Digital Rock Analysis

Integrating drill cuttings analysis with subsurface data

Alex Mock and Håkon Ruelåtten
Numerical Rocks

April 2011

Outline

numericalrocks

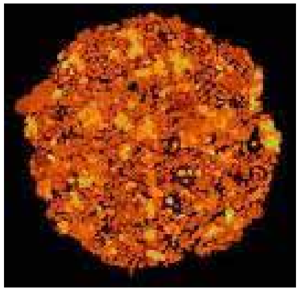
- Introduction to the e-Core technology and pore-scale modeling
- Using drill cuttings as source material
- Case studies

Digital Rock Analysis

The e-Core Technology

Pore-scale Modelling - Summary

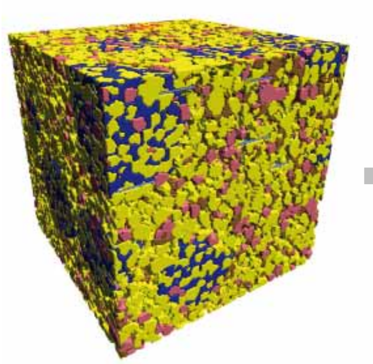
Thin Section



Micro-CT

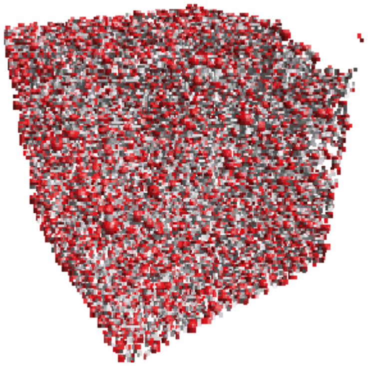
Thin sections and micro-CT prepared from core plugs, drill cuttings or sidewall samples.

3D Model



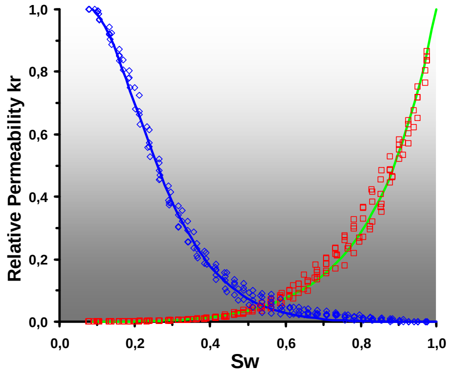
Calculation of petrophysical/single phase parameters such as porosity, absolute permeability, formation factor, NMR, elastic properties, etc.

Network Model

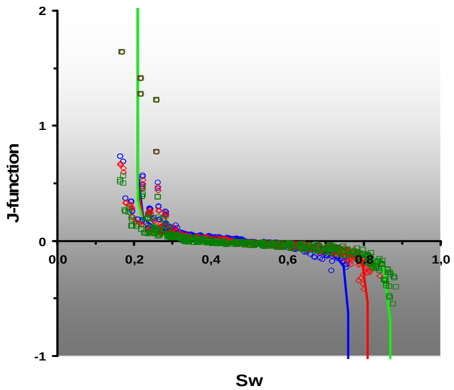


Calculation of two phase parameters such as capillary pressure, relative permeability & resistivity index. Plus wettability sensitivity tests.

Core Scale Properties



Relative Permeability Curve



Capillary Pressure Curve

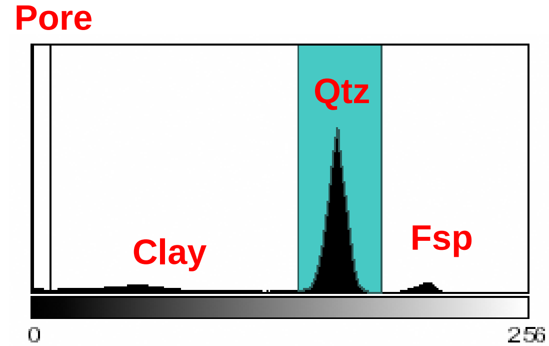
www.numericalrocks.com

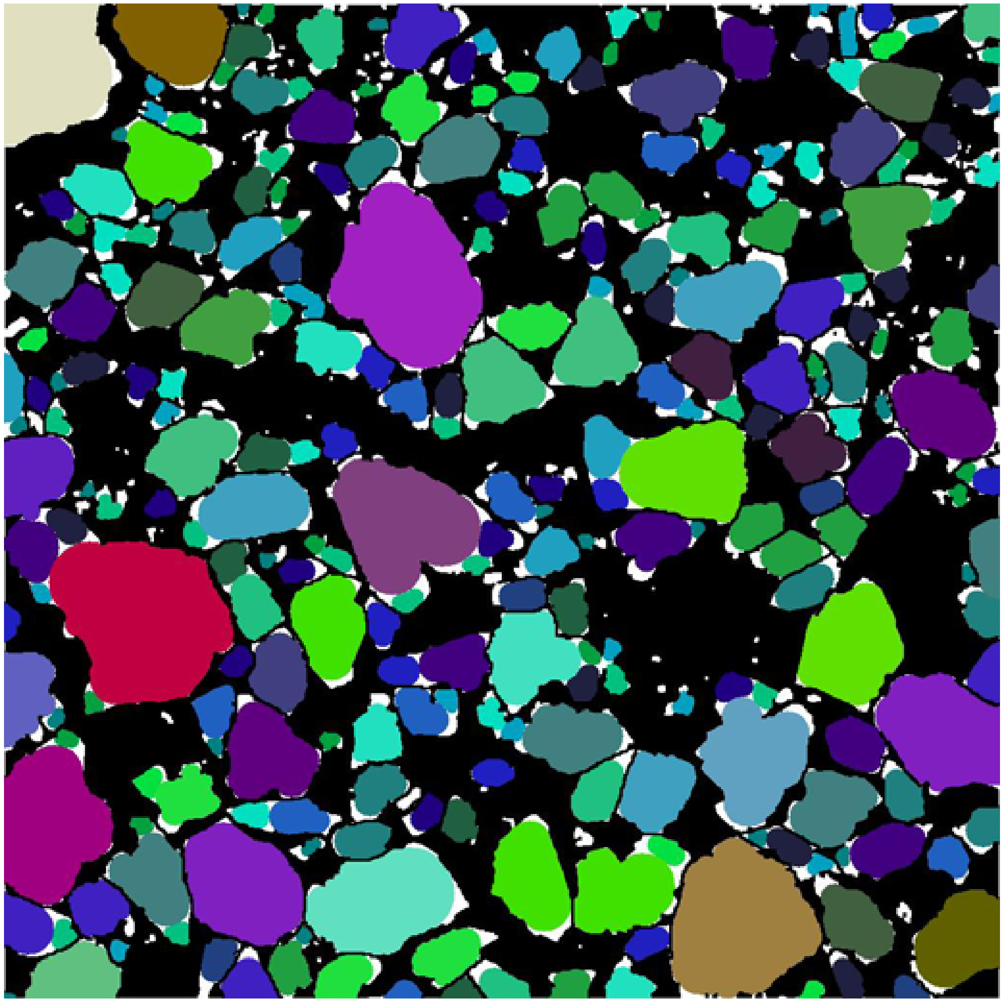
Thin Section Analysis

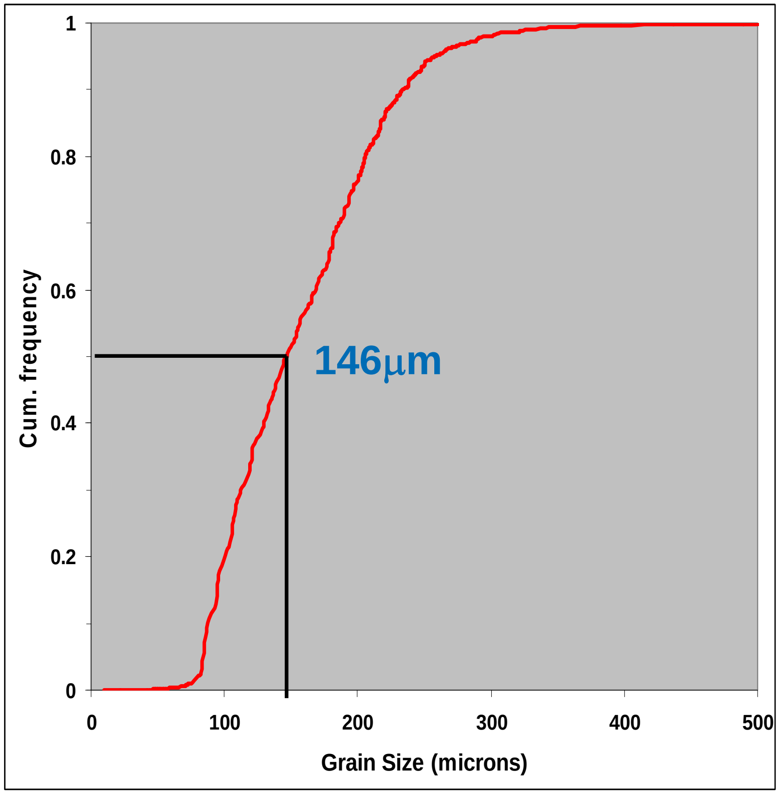
- porosity
- cement & clays
- grain size distribution

Grain Size:

- binarize image
- distance tranform
- stereological correction
- grain size distribution



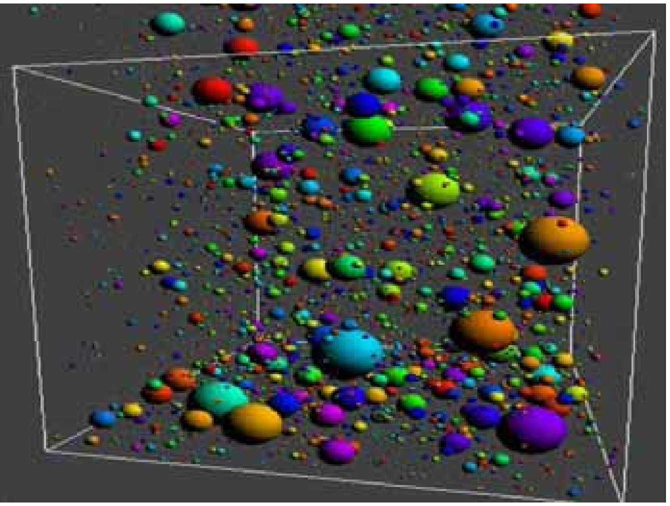




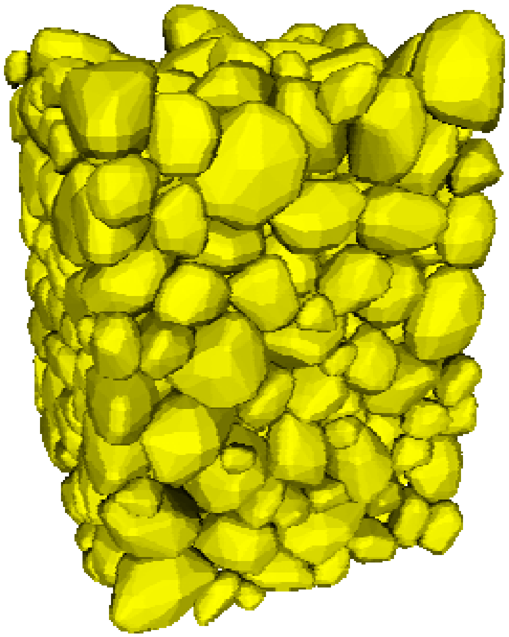
www.numericalrocks.com

Process Based Modeling

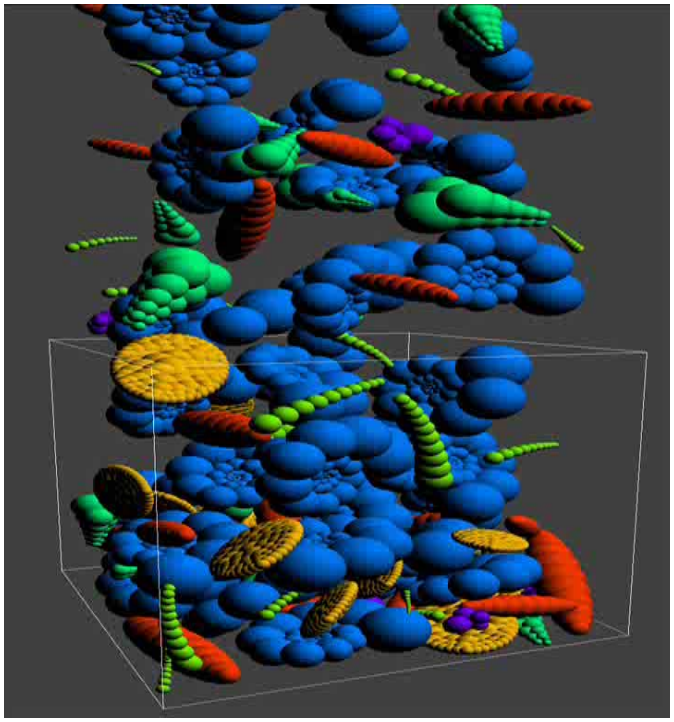
(1) Sedimentation and Compaction:



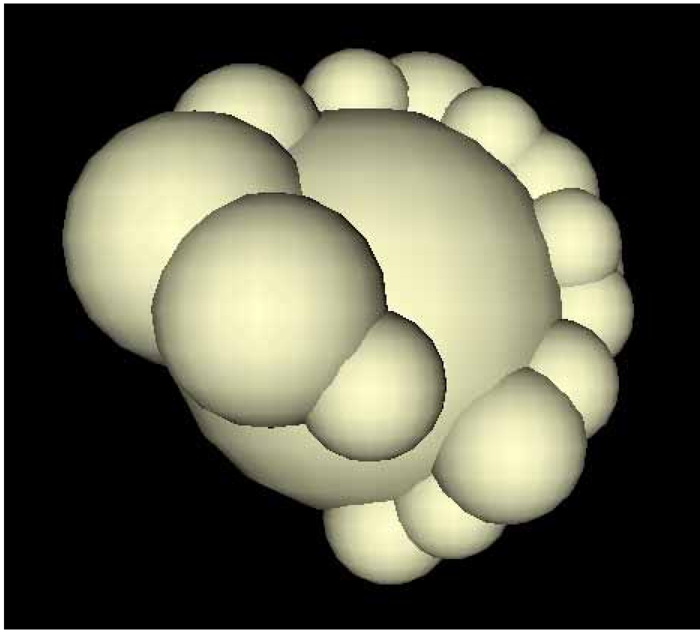
(2) Realistic Grain Shapes:



(3) Carbonate Grainstones:

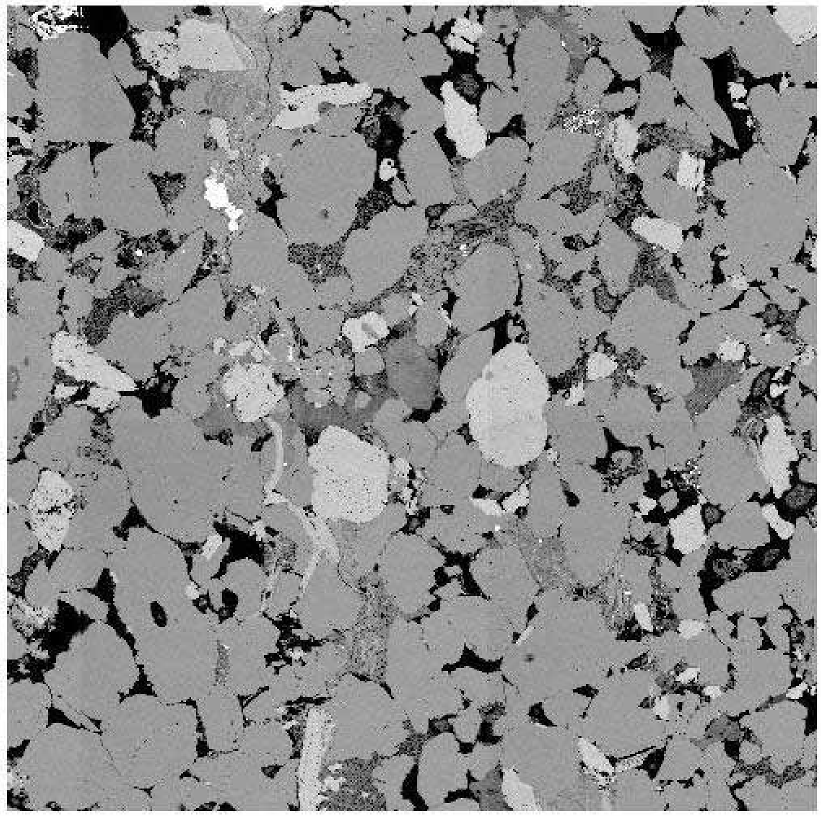


(4) Diagenesis:

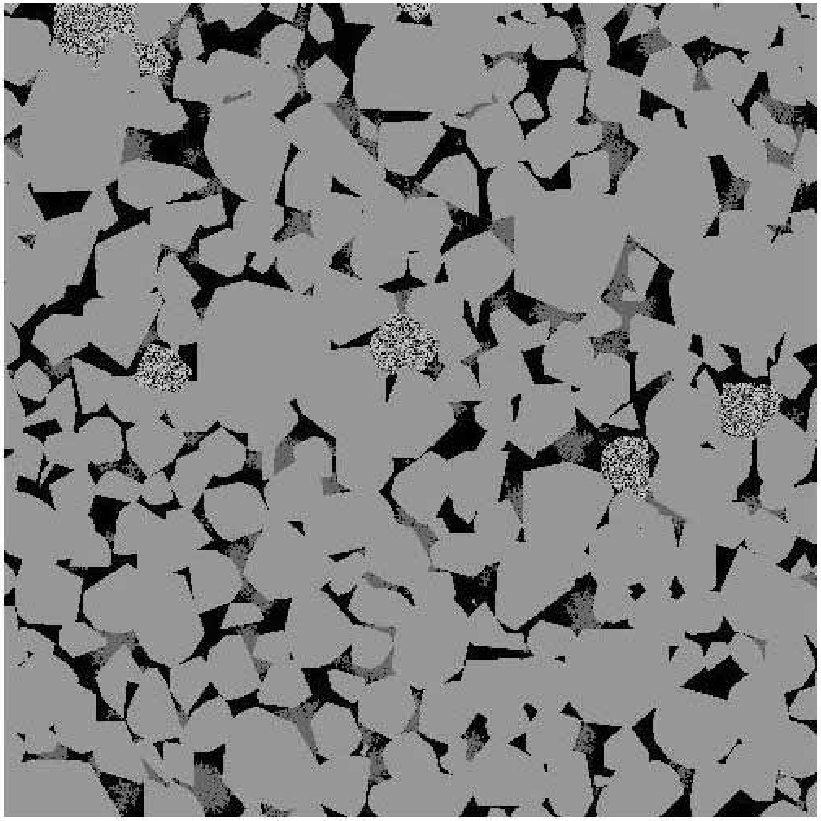


Process Based Modeling

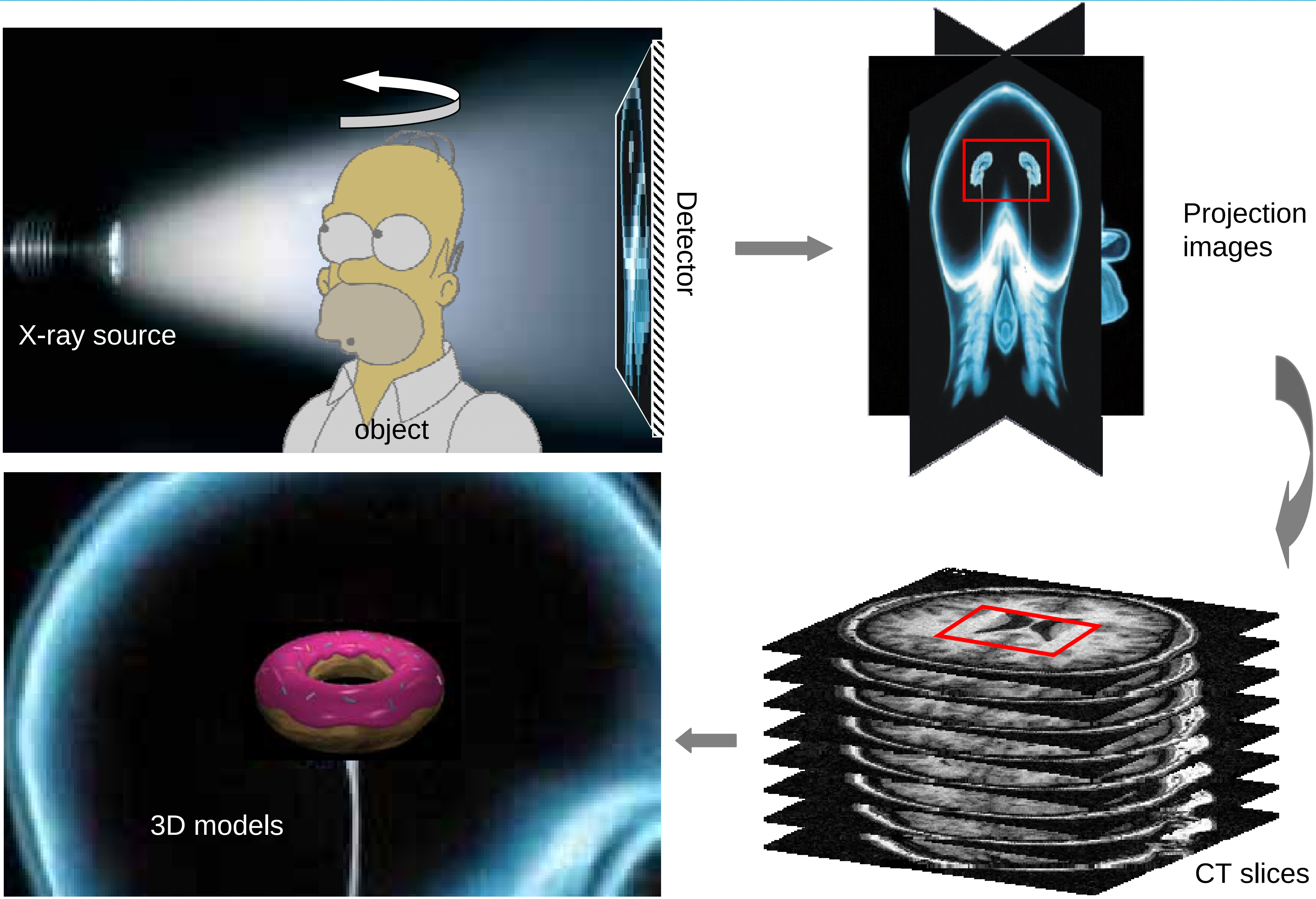
Thin Section Reservoir Rock



2D section in a reconstructed 3D model



MicroCT Imaging



www.numericalrocks.com

MicroCT Imaging

numericalrocks

Max. tube voltage	180 kV
Max. output	15 W
Detail detectability	Up to 200nm (0.2µm)
Min. focus-detector-distance	0.4mm
Max. voxel resolution (depending on object size)	< 500nm (0.5µm)
Geometric magnification (3D)	1.5 times up to 100 times
Max. object size (height x diameter)	150mm x 120mm / 5.9" x 4.7"
Max. object weight	2 kg/ 4.4 lb
Image chain	5-Megapixel fully digital image chain
2D X-ray Imaging	no
3D computed tomography	yes
Advanced surface extraction	yes (optional)
CAD comparison + dimensional measurement	yes (optional)
System size	(1640 x 1430 x 750 mm), (64.6" x 56.3" x 29.5"), larger cabinets on request
System weight	1300kg / 2866 lb

Sample Preparation

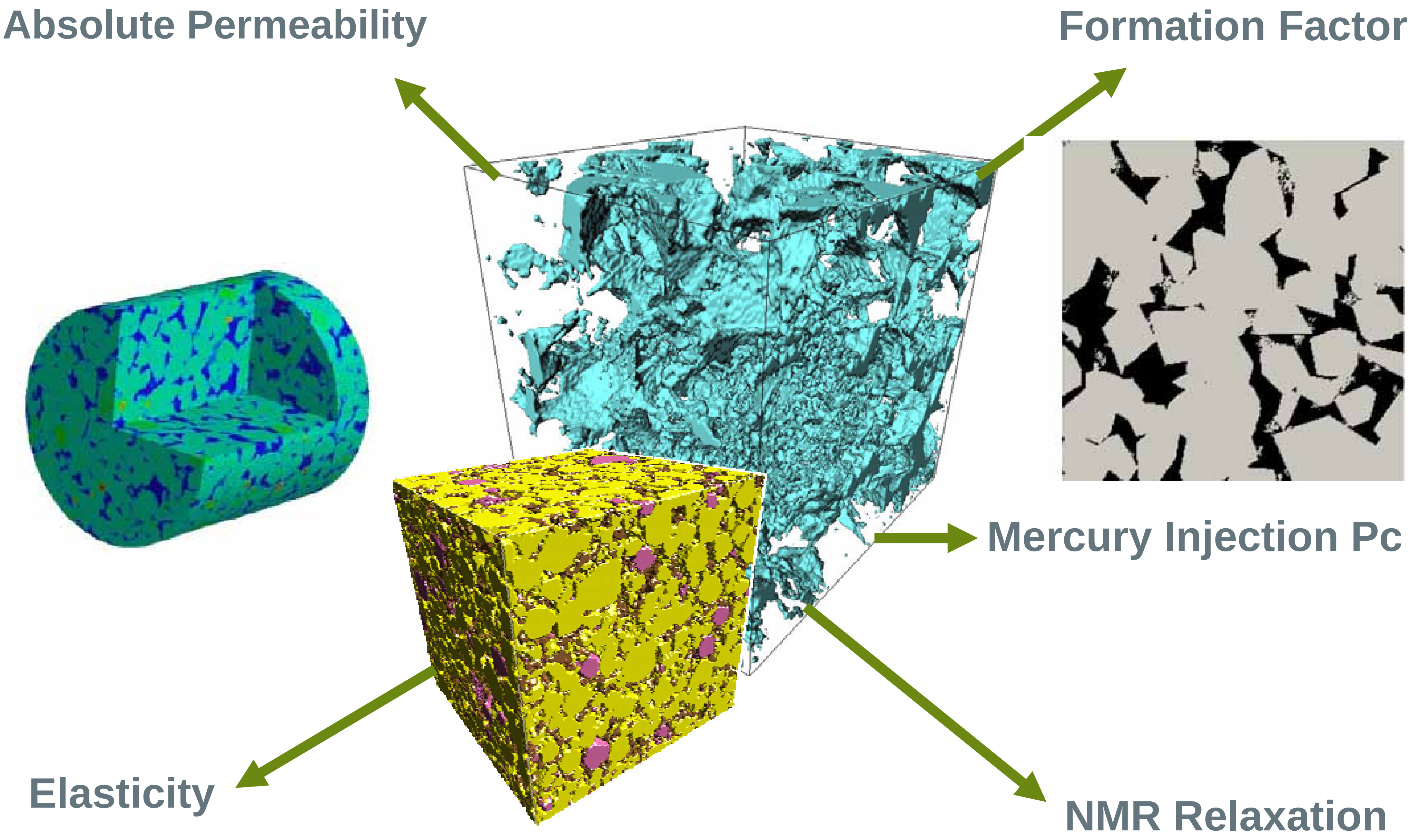
Cutting

Bit size: 0.5mm to 10mm

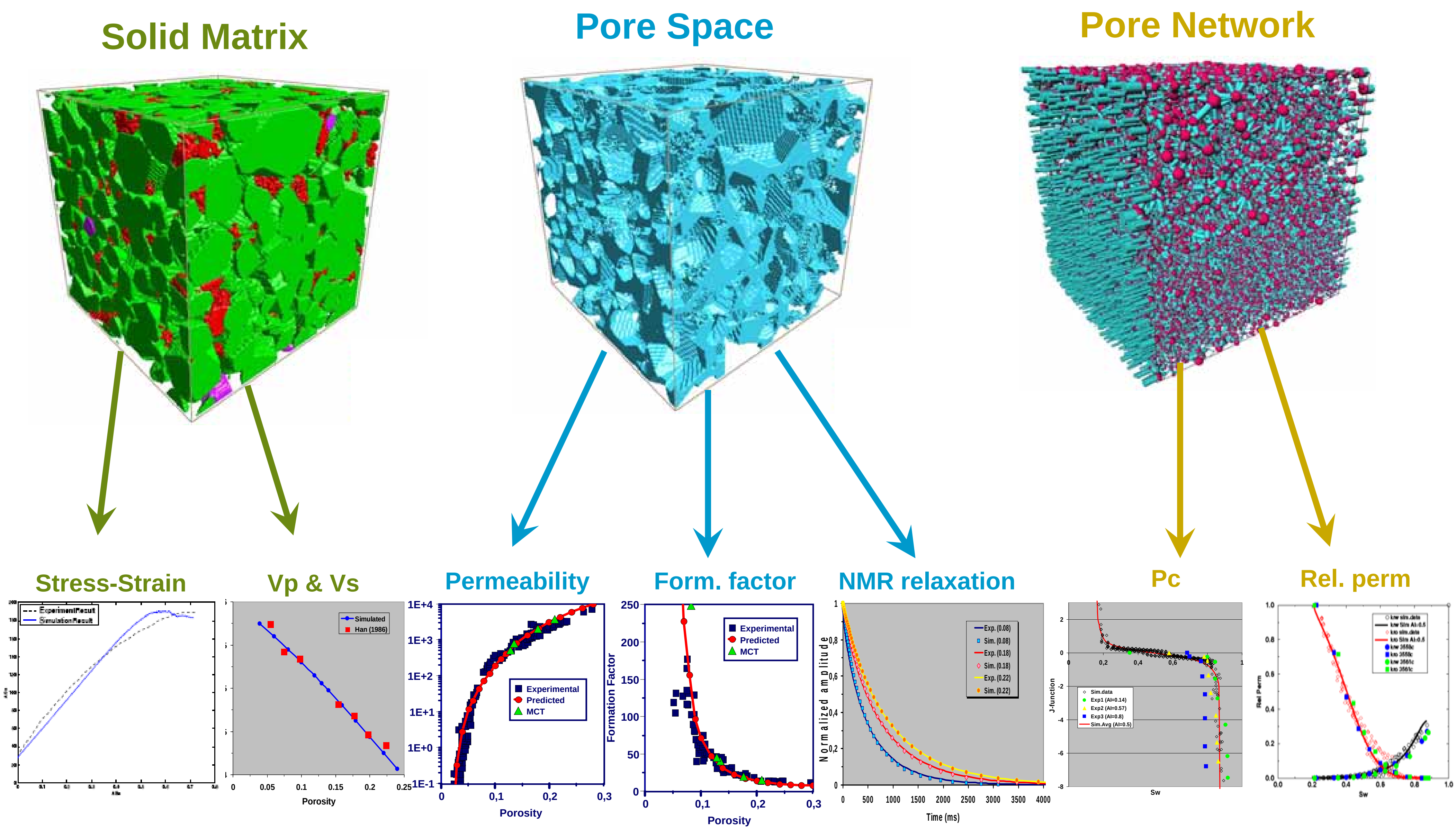
Drilling

Impregnation

Rock Model and Computed Petrophysical Properties



Overview and Summary

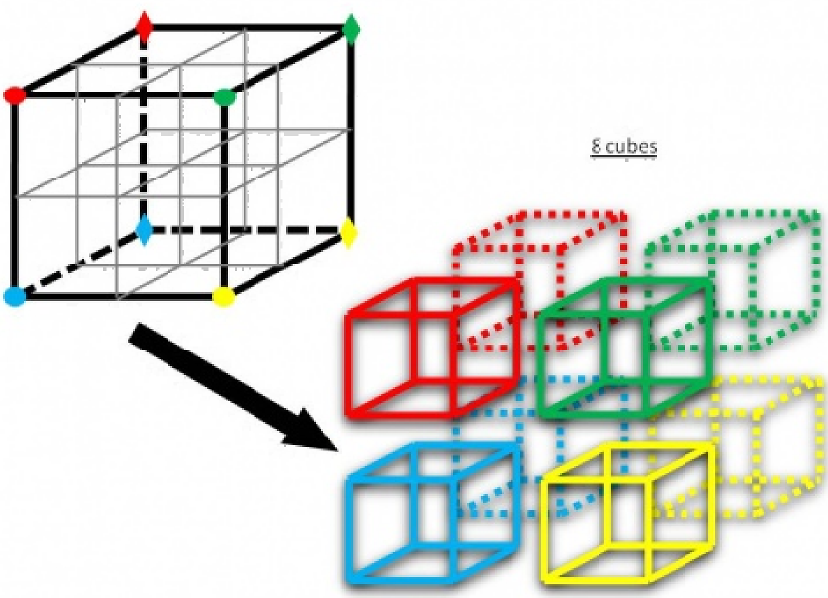


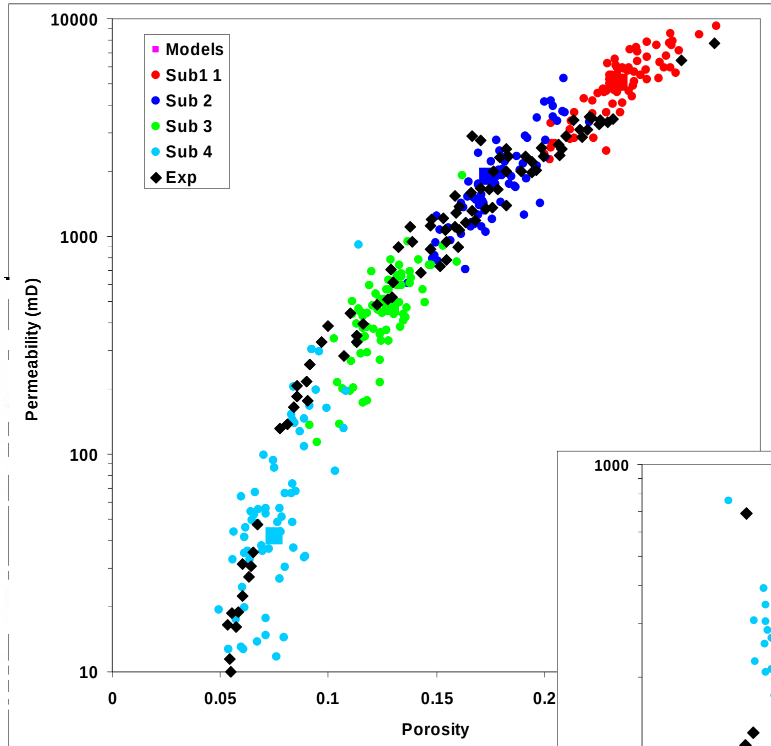
MICP and NMR pore size distributions

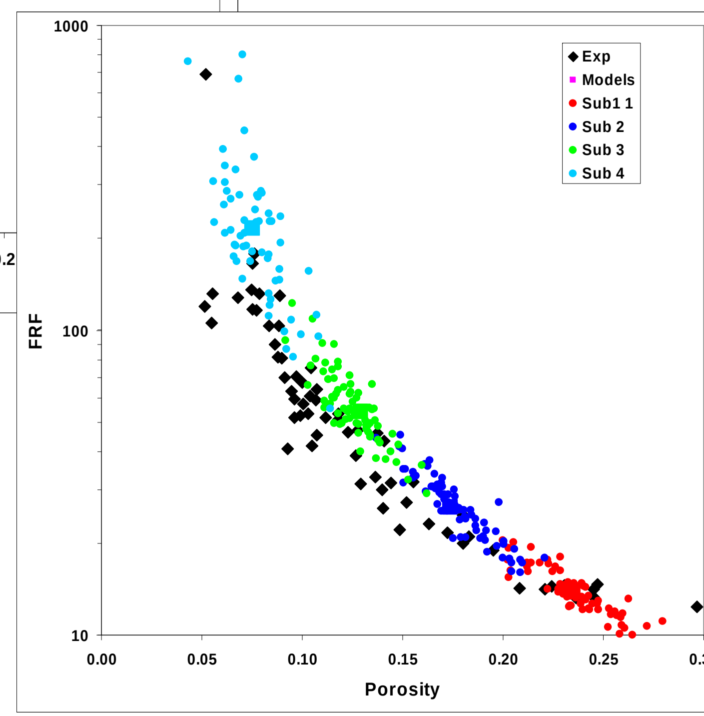
www.numericalrocks.com

Property Correlations from few samples

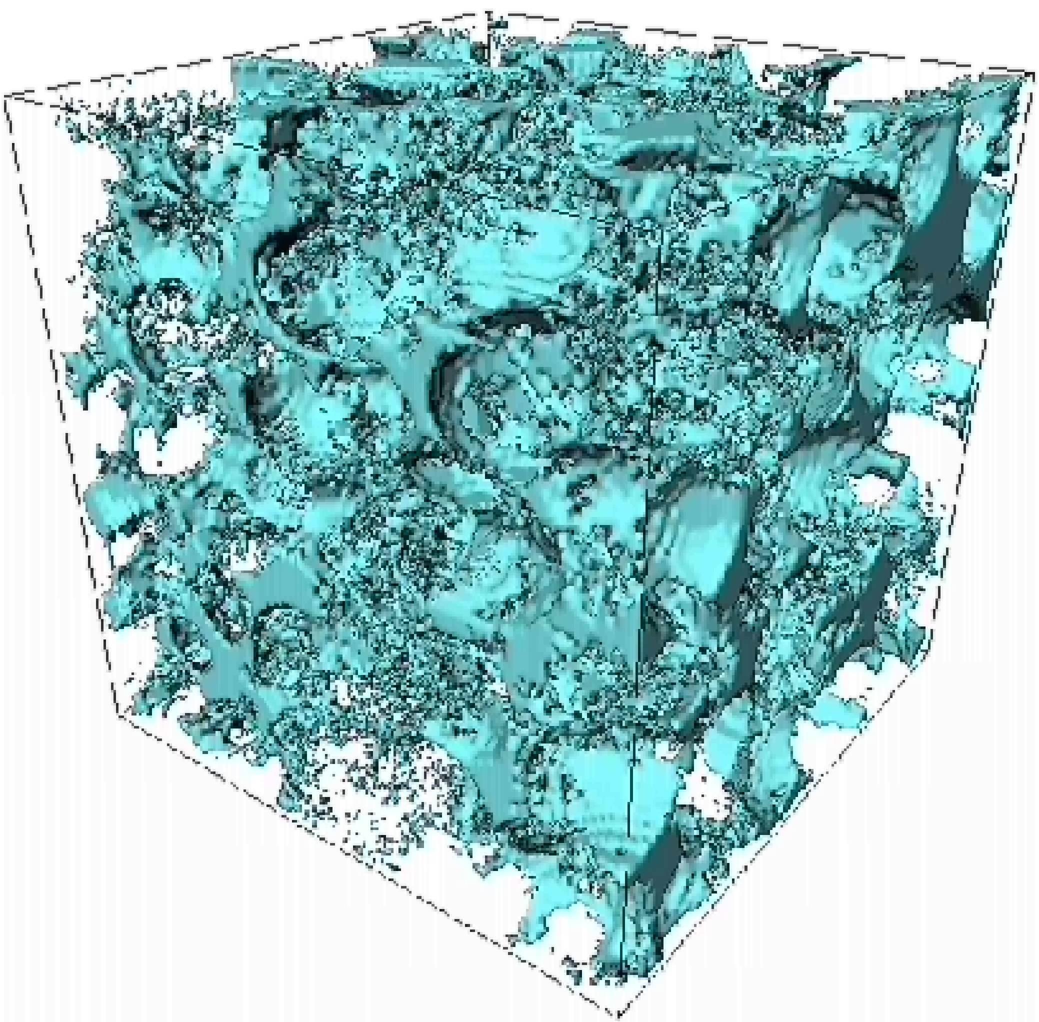
- Heterogeneous at all scales – including the pore-scale
- Replace single data points (non-stationary) with ”stationary” transforms (i.e. cross-correlations)



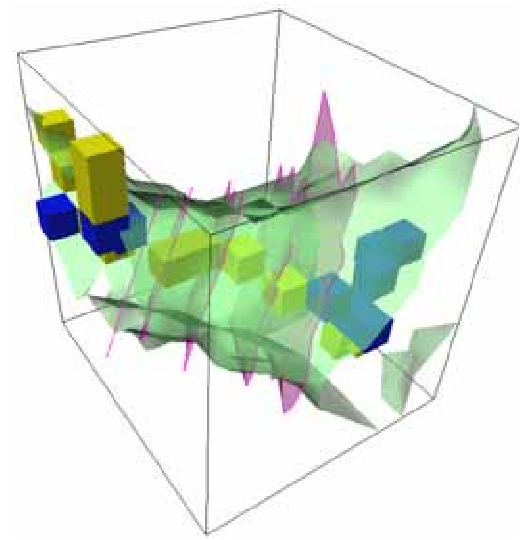




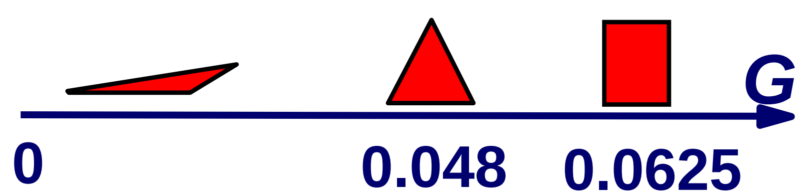
Pore Network Extraction for Multi-Phase Flow



Single Pore

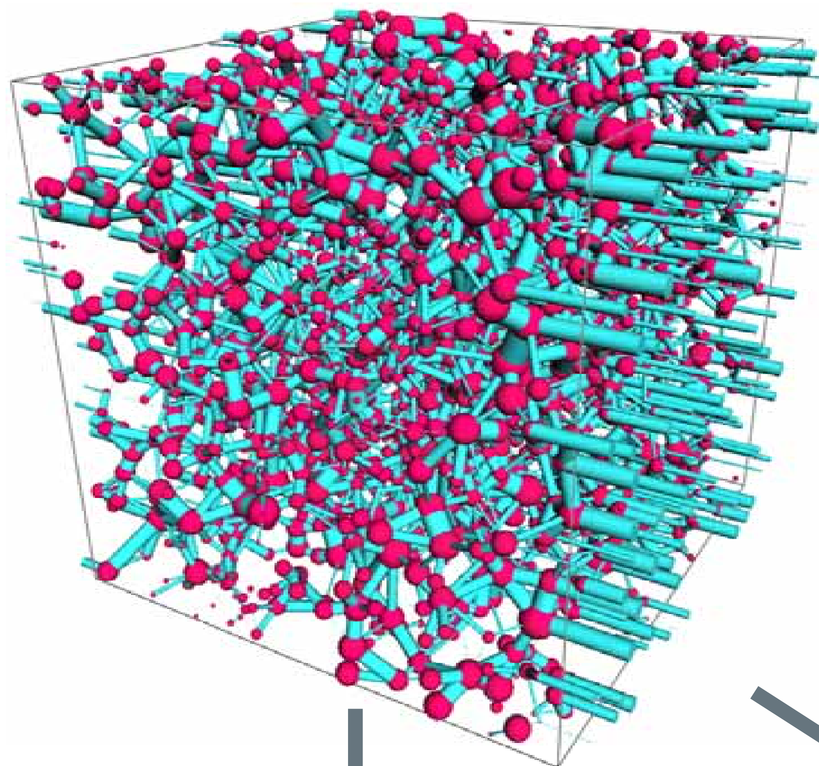


- *pore sizes*
- *pore volumes*
  - *intergranular & clay*
- *cross-sectional shape*
- $G = A/P^2$



Multi-Phase Flow Simulations

numericalrocks



Primary Drainage

kr, Pc, RI, Swi

Waterflooding

kr, Pc, RI, Sorw
wettability effects

Secondary Drainage

kr, Pc, RI, WI

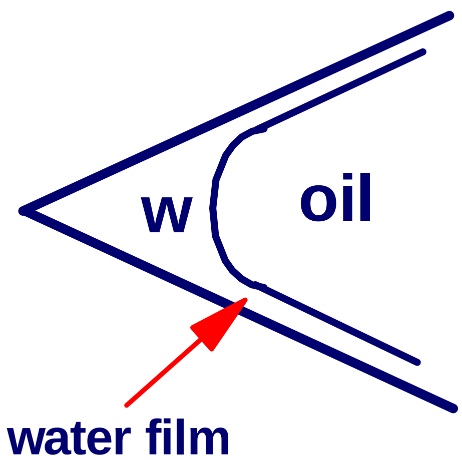
Hysteresis modelling

3-phase flow

kr, Pc, RI, Sor

Mixed Wettability Model

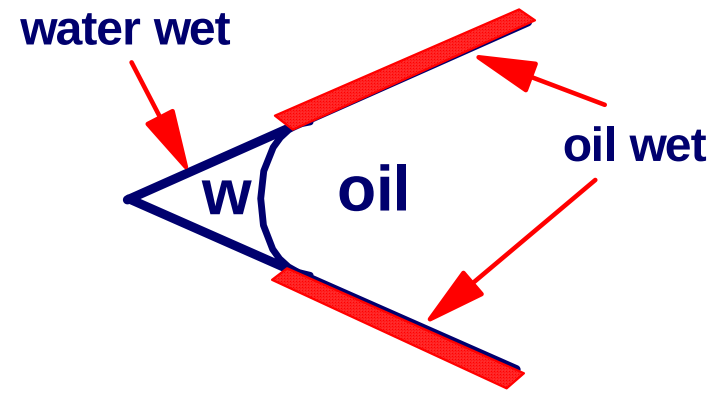
Primary Drainage



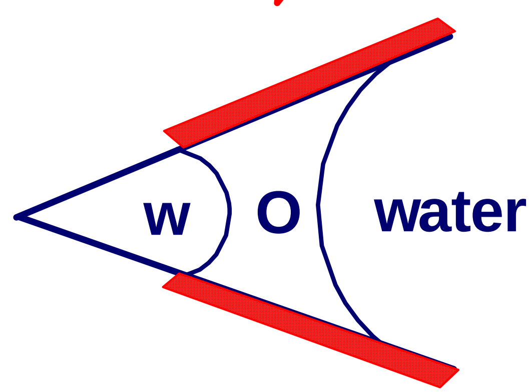
Aging

$$P_c \geq \Pi_{\max} + \sigma_{ow} C$$

Mixed Wet Pore



Waterflood



<u>Oil film thickness:</u>

- $P_{c,max}$ (i.e. S_{wi})
- Pore Geometry
- Advancing contact angle

Digital Rock Analysis

Using Drill Cuttings

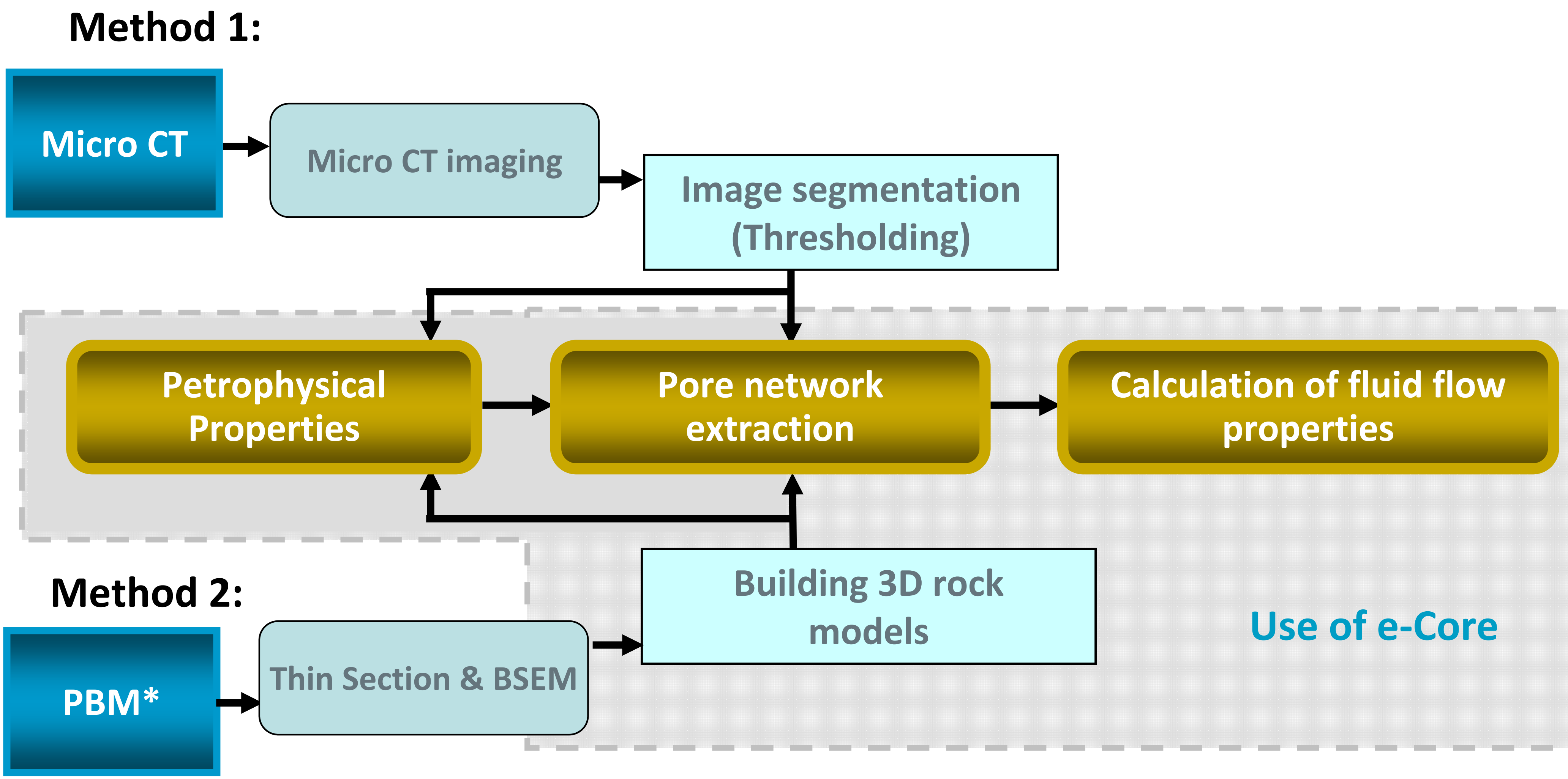
- **Use drill cuttings during well drilling to obtain the basic reservoir properties; e.g., absolute and relative permeabilities, capillary pressures, residual saturations, petrophysical characteristics, formation factor, sonic velocities, NMR relaxation.**

- **To start with, we need a representative 3D digital model of the rock, that**

  - ***has sufficiently high resolution in order to see the connectivity of the pore system, and***
  - ***contains a "Representative Elementary Volume" (REV) of the rock.***

  - ***We have two approaches to obtain such a model:***

Numerical Rocks Methodologies
Two Approaches

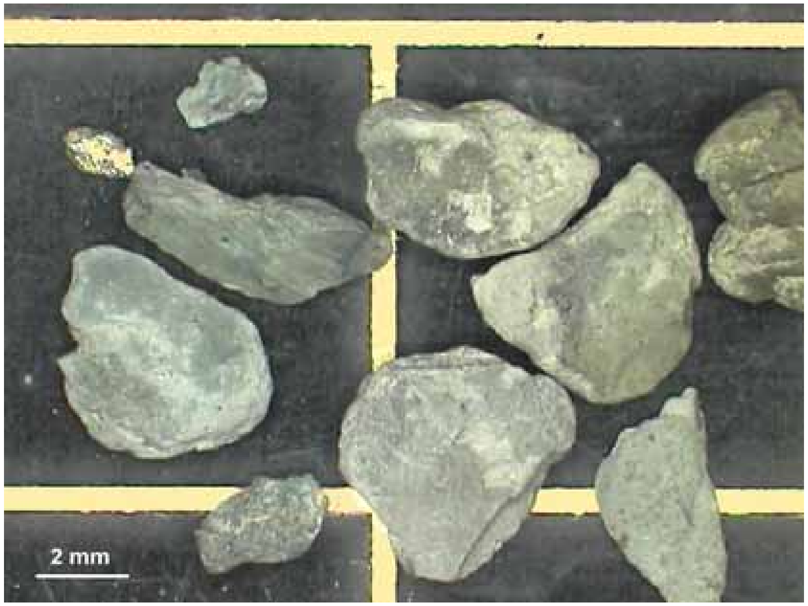


*Process Based Modelling

- **We can use drill cuttings to construct representative rock models:**

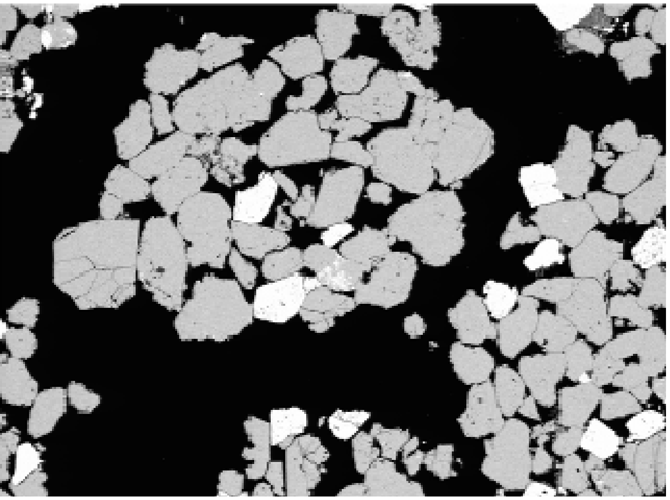
Drill Cuttings

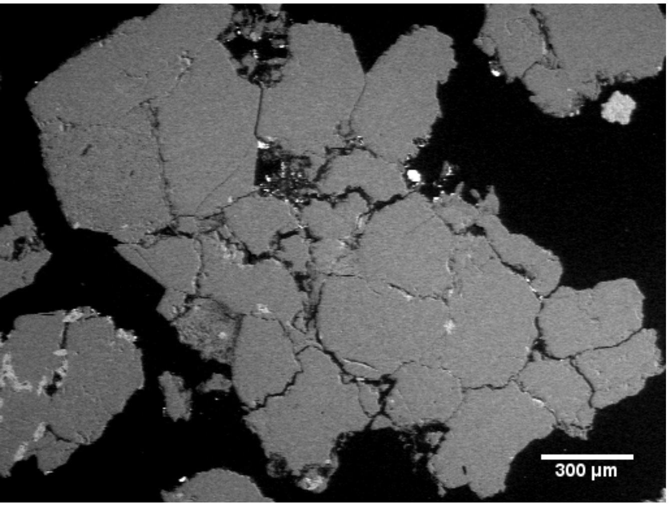
Cleaned and dried cuttings with chip sizes up to several mm → original rock texture is well preserved

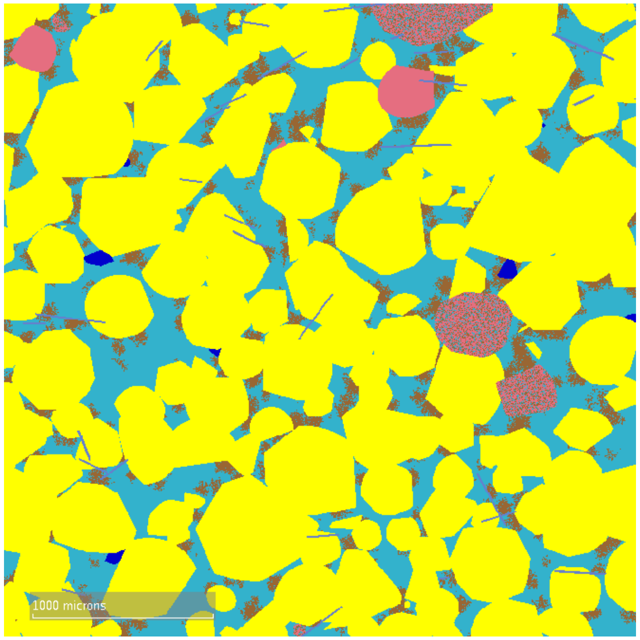


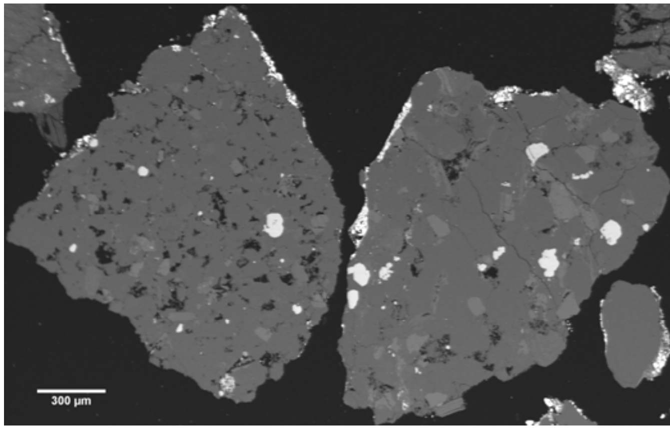
Sandstone Cuttings

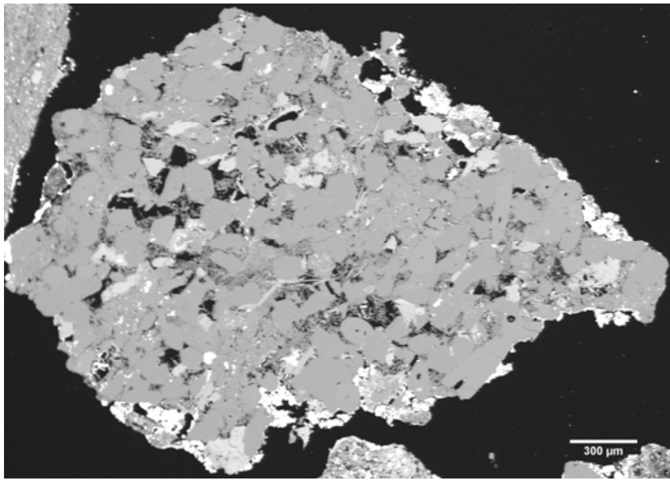
Cleaned and dried cuttings with chip sizes up to several mm → original rock texture is well preserved



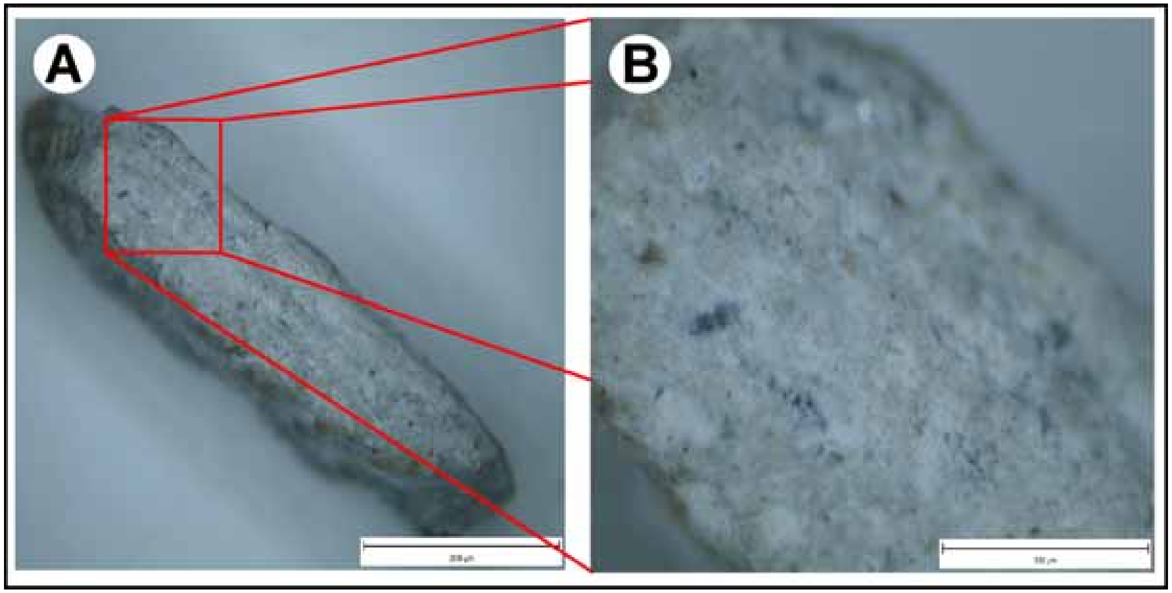


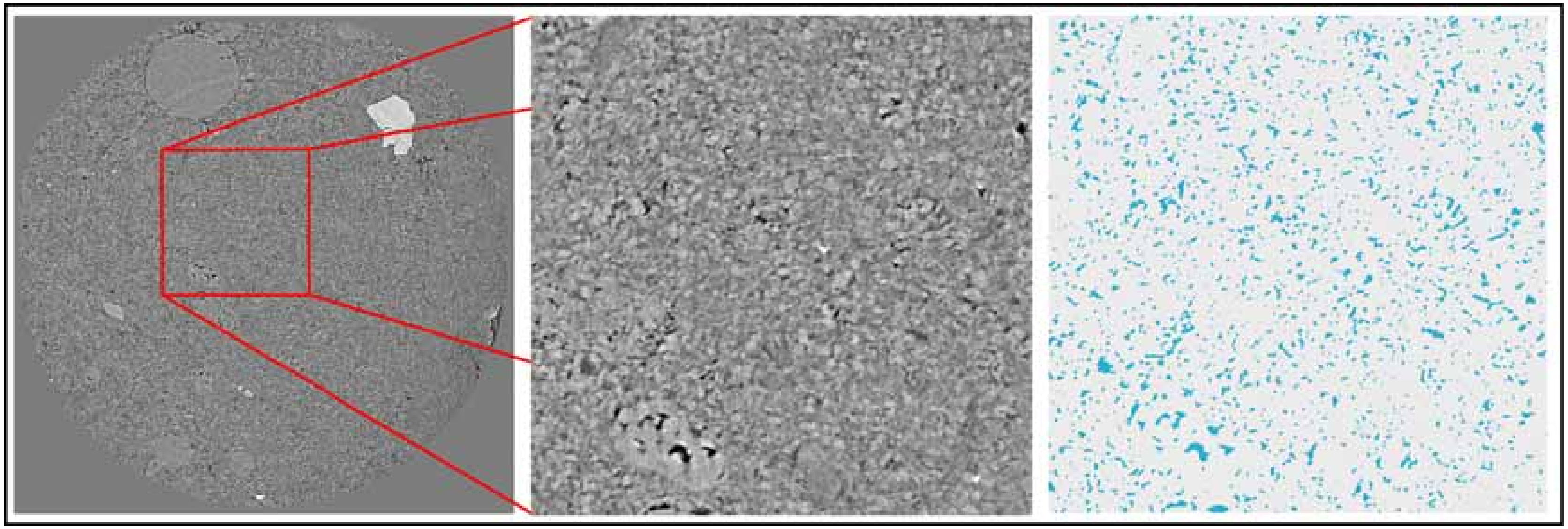




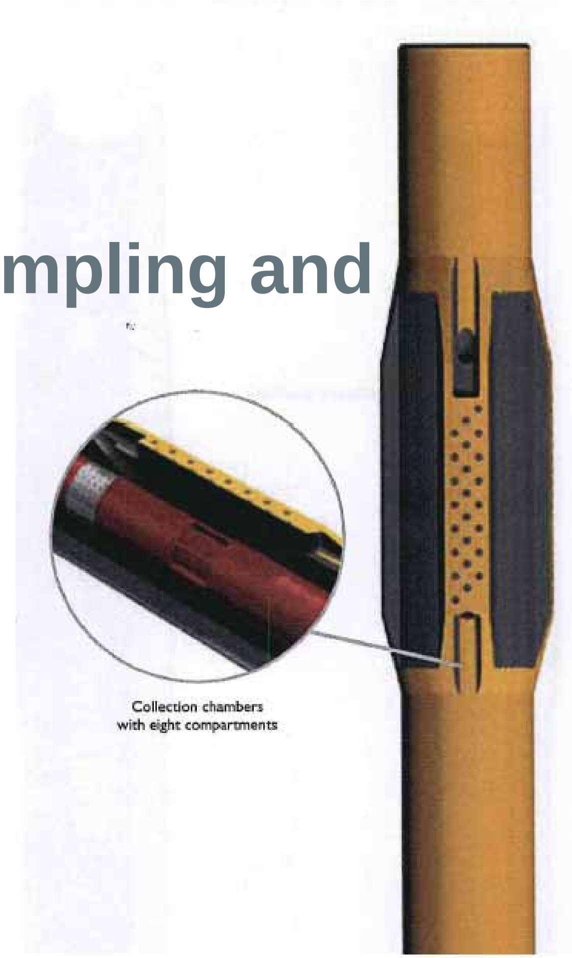


Carbonate Cuttings





- **Integrate available data into the modeling process:**
  - ***Logs***
  - ***Geological Models***
  - ***Electromagnetic ?***
  - ***Seismic ?***
- **Use purpose built drill bits for accurate sampling and good samples**
  - ***e.g. PLATYPUS drill cuttings sampler***

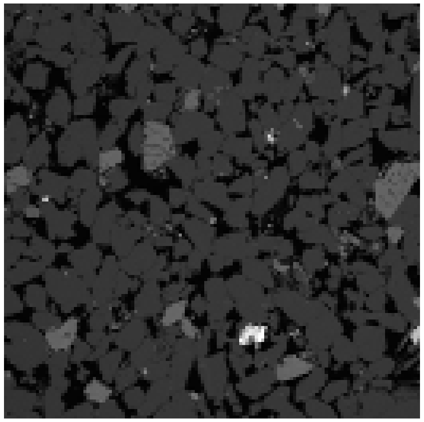


Digital Rock Analysis

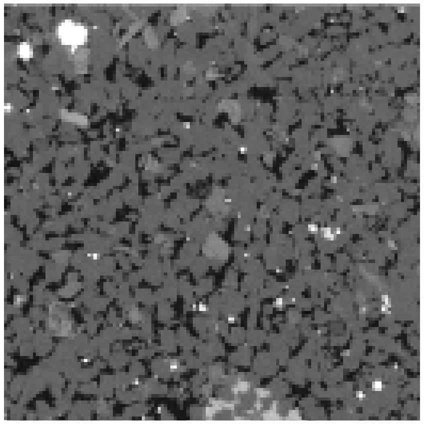
Case Studies

Examples – Case Study I

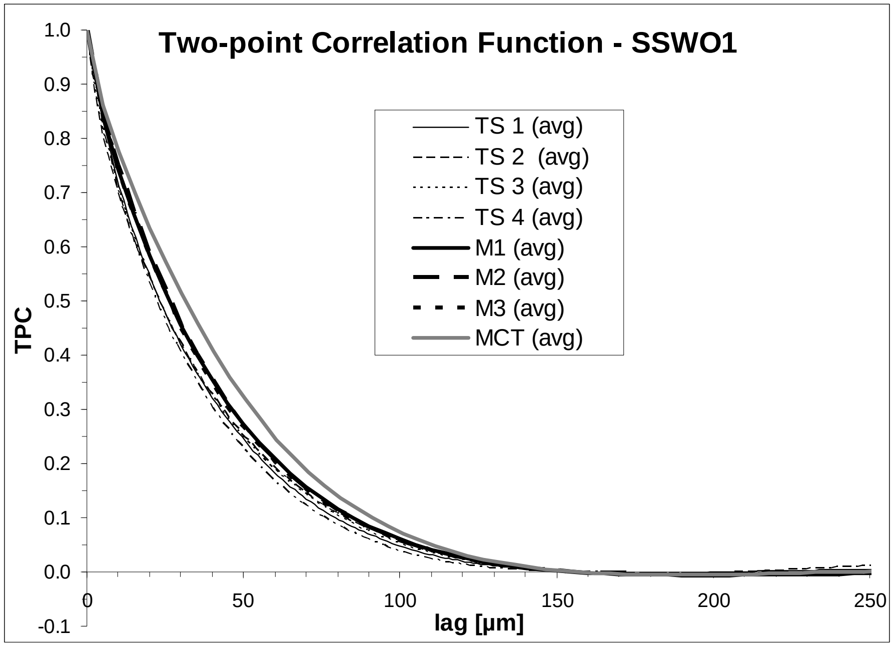
Client	North African Oil Company
Operating field area	North African oil reservoir
Sample Type	2 well consolidated and heterogeneous sample
Methodology used	Micro-CT and process based modelling /Anchoring to SCAL data



SEM image



Micro-CT image



www.numericalrocks.com

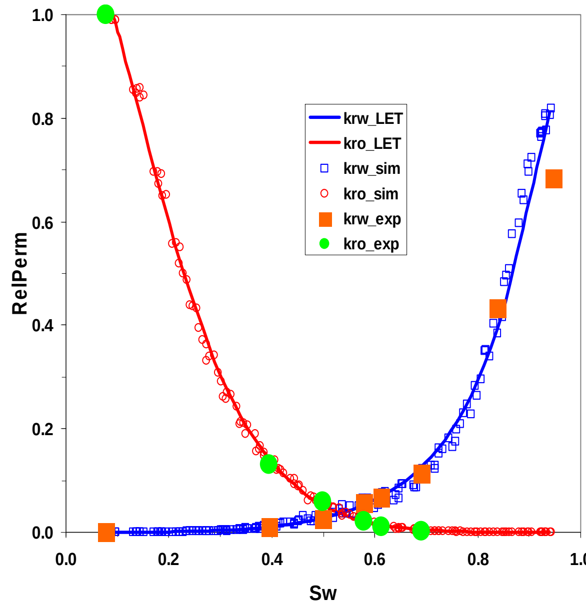
Examples – Case Study I

Sample	SSWO1		
Data set	Model	MCT	lab
k hor.	1305	1301	
k vert.	946	966	1442*
k avg	1185	1189	
FRF	24.6	29.4	---

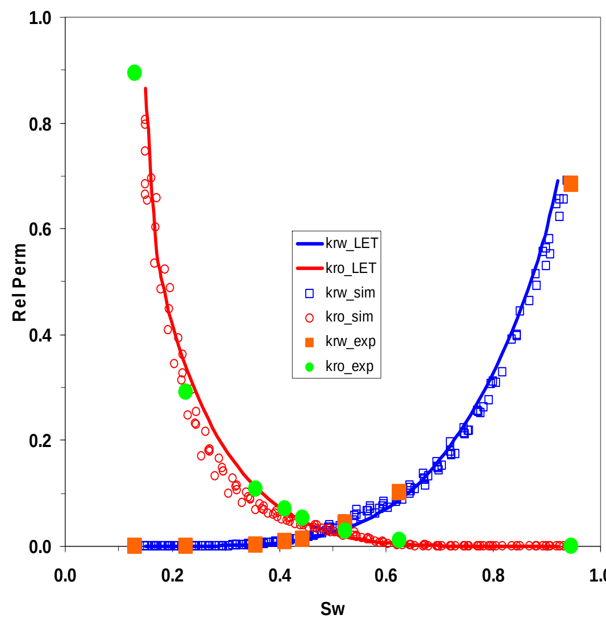
*measured on stacked cores

– Simulation results match experimental data confirming mixed wettability.

– This physical description of wettability was applied to 12 additional samples without SCAL data.



Relative Permeability Imbibition

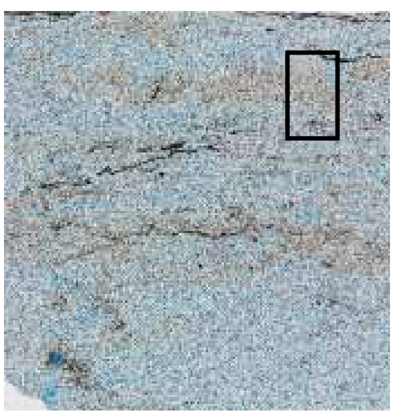


Relative Permeability Sec. Drainage

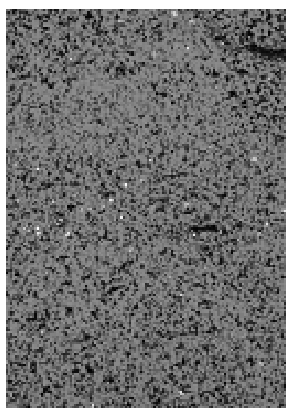
Examples – Case Study II

Heterogeneous Clastic Rocks

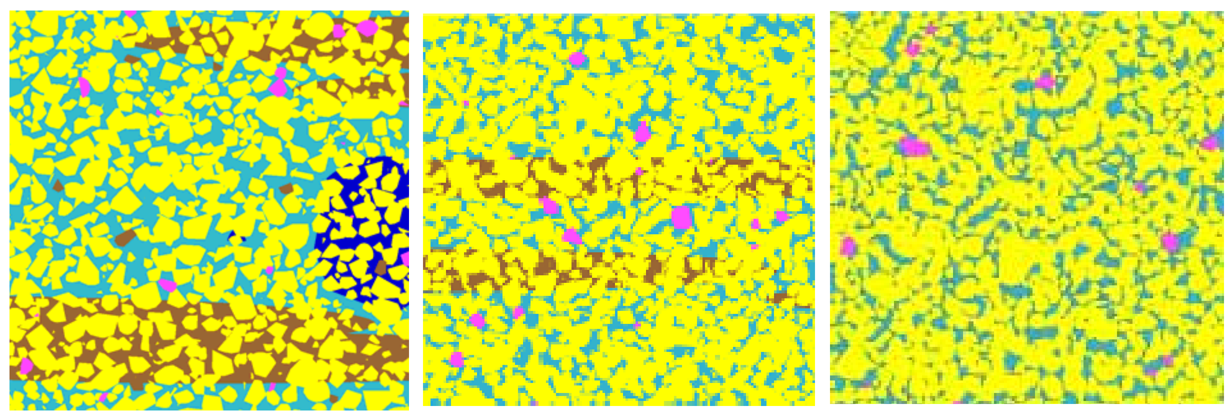
Client	Middle Eastern Oil Company
Operating field area	Middle East oil reservoir
Sample Type	2 consolidated and very heterogeneous clastic sample with several micro-facies on thin section scale
Methodology used	Process based modelling for different micro-facies



Thin section



SEM image



Models for 3 different micro-facies

Examples – Case Study II

Sample	1	
	Model	Lab
Effective Porosity [frac.]	0.227	**n/a**
Total ("He") Porosity [frac.]	0.247	0.237
Abs. Permeability [mD]	762	749

Porosity and permeability of different micro-facies were averaged according to observed area fractions in thin section

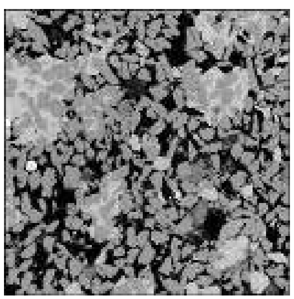
– In spite of sample heterogeneity, petrophysical properties were predicted accurately.

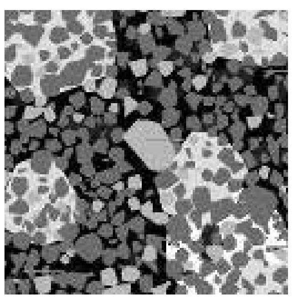
Examples – Case Study III

numericalrocks

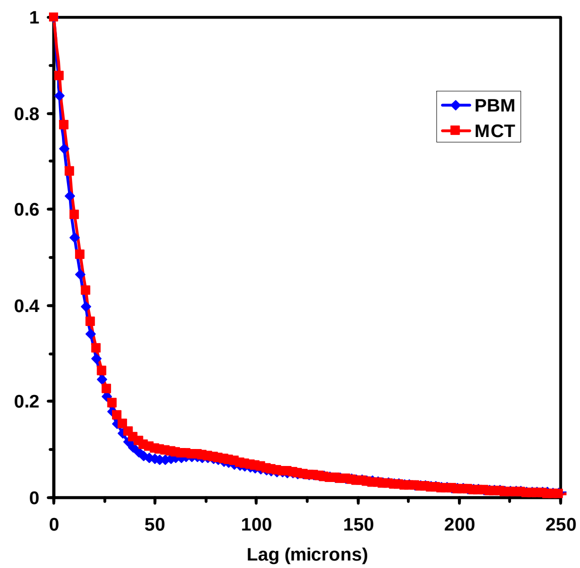
Client	Norwegian giant
Operating field area	North Sea
Sample Type	Poorly consolidated and heterogeneous sample
Methodology used	Micro-CT and process based modelling (PBM)

Comparisons

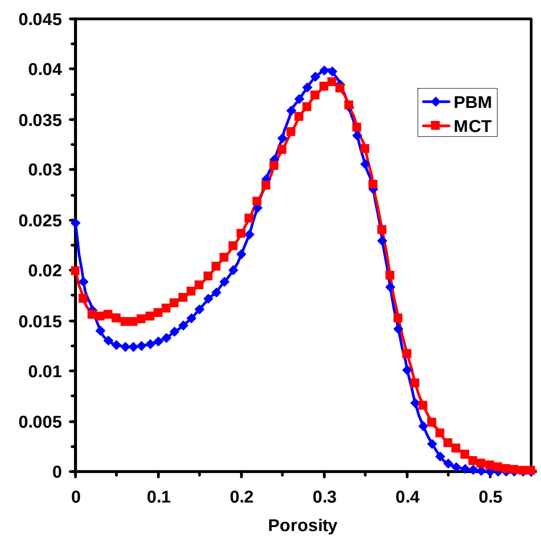




MCT image (left) and PBM image



Correlation Function

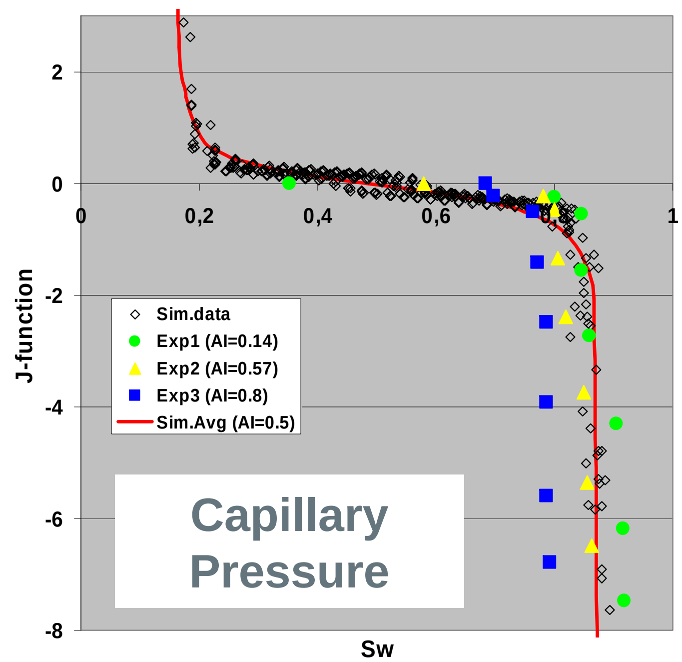


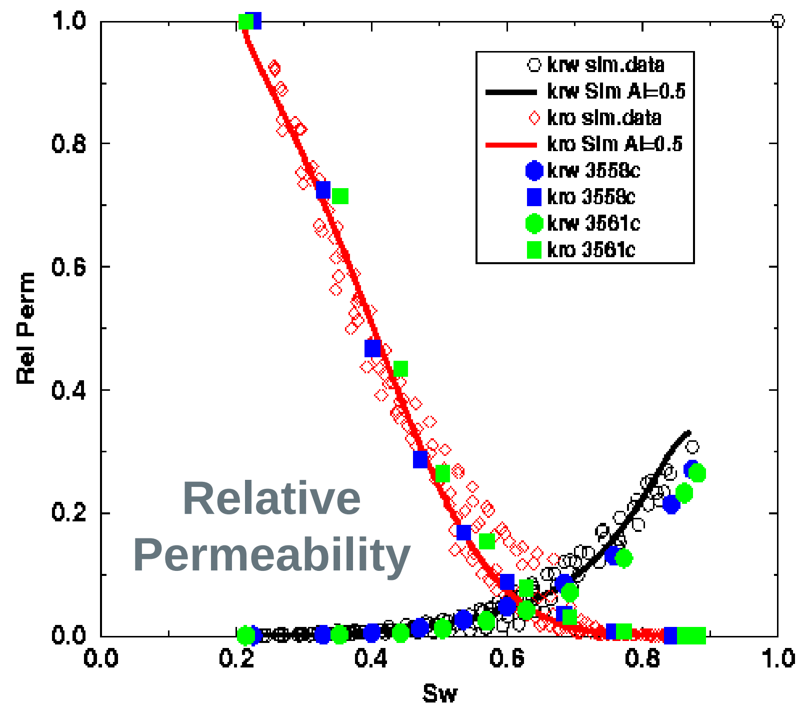
Porosity Distribution

Examples – Case Study III

	MCT	PBM
kx (mD)	736	828
ky (mD)	630	731
kz (mD)	852	778
k_avg	739	779

	MCT	PBM
Fx	17.5	12.2
Fy	16.0	12.4
Fz	13.6	12.6
F_avg	15.5	12.4

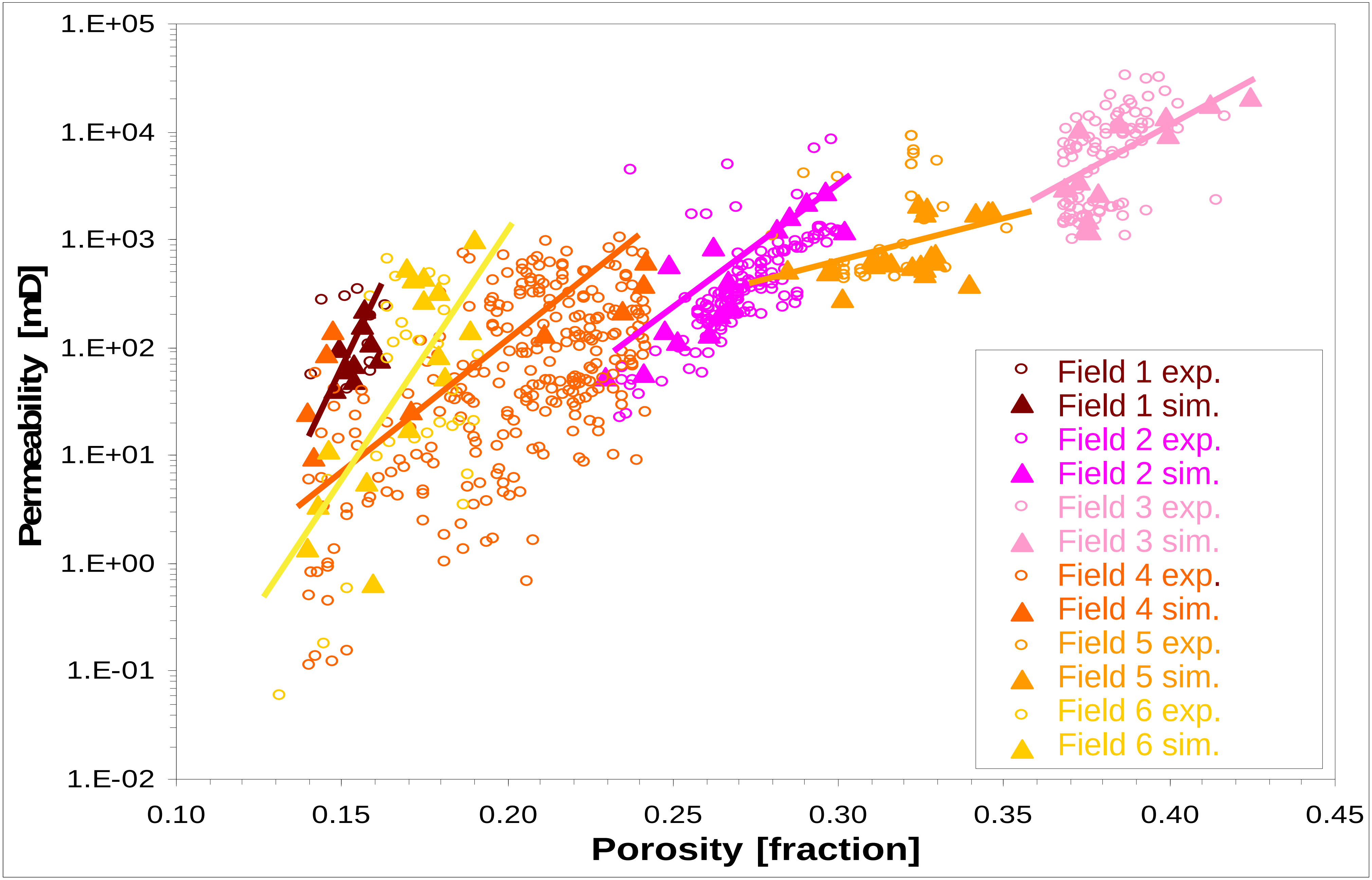




– Simulation results propose AI of ~0.5.

– Relative permeabilities match lab results.

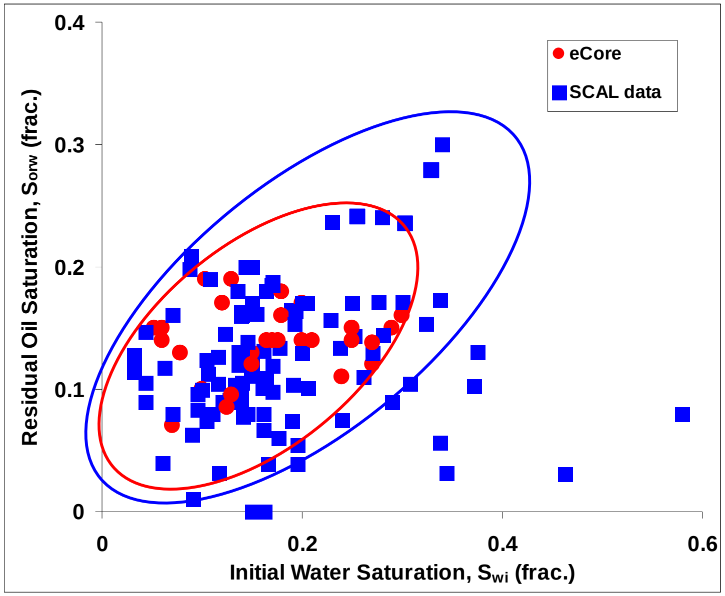
Examples – Case Study IV

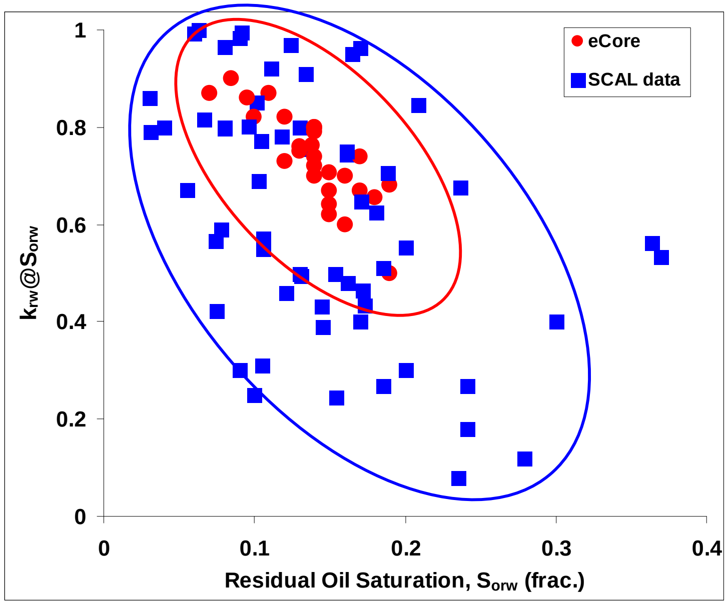


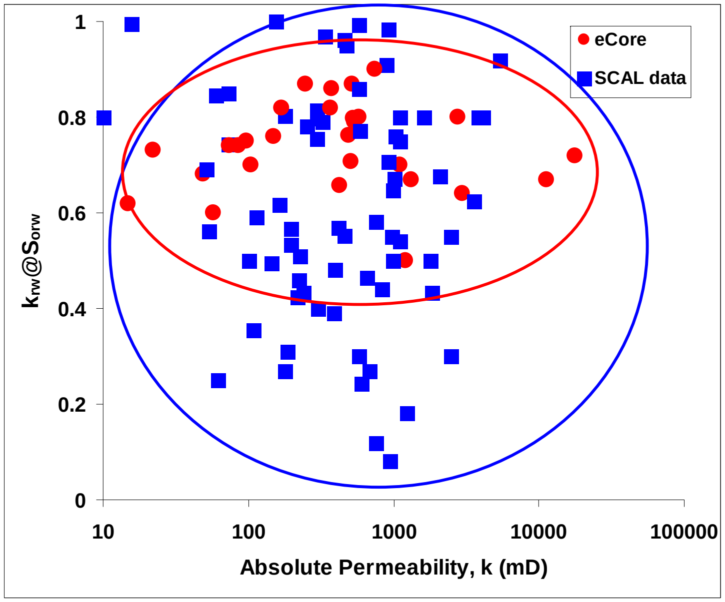
Examples – Case Study IV

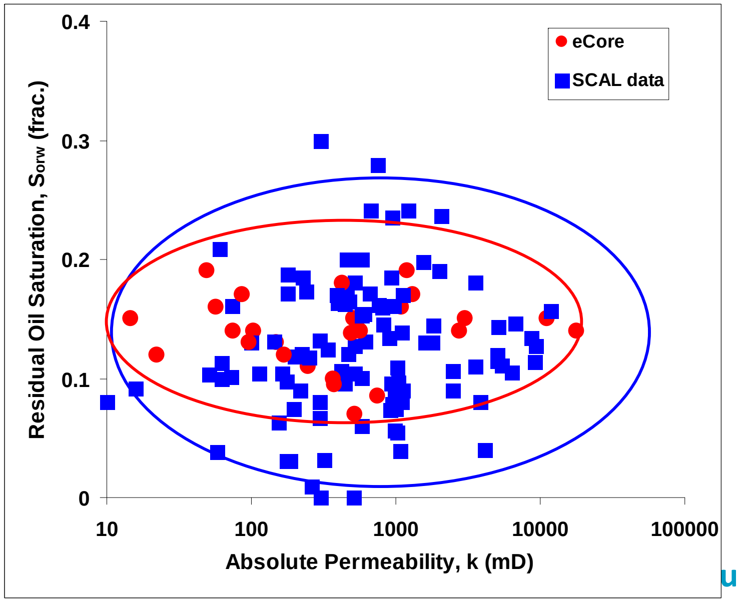
numericalrocks

Endpoints from Relative Permeability Simulations – All Fields





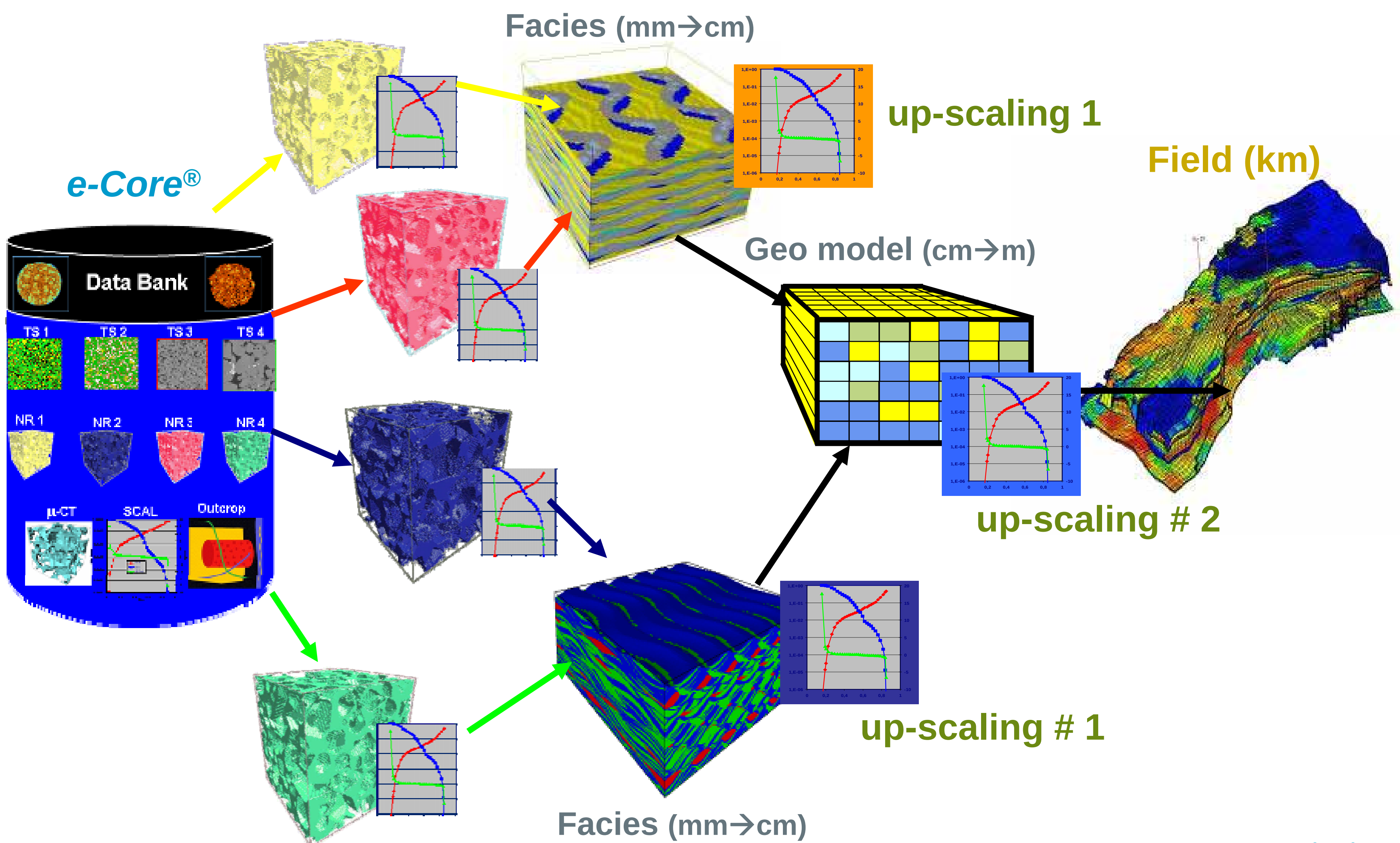




Benefits of Using e-Core

- Single sample --- Multiple data sets --- Better solutions
- Obtain early reservoir evaluation of a well (e.g. directly from drill cuttings)
- Re-use of models for multiple fluid flow simulations and for future use (extremely time and cost efficient).
- Sensitivity tests can be easily performed for different wettability preferences and different irreducible water saturations.
- Compare, complement, explain and extend core plug SCAL data

Pore-to-Field Upscaling



www.numericalrocks.com

Conclusions

numericalrocks

- The *e-Core* technology is a powerful tool for rock and reservoir characterization. The analysis can provide input data throughout the lifetime of the field; from exploration wells to reservoir characterisation; evaluation of EOR potential and Tail-end IOR.

- Input to the analyses must be rock samples that contain 'a representative elementary volume (REV)'. Drill cuttings may represent REV.

- *e-Core* analyses based on drill cuttings may provide advanced petrophysical and reservoir parameters for formation characterization 'while drilling', and thereby

- Improve the decision making regarding well completion and production strategy.