Poromechanical properties of carbonate rocks: approach to chemical alteration impact

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Summary

This work proposed an integrated experimental approach to the characterization of CO\textsubscript{2} injection chemical impact on the poromechanical properties of carbonate rocks. Triaxial tests and acoustic measurements have been performed on intact and homogenously altered carbonate samples. The obtained results show clear trends of mechanical weakening due to alteration. Decrease in static and dynamic elastic moduli and in failure strength has notably been observed. NMR measurements and microscanner imaging performed before and after alteration have provided an insight into the alteration mechanisms at the microscopic scale. The obtained results will be useful to derive micromechanical models of carbonate rocks able to reproduce the weakening of their poromechanical properties under the effect of chemical alteration.

Introduction

The viability of a CO\textsubscript{2} geological storage in deep saline aquifers rests on the combination of adequate storage capacity, injectivity and integrity (Bachu, 2003). Those characteristics need to be assessed at the beginning of the project and updated over its lifetime. The injected CO\textsubscript{2} will moreover have to be followed through geophysical monitoring to ensure that it remains sealed within the expected area (Lumley, 2010).

The weak acid formed when CO\textsubscript{2} dissolves into the brine is likely to react with the host rock. The associated dissolution mechanisms will induce changes in the rock properties, among which its petrophysical, geomechanical and petroacoustic characteristics. Site-scale modelling of CO\textsubscript{2} injection can be addressed through the coupling of reactive transport and geomechanical softwares (Vidal-Gilbert et al., 2009). To ensure consistent information exchange between the two softwares, static elastic moduli and failure strength of the reservoir formation have to be updated to take into account geochemical effects (Bemer et al., 2011). The interpretation of 4D seismic data, obtained through successive 3D seismic surveys, will likewise require separating the saturation effect from the chemically induced variations of the dynamic elastic moduli (Bemer et al., 2013). The present experimental work aims at providing variation laws describing the effect of acid alteration on the poromechanical properties of carbonate rocks.
Methods

The studied rock formation is Euville limestone, which comes from an outcrop of Paris Basin. This crinoidal grainstone is composed of roughly 99% calcite with a mean porosity around 17% and a permeability about 100 mD. A key issue of this experimental work was to ensure consistent physical measurements on samples at various alteration levels, which requires that each studied sample remains a representative elementary volume. A homogenous alteration method based on the injection of a retarded acid solution, which is activated only under specific temperature conditions, has then been used (Bemer and Lombard, 2010). The rock samples have been submitted to several retarded acid treatments (RAT).

Petrophysical, geomechanical and petroacoustic properties of Euville samples have been measured under their native state and two levels of alteration corresponding respectively to 3 and 6 RAT. Two separate experimental workflows have been applied: a semi-parallel geomechanical workflow designed for 40-mm diameter and 80-mm height samples (Figure 1) and an integrated petroacoustic workflow designed for 40-mm diameter and 60-mm height samples (Figure 2).

![Figure 1. Semi-parallel geomechanical workflow.](image1)

The geomechanical workflow, which includes destructive triaxial tests, is based on the characterization of two sets of companion samples. Tested samples have been selected according to initial porosity and homogeneity criteria. Set 1 samples have been characterized in their native state to assess the sensitivity of static elastic moduli and failure strength to initial porosity. The triaxial tests have been performed at three confining pressures. Set 2 samples have been altered at 3 or 6 RAT before being tested along the same stress paths than the intact samples.

![Figure 2. Integrated petroacoustic workflow.](image2)
The petroacoustic workflow includes only non-destructive tests: intact and altered properties can then be measured on the same samples at successive levels of alteration. The limited length of the petroacoustic samples has allowed their analysis in the NMR device. The T2 pore size distribution has then been determined before and after each alteration level. The samples have also been imaged at different states of alteration using local microtomography technique with a resolution of 6 μm.

**Results**

The alteration process has induced porosity increase of about 1% for 3 RAT and 2% for 6 RAT. Permeability variations associated to the observed porosity increases did not follow a clear trend: 6 RAT have induced a significant permeability increase, whereas 3 RAT had no sensible effect on the permeability. These observations can be related to opposing phenomena: global increase of the pore size confirmed by NMR analysis and clogging of pore throats by fine particles. Subtraction of microscanner images registered before and after alteration has provided a visual confirmation of fine particle migration, which could become a key issue for CO2 injection modelling.

Triaxial tests have shown that chemical alteration induced a clear decrease of Euville limestone failure strength. At the beginning of each triaxial experiment, static drained elastic moduli have been measured during the unloading phase of a small axial loading cycle performed at an effective confining pressure of 2 MPa. Intact and altered data can then be compared independently of the final confining level of the considered tests. Figure 3a shows that chemical alteration has induced a significant decrease of both static drained bulk modulus and shear modulus.

The acoustic tests have been performed under an isotropic effective confining pressure of 10 MPa. P- and S-wave velocities have been measured for various saturating fluids of different bulk modulus (Rasolofosaon and Zinszner, 2012). Euville limestone fully verifies two key results of poroelastic theory (Coussy, 2004): saturated bulk moduli follow Biot-Gassmann’s equation with derived matrix bulk moduli close to the value expected for calcite, and saturated shear moduli are independent of the saturating fluid. Figure 3b shows that, likewise static moduli, both dynamic drained bulk modulus and shear modulus have significantly decreased under the effect of alteration, which should be taken into account when analysing acoustic data.

*Figure 3. Static (a) and dynamic (b) drained elastic moduli at different alteration levels.*
Conclusions

This paper has presented an experimental work aiming at providing variation laws describing the evolution of carbonate rock poromechanical properties induced by chemical alteration. Petrophysical, geomechanical and petroacoustic characteristics of Euville limestone samples have been measured in their intact state and at different levels of homogeneous alteration. A significant decrease in stiffness and failure strength has been observed. Additional analyses using NMR and microscanner imaging have been performed to comprehend the modifications induced by the alteration process at the microscopic scale. The obtained results will be useful to derive representative micromechanical models able to reproduce chemically-induced mechanical weakening.

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