Mechanisms of Slow Slip in the Seismogenic Zone

(*Proposer: Prof. Telemaco Tesei*)

Slow slips are movements along tectonic faults that occur at rates faster than plate-rate creep (mm/y) but slower than regular earthquake slip (cm/s to m/s, *Sacks, 1978; Linde et al. 1996; Rogers and Dragert 2003; Rubinstein et al., 2010*). These events occur at all depths along tectonic faults, from the brittle-ductile transition up into the seismogenic zone and into shallow fault portions, in all tectonic environments and are often spatially correlated with small regular earthquakes and/or low frequency earthquakes (*Peng and Gomberg, 2010, Saffer et al., 2015, Harris, 2017)*. Slow earthquakes have sparked the interest of the scientific community because they illuminate fault slip behavior that is transitional between aseismic creep and seismic slip, providing the chance to further advance our knowledge about the mode of fault motion. In particular, slow slips may represent a major mechanism for stress transfer and fluid redistribution in the seismogenic zone and may even be analogous to the nucleation stage of large earthquakes giving us the opportunity to advance our understanding of the seismic cycle (e.g. *Obara and Kato, 2016*).

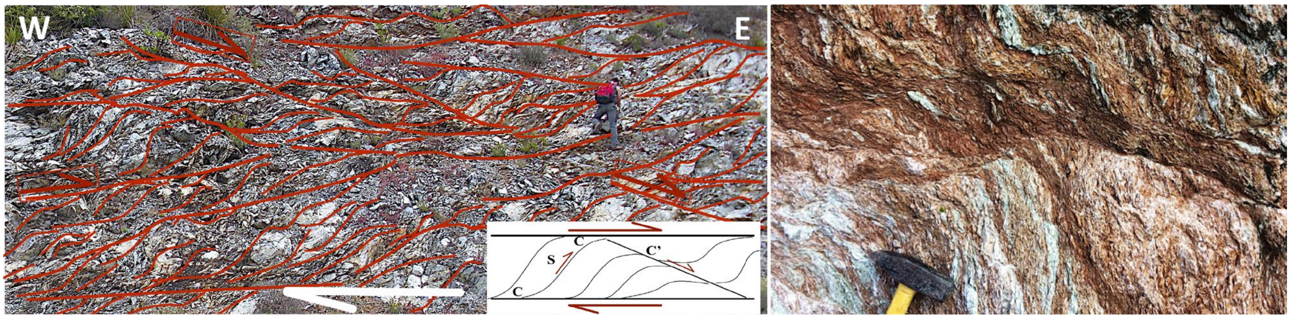
Slow slips are often detected by geodetic and seismological techniques, but their actual physical manifestation in the geological record is still matter of debate. Slow slips at the brittle-ductile transition, in deep faults, are often inferred to occur via viscous flow coupled with brittle failure in viscous shear zones containing competent lens and in the presence of high fluid pressures (*Fagereng and Sibson, 2010; Ujie et al., 2018; Behr et al., 2018*). However, the mechanism of slow slip in shallower, brittle seismogenic zones, in which slow slip could be relevant for earthquake generation, is still mostly unexplored. Some geometrically and lithologically complex fault zones are inferred to represent multi-mode slip (i.e. seismic and/or aseismic slip) because of fault patches that have both different structural and frictional properties (*Collettini et al., 2011; Tesei et al., 2013, 2014)* but what could be the mechanism(S) for the nucleation, propagation and arrest of shallow slow slips is still debated (Saffer et al., 2015).

This PhD project aims to tackle the following unresolved questions:

1) what could constitute a reliable geological evidence of slow slip at seismogenic depths?
2) how slow slip begins in brittle, chemically active and geometrically complex faults?
3) how do slow slips transfer stress and fluids in fault zones?
4) how do slow slips arrest and/or accelerate into regular earthquakes?

The candidate will study the mechanisms of slow slip starting from well-exposed fault zones that are considered to have heterogeneous fault patches, exposed in different lithologies and exhumed from different depths in the seismogenic zone (examples may include Monte Fico thrust serpentinites, Elba Island, IT; metasediments and basement along Ben Hope & Moine thrust, NW Scotland, UK; non-metamorphic carbonates Sibillini thrust; Umbria-Marche Apennines, IT).
In particular, the candidate will explore the geometry of the fault zones, focusing on the structural complexity (e.g. cross-cutting and slip distribution of main vs. minor faults, off-fault damage, lithological and structural *along-strike* variability) fluid activity (e.g. vein nature, distribution and texture) along the exposed fault zones.
Field studies will be complemented by extensive microstructural/microanalytical investigations aimed at understanding the mechanisms of deformation, mass transfer, origin and evolution of fluids in faults, leveraging the advanced microscopy facilities of the Department of Geosciences (FEG-SEM equipped with CL, WDS & EBSD, image- analysis, XRF, XRPD, micro-Raman spectroscopy, etc.).
In addition, the candidate will have the opportunity to further explore the mechanics of slow slip by

either: 1) performing friction experiments at hydrothermal and slow slip conditions (HYDROS hydrothermal rotary apparatus, UniPD and biaxial apparatus, INGV Rome in collaboration with Dr. G. Pozzi and Prof. C. Collettini, UniRoma1) to constrain the properties of fault rocks observed in the field. OR 2) perform numerical simulations of slip in geometrically complex fault via elasto-visco-plastic Finite Element Modelling FEM (in collaboration with Prof. M. Faccenda, UniPd) to upscale field and/or laboratory observations to natural large-scale fault zones.



Geometrically complex fault zones potentially hosting the evidence of slow slip. Left: serpentinites in Monte Fico thrust zone (Elba Island, IT). Right: carbonates in the Sibillini Mounts thrust zone (Northern Apennines, IT)

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