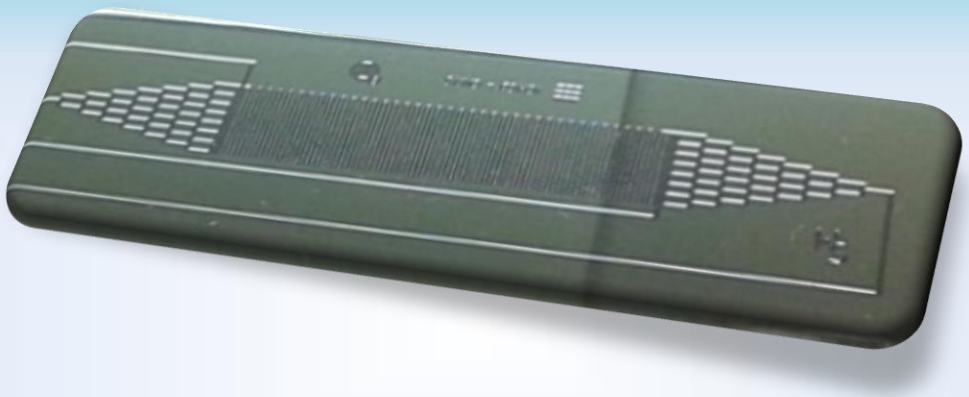


Geological Labs On Chip (GLoCs)

New tools for investigating key aspects of CO_2 Geological Storage

Sandy Morais

Sous la direction de :

Dominique Bernard (Groupe 1)

Samuel Marre (Groupe 7)

Projet ANR porté par

Yves Garrabos (Groupe 7)

Outlines

Outlines

I Context

II Geological Labs On Chip

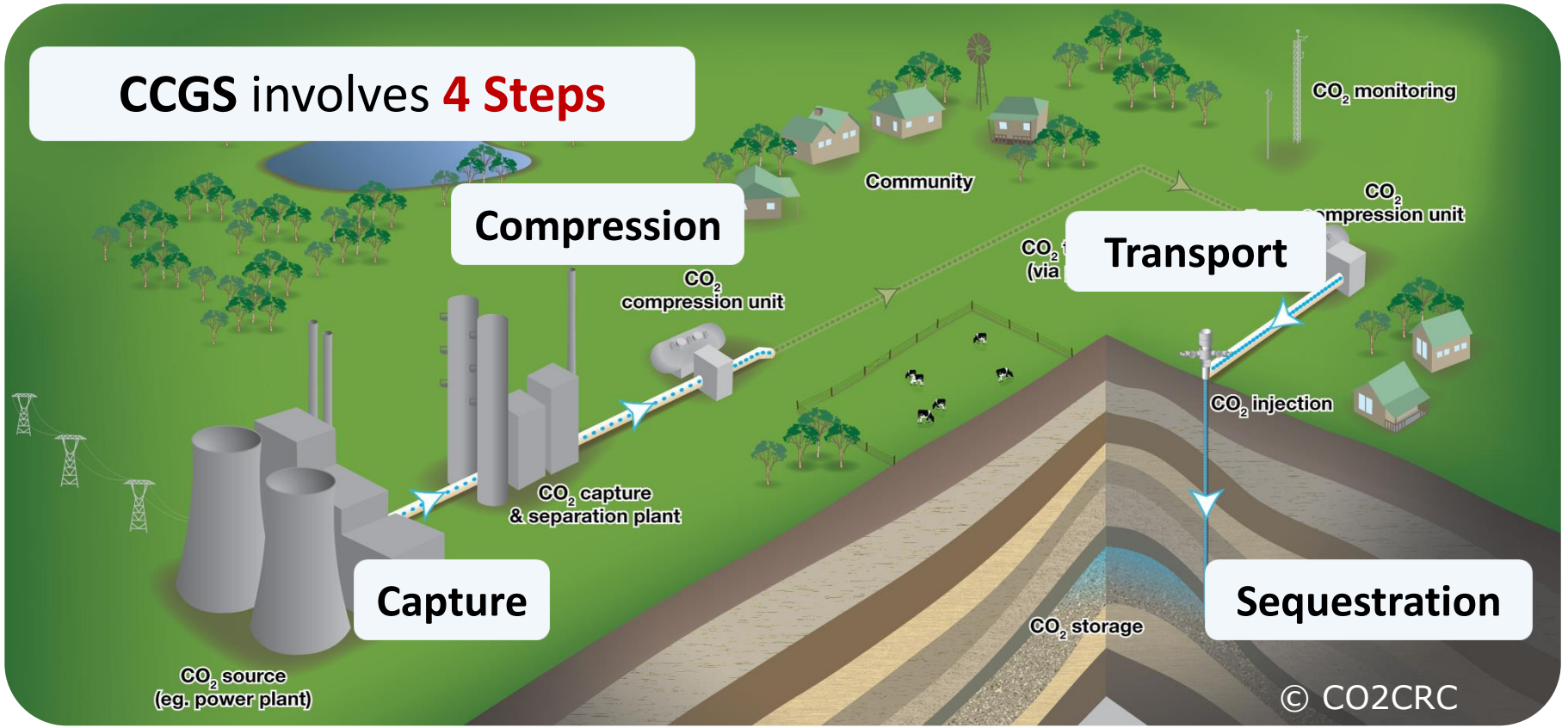
III Results – Monophasic Study

IV Results – Diphasic Study

V Ongoing Work

I Context : CO_2 Geological Storage in Deep Saline Aquifers

Carbon Capture and Geological Storage remains an option to reduce CO_2 emissions to atmosphere from point sources



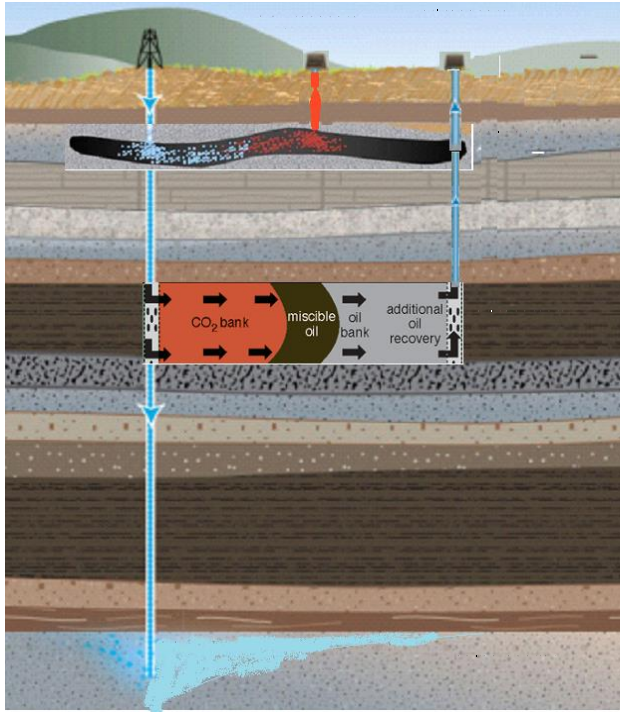
S. Morais et al. *Geological labs on chips: microfluidic strategies for studying key processes related to CO_2 storage (in preparation)*

I Context : CO_2 Geological Storage in Deep Saline Aquifers

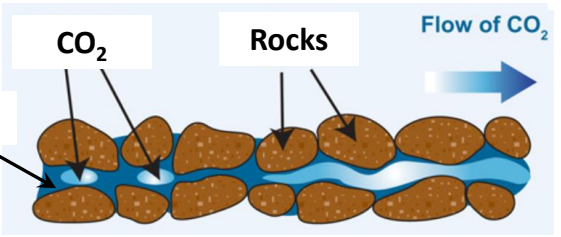
Coal beds
Estimated storage capacity
(**100 – 200 Gt**)
+ Enhancement of methane production

Oil / gas Reservoirs
Estimated storage capacity
(**1,000 – 1,500 Gt**)
+ Enhance Oil Recovery

Deep Saline Aquifers (DSA)
Estimated storage capacity
(**10,000 – 100,000 Gt**)

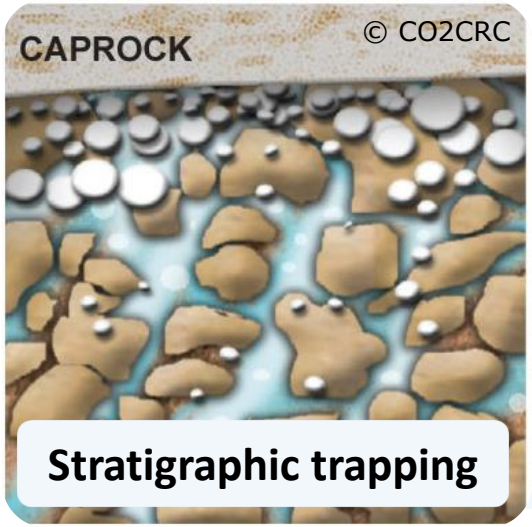


Deep Saline Aquifer



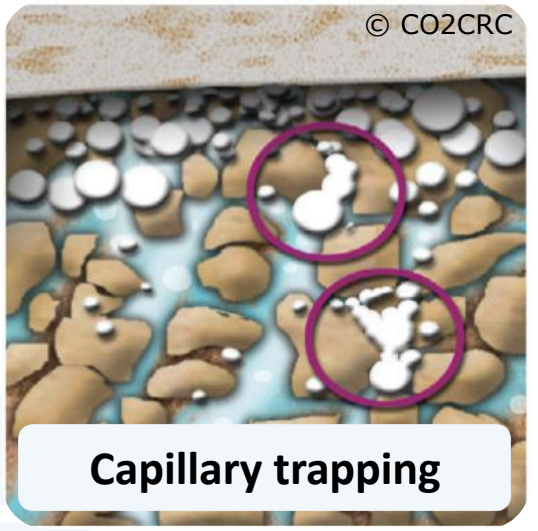
0.5 < Porosity < 30 %
10^{-1} < Permeability < 10^3 mD
30 < T < 100°C
60 < p < 150 bar

I Context : 4 trapping mechanisms in Deep Saline Aquifers



Stratigraphic trapping

www.anr-cgsmicrolab.cnrs.fr



Capillary trapping

How CO_2 **travels** with brines?

Solubility trapping

How much CO_2 is trapped by capillary forces, what **fraction of pore space** is filled?

How much and how quickly CO_2 **dissolves** in brine?

How CO_2 forms **carbonates** and what are the **precipitation rates**?

Mineral trapping

Outlines

I Context

II Geological Labs On Chip

III Results – Monophasic Study

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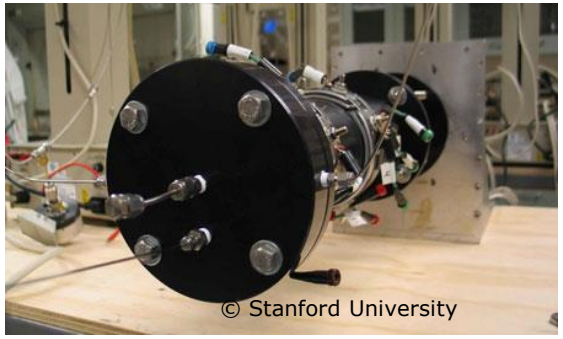
V Ongoing Work

II GLoCs : Investigation Tool : High Pressure 2D Micromodels

Core-scale approaches

- limitation of the control of operating parameters
- time-consuming
- limited number of *in situ* characterizations



Complementary

approaches

Microfluidic systems (GLoCs)

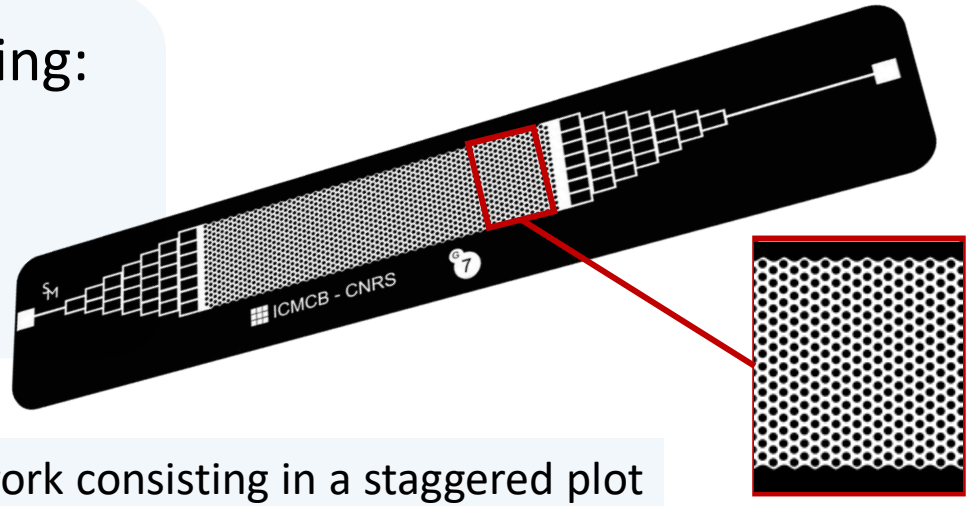
- excellent heat and mass transfers
- fine control of process parameters
- design flexibility through lithography

Si/Pyrex microsystems

- optical access through the Pyrex side
- *in situ* characterizations
- HT/HP capability

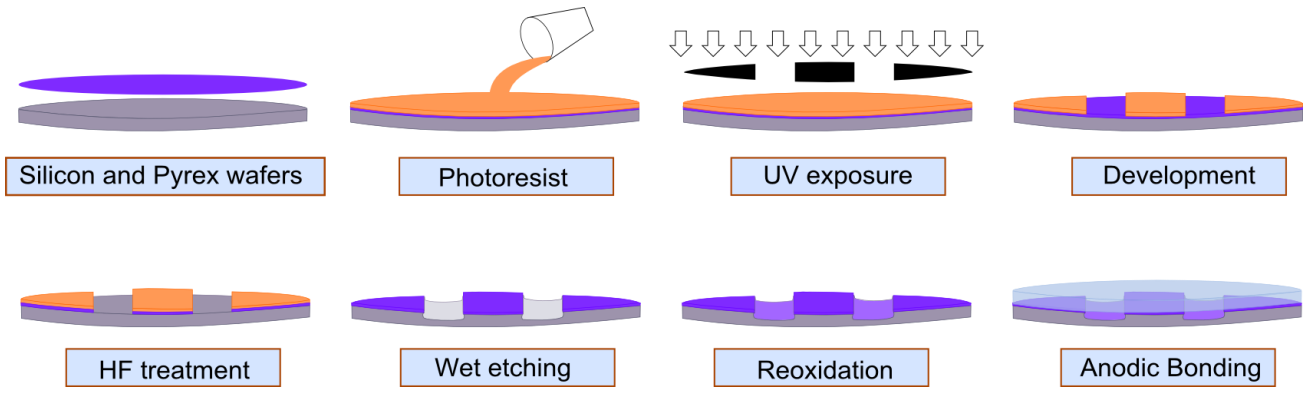
II GLoCs : Geological Labs On Chips

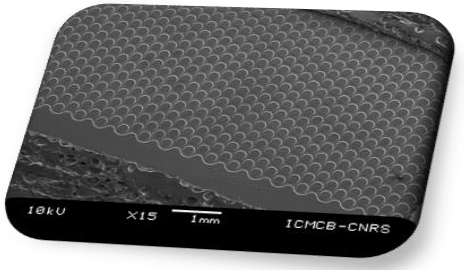
GLoCs mimicking:
- Porosity
- Permeability
- Wettability

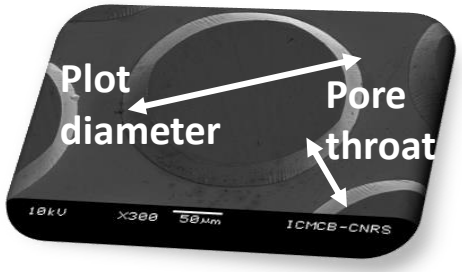


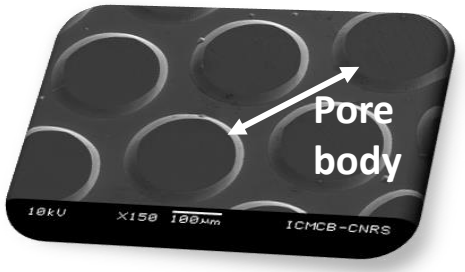
Parameter	Range
Depth (µm)	12 - 35
Plots mean diameter (µm)	190 - 230
Pore body (µm)	280 - 325
Pore throat (µm)	70 - 120
Porosity	0.44 – 0.63

Simple pore network consisting in a staggered plot disposal following a triangular pavement

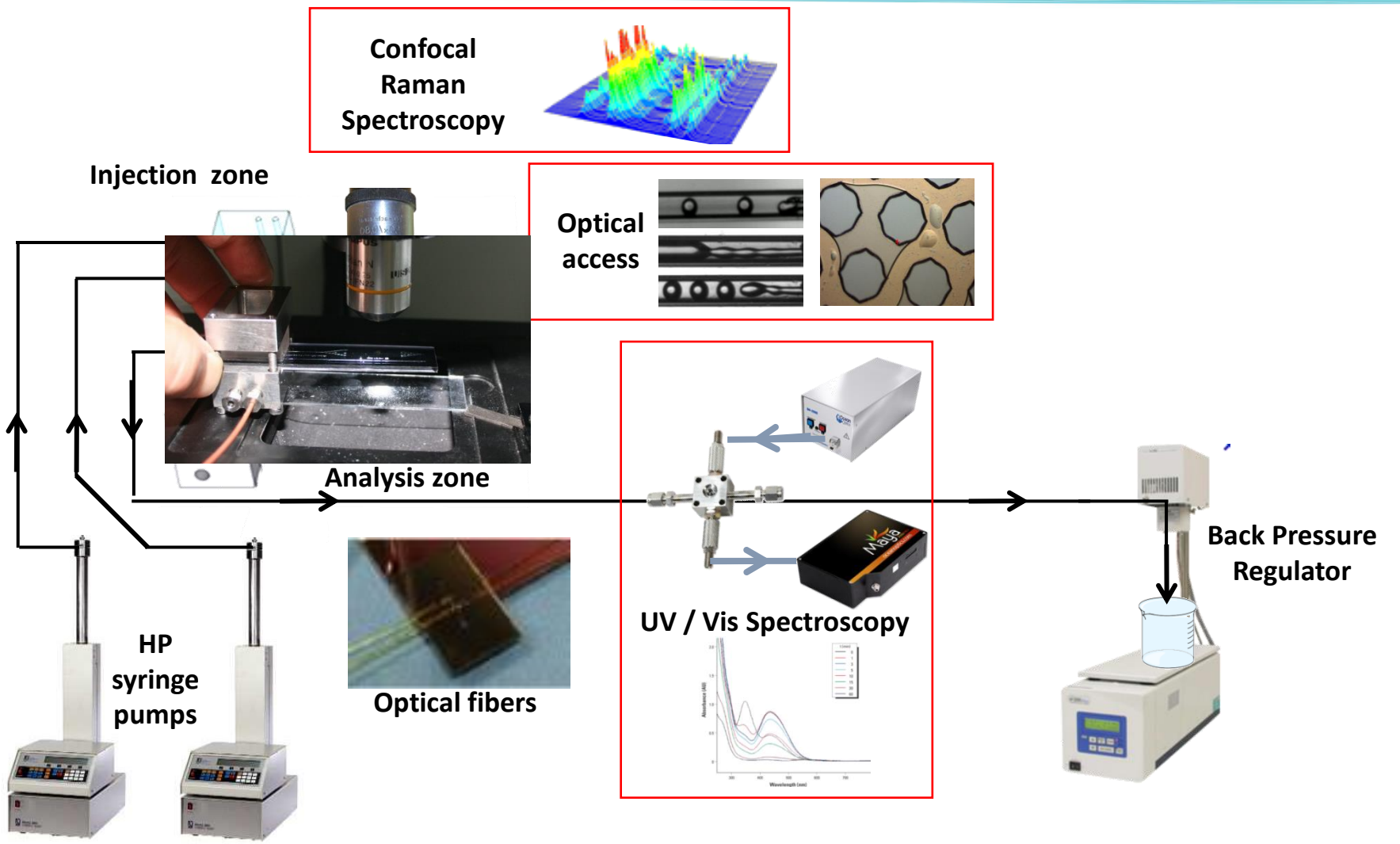








II GLoCs : Setup



Outlines

I Context

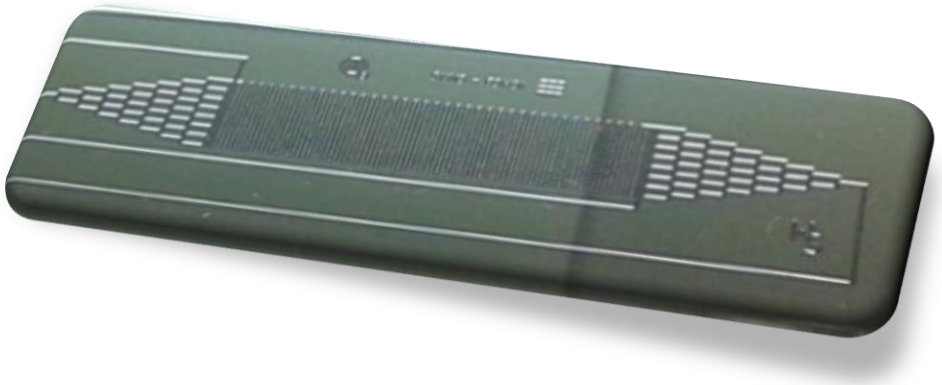
II Geological Labs On Chip

III Results – Monophasic Study

IV Results – Diphasic Study

V Ongoing Work

III Results : Permeability determination



Darcy Law

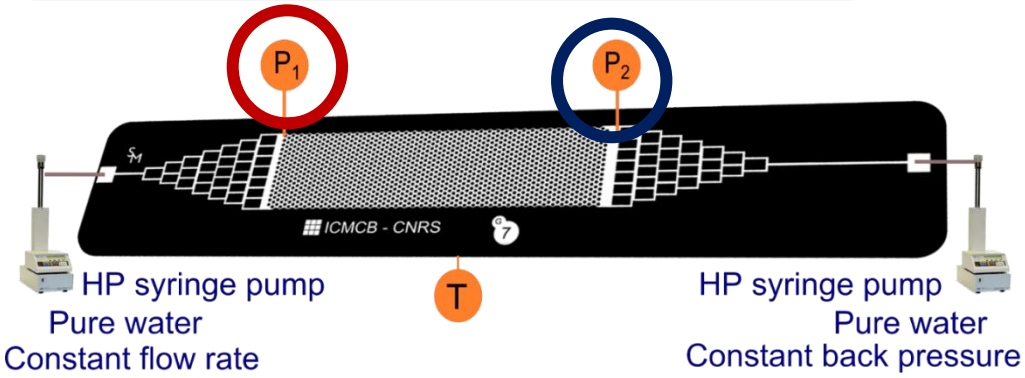
Permeability

$$u = -\frac{K}{\mu}\nabla P$$

S. Morais et al.
Pressure drop and permeability in Geological Labs on Chip (GLoCs) (In preparation)

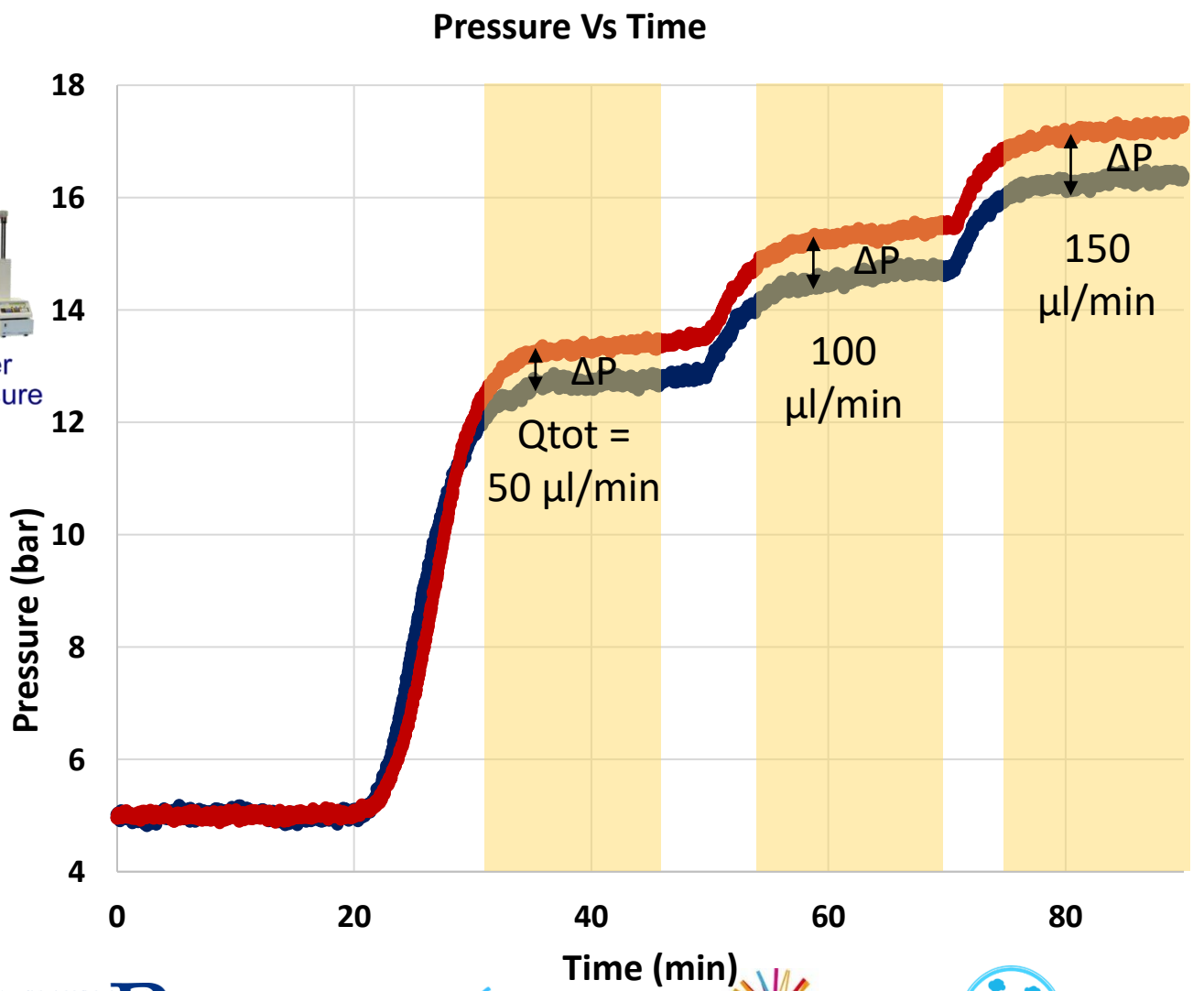
III Results : Permeability determination

Pressure drop measurement

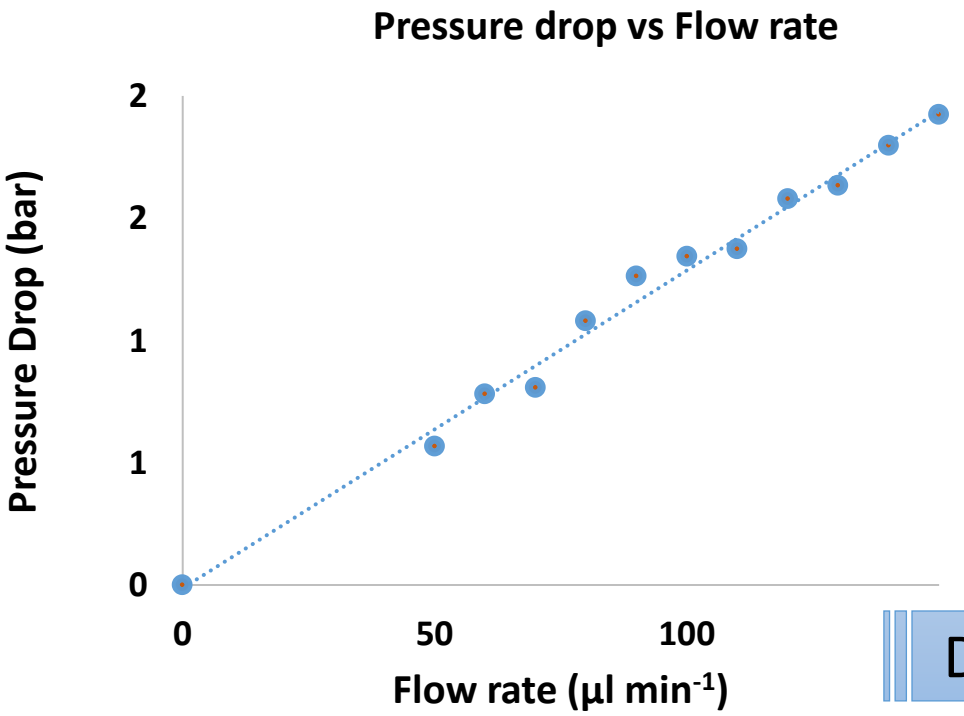


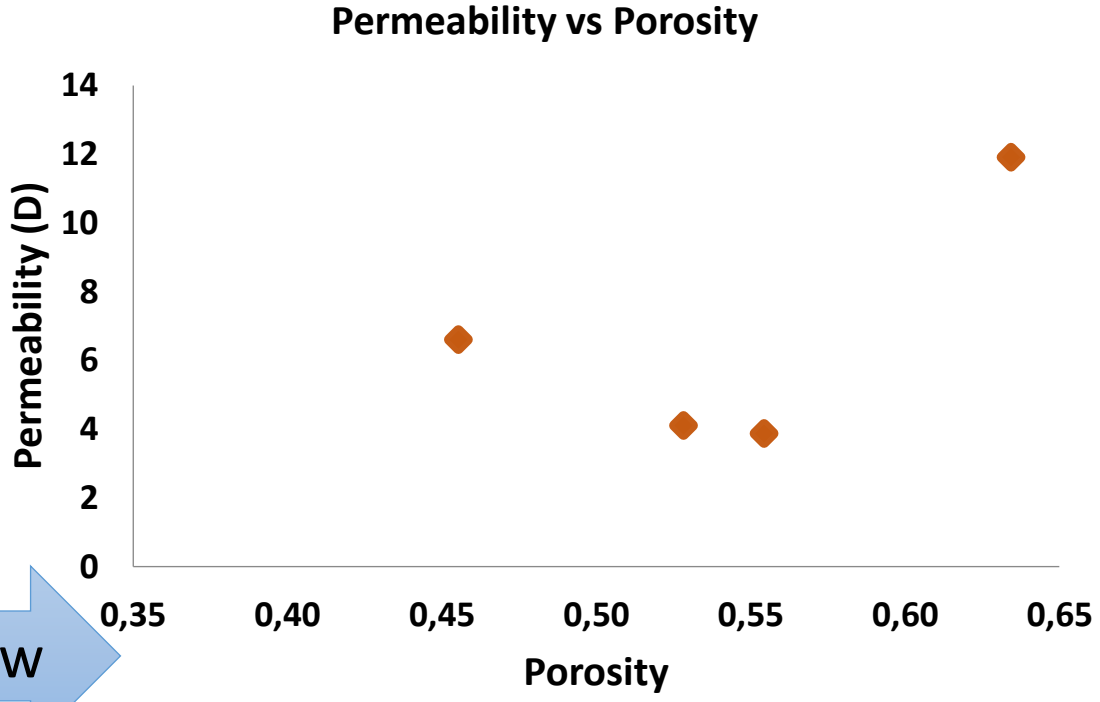
Side channels for pressure measurements through the porous medium

Different flow rates applied



III Results : Permeability determination





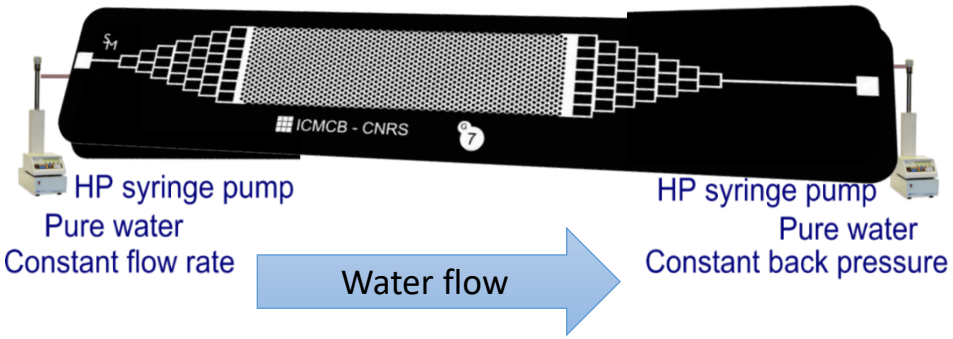
Darcy Law

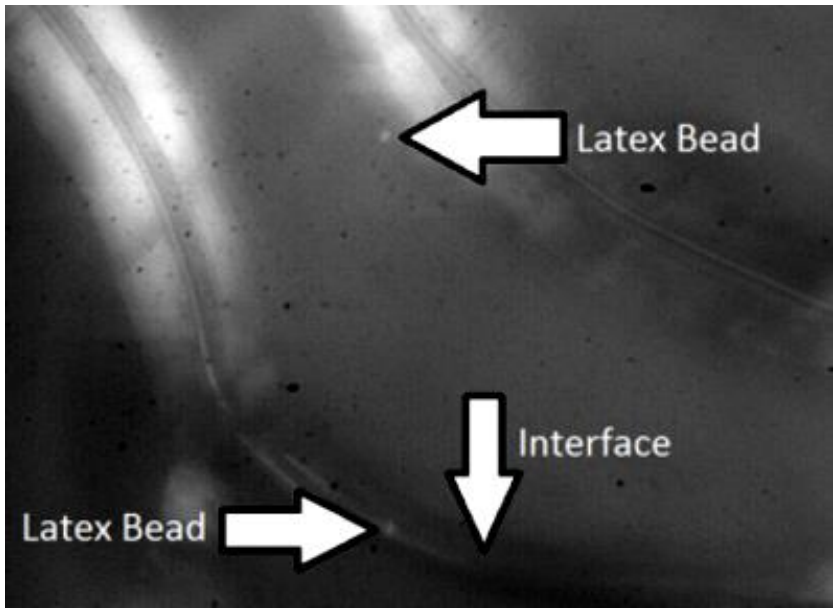
$$u = -\frac{K}{\mu}\nabla P \quad \Leftarrow \quad \frac{Q}{A}$$

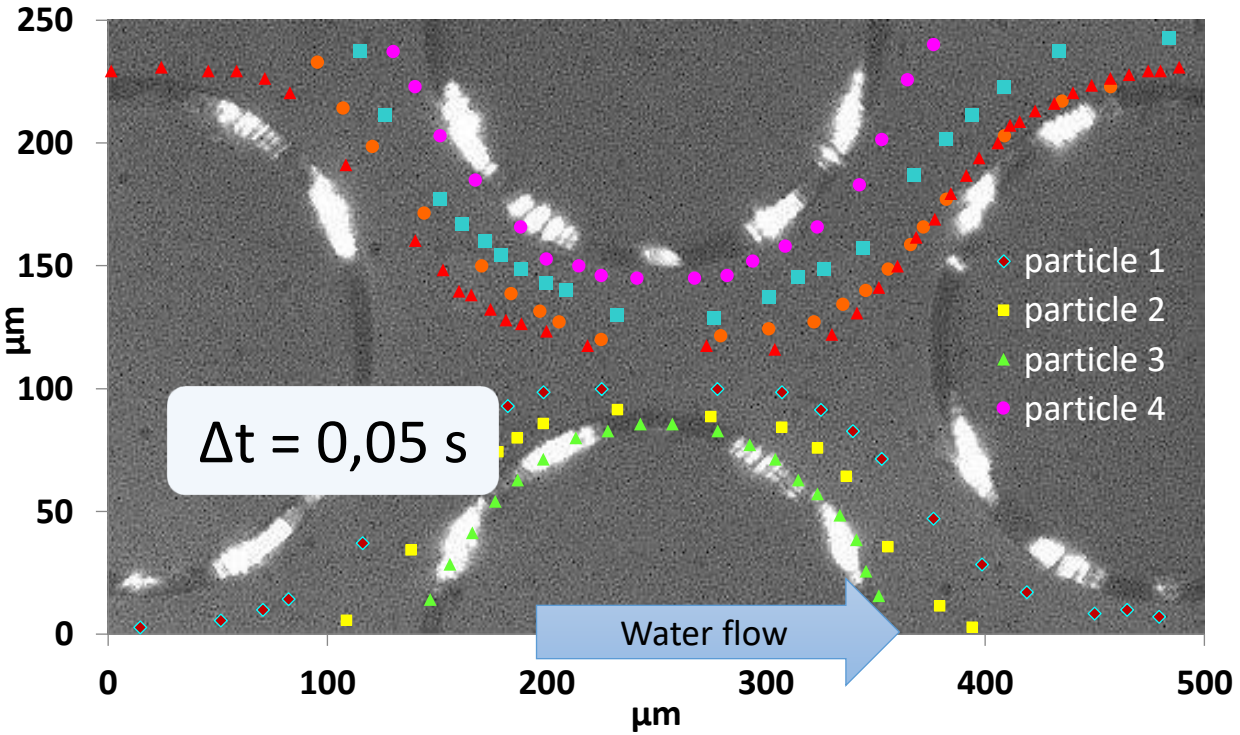
Permeability is not proportional to porosity

III Results : Local velocities measurements

Particle Tracking



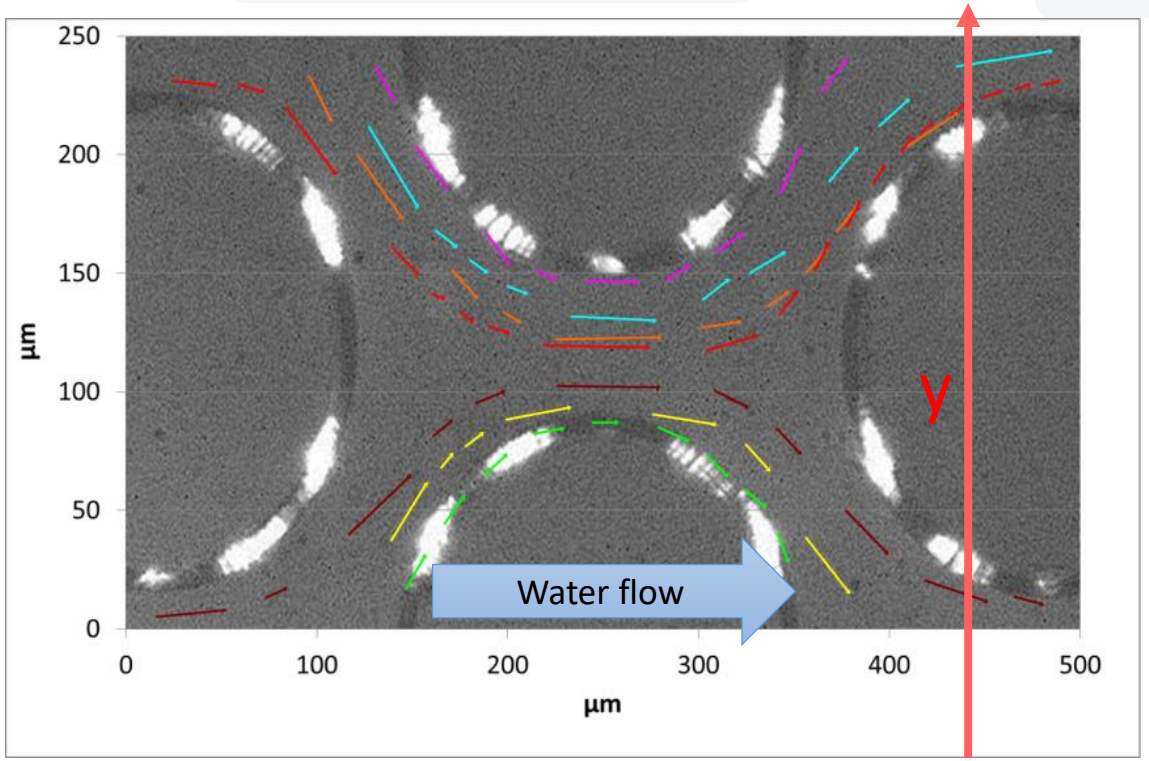




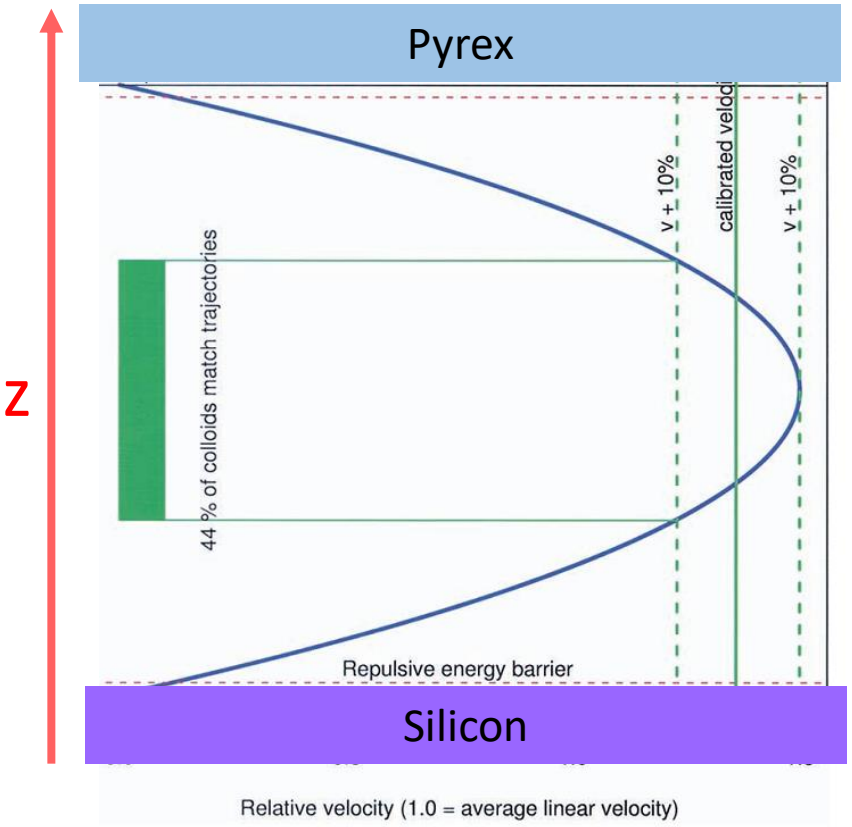
Possibility to follow each particle frame by frame

III Results : Local velocities measurements

Local velocities



V(global with PTV) ≈ + 10% V(global Q/A)



V(pore throat) ≈ 5 times V (pore body)

Baumann et al. 2004

Outlines

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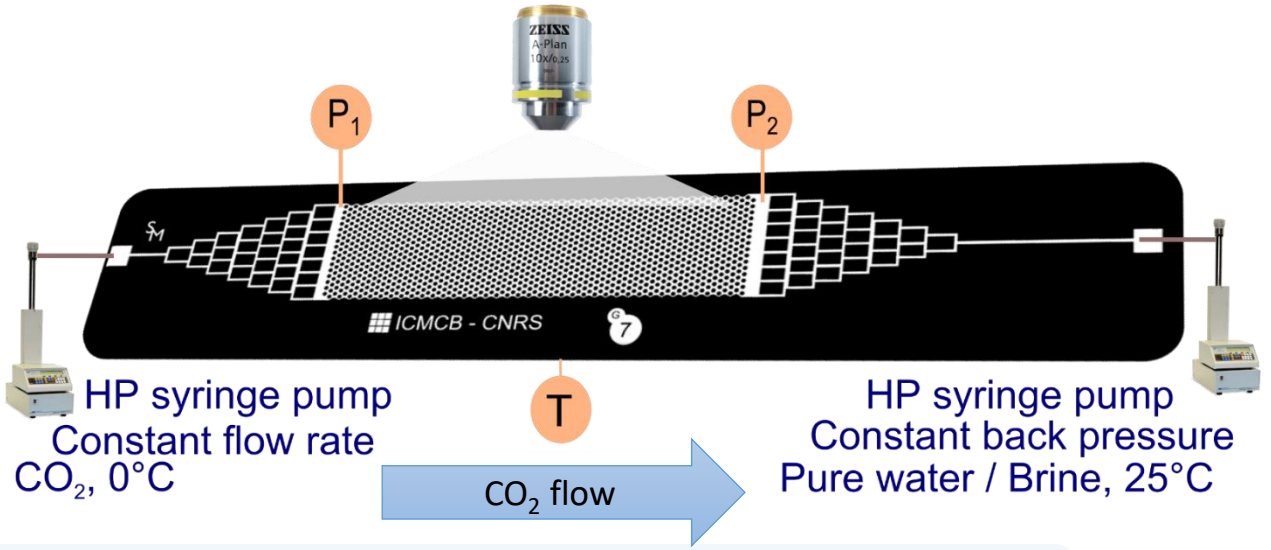
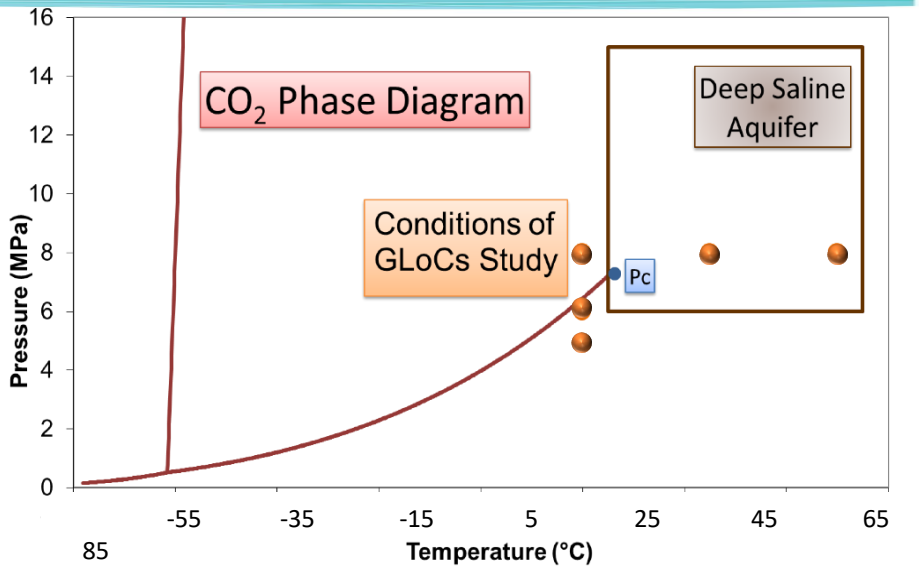
IV Results : CO_2 invasion process at pore scale





Goal: accessing CO_2 saturation values

S. Morais et al.
Monitoring CO_2 invasion using Geological Labs on Chip (GLoCs) (In preparation)

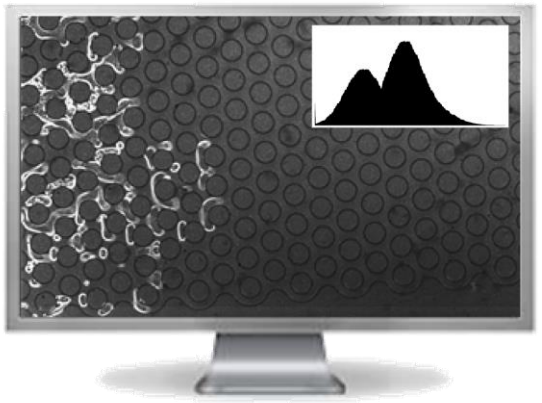
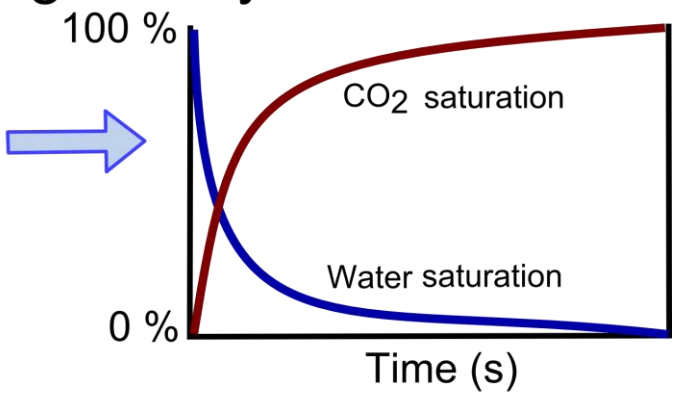


Image Analysis



$$saturation = \frac{CO_2\ area}{total\ area}$$

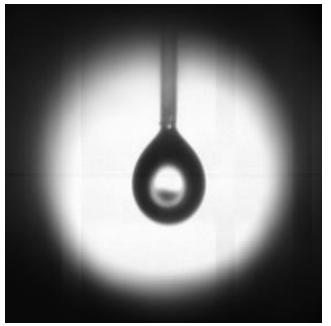
IV Results : CO_2 invasion process at pore scale

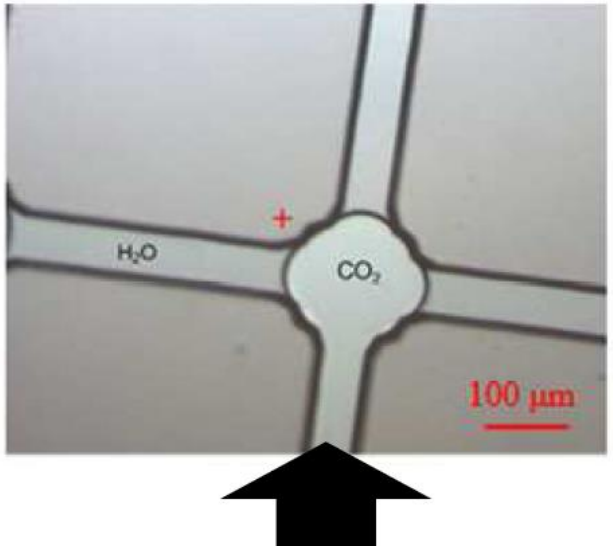
Ratio between viscous forces and capillary forces

$$Ca = \frac{\mu u}{\gamma \cos\theta}$$

Interfacial tension and contact angle measurements

Pendant drop method in a high pressure cell





Forces :
- Capillary (interfacial tension)
- Viscous

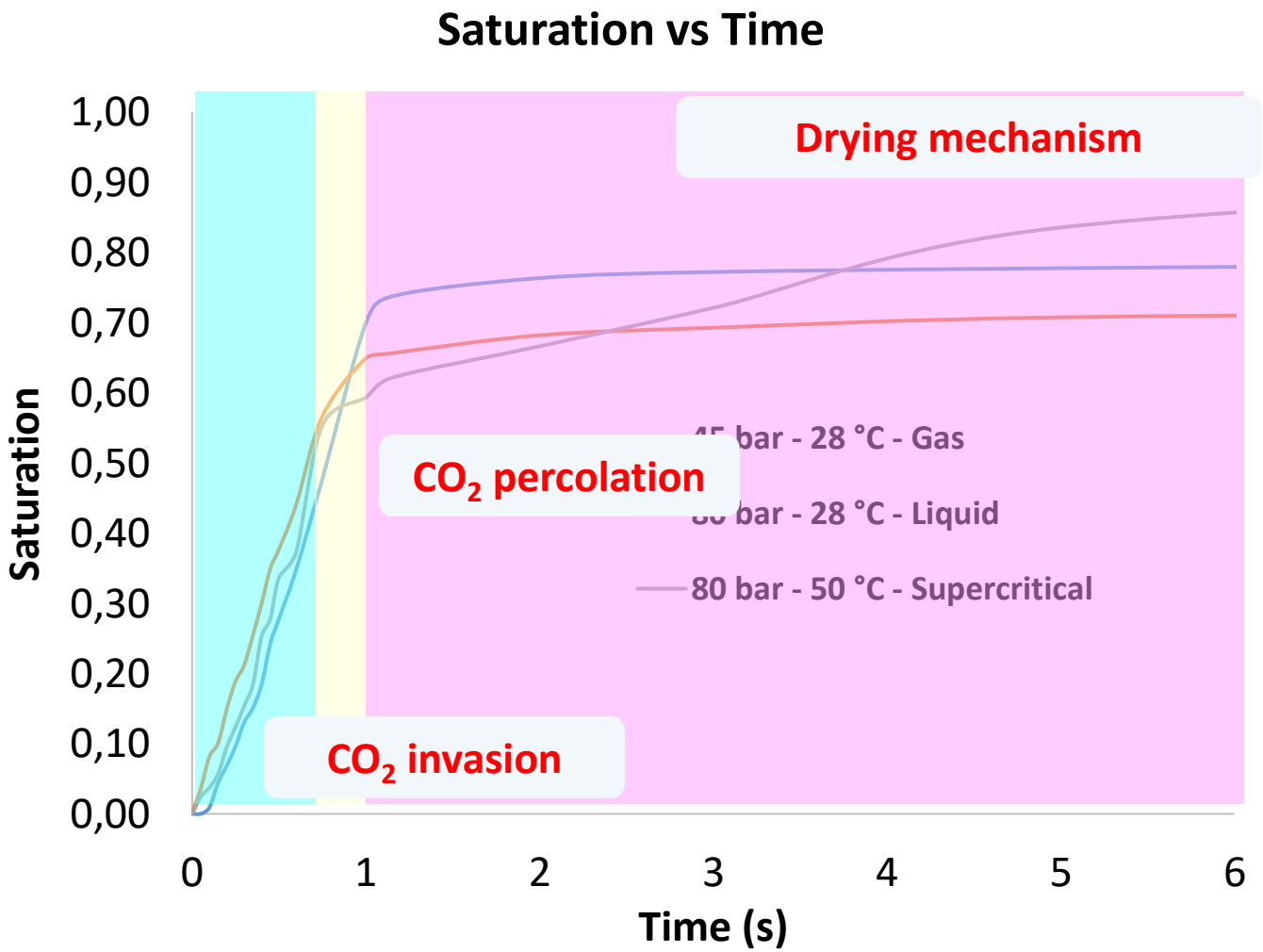
IV Results : CO_2 invasion process at pore scale

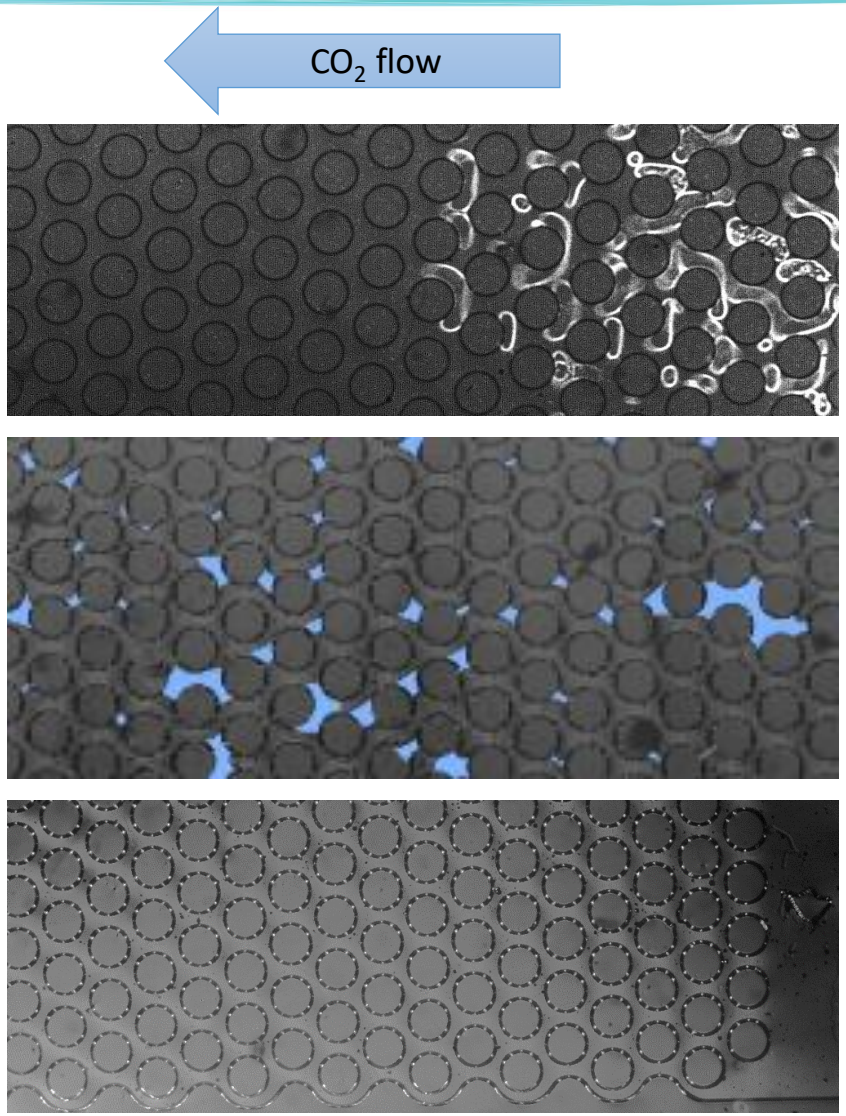
2 different GLoCs

	M1	M2
Depth (µm)	22.3 ± 0.2	17.5 ± 0.2
Plots mean diameter (µm)	235 ± 3	229 ± 3
Pore body (µm)	279 ± 3	287 ± 3
Pore throat (µm)	62 ± 3	67± 3
Porosity (%)	0.44	0.47

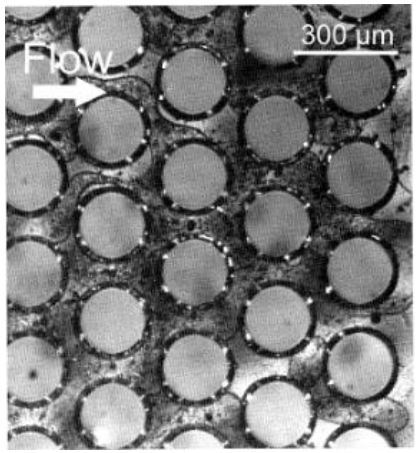
		M1			M2		
p,T conditions	**Q_{pump} (µl min^{-1})**	**Log Ca**	**Global velocity (m s^{-1})**	**Reynolds number**	**Log Ca**	**Global velocity (m s^{-1})**	**Reynolds number**
4.5 MPa 28 °C	100	-3.93	0,28	41,1	-3.85	0,33	38,5
6 MPa, 28°C	100	-4.02	0,17	37,9	-3.94	0,21	35,5
8 MPa, 28°C	100	-3.99	0,04	11,5	-3.92	0,05	10,8
8 MPa, 50°C	100	-4.02	0,14	34,1	-3.94	0,17	31,9
8 MPa, 75°C	100	-3.92	0,19	35,0	-3.84	0,22	32,7
8 MPa, 50°C	200	-3.72	0,29	68,2	-3.64	0,34	63,9

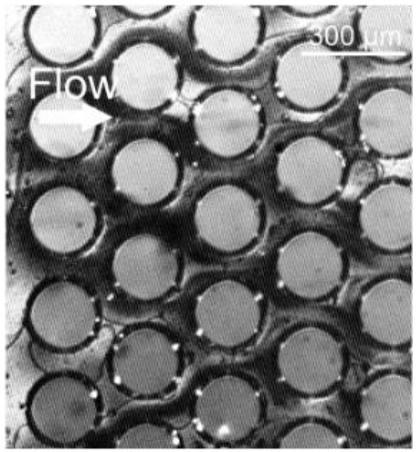
IV Results : CO_2 invasion process at pore scale

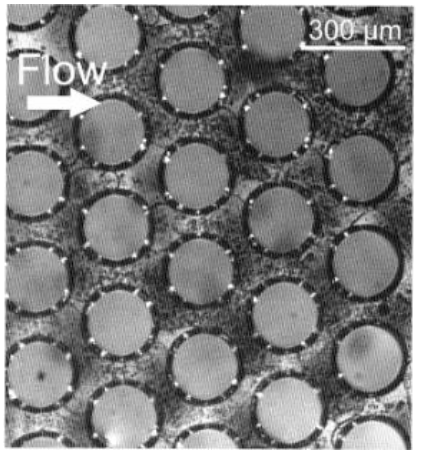


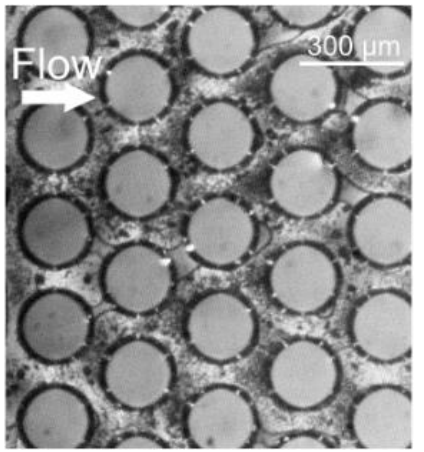


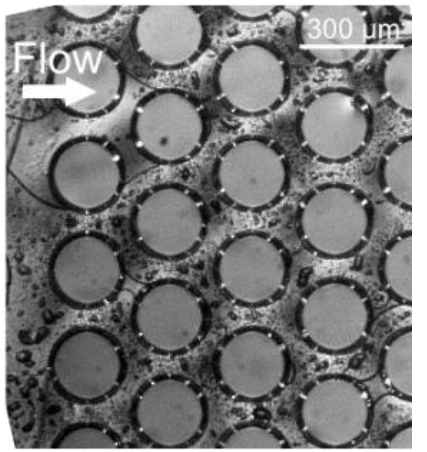
IV Results : CO_2 invasion process at pore scale











45 bar – 25 °C
Gas

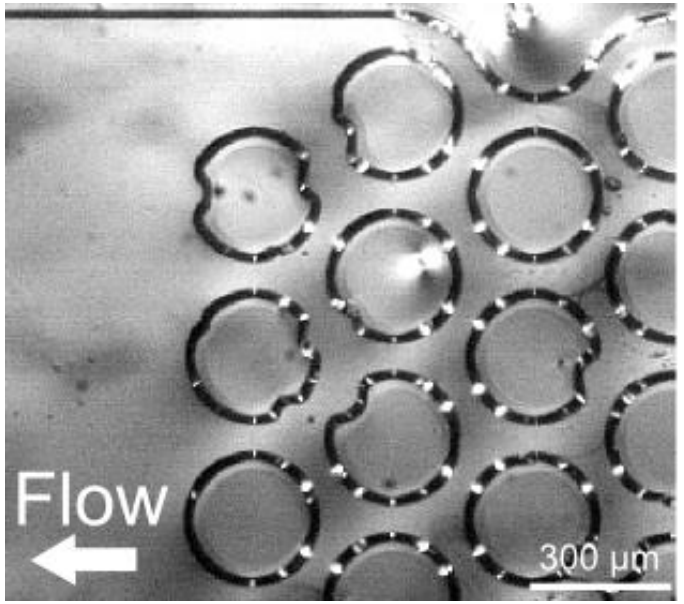
60 bar – 25 °C
Gas

80 bar – 25 °C
Liquid

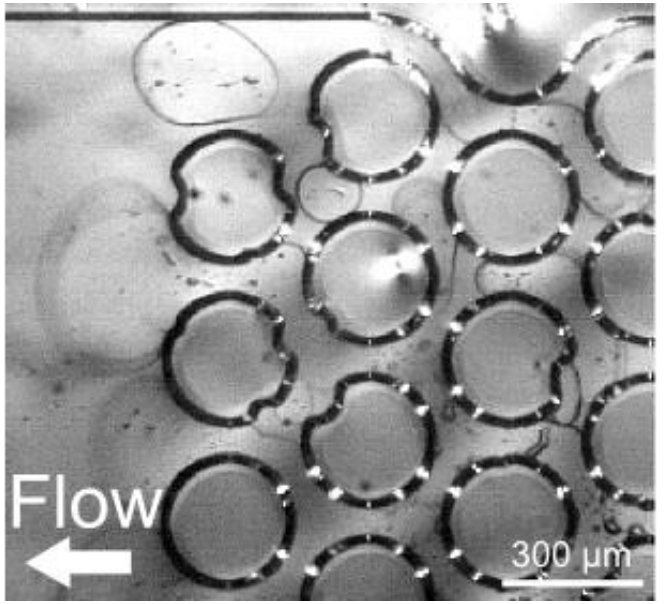
80 bar – 50 °C
Supercritical

80 bar – 75 °C
Supercritical

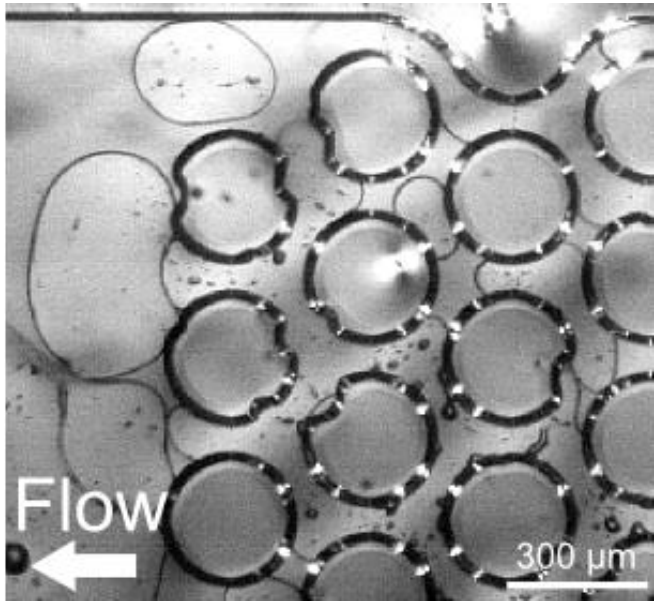
IV Results : CO_2 invasion process at pore scale



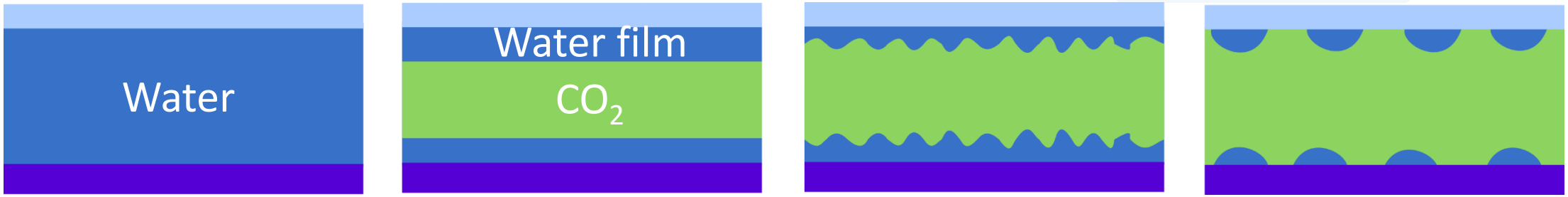
t = 0 s



t = 0.05 s

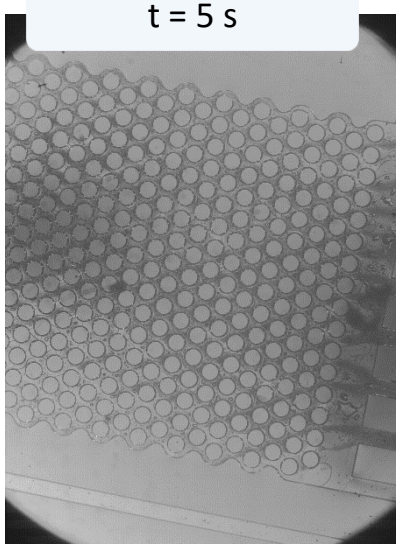
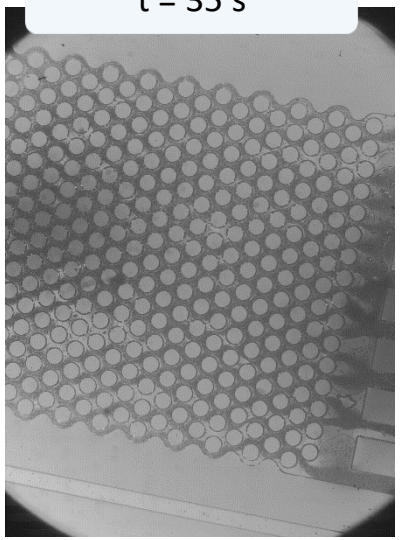
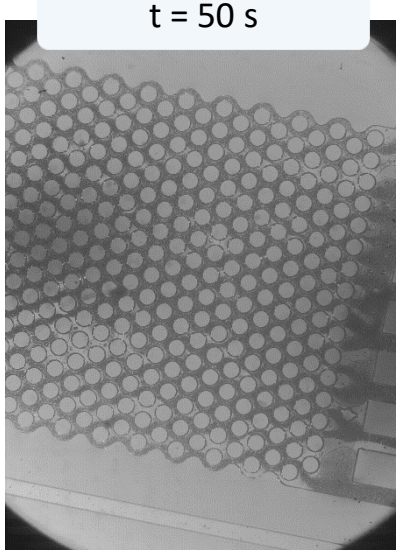
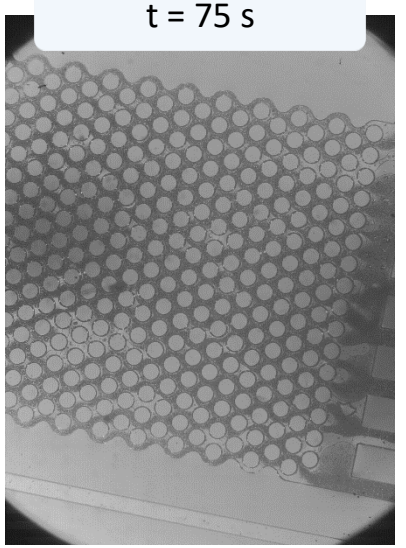
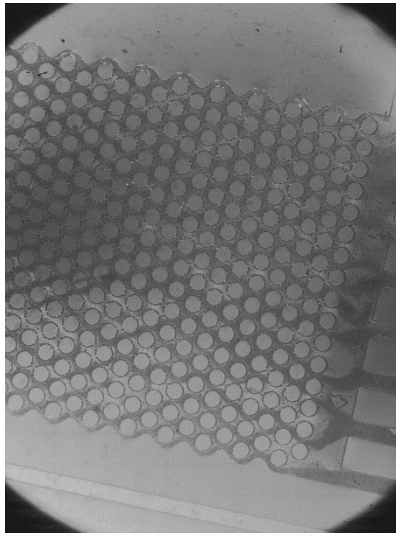
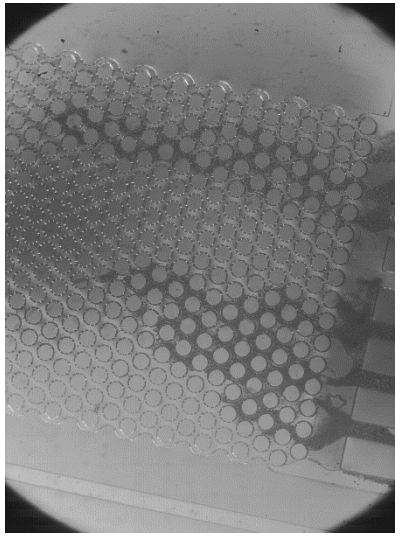
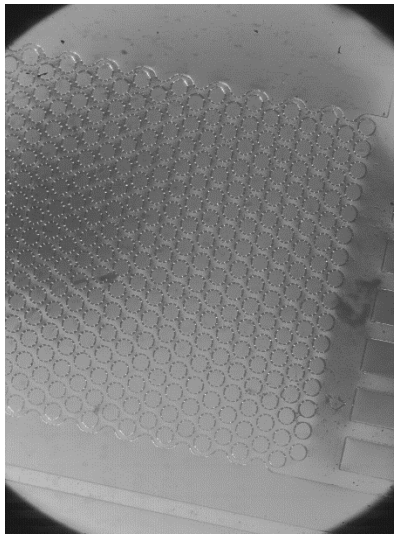
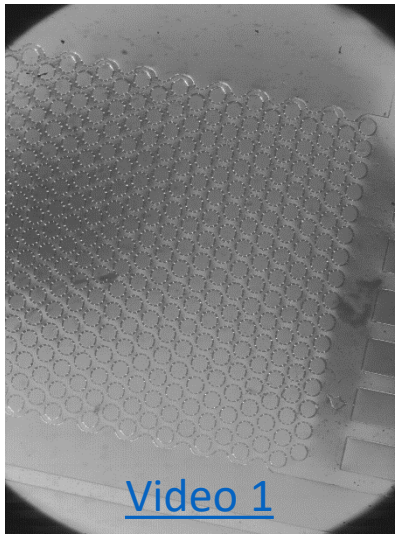


t = 0.10 s



The amount of water droplets impacts the final CO_2 saturation value

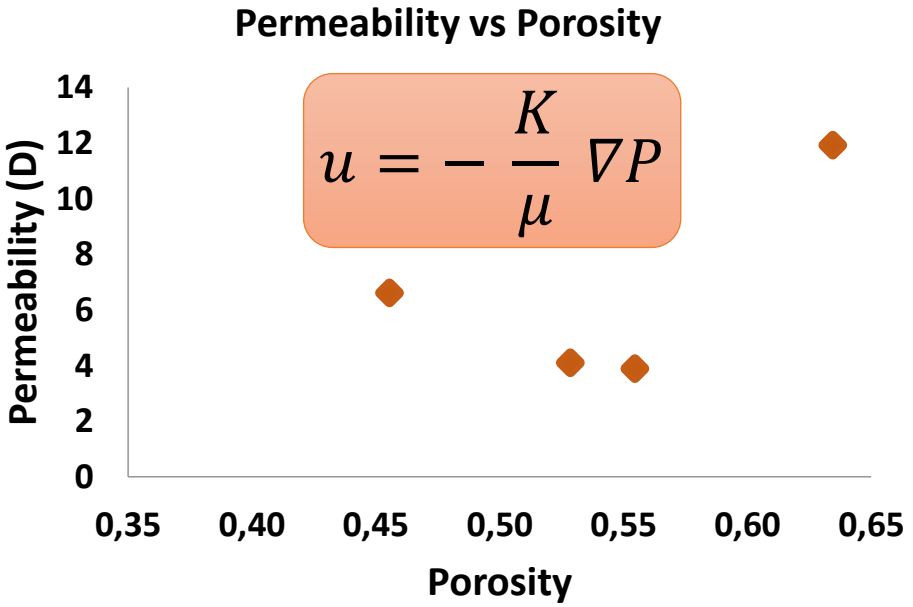
IV Results : CO_2 invasion process at pore scale

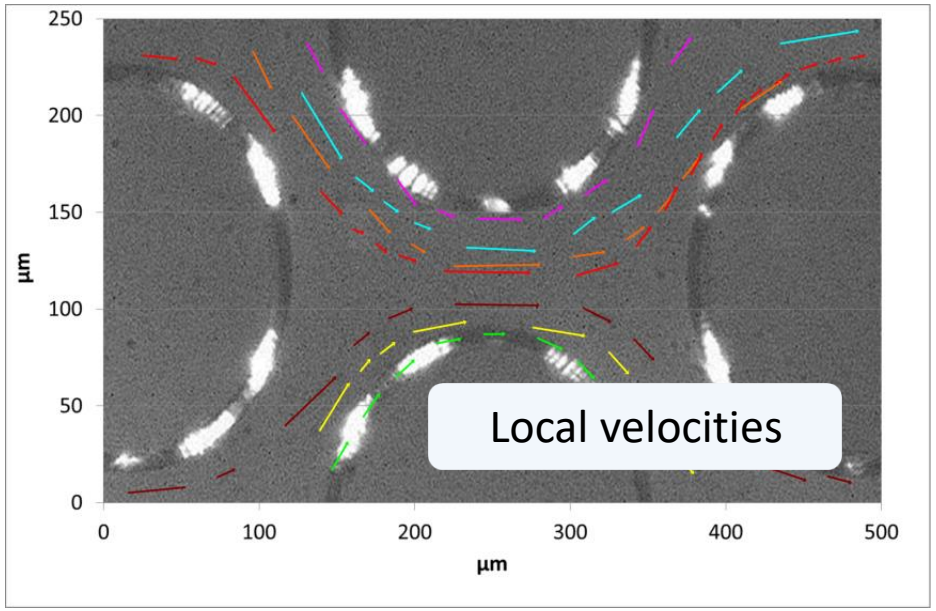
	t = 5 s	t = 35 s	t = 50 s	t = 75 s
80 bar – 50 °C				
80 bar – 75 °C				

Video 1

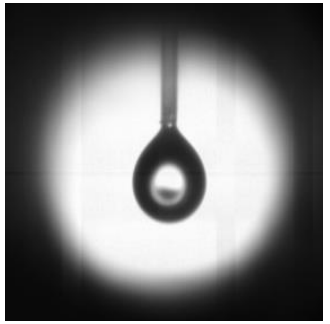
Results - conclusion

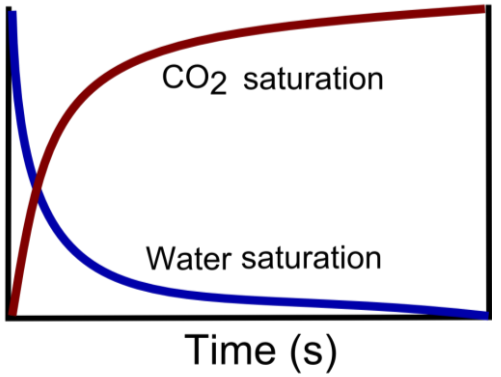
Monophasic Study

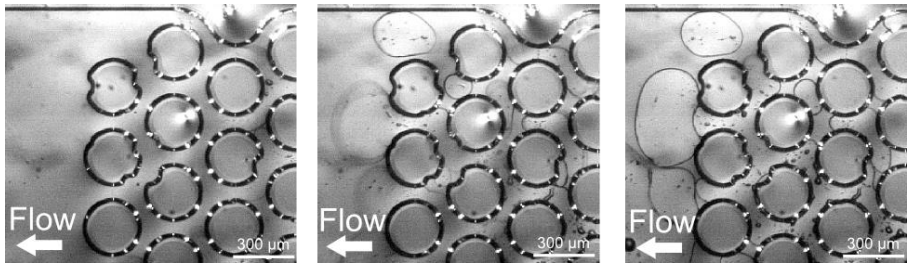




Diphasic Study







Outlines

I Context

II Geological Labs On Chip

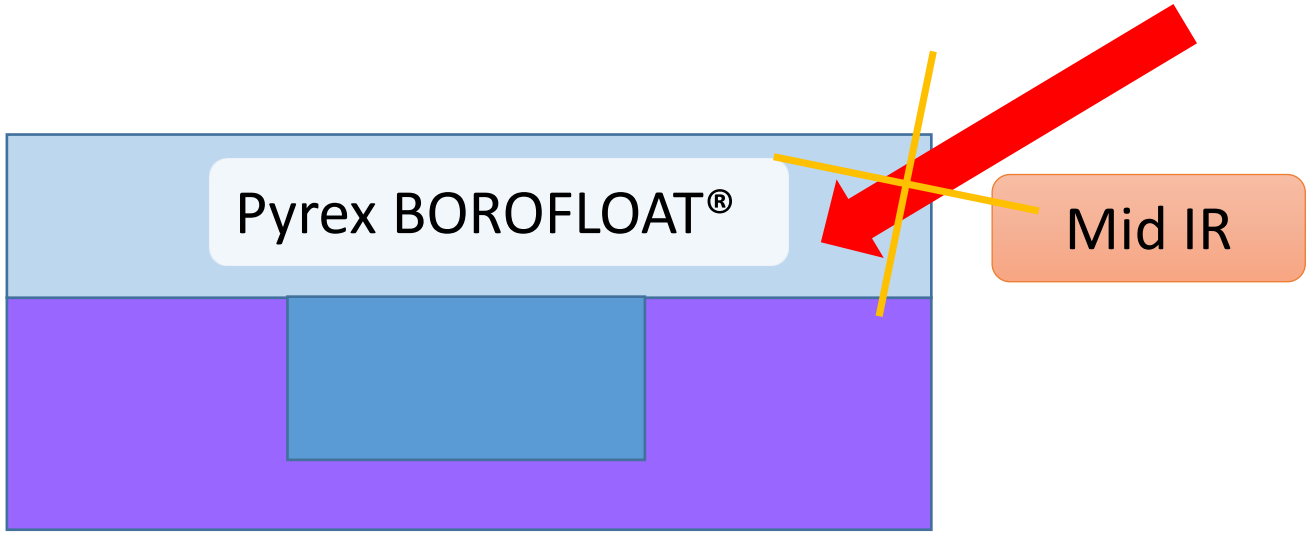
III Results – Monophasic Study

IV Results – Diphasic Study

V Ongoing Works

V Ongoing Work : *In situ* characterization with optic fibers

Spectroscopic characterization of CCS gas (CO_2, H_2S, NO_x)



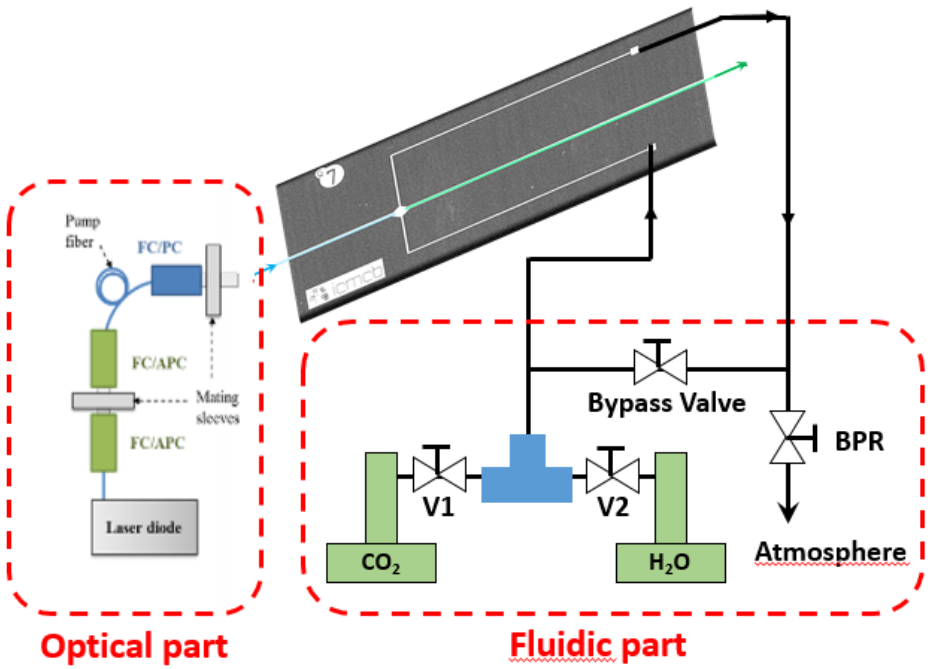
Different glass
→ µHPI project
(Défi d'intrumentation aux limites)

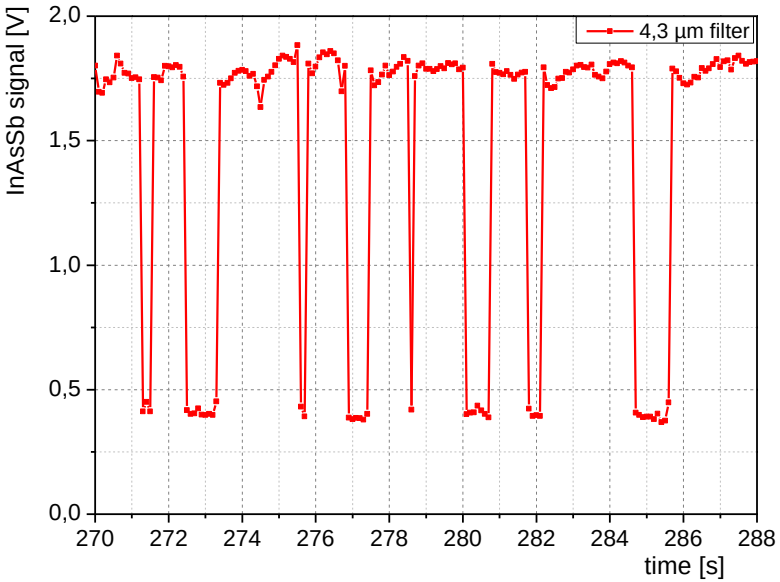
Integration of optic fiber into GLoCs

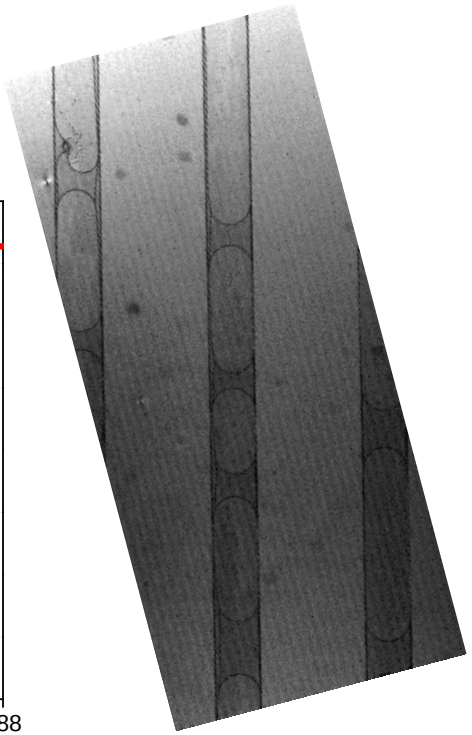
V Ongoing Work : *In situ* characterization with optic fibers

Integration of optic fiber into GLoCs

F. Starecki, S. Morais et al.
IR emitting Dy3+ doped GaGeSbS fibres for in situ CO_2 monitoring in high pressure microsystems (Submitted)

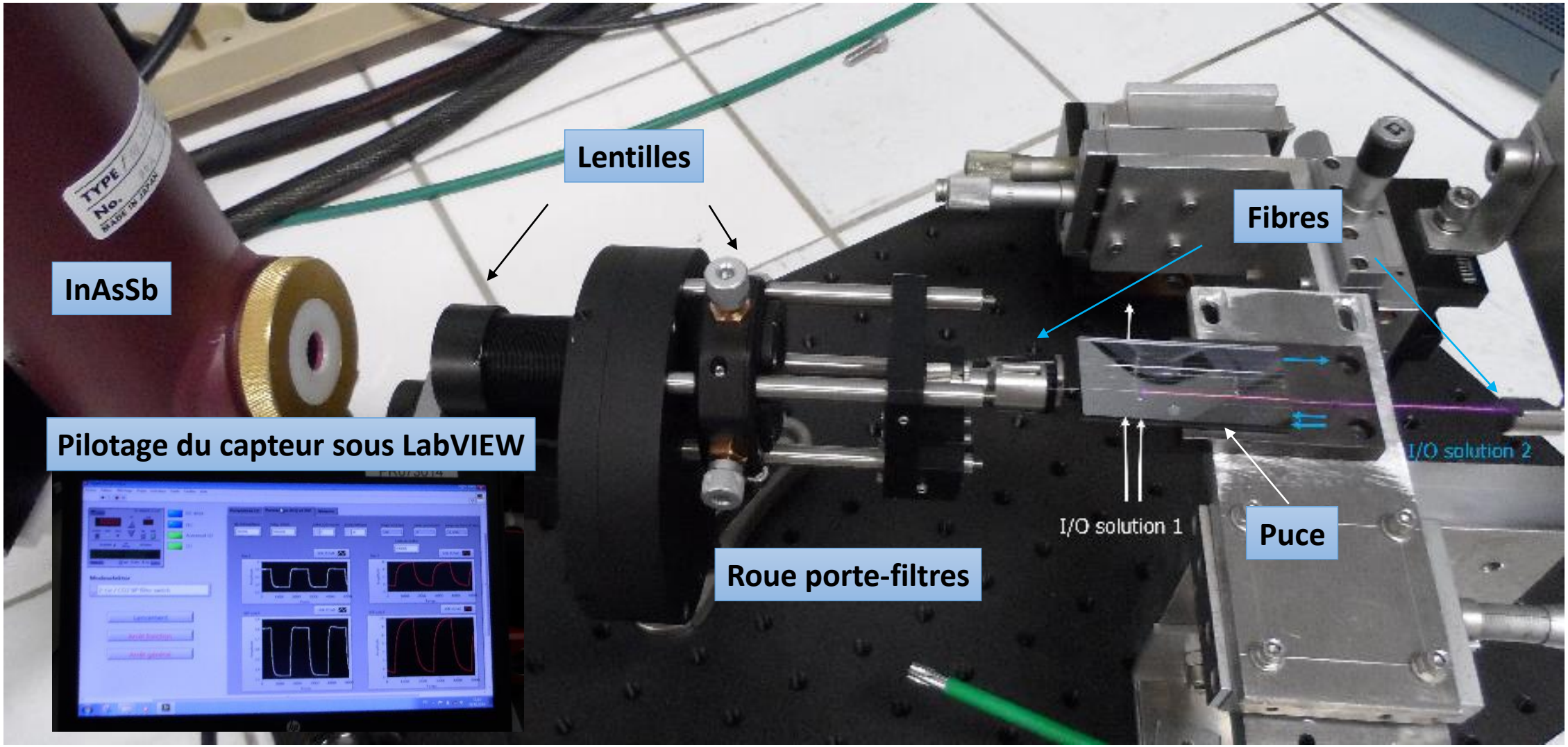




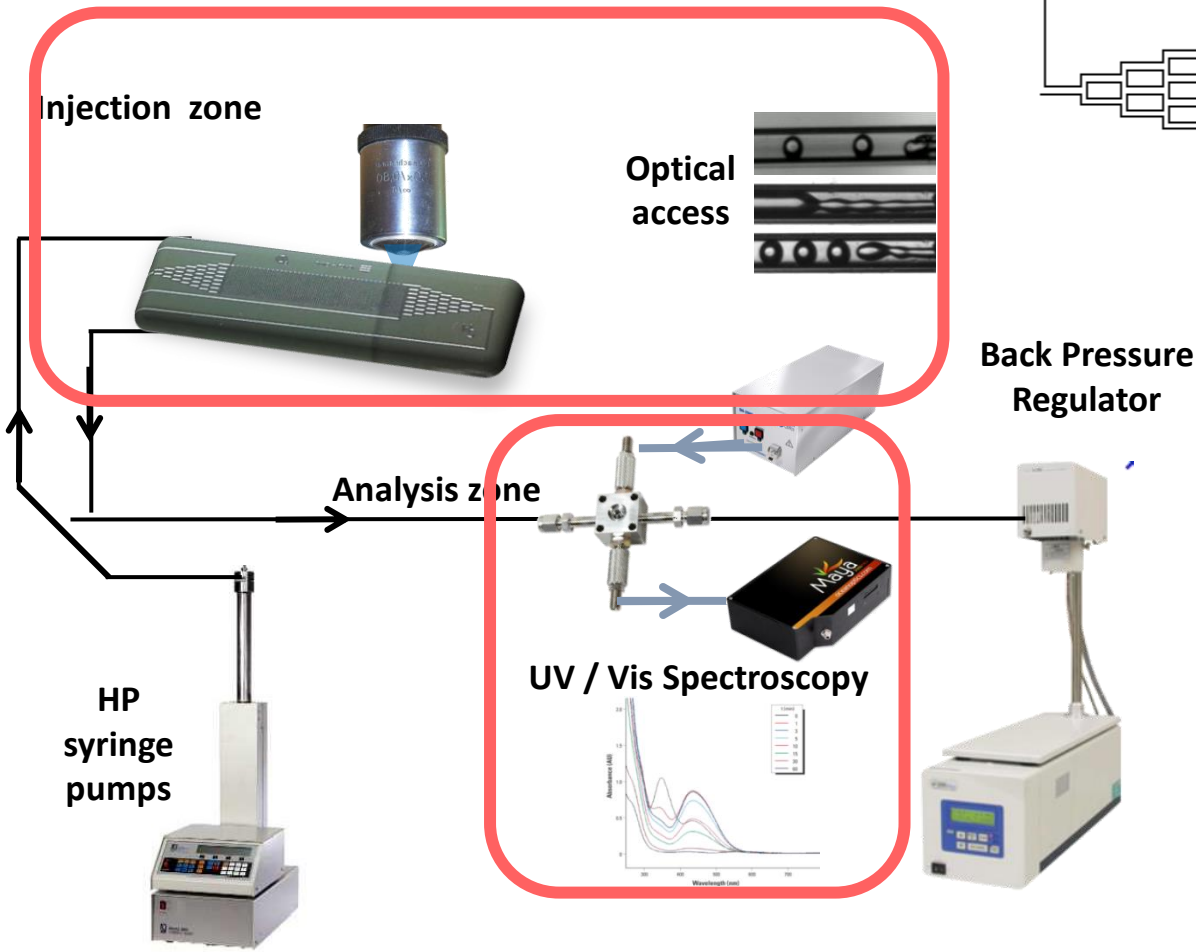


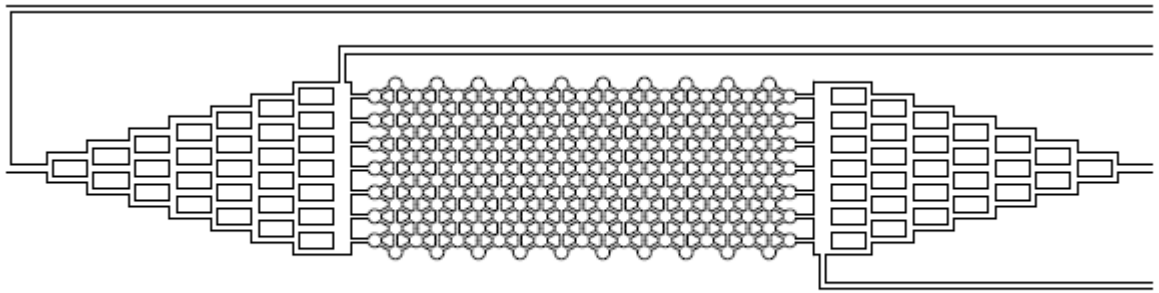
Detection of CO_2 bubbles in microfluidic systems (generated with a coflow system)

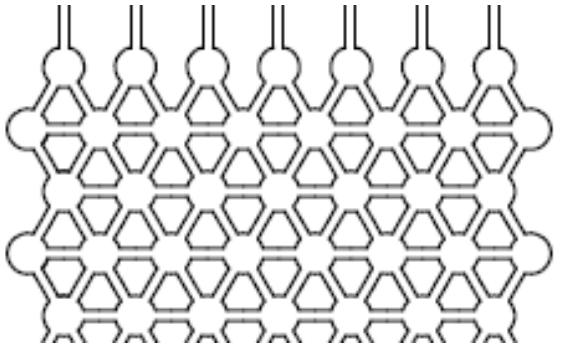
V Ongoing Work : *In situ* characterization with optic fibers



V Ongoing Work : Future work







- Fluorescent Tracer
- Dead Zone
- Residence Time Distribution

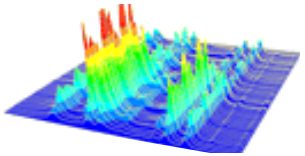
V Ongoing Work : Future work

RYAN L. HARTMAN

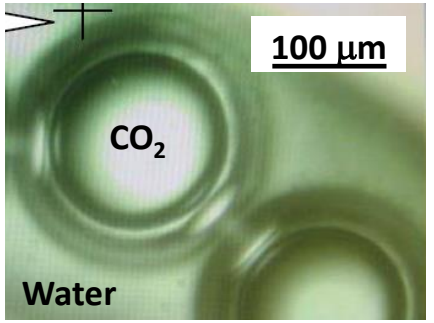
NYU

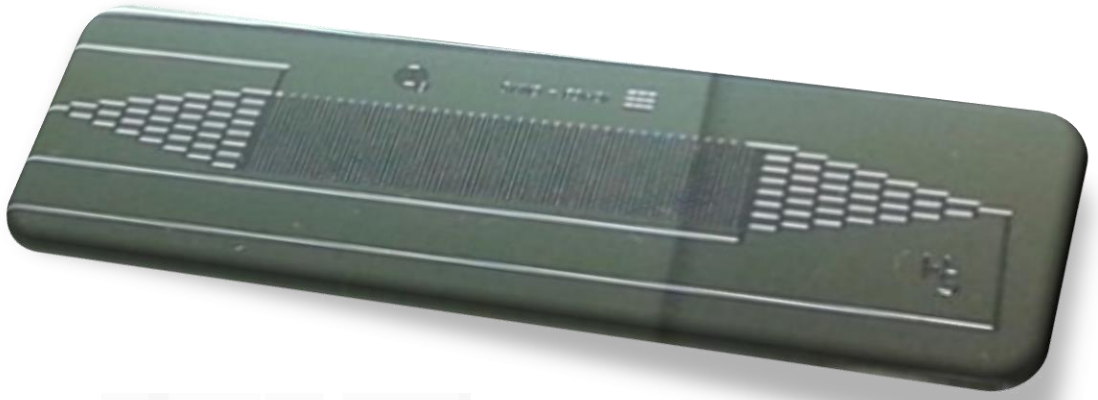
Hydrate formation

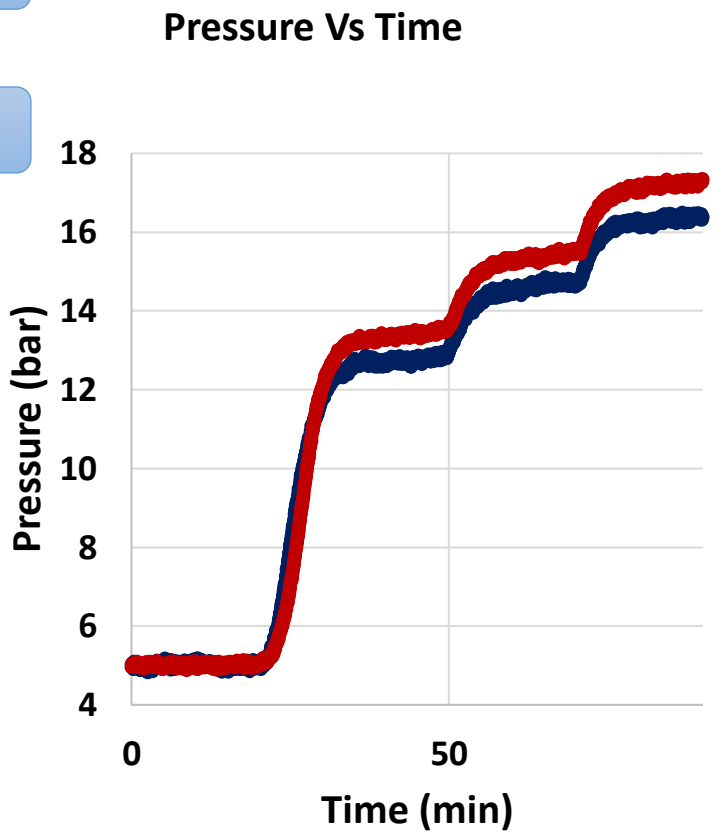
Low temperature



Confocal Raman Spectroscopy







icmcb Institut de chimie de la matière condensée de bordeaux

cnrs

Agence Nationale de la Recherche ANR

université de BORDEAUX

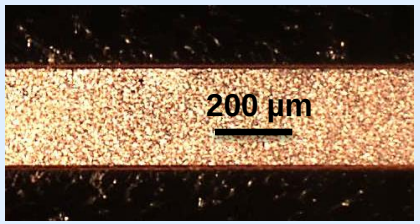
Bordeaux INP AQUITAINE

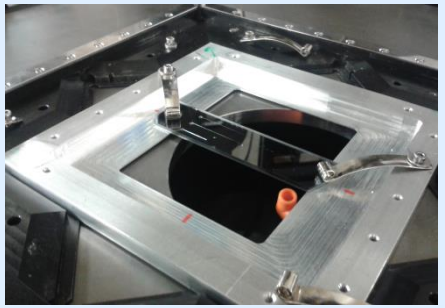
CGSULab

V Ongoing Work : 3D studies

Toward 3D realistic micromodel

Packed bed of real minerals in microchannels

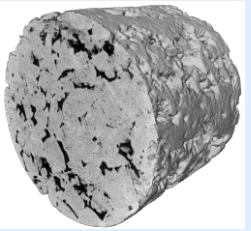




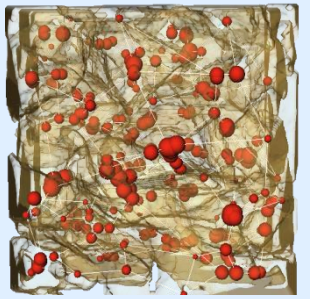
X-Rays microtomography

Laminography

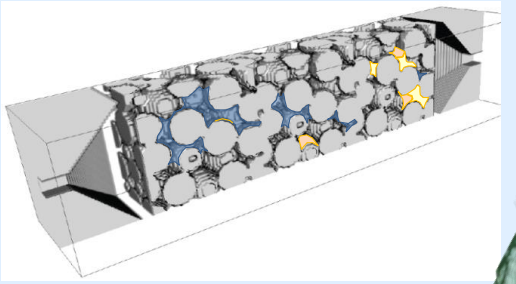
Synchrotron measurements



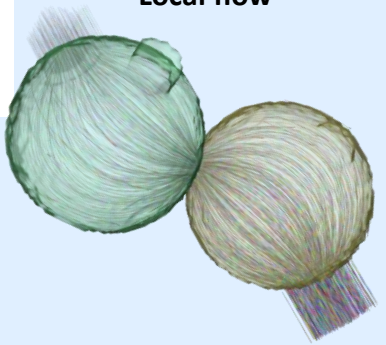
Pore Network model construction



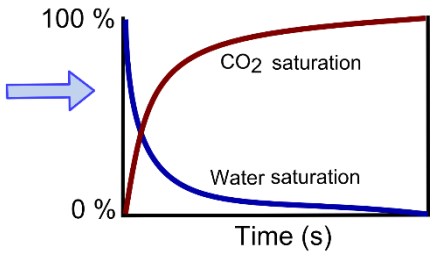
Direct numerical modeling

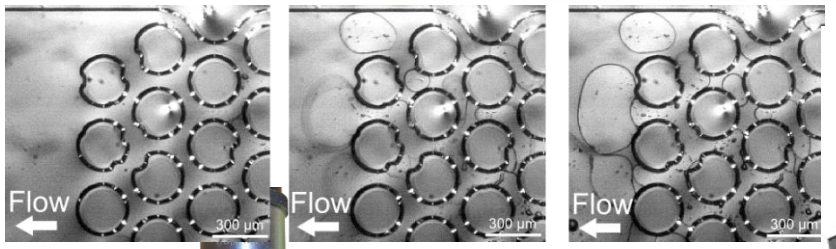


Local flow

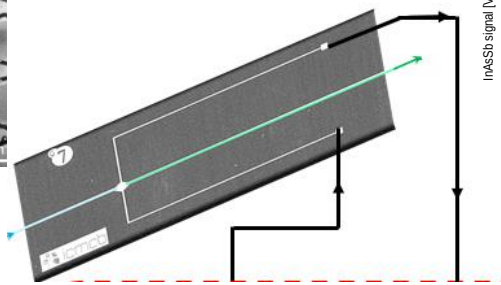


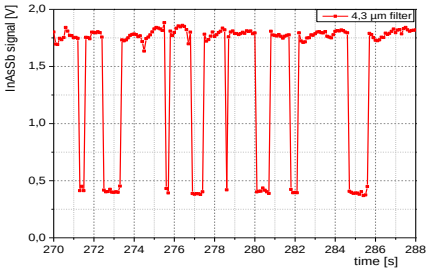
Conclusions



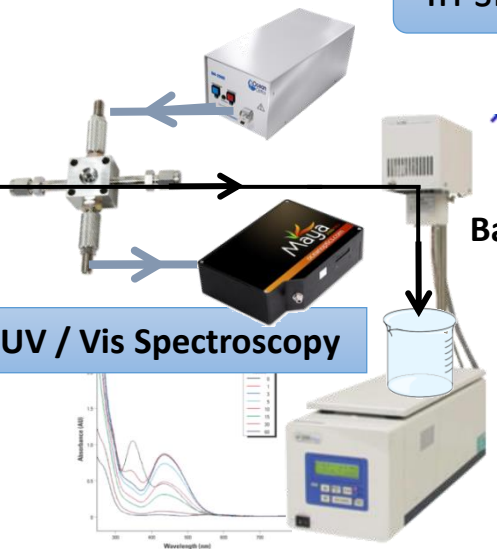


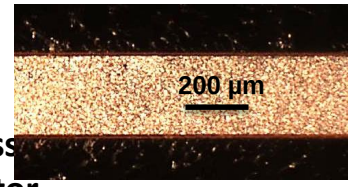
Optical access



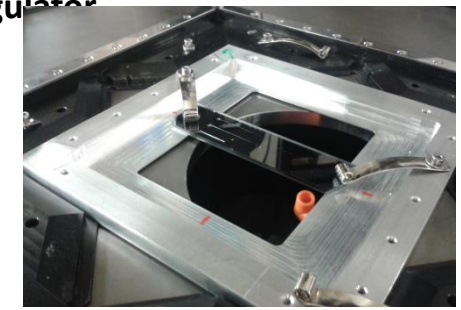


In situ characterization

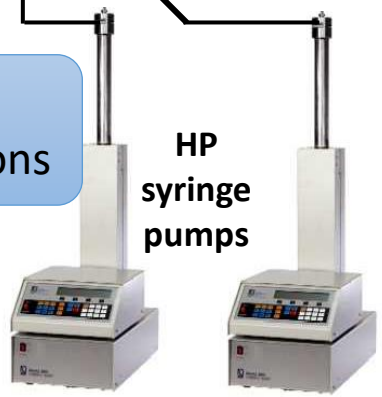




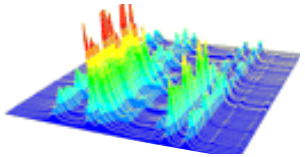
Back Press
Regulator

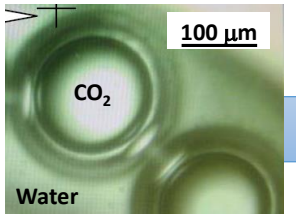


p,T conditions



HP syringe pumps





Confocal Raman Spectroscopy

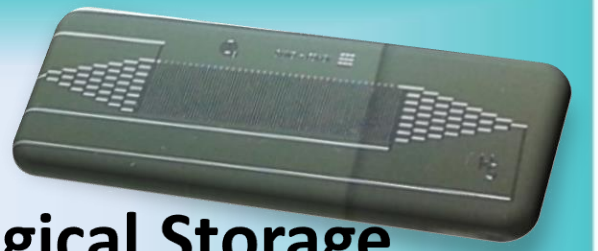
UV / Vis Spectroscopy

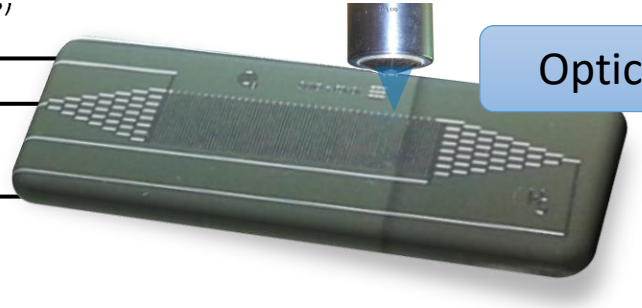
Injection zone

3D realistic micromodel

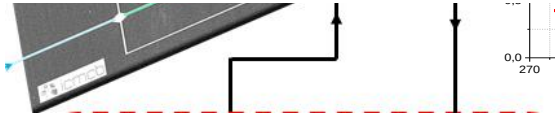
Geological Labs On Chip (GLoCs)

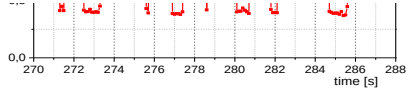
New tools for investigating key aspects of CO_2 Geological Storage



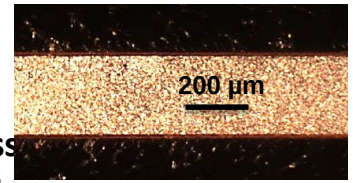


Optical access





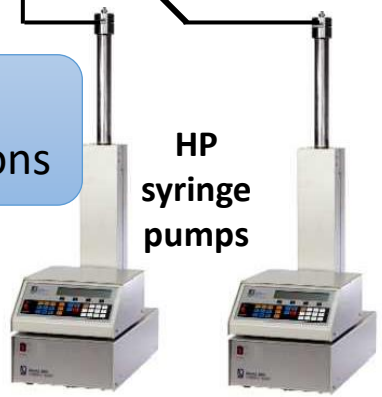
In situ characterization

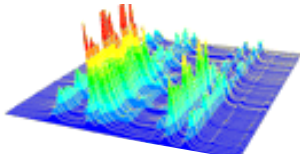


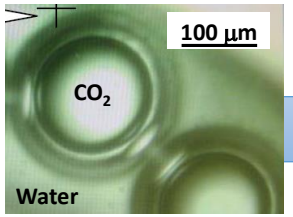
Back Press
Regulator

p,T conditions

HP syringe pumps

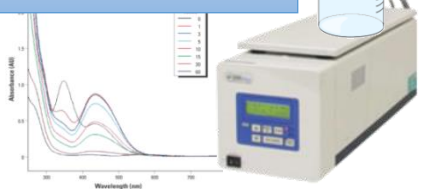


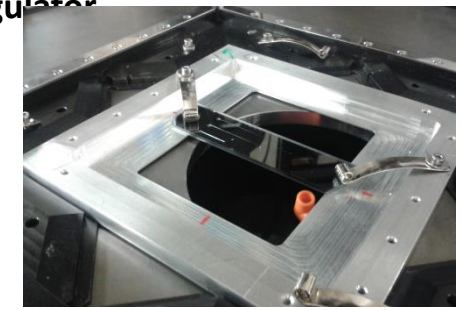




Confocal Raman Spectroscopy

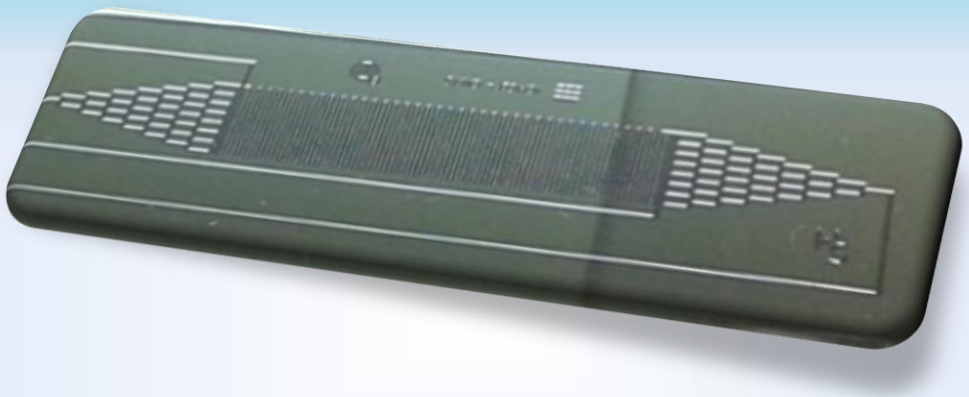
UV / Vis Spectroscopy





3D realistic micromodel

Injection zone



Geological Labs On Chip (GLoCs)

New tools for investigating key aspects of CO_2 Geological Storage

Sandy Morais

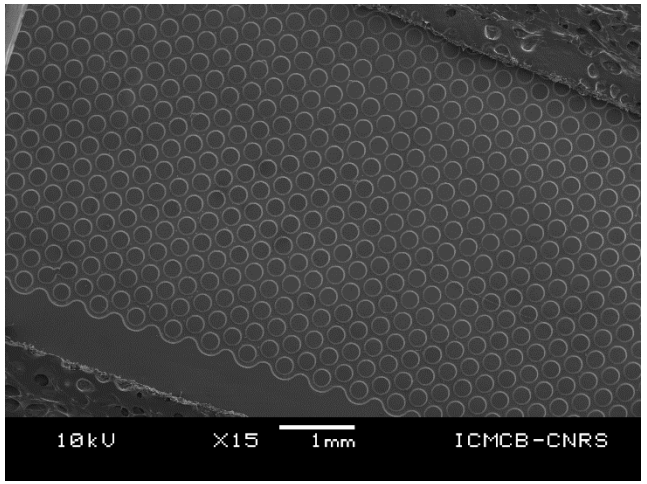
Sous la direction de :

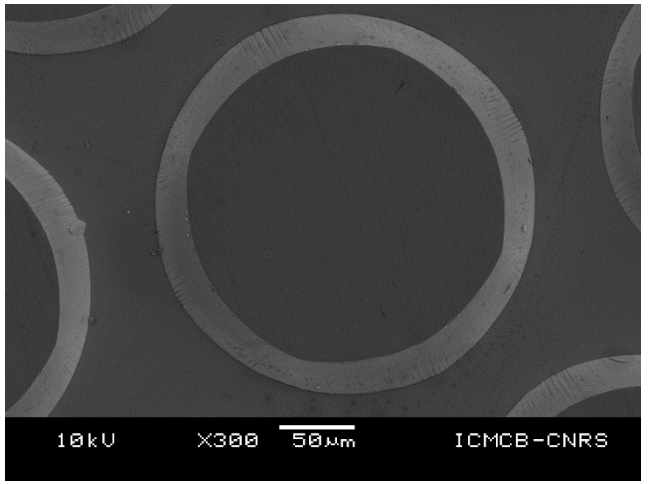
Dominique Bernard (Groupe 1)

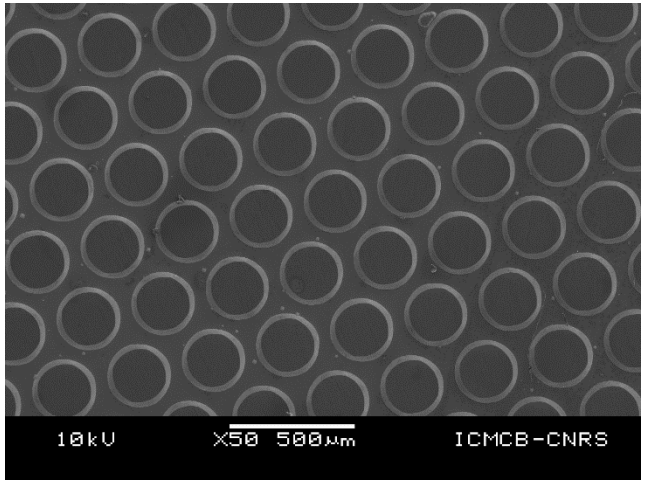
Samuel Marre (Groupe 7)

Projet ANR porté par

Yves Garrabos (Groupe 7)


10kU X15 1mm ICMCB-CNRS


10kU X300 50µm ICMCB-CNRS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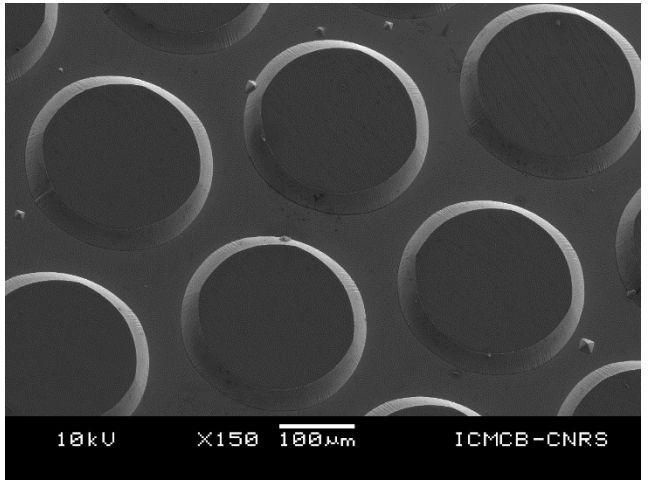
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