Active degassing and Volcanic Vortex Rings: implications for the state of the volcano and its eruptive behaviour

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1. INTRODUCTION AND STATE OF THE ART

Active degassing activity presents a wide range of volcanic manifestations, from puffing (intermittent degassing, no particles emitted), spattering (degassing and some scoriae ejections) until the effective eruptive activity in terms of lava fountainings that, possibly, can develop into ordinary Strombolian activity. Puffing is the repeated emission of discrete gas volumes, sometimes associated with a few incandescent bombs, with inter-event duration of few seconds (Gaudin et al., 2017), which may develop volcanic vortex rings (VVRs). VVRs are gaseous donut-shaped structures, constituted mainly by water vapor, which are emitted by volcanic vents (Fig.1).

Fig. 1 Photo by Giuseppe Di Stefano (04.2024): "What are volcanic vortex rings? Mt.Etna blows spectacular 'smoke rings' into the sky" (Euronews).

They have been observed and reported on numerous occasions since the 1700s (Fuentes, 2014) and they have been observed at different volcanoes around the world: e.g. Mt. Etna (Italy), Redoubt (Alaska), Tungurahua (Ecuador), Pacaya (Guatemala), Eyjafallajökull and Hekla (Iceland), Stromboli (Italy), Aso and Sakurajima (Japan), Yasur (Vanuatu), Whakaari (New Zealand) and Momotombo (Nicaragua) (Pulvirenti et al., 2023). VVRs form when a puff of hot water vapor is quickly emitted, the water vapor then rolls-up at the vent borders forming tube vortices, while its central part is pushed out at higher speed dragging all the vortices with it (Pulvirenti et al., 2023). The ring forms and becomes visible by condensation, with a radius comparable to the one of the emitting vent. Pulvirenti et al. (2023) affirm that VVRs' formation is attributable to pressurized gas slugs explosions when they reach the top of magma conduit. These slugs explosions create an overpressure pulse that is converted in compressive waves: such overpressure must be as small as that generated by a short time pulse during transient Strombolian eruptions. The magma viscosity, that can permit the VVRs' formation, has to be low to moderate (SiO_2 content between 50-60%) (Pulvirenti et al., 2023). Small rings, which contain only a small portion of water vapor and do not show a trailing jet, disappear in tens of seconds; instead, large rings, with a radius of tens of meters, have been observed to last for tens of minutes, reaching even a maximum height of a few kilometers above the vent (Suwa et al., 2014; Pulvirenti et al., 2023). It has been suggested that during low intensity Strombolian activity VVRs may not be observed, since thermal and viscous diffusion processes become predominant. Furthermore, if a part of the vent border is broken or its border level is not uniform, VVRs may not form or be subject to instabilities (Pulvirenti et al., 2023). Nonetheless, still a great effort has to be made in order to better understand what active degassing (and VVRs) may indicate about the state of a volcano.

2. RESEARCH OBJECTIVES

I will follow two different approaches: the first one regards thermal videos and acoustic signals analysis, acquired during field work; the second one concerns making experiments at the HPHT-Laboratory (INGV-Rome). The first approach will be employed to study the active degassing in general, while the second one will focus on VVRs.

2.1 General objective

Understanding the relationships between the measurable parameters related to active degassing and the volcanic conduit's intrinsic dynamics.

2.2 Specific objectives

a) Magma degassing modelling in the shallow plumbing system;

b) Volcanic conduit's dynamics definition;

c) Meteorological conditions' influence evaluation;

d) State of the volcano and its eruptive behaviour assessment, with constraints for the volcanic hazard.

3. IMPLICATIONS AND/OR APPLICATIONS

Probable benefits are a better evaluation of the volcano's activity, to forecast its eruptive behaviour in the shortest time possible.

4. WORK PLAN

Phase 1

I will analyse some videos recorded with thermal cameras at Bocca Nuova (Mt.Etna), provided by INGV-Rome. Since this vent is characterized by an intense degassing (puffing, VVRs, spattering. Fig.2), it is an ideal case-study by which defining a generalized magma degassing and conduit's dynamics model. At first, I will collect all the VVRs and their relative features in order to characterize them. Attention will be given to: internal and external radius, shape, thickness, residence time in air, height from the vent, axial rise velocity and radial growth velocity. An index will be set on the aforementioned parameters, in order to classify them. If a volcano (Mt. Etna and/or Stromboli) will show a peculiar degassing behaviour, it is not excluded a new field study to acquire new data.

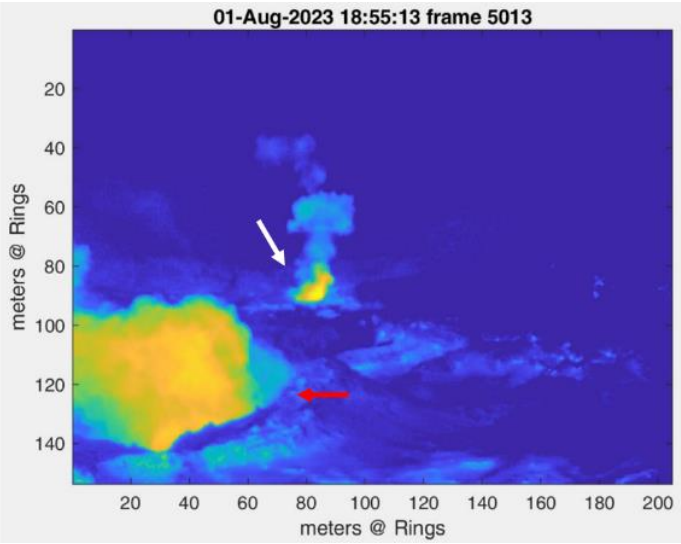

Fig. 2 Thermal video frame, recorded at Bocca Nuova (Mt. Etna) in 1.08.2023 (provided by INGV-Rome). The red arrow indicates the vent characterized by puffing activity; the white arrow indicates the vent generating VVRs.

Phase 2

I will make a series of experiments with the shock-tube device (HPHT Laboratory at INGV-Rome), in order to understand what puffing and VVRs may indicate in terms of magma degassing mechanism and conduit geometry. This device has already been used for volcanological purpose but not yet to study active degassing phenomena. I will evaluate which 'internal factors' permit VVRs'formation and how they influence their dynamics; then, I will determine the conditions that allow only puffing degassing at the vent. Such factors are: fluid's geochemistry composition, possible presence of suspended particles in the fluid, intensity of gas input. Other 'internal factors' regard the shock-tube features, such as its length and walls roughness, and the minimal overpressure (necessary to generate a vortex ring at the nozzle exit). Varying the shock-tube characteristics, it will be possible to make considerations on the conduit geometry, wall roughness and magma level when active degassing manifestations (puffing or VVRs) are observed at a particular vent. I will conduct new experiments with the shock-tube, this time adding a cap inside the upper portion of the tube, in order to study if the presence of a plug inhibits the vortex rings' formation at the vent exit. The purpose is to discover if VVRs are related only to open-conduit volcanoes with a presistent eruptive activity or are generated by quiescent obstructed volcanoes too. Afterward, 'external factors' will be considered, as the meteorological conditions (wind velocity, air humidity, atmospheric pressure), and the way these ones may influence the degassing manifestations' dynamics at the volcanic vent. A collaboration with Catania-Fontanarossa International Airport would be beneficial, in order to acquire meteorological data of the Etnean area (weather baloons).

Phase 3

Since recent studies have been focused on puffing and spattering activities at the volcanic vent, through acoustic and thermal investigations, I will continue and deepen such studies. Some data are already available, acquired at Bocca Nuova during the summer 2023 and provided by INGV-Rome. The data were recorded with a thermal camera (16 FPS, temperature range 150°C to 900°C) and a broadband microphone (infrasound to audible range acquired at 20 kHz). The aim of this phase is to propose a conceptual model of how magma degassing process occurs in the shallow plumbing system, when a particular volcano is characterized by active degassing (puffing, sometimes with VVRs).

Phase 4

I will examine how the specific volcano behaves in the periods before and after VVRs'occurrence, taking into account worldwide volcanoes. It will be necessary a careful bibliographic research and consultation of volcanological bulletins and catalogues. If a peculiar chain of events will be noticed, possibly VVRs may foreshadow a particular eruptive behaviour. In that case, VVRs may represent an additional tool to better outline the state of the volcano and its eruptive scenarios, with implications for the volcanic hazard assessment.

5. MILESTONES

a) Analysing thermal videos and VVRs characterization and classification (1-4 trimesters);
b) Shock-tube experiments to investigate 'internal factors' (1-6 trimesters);
c) 'External factors' analysis, in particular weather conditions (4-5 trimesters);
d) Thermal and/or acoustic analysis of the puffing degassing (probably spattering activity will be considered too) (5-9 trimesters);
e) Pre- and post- VVRs' occurrence volcanic activity study, considering worldwide volcanoes (8-9 trimesters);
f) Overall magma degassing and shallow plumbing system conceptual modelling, with implications for eruptive scenarios and volcanic hazard (9-10 trimesters).

6. DISSEMINATION PLAN

I will attend national and international conferences, seminars and workshops (AIV, AGU, EGU, IAVCEI, Rittmann) to present the outcomes from my PhD research (as abstracts, posters, articles). I will partecipate to local conferences, as 'Roma chiama Roma' and other activities may be added.

7. NATIONAL AND INTERNATIONAL TRAINING ACTIVITIES

I will attend PhD courses and seminars held by Earth Sciences Department (University of Rome 'La Sapienza') as well as national conferences/workshops. I will cooperate with INGV-Rome to make experiments at HPHT Laboratory. A collaboration with Catania-Fontanarossa International Airport would be advantageous, as well as a formation time at INGV-Catania. Possibly, I will partecipate to the 'B. Capaccioni' school (AIVULC) and AIV International summer school for PhD students and early career researchers. Divulgation activities regarding the volcanological topics will be carried on at schools and during open-days at INGV-Rome. Then, I will attend international conferences and

workshops. During my PhD, I will undertake a collaboration with Professor Jörn Sesterhenn from the University of Bayreuth (Department of Technical Mechanics and Fluid Mechanics). A cooperation with researchers from Munich may be envisaged.

8. GANTT CHART

Research activities	First year				Second year				Third year			
	1 trim	2 trim	3 trim	4 trim	5 trim	6 trim	7 trim	8 trim	9 trim	10 trim	11 trim	12 trim
Bibliographic study	x	x	x	x	x	x	x	x	x	x	x	x
VVRs videos analysis, characterization and classification	x	x	x	x								
Shock-tube experiments at INGV-Rome	x	x	x	x	x	x						
External factors' analysis				x	x							
Thermal and/or acoustic study of active degassing					x	x	x	x	x			
Pre- and post- VVRs' occurrence volcanic activity study								x	x			
Magma degassing and shallow plumbing system modelling									x	x		
Istitutional PhD courses and seminars	x	x	x	x	x	x	x	x	x	x		
Divulgation activities at schools/open-days				x	x	x		x	x			
Attending international conferences					x	x	x	x	x	x		
Formation at INGV-Catania					x	x						
Formation at University of Bayreuth							x					
Writing of PhD thesis											x	x
Publications						x				x		

9. BIBLIOGRAPHY

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