SAPIENZA
UNIVERSITÀ DI ROMA

Research project proposal for the XLI cycle of the PhD program in Earth Sciences

University of Roma "Sapienza"

Project title:

Modeling spatio-temporal variations in Strombolian to Vulcanian-Strombolian eruptive activity.

Candidate

Name: Giorgia

Surname: Guarnieri

Place and Date of Birth: Roma, 09/07/1999

Suggested internal supervisor: Prof. Gianluca Sottili

Email: gianluca.sottili@uniroma1.it

Suggested co-supervisor: Jacopo Taddeucci

Email: Jacopo.taddeucci@ingv.it

Introduction

The Strombolian and Vulcanian eruptive dynamics are among the most common in volcanic complexes on our planet. Their names derive, respectively, from the stratovolcanoes Stromboli, and Vulcano, both located in the Aeolian archipelago. Due to their spatial and temporal variability, Strombolian and Vulcanian eruptive styles are still the subject of debate and investigation within the scientific community. Given this unpredictability, understanding the controlling mechanisms underlying the variability of explosive volcanic eruptions of mafic magmas - particularly Strombolian and Vulcanian eruptions, which are the most common- has become a major goal of the volcanological community. Defining the factors governing the abrupt changes in magnitude and intensity of explosive volcanic activity from Strombolian to Vulcanian-Strombolian, could increase awareness of associated risks (Taddeucci et al., 2015) and, at the same time, improve ongoing monitoring activities with significant implications for eruptive risk mitigation (Taddeucci et al., 2015;Taddeucci et al., 2021)

State of art

Over the years, volcanologists (e.g. Mercalli, 1907; Walker, 1973) have analyzed the explosive activity of different volcanoes to identify common features that might suggest similar eruptive mechanisms. However, no volcanic system can be considered identical to another: explosive eruptions are characterized by significant variations in magnitude, duration, intensity, and type of emitted products- in some cases even within the same eruptive event. Multiparametric analyses conducted in recent years (Calvari et al.,2004; Delle Donne & Ripepe, 2012; Delle Donne et al., 2006; Harris et al., 2013) have documented these variations mainly by investigating the frequency, intensity, and source of the explosions, recorded by continuous video surveillance networks and geophysical monitoring. However, magma properties, conduit geometry, and their relationship with explosive dynamics are also crucial aspects of the explosive activity fed by mafic magmas (Taddeucci et al., 2021) and, so far, have been studied only in a fragmented way, despite their potential to answer fundamental questions about the factors controlling transition among eruptive types.

From 2020 to 2024 the National Institute of Geophysics and Volcanology (INGV) conducted several volcanological expeditions to Stromboli as part of the UNO-Stromboli project (*UNderstanding the Ordinary*), a multidisciplinary project that combined fieldwork with simulation and numerical modeling of volcanic processes. The overall goal of UNO-Stromboli project was to improve our understanding of the mechanisms driving the transition among eruptive types and to define key parameters possibly representing precursors of these changes. On these grounds, during my master's thesis, in collaboration with INGV, I researched and developed a reliable technique for studying the variability of Stromboli's volcanic activity (Bombrun et al., 2015; Gaudin et al., 2017) combining image analysis and numerical modeling of its volcanic events. The results I obtained demonstrated the great potential of this innovative approach, which could be applied to basaltic volcanic complexes characterized by Strombolian to Vulcanian-Strombolian eruptive styles over long acquisition periods.

The causes of changes in eruptive styles are still poorly documented and reported in literature. Gaudin et al. in 2017 theorized that the main controlling parameters are:

1. The relationship between the length of the gas slug (or gas pocket) located within the volcanic conduit and the diameter of the conduit itself, which is thought to be related to the magnitude of the eruptive event (Fig. 1).

2. The thickness of a layer of cooled high viscosity magma (i.e., the High Viscosity Layer) in the shallow portion of the volcanic conduit formed during inter-eruptive intervals (Fig 1).

Spina et al. (2017), based on thermal infrared images analysis of Etna, described a possible geometry of the shallow branches of the main volcanic conduit. The inclination of the branches influences the amount of gas transported to the surface and subsequently emitted from a specific eruptive vent. An increase in magma flux could lead to a redistribution of gas slugs within the branches, thus resulting in a change in explosive activity at the surface. In summary, volcanic conduit geometry could be considered a key factor controlling variations of volcanic activity (Spina et al., 2017; Spina et al., 2023, Tournigand et al., 2017).

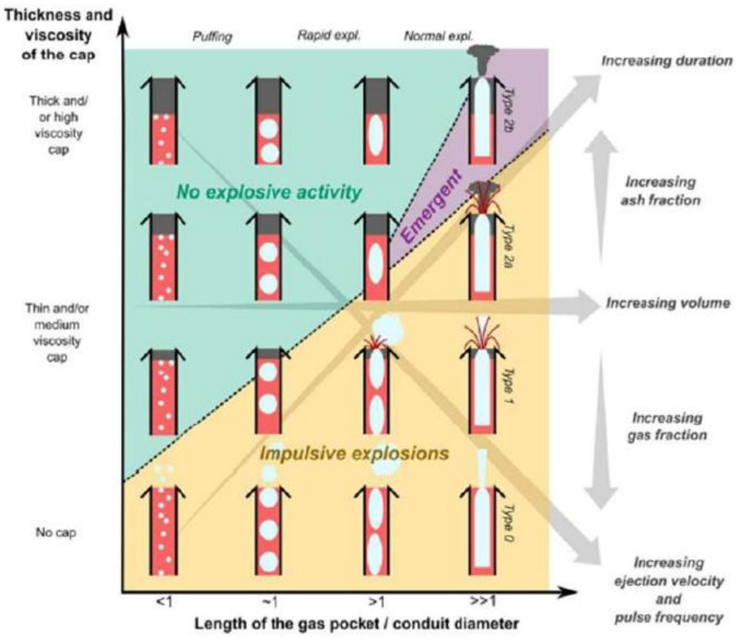

Fig 1. Classification of Strombolian explosions based on the interaction between the thickness of the High Viscosity Layer and the relationship between the length of the gas pocket and the conduit's diameter (Gaudin et al., 2017).

Overall objective

To identify the causes of variability in space and time of Strombolian to Vulcanian-style explosive eruptions by analyzing and parameterizing them in the field and in the laboratory.

Specific objectives

- Qualitative analysis of infrared footage acquired at several volcanoes to visually filter the type of eruptions.
- Parameterization of vent, plume, and jet dynamics to obtain quantitative information about eruption source conditions and atmospheric dispersal in terms of temperature, eruption duration, frequency and ejection modes using thermal, high speed footage and acoustic data.
- Application of Gaudin et al. (2017) and Spina et al. (2017) studies to define the factors that cause the spatio-temporal variability of eruptive dynamics from Strombolian to Vulcanian-Strombolian.
- Laboratory shock tube experiments to model the eruption processes and validation of previous models (e.g., Gaudin et al. 2017, Spina et al. 2017).

Implication and application

Using an innovative approach supported by INGV -which will provide thermal, high speed and acoustic data-, the project aims to identify the main factors controlling the transition between different types of eruptions. This research combines parameterization with conduit geometry, two factors that so far have only been studied individually. Through the modeling and the identification of the main controlling factors, this framework could lead to future developments in the acquisition and interpretation of monitoring data in order to better constrain the risks associated with Strombolian/Vulcanian-Strombolian phenomena.

Work Plan

The research activity will be conducted on four volcanoes characterized by Strombolian to Vulcanian-Strombolian eruptive styles (Fig. 2):

1. ***The Stromboli volcano*:** showing Strombolian eruptions of mild to moderate intensity, alternating with paroxysms, producing trachybasaltic products (Bombrun et al., 2015; Delle Donne & Ripepe, 2012; Delle Donne et al., 2006).

2. ***The Etna volcano*****:** characterized by Strombolian activity, lava fountains during intensification, and basaltic-trachybasaltic products (Petrelli et al., 2025).
3. ***The Cumbre Vieja volcano*****:** exhibiting violent Strombolian eruptions with basanite to tephritic compositions (Taddeucci et al., 2015).
4. ***The Fuego volcano*****:** displaying a transitional style between Strombolian and Vulcanian, emitting basaltic-andesitic products (Mercalli, 1907)

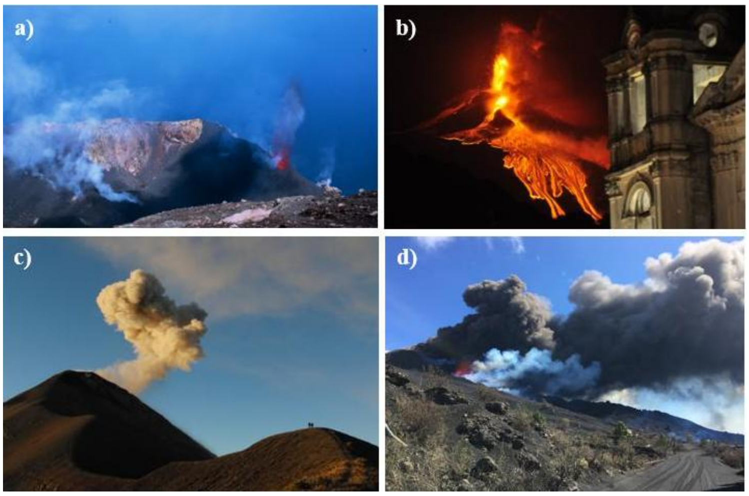

Fig 2. The four volcanoes that will be analyzed in this project. A) Stromboli Volcano (Italy), b) Etna Volcano (Italy), c) Fuego volcano (Guatemala), d) Cumbre Vieja Volcano (Spain, Canary Islands). [all the pictures were taken from INGV website].

First phase (I semester of first year)

In order to optimise the organisation of the available data, I will develop a comprehensive database in which all data will be collected and systematised. The creation of the database will be essential to facilitate the identification of the acquisition periods of greatest interest. Next, I will focus on the analysis of infrared images. The first stage of this analysis will be qualitative: I will examine the thermal footage of the four selected volcanoes and carry out a preliminary classification of the observed eruptive events into four categories:

- *Normal explosions* → Explosions producing a convective plume with ballistic and/or ash emission.
- *Rapid explosions* → Low-intensity explosions with the emission of ballistic ejecta.
- *Puffing* → Rapid and repeated emission of discrete amount of high-temperature gas.
- *Vulcanian-Strombolian explosions* → energetic explosions with high convective clouds.

The goal of this phase is to identify possible patterns or recurrent trends within the temporal sequence of the explosions.

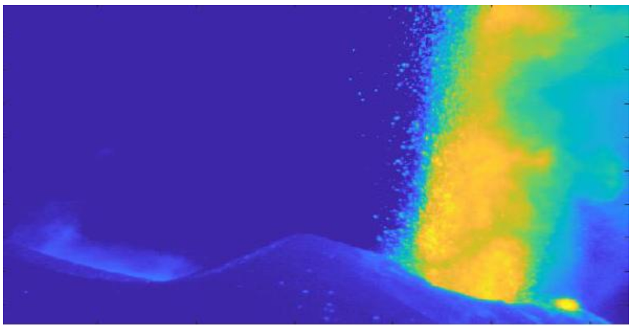

Fig 3. Example of thermal infrared image of Stromboli acquired with OPTRIS PI640 thermal camera.

Second Phase (II semester of first year-I semester of second year)

Subsequently, quantitative parameterization of explosive events will be performed using MATLAB and machine learning techniques (Longo & Ripepe et al., 2024; Naismith et al., 2019). The parameterization will initially be carried out on thermal images, in order to model the eruptive processes in terms of temperature, eruption duration, and eruption frequency. Between the first and second year, I will analyze and parameterize high-speed camera footage to derive information on ejection dynamics, such as the ejection velocity, size and number of pyroclasts, plume expansion. In addition, I will analyze and parameterize acoustic data which will provide further information about eruption duration, frequency, and pulse patterns and will complement and validate the results obtained from the thermal and high-speed video analyses.

Third Phase (II semester of second year)

In this phase, I will apply the results obtained from the parameterization to the theoretical framework proposed by Gaudin et al. (2017) and Spina et al. (2017), who identified three main factors controlling variations in Strombolian eruptive styles:

1. The relationship between the length of the gas pocket within the conduit and the conduit diameter itself (Gaudin et al., 2017);
2. The influence of high-viscosity layers in the upper portion of the conduit on the eruptive style (Gaudin et al., 2017);
3. The geometry and inclination of the shallow branches of the volcanic conduit and their relationship to variations in eruptive dynamics (Spina et al., 2017).

The effects of these controlling factors will be theoretically modeled following the approaches proposed by Gaudin et al. (2017) and Spina et al. (2017), and then applied to the results obtained from both the qualitative analysis and the quantitative parameterization. This phase aims to integrate theoretical modeling with analytical data, thereby improving the understanding of the mechanisms driving the shift between eruptive styles.

Fourth Phase (II semester of second year-I semester of third year)

In the final phase of my PhD, I will conduct a series of experiments using a shock tube apparatus at the University of Munich. This device allows the reproduction of tephra emission under controlled physical conditions. The experiments will be designed to replicate the conditions described by Gaudin et al. (2017) and Spina et al. (2017), with the aim of reproducing the theoretical results obtained through parameterization. By comparing the experimental results with both the theoretical predictions and the parameters obtained during the third phase, this concluding stage will serve to validate the proposed model and to better constrain the physical mechanisms governing explosive volcanic activity. In the last part of my PhD I will focus on writing my doctoral thesis.

Milestones

- Development of a database and qualitative analysis of thermal videos for all volcanoes (I semester of first year).
- Quantitative parameterization of eruptive events (II semester of first year-I semester of second year).
- Application of the theoretical frameworks proposed by Gaudin et al. (2017) and Spina et al. (2017) to the parameterized data (II semester of second year).
- Shock tube experiments and model validation (II semester of second year-I semester of third year).

Dissemination Plan

The results obtained over the three years will be shared with the scientific community through publications in open-access journals on volcanology and related fields, as well as through participation in thematic meetings (e.g., A. Rittmann Conference, EGU, IAVCEI), in order to foster discussion with other researchers and develop future collaborations.

Training activities

I will attend courses and seminars at Sapienza University of Rome and other international institutions (e.g. AIV summer school, IAVCEI international training school), as well as participate in relevant conferences.

International mobility

I plan to spend six months at Ludwig-Maximilians University in Munich to perform shock tube experiments recorded by high-speed video system to reproduce conduit conditions and study tephra ejection modes. This experimental approach, reproducing tephra ejection modes in different conduit conditions, may help understand the influence of the main controlling factors on eruptive transition and spatio-temporal variability.

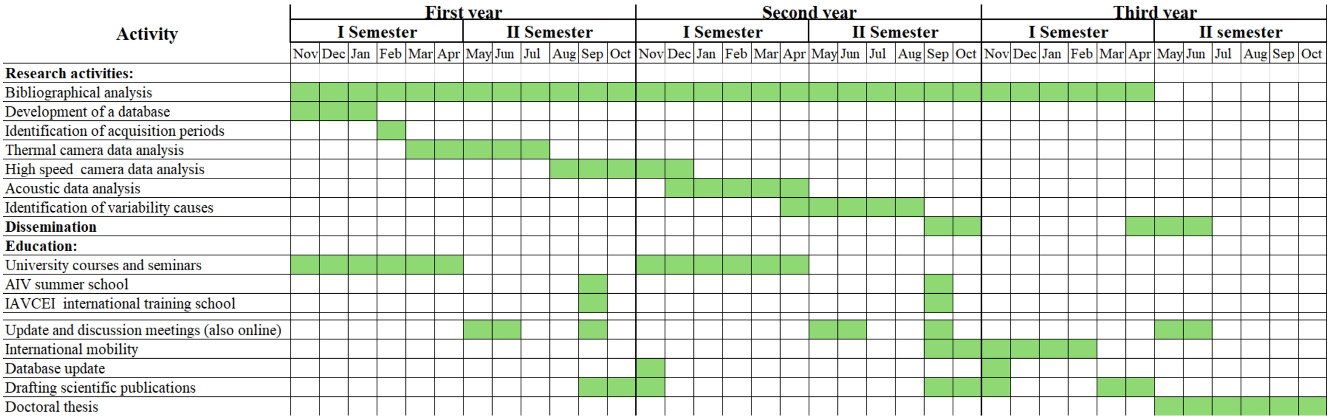

Fig. 4 GANTT chart

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