Structure, evolution and deformation mechanisms in seismogenic faults in the continental crust

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Earthquakes result from fast (few km/s) rupture propagation and slip (few m/s) along a frictional interface called fault. As a consequence, (1) fracture mechanics, (2) frictional and other deformation processes occurring in the seismic slipping zone and in the wall rocks and (3) the geometry and architecture of faults and fractures networks control individual earthquakes and the evolution of seismic sequences (Scholz, 2019). Though seismological and geophysical studies provide fundamental information about several earthquake source parameters (e.g., seismic slip, rupture length and speed) and hypocentral distribution, they yield limited information on the deformation mechanisms operating during rupture propagation and on fault geometry (see Rowe and Griffith, 2015 for a review). Moreover, the nucleation and evolution with time of major fault zone networks remains poorly known. As a consequence, the geological and experimental determination of both fault zone structures and the deformation processes active during the seismic cycle may provide fundamental information on earthquake mechanics complementary to the seismological and geophysical ones (e.g., Demurtas et al., 2016). However, field investigation of seismogenic faults that were capable of producing moderate to large in magnitude earthquakes (faults > 20 km in length), is commonly hindered by the limited exposure (usually << 1 km in length) of such major faults because of Quaternary cover or weathering.

In this Ph.D. project, by exploiting the geological expertise and logistic support from Pontifical Catholic University of Chile (PUC) in Santiago and University College in London (UCL), and the experimental and microanalytical facilities available at the HT-HP laboratories of the Istituto Nazionale di Geofisica e Vulcanologia in Rome (HPHT-INGV) and at the Dipartimento di Geoscienze at the Università di Padova (DG-UNIPD) in Padua, we propose to link: (1) field studies of ancient seismogenic faults exceptionally exposed in the Atacama desert (Northern Chile) with (2) rock deformation experiments conducted with rotary shear machines and (3) high resolution microstructural, mineralogical and geochemical investigations. The aim is to:

1) reconstruct the geometry and fault rock distribution of a large scale seismogenic fault hosted in the continental crust;
2) identify the mechanism of strain localization in the upper crust and the formation and evolution of major seismogenic continental faults;
3) determine the deformation processes occurring during the seismic cycle in the continental crust.

The field study will focus on the Bolfin Fault Zone (BFZ), a sinistral-strike slip > 40 km long fault splay of the ~1000 km long strike-slip Atacama Fault System (AFS). The AFS formed in the Early Jurassic – Early Cretaceous during the oblique subduction of the oceanic Phoenix plate beneath South America and was partly coeval with the intrusion of a large belt of plutonic rocks (gabbros, diorites, tonalites, etc., Scheuber and Gonzalez, 1999). The AFS, including the BFZ, records high strain ductile (granulitic to greenschist facies conditions) and brittle deformation events from its early development to mid-Cretaceous exhumation (Gonzalez, 1996; Scheuber and Gonzalez, 1999; Cembrano et al., 2005). Preliminary field and microstructural studies conducted in the last three years suggest that the well-exposed strike-slip "seismogenic" structure of the BFZ, recorded by the widespread occurrence of pseudotachylytes, occurred 125-120 Ma ago in hydrothermally altered rocks located at 5-6 km depth at an ambient temperature of 280-350 °C (Arancibia et al., 2014). The strike-slip "seismogenic" BFZ exploits pre-existing igneous (magmatic foliations, dyke swarms) and ductile (mylonites) structures. These preliminary observations require further in-depth studies to constrain the architecture and evolution with time of this exceptionally exposed seismogenic fault and the deformation processes activated during the seismic cycle. Motivated by the preliminary results presented above and by the challenging questions on earthquake mechanics to address, this Ph.D. project will include **(Fig. 1)**:

1) high resolution (1:100 to 1:1000) field geological surveys of the BFZ and host rocks which will be mapped along 5 to 7 transects affecting different rock types also by exploiting Unmanned Aerial Vehicle imagery to produce 3-D models (e.g., geometry and fault zone rock distribution) of the faults and fractures networks. The analysis of the data will be performed with dedicated software and hardware at PUC, UCL, HPHT-INGV and DG-UNIPD;

2) deformation experiments on rocks from the Bolfin Fault area with the rotary machines SHIVA (at HPHT-INGV) and with the RoSA (at DG-UNIPD) to identify (see also point 3) the deformation processes occurring during the seismic cycle. The utilization of the two machines will allow the Ph.D. student to perform experiments over a large range of loading (from sub-seismic to seismic slip rates) and ambient (presence of pressurized fluids, temperatures up to 350°C) conditions;

3) microstructural (Field-Emission Electron Scanning Microscopy, Electron Back-Scatter Diffraction, image analysis), mineralogical (X-ray Powder Diffraction, Micro-Raman Spectroscopy) and geochemical (Cathodoluminescence, X-ray Fluorescence Spectroscopy, Electron Micro-probe Analyzer) investigations at HPHT-INGV and DG-UNIPD of the fault zone rocks to support studies at points 1-2 and to discriminate the deformation processes occurring during fault zone evolution and fluid-rock interaction.

The above activities will require the PhD student, advised by the supervisors, to develop a collaborative network during the project, as the activities will be performed at HPHT-INGV, PUC, UCL and DG-UNIPD. Thanks to this approach, we anticipate the following results:

1) formation of a researcher with ability to exploit and integrate field, experimental and microanalytical methods (also for industrial applications, e.g., fluid-rock interaction in geothermal fields) with strong background on earthquake geology;
2) submission to international peer-reviewed journals of three manuscripts on the topics discussed above.

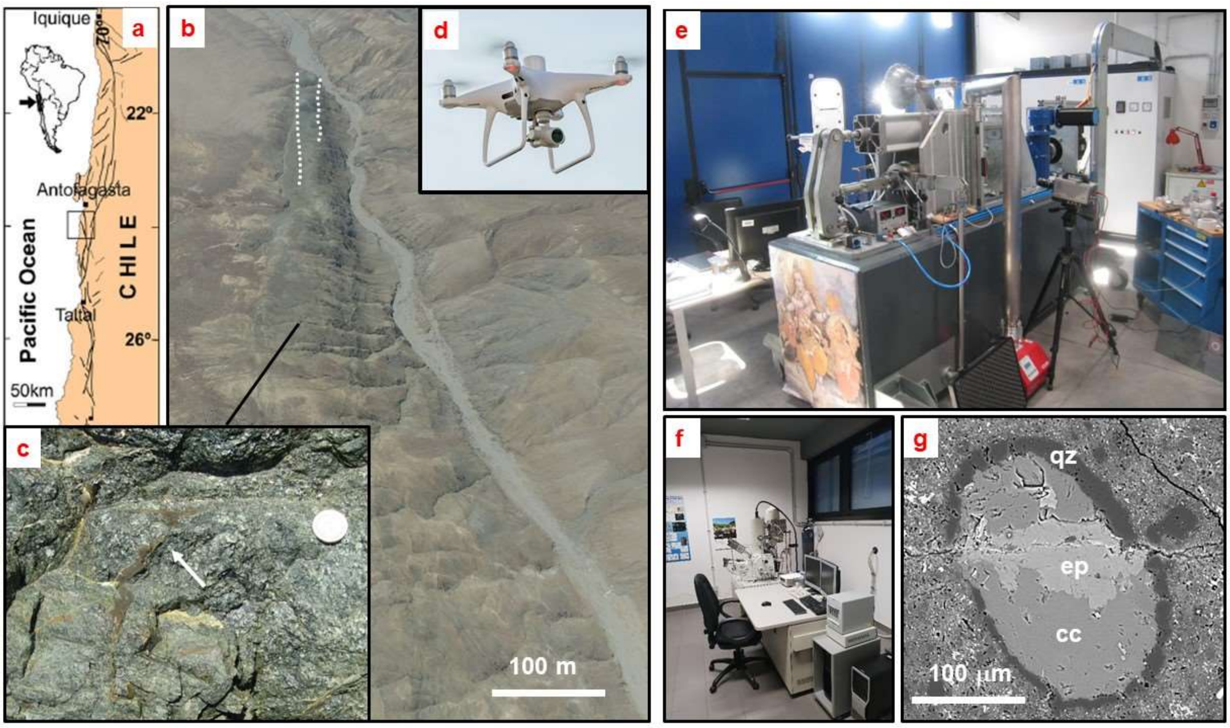

Fig. 1. Summary of the Ph.D. project. *The Bolfin Fault Zone crops out in Northern Chile* ***(a)*** *and it is beautifully exposed in the Atacama desert (****b****, white dashed lines bounding the greenish in color fault zone). The fault zone rocks are greenish in color because of hydrothermal alteration under sub-greenschists facies conditions and include vesiculated pseudotachylytes (arrow in* ***c****, coin for scale). The field geological survey will exploit Unmanned Aerial Vehicles (see image in* ***b*** *obtained with drone in fig.* ***d****). Experiments will be performed at the HP-HT labs at INGV in Rome with SHIVA (****e****) and at the Dipartimento di Geoscienze in Padua with RoSA (not shown). Both field and experimental products will be investigated with several microanallytical facilities available at INGV (see EPMA in* ***f****) and at DG-UNIPD. (****g****) Example of Back Scattered Field Emission Scanning Electron image of an amygdala (elliptical in shape and filled by quartz (qz), calcite (cc) and epidote (ep)) hosted in the strongly hydrothermally altered vesiculated pseudotachylytes from the Bolfin Fault Zone shown in* ***c****.*

References

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