Single & Two-Phase Flow: Pore-Scale Models & Applications

I. Bogdanov, F. Guerton (Pau U., France), I. Bondino (Total)

1. INTRODUCTION

Our approach combining the computed micro-tomography (µCT) based pore volume (PV) imaging and direct numerical simulations (DNS) belongs to a rapidly advancing porous medium research branch. To build, validate and exploit the relevant DNS models for pore-scale flow in real media geometry for different oil recovery applications is our primary objective. Currently our models are approaching the REV scale description. The image-based computations were focused on the single and two-phase stationary flow configurations.

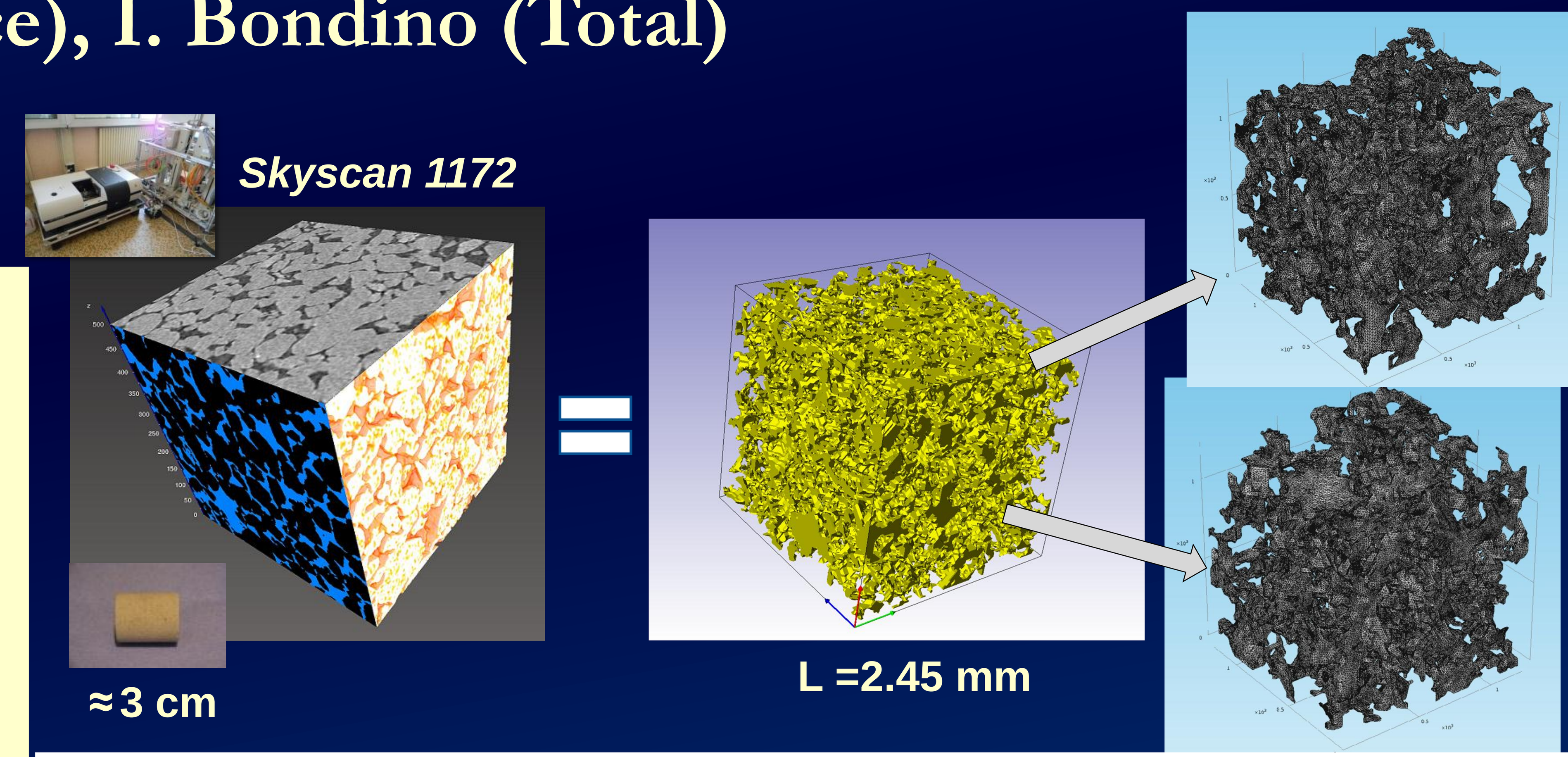


Figure 1. The *Bentheimer* rock sample (bottom left insert), raw reconstructed slice (left image: upper face), sample texture (right face), segmentation (left face); extracted pore volume (middle image) resulted from post processing in *ScanIP*; grid examples (COMSOL, right images).

2. MODEL GEOMETRY & GRID

The *Bentheimer* cylindrical sample was investigated to build a virtual cube (500^3 voxels, 4.6µm resolution). The PV geometry selected in *ScanIP*, was then imported and meshed in COMSOL (cf. **Figure 1**). The pore-scale modelling (PSM) was based on Navier-Stokes equations system and so-called diffuse interface method (cf. *Cahn and Hilliard*, 1958) enabling to automatically handle the interface morphology and its dynamics.

3. DNS OF DRAINAGE & IMBIBITION

The DNS of drainage and imbibition in the *Bentheimer* sample for the capillary number (NC) variation $10^{-3} \leq NC \leq 3\cdot10^{-7}$, were done. The boundary conditions (BC) chosen for imbibition were:
BC1=given input/output pressure, $P_{in}=P_{out}=0$, and
BC2= given flowrate ($Q_{in}=1$ & output pressure, $P_{out}=0$). Different *end-point* saturations resulted from these BC.

The imbibition after drainage at low NC (see **Figure 2** for drainage stage) showed systematic over-estimation of the non-wetting phase *end-point* saturation compared to laboratory measurements by *Oughanem et al.* 2013. This may be a result of the small, i.e. under-REV size of the sample and the flow perturbation by the BC.

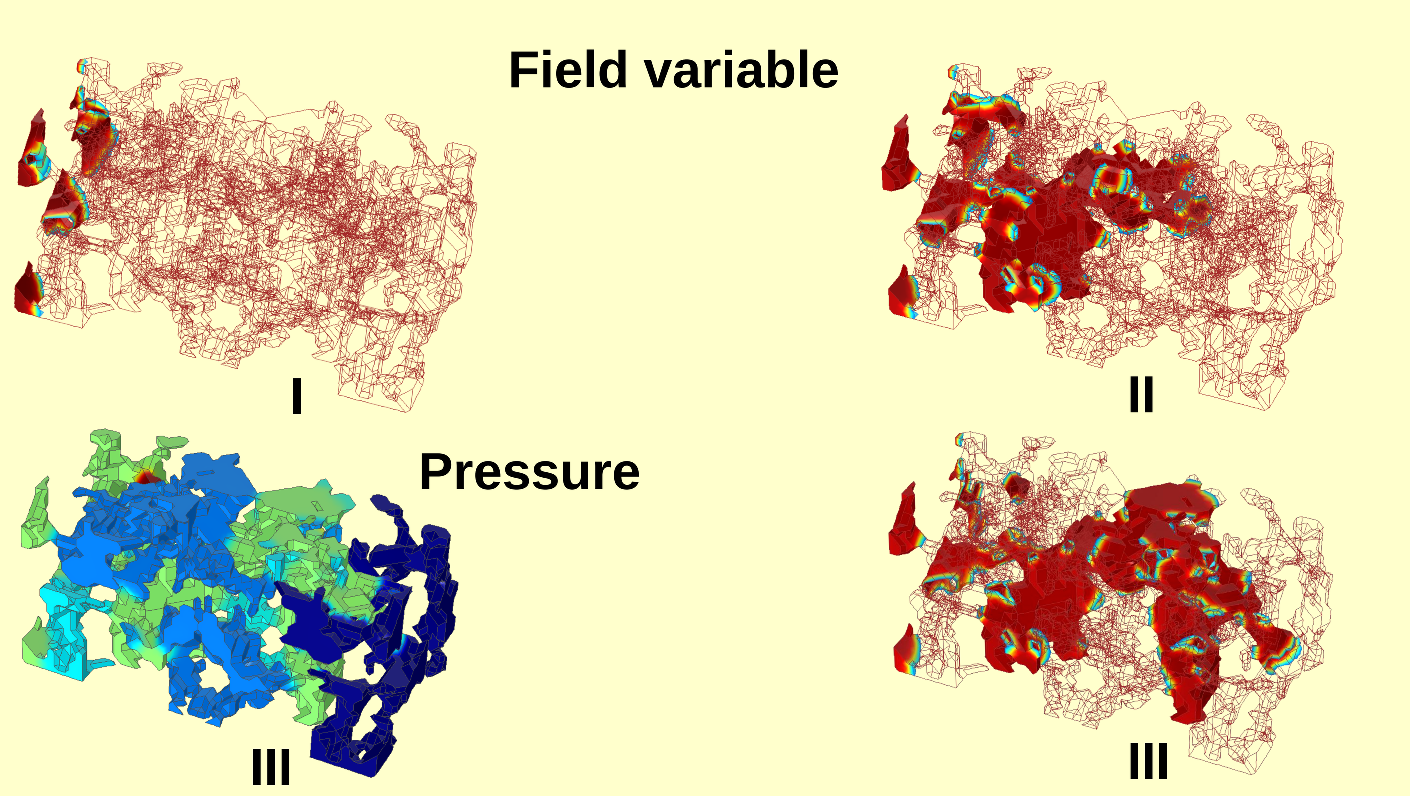
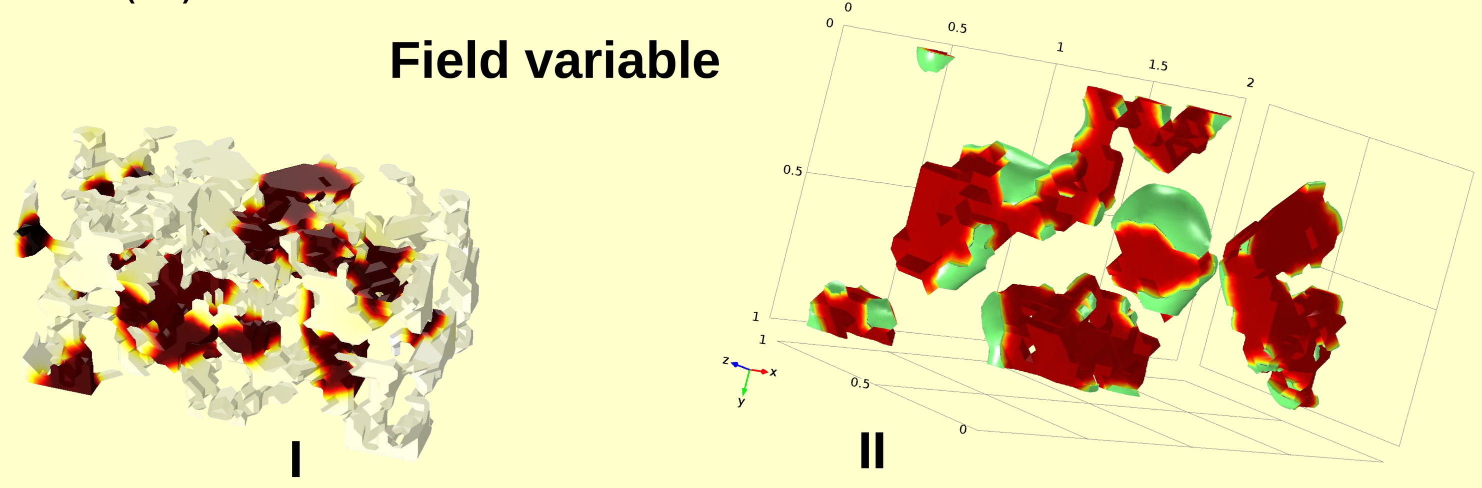


Figure 2. Drainage at three different PV injected (I to III), $NC\approx3\cdot10^{-7}$, viscosity ratio 1, constant flowrate (BC2), no gravity, $S_{nwet}\approx0.51$ (III).



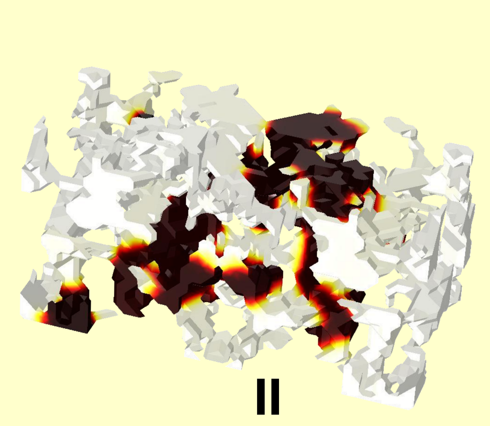


Figure 3. Imbibition after drainage in *Bentheimer* sample (left images, I & II). The *critical* non-wetting phase configuration, $S_{nwet}\approx0.35$, is on right image (cf. *Oughanem et al.* 2013).

4. DESATURATION OF *BENTHEIMER* ROCK

Study of capillary force dominated 2P flow in its dynamics provides its better understanding and quantitative description. An example of the pure imbibition (at BC1, **Figure 4**, top line) followed by desaturation due to the IFT diminishing (right column) is provided. The *end-point* saturation and its dependency on NC for the *Bentheimer* rock sample, have been examined (left graph at bottom).

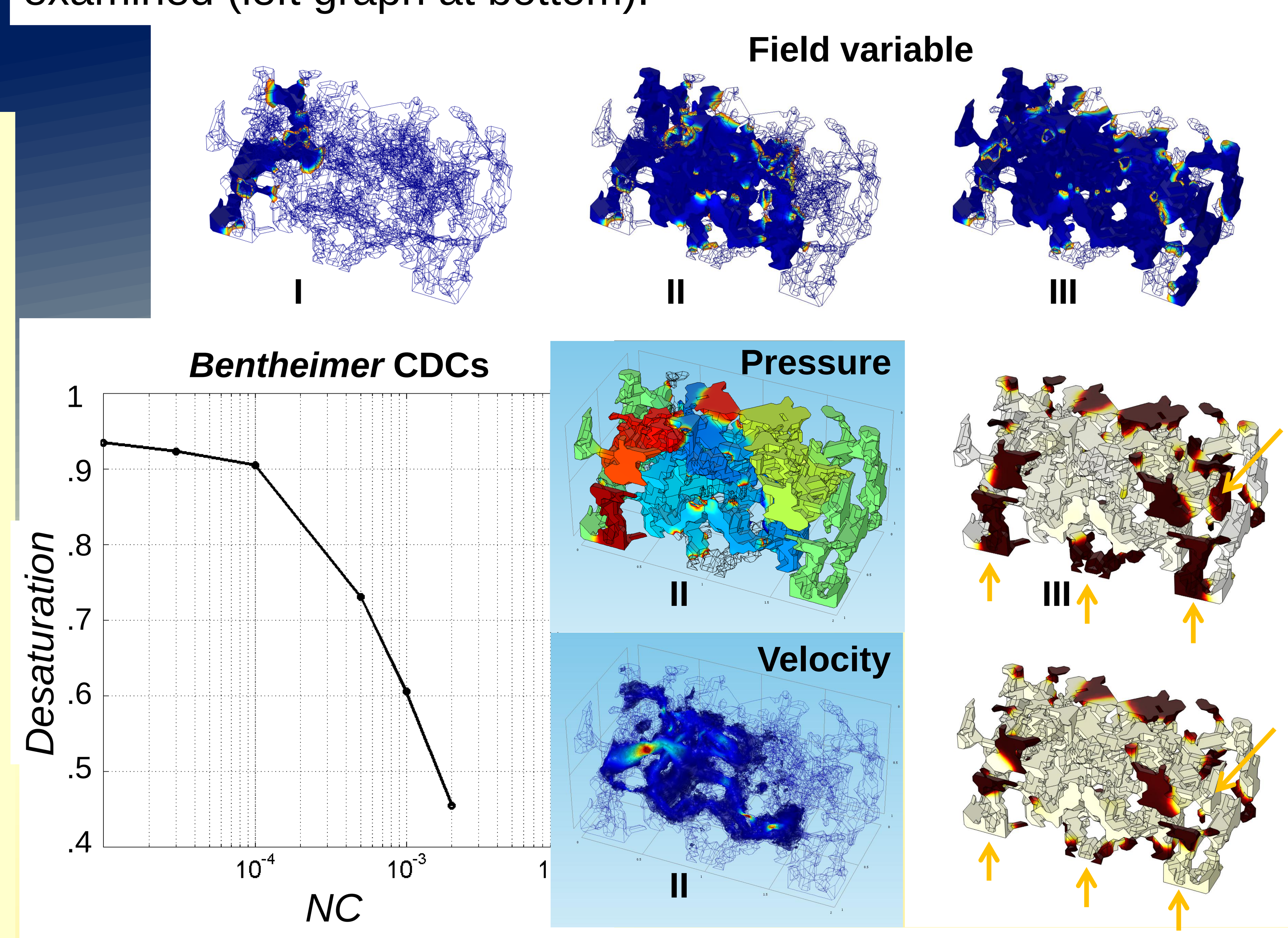


Figure 4. Summary of results for desaturation following imbibition.

5. CONCLUSIONS & PERSPECTIVES

- The methodology of image-based DNS of pore-scale flow is addressed and presented in some detail making use of *Bentheimer* rock µCT-based images.
- As a main objective of the DNS we consider the determination of dynamic fluids distribution and their behavior inside a “real” pore volume.
- The application of this technology for oil and gas industry is not straightforward, at least at quantitative and/or predictive level, so numerous challenges of such a type remain to be tackled.

6. ACKNOWLEDGEMENT

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7. LITERATURE

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*) e-mail: *igor.bogdanov@univ-pau.fr*