Formation of polished surfaces in natural rocks: experimental and field constraints

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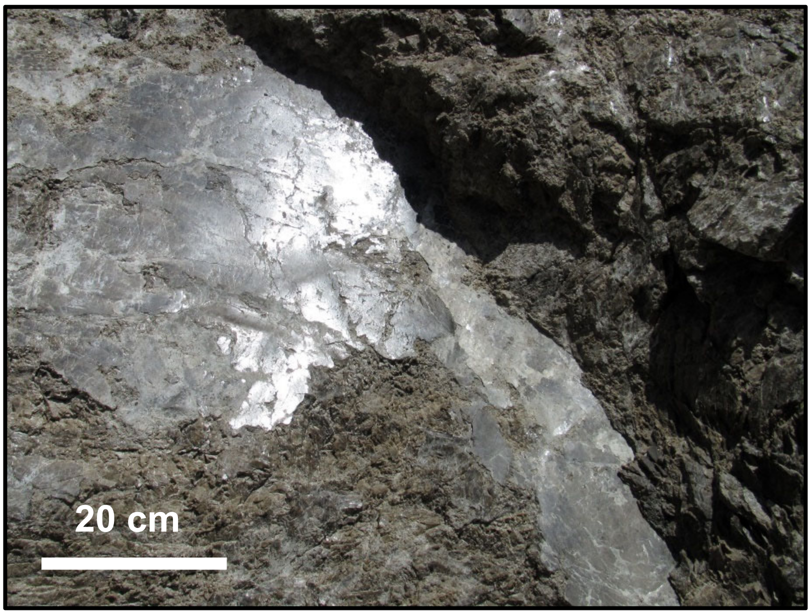
Motivations and goals

Polished rock surfaces, called "fault-mirrors" when ultra-polished as they reflect sunlight, are a common structural feature in exposed faults cutting silicate- and carbonate-built host rocks (Siman-Tov et al., 2013; Houser et al., in press) (**see photo of a "fault-mirror"** hosted in Triassic dolostones, Vado di Ferruccio, Central Apennines, Italy).



According to experimental evidence, ultra-polished fault surfaces can form both under aseismic or seismic deformation conditions (Fondriest et al., 2013; Verberne et al., 2013). Given the large differences in loading conditions between aseismic (fault slip rates << 1 mm/s) and seismic (fault slip rates >> 1 mm/s) faulting, even if all fault mirrors may look similar, there might be subtle differences which may allow us to discriminate if they were produced during earthquakes or not. For instance, given the higher fault slip rates achieved during seismic rupture propagation, the temperatures achieved in the fault slip zones are expected to be higher during seismic than aseismic slip and this may result in the activation of different deformation mechanisms, including grain-size and temperature-dependent ones (De Paola et al., 2015; Pozzi et al., 2018; Demurtas et al., 2019; Rempe et al., 2020). Moreover, inter-seismic processes (e.g., diffusive mass transfer driven by pressure-solution processes), also under hydrothermal conditions, may also contribute to the formation of ultra-polished slip surfaces (Mercuri et al., 2018). The current understanding is that in natural faults different loading conditions may lead to a morphological convergence down to the microscale (scale > 300 nm). However, recent studies suggest that at the nanoscale (<< 300 nm) there are different microstructures and reaction products (e.g., amorphous carbon) that may be related to seismic or aseismic deformation conditions (Spagnuolo et al., 2015; Ohl et al., 2020a,b).

The main goals of this Ph.D. project are to identify (1), if any, the nanostructures that allow to discern between a seismic or aseismic origin of natural polished fault surfaces and (2) understand better the deformation mechanisms that lead to their formation.

Scientific approach

To further unravel the origin of ultra-polished fault mirrors, in this Ph.D. project we propose to exploit a multidisciplinary scientific approach that will include:

(1) Field studies of exhumed fault zones hosting ultra-polished fault surfaces in the Central Apennines (carbonate-built rocks) and Northern Corsica (silicate-built rocks) plus the investigation of the large collection of polished and ultra-polished fault rock samples collected in the years by our research group;

(2) Dedicated experiments to be performed with the two state-of-the-art rotary machines SHIVA, installed at the Istituto Nazionale di Geofisica e Vulcanologia (INGV, Di Toro et al., 2010) in Rome, and RoSA installed at the Dept. of Geosciences in Padua (Rempe et al., 2014). These two fully complementary machines (SHIVA: slip rates from 10^{-5} to 6.5 m/s, injection of pressurized CO_2 and H_2O-rich fluids, measure temperatures in the slipping zone, record acoustic emissions; RoSA: slip rates from 3 10^{-8} to 1.3 m/s, T up to 500°C, injection of pressurized water up to 70 MPa) will allow the Ph.D. student to investigate both seismic and aseismic (including to some extent "ultra-slow" pressure-solution related) deformation mechanisms;

(3) Dedicated structural and analytical studies to determine the nano-roughness, nano-structure and composition of natural and experimental ultra-polished fault surfaces. This approach will include the exploitation of white light interferometry, atomic force microscopy, scanning and transmission electron microscopy, micro-Raman spectroscopy and X-ray diffraction. These facilities are available at the Dept. of Geosciences, INGV and Utrecht University.

Impact

Ultra-polished fault surfaces are a common structural feature in exhumed faults and their origin deserves to be investigated in detail to understand better the seismic cycle and earthquake mechanics. Active faults can be seismic or aseismic. But if some specific micro- and nano-structures found in fault mirrors hosted in active faults are associated to seismic slip, this would be a relevant information for seismic hazard studies and may have societal impact. Moreover, polishing, release of residual tensions and wear of rocks are of interest for the industry and the results of this Ph.D. project may find application outside the academia.

We foresee that the research activities here proposed will also impact positively on the Ph.D. student cultural growth. She/he will learn different technical skills and will conduct her/his research activities in an active and multidisciplinary research group that owns different expertise spanning from structural geology, microtectonics, experimental rock deformation, mineralogy, material science and seismology.

Collaborations and research partners

- Gilberto Artioli, Claudio Mazzoli and Telemaco Tesei (Padua University, Italy)
- Oliver Plümper and Markus Ohl (Utrecht University, Netherlands)

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