The CO2-FIX Project:

In situ [bio]-mineralization in mafic and ultramafic context: A combined experimental and numerical approach

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INTRODUCTION

Most typical injection sites with sedimentary rocks have mineralogy that is, besides carbonate minerals, dominated by quartz and aluminosilicates poor in alkaline elements thus providing low mineral carbonation potential. In contrast, mafic rocks, such as basalt are rich in magnesium and calcium silicate minerals (olivine, Ca-plagioclase) displaying high potential of mineral trapping.

However, there are a large number of challenges for developing a successful, effective, and validated CO_2 sequestration in basalt rocks. When CO_2 is injected into basalts a large number of competing mineral/fluid reactions occur. While one can study the rates and thermodynamics of these reactions in the laboratory, their application to the field can only be validated if they are incorporated into comprehensive geochemical models, and results are compared directly with quantitative field observations.

GOAL

The goal of this proposed research program is to provide the scientific basis for in-situ carbon mineralization.

This research program consists of:

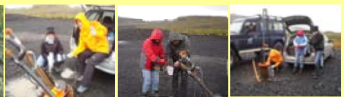
1) quantifying the rates and efficiencies of transformation of basalt and ultramafic rocks into carbonate minerals by CO_2-rich fluids, 2) assessing the potential of microorganisms to enhance these rates and efficiencies through biomineralization, 3) determine the degree to which the in-situ precipitation of carbonate and other potential secondary minerals alters the porosity, permeability and hydrodynamics of the host basalt or ultramafic rock, 4) to incorporate these results into improved reactive transport computer programs, and 5) compare experimental and model results to the first full-scale in-situ carbon mineralization project in Hellisheidi, Iceland.

TASKS

Six complementary and integrated tasks, including laboratory experiments, numerical modeling and field observations will be performed in CO2-FIX

Task 1: Samples collection from pilot sites (Hellisheidi, Iceland)

Hellisheidi CO_2 injection pilot site in Iceland (CARBFIX project)



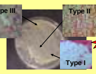
Deep and shallow underground fluids sampling, October 2008: *Bénédicte Ménez, Emmanuelle Gérard, Pascale Bénézeth, Pierre Agrinier and Einar Örn*

Define the geochemical (major elements, T, pH, stable isotopes) and microbiological initial state

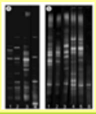
Isolation of microorganisms in pure cultures (LMTG)

Molecular methods (IPGP)

Morphological characteristics of aerobic heterothrophic bacteria extracted from HK-31 well (Shirokova et al., 2009). The enzymatic (functional) diversity has been evaluated using Biolog Ecoplates.



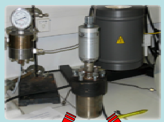
Their genetic identification are being performed using 16-S RNA analysis.



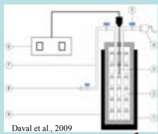
Task 2: Determination of minerals dissolution and carbonate precipitation rates as a function of temperature, pressure, and solution composition

LMTG

Titanium flow-through cell reactors with in situ pH measurements (LMTG)



IPGP



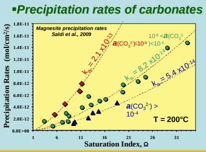
Batch reactors: 30°C<T<200°C 1<P<250°C

1. Autoclave (120 ml, Ti); 2. Teflon capsules; (dimensions: Θ = 1.3 cm, h = 2.5 cm); 3. Thermocouples; 4. Pressure sensors; 5. Tap; 6. Temperature regulator; 7. Flexible tubing for CO_2 supply (Ti); 8. Flexible tubing connected to an external source of CO_2; 9. Furnace.

▪*determination of crystalline basalt (from Iceland) and mafic/ultramafic minerals dissolution rates,*

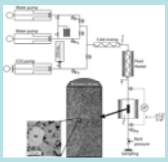
▪*Quantification of the effect of cell excudates and organic ligands issued from cell degradation on basaltic glass, olivine, pyroxene and plagioclase dissolution rates.*

▪*Precipitation rates of carbonates*



Carbonation experiments will be performed on powdered individual minerals in order to produce kinetic laws for the carbonation reaction. These experiments will be complemented with fine scale mineralogical studies.

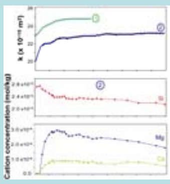
Task 3: Plug-flow experiments in basalt cores: hydration and carbonation reactions and feedback effects on permeability (Géosciences Montpellier)



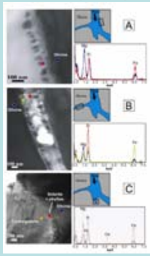
3 percolation apparatus

Permeability measurement

Chemistry analyses



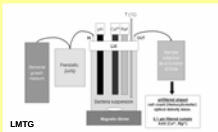
Andreani et al., 2009



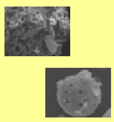
$T \leq 400°C$; $P \leq 400$ bar;
$Q = 6.10^{-5}$ - 2 ml.min^{-1}
Permeability k = 0.0006 to 210 mD
Sample diameter 6.35 and 9 mm

Task 4: Effects of microbial interactions on basaltic carbonation processes (IPGP-LMTG)

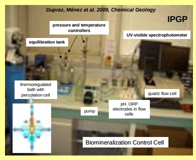
➢*Mechanisms of biomineralization via silicate mineral dissolution and carbonate mineral precipitation*



➢*Imaging*



➢*Flow-through experiments in biotic context*



➢*Isotopic fractionation during mineralization processes*

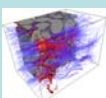
Task 5: Comparison of experimental results with field observation

Rock samples obtained from both the injection site *(Task 1)* and from batch and plug-flow reactor tests (*Tasks 2-4*) will be analyzed by a variety of techniques to determine the effects of the CO_2 injection on the mineralogy. In particular, TEM will be used to study nanoscale dissolution features, as well as growth zonations in secondary carbonates. Additionally, coupling TEM-STXM imaging of organic matter is possible to determine if biofilms are present or if abiotic CO_2 conversion to organics has occurred. Techniques of focused ion beam (FIB) will be used if needed to improve characterization of mineral transformation in the field and large scale plug-flow reactor samples.

Task 6: Geochemical modeling

Comprehensive geochemical modeling will be performed in CO2-FIX to understand the consequences and fate of CO_2 injected into subsurface basalts and ultramafic rocks.
Two types of modeling efforts will be emphasized: pore-scale modeling and reservoir-scale modeling.

Pore-scale modeling (ICMCB, LMTG, IPGP)



A fully coupled reactive transport model at pore-scale has been developed (Flukiger and Bernard, 2009) based on a finite volumes formulation. This model will be improved to incorporate biotic, as well as abiotic processes at mineral surfaces as part of *Tasks 2 and 4*.

Reservoir-scale modeling (ICMCB, LMTG, IPGP)

1) All experiments described in *Tasks 2 to 4* above will be interpreted with the aid of geochemical calculations performed using the PHREEQC computer code.
2) CHESS and HYTEC codes will be adapted for taking into account biogeochemical processes. This will allow assessing the potential role of microbes on *in-situ* carbon mineralization.
3) Use the experimental results to calibrate and/or validate parameters of reaction-transport numerical codes to model mineral trapping of CO_2 at the reservoir scale.

Acknowledgements:

This research is funded by the French National Agency of Research (ANR) within the framework of the CO2-FIX Project under contract ANR08-PCO2-003-01.
The authors thank colleagues at Reykjavik Energy and at the University of Iceland for organization and field operation during sampling, especially: Hólmfridur Sigurdardóttir, Einar Örn Þrastarson, Helgi Arnar Alfreðsson and Sigurdur Gislason

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