The Impact of Dual Porosity on Pore-Scale Fluid Distributions During Steady State Flow*

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Abstract

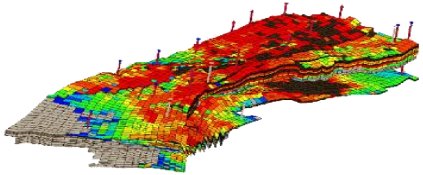
The last 5 years have seen a rapid advance in the ability of petroleum scientists to examine reservoir processes directly at the pore scale, principally through coupling Special Core Analysis (SCAL) techniques with non-invasive x-ray micro-CT imaging. These techniques have been used to investigate processes such as trapped gas saturation, wettability changes, and even dynamic multiphase displacements. Such experimental developments have, however, not typically focused on relating flow behavior to the pore structure of the host rock. In this study we present the first comparison of steady state core-flood experiments, conducted at reservoir conditions and imaged at the pore scale with resolutions of around 4.5 μm. Experiments were conducted in two qualitatively different pore structures; a single porosity sandstone and a dual porosity carbonate. During steady state fluid flow the single porosity sandstone showed a well-connected wetting phase flow path. The dual porosity carbonate, however, showed the wetting phase to be poorly connected through the macroporosity. Wetting phase flow (and so relative permeability) can only be explained by including connectivity through the microporous network. A multi-scale computational model was constructed which was able to reproduce the measured relative permeability of the carbonate better than when the model was constructed using macroporosity alone. The multi-scale model was created by populating microporosity from the micro-CT images with permeabilities modelled from high resolution nano-tomography images (with voxel sizes of around 50 nm), proscriptively sampled from microporous regions. This work has important implications for the characterization and modelling of flow in such systems. It is often assumed that microporosity, while important for volumetric petrophysical measurements (such as fluid saturation), has only a minor contribution to displacement and flow, as the permeability of the microporous network is often much lower than the permeability of the macroporous network. For this reason it is frequently ignored. This assumption makes pore-scale modelling of petrophysical properties much more computationally efficient, however may not capture physics critical for multiphase flow in

dual porosity rocks. The ability to conduct full steady state core-flooding experiments, imaged at the pore scale, shows the difficulty of such assumptions, and the value of a full multi-scale description of pore structure.

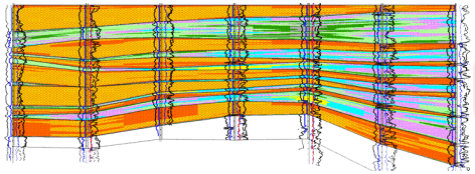
The Impact of Dual Porosity on Pore-Scale Fluid Distributions During Steady State Flow

Dr. M. Andrew
Carl Zeiss X-ray Microscopy
2016-06-20

What is relative permeability, and what controls it?



Static reservoir geomodel



Wireline logging, lithological classification & core correlation

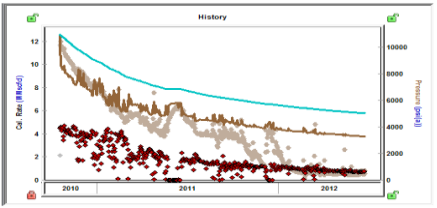
Core plug sampling

Bridge to the pore scale

Experimental measurement of petrophysical properties

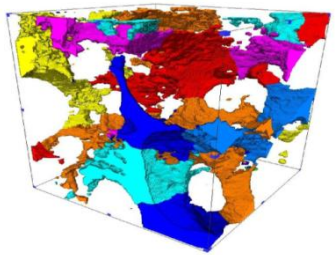
Population of dynamic reservoir model

History matching

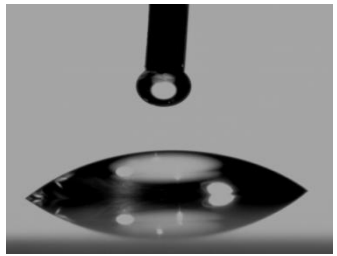


Production prediction & management decisions

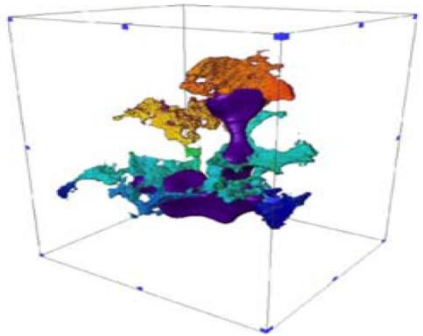
The problem's with pore-scale analysis 2: The problem of process



Pore-structure

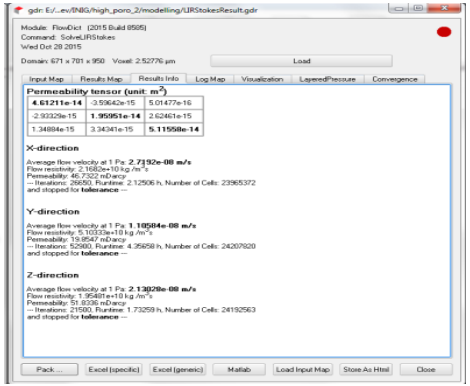


Fluid properties



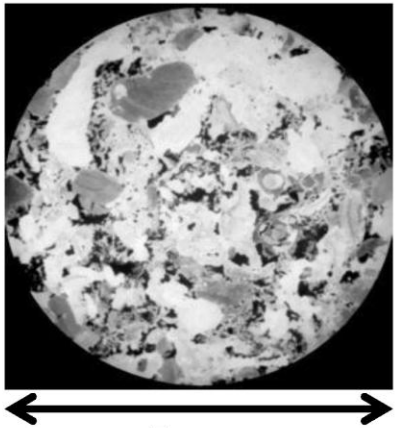
Model

- Complex multi-physics
- Wettability
- Pore structure changes
- Solubility changes
- Geomechanical effects
- Displacement processes
- ….!!!

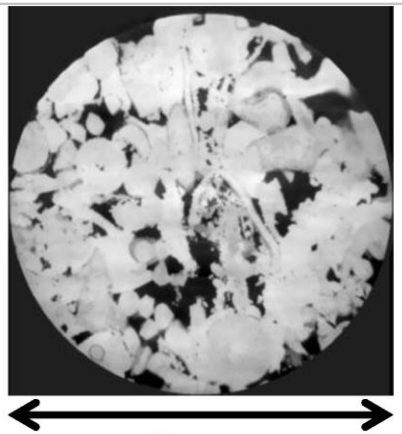


Prediction

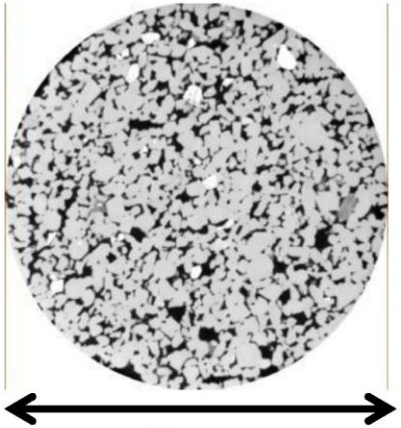
Micro-CT scanning – Carbonates and Sandstone



5 mm
Estaillades



5 mm
Portland



5 mm
Bentheimer

Application of dry scanning:

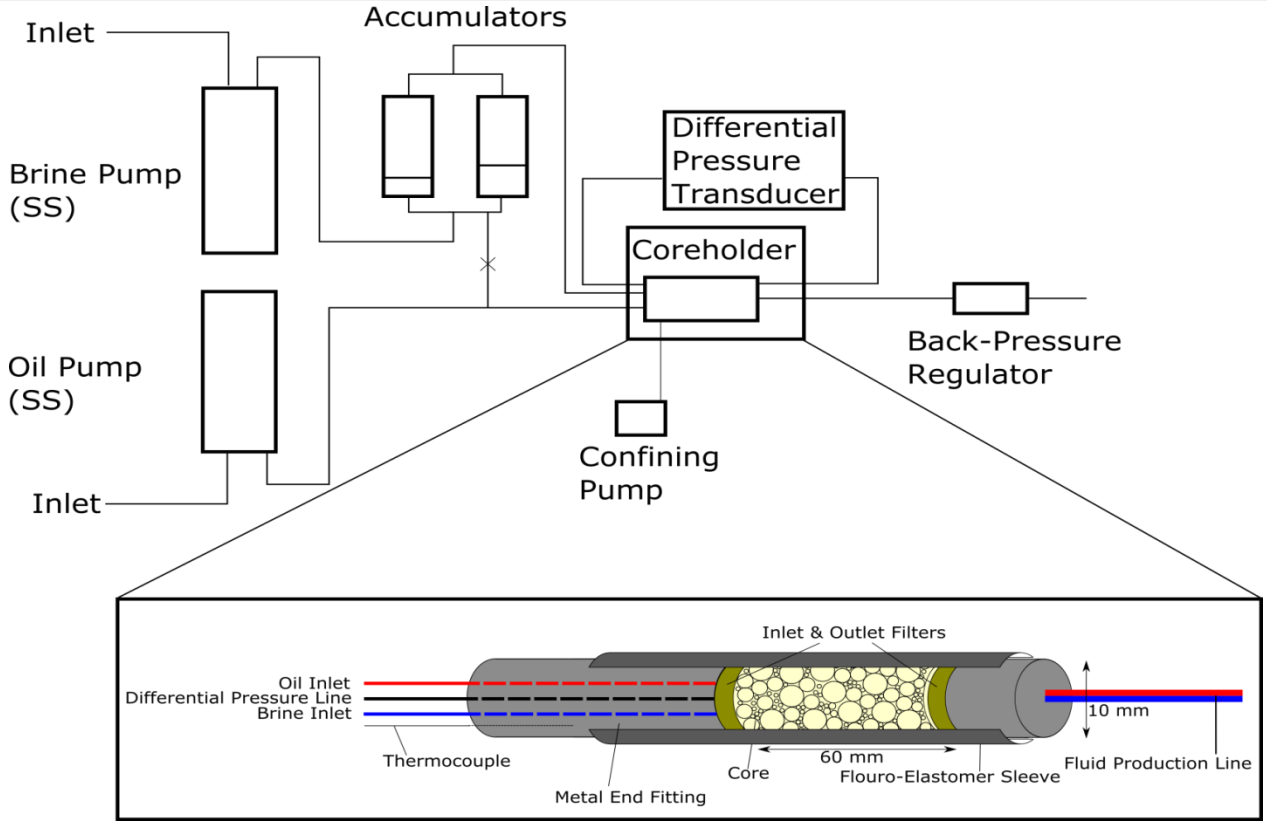
- Porosity analysis.
- Input spaces for pore-scale models, determining absolute and relative permeability.
- Network analysis, to find metrics for pore size distributions and connectivity.

Presenter's notes: Micro-CT scanning to most people means images like this; dry unsaturated samples with no concern about in-situ fluid flow. Here we have some reconstructed cross-sections from three of those dry-scans, two carbonates and a sandstone. The darkest phase represents pore and the lightest phase represents rock grain. The intermediate phase seen here represents microporous grains, underlining that there remains portions of the pore-space which micro-CT cannot directly access. It is, however, still possible to make conclusions about changes in saturation and concentration in those regions based on changes in grey-scale attenuation, and some of that work will be shown at the end of the presentation when we discuss salt precipitation.
(Presenter's note continued on next slide)

(Presenter's note continued from previous slide)

Now, these dry scans are very useful, and can be used for porosity analysis, as input spaces for pore-scale models or in network analysis. I think, however, that they represent only a fraction of what micro-CT can be used for, as they fail to really take advantage of the principal advantage of x-ray imaging; it is non-invasive. This ability allows you to place a whole load of material (most critically the wall of a pressure vessel) between the sample and the source and detector, which allows you to not only do in-situ fluid flow, but to do it under representative process conditions, essentially creating a mini reservoir or aquifer which you can look inside of directly at the pore scale.

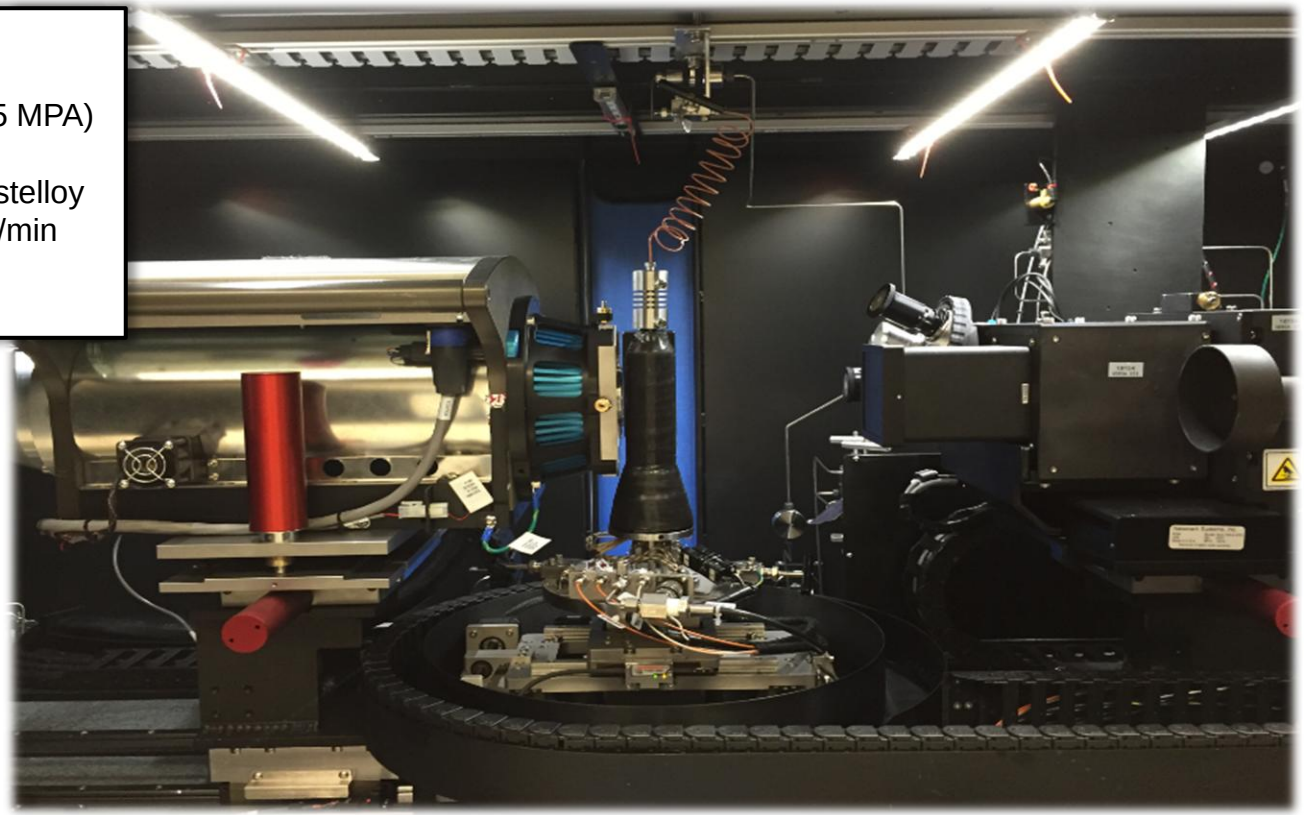
In-situ Flow @ Zeiss: Rig Design



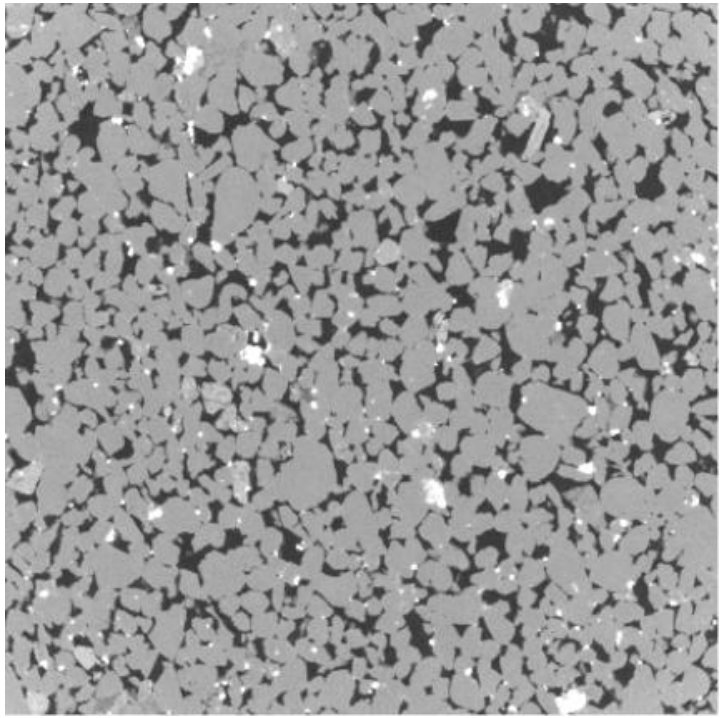
ZEISS in situ flow 2-phase system

System Capabilities

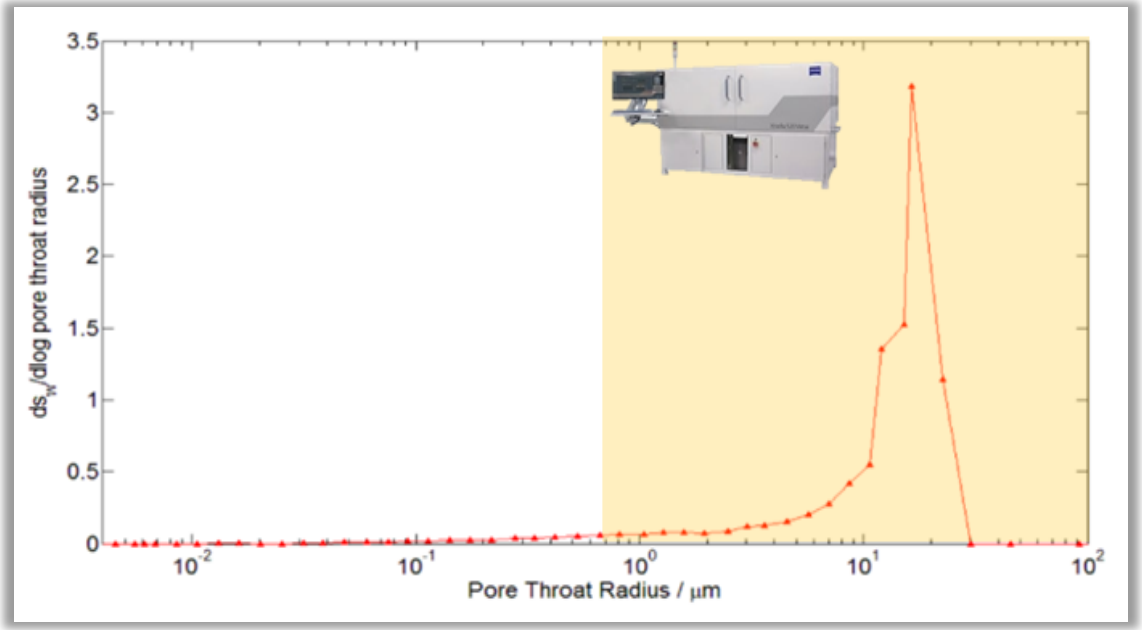
Max. Pressure:	5000 PSI (35 MPA)
Maximum Temperature:	130 ^{o}C
Wetted components:	PEEK or Hastelloy
Flow Rate Range:	0.01 – 30 ml/min
Min. Differential Pressure:	<0.1 PSI
Max Image Resolution:	<1 µm



Steady State Flow in Estaillades Limestone Carbonate Single & Dual Porosity Systems

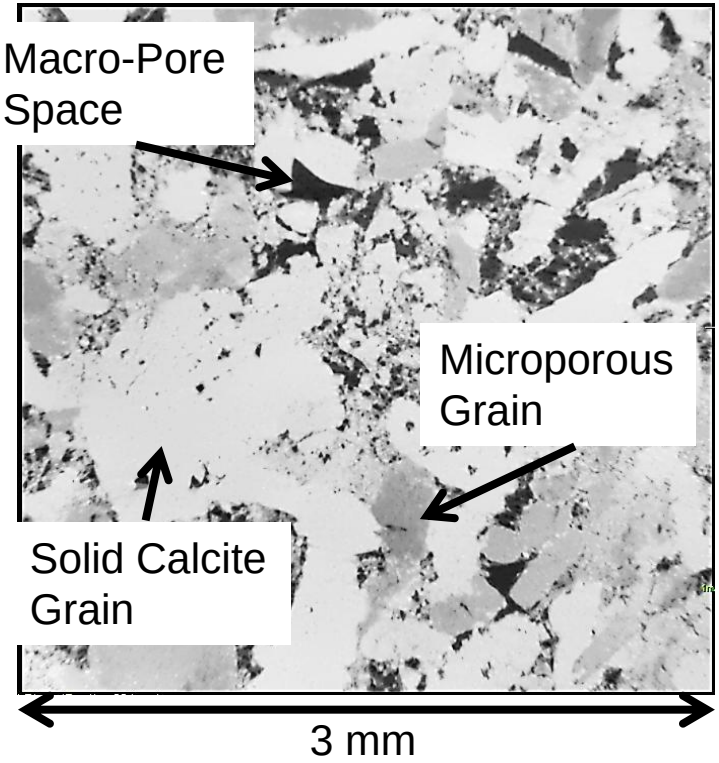


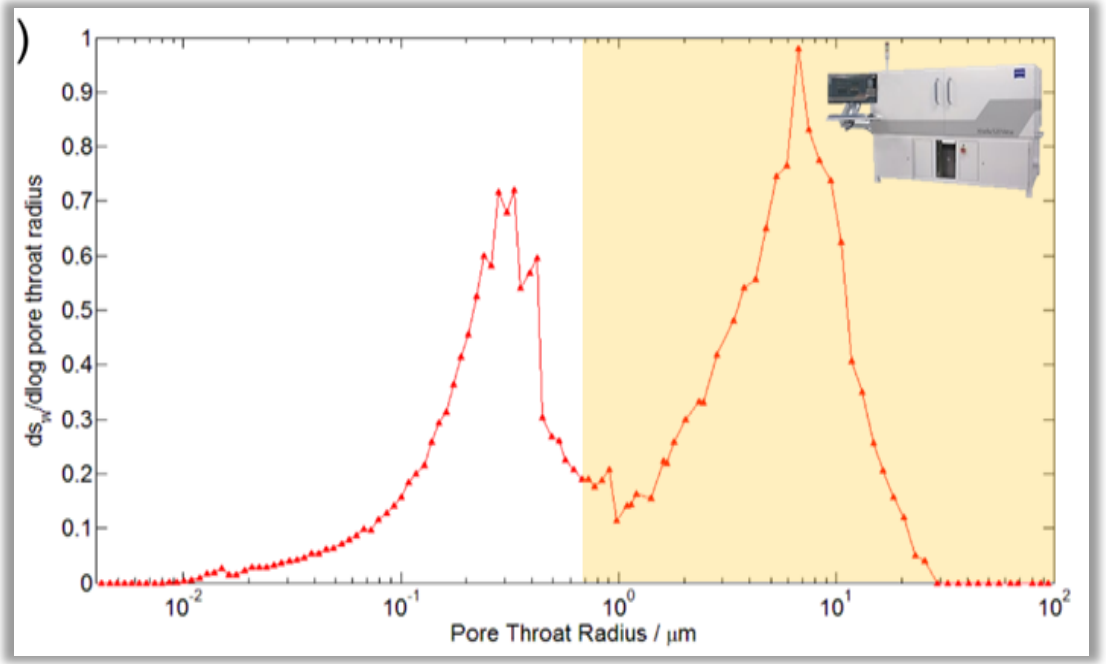
7 mm



Unimodal pore throat size distribution single porosity system

Steady State Flow in Estaillades Limestone Carbonate Single & Dual Porosity Systems

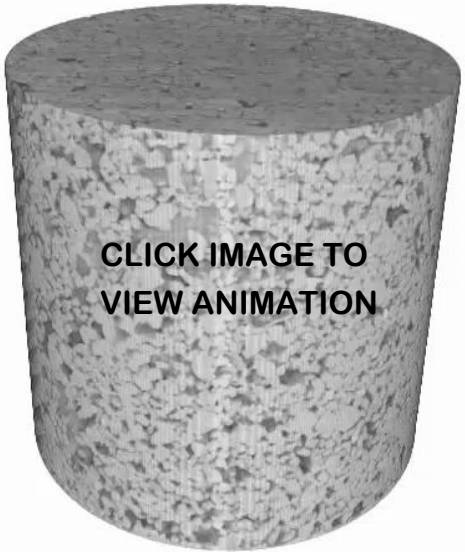




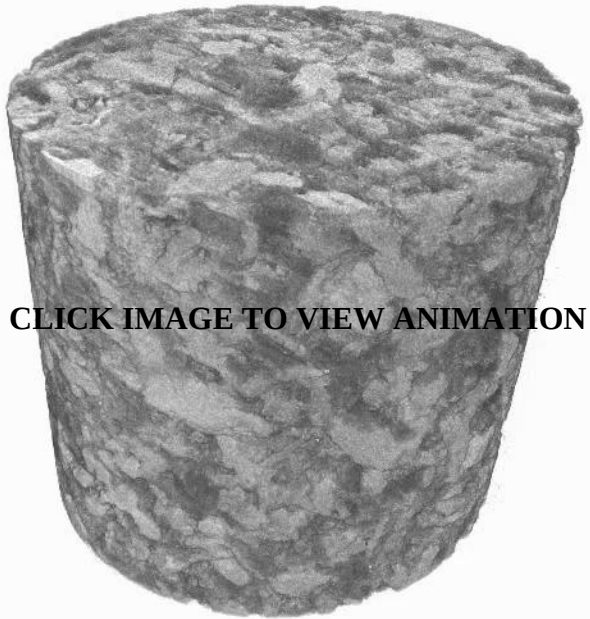
Bimodal pore throat size distribution
Dual Porosity system

Steady state pore occupancy analysis

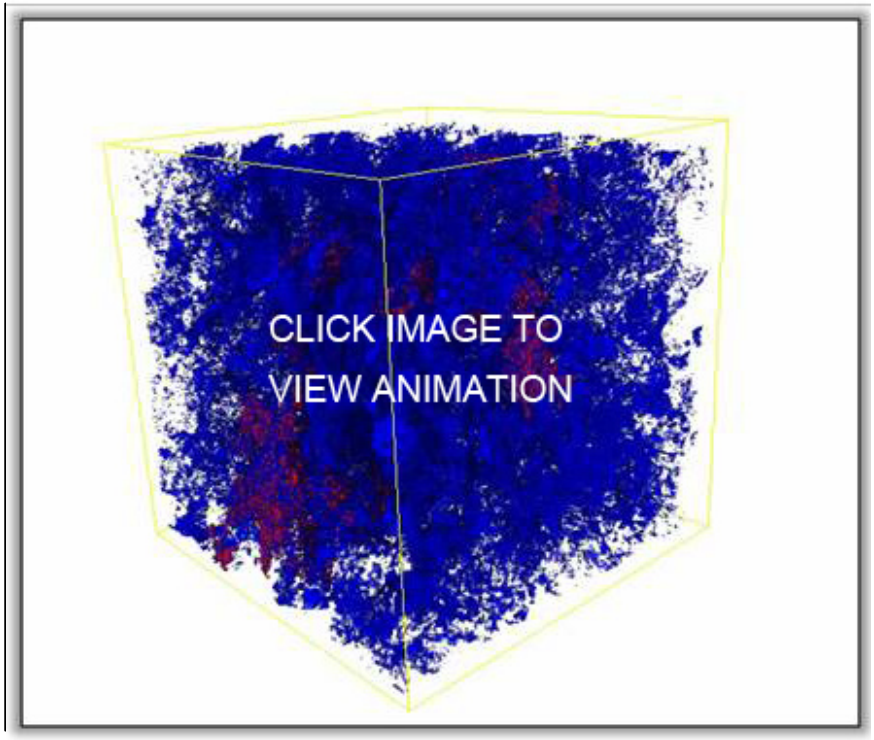
Reservoir Condition Steady State Flow - Versa XRM 520



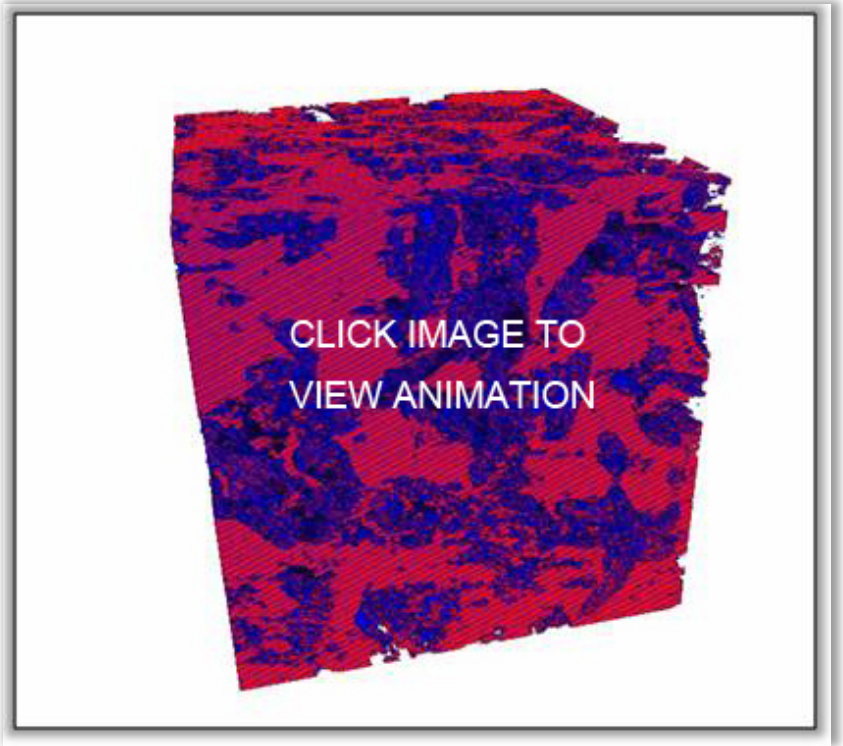
In situ wettability analysis



Wetting phase connectivity

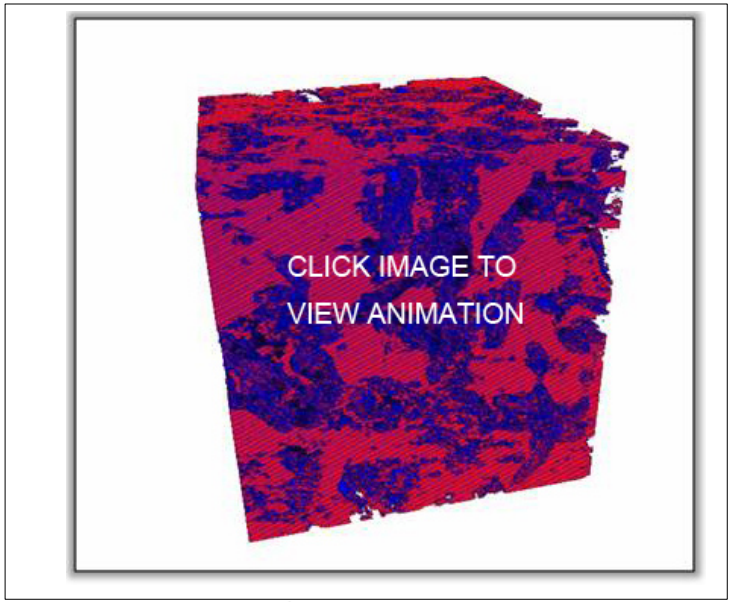


Connectivity through macroporosity

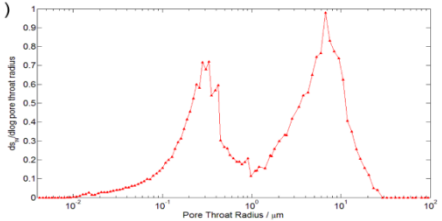


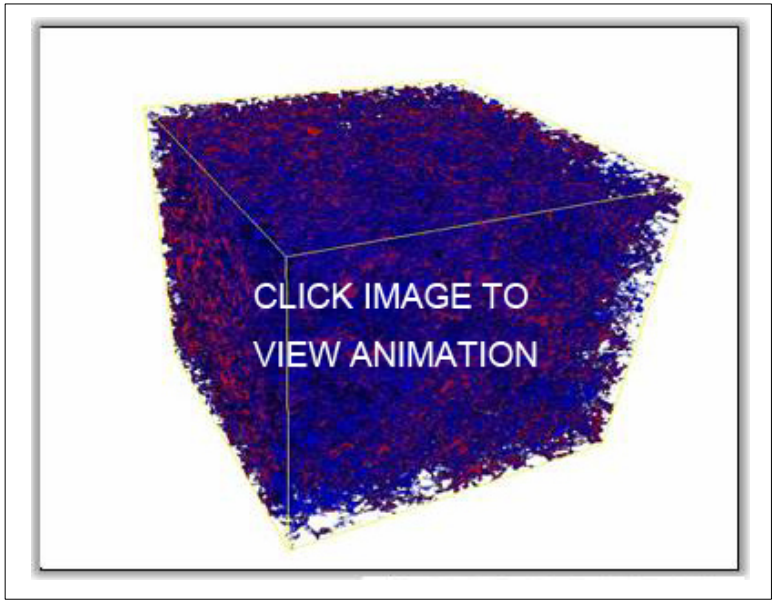
Connectivity through macro & micro porosity

Wetting phase connectivity
Dual porosity & Single porosity connectivity

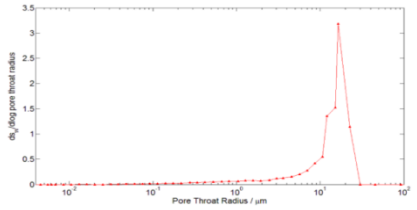


Dual porosity system

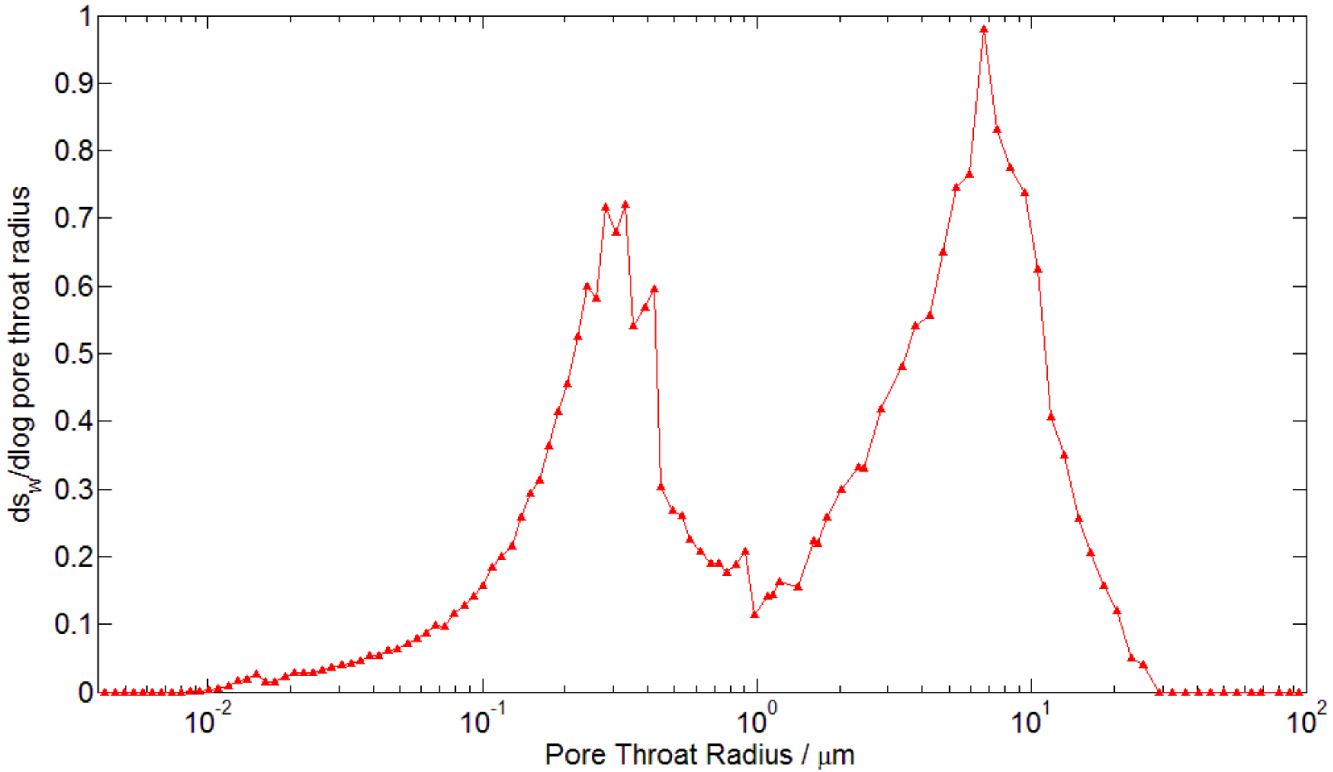




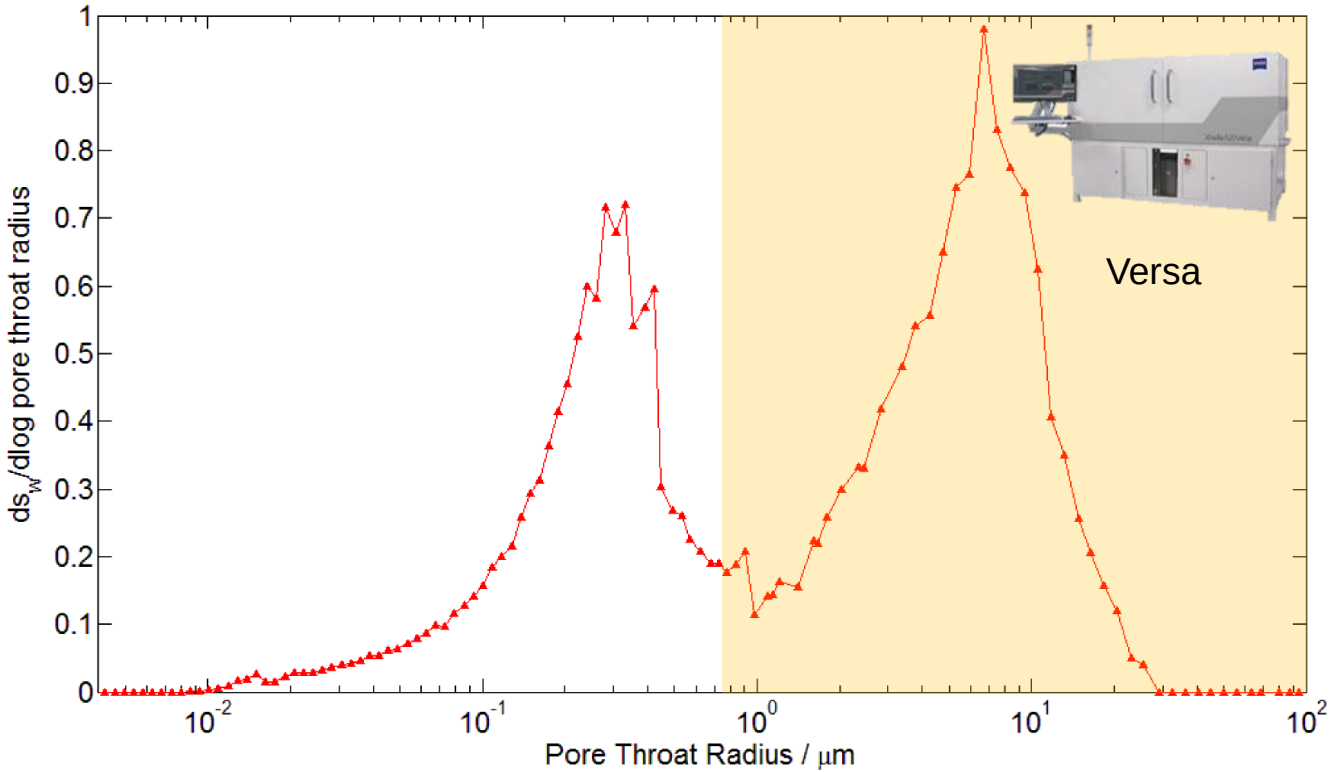
Single porosity system



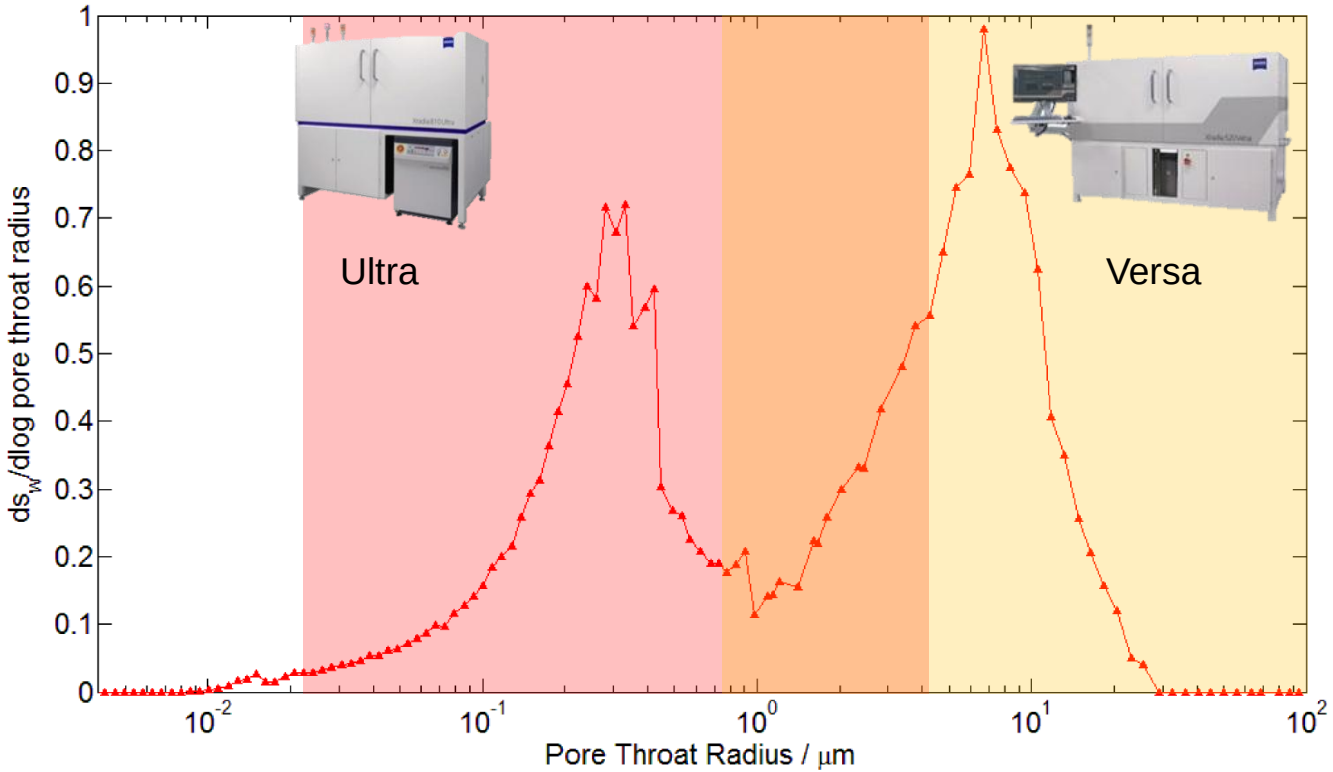
Multi-scale sampling



Multi-scale sampling

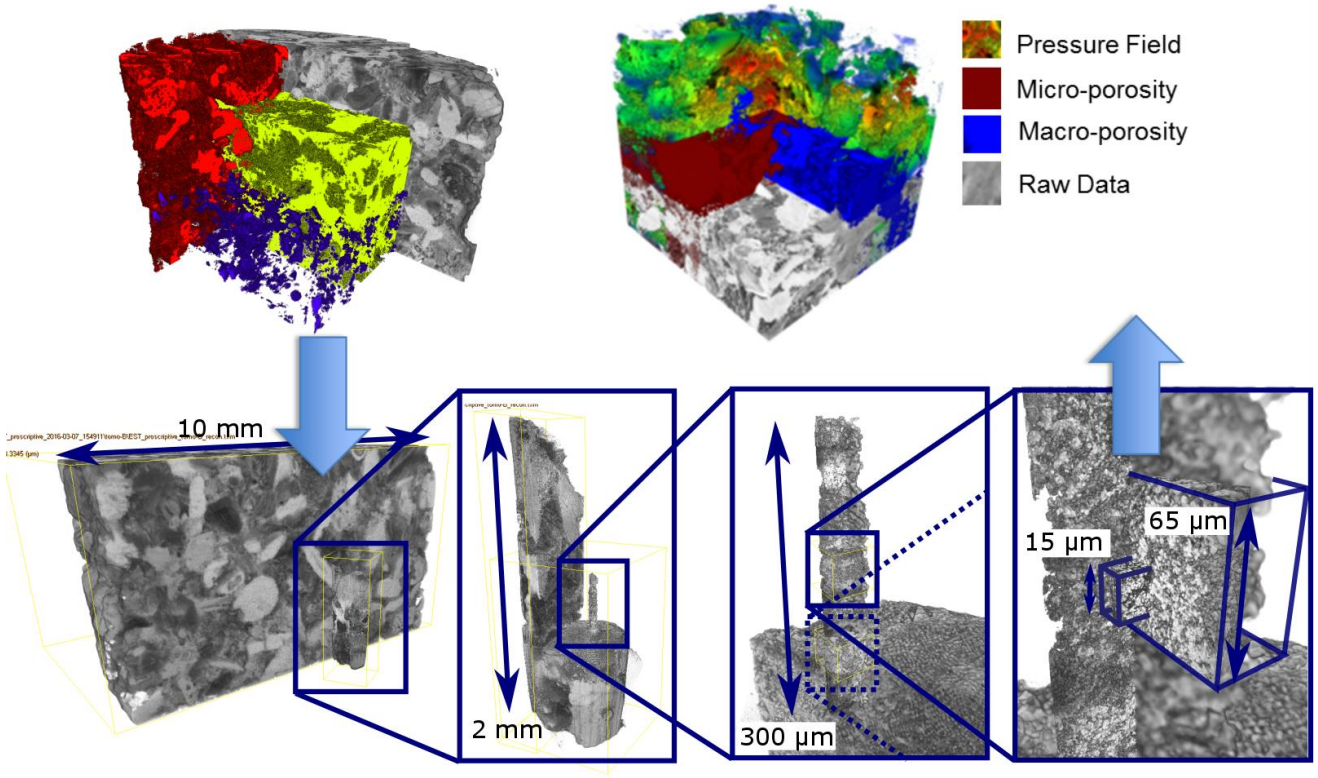


Multi-scale sampling

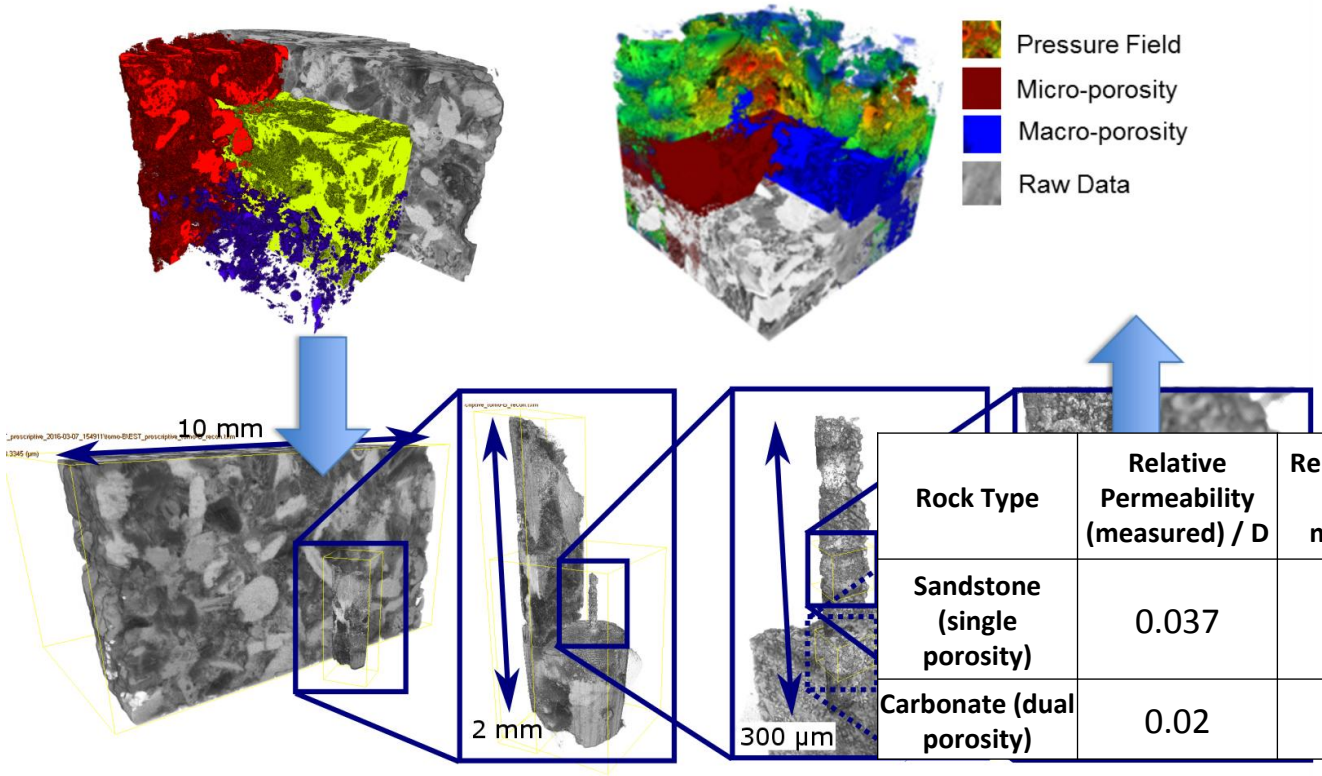


Multi-scale sampling

Up-scaled results



Up-scaled results



Rock Type	Relative Permeability (measured) / D	Relative Permeability (calculated) - macroporosity / D	Relative Permeability (calculated) - micro + macroporosity
Sandstone (single porosity)	0.037	0.066	N/A
Carbonate (dual porosity)	0.02	N/A	0.06


ZEISS