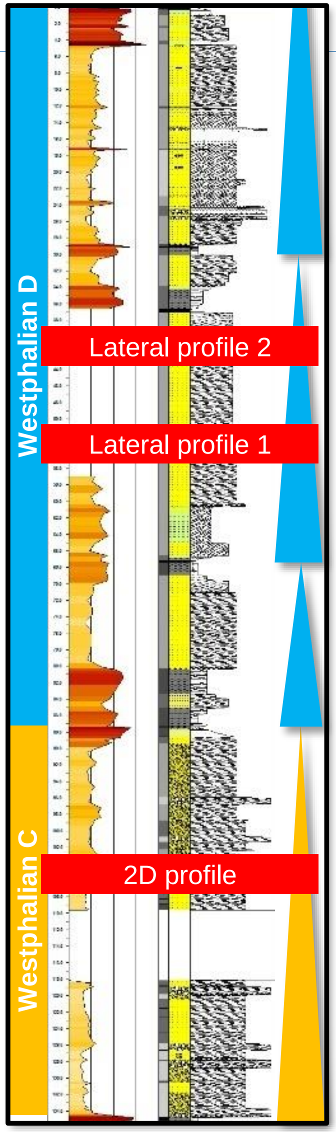
Structurally controlled matrix porosity

- Enhanced matrix porosity in 4 fault zones







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Diagenesis and Porosity

- Early primary porosity loss during eodiagenesis

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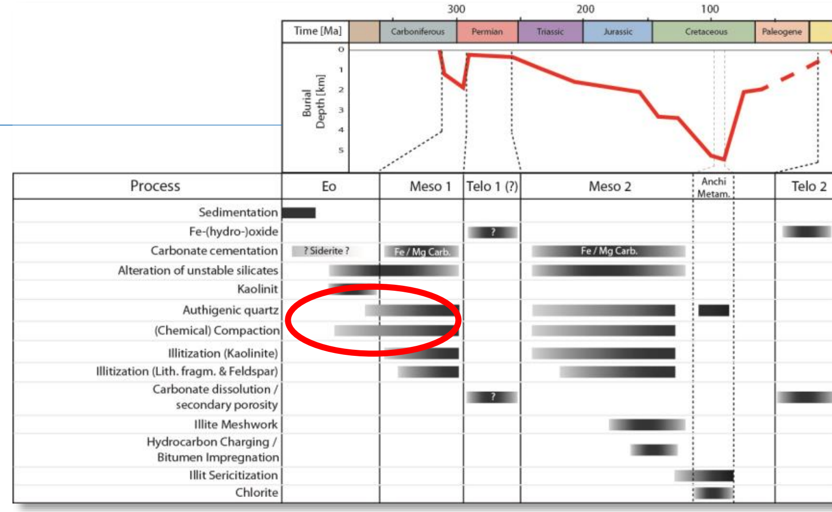
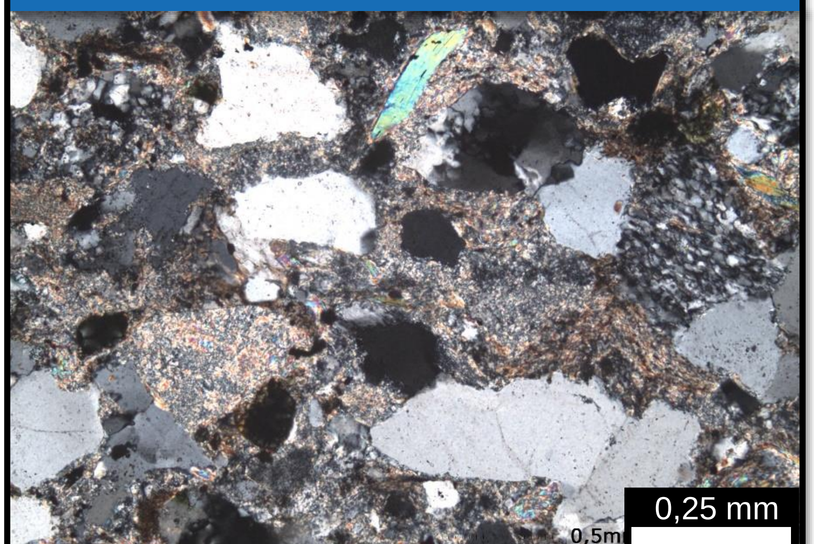
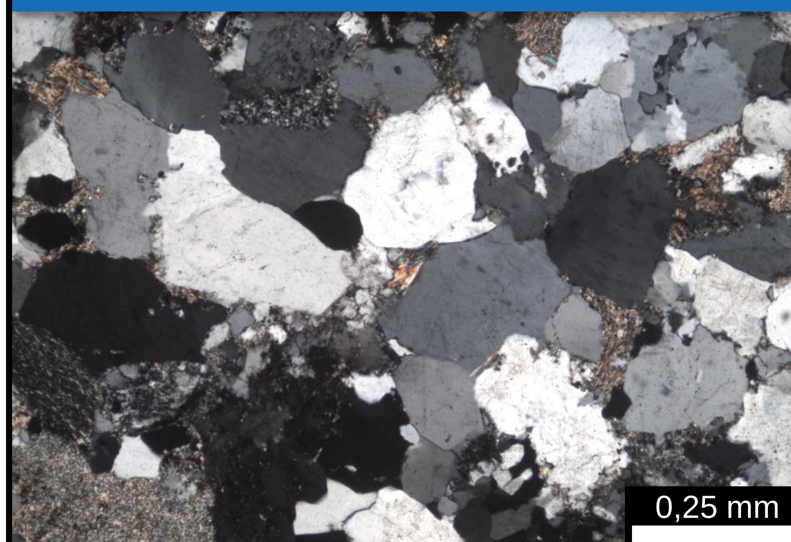


Development of a pseudomatrix



Chemical compaction + authigenic quartz



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Diagenesis and Porosity

- Secondary porosity evolution during telodiagenesis

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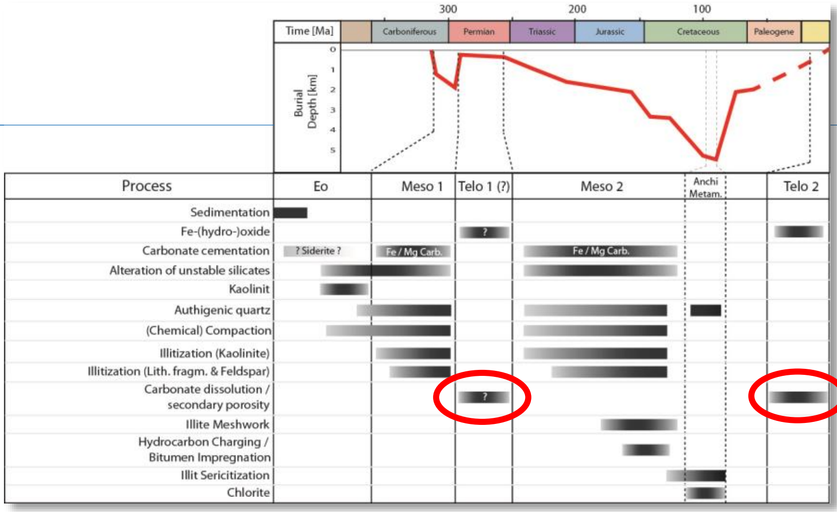
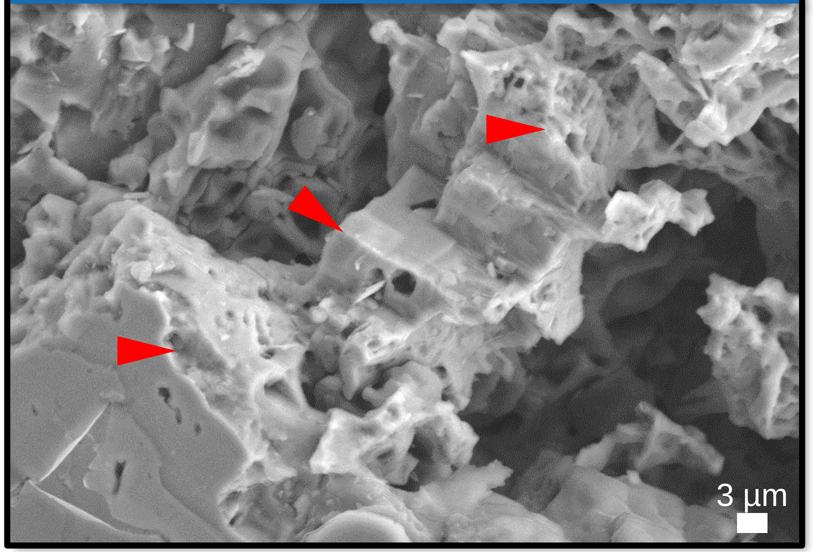
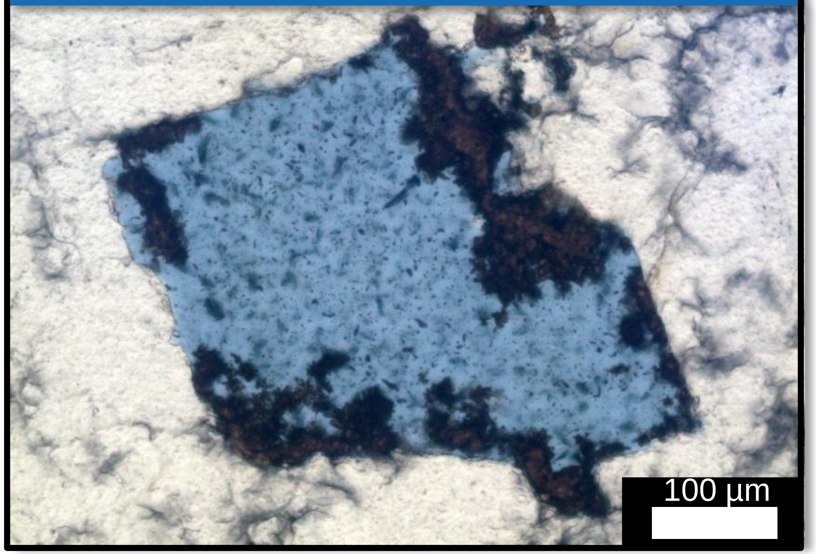


Carbonate (Ankerite) dissolution



Rhomboidal pores, carbonate dissolution



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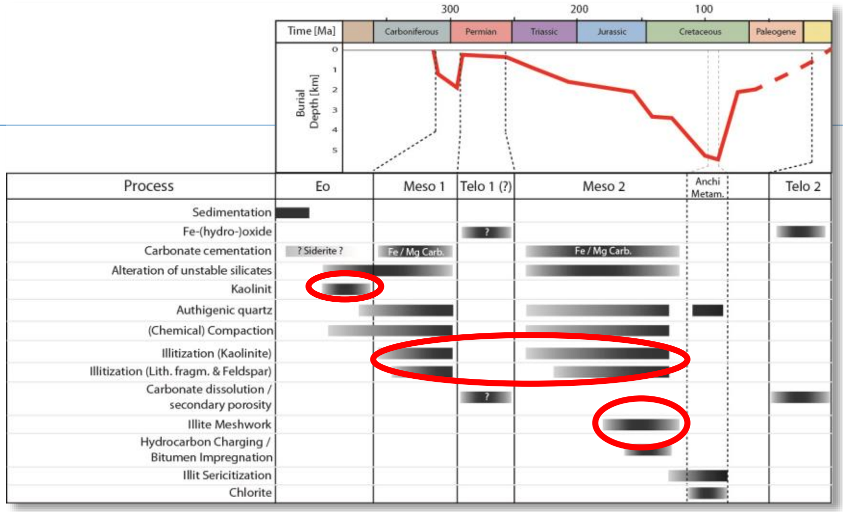
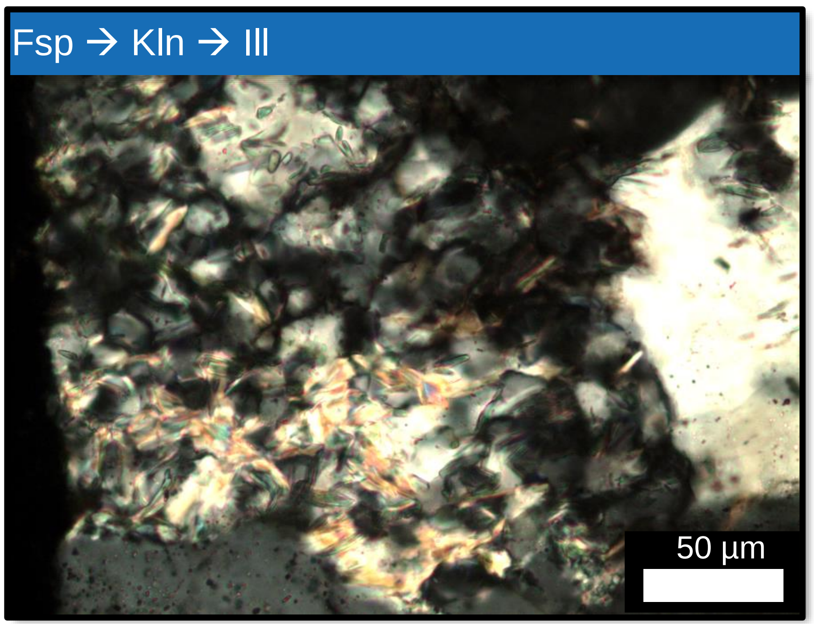
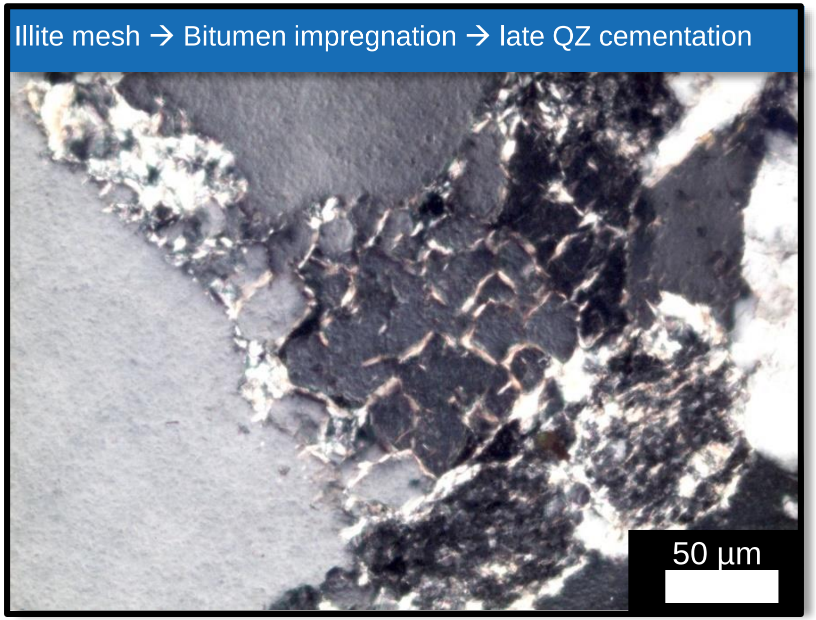
Diagenesis and Porosity

- Dissolution of detrital components
  → Clay mineral replacement
- HC charging early Cretaceaous







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Conclusions

- Outcrop reservoir analog for N-German tight gas fields identified
    - → 3D architecture of sedimentary bodies
    - → 3D heterogeneity of rocks & porosities
- Extraction of main fracture sets from digital outcrop model
    - → 3D digital fracture network
- Porosity changes with respect to stratigraphic position (base of 4th – order cycles) and distance to faults
    - → Stratigraphically controlled porosity variations
    - → Structurally controlled porosity variations
- Paragenetic sequence established to understand complex diagenesis and to compare with well data
    - → Primary porosity destroyed
    - → Secondary porosity due to carbonate dissolution

Outlook

- 2D wall panels for variogram analysis displaying the lateral reservoir quality variations
- High resolution subseismic to seismic 3D reservoir model
  - → Fracture network modeling based on LIDAR data
  - → Documentation of field-scale 3D reservoir heterogeneities
- Regional correlation with subsurface data (Düste & Rehden fields) to establish exploration-strategy with respect to tectonic setting

Acknowledgements

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