PhD Project in Earth Sciences – XLI Cycle

INFILTRATES - orIgin and asceNt oF magmatIc fLuids
from The eaRth's mAntle to ThE atmoSphere

Funded by INGV in the frame of EarthTelescope

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Introduction

Fluids with chemical composition within the carbon-oxygen-hydrogen-sulfur (C-O-H-S) system trapped as inclusion (along with other elements in traces) are known to occur in rock-forming minerals (e.g., olivine and clinopyroxene) of mantle-derived peridotite rocks with element ratios that must be controlled by the pressure (P), temperature (T) and oxygen fugacity (fo_2) conditions at which they might have formed. These fluids rise through the mantle behaving as carrier of other volatile-loving elements used often as geochemical proxies (i.e., Hg, Cl, F, etc) and then, infiltrate the upper crust and reach the atmosphere. Eventually, mantle-derived fluids can play a role in driving the local seismicity as evidenced by the correlation between the distribution of seismic events and the large, measured CO_2 outflux worldwide and, in particular, in the Apennine belt in central Italy. Fluid inclusions observed in natural mantle and crustal rocks sampled at the surface and in near-fault systems might have, however, undergone several processes (e.g., exsolution, crystallization, re-equilibration) that make difficult to use them to retrieve the conditions of their origin and, hence, the P-T-fo_2 path.

This project seeks to bridge the gap between microscopic fluid dynamics and macroscopic geophysical observations, thereby advancing our understanding of the mechanisms at the microscale of origin and transport of deep volatiles, the role played in mechanisms of seismic attenuation, with future applications on the interpretation of fluid-induced anomalies in subduction and volcanic environments.

State of the art

There is evidence of the correlation between gas discharges and extensional tectonic regimes suggesting that geodynamic processes play a key role in affecting the rising gases such as CO_2, in increasing the rock permeability and connecting the deep crust to the earth surface[1,2,3,4]. On the other hand, fluids can actively affect fault nucleation and trigger seismicity in natural fault zones to slow slip events[5] as observed in rocks sampled from active normal faults[6]. Pore fluids (over)pressure has a key role in causing hydro-mechanical heterogeneity of faults with the presence of infiltrating fluids revealed by P and S waves attenuation as shown in the case of the normal faulting along the Apennine belts (Fig.1)[7]. Importantly, on geochemical basis, it has been proposed that the degassed CO2 that modulates the seismicity underneath the seismically active Apennines has a deep origin likely related to the formation by melting of carbonated subducted rocks and rises to accumulate within crustal reservoirs[3].

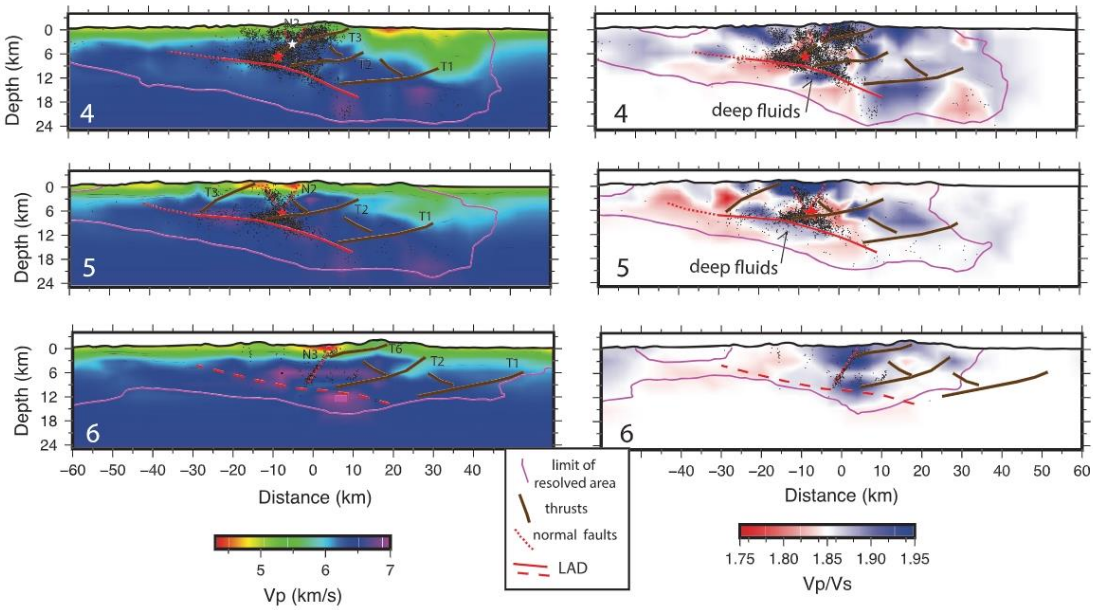


Figure 1. Depth profiles of Vp and Vp/Vs models across the main sectors of the normal faulting system of Apennines. The seismicity is plotted along with the geometry of the main compressional faults (see references in 7). The red stars are two mainshocks that occurred in 2016.

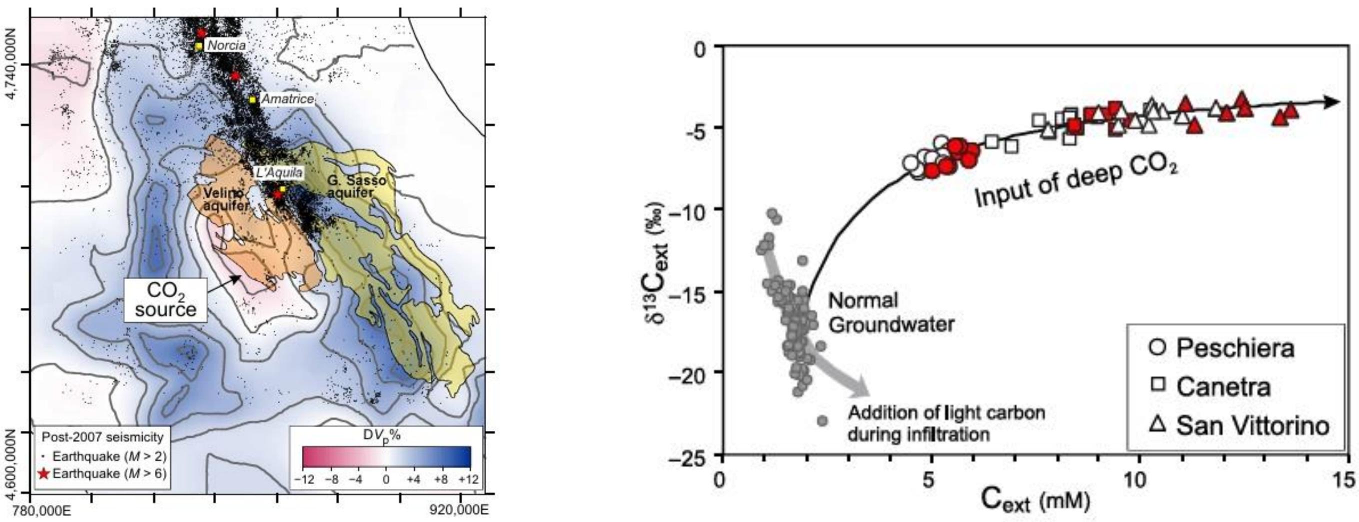


Figure 2 a) The image shows a negative anomaly in the seismic velocity variations (DVp%) interpreted as due to deeply derived CO_2 to the above located Velino aquifer. b) Shown is the mantle isotopic signature of C from degassed/dissolved CO_2. Both panels are after Chiodini et al. (ref. 3).

Laboratory experiments performed over the last decades have shown that C-O-H-S fluids form under different T-P-fo_2 conditions[8,9] and get trapped within different mineral hosts, including olivine, clinopyroxene, pyroxene, and diamonds[10-11-12]. These fluid inclusions, distinguished into primary inclusions (i.e., trapped during crystal growth) and secondary inclusions (i.e., trapped in healed fractures formed during ascent)[8,9], provide direct evidence of their pressure, temperature, and redox path from the time of their entrapment by acquired data regarding their chemical composition, isotopic signature of noble gases and composition of daughter minerals[13,14]. In contrast, a detailed study of the inclusions in minerals of mantle xenoliths supported by oxy-thermobarometric models and laboratory experiments that would provide robust constrains on the P-T-fo_2 conditions for their origin and entrapment is missing to date. Current knowledge of the origin and stability of mantle fluids from the mantle to the crust, migration and changes when trapped driven by cooling and decompression, and their influence on the propagation of elastic waves is still limited despite the implementation and development of top-notch analytical techniques supported, for instance, by synchrotron radiation. Open issues that INFILTRATES project will address are regarding 1) P-T-fo_2 needed for the formation of C-O-H-S fluids from CO_2- and H_2O sulfide-bearing peridotites and subsequent entrapment in coexisting minerals (e.g., olivine and clinopyroxene); 2) the budget of chalcophile elements transported by mantle fluids to the surface that might be used as geochemical proxies within seismically active areas (e.g., Hg); 3) how cooling and decompression affect the chemistry and morphology of mantle-derived fluid inclusions; 4) how the chemical composition of C-O-H-S fluids affect the properties of their host minerals, hence, the Vp/Vs.

General objective

Understanding the origin and ascent of mantle fluids with implications for the seismicity.

Specific objective

1. Petrological model of the origin of C-O-H-S fluids from a carbonated peridotite under mantle-relevant P-T-fo_2 conditions and their budget of chalcophile elements (*TASK 1*).
2. Chemical and morphological changes of trapped fluids as result of T and P variations by X-ray tomography (*TASK 2*).
3. Elastic wave velocities of both CO_2-bearing fluids and fluid-bearing minerals as function of P and T by Brillouin spectroscopy and by ultrasonic interferometry using the multi anvil press (*TASK 3*).

Implications of the specific objectives

1. Retrieving the P-T-fo_2 of fluid inclusions in nature by determination of their chemical composition and application of oxythermobarometric models.

2. Understanding whether fluid inclusions in nature have undergone processes that changed their pristine morphology and chemical composition and, therefore, a better understanding of the message these deliver on the surface.

3. A preliminary quantitative model of the effect of fluids on V_p/V_s variation (see Fig. 1)

Work plan

Year(Y) 1

TASK1 *Task 1.1* - Pressure calibration of multi anvil press, and *Task 1.2* - experiments with a carbonated peridotite at 2.5 – 7 GPa using a mixture of natural dolomite, olivine, pyroxene, spinel, graphite, brucite and sulfide plus addition of iridium as redox sensor[13]. *Task 1.3* - The run products will be analysed by scanning electron microscopy and electron microprobe at INGV of Rome, Fe oxidation state (ESRF, Grenoble, in according to slot availability), noble gases (INGV, Palermo) and chalcophile elements (i.e. Hg with a new DMA80 at DST, Sapienza and INGV Palermo) of natural fluid-bearing mantle peridotites from Mt. Vulture, Raman spectroscopy (Lione, France). At the end of Y1 determination of the P-T-fo_2 for natural fluid inclusions are expected, along with a calibration of a new oxybarometer for spinel-peridotites

Year (Y) 2

TASK 2 *Task 2.1* – Selection of natural crystal (olivine) with fluid inclusions for computed tomography (INGV-OV); high P-T treatment of the same samples with HP-T facilities (DST, Sapienza) and re-analyses by CT (INGV-OV); analyses of noble gases (INGV-Pa) and Raman spectroscopy (Lione, France) of inclusions before and after HP-T treatment. In-situ CT on fluid-bearing crystals at ESRF will be performed according to slot availability. At the end of this year, important achievements will be represented by the development of new interpretative tools (e.g., morphological, spatial distribution, geochemical) of inclusions in minerals of natural rocks.

Year(Y) 3

TASK 3 *Task 3.1* Preparation of aqueous solutions with 3 different compositions for elastic measurements by Brillouin spectroscopy (in the frame of abroad mobility in Germany). Elastic properties of crystal + fluid (3 natural olivines) by Brillouin spectroscopy (in the frame of abroad mobility in Germany). P and S wave velocity by in-situ interferometric acoustic measurements[14] at HP-T (in the frame of abroad mobility USA/Japan). The quantitative data obtained throughout the project will be scaled preliminarily to nature for seismological implications to better understand the volatile activity in the mantle. Finally, I will complete my doctoral project, prepare manuscripts for peer-reviewed journals, and present my findings at major conferences such as AGU, EGU and SIMP according to the availability of funds.

MILESTONES: *TASK 1* - Petrological model for the origin of fluids and their composition at mantle conditions by October 2026; *TASK 2* - A model of correlation between noble gases and morphometric data of fluids by October 2027; *TASK 3* - Effect of fluid inclusions on Vp/Vs by June - July 2028.

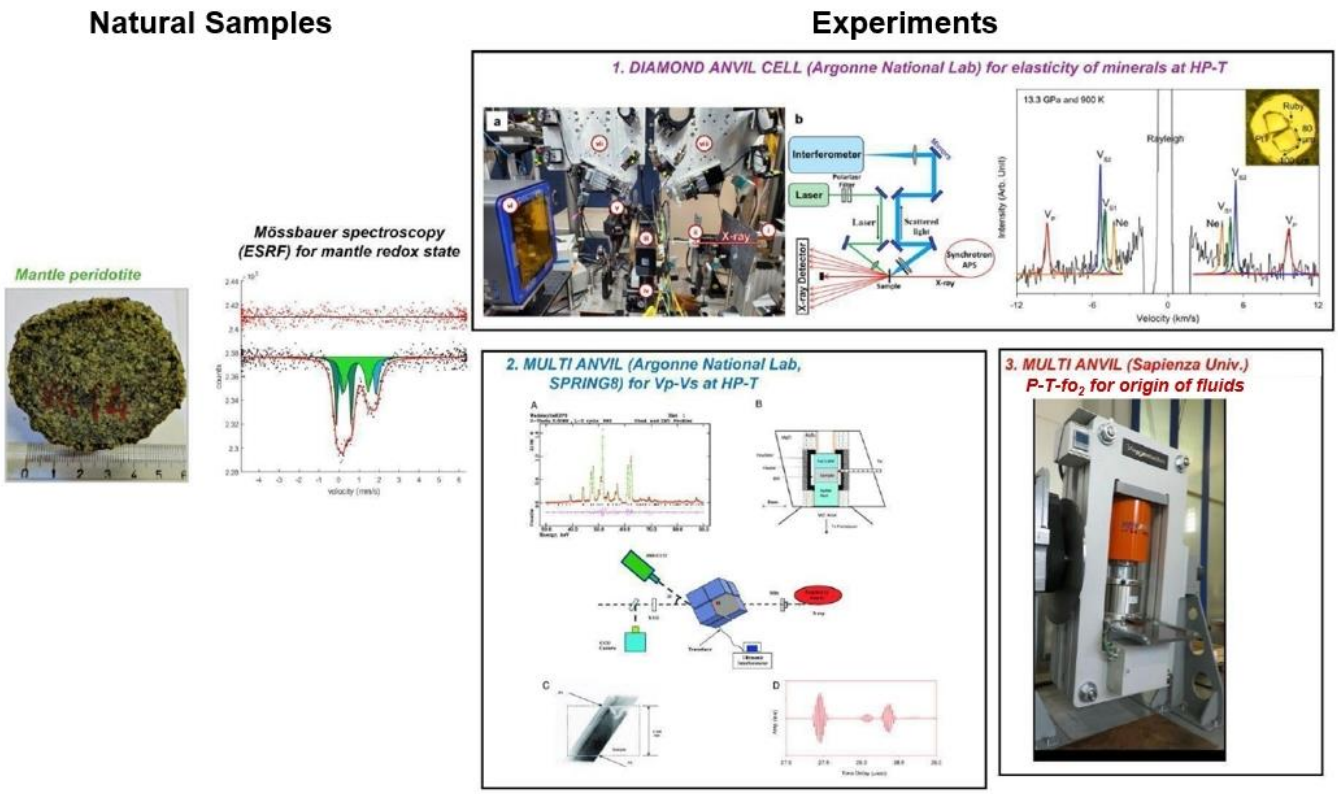


Figure 3 is a summary of the methodology used to achieve the goals of this project.

Dissemination of the results

I plan the following activities for each year,

Y1: participation in EarthTelescope workshop in November 2025; participation in workshop on HP-T techniques in February 2026. Creation of a database in Spring 2026. participation in ESRF beamtime proposal in March 2026; participation in ESRF beamtime in Spring/Summer 2026; Attendance of workshop on fluid inclusions; attendance of SIMP-SGI meeting in Padua in September 2026; submission of proposal for Fondi Avvio alla Ricerca Sapienza; participation at classes offered by DST, Sapienza. Manuscript preparation for peer-review journals.

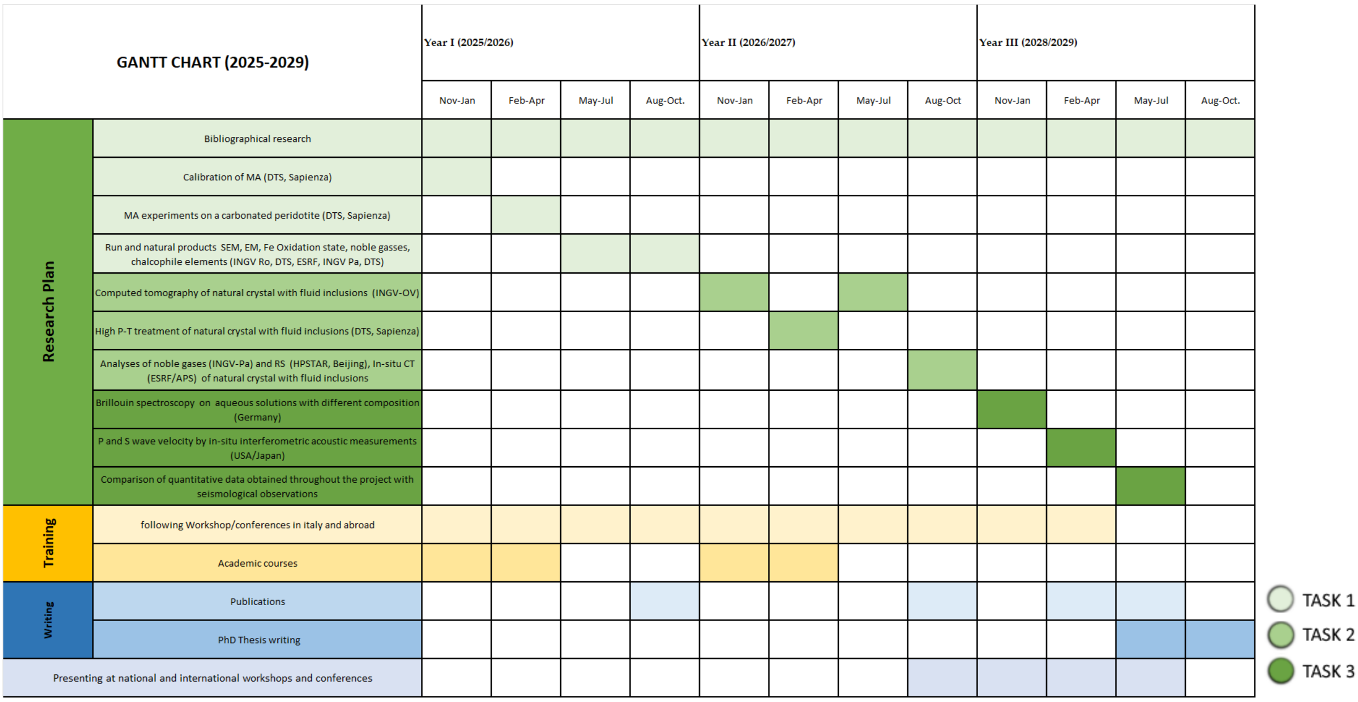
Y2: participation at ESRF beamtime in Autumn; attendance of EGU conference; submission of beamtime proposal for ESRF; Participation at SIMP-SGI conference participation at classes offered by DST, Sapienza. Manuscript preparation for peer-review journals.

Y3: submission and participation at beamtimes in APS/Spring8; abroad mobility periods in Germany and Japan with institutes with ongoing collaborations. Participation at AGU and SIMP-SGI. Manuscript preparation for peer-review journals. PhD thesis preparation and submission. Job interview.

International mobility

I will carry out a 6-month research stay at a high-pressure laboratory abroad, such as the Bayerisches Geoinstitut and Munster Univ. (Germany), GRC (Ehime University) to perform high-temperature and high-pressure measurements such as Brillouin spectroscopy, ultrasonic velocity measurements and in-situ Raman spectroscopy. Duration and location may vary with research needs.

Gantt Chart



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