THMC-Coupled Modelling of Muschelkalk Diagenesis and Reservoir Simulation in the NGB

Tian, Deyan[1]; Blöcher, Guido[1,5]; Maerz, Sven[2]; Winterleitner, Gerd[2]; Niederau, Jan[2]; Meier, Nadezda[2]; Siever-Wenzlaff , Christian[3]; Meeder, Alexander[3]; Frigo Samuele[1,5]; Cacace Mauro[1]; Bruhn, David[4]

1. GFZ German Research Centre for Geosciences; Telegrafenberg, 14473 Potsdam, Germany
2. Fraunhofer IEG - Fraunhofer Institute for Energy Infrastructure and Geothermal Systems Gulbener Strasse 23, 03046 Cottbus, Germany
3. GASAG Solution Plus GmbH (GSP); EUREF-Campus 23–24, 10829 Berlin, Germany
4. Department of Geosciences and Engineering, Delft University of Technology, Delft, Netherland
5. Technical University Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany

1. Introduction

Motivation & Challenges

➔ Growing demand for **sustainable geothermal energy** in the Berlin–Brandenburg region.
➔ The **Muschelkalk** is a promising geothermal formation in Berlin–Brandenburg, providing potentials for **future site selection** and **doublet systems**.
➔ Integration of **T**hermal, **H**ydraulic, **M**echanical, and **C**hemical (**THMC**) processes modelling (e.g., dolomitization, halokinesis) to better understand **diagenetic evolution** and **improve geothermal assessment.**

But **Complex coupling** between THMC-coupled process; Multiscale **heterogeneity**. **High computational** demand and **parameter uncertainty**

2. Objectives

⇨ Develop a **THMC-coupled modelling** framework to simulate **diagenetic and geothermal processes** in the Muschelkalk Formation.
⇨ Quantify the impact of **THMC parameters and geochemical reactions** (e.g., dolomitization, dissolution) on porosity–permeability evolution.
⇨ Perform **basin- to reservoir-scale simulations** with doublet systems to evaluate geothermal productivity and reservoir process behavior.

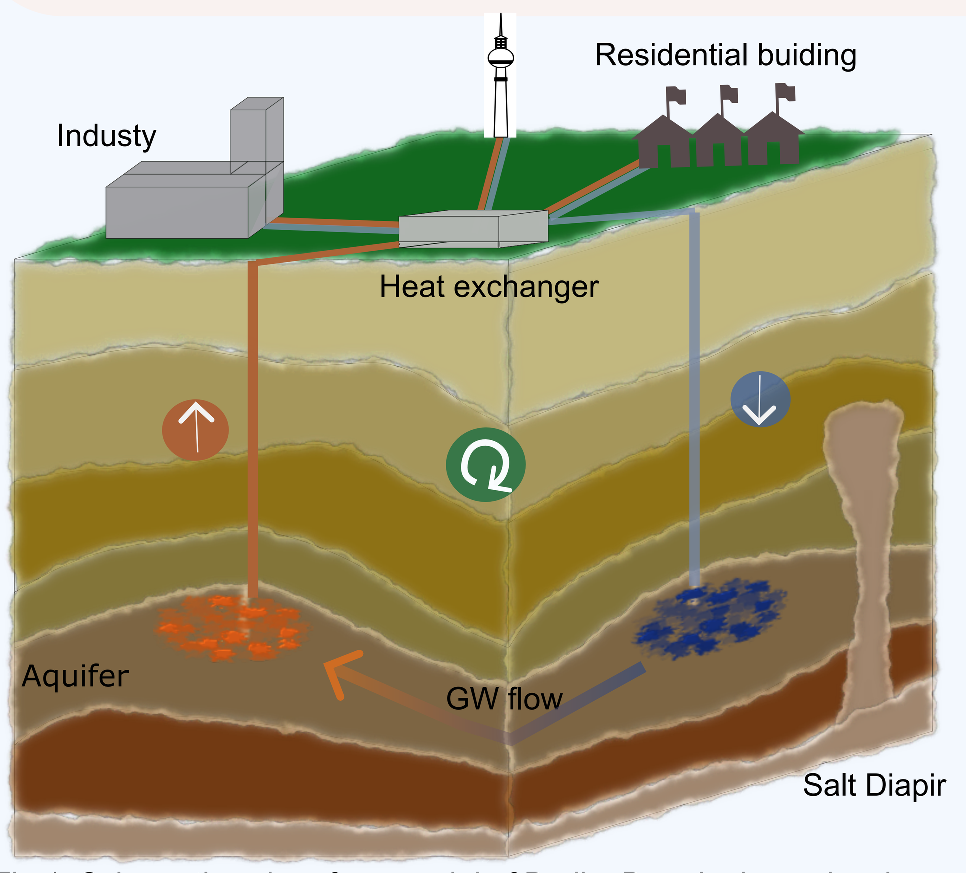


Fig.1: Schematic subsurface model of Berlin–Brandenburg showing a continuous operation geothermal doublet circulation system(carbonate aquifer).

Continuous geothermal circulation
Goal: Test 100 doublet systems

Potential of the Muschelkalk Reservoir

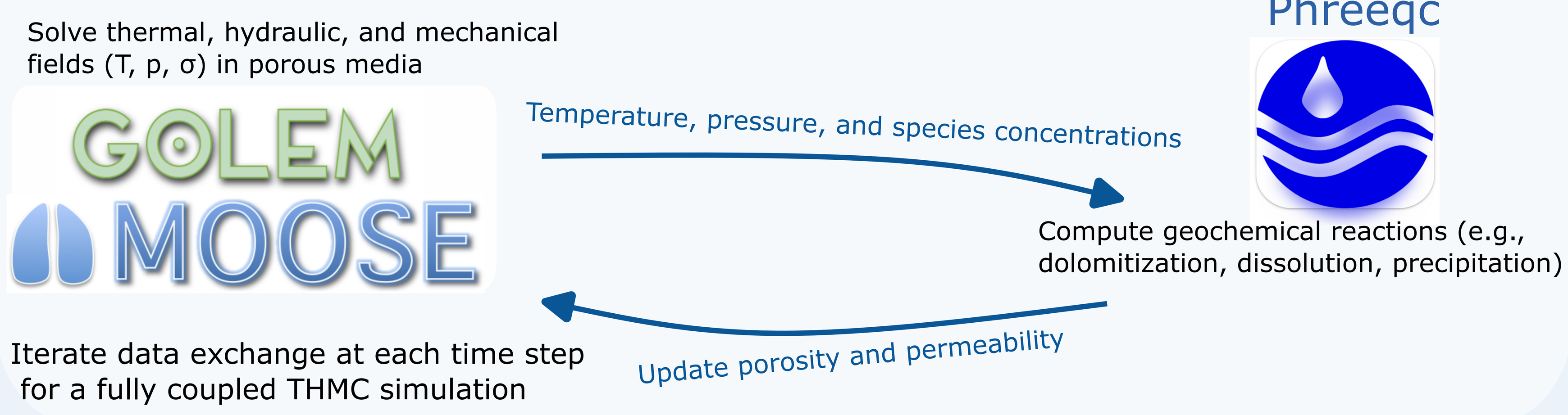
- High porosity–permeability
- Favorable hydrochemistry
- Secondary porosity
- Existing well data

3. Methods & Modelling Framework

THMC coupled Challenges

➔ Coupling multiphysics interactions (THMC) across **different time and spatial scales**.
➔ Ensuring **stable data exchange** between mechanical, flow, and geochemical solvers.
➔ Managing **high computational deman**d of fully coupled THMC simulations.

How the THMC Coupling Works?



Framework Validation

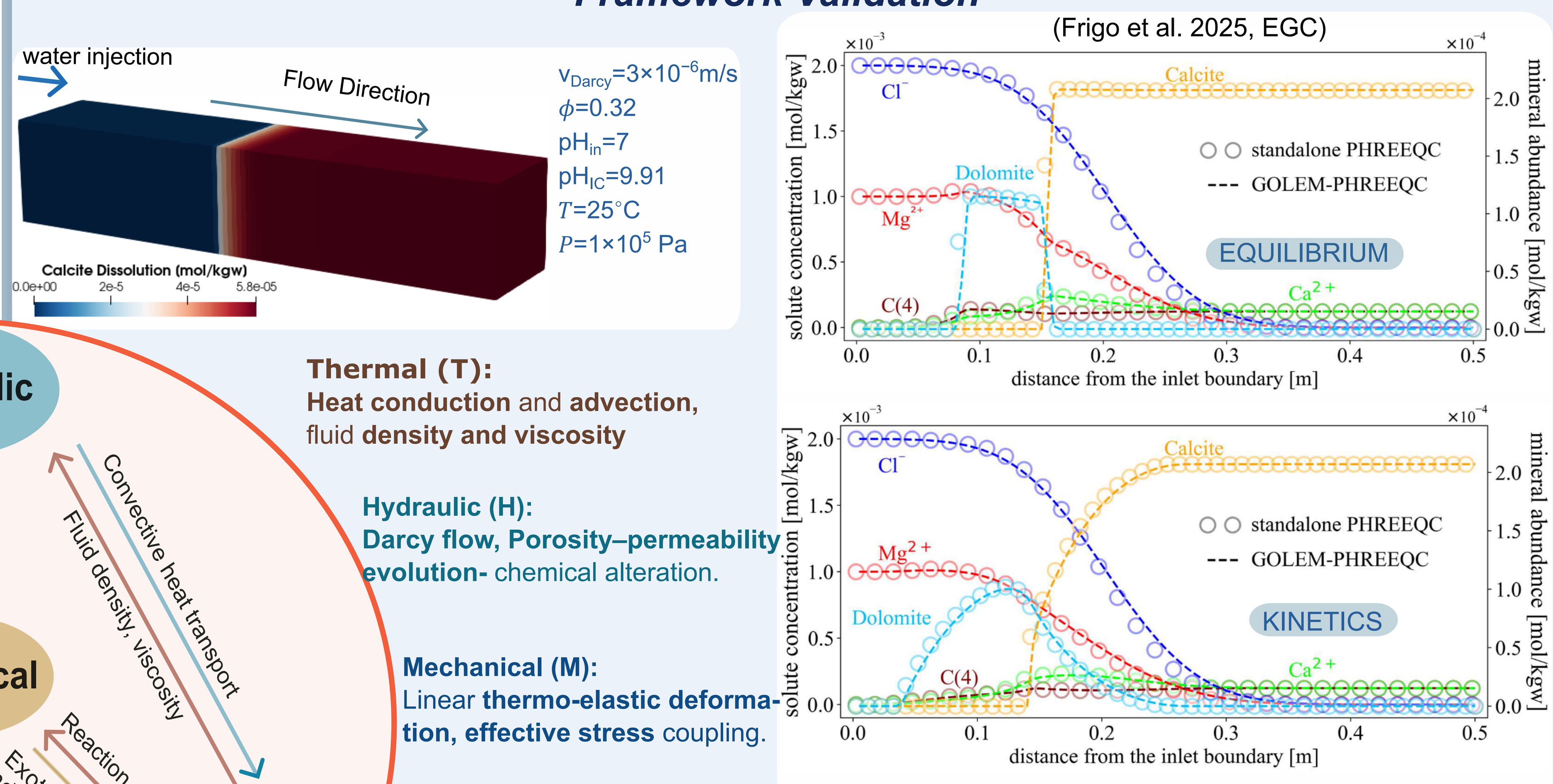


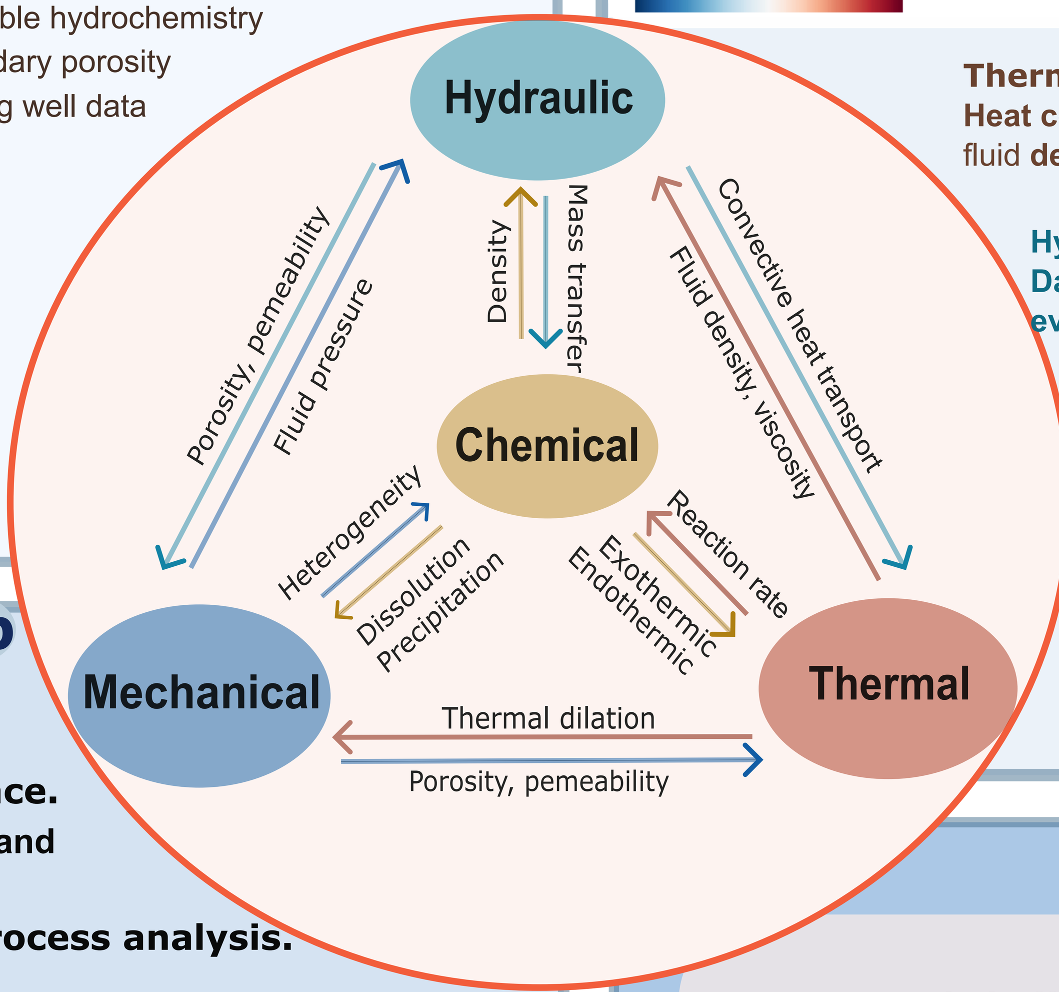
Fig.2: Code validation against PHREEQC. good agreement (R² > 0.95) under equilibrium and kinetic condition

Thermal (T):
Heat conduction and **advection**, fluid **density and viscosity**

Hydraulic (H):
Darcy flow, Porosity–permeability evolution- chemical alteration.

Mechanical (M):
Linear **thermo-elastic deformation, effective stress** coupling.

Chemical (C):
Dolomitization, calcite dissolution /precipitation, key mineral reactions



4. Conceptual & Facies Model Setup

Geological Context

➔ Muschelkalk formation within the **Berlin–Brandenburg subsurface.**
➔ The basin-scale model iwith multiple subsurface facies, e.g.**dolomitic and limestone**
➔ Data derived from **regional stratigraphic and 8 boreholes process analysis.**

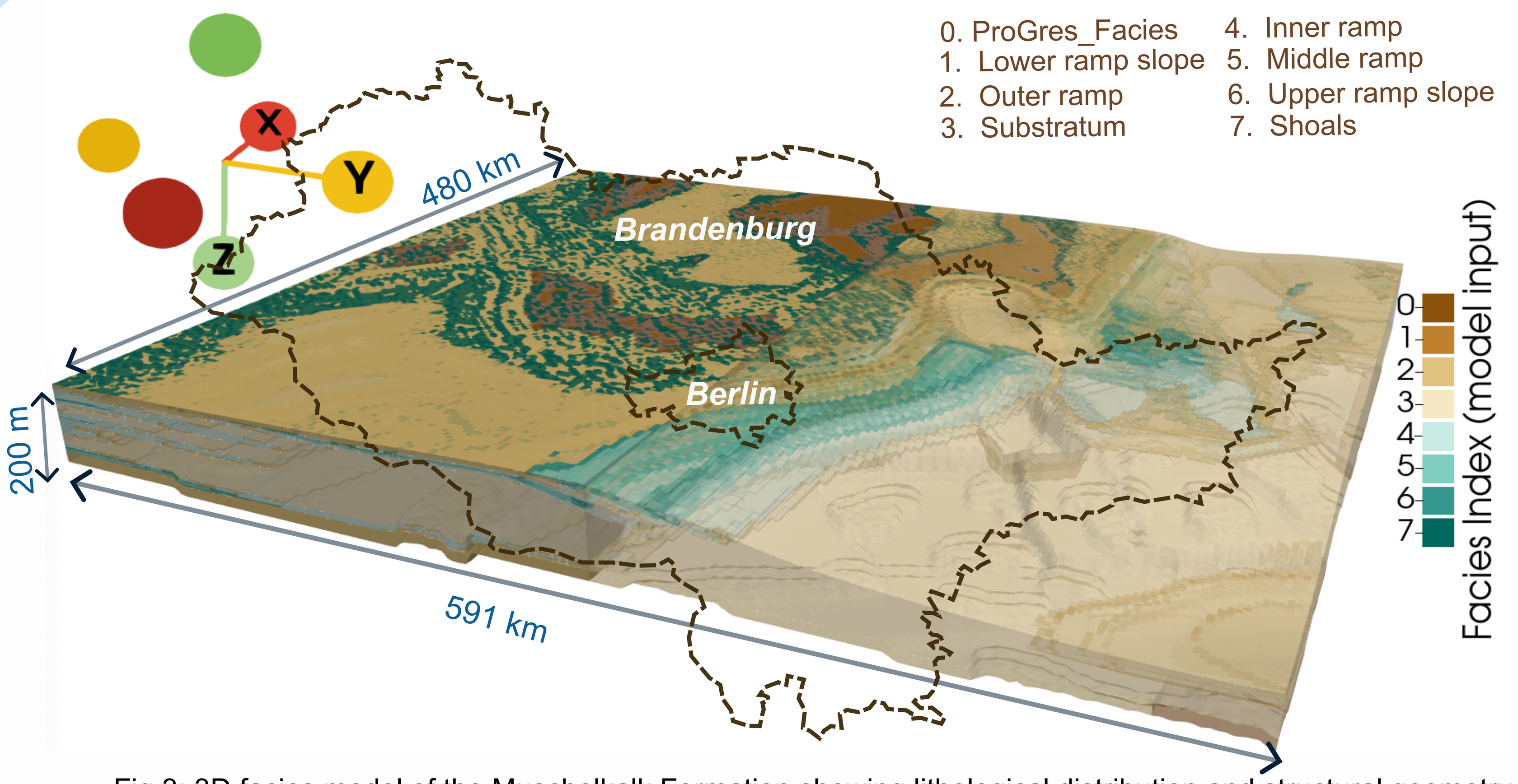


Fig.3: 3D facies model of the Muschelkalk Formation showing lithological distribution and structural geometry

Facies Model Description

➔ 3D facies distribution created from **stratigraphic layering and depositional patterns.**
➔ Each facies assigned **distinct petrophysical properties** (porosity, permeability).
➔ **Corner-point grid** to hexahedral **mesh conversion**
➔ Model imported into **GOLEM** for mesh generation and property mapping.

Property Type	Parameter	Symbol	Range / Value	Unit
Thermal	Thermal conductivity	λ	2.7 – 5.8	$W\,m^{-1}\,K^{-1}$
	Volumetric heat capacity	c_s	2.2 – 2.5	$MJ\,m^{-3}\,K^{-1}$
Hydraulic	Porosity	ϕ	0.10 – 0.27	–
	Permeability	k	$1\times10^{-14} - 1\times10^{-12}$	m^2
Mechanical	Bulk density	ρ	2000 – 2700	$kg\,m^{-3}$
	Young's modulus	E	9 – 40	GPa
	Poisson's ratio	ν	0.20 – 0.30	–
	Thermal expansion coeff.	α_T	$1\times10^{-5} - 3\times10^{-5}$	K^{-1}
Chemical	Calcite dissolution rate	k_c	$1\times10^{-7} - 1\times10^{-6}$	$mol\,m^{-2}\,s^{-1}$
	Dolomite dissolution rate	k_d	$1\times10^{-10} - 1\times10^{-9}$	$mol\,m^{-2}\,s^{-1}$

Table 1. Representative THMC Properties of the Muschelkalk Formation, Berlin Region

5. Model Analysis (Ongoing)

Key Research Focus

⇨ **THMC-coupled effects** on porosity, permeability, and **relarted uncertainties** driven by diagenetic evolution.
⇨ **Diagenetic processes** (e.g., dolomitization, dissolution) controlling reservoir quality and **heterogeneity.**
⇨ **Sensitivity analysis** of coupled parameters and **injection–extraction** on reservoir performance.
⇨ **Basin-scale simulation** and assessment of **doublet system** in the Muschelkalk Formation.

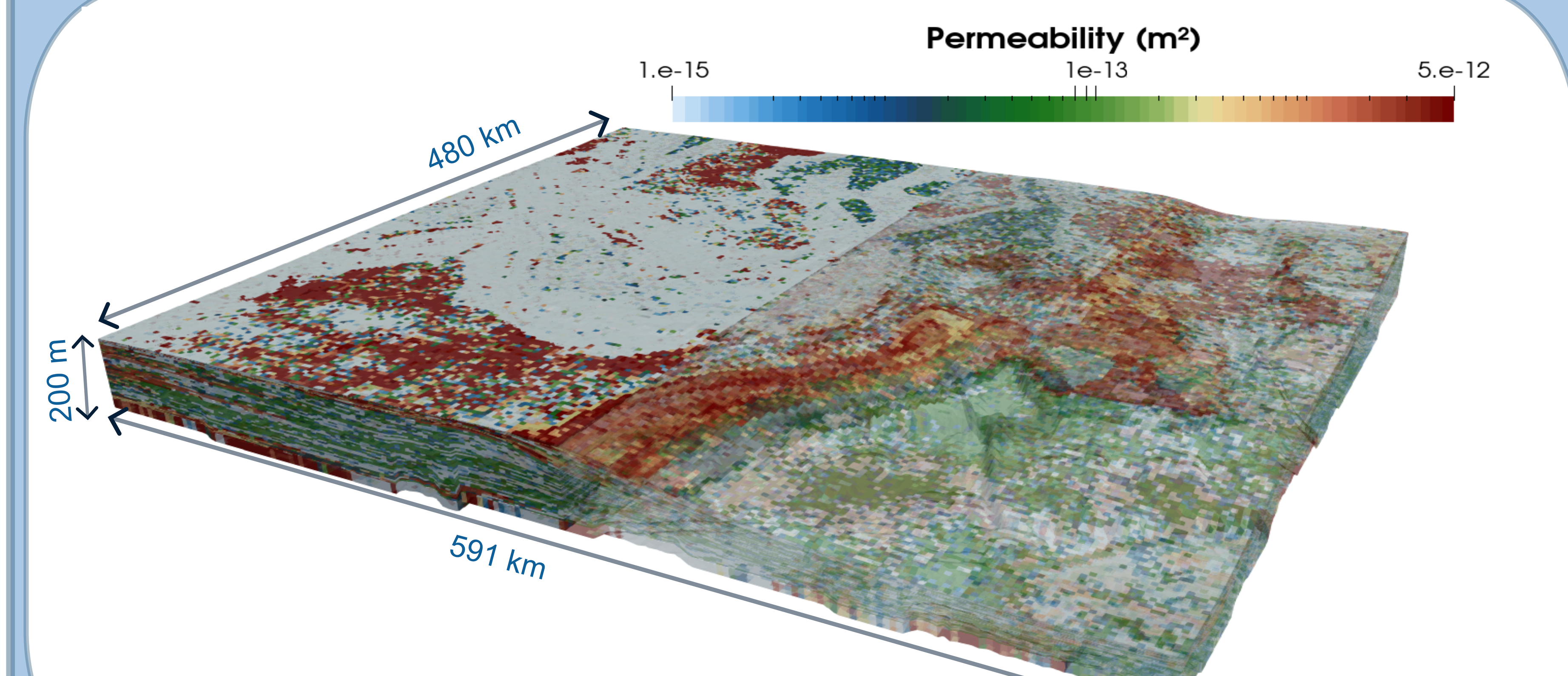


Fig.4: Permeability model derived from facies data, illustrating high heterogeneity and spatial variability in reservoir properties.

6. Summary & Outlook

- **THMC-coupled workflow** reproduces key diagenetic processes and property evolution.
- Demonstrates **process-based integration** of THMC-coupled **mechanisms.**
- Evaluate **porosity–permeability evaluation** and reservoir doublet sytems.

Next:
➔ Apply model to **regional-scale Muschelkalk reservoir** (Berlin–Brandenburg).
➔ Extend to **doublet well simulation** for long-term production assessment.
➔ Implement **uncertainty quantification** to evaluate model sensitivity and reliability.

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Reference

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GFZ Helmholtz Centre for Geosciences
www.gfz.de

Contact:
Deyan Tian – deyan.tian@gfz.de. Section 4.3 **Geoenergy**
THMC Modelling & Numerical Simulation of Geoenergy Storage Systems

Expertise Highlights:
⇨ Multi-scale, coupled thermo-hydro-mechanical-chemical **(THMC)** modelling of subsurface processes
⇨ **Numerical simulation and constitutive modelling** using FEM **(MOOSE Framework, Golem)**
⇨ High-performance computing **(HPC) for multi-scale** geoscientific simulations

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