Experimental studies of frictional instabilities of basalts triggered by injection of pressurized H_2O- and CO_2- rich fluids for CO_2 storage purposes

Piercarlo Giacomel[1*†], Elena Spagnuolo[3], Manuela Nazzari[2,3], Andrea Marzoli[1], Nasrrddine Youbi[4,5], Giulio Di Toro[1,3]

[1] Dipartimento di Geoscienze, Università degli Studi di Padova, Padua, Italy
[2] Dipartimento di Scienze della Terra, Sapienza Università di Roma, Rome, Italy
[3] Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy
[4] Geology Department, Faculty of Sciences-Semlalia, Cadi Ayyad University, Marrakech, Morocco
[5] Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal
* piercarlo.giacomel@uniroma1.it
[†] Now at Dipartimento di Scienze della Terra, Sapienza Università di Roma, Rome, Italy

Introduction

Mineral carbonation of basaltic formations by underground injection of CO_2-rich water is one of the most promising options for carbon geological sequestration. In this form of sequestration, CO_2 is directly trapped into minerals following CO_2-rich water - divalent cations interaction (mainly Ca^{2+}, Mg^{2+} and Fe^{2+}, leached from basaltic rocks), providing a long lasting, thermodynamically stable carbon storage solution. The advantages of this storage technique in comparison to conventional methods (e.g., Bachu et al., 2007), are that a) once dissolved in water, CO_2 is no longer buoyant, mitigating the risks of CO_2 escaping back to the surface through pores and fractures and b) CO_2-rich water accelerates considerably the dissolution-precipitation reactions at the storage site timescale (95% of the CO_2 injected may be trapped in less than two years: Matter et al., 2016).

So far, this method has been employed in the framework of the CarbFix pilot project (Iceland, Gislason et al., 2010), aimed at developing a null net CO_2 emissions geothermal power plant. In this regard, the injection of CO_2-rich water has targeted a subsurface basaltic reservoir located at ∼ 500 m depth at a fluid pressure $pCO_2 = 2.5$ MPa and temperature $T \approx 20\text{-}30$ °C. However, the low solubility of CO_2 in H_2O (∼30 g CO_2/kg H_2O) at the reservoir's P-T conditions, renders the effectiveness of this technique conditional to the injection of large volume of fluids. As a consequence, the assessment of the seismic hazard is of paramount importance to apply this storage method to this and to other voluminous basaltic occurrences diffused worldwide.

Methods

We performed twenty-two friction experiments with the rotary shear apparatus SHIVA (Slow to High Velocity Apparatus) installed at the HP-HT Lab of INGV, Rome (Di Toro et al., 2010). In order to understand the possible role of the state of alteration of basalts and of the fluid chemistry on fault reactivation, the experiments were conducted on dense (effective porosity < 1 %) pre-cut (experimental fault) hollow (50/30 mm external/internal diameter) basaltic cylinders exhibiting variable degree of alteration- The experimental faults were pressurised with distilled H_2O, pure CO_2, H_2O+CO_2 mixtures and Ar, respectively. The tests were carried out in load and fluid pressure control by applying a constant normal stress ranging from 10 to 20 MPa and a constant shear stress of 5 MPa. The initial fluid pressure Pf ranged from 0.5 to 5 MPa. Then, the Pf was increased stepwise of 0.1 MPa every 100 s, resulting in a progressive reduction of the effective normal stress acting on the experimental fault till the triggering of a macroscopic frictional instability (Fig.1). The latter is equivalent to a main shock in nature. The main instability was preceded by fault creep and in some tests by short-lived slip bursts with slip velocity ranging from 10^{-3} to 0.3 m/s. Slip bursts with lower slip rate, if any, could not be distinguished from the background noise and creep events.

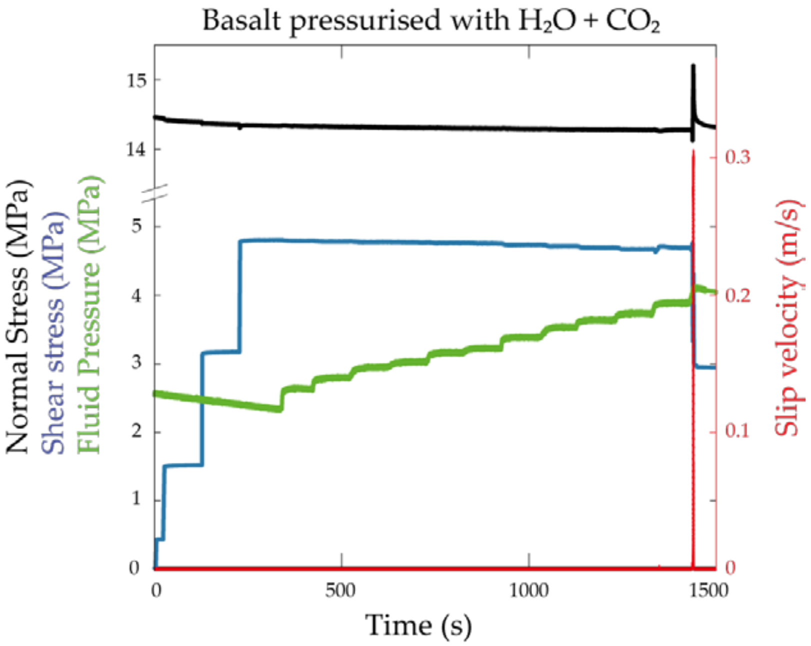

Fig. 1: Example of friction experiment conducted under fluid pressure control at constant normal (black curve) and shear stress (blue curve) pressurised with H_2O+CO_2. Fluid pressure (green curve) was increased stepwise to induce fault main instability (MI). At MI, the slip velocity (red curve) was forced to 0.3 m/s.

Results and Conclusions

Our data show that the fluid pressure necessary to trigger the macroscopic frictional instability scales linearly with the normal stress acting on the experimental faults. Notably, faults reactivate at comparable fluid pressures and friction coefficients given the same applied normal stress, independently of the fluid composition and the degree of alteration of basalt-built faults. Therefore, we posit that similar processes were occurring at the asperity contacts of the fault, and we rule out significant chemical fault weakening stemming from prolonged H_2O-rich fluids (distilled H_2O or H_2O+CO_2 mixtures) – rock interaction.

Further work needs to be done to investigate the role of porosity and of the injection pressure rates in triggering the macroscopic frictional instability. This is pivotal to forecast the seismic potential of basaltic reservoirs exploitable for geological carbon storage by means of injection of CO_2-charged water.

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