Origin and circulation paths of mineralizing paleofluids along normal fault zones of the Southern Apennines, Italy

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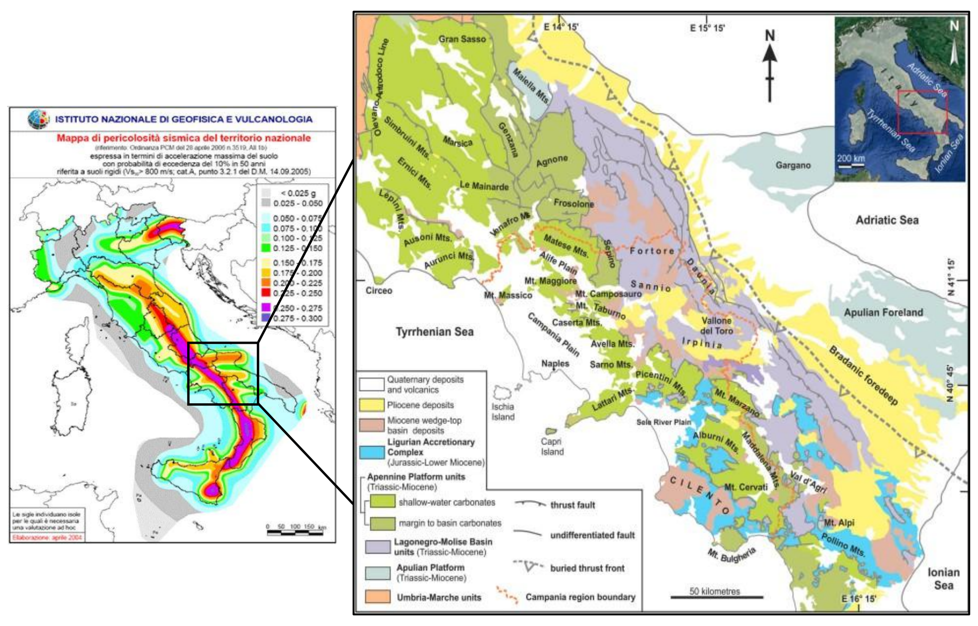
INTRODUCTION

Fault zones act as conduits, barriers, and/or combined conduits-barriers hydraulic structures, channeling C-rich geofluids (CO_2 or CH_4)[1] and influencing the mechanical behavior of the brittle upper crust[2]. Within fault zones, fluid-rock chemical and thermodynamic (T, P) disequilibria are increasingly recognized as potential earthquake precursors[3].

The aim of this project is to characterize the origin and evolution of mineralizing paleofluids, to determine the degree of crust-mantle contribution and to reconstruct the timing of paleofluid migration events. Furthermore, the study investigates the relationships among fluid overpressure, energy accumulation, and release during seismic cycles, with the goal to parameterizing fault zone processes as a function of thermobaric conditions and stress field variations.

The project focuses on the Irpinia region, characterized by: deep CO2 reservoirs (8-12 km), active mantle-derived degassing (e.g. Mefite d'Ansanto)[4] and high seismic hazard (Mw 6.9, 1980 earthquake). This area is located in the western sector of the Southern Apennines fold-and-thrust belt, Italy.



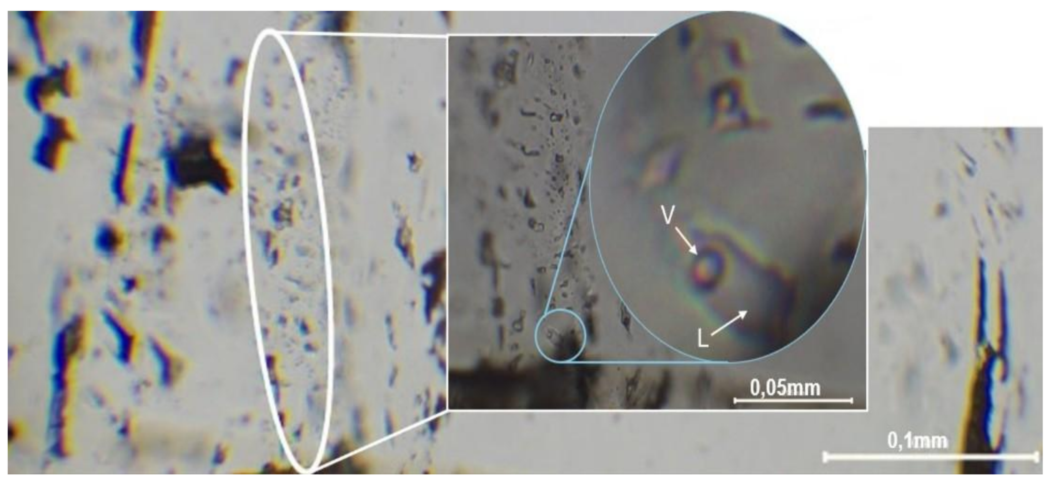
Overview of the study area through the seismic hazard map and a geological map.

Mefite d'Ansanto with active degassing, Rocca San Felice, Southern Italy.

METHODS

- **Field and microstructural analysis**: detailed geological mapping and thin-section study are important to characterize the fracture network and vein textures (*crack-seal*). These observations are crucial to reconstruct fluid-flow mechanisms and identify evidence of the *fault-valve* mechanism[2].
- **Fluid geochemistry and isotopic analyses:** The origin of paleofluids is investigated through: stable isotopes ($\delta^{13}C$, $\delta^{18}O$),radiogenic isotopes (Sr–Nd), and noble gases (He, Ne, Ar). Fluid inclusions (FIs) and micro-Raman spectroscopy are used to constrain: pressure–temperature (P–T) conditions, fluid composition and evolution during seismic cycles
- **Geochronology:** U-Pb dating of calcite mineralizations is applied to constrain the timing of fluid circulation and to correlate fluid events with regional tectonic activity.
- **Rock mechanics and physics:** High-velocity deformation tests (***SHIVA*** apparatus), coupled with permeameter measurements, are used to simulate seismic slip, to quantify porosity and permeability evolution and to assess fluid pressurization during faulting.

SHIVA apparatus during an experiment, HTHP laboratory, INGV.



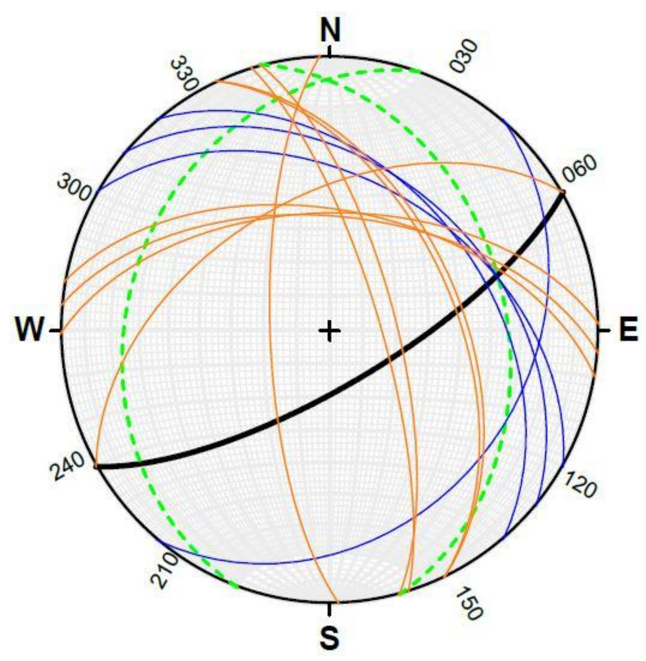
Microscopic fluid inclusion hosted in calcite crystals.

RESULTS

Field mapping in the Irpinia region identifies high-angle normal fault zones, where veins distribution shows a strong spatial correlation with principal slickensides. These mineralizations consist of comb and slip parallel types, other vein sets are classified as low angle-to-bedding or high angle-to-bedding sets.

Preliminary observations conducted on oriented rock slabs and hand samples reveal syntaxial calcite veins with blocky textures, reflecting episodes of abrupt fracture opening. These features indicate multiple cycles of fracturing and mineral precipitation, consistent with *crack-seal* processes and transient fluids overpressure within the fault zones.

Field mapping: mesoscale evidence of a high-angle normal fault plane in the Irpinia region.



Stereonet diagram of the Colliano site, Southern Italy.

Sample VRD 6: veins set with millimetric and angular wall-rock clasts.

CONCLUSIONS

Preliminary data constrain the origin, evolution and timing of mineralizing paleofluids in the Irpinia region. Geochemical analyses will distinguish meteoric, crustal and from deep-seated paleofluids, rock mechanics and petrophysical data will help evaluate whether part of the CO_2 may originate from dynamic decarbonation during seismic slip. Within the Sibson fault-valve model, we reconstruct fluid evolution throughout the seismic cycle. Co-seismic and early post-seismic phases are characterized by mineralizations with a deep geochemical signature, reflecting episodic release of overpressured fluids. In contrast, the interseismic period is characterized by fluids of shallow origin or isotopically equilibrated with host rocks. This integrated framework links fluid circulation, stress accumulation, and energy release, providing new insights into the coupling between fluid dynamics and seismic processes in active extensional settings.

Exhumed fault plane in an abandoned quarry, Sant'Angelo dei Lombardi,Southern Italy.

Slickenside with slickenfibers and striations, Sant'Angelo dei Lombardi, Southern Italy.

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