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# Exploring CO<sub>2</sub> geological storage mechanisms at the pore scale using microfluidics approaches

Anaïs Cario, Yves Garrabos, Carole Lecoutre, Olivier Nguyen, Samuel Marre\*

CNRS, Univ. Bordeaux, ICMCB, F-33600, Pessac Cedex, France

[samuel.marre@icmcb.cnrs.fr](mailto:samuel.marre@icmcb.cnrs.fr)

## 1. Introduction

The management of anthropogenic CO<sub>2</sub> will be one of the main challenges of this century given the dramatic impact of greenhouse gases on our living environment. It is now critical, not only to develop technologies allowing the reduction of CO<sub>2</sub> emissions, but also to provide solutions to capture and use/store industrial CO<sub>2</sub> emissions. Among the various Carbon Capture Utilization and Storage (CCUS) strategies, CO<sub>2</sub> geological storage in deep saline aquifers represents a viable mediation solution for reducing the anthropogenic CO<sub>2</sub> emissions. So far, little is known about both the CO<sub>2</sub> storage impact on the underground geochemistry and on the microbial diversity inhabiting deep aquifers. Consequently, this kind of storage required adequate scientific knowledge and tools at the pore scale to evaluate injection scenarios or to estimate reservoir capacity. In this context, high pressure / high temperature microfluidic reactors (micromodel or geological labs on chip – GLoCs) turn out to be excellent tools to investigate the different mechanisms associated with CO<sub>2</sub> geological storage in deep saline aquifers.

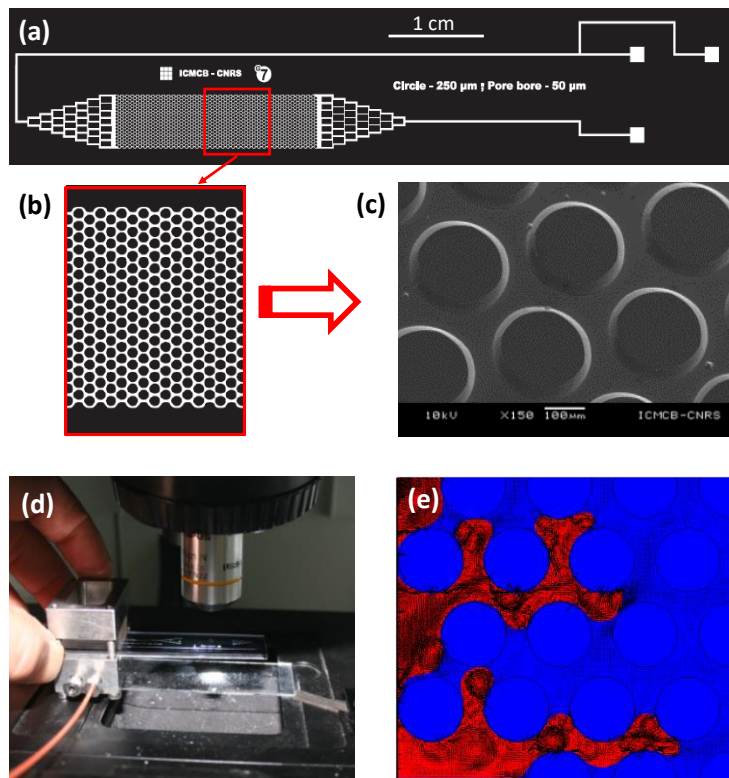
## 2. Results and discussion

When CO<sub>2</sub> is injected in deep saline aquifers, it can undergo four trapping mechanisms, namely: (i) the stratigraphic trapping, (ii) the capillary trapping, (iii) the solubility trapping and (iv) the mineral trapping. Each of these mechanisms participate in the overall storage capacity of a reservoir and provide various time dependent processes resulting in the final CO<sub>2</sub> storage. The phenomena involved in these trapping mechanisms depend on coupled effects of thermodynamics, hydrodynamics, geochemistry and biology, which primarily found their origin at microscale (mass and heat transfer processes, surface chemistry, etc.). It is therefore highly desirable to obtain experimental data at the pore scale to feed and to develop models able to predict the final storage capacity at the reservoir scale.

Conventional lab scale tools used for such investigations (cores-scale experiments or batch reactors) cannot easily provide such data due the lack of *in situ* characterization techniques. Oppositely, by adapting high pressure microfluidics approaches to porous media, “Geological Labs on Chip” tools (Figure 1) were developed and adapted to studies dealing with fluidic within porous media. They turn out to be excellent tools to complement the classical core-scale experimental approaches to investigate the different mechanisms associated with CO<sub>2</sub> geological storage in deep saline aquifers.

We will first highlight the fabrication, the use and the application of the GLoCs to study the invasion processes of CO<sub>2</sub> in water and brine saturated GLoCs. In particular, direct optical visualization and image treatments allow following the evolution of the CO<sub>2</sub>/brine phase distribution within the pores, including displacement mechanisms, pore saturation levels and reactive transport (dissolution / precipitation). Indeed, the ability to easily and quasi-instantaneously monitor fluid flow and pressure inside the HP micromodels, allows us to access data such as pressure drop and saturation that are linked to the permeability of the pore network. These two parameters have been studied experimentally with several type of GLoCs in order to determinate the influence of each geometrical feature in realistic p,T conditions.

We will then present some ongoing works aiming at integrating *in situ* spectroscopy techniques (Raman, IR and X-Rays imaging) in HP microreactors to get information about the solubility, dissolution and mineralization trapping. In particular, we have developed an experimental set-up to recreate 3D reactive porous media within a microfluidic channel (fixed packed bed of calcium carbonate). Thanks to X-Rays laminography carried out at the ESRF, we have observed on reconstructed 2D images, the dissolution phenomena occurring during the successive injection of constant volumes of non-equilibrium solution. This proof of concept has opened new possibilities for using this methodology to acquire kinetic data on 3D reactive front phenomena in porous media.



**Figure 1.** (a) Full view of the micromodel design with a typical 2D porous pattern, (b) enlargement of a 4.4×5 mm rectangular area, (c) SEM images of the etched porous media, (d) GLoC device placed under a confocal Raman spectrometer and (e) numerical modelling of CO<sub>2</sub> invasion within a porous media

### 3. Conclusions

The recently developed Geological Labs on Chip (HP micromodels) have been confirmed as fast and accurate microfluidics tools to identify and quantify dissolved carbon dioxide in water and salted water, but also to study invasion mechanisms depending upon flow rates, porous medium characteristics and brine composition (in particular for studying carbonate precipitation and drying mechanisms). These approaches are proved viable in the laboratory, and can be used to simulate and analyze various CO<sub>2</sub> geological storage issues or other geological-related topics such as Enhanced Oil Recovery (EOR), shale gas recovery, geothermal energy or investigations of CO<sub>2</sub> biogeoconversion to methane (ERC project “BIG MAC”) [1].

### References

- 1 <http://www.erc-bigmac.cnrs.fr/>