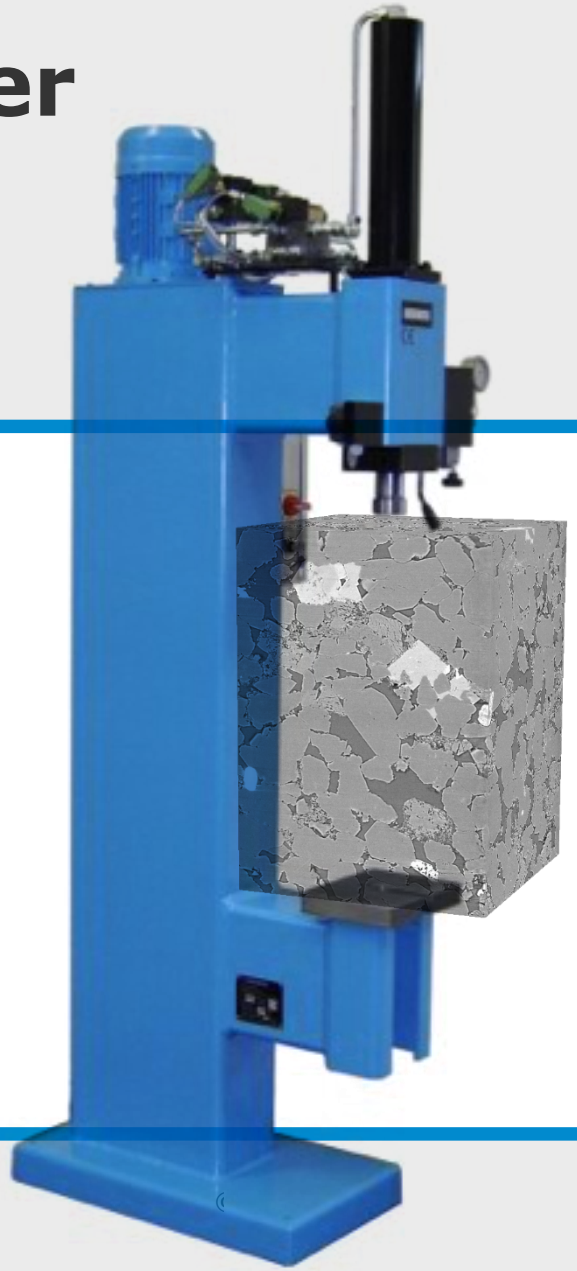
Berücksichtigung von In-Situ-Bedingungen in der digitalen Gesteinsphysik



DGMK / ÖGEW – Frühjahrstagung

22. & 23. April 2015

Sven Linden

Tom Cvjetkovic

Erik Glatt

Jens-Oliver Schwarz

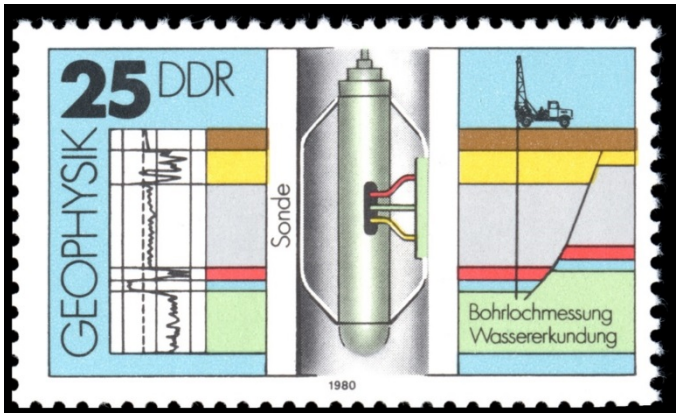
Andreas Wiegmann

MATH 2 MARKET

(Reservoir) Rock Physics

Analog outcrop

Well logging



Core analysis

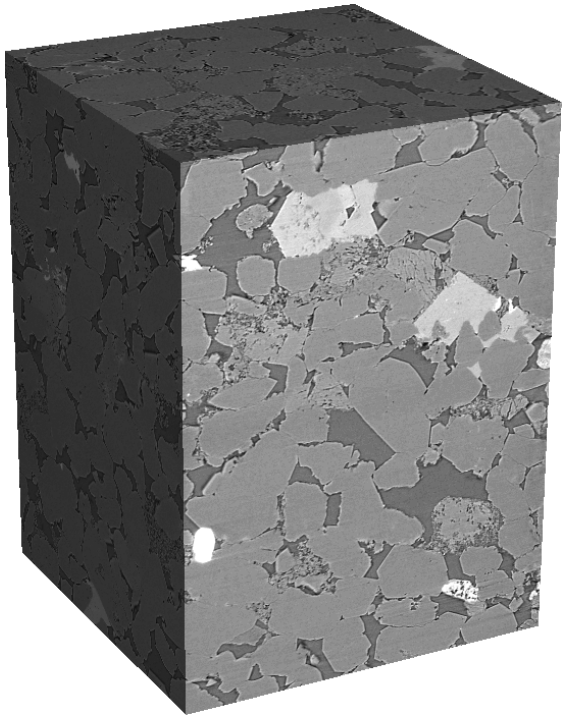
Core Analysis

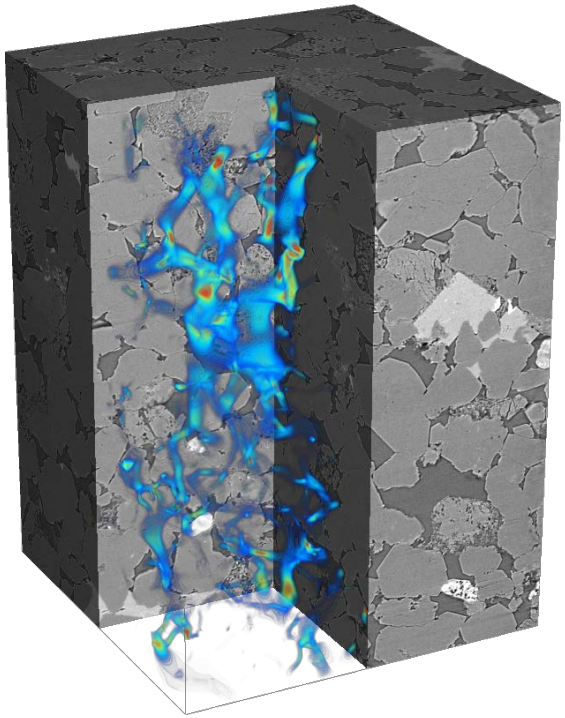
Image courtesy of M. Halisch (LIAG)

Core analysis provides data available from no other source:

- Allows visual examination of reservoir rocks
- Direct evidence of presence, quantity, distribution and deliverability of hydrocarbons
- Characterization of the pore system in reservior rocks (e.g. permeability, wettability)
- Allows to calibrate well log interpretation

Basic Principle of *Digital* Rock Physics (DRP)

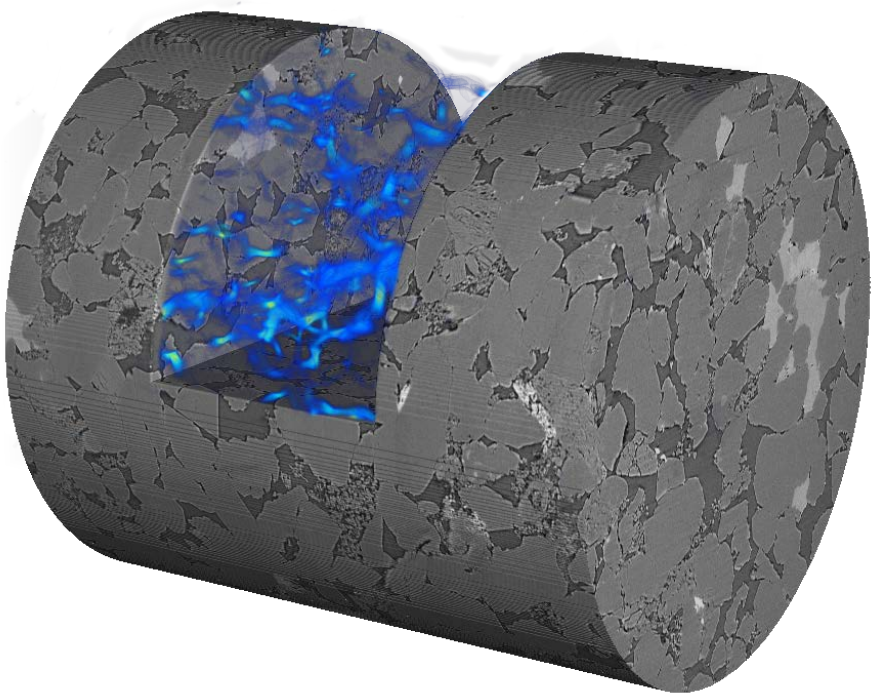




Sampling → Imaging → Computing

Why DRP?

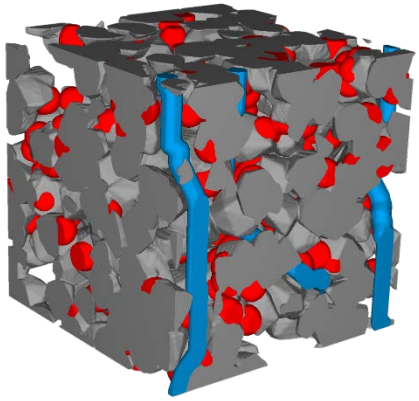
- Generates results faster and at lower costs
- Lower demand on the quality of rock material (e.g. cuttings)
- Non-destructive: derive all parameters from one core
- Fast solvers enable studies on the sensitivity of parameters
- Multi-scale analysis of parameters enables up-scaling

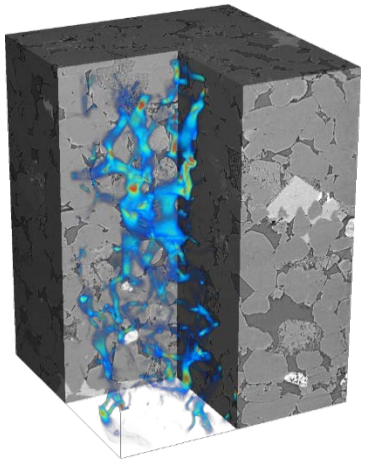


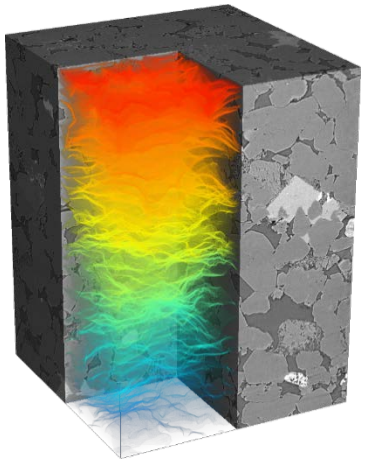
MATH 2 MARKET

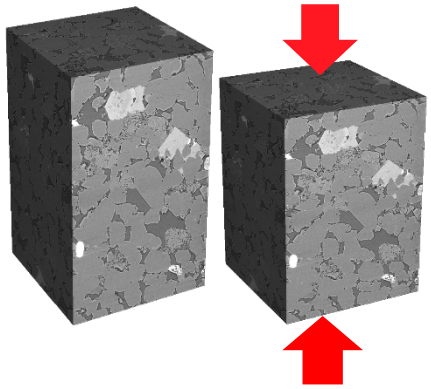
Math2Market
Digital Rock Physics Portfolio

GeoDict







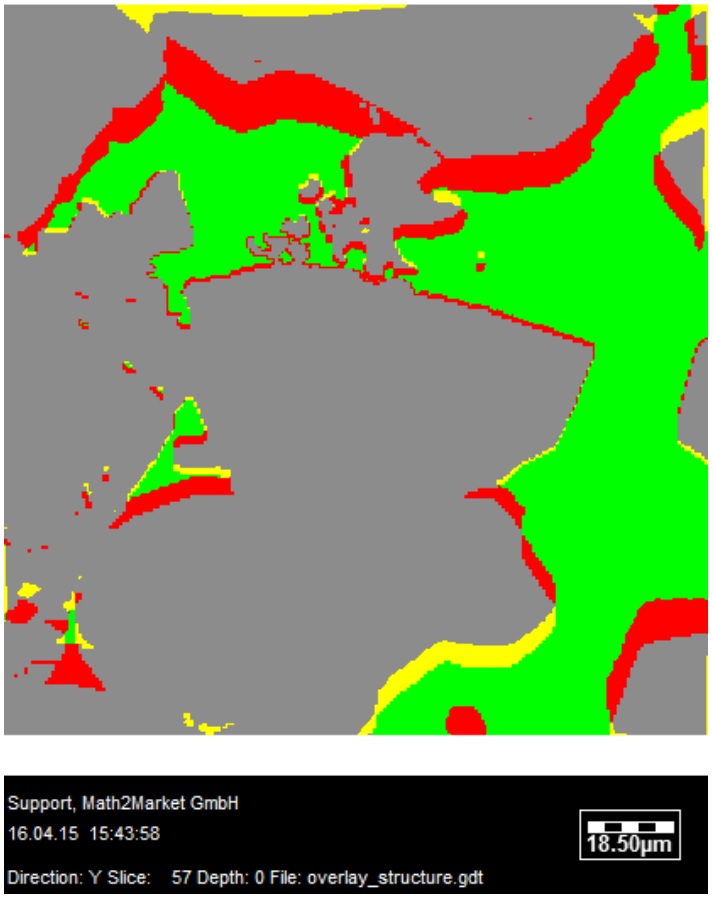


Geometrical parameters	Flow parameters	Electrical Parameters	Mechanical parameters
▪ Porosity	▪ Absolute permeability	▪ Formation factor	▪ Elastic moduli
▪ Pore size distribution	▪ Relative permeability	▪ Resistivity index	▪ Stiffness
▪ Percolation	▪ Multi-scale flow	▪ Saturation exponent	▪ In-Situ conditions
▪ Surface area	▪ Capillary pressure curve	▪ Cementation exponent	
▪ Tortuosity			

MATH 2 MARKET

Need for in-situ conditions in DRP

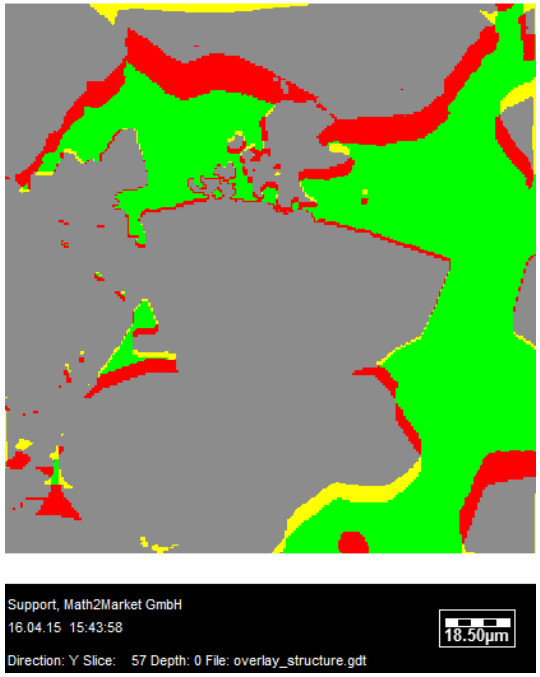
- Rocks in a reservoir are exposed to elevated pressures and temperatures (in-situ conditions)
- Generally in-situ conditions are not maintained during DRP workflows
- Changes in the pressure and temperature conditions
  - impact the properties of fluids: density, viscosity, solubility of phases in the fluid
  - lead to changes in the pore space



Need for in-situ conditions in DRP

Uncompressed image

Compressed image



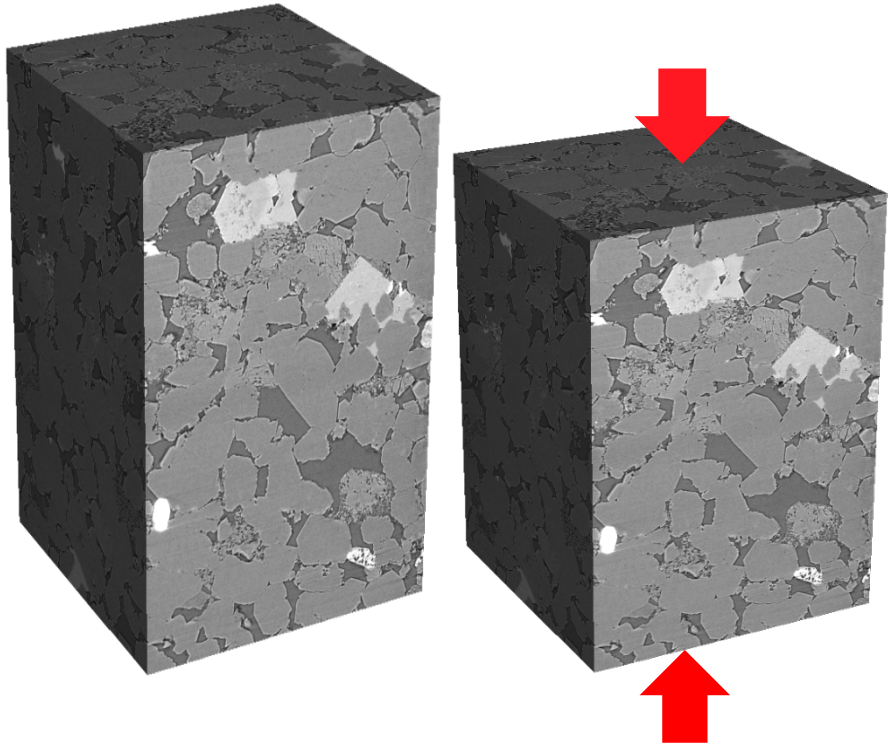
Overlay image

MATH 2 MARKET

In-Situ DRP techniques

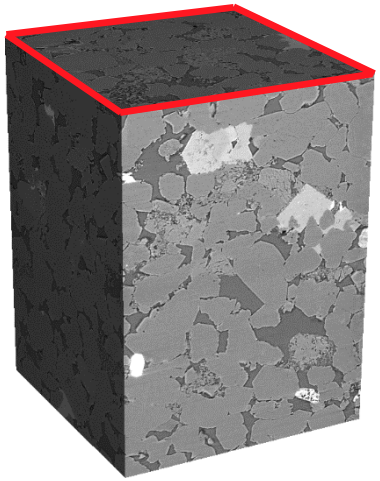
In-Situ imaging

In-Situ modelling



Detailed In-situ DRP workflow
In-situ simulation I

- Cropping
- Noise reduction
- Artifact reduction[1]

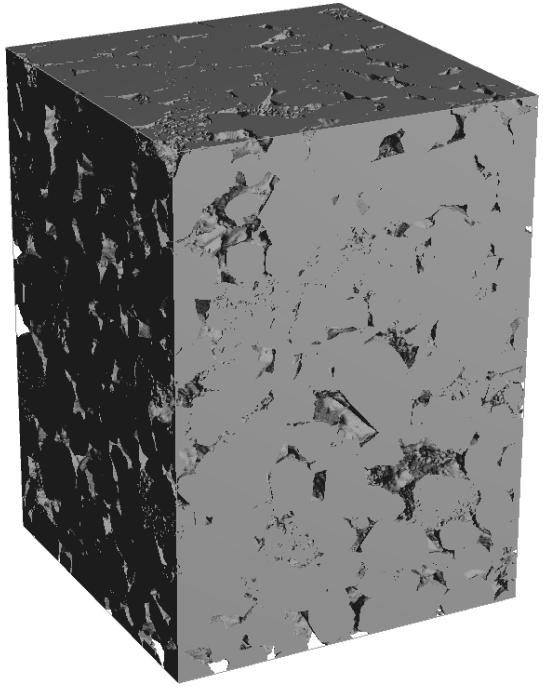


Sampling → Imaging → Processing

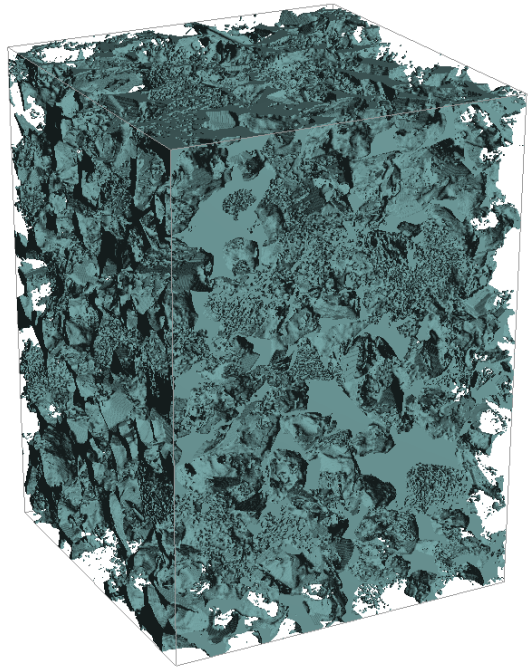
[1] H. Andrä *et al.*, „Digital rock physics benchmarks—Part I: Imaging and segmentation," *Computers & Geosciences*, 2013 (43), pp. 25-32.

Detailed In-situ DRP workflow
In-situ simulation II

Solids



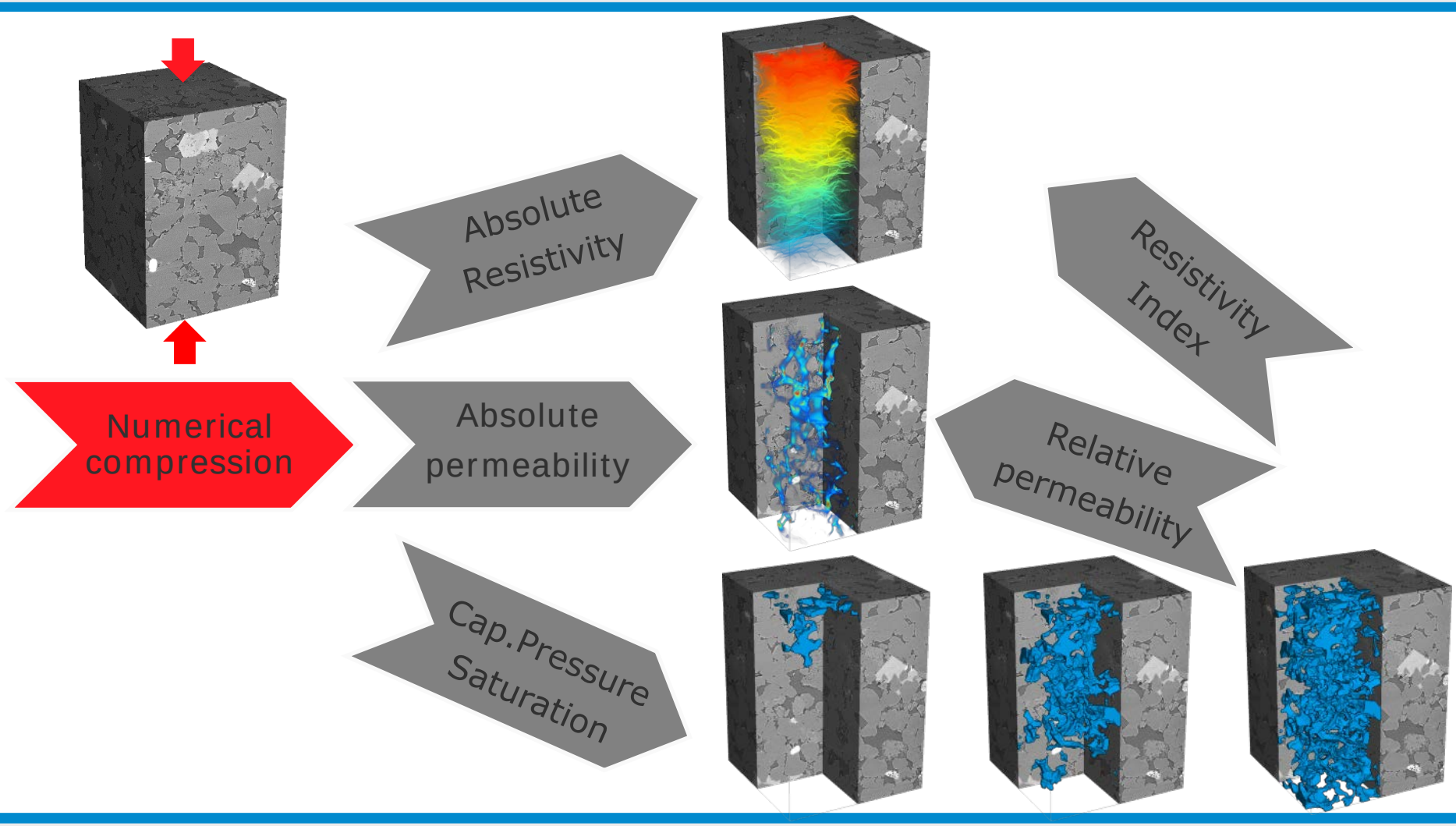
Pore space



Segmentation

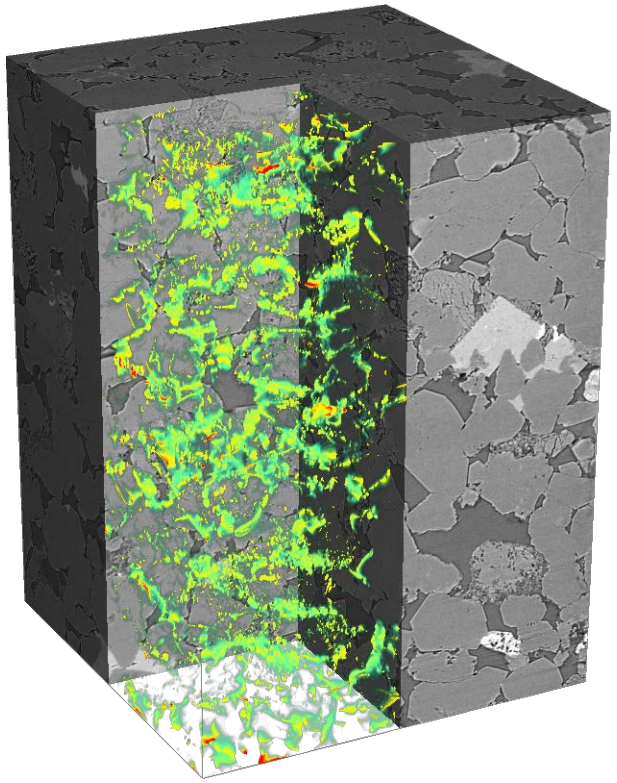
[1] H. Andrä *et al.*, „Digital rock physics benchmarks—Part I: Imaging and segmentation," *Computers & Geosciences*, 2013 (43), pp. 25-32.

Detailed In-situ DRP Workflow
In-situ simulation III



Mechanical Properties

- Two mineral phases
  - Quartz (E = 94.5 GPa, v = 0.074)
  - Void (E = 0 GPa, v = 0)
- Elastic properties
  (E = 46.9 GPa, v = 0.108)
- FeelMath solver
  - Lippmann-Schwinger formulation for linear / non-linear mechanics
- Uniaxial macroscopic stress
  - Periodic boundary conditions
  - Stages [GPa]: 0.12, 0.24, 0.48, 0.71, 0.95, 1.43

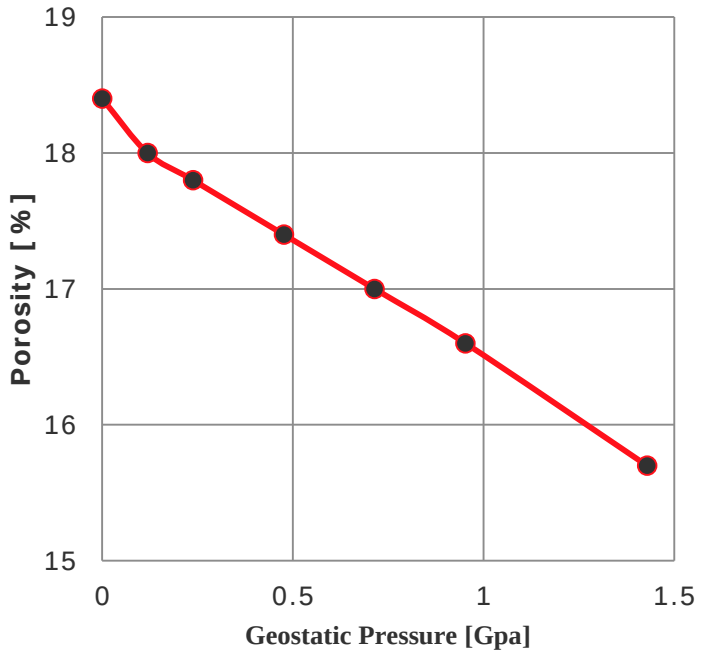


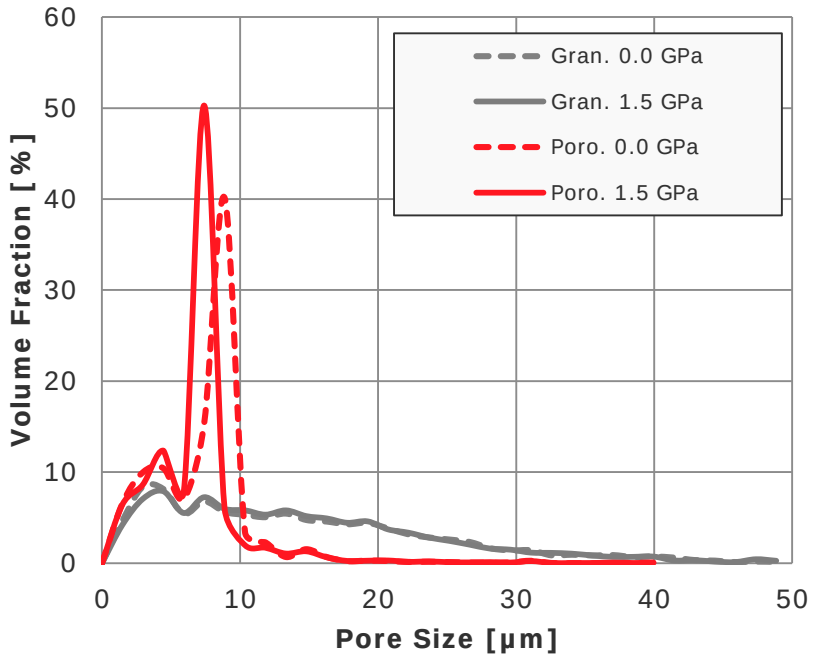
Von-Mises-Stress field

Porosity and Pore Size Distribution

PoroDict

- Porosity: 18.4 changes to 15.7%
- Most frequent pore throat diameter: 8.8 changes to 7.4 µm
- Granulometry and Porosimetry

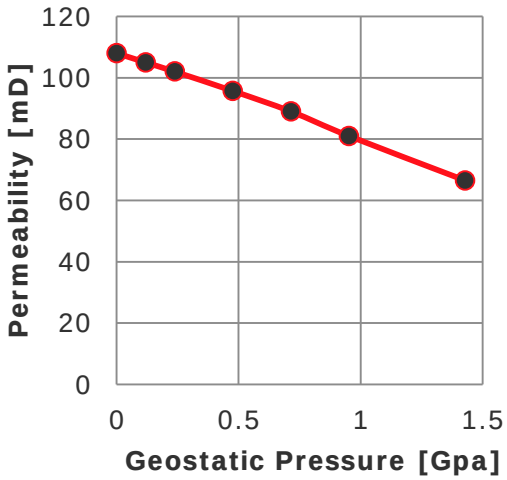


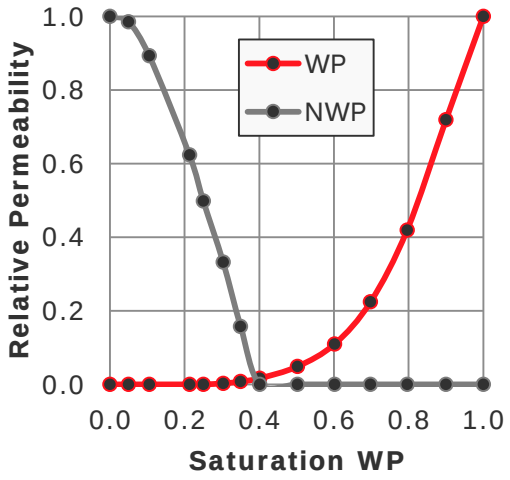


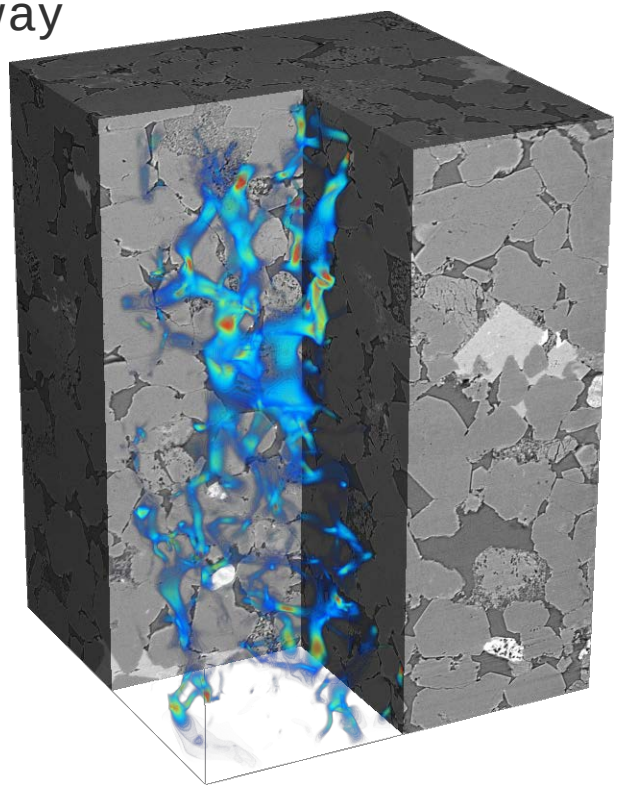
MATH 2 MARKET

Absolute and Relative Permeability

- Absolute permeability: 108 changes to 66 mD
- Relative permeability of uncompressed state
  - Compressed states computations are under way
- Two flow solver: LIR-Stokes and SIMPLE-FFT





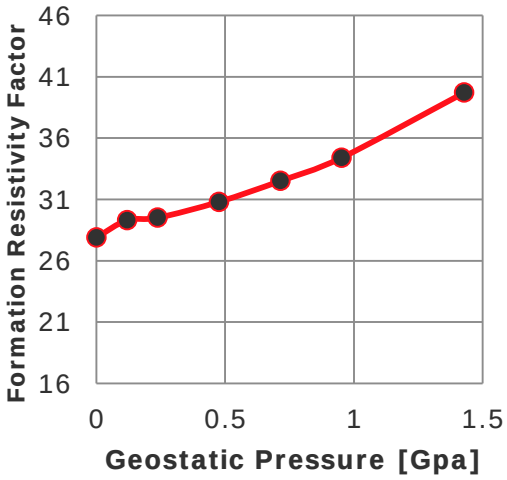


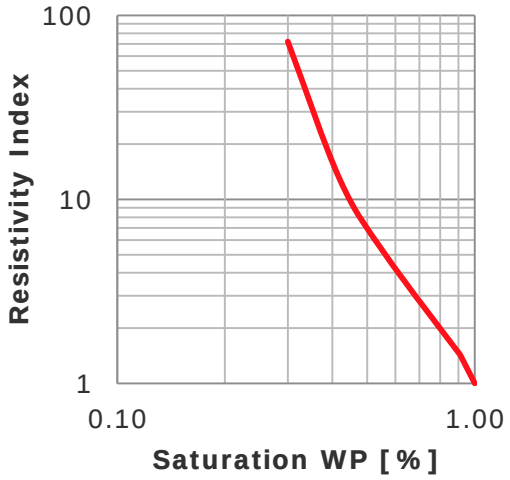
Velocity field

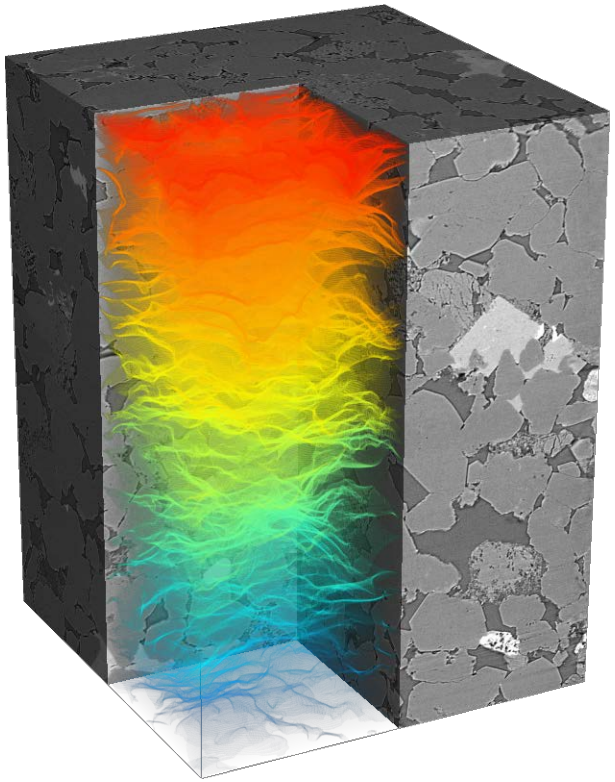
Electrical Conductivity

- Electrical Conductivity (Brine 5 S/m): 0.17 S/m
- Formation resistivity factor: 27 changes to 39

- Explicit-Jump immersed interface method





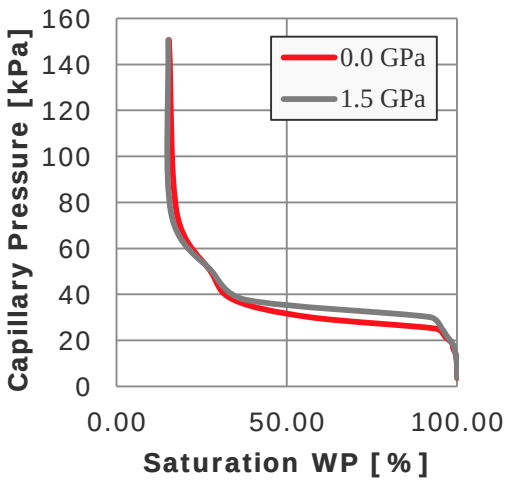


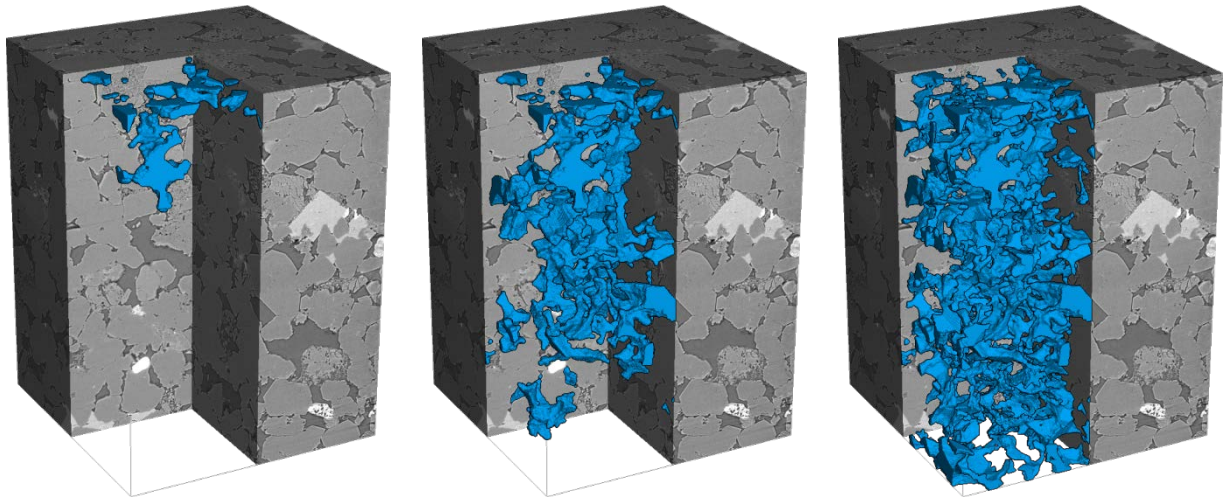
Potential field

Capillary Pressure

- Irreducible WP saturation: 18%
- Displacement pressure changes from 24 to 29 kPa

- Pore morphology method





Air drains Brine with saturation stages 75%, 50% and 25%

Solver Performance

- Flow and mechanics are expensive to compute
  - Relative permeability is most expensive
- Efficient solver allow:
  - Property simulations overnight
  - simulations on large data sets (>2000³)
  - sensitivity analysis

Porperty	Flow	Flow	Conductivity	Two phase distribution	Elasticity
Solver	SIMPLE-FFT	LIR Stokes	Explicit Jump	Pore Morphology	FeelMath
Runtime [h]	3.6	3.1	0.6	0.8	8.3
Memory [GB]	42.3	5.4	9.4	5.0	97.1

Runtime and memory requirements per direction for a data set of 720x720x1024 voxels.
Computer with 16 Cores and 128 GB RAM.

Conclusions

- In-situ conditions for reservoir rocks are characterized by elevated pressure and temperature conditions
- Influence of temperatur can be considered by adjustment of the fluid and mineral phase input parameters
- Pressure changes affect the 3D geometry of the rock and have to be corrected
- Non-consideration of the in-situ pressure can lead to substantial errors in the derived DRP parameters
- Simulation of the in-situ conditions represents an alternative for in-situ measurements

Outlook

- **Evaluation** - comparison of structures generated by:
  - in-situ CT measurements (Zeiss Xradia)
  - numerical compression of conventional CT scans

- **Improvements** of the workflow:
  - Segmentation of all present phases
  - Incorporation of special properties for grain-grain contacts in the simulation of elastic deformation

Thank you for your attention!