Volatile influence on phase relations in the K-phonolitic magmas: P-T constraints for peri-Tyrrhenian explosive volcanism

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1. Introduction

In the context of better understanding the eruptive dynamics that characterized a given volcanic complex, placing constraints in P-T and $X_{H2O-CO2}$ conditions of magma system is crucial to assess the volcanic risk. In order to achieve this goal, investigations aimed at identifying and quantifying the volatile component of volcanic products play an important role, as well as the study of phase relationships as a function of volatile content (i.e., H_2O-CO_2) of the magmatic system and the definition of stability fields of crystalline phases sensitive to P-T variation (e.g., pyroxene, amphibole, and feldspars). Indeed, this type of studies, approached also by experimental petrology tools, can make a significant contribution to shedding light on the magma differentiation processes and crystallization conditions (e.g. see Perinelli et al., 2019 for the differentiation path of Campi Flegrei Caldera, CFC parental magmas).

2. State of the art

The central peri-Tyrrhenian volcanism is mainly characterized by potassic alkaline magmas, (Peccerillo, 2017) that fed the most violent explosive eruptions in this region. This kind of explosive eruptive events poses a major risk to the densely populated areas near volcanoes, for example the area of CFC. In fact, some of the most controversial questions today, regarding Campi Flegrei, concern the depth of the magmatic chamber(s) and whether seismic unrest occurred in last decades is related to hydrothermal activity or directly to injection of fresh magma (e.g. see Giacomuzzi et al., 2024). To better constrain the topic of magmatic chambers depth, an important role is played by petrological modeling, in synergy with geophysical and volcanological approaches.

In this context, in the study conducted during my thesis work focusing on pyroclastic deposits related to the Plinian events of the Ventotene volcano (Pontine Islands) primary analcime was observed in the trachy-phonolitic fall deposit of the Cala Battaglia eruption (UCB Unit) but it was not found in the products of the caldera-forming event of Parata Grande (PG). The variation in the eruptive styles could be due to the differences in volatile content in the magmas that fed these two eruptions and, consequently, to the difference in the depth of the respective magma chambers. Thus, constraints on volatile content in magmas that fed the two above mentioned eruptive events, as well as on the stability fields of P-sensitive mineral phases in these highly differentiated alkaline magmas can provide insights into the magma storage conditions of these and other major explosive events of central peri-Tyrrhenian area, such as Campanian Ignimbrite (CI) and Neapolitan Yellow Tuff (NYT). This matter assumes an importance in terms of volcanic risk, since it is well known that the depth of magmatic chambers and volatile contents in silicate melts affect the eruptive style and the intensity of a volcano. In the light of what said, the study of melt inclusions and natural glass can allow tracking changes in the content and composition of volatiles in a magma during its rise to the surface.

In order to constrain the P-T and $X_{H2O-CO2}$ conditions of magma plumbing systems, lots of studies were carried out about the potential use of minerals or mineral-melt equilibria as geo-thermometers and geo-barometers (e.g. Putirka, 2008; Masotta et al., 2013; Gomez et al., 2022), conversely, just a few studies were carried out to calibrate the thermo-barometers for highly differentiated magmas, one of which is Masotta et al. (2013). Despite this paper highlights the potential of thermo-barometry applied to clinopyroxene in alkaline differentiated magmas (trachytes and phonolites), it also points out that the Standard Estimate Error (SEE) associated with the estimates P-T are still too high (i.e., SEE often is equal or higher of the estimates pressure). Moreover, attempting to use these geo-thermo barometric approaches on different compositions than those used to calibrate the specific thermo-barometer would produce high errors (Putirka, 2016). Nevertheless, an important contribution to barometric determination of pre-eruptive systems it's represented by solubility models of volatiles (H_2O-CO_2) in silicate melts whose limit lies in the difficulty in obtaining pristine microchemical quantitative analyses of volatile content in melt inclusions within phenocrysts. Currently, a promising method to perform this type of analysis in igneous rocks is represented by RAMAN technique (Bonechi et al., 2022). In addition, a further aid to completing the knowledge of the depths of the magma chamber of a given volcano is to combine volatile-based geobarometry applied to juvenile products with the study of lithic clasts deriving from the magma chamber walls.

Because highly differentiated magmas feed some of the world's most voluminous, explosive, and menacing volcanic eruptions, accurate determination of magma-storage conditions is pivotal to a better understanding the dynamics of magma plumbing systems of a volcano, thus providing information for interpretation of past and current eruption behavior to improve hazard assessments and eruption forecast. With my PhD studies I will provide a useful tool for this goal by creating modeling of chemical-physical conditions and architecture of magmatic chambers in peri-Tyrrhenian context that could be applied at similar volcanic complexes worldwide.

3. Research objective

General objective:

My PhD project will focus on the determination of magmatic chambers depth from which derive the explosive eruptive events of peri-Tyrrhenian central area.

Specific objective:

To attain the general objective, I will focus my work on the following paramount topics:

- analyses of melt inclusions and glasses in natural samples of Plinian eruptions (caldera-forming and not), as in the case of Ventotene
- experimental determination of phase relations in K-phonolitic magmas
- microchemical analyses of experimental products
- modeling P-T and $X_{H2O-CO2}$ conditions in plumbing systems of explosive eruptions such as, Cala Battaglia and Parata Grande (Ventotene Island), Campanian Ignimbrite, Neapolitan Yellow Tuff (CFC)

4. Implication and/or Application

My P, T and $X_{H2O-CO2}$ petrological model can contribute to the determination and mitigation of volcanic risk in the peri-Tyrrhenian area, and it can be, potentially, applied to similar volcanoes worldwide.

5. Work plan

a. Phase 1

In the first phase of PhD program (first year), I will use the RAMAN technique (Roma Tre Earth Science department) to perform volatile content analyses on melt inclusions and natural glasses in pyroclastic samples (Ventotene Island and Campanian Ignimbrite). Moreover, I will perform a set of hydrous experiments at different P-T conditions. The starting materials (pumices sampled from Ventotene Island) employed in these experiments are K-phonolitic in composition. The initial P-T experimental conditions will be constrained by thermodynamic code (e.g. rhyolite-MELTS; Gualda et al., 2012) and available literature (e. g. Henderson et al., 2014), and the initial volatile content will be decided on the basis of microchemical analyses results (RAMAN). To perform my experiments, I will use piston-cylinder as experimental apparatus at La Sapienza University of Rome (Earth science Department), and University of Prague (Institute of Petrology and Structural Geology). If any problems occur with the experimental equipment, I will have the possibility to perform the experiments at INGV (Istituto Nazionale di Geofisica e Vulcanologia) of Rome.

b. Phase 2

In this phase I will start to analyze the experiments, performing textural analyses of the products with Scanning Electron Microscope (SEM) and microchemical analyses with Electron Microprobe Analyses (EPMA) of CNR c/o La Sapienza University of Rome and at University of Manchester analyzing both glass and minerals. I will quantify the volatile contents in the experimental glasses by using the RAMAN technique, (first and second year of PhD program).

c. Phase 3

In this step I will use the data collected in the previous two research steps, to identify the mineral assemblage that can be used as markers of plumbing systems depth, and I will study their stability fields. I will calibrate and validate these mineral phases as geothermo-barometers and I will compare my experimental results with the literature available on geothermo-barometers (e.g. Masotta et al., 2013), (second year of PhD program).

d. Phase 4

In the last period of my PhD program, I will process the acquired data, and I will use them to provide a modeling to constrain P-T and volatile conditions of magmatic systems in the context of peri-Tyrrhenian and PVD areas, that may be applied in other volcanoes around the world. Furthermore, I will work on the PhD thesis writing, (third year of PhD program).

6. Milestones

- Quantification and determination of volatile contents in melt inclusions and glasses in natural samples with RAMAN techniques (II, III and IV trimesters of first year).
- Constraining the starting P-T and $X_{H2O-CO2}$ conditions by using thermodynamic code (e.g. Rhyolite-Melts), literature and the results of RAMAN analyses to start performing the experiments (IV trimester, first year).
- Performing set of experiments (IV trimester of first year, I and II trimesters of second year).
- Textural and microchemical analyses (SEM, EPMA, and RAMAN) of experimental products (to IV trimester of first year from III trimester of second year).
- Realization of a petrological model by using the data collected and processed during my work (IV trimester of second year and I trimester of third year).

7. Dissemination plan and training activities

During my PhD program, I will follow institutional courses, workshops, and seminars organized by the PhD school in Earth Science of La Sapienza University of Rome, AIV and INGV and I want to take part in schools organized by SIMP, AIV and other scientific institutions. Moreover, I will also attend national and international conferences such as AGU, EGU, IAVCEI, RITTMANN and Goldschmidt in order to present the outcomes from my research.

8. International mobility

During my PhD program I will collaborate with the laboratory of University of Manchester, to perform microchemical analyses thanks to consolidated collaboration with Dr. Barbara Bonechi. Moreover, I will perform experiments at the University of Prague, thanks to the collaboration with Prof. Alessandro Fabbrizio.

9. Gantt chart

RESEARCH ACTIVITIES	First year				Second year				Third year			
	I trim	II trim	III trim	IV trim	I trim	II trim	III trim	IV trim	I trim	II trim	III trim	IV trim
Bibliography study	x	x	x	x	x	x	x	x	x	x	x	x
RAMAN analyses on natural samples (Roma Tre)		x	x	x								
Experimental work at La Sapienza				x	x							
Experimental work at University of Prague						x						
Analyses of experimental products (La Sapienza)				x	x	x						
Analyses at University of Manchester					x	x						
RAMAN analyses on experimental products						x	x					
P-T modeling								x	x			
Courses, seminars and workshops			x	x	x	x	x	x	x	x	x	x
International conferences						x	x	x		x	x	x
PhD thesis writing											x	x
Publications							x	x	x	x		

Figure 1: Gantt chart with all the activities (training, research and divulgation) that I will attend during my PhD program. The years are divided into 4 trimesters (trim. =trimester).

10. References

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