DIPARTIMENTO
DI SCIENZE DELLA TERRA

SAPIENZA
UNIVERSITÀ DI ROMA

DOTTORATO DI RICERCA
IN SCIENZE DELLA TERRA

1. Research activity:

TRAPS: lab-s**T**udy on the f**R**iction**A**l **P**roperties of basalt**S** interacting with H_2O- and CO_2- rich fluids and implications for CO_2 storage

Abstract:

Underground injection of CO_2-rich water into basaltic reservoirs is one of the most appealing options for CO_2 sequestration. This method provides permanent and safe CO_2 storage in extremely short amount of time: more than 95% of the injected carbon in the CarbFix pilot project (Iceland) was trapped into carbonates in less than 2 years. However, to apply this method also to commercial scale, a thorough assessment of the induced seismic potential stemming from this technique is critical. In this regard, laboratory frictional experiments will be performed to: (i) understand the role of fluid pressure on basalt-built fault reactivation and (ii) determine the constitutive friction parameters and thus unravelling the mode of fault slip at a given fluid pressure.

Rationale and relevance of the project:

Frictional instabilities are the main responsible for earthquakes nucleation (*Brace & Byerlee, 1966*), which generally occur along pre-existing faults and fractures (*Scholtz, 2002*).
So far, only a few set of experiments have attempted to investigate the behaviour of lab-scale faults to injection of pressurized CO_2 (in anhydrites, e.g., *Samuelson & Spiers, 2012*) and H_2O+CO_2 fluid mixtures (in intact basalts cores potentially acting as cap-rocks, exhibiting different degree of alteration, *Giacomel et al.*, under review for *Geophysical Research Letters*). However, to date the frictional properties of porous basalts in the presence of pressurized fluids, exhibiting comparable porositiy values as in basaltic aquifers suitable for CO_2 storage (e.g. effective porosity: 8-15%) remain still largely unknown, and the friction constitutive parameters required to assess the seismic potential stemming from geological CO_2 storage still need to be determined.

Therefore, this PhD project is aimed to determine the friction parameters of porous and dense basalts, at the typical CarbFix-site P, T conditions (i.e., pCO_2 = 2.5 MPa, T = 20-30°C), which govern the nucleation of the frictional instabilities and the mode of fault slip. This is the *sine qua non* for an in-depth assessment of the induced seismic potential and for an effective appraisal of the seismic hazards and risks caused by this storage method.

<u>Research methodology and approach</u>:

1) SAMPLE PROVISION

I intend to get Mt. Etna dense (effective porosity < 1%) basaltic specimen from local quarries. As the experiments will be carried out on both dense and porous basalts, to overcome the problem of porous sample supply and to better constrain data reproducibility, the latter will be obtained by inducing a secondary porosity on dense basalts through thermal cracking. The samples will be prepared and subjected to a robust pre-experiment chemical (X-Ray Fluorescence), mineralogical (X-Ray Powder Diffraction), petrological (thin sections) and petrophysical (effective porosity using the helium pycnometer and pre-experimental Vp/Vs as a frame of reference) characterization, at the laboratories available at the University "La Sapienza", INGV- Rome and Padua University.

2) SHIVA (Slow to HIgh Velocity Apparatus) EXPERIMENTS

To evaluate the evolution of frictional properties of porous basalt-built faults as a result of fluid injection, experiments will be performed using an unconventional technique that allow us to control the shear stress (i.e., to work under constant shear stress) on 50/30 mm ext/int diameter porous basaltic hollow cylinder, to reproduce the environmental conditions of typical H_2O+CO_2 storage sites (for instance, confining pressure ≤ 15 MPa and T< 31°C, i.e. ambient conditions relevant for the Icelandic CO_2-storage site). Fluid pressure will be increased stepwise up to induce a frictional instability.

To investigate the effect of different injection rates on fault stability, the data-set will comprise experiments with different duration of the fluid pressure steps (e.g., 0.1 MPa every 10-40-100-180 s). The results will be directly relevant to understand the role of porosity on fault instabilities.

3) BRAVA (Brittle-Rock investigAtionVersatile Apparatus) EXPERIMENTS

To characterize the mode of fault slip in basalt-built faults, the retrieval of laboratory-derived constitutive law for rock friction (e.g. rate and state friction law, *Dieterich, 1979*), is critical. In this regard, experiments will be run at room temperature and shear velocities from 0.1-100 μm/s on bare rock surfaces of porous (effective porosity ~8.5-15%, typical reservoir values) and dense (effective porosity < 1%) basalts, to address the nucleation phase of dynamic slip. The sheared samples will have a ~ 4 X 4 cm^2 nominal area and ~ 1 cm thickness as in *Tesei et al., 2014*. First, samples will be sheared under dry conditions to investigate the friction parameters and the effect of porosity on rate and state friction in the absence of fluids. After this, basalts will be sheared in the presence of H_2O and H_2O+CO_2 fluid mixtures at atmospheric pressure to understand the role of fluid chemistry on fault slip behavior.

4) DIRECT SHEAR EXPERIMENTS WITH PRESSURIZED FLUIDS

Since fluid pressure plays a potential role in controlling friction constitutive parameters (*Scuderi and Collettini, 2016)*, the study of laboratory-derived constitutive laws for rock friction in the presence of pressurized H_2O+CO_2 fluids is required to characterize the mode of fault slip of basalt-built faults located in a CO_2 storage site, whereby pressurized fluids are injected. To do so, I intend to perform single direct shear experiments on bare rock surfaces of porous basaltic samples at room temperature, using either an inverted shear assembly with two L-shaped forcing blocks (e.g. the one described in *Samuelson and Spiers, 2012*) or another on-purpose designed forcing block system.

In particular, as the fluid pressure in the Icelandic CarbFix storage site is pCO_2 = 2.5 MPa and the principal normal stress $\sigma_1 \sim$ 15 MPa, first tests at sub-hydrostatic condition will be performed and then higher fluid pressures up to hydrostatic, supra-hydrostatic or near lithostatic conditions will be reached. This activity will be directly relevant to predicting the evolution of the mode of frictional parameters of faults located in CarbFix-like CO_2 storage sites.

The experiments are anticipated to be carried out during a research visit at the European rock-mechanics in order to develop a collaborative scientific network.

2. Research products

a) Manuscripts (submitted, in press)

Giacomel, P., Spagnuolo, E., Nazzari, M.,Marzoli, A., Passelegue, F., Youbi, N., Di Toro, G.
Frictional instabilities and carbonation of basalts triggered by injection of pressurized H_2O- and CO_2- rich fluids. Submitted to Geophysical Research Letters (under review).

b) Abstracts

Giacomel, P., Spagnuolo, E., Nazzari, M.,Marzoli, A., Youbi, N., Di Toro, G.,**11thEURO -conference on Rock Physics and Geomechanics.** *Frictional instabilities and mineral carbonation of basalts triggered by injection of pressurized H_2O -and CO_2 -rich fluids.* Ambleside (UK), 7/10/2015