1. Research activity

During this first year of my research, I focused on the role of the basement in the seismic context of northern Apennines. I sampled rocks from exhumed outcrops of Apenninic basement set in southern Tuscany (Elba island, Monte Argentario, and Monti Romani). For each sampling area I made structural observations to understand the style of deformation and I noted that the studied outcrops are characterized by heterogeneous and pervasive deformation where foliated and phyllosilicate-rich rocks surround more competent quartz-rich lenses of ten to hundreds of meters of thickness. Phyllosilicate horizons deform predominantly by folding and foliation-parallel frictional sliding whereas quartz-rich lenses are characterized by brittle signatures represented by extensive fracturing and minor faulting. On the sampled rocks, mineralogical analysis (XRD) and microstructural observation (OM) were made to better describe these rocks. To test their frictional properties, I produced powder from milling and sieving rocks and for foliated rocks I produced intact wafers. Experiments were carried in BRAVA at wet condition (100% saturated) at different normal stress (25, 50, 75 and 100 MPa for powders and 10, 25, 35 and 50 for wafers). At the end of each experiment, deformed samples were recovered and preserved in epoxy resin for microstructural analysis made with SEM. Frictional data showed that Quartz-rich lithologies are characterized by relatively high friction, $\mu = 0.5$, velocity strengthening-neutral behaviour, and significant healing rates. Phyllosilicate-rich (muscovite, paragonite, chlorite) lithologies show low friction, $0.23 < \mu < 0.31$, a marked velocity strengthening behaviour, which becomes more and more velocity strengthening with increasing sliding velocity, and null healing rates. These data suggest that the Apenninic acoustic basement represents a distributed zone of deformation, with thickness up-to several kilometres, where the frictionally stable foliated and phyllosilicate-rich horizons favour aseismic deformation and therefore the confinement of the major earthquake ruptures at depth. In the basement, continued aseismic deformation, can concentrate stress within and around the strong and potentially unstable quartz-lenses, which may lead to minor earthquakes, in particular following increments of shear strain rates.

From March 2022, I will start doing experiments on the same rocks with confining and fluid pressure to test the potential fault slip behaviour during increase of fluid pressure or stressing rates. These experiments will be integrated within an on-going seismological study of the seismicity within the basement during the Central Italy seismic sequence.

From December 2021, I started the microstructural characterization of 24 experimentally deformed samples from the Apenninic basement. At the end of this characterization, I will produce a paper about the relation between mineralogy, microstructures and frictional behaviour.

During this first year of PhD, I have participated at different and complementary activities that allowed me to interact with oil companies and with the problems related to induced seismicity of leakages of sealing horizons. From November 2020 to May 2021, I developed 30 experiments within the FAST2 project to study frictional properties of rocks interested by induced seismicity in oil field of the Apennines. The results show a strong correlation of frictional and fluid flow properties of fault rocks with their mineralogical content: phyllosilicate-rich lithologies showed low friction ($\mu < 0.3$), low to null healing rate and a marked velocity strengthening behaviour and very low values of permeability $k = 2*10^{-20}$; carbonate rocks showed higher friction ($\mu > 0.6$), high healing rate and, a low velocity strengthening behaviour and relatively high permeability $4*10^{-17}$. With confining and fluid pressure a tendency of the carbonate fault rocks to became instable is documented. Fluid injection/pressurization experiments showed the tendence of carbonate gouge to evolve into a dynamic rupture during fluid pressure stimulation. From September 2021, I also developed 30 experiments within the TAPAS project to study the frictional properties of rocks interested by CO_2 storage in Adriatic sea. The results highlight a strong correlation between frictional properties (e.g., friction and Rate and State parameters) and sample mineralogy. Permeability tests showed a non-trivial dependence between permeability and sample mineralogy especially for the carbonate-rich samples that showed lower permeability values comparable to samples with same phyllosilicate content.

From March 2021, I started the collaboration in the FEAR project with INGV, ETHZ and BedrettoLab. The project aim is to reactivate at about 1.5 km of depth in a tunnel and via fluid pressure stimulation, a fault hosted in a highly monitored area, to improve our understanding of earthquake physics. In July I sampled rocks from the Rotondo granite (Bedretto, Ticino) from the Alpe Nuova and from the Bedretto tunnel. On the outcrops I also carried out structural observations to reconstruct the deformation history. On these rocks I performed microstructural analysis on natural samples and frictional experiments in wet condition and at different normal stress (5, 15, 25, 35 MPa). The microstructural results highlight the presence of brittle reactivation along previous ductile shear zone with the development of a gouge rich in quartz and feldspars (> 70%) and a non-negligible amount of phyllosilicates (muscovite, chlorite and minor clays). The results of the frictional experiment showed that this gouge is characterized by relatively high friction, μ = 0.5, velocity strengthening-neutral behaviour, and significant healing rates. Until the end of February I am going to perform 2 experiments in load control with confining and pore fluid pressure to characterize the behaviour of the gouge during fluid injection activities using the same injection protocol that is going to be used during the fault reactivation in BedrettoLab.

2. Research products

a) Publications (ISI journals)

Trippetta, F., Barchi, M. R., Tinti, E., **Volpe, G.**, Rosset, G., & De Paola, N. (2021). Lithological and stress anisotropy control large-scale seismic velocity variations in tight carbonates. Scientific reports, 11(1), 1-14.

b) Publications (NON-ISI journals)
c) Manuscripts (submitted, in press)

Volpe, G., Pozzi, G., Carminati, E., Barchi, M.R., Scuderi, M.M., Tinti, E., Aldega, L., Marone, C., Collettini, C. (2022). Frictional control on the seismogenic zone: insights from the Apenninic basement, Central Italy. Earth and Planetary Science Letters (in press)

d) Abstracts