Laboratory investigation of CO_2-rich fluid injection and induced seismicity in basaltic reservoirs

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Global warming is the most important environmental challenge that humanity has to face in the 21st century. The increase of the concentration of carbon dioxide in the atmosphere is one of the main responsible (greenhouse effect) of the global temperature increase in the last century. To reduce the concentration of CO_2 in the atmosphere, large scale capture and geological sequestration of CO_2 in geological reservoirs has been proposed [*Bachu et al.*, 2007; *Matter and Kelemen*, 2009]. In particular, the injection of H_2O+CO_2 mixtures in basalts has been proposed for CO_2 storage as an appealing option to the injection of CO_2 fluids in exploited oil and gas reservoirs. In fact, H_2O+CO_2 fluids react with basalts and induce the precipitation of dolomite and calcite (mineral carbonation), providing a long lasting, thermodynamically stable and environmentally benign carbon storage [*Oelkers et al.*, 2008]. The huge advantage of this storage technique is that, by "*turning CO_2 into rock*" (New York Times, 9/2/2015), it prevents the risk of CO_2 leakage driven by boundary forces in storage site.

However, the amount of dissolved CO_2 at operation depth is in the ratio 30-70 g CO_2/kg H_2O, implying that the efficiency of carbon storage is conditional to the injection of large volumes of fluids. Because fluid-rock interaction controls the nucleation, propagation and arrest of natural and man-induced seismic sequences [*Raleigh et al.*, 1976; *Hubbert and Rubey,* 1959], the study of the frictional behaviour of basaltic rocks in the presence of pressurized CO_2- and H_2O+CO_2 fluids is of paramount importance, though to our knowledge, it remains largely unknown. In fact, assessment of the hazards and risks of seismicity associated with these anthropogenic activities must be based on a fundamental understanding of how earthquakes can be induced by fluid injection/extraction.

In this lab-oriented PhD project, to provide insights on the induced-seismicity potential of this CO_2 storage technique, we aim at:

1) reproducing the ambient conditions of typical H_2O+CO_2 storage sites (for instance, confining pressure < 15 MPa and T < 30° C, e.g., ambient conditions relevant for Hellisheidi (Iceland) CO_2-injection site (CarbFix pilot project: [*Gislason and Oelkers*, 2014; *Matter et al.*, 2009]) in the laboratory;

2) investigating, thanks to on-purpose designed fluid vessels, fluid-pressurizing circuit and other devices (e.g., *Violay et al*, 2013), the effects on the frictional behaviour in pre-loaded basalt-built experimental faults of the progressive injection of H_2O+CO_2 , H_2O and CO_2 fluids by exploiting the most powerful frictional apparatus installed worldwide (SHIVA, INGV-Rome, Italy, *Di Toro et al.,* 2010);

3) measuring, by means of Acoustic Emission recording systems and high resolution on-purpose designed physical properties modules, the slip and (laboratory) seismic events and the evolution of several rock-physical parameters (including *V*p/*V*s and seismic attenuation) precursory to the main frictional instabilities and main fault failure episodes;

4) investigating, by means of experiments conducted also at higher temperatures and confining pressures in triaxial machines installed at SEES-UoM, the evolution of permeability in basalt fault/fractures during mineral carbonation processes;

5) investigating, by means of microstructural and mineralogical (scanning and transmission electron microscopy, X-ray powder diffraction, micro-Raman spectroscopy, micro-tomography, etc.) and geochemical (electron microprobe analysis, chemical analysis of the fluids, etc.) characterization, the physical and chemical processes associated to the main frictional instabilities and to the precipitation of carbonation products in experimental faults.

The above activities will force the PhD student (advised by the supervisors) to develop a collaborative network during the entire duration of the project, as the activities will be performed at INGV-Rome (1-2-3-5), UNIPD-DG (5) and SEES-UoM (4-5). Thanks to this approach, we anticipate the following outputs:

- formation of a young researcher with background on rock and reservoirs mechanics;
- the characterization of frictional instabilities associated to the injection of pressurized fluids (CO_2, H_2O, CO_2+H_2O) in pre-loaded faults in basalts - this might be relevant also for natural seismicity;
- investigation of the precursory activity leading to main frictional instabilities;
- the submission of two-three papers on experimental and theoretical investigations of fluid injection in basaltic-built reservoirs.

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