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Joint workshop on "Experimental and numerical modelling approaches to investigate gravity flows"

Bari, 15-17 September 2025

Rende (CS), 17-19 September 2025

Università degli Studi di Bari Aldo Moro

Università della Calabria

Return

AIV Associazione Italiana di Vulcanologia

Table of Contents

Organizing committee........3
List of participants........3
Invited speakers and delegates........3
PhD Students and Early Career Researchers........3
Programme........5
Workshop day 1 – 15/09/2025........5
PhD-ECR day........5
Workshop day 2 – 16/09/2025........6
Workshop day 3 - 17/09/2025........6
Workshop day 4 - 18/09/2025........6
Workshop day 5 - 19/09/2025........7
Abstracts – invited speakers........8
From laboratory experiments to the field: the use of laboratory data for understanding the real flows........8
Mechanics of Dense Granular Avalanches........9
Rheology of Dense Suspensions in Two-Phase Modeling for Bedload Transport........9
Particle modification in granular flows and the associated impact on flow properties........10
Laboratory modeling of gravity-driven flows: The emblematic dam-break configuration 11
Principles and Applications of Quantitative Textural Analysis........11
Multiscale modelling of rainfall triggered debris flows: Case studies from diverse geoenvironmental settings........12
Abstracts – PhD-ECR day........13
Rheological Properties of Fluidized and Non-Fluidized Pyroclastic Material........13
Rheological control on deposit-derived pyroclastic density currents........15
(DD-PDC)........15
Rheological Characterization of Volcanic Finse Sediment Suspensions: Intregrating Hyperconcentrated and Debris Flow Conditions........16
Pysammos: a new open-source Coarse-Graining tool to analysing the rheology of diverse volcanic granular flows.........17
CARG-based (Sheet 416, 417, and 364) volume reassessment for the VEI 6/7 ignimbrites along the Roman Magmatic Province........19
Modelling approaches for building probabilistic hazard maps of lahars inundation at Campi Flegrei caldera (Italy)........19

Investigating PDC-Forming Mechanisms at Basaltic Volcanoes through Large-Scale Granular Flow Experiments 21
Multi-parametric study of the 2020-2022 paroxysmal activity at Mt. Etna: the role of fluids in the trigger mechanisms, durations and energy of the eruptive phenomena 23
The Role of Soil Moisture and Rheology in Sarno Volcaniclastic Debris Flows: Insights from Laboratory and Flume Experiments 24
Numerical modelling of cliff stability problems in soft calcarenites: in-sights from MPM technique applications 26
Visits to the experimental facilities 28
University of Bari 28
University of Calabria 29
Round table discussions 31
Towards accurate and efficient numerical modelling (Claudia Eljias Parra) 31
From the laboratory to the field and vice versa (Giorgio Costa) 32
Validating laboratory-based hypothesis in the field (Letizia Pace) 33
Funding acknowledgments 35

Organizing committee

Eugenio Nicotra (University of Calabria)
Fabio Dioguardi (University of Bari “Aldo Moro”)
Giovanna Capparelli (University of Calabria)
Roberto Sulpizio (University of Bari “Aldo Moro”)
Pierfrancesco Dellino (University of Bari “Aldo Moro”)
Alexis Bougouin (University of Calabria)

List of participants

Invited speakers and delegates

Fabio Dioguardi (University of Bari “Aldo Moro”, Italy)
Roberto Sulpizio (University of Bari “Aldo Moro”, Italy)
Francesco Neglia (University of Bari “Aldo Moro”, Italy)
Thomas Jones (University of Lancaster, United Kingdom)
Alexis Bougouin (University of Calabria, Italy)
Damiano Sarocchi (Autonomous University of San Luis Potosi, Mexico)
Nikhil Vasu Nedumpallile (British Geological Survey, United Kingdom)
Franco Antonio Tapia Uribe (Dresden University of Technology, Germany)
Lizeth Caballero Garcia (National Autonomous University of Mexico, Mexico)
Eugenio Nicotra (University of Calabria, Italy)
Pierfrancesco Dellino (University of Bari “Aldo Moro”, Italy)
Giovanna Capparelli (University of Calabria, Italy)
Francisco Rocha (Aix-Marseille University, France)

PhD Students and Early Career Researchers

Carla Gisela Tranquilino Espinoza (University of Bari “Aldo Moro”, Italy)
Dario Milella (University of Bari “Aldo Moro”, Italy)
Giorgio Costa (University of Catania, Italy)
Letizia Pace (University of Bari “Aldo Moro”, Italy)
Muhammad Ammar (University of Bari “Aldo Moro”, Italy)
Marta Minniti (University of Calabria, Italy)
Massimiliano Cardone (University of Catania, Italy)
Claudia Elijas Parra (University of Edinburgh, United Kingdom)
Silvia Massaro (University of Bari “Aldo Moro”, Italy)
Teresa Oreade Grillo (Roma Tre University, Italy)
Alessandro Frontoni (Roma Tre University, Italy)

Figure 1. Picture of the participants taken at University of Bari "Aldo Moro"

Figure 2. Picture of the participants taken at Polo "Sila", University of Calabria

Programme

Workshop day 1 – 15/09/2025

- 08:30 – 09:00 **Welcome**
    - Prof. Giuseppe Mastronuzzi, Director of the Department of Earth and Geoenvironmental Sciences, University of Bari "Aldo Moro"
    - Prof. Roberto Sulpizio, Coordinator of the National Interest Doctoral School "Earth Processes and Management of Resources and Risks for a Resilient Society and Territory"
    - Prof. Pierfrancesco Dellino, RETURN Foundation.
- 09:00 – 10:00 Roberto Sulpizio. **From laboratory experiments to the field: the use of laboratory data for understanding the real flows**
- 10:00 – 11:00 Francisco Rocha. **The mechanics of granular avalanches**
- 11:00 – 11:30 Break
- 11:00 – 12:00 Franco Tapia. **Rheology of Dense Suspensions in Two-Phase Modeling for Bedload Transport**

PhD-ECR day

- 12:00 – 12:20 Muhammad Ammar. **Rheological Properties of Fluidized and Non-Fluidized Pyroclastic Material**
- 12:20 – 12:40 Teresa Oreade Grillo. **Rheological control on deposit-derived pyroclastic density currents (DD-PDC)**
- 12:40 – 13:00 Carla Tranquilino Espinoza. **Rheological Characterization of Volcanic Fine Sediment Suspensions: Intregrating Hyperconcentrated and Debris Flow Conditions**
- 13:00 – 14:30 Break
- 14:30 – 14:50 Claudia Elijas-Parra. **Pysammos: a new open-source Coarse-Graining tool to analysing the rheology of diverse volcanic granular flows**
- 14:50 – 15:10 A. Frontoni. **CARG-based (Sheet 416, 417, and 364) volume reassessment for the VEI 6/7 ignimbrites along the Roman Magmatic Province**
- 15:10 – 15:30 Silvia Massaro. **Modelling approaches for building probabilistic hazard maps of lahars inundation at Campi Flegrei caldera (Italy)**
- 15:30 – 16:00 Break
- 16:00 – 16:20 Giorgio Costa. **Investigating PDC-Forming Mechanisms at Basaltic Volcanoes through Large-Scale Granular Flow Experiments**
- 16:20 – 16:40 Massimiliano Cardone. **Multi-parametric study of the 2020-2022 paroxysmal activity at Mt. Etna: the role of fluids in the trigger mechanisms, durations and energy of the eruptive phenomena**
- 16:40 – 17:00 Letizia Pace. **The Role of Soil Moisture and Rheology in Sarno Volcaniclastic Debris Flows: Insights from Laboratory and Flume Experiments**

17:00 – 17:20 Dario Milella. **Numerical modelling of cliff stability problems in soft calcarenites: in-sights from MPM technique applications**

Workshop day 2 – 16/09/2025

- 9:00 – 10:00 Thomas Jones. **Particle modification in granular flows and the associated impact on flow properties**
- 10:00 – 11:00 Alexis Bougouin. **Laboratory modelling of gravity-driven flows: The emblematic dam-break configuration**
- 11:00 – 11:30 Break
- 11:30 – 12:30 Damiano Sarocchi. **Principles and Applications of Quantitative Textural Analysis**
- 12:30 – 14:00 Break
- 14:00 – 15:00 Nikhil Nedumpallile Vasu. **Multi-scale modelling of rainfall triggered debris flows. Case studies from diverse geoenvironmental settings**
- 15:00 – 16:00 Lizeth Caballero Garcia. Calibration of lahar numerical models: **The challenge of limited data**
- 16:00 – 16:30 Break
- 16:30 – 18:30 Visit to the University of Bari experimental facilities

Workshop day 3 - 17/09/2025

- 08:00 Bus leave the Hotel, stops to the UniBa Campus to pick PhD students up
- 12:00 Arrival at Rende and Check-in at the Hotel
- 13:00 – 14:30 Light lunch at the University of Calabria (15/A cube)
- 14:30 – 15:00 Welcome and presentation of the CAMILab activities. Prof. Ing. Giovanna Capparelli, Director of CAMILab, University of Calabria (CAMILab Sezione SILA).
- 15:00 – 17:00 Presentation of the CAMILab laboratory (41/Z cube) and experimental setting. Demonstration experiment.

Workshop day 4 - 18/09/2025

- 08:30 – 09:00 Transfer by bus to CAMILab Lab (41/Z cube)
- 09:00 – 10:30 Discussion about the previous day’s experiment
- 10:30 – 11:00 Break
- 11:00 – 13:00 Workshop (CAMILab Sezione SILA): round table discussion on open topics
- 13:00 – 14:30 Break

- 14:30 – 16:30 Workshop (CAMILab Sezione SILA): round table discussion on open topics
- 16:30 – 17:30 Round tables' leaders present outcomes of their discussion
- 17:30 End of works

Workshop day 5 - 19/09/2025

- 09:00   Transfer by bus to Bari
- 12:30 Arrival at Bari – End of the event

Abstracts – invited speakers

From laboratory experiments to the field: the use of laboratory data for understanding the real flows

Sulpizio, Roberto[1]

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Geophysical mass flows such as landslides, debris flows, and pyroclastic density currents pose significant hazards in mountainous and volcanic regions. Despite advances in modeling and monitoring technologies, predicting their behavior—particularly their mobility and runout—remains a major challenge. This is largely due to the complex interplay of material properties, topography, fluid/solid ratio and friction laws, which are difficult to constrain in natural settings. Laboratory experiments offer a controlled framework to investigate these factors, allowing researchers to isolate individual variables and test physical hypotheses with high precision. The translation of laboratory-scale insights to real-world scenarios, however, requires careful consideration of scaling laws, material analogs, and field variability. This contribution explores the role of laboratory experiments in improving our understanding and modeling of natural granular flows, with a particular focus on the influence of basal surface conditions, material properties, and initial flow parameters.

I will present some examples of contribution of laboratory experiments to the understanding of diluted and concentrated geophysical flows, which provided a step forward in unravelling some physical characteristics of moving flows and validated sedimentological models for gaining flow parameters from real deposits.

Of particular interest are also some examples on flow substratum interaction. They include the entrainment behaviour of loose clasts into the moving flow during deposition, and the reduced mobility of non-fluidised, fine-rich flows due to the enhanced friction among particles and substratum, including the identification of a dimensionless parameter—the ratio between surface roughness and grain size (λ/d)—that governs the transition between smooth and rough basal flow regimes.

I will also stress the value of integrating experimental data into numerical models and risk analysis frameworks. Laboratory-derived parameters can be used to constrain model inputs, reduce uncertainty, and provide a physical basis for scenario simulations. This is particularly relevant in regions where direct monitoring is limited or historical data are sparse. By enhancing the physical realism of models, laboratory insights contribute to more robust hazard maps, early warning systems, and emergency planning strategies.

In this framework, laboratory experiments serve as a critical link between theoretical modeling and field observations. When carefully designed and interpreted, they offer scalable insights into the dynamics of real granular flows. This integration of controlled experimentation and field application represents a powerful strategy for advancing geohazard science and improving societal resilience to mass flow events.

Mechanics of Dense Granular Avalanches

Rocha, Francisco[1]
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How do grains move when they flow collectively in a dense state? Although this question has been puzzling scientists since the ancient Egyptian civilisation, modelling dense granular flows is still a significant challenge. From a technological point of view, predicting how grains flow (or not) is of substantial economic interest since grains are the second most used material in the industry. On the other hand, granular flows are at the core of large-scale geophysical flows, such as debris flows and landslides, which are among the most dangerous natural hazards that pose risks to people and infrastructure. In this talk, we will discuss the main reasons that make these flows so challenging and the progress made over the last two decades in the physical understanding and mathematical modelling of dense granular flows in the light of continuum theories. Along these lines, we will discuss simple techniques to characterise constitutive flow rules to describe the flow of granular materials and how this intrinsic rheology leads to very peculiar self-organisation patterns and flow instabilities.

Rheology of Dense Suspensions in Two-Phase Modeling for Bedload Transport

Tapia, Franco[1]; Pouliquen, Olivier[2]; Hong, Chong-Wei [2]; Aussillous, Pascale[2]; Guazzelli, Elisabeth[3]
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The accurate modeling of bedload transport in natural and industrial environments requires a comprehensive understanding of the flow behavior of dense granular suspensions. These systems—composed of solid particles suspended in a fluid—display rich and complex rheological responses that evolve across flow regimes and depend on various particle-level properties. This contribution introduces the rheology of dense suspensions and its crucial role in two-phase flow modeling, emphasizing the momentum and continuity equations that govern mixture behavior in bedload transport problems.

Suspension rheology can be described using two complementary frameworks. From the fluid dynamics perspective, rheology is formulated via effective viscosities—shear and normal—dependent on volume fraction and flow conditions. Alternatively, a granular physics approach describes the system through a frictional–dilatant framework, using the effective friction coefficient ($\mu = \tau/P$) and packing fraction ϕ, both functions of a dimensionless number: the viscous number $J = \eta_f \dot{\gamma}/P$ or its inertial counterpart, $I = d\dot{\gamma}\sqrt{\rho_p/P}$, depending on the dominant dissipation mechanism. These formulations unify the treatment of dry granular flows and immersed suspensions, enabling consistent integration into two-phase continuum models.

Particle shape and surface roughness reduce the maximum flowable packing fraction ϕ_c, revealing their geometric influence on the system size and the onset of jamming. These microstructural effects constrain how densely particles can pack and thus how the suspension flows under stress. In contrast, as particle inertia increases, the stress scale transit from a Newtonian-like ($\sim\dot{\gamma}$) to Bagnoldian ($\sim\dot{\gamma}^2$) behavior, inducing a transition from viscous to inertial regimes. This transition occurs at a fixed Stokes number (~10), independent of volume fraction, and enables a unified rheological description based on the principle of stress additivity.

To further broaden this unified framework, particle softness must be considered. Unlike rigid particles, soft particles deform under stress, allowing flow even beyond the jamming point. This introduces a second layer of complexity, linking rheology not only across flow regimes but also across the jamming transition itself. By incorporating pressure-dependent critical states, the resulting Soft Granular Rheology (SGranR) organizes data into two master curves—above and below jamming—capturing the full rheological spectrum of dense suspensions. This extended framework offers a robust foundation for modeling both natural and engineered flows involving soft or deformable granular materials.

Particle modification in granular flows and the associated impact on flow properties

Jones, Thomas[1]; Lipiejko, Natalia[1]

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Pyroclastic density currents (PDCs) are gravity-driven, hot, gas-particle mixtures that travel away from volcanic vents at speeds typically of the order of tens of metres per second. PDCs transport particles from micron-sized ash to clasts larger than a metre. High temperatures, large velocities and their ability to travel great distances on slopes of just a few degrees makes PDCs one of the most lethal geophysical flows. Such properties also make PDCs incredibly complex and, due to their destructive nature which limits direct observations, one of the least understood volcanic phenomena. One element of this complexity is particle size and shape modification which occurs through a range of non-linear processes that vary both spatially and temporally. These changes in grain size (i.e., size reduction) and grain shape (i.e., rounding) in turn effect the flow physical properties, such as the friction angles, fluidization behavior, permeability, and rheology. Here, we outline a set of experimental approaches to measure these physical properties both in the fluidized and unfluidized state. We further illustrate how grain size and shape both influence the rheology of fluidized gas-particle mixtures. We find their rheology to be non-Newtonian featuring (i) a yield stress where deposition occurs; (ii) shear-thinning behavior that promotes channel formation and local increases in velocity and (iii) shear-thickening behavior that promotes decoupling and potential co-PDC plume formation. To conclude, and to promote discussion, we will highlight some outstanding issues that require future experimental innovation and/or a numerical approach.

Laboratory modeling of gravity-driven flows: The emblematic dam-break configuration

Bougouin, Alexis[1]; Lacaze, Laurent[2]; Bonometti, Thomas[2]; Lhuissier, Henri[3], Metzger, Bloen[3], Forterre, Yoel[3], Dioguardi, Fabio[4], Capparelli, Giovanna[1], Nicotra, Eugenio[1], Sulpizio, Roberto[4]

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Geophysical gravity-driven flows – such as landslides, pyroclastic density currents, snow avalanches, and lava flows – are common events that actively shape landscapes at the Earth's surface, while posing serious hazards to populations and infrastructure. Despite significant advances, modeling these flows is still challenging because of their inherently complex, intermittent, and destructive nature.

To deepen our physical understanding of gravity-driven flows, laboratory-based approaches – combining analog experiments, numerical simulations, and theoretical models – offer an effective and insightful path forward. In this context, the emblematic dam-break configuration, which typically involves the sudden release of a heavy fluid into a lighter one, has been intensively studied for its conceptual simplicity, while accounting for gravitational forcing and unsteadiness of natural flows. Furthermore, this idealized setup provides a unified framework for simultaneously investigating the dynamics of flow triggering, propagation and deposition patterns.

In this lecture, we will cover the history of the dam-break configuration, from pioneer advances in describing classical Newtonian fluids – from inertial- to viscous-dominated regimes – to more recent studies extending to complex multiphase mixtures. This will show how the complexity of geophysical flows, particularly grain-fluid interactions that modulate flow dynamics, has been progressively integrated into modeling. This idealized setup has also played a key role in the development of numerical modeling and has become a widely used benchmark today. Finally, we will demonstrate the relevance of the dam-break configuration for investigating up-scaling from laboratory to field scales, as well as the influence of environmental factors like substrate roughness, through large-scale experiments currently performed at the University of Calabria (Rende, Italy).

Principles and Applications of Quantitative Textural Analysis

Sarocchi, Damiano[1]

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Quantitative textural analysis of sediments — focusing on grain size, shape, and fabric — has become a fundamental tool in modern sedimentology. The discipline has evolved from traditional techniques such as sieving and manual measurement of clasts to advanced methods that utilize digital image analysis to obtain precise and reproducible data.

This seminar aims to introduce participants to the principles and applications of quantitative textural analysis, combining an overview of classical approaches with a focus on innovative techniques developed at the Laboratory for Image Analysis and Analogue Modelling (LAIMA). These techniques enable the automatic measurement of key textural properties from digital images, supporting the detailed study of sedimentary and volcaniclastic deposits.

Throughout the seminar, participants will be introduced to the methodologies employed, the software available for each type of analysis, and examples of their application to real-world cases. Strategies for interpreting the resulting data will be discussed, along with case studies illustrating how quantitative textural analysis can contribute to deposit characterization, stratigraphic differentiation, process interpretation, and provenance analysis.

This seminar is intended for students, interested in applying modern tools to the study of volcaniclastic sediments, and seeks to provide a solid foundation for implementing these methodologies in academic contexts.

Multiscale modelling of rainfall triggered debris flows: Case studies from diverse geoenvironmental settings

Nedumpallile Vasu, Nikhil[1], Kumar, Sajin[2]; Krishna Priya, VK[2], Rajaneesh, A[2], Banks, Vanessa[1], Arnhardt, Christian[1], Hicks, Anna[1], Dashwood, Claire[1]

[1] British Geological Survey, UK

[2] University of Kerala, India

Rainfall-triggered debris flows are rapid mass movements involving saturated mixtures of soil, rock fragments, organic material, and water, capable of moving swiftly and destructively down steep slopes. These flows typically initiate through mechanisms such as runoff-generated and fluidisation of shallow landslides. Additionally, debris flows often coincide with flooding events, amplifying their combined destructive impacts. Their societal consequences are severe, ranging from fatalities and extensive economic losses to major disruptions of critical infrastructure, issues likely to escalate with climate change-driven increases in extreme rainfall events. A stark example occurred in 2024 in the southern Indian state of Kerala, resulting in over 200 fatalities and substantial economic losses. Such incidents highlight the vulnerability of densely populated regions, particularly in the Global South, and underscore the necessity for precise hazard assessments. Traditional landslide susceptibility mapping used in planning predominantly addresses initiation zones but doesn't give emphasis to the post-failure runout. Consequently, risks may be underestimated for populations residing beyond initial landslide-prone areas.

Addressing these shortcomings requires analyses at multiple scales, each tailored to distinct stakeholder needs and policy contexts. At the regional scale, models such as Flow-R rapidly evaluate extensive geographical areas, identifying high-risk corridors for debris flow. This scale of analysis is essential for policymakers, regional planners, and disaster management authorities who require broad overviews to inform strategic land-use decisions, climate-resilient policies, and allocation of monitoring resources. Conversely, at a local or site-specific scale, detailed physics-based models such as RAMMS provide refined simulations of debris flow behaviour. These models generate detailed predictions of flow velocity, depth, runout extent, and deposition patterns, directly informing the design of protective infrastructure, engineering stabilisation measures, and emergency response planning.

This presentation will showcase comparative case studies conducted at these different scales, reflecting diverse geoenvironmental contexts. Examples include regional-scale Flow-R modelling on the volcanic terrains of Tristan da Cunha and along the critical infrastructure corridor in Lobito, Angola, as well as site-specific Dan3D and RAMMS modelling in Kerala's steep tropical environments, temperate landscapes around Glenfinnan, Scotland, and monsoonal terrains in South Korea. These case studies illustrate the importance of conducting analyses at appropriate scales based on data availability, computational resources, and specific stakeholder requirements. Recognising the significance of scale-specific analyses ensures targeted, informed decisions across multiple levels of governance, ultimately enhancing community resilience against debris-flow hazards.

Abstracts – PhD-ECR day

Rheological Properties of Fluidized and Non-Fluidized Pyroclastic Material

Muhammad, Ammar[1]

[1] Department of Earth and Environmental Sciences of the University of Bari, Aldo Moro

The term "granular materials" or "bulk solids" refers to individual particles that are in the fluid phase and can flow under stress, which includes dry particles, pastes, suspensions, and slurries. The essential mechanical aspect of granular materials is the interaction between their particles and their interstitial fluids (Savage, 1993). Natural or man-made granular materials consist of different sizes, frictional properties, and shapes of grains. For decades, many scientists and geologists have been interested in the liquid-like behavior of granular flows because, unlike solid materials, their fluid-like behavior is fascinating. Among all natural geophysical mass flows, granular systems are considered the most complex

because these systems act like both fluids and solids at different times. The dynamics of granular materials are controlled by interstitial fluid, allowing us to predict how models simulate the flow of these systems. This understanding can inform us about the locations of solid stresses and pore fluid pressure within these currents. Geophysical flows like avalanches and pyroclastic flows are non-fluidized and fluidized at the same time, so a single model is required that can simulate all types of behavior within natural geophysical flows like pyroclastic currents, debris flows, and avalanches. (Eric C. P. Breard, 2022). Pyroclastic density currents are granular flows of volcanic particles (ash, pumice, and rock fragments) and hot gases (SO2, CO2, and water vapors) that move downslope, generated by explosive volcanic eruptions. These may be concentrated flows or dilute flows. When granular mixtures are immersed in fluids, they become fluidized and act like fluids. Over time, fines enter into the gaps or voids between blocks and cause the packing of mixtures, and fluidization depends on this particle packing. Based on Eric C. P. Breard's analysis, the packing density will be 0.637 if these particles are spherical. The fine true packing density is 0.48 to 0.54 because these are not exactly spherical. Packing density rests on sorting and GSD of particles (Eric Breard, 2023). In fluidized granular beds, a vertical gas flux lifts particles against gravity, making particles lighter, whereas grain-to-grain contact of particles reduces and makes it fluidized, in response inertial number increases (Eric C. P. Breard, 2022). The material will be called fluidized when gas velocity increases, at which time the dynamic pressure drop equals the bed weight per unit area. This is due to the decrease in interparticle friction and the material adopting fluid-like behavior (T. H. Druitt, 2004). When pyroclastic material is non-fluidized, these flows through the Brazil nut effect, where larger particles come to the surface while smaller particles move down by passing through the voids of larger grains. This phenomenon is known as the Brazil nut effect, and it occurs in geophysical flows. It is also known as an inversely graded deposit (T. Barker, 2020).

References

Eric C. P. Breard, et al. (2023). The fragmentation-induced fluidisation of pyroclastic density currents. doi: https://doi.org/10.1038/s41467-023-37867-1

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Rheological control on deposit-derived pyroclastic density currents (DD-PDC)

Teresa Oreade, Grillo[1], Alessandro, Vona[1], Federico, Di Traglia[2], Alessandro, Frontoni[3], Claudia, Romano[1]

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[3] Consiglio Nazionale delle Ricerche, CNR-IGAG Roma (Italia)

Deposit-derived pyroclastic density currents (DD-PDC) originate from the gravitational instability of materials deposited during eruptive activity. The collapse of hot volcanoclastic material generates incandescent avalanches, a hybrid phenomenon that has intermediate characteristics between pyroclastic density currents (PDC) and rock avalanches. These events typically involve relatively small volumes (ranging from tens of thousands to tens of millions of cubic meters) but can travel several kilometers from the source area and are released at very high temperatures, posing potential dangers to nearby communities and tourists.

DD-PDCs are more common than previously thought, and increased observations in recent years have shown that they are quite frequent in mafic-intermediate volcanoes with low to moderate activity. The steep slopes of volcanoes and material accumulation near vents promote instabilities.

This project aims to study the predisposing factors and triggering processes of DD-PDCs.

The cases of study are Vesuvius and Stromboli volcanoes because this phenomenon occurred during their recent history, respectively in 1944 eruption of Vesuvius and in 1930 eruption of Stromboli.

The study employs various methodologies, from the classic petrographic and geochemical characterization of selected volcanic deposits to the analysis of hightemperature mechanical strength variations in rock/deposit, to consider the effects of different accumulation rates and degrees of deposit welding, as well as variations in porosity and crystallinity of the materials.

High-temperature deformation experiments are performed to investigate the complex rheology of the multiphase mixture (melt + crystals + pores) by exploring directly the rheological behavior from brittle to viscous deformation. These experiments are conducted using the Volcanological In-situ Deformation Instrument (VIDI), capable of uniaxial deformation of natural silicate melts at up to 1100°C.

The analysis of the resulting flow curves is necessary to define uniaxial strength and mechanical weakening in response to the formation of shear bands and brittle/viscous deformation. This information helps to characterize the transition between volcanoclastic accumulations that evolve into lava flows or fragmented material prone to forming deposit-derived PDCs.

Understanding the rheological constraints of DD-PDCs will contribute to mitigating the short- and long-term risks associated with these events, interpreting monitoring data from active volcanoes, and supporting appropriate land-use planning in surrounding areas.

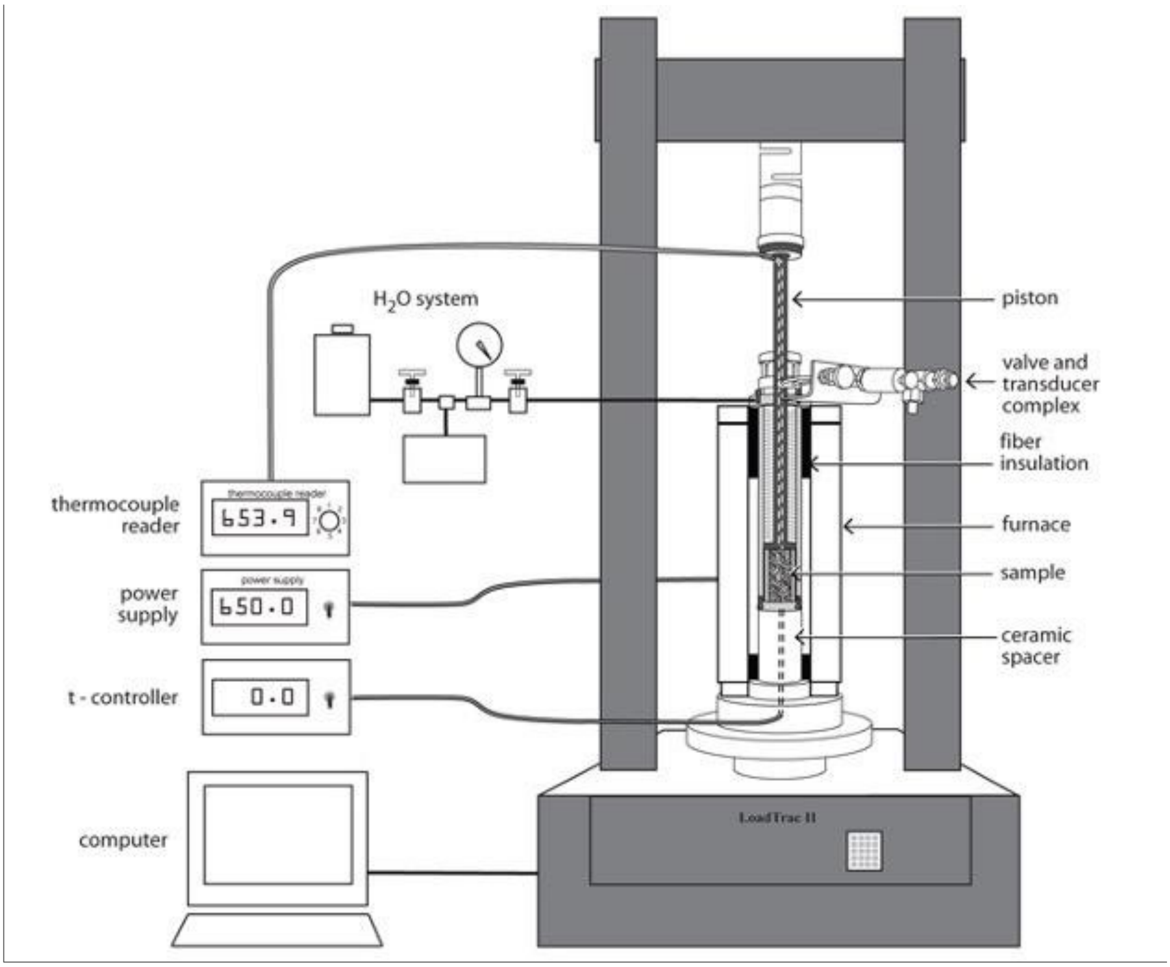

Figure 3. Schematic representation of the experimental apparatus (Quane et al., 2004).

Rheological Characterization of Volcanic Finse Sediment Suspensions: Intregrating Hyperconcentrated and Debris Flow Conditions

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Lahars are two-phase gravity flows whose behavior strongly depends on the interaction between the large clast phase and the fine sediment suspension phase. In particular, the rheological behavior of the fine sediment suspension has the greatest influence on the lahar movement, as it controls the transportation and sedimentation of large clasts. Fine sediments are considered to be particles smaller than 63 microns (silt and clay fractions) and in some cases, particles as large as 125 microns (very fine sand).

This work proposes an appropriate measurement protocol for the rheological characterization of fine sediment suspensions of volcanic origin. This protocol establishes the physical conditions necessary to achieve laminar and steady flow within a homogeneous suspension. It involves testing within a shear rate range of 102 and 10-2 s-1 with pre-shear and homogenization steps, using both absolute concentric cylinder and relative vane geometries. Sediment suspensions were studied with volumetric particle concentrations ranging from 45 to 60%. This ranges incorporates hyperconcentrated flows and debris flows into the experimental framework to better represent natural processes.

The results suggest that the suspensions follow a Herschel-Bulkley behavior, with yield strength values ranging from 10-3 to 10-1 Pa under shear rates between 10-2 and 10-1 s-1. Additionally, an increase in apparent viscosity values was observed at shear rates greater than 5x101 s-1 across all suspension concentrations, indicating thickening behavior. At lower shear rates, between 10-1 and 5x101 s-1, an inverse relationship between apparent viscosity and shear rate suggests a thinning behavior.

Finally, the study shows similar trends in rheological data obtained using vane geometry, with a scaling factor that allows for comparison with data obtained from absolute geometry, even when values differ by at least one order of magnitude. This highlights the importance of geometry selection as a critical tool in the characterization of sediment suspensions and critiques the widespread use of relative geometries by the geological community, sometimes without considering the implication of data scaling.

Pysammos: a new open-source Coarse-Graining tool to analysing the rheology of diverse volcanic granular flows.

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Granular flow processes with varying types of interstitial fluid and coupling regimes are ubiquitous in volcanology: from concentrated underflows in pyroclastic density currents, to debris flows, and crystal mushes in magma. However, the behaviour of these highly complex granular flows remains poorly understood. Modelling of granular flows through software packages that couple the Discrete Element Method (DEM) with Computational Fluid Dynamics (CFD) can provide detailed information at high temporal and spatial resolution of particle-particle and particle-fluid interactions. As such DEM-CFD approaches provide an invaluable tool to study the small-scale behaviour of granular flows, and are instrumental in the development of constitutive models used to understand rheology of granular materials. DEM-CFD models yield fundamental physical properties, for instance: particle force and velocity, (for solid phase) and fluid pressure (for fluid phase). To obtain continuum fields of relevant variables from discrete data (e.g., stress and strain tensors, pressure etc.), DEM-CFD outputs must be processed through a method called Coarse-Graining (CG). In this work we present Pysammos, a new python-based CG package designed to: maximise computational efficiency through -amongst other strategies- parallel computing; be user-friendly; and open source. Our CG code is able to process polydisperse granular mixtures of any particle shape, as well as offering the option to separately analyse different particle phases. Pysammos postprocesses output files of DEM-CFD software packages, such as MFiX and LAMMPS, and yields vtkhdf outputs ready to render on the open-source ParaView visualisation software, as well as a more generic h5 format for further data analysis. Pysammos is able to operate in a regular computer as well as in HPC, as it runs with Numba. We present exemplar applications such as crystals and magma in a conduit, bedload transport and impact cratering.

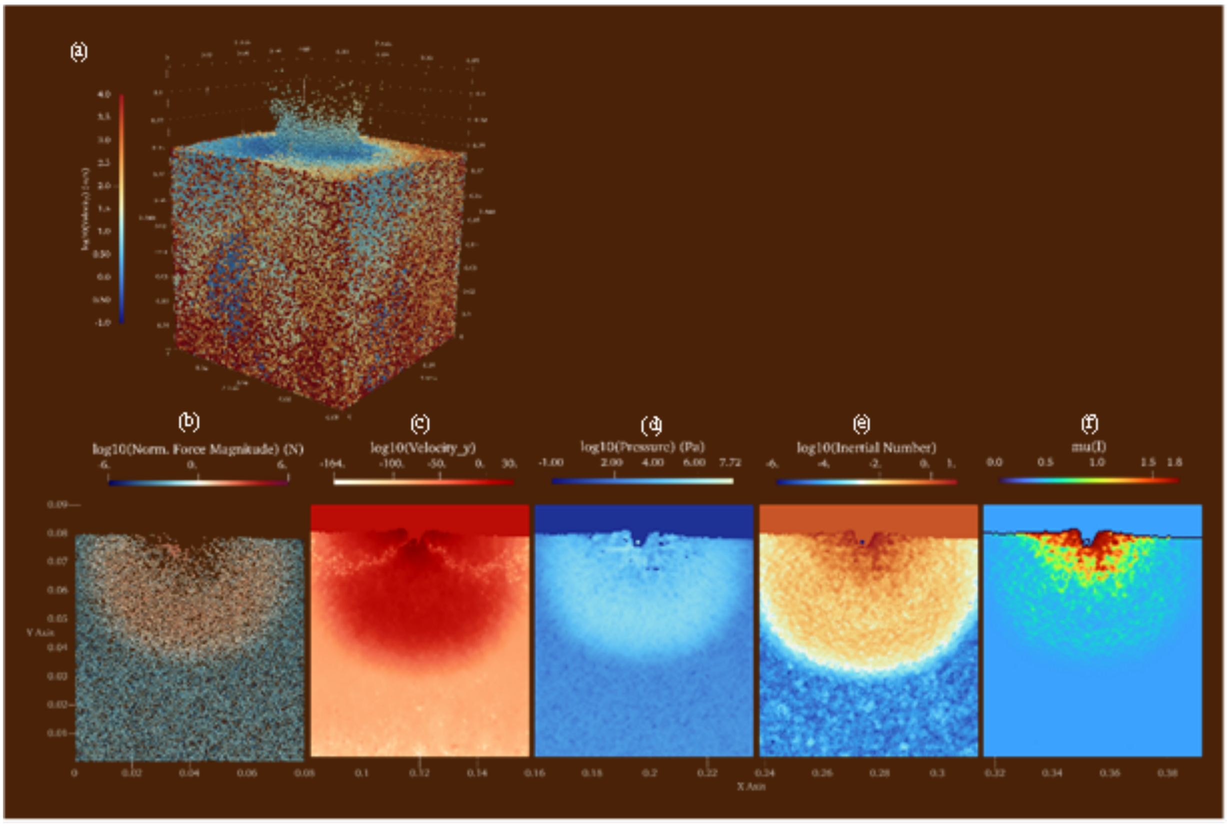

Figure 4. Application of Pysammos coarse-graining on a DEM model of a high-speed ballistic impacting into a polydisperse granular cube (volume-weighted average diameter d43 = 0.0008m) of side length 8cm. (a) Snapshot of the impactor hitting the bed. Slices at 4cm depth of the particle contact forces (b) and coarse-grained fields of the vertical velocity (c), pressure (d), inertial number (e) and coefficient of friction as a function of inertial.

CARG-based (Sheet 416, 417, and 364) volume reassessment for the VEI 6/7 ignimbrites along the Roman Magmatic Province

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The renewed start and funding of the CARG project in volcanic areas have enabled new surveys and refinements of data on the volumes and extents of ignimbrites across the Roman Magmatic Province (RMP). To date, the investigation has focused particularly on the Roccamonfina volcano (Sheets 416 Sessa Aurunca and 417 Teano) and the Bracciano caldera (Sheet 364 Bracciano). The project is enhancing field data from areas already surveyed in past decades, while integrating new models and technologies to obtain more accurate quantifications of erupted magma volumes and a consequent re-evaluation of eruption magnitudes. Preliminary results indicate that the volume of some ignimbrites increases by more than one order of magnitude, suggesting that many other ignimbrites within the RMP may have been significantly underestimated, such as the Brown Leucitic Tuff and the White Trachytic Tuff pertaining to the Roccamonfina volcano. This reassessment potentially characterizes the RMP as an ignimbrite flare-up system, comparable to some of the largest and most impactful volcanic provinces worldwide, such as the Taupo Volcanic Zone. In this framework, new field and literature data, borehole stratigraphy, and GIS-integrated methodologies were combined to refine the bulk volume, areal extension, and magnitude of a case-study ignimbrite, with the aim of developing a standardized procedure for computing and integrating field surveys applicable to all ignimbrites.

Modelling approaches for building probabilistic hazard maps of lahars inundation at Campi Flegrei caldera (Italy)

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Following a volcanic eruption, the formation of lahars, dense flows composed of volcanic debris and water with a mud-like consistency, can occur. These flows typically channel through valleys and settle at the base of slopes, representing a very hazardous volcanic phenomena due to their high mobility, energy, and destructive potential.
The Campi Flegrei caldera (Italy) is particularly vulnerable to lahar-related hazards since the slopes of the inner craters, as well as nearby valleys are mantled with tephra deposits originating from past explosive eruptions. These deposits are highly susceptible to remobilization, especially during periods of intense or prolonged rainfall. The area is also densely urbanized with significant human activity that, in places, has profoundly altered the stratigraphy of the shallowest layers of the stratigraphic sequences. Following the methodological approaches proposed in previous studies (de' Michieli Vitturi et al., 2024; Sandri et al., 2024), in this contribution we aim to show the numerical modelling approaches used to simulate the lahar inundation within the Yellow Zone area (approved by the Campania Region in 2015; Fig. 5a) resulting from remobilization of tephra deposits from a medium-sized eruption at the Campi Flegrei (Astroni type), which generates a lahar from at least one of the macro-basins considered (Fig. 5b).
Using the last version of the IMEX_SfloW2D model (de' Michieli Vitturi et al., 2023;2024) combined with the availability of computational resources provided by the Supercomputing ICSC (Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing) through the Istituto Nazionale di Geofisica e Vulcanologia and University of Bari, we are able to take into account the spatial probability of opening vents and to explore the uncertainty of the initial flow conditions on the invasion of lahars in the target area by sampling coherent sets of values for the input model parameters and performing a large number of simulations (ca. 100 for each catchments).
Field data, when available, were used to constrain the range of parameters values (e.g. GSD, sediment porosity, density), along with the maximum-ignorance uniform probability distributions to set probabilistic distributions describing relevant parameters. The post-processing of the simulation outputs led to the production of probabilistic hazard curves and maps for the maximum flow thickness reached on a grid of points covering the investigated area. This is an ongoing study that can offer a valuable support for civil protection planning and risk mitigation efforts.

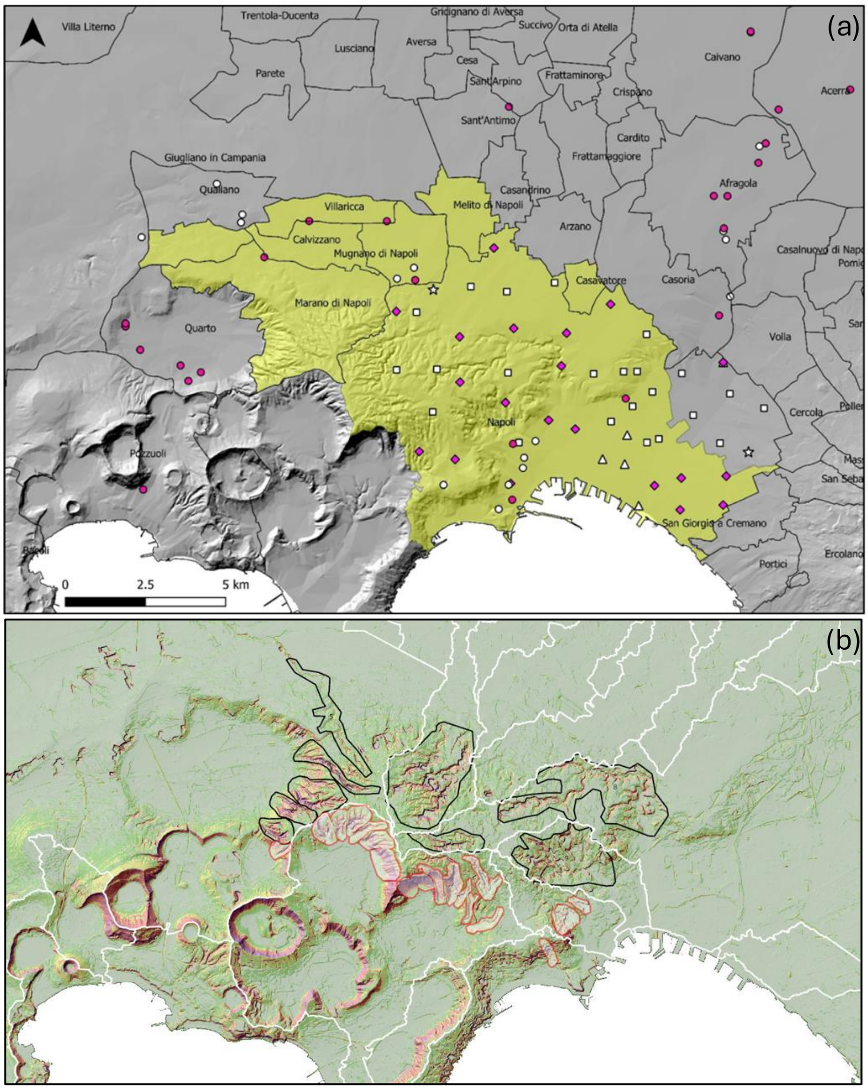

Figure 5. a) DEM showing Campanian region with the highlighted Yellow Zone area and districts limits (white lines). Symbols (white circle and pink squares represent the drillings within the alluvial material (from internal report INGV, 2018); b) 5m resolution DEM showing the macro-basins (white lines) selected for numerical simulations. In orange the inner catchments within the Red Zone area.

Investigating PDC-Forming Mechanisms at Basaltic Volcanoes through Large-Scale Granular Flow Experiments

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Pyroclastic density currents (PDCs) represent one of the most hazardous phenomena produced by volcanic eruptions. They are typically associated to intermediate to felsic magmas and are commonly triggered by mechanisms such as eruptive column collapse, lateral explosions, or gravitational dome failures. However, even eruptions of small to moderate magnitude involving basaltic magmas have recently been able to generate dangerous PDCs. Notable examples include recent activity at Volcàn de Fuego (Guatemala), Klyuchevskoy (Russia), Stromboli and Etna (Southern Italy). In several cases, these granular flows displayed remarkable mobility, traveling unexpectedly long distances despite their intrinsically high basal friction. Such flows are primarily generated by the instantaneous collapse of a lava fountain/column and more frequently by the gravitational collapse of pyroclastic material deposited on steep volcanic slopes, often near the angle of repose of granular volcanic material (30-35°). As a result, they pose a potential hazard both to local communities inhabiting the slopes of these volcanoes and to the numerous tourists and hikers who frequently visit them. Despite their significance, PDCs originating from the collapse of pyroclastic deposits on basaltic volcanoes remain underexplored and are still poorly understood.

To contribute to filling this gap, this study is focused on conducting large-scale experiments, carried out through the “GRANFLOW,” an experimental flume designed and built at the Laboratory of Image Analysis and Analog Models (LAIMA) of the Institute of Geology at the Universidad Autónoma de San Luis Potosí, Mexico. In particular, the primary goal of these experiments is to simulate and compare the two dominant types of PDC-forming mechanisms observed in both mafic and silicic volcanoes, using basaltic scoria and latitic material as terms of comparison. The first mechanism, associated with the collapse of the eruptive column, was reproduced through a “Free-Fall” release setup. The second, related to the gravitational failure of portions of the volcanic cone, was simulated using a “Dam-Break” configuration. These experimental setups allowed for the investigation of how bulk density and clast morphology influence the rheological and dynamic behavior of the flows, as well as the kinematics and depositional architecture of the resulting deposits.

Furthermore, a quantitative morphological analysis of the clasts was carried out to evaluate particle abrasion during transport in granular flows driven by particle-particle interactions. For this purpose, the mixtures were placed for specific time intervals in a standard rotating drum known as the Los Angeles Abrasion Machine (LAAM), commonly used in civil engineering to assess the abrasion resistance of materials.

This type of approach offers new insights to improve the understanding of the complex processes leading to the formation and emplacement of PDCs, which still remains a challenging task. Moreover, this type of study is essential also for a more detailed assessment of the hazards related to this type of phenomena, with the aim of reducing the risk especially in the proximal areas of active basaltic volcanoes frequented by numerous tourists.

Multi-parametric study of the 2020-2022 paroxysmal activity at Mt. Etna: the role of fluids in the trigger mechanisms, durations and energy of the eruptive phenomena

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Between December 2020 and February 2022 Mt. Etna exhibited a sequence of 62 paroxysms. A comprehensive petrological and geophysical investigation was conducted to understand the dynamics of magma storage, transfer, and eruption at the South East Crater during this intense period of activity. Petrological approach focused on quantitative chemical microanalysis applied on glasses and compositional core to rim profiles of 220 olivine crystals selected from each paroxysmal event. Analysis of the compositional zoning in olivines combined with thermodynamic modeling and the application of diffusion modeling of FeMg in olivine lattice revealed that the first phase of the 2020–22 sequence (December 13, 2020 – April 1, 2021) was marked by the rapid migration of mafic magma from the deepest levels of the plumbing system to intermediate and shallow levels, similar to the behavior observed during the 2015–16 paroxysmal eruptions at the Voragine Crater. This fast migration facilitated more frequent eruptions, driven by efficient drainage at shallow levels, with patterns reminiscent of the 2011–13 sequence. At the same time, geophysical data, particularly tilt deformations, volcanic tremor amplitudes and gravimetry, were analyzed to characterize the eruptions and their preparatory phases. The study identified three distinct periods based on deflation amplitudes associated with lava fountains and other key parameters such as inflation and deflation velocities, and volcanic tremor amplitudes. Period I, that overlaps the first phase, was characterized by higher values of these parameters, indicating the transfer of large volumes of volatile-rich magma towards the surface. Nonetheless, gravity shows no significant variations in this period pointing out to a gravity balance determined by a continuous influx of new magma from the deep portion of the plumbing system, in agreement with petrological data. The second phase (May 19, 2021 – February 21, 2022) showed slower magma transfer timescales, primarily involving the intermediate and shallow levels of the volcano's feeding system. Geophysical data highlight two different periods within this second phase: Period II (19 May - 28 June 2021) and Period III (28 June - 23 October 2021). Period II showed lower values, suggesting a lack of significant new magma injections from depth. Period III, however, exhibited a general increasing trend, possibly linked to gas flushing from magma in deeper parts of the plumbing system. Notably, the gravity decrease observed during the second phase indicates an imbalance between the quantities of incoming and outgoing magma. Also, detailed analysis of tilt signals revealed short-lived inflations during the early stages of lava fountains in Period II, underscoring the critical role of gas in driving the inflation-deflation cycles associated with these eruptions.

The study emphasized that the influx of volatile-rich magmas from the deepest parts of the plumbing system has been a recurring trend at Mt. Etna over the past decade, influencing whether volcanic activity at the surface is effusive.

The Role of Soil Moisture and Rheology in Sarno Volcaniclastic Debris Flows: Insights from Laboratory and Flume Experiments

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Volcaniclastic debris flows are hazardous, gravity-driven mass movements involving saturated mixtures of volcanic sediments, mud, and water. Their initiation requires the co-occurrence of steep slopes, unconsolidated materials, and sufficient moisture. This study focuses on the Campanian Volcanism area, particularly the Sarno region, which experienced catastrophic debris flows in May 1998, resulting in approximately 160 fatalities. The area's geomorphological and lithostratigraphic characteristics make it particularly prone to slope instability due to the presence of steep calcareous bedrock overlain by alternating pyroclastic and colluvial deposits, combined with both natural and anthropogenic scarps. To investigate the hydrological and mechanical processes contributing to debris flow initiation, a multimethodological research strategy was adopted. (i) Laboratory rheological tests were performed using an Anton Paar Multidrive MCR702e rheometer to evaluate the effect of progressive increase in volumetric water content on the shear strength of volcanic ash samples under controlled temperature and humidity conditions (T = 27 °C, RH = 50%). The resulting data were used to define failure envelopes based on the Mohr–Coulomb failure criterion. (ii) Mineralogical analyses via X-ray diffraction were conducted to identify the presence of clay minerals within the samples, as these are known to influence the rheological behaviour and water retention capacity of volcanic soils. (iii) In parallel, large-scale flume experiments were carried out using a three-layer ash–pumice–ash configuration with a 38° slope inclination (Fig.6).

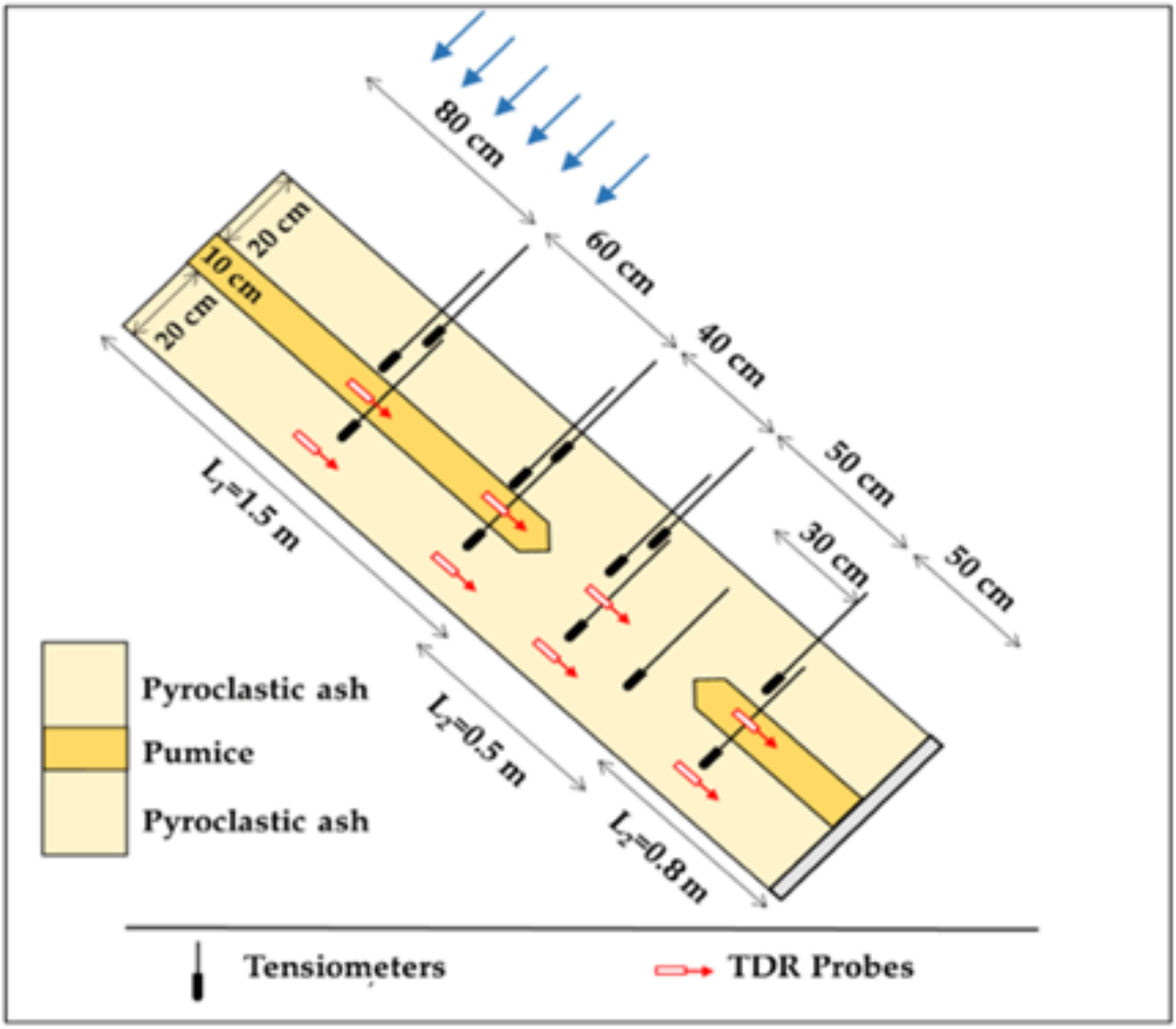

Figure 6. General sketch of the 3-layer geometry (ash-pumice-ash) with 38 degrees of inclination experiment.

These tests simulated rainfall infiltration and monitored the evolution of important hydrological parameters, including suction, pore water pressure, and deformation, through the use of integrated sensors and high-frequency image acquisition.

The combined results derived from this multidisciplinary approach highlight the influence of soil moisture on slope failure processes. These findings contribute to a better understanding of debris flow triggering mechanisms and provide a valuable framework for improving early-warning systems and hazard mitigation strategies in volcanically active areas.

Numerical modelling of cliff stability problems in soft calcarenites: insights from MPM technique applications

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Rockfalls and rock sliding processes induce high risk conditions for communities and infrastructures located along the coast-lines, in terms of both people safety and exposed economy. Hence, advancements in the methodologies for hazard assessment of coastal rocky cliffs need to be developed. The Finite Element Method (“FEM”) is widely used in the simulation of geotechnical applications. However, as regards the specific field of slope stability, owing to the limitations of FEM to model problems involving large deformations, many efforts have been made to develop methods free of mesh entanglement.

The stability of soft rock cliffs can be also treated nowadays by using advanced calculation techniques, such as the Material Point Method (“MPM”, Sulsky et al., 1994) approach, which is capable of simulating in a proper way the large-strain evolution of soil/rock masses. MPM discretizes the continuum by means of a set of lagrangian points (“material points”), each one represents a subdomain of the media and carries all the information. Besides, governing motion equations are solved at the nodes of a background computational mesh which remains fixed throughout the calculation and covers the full domain of the problem.

This work is aimed at highlighting the role of large-strain formulations for numerical analyses dealing with sea cliff stability problems involving soft calcarenites by means of the application of MPM, as compared with traditional FEM analyses.

The application of the method to a case study is then presented and discussed; it regards a 600m long sea rocky cliff located at Sant'Andrea (Melendugno, Italy), along the southern Adriatic Sea coastline. Here, the cliff is made up of an about 15 m-thick sequence of laminate calcisiltites alternate with bioturbated calcarenites belonging to the Uggiano la Chiesa Fm. (Middle-Upper Pliocene).

Finally, a parametric analysis is conducted to investigate the failure mechanisms and emphasize the importance to further investigate the behavior of weathered rocks subjected to erosion and dynamic loading.

Visits to the experimental facilities

University of Bari

On the second day of the workshop the participants visited the experimental facilities of University of Bari most relevant to the workshop topics, namely:

- Anton Paar FRS1800 furnace rheometer.

  Fabio Dioguardi gave a brief introduction on this facility that is designed to characterize the rheological properties of melts. Specifically, the instrument can be used to obtain the rheology of magmas, which has applications in magma rise and lava flow modelling. Furthermore, the instrument can identify the transition point between a viscous and an elastic behaviour of the melt at varying temperature, a fact that has important implications in understanding eruption style transitions, e.g., the from effusive to explosive eruptions.
- Micromeritics Ultrapyc 1350 gas pycnometer.
  The instrument is designed to measure the density of objects. In the laboratory, it will be used for measuring the density of volcanic particles, which is a difficult task particularly for fine particles (e.g., ash). This pycnometer can analyse the density of varying volumes of granular materials.
- Anton Paar Autosorb 6200 High Vacuum Physisorption Analyzer.
  With this equipment, it is possible to determine the specific surface area of particles (surface area / mass), together with their microporosity. The specific surface can be seen as a proxy of particles' irregularity and surface roughness, which is responsible, among other processes, of the particles/fluid and particles/particles drag. The particles/fluid drag can be modelled in a quite straightforward way for single particles, but there is still a significant knowledge gap for particles mixtures, in particular for non-spherical particles.
- Anton Paar MCR702e Modular Compact Rheometer.
  This rheometer is a powerful tool since it allows characterize several rheological properties of fluids and granular materials thanks to the availability of multiple geometries. Currently, it is being employed for characterizing:
  - The failure envelope (Mohr circle) of volcaniclastic sediments, which is a parameter that can be used to predict in which conditions a sediments' deposit would fail and eventually trigger a gravity current.
  - The rheology of slurries, i.e., water/particles mixtures, with both absolute (e.g., the concentric cylinders) and relative (e.g., vane) geometries. The former measure the real rheology of the material, but are limited to very small gaps (mixture quantities), which in turn limit the range of applicability (e.g., the maximum particles size in the slurry). The latter are generally characterized by much wider gaps, hence allow exploring wider grainsize distributions, but provide only qualitative information. Therefore, the two geometries are used together to characterize the complex rheological properties of water-particles mixtures in the volcanological contexts (e.g., lahars).

- The rheology of powders in both fluidized and not-fluidized conditions. The facility is applied to volcanic particles as to characterize the rheological properties of pyroclastic density currents.

University of Calabria

On the third day, a demonstration of current dam-break granular flow experiments at the CAMILab (University of Calabria) was conducted. This demonstration had two main objectives:

1. to showcase the multi-purpose large-scale laboratory flume with dimensions of 6 meters long, 1 meter wide and 1 meter high, and equipped with multiple measurements systems (e.g., camera, height and pressure sensors), and
2. to disseminate the ongoing research activities within the laboratory (Figures 7 and 8).

Figure 7. Picture showing the flume already loaded with granular material.

Figure 8. Detail of the laser distance meters and the rough carpet.

The experimental demonstration involved the sudden release of approximately one-third of a tonne of building sand (2-3 mm, provided by Varga) by opening a vertical gate manually with a steel cable, along a plane roughened by fine building sand and inclined at about 36 degrees from the horizontal.

[Link to the video, stored in the project folder]

The recorded data (e.g., camera movies, pressure signals) were then presented to the audience, and the ongoing series of experiments was discussed in detail the following day.

Round table discussions

On the last day of the workshop round table discussions were conducted. Three topics were identified:

- **Towards accurate and efficient numerical modelling**
  How can we move from complex, time-consuming simulations to fast, user-friendly numerical models for forecasting natural granular flows – without reducing accuracy?
  Reliable predictions of natural gravity-driven flows require accounting for the wide range of mechanisms (segregation, pore pressure, topography, etc.) governing granular flows, yet doing so often results in computationally intense models unsuitable for predicting applications, especially in crisis period. What strategies could resolve this issue? Should we enhance depth-averaged models to better incorporate complexity, or should we explore alternative modelling approaches?
- **From the laboratory to the field and vice versa**
  One major barrier to accurate modelling is the unexplained high mobility of natural granular flows. Although many laboratory experiments have been conducted on specific physical mechanisms, which processes should now be prioritized to significantly advance our understanding and modelling capabilities?
  Fragmentation, unknown scale effects, fluid effects, dense-dilute exchange, underexplored processes – disregarding, from now, the practical challenges of conducting such experiments
  In laboratory, we have powerful tools at our disposal, such as the mu(I)-rheology, helping to describe granular flows. However, these tools often depend on material and environmental-dependent parameters, which are unknown at the field scale. How can we better transpose these tools into field applications?
  What methods can be used to constrain the necessary parameters in situ?
- **Validating laboratory-based hypothesis in the field**
  Many mechanisms identified in laboratory appear to significantly influence the behaviour and deposition of granular flows. Yet, confirming their relevance in the field remains a challenge due to the intermittence, complex and destructive nature of real events.
  What are the most promising strategies for validating or refuting these mechanisms in natural events – through enhanced field instrumentation, numerical simulations or other approaches?

The round tables mixed senior, early-career researchers and PhD students, with one PhD student identified as the representative of the table who presented the outcome of the discussions to the general audience at the end. All participants could take part to any table at any time.

Towards accurate and efficient numerical modelling (Claudia Eljias Parra)

The table identified two key topics:

1. **How to move from complex/computationally costly models to easy/fast numerical models still conserving accuracy?**

   Categorise existing models depending in the aim of the simulation:

   - Depth-averaged models (DAMs)
     They are able to incorporate a decent amount of complexity while still providing a fast and accurate enough results for hazard assessment.
     Their use should be pragmatic, whose users don't necessarily need to know about the details of the numerical strategies. For that reason, we suggest the release of a report that informs users of DAMs for hazard assessment about the qualities of each code in relevant terms:
     - Model relevant for each type of flow (even in the shape of a flowchart to aid protocols)
     - Input parameters needed
     - Most sensitive input parameters
     - Etc…
   - "Oracle" complex models (e.g., 3D multiphase flow models, lagrangian-eulerian, etc. …)
     These models are able to incorporate a high level of complexity. They can be used to test hypothesis in order to inform changes (e.g., simplifications, implementations) of DAMs. For instance: do large blocks in lahars affect the flow dynamics significantly?

   Furthermore, in order to decrease the computation time of the production of probabilistic hazard maps, new mathematical tools should be employed/developed in order to reduce the number of simulations to consider and therefore run.

2. **How can we improve the design of experiments to better understand the physics of flows to implement them in the models?**
   It is suggested to measure the processes that the scientific community want to implement in these models (e.g., particle fragmentation, energy dissipation due to contacts, textural and compositional analysis) in a way that the numerical models can incorporate them directly (e.g., mass balance equation).
   Furthermore, the uncertainty of the physical models included in the numerical models should be quantified. To fulfil this purpose, benchmarking to experiments could be a good option as the inputs and characteristics are controlled. However, the experiment should be carefully designed in order to capture the real difference between the experiment and the theory.

From the laboratory to the field and vice versa (Giorgio Costa)

The table identified the key issues and limitations of the experiments that should be addressed in order to bridge the gap between the experimental and the natural scale:

- Grain size and particle shape: Granulometry and particle shape are crucial in influencing flow dynamics, yet they cannot be reproduced in full in a laboratory experiment due to scaling constraints.
- Pore pressure and fluidization: This remains a major unknown both in natural cases and in laboratory experiments. Pore pressure can be measured in granular flows experiments, but it is difficult to quantify its effective influence on the flow dynamics. In most experiments, the measured pore pressure is negligible compared to the static load of the flowing material. Is this the case in natural flows?
- Segregation: Fine material can migrate to the base of the flow, potentially altering its dynamics. Whilst this is not necessarily an issue (natural flows are normally polydisperse), it can be in the lab since it represents an additional parameter to be considered in the design and analysis of experiments.
- Topography: Reproducing the effective topography is difficult because the whole process would need to be scaled. We can consider changes in slope or obstacles, hence focusing on specific topographic features.
- Sustained vs. Impulsive flows: Most laboratory experiments simulate short, impulsive releases. However, natural currents can be sustained over longer durations.

Validating laboratory-based hypothesis in the field (Letizia Pace)

The table discussed about which parameters should be measured in the field (during and after the occurrence of a gravity flow) for the purpose of validating laboratory-based hypotheses in the field. They identified the following parameters:

- Flow thickness
- Flow velocity
- Flow acceleration
- Deposit grain size
- Erosion / Deposition
- Slope angle
- Basal roughness
- Flow temperature
- Pore pressure

Whilst measuring these parameters is always possible in the laboratory, this is often not the case in the field, in which case the flows are normally very challenging to monitor in real time. The table therefore discussed on the sensors and new technologies that can be potentially employed to improving the real-time monitoring of these flows. They identified the following sensors:

- Radar Doppler to measure the bulk flow velocity
- Catching boxes, to measure the particles' grain size distribution along the flow path
- Accelerometers, for following the flow and get information about particles contacts. These may be useful also for cliffs.

- Normal pressure sensors, for estimation of density from the measured static loads.
- Thermocouples for measuring the temperature.
- Geophones and infrasound sensors, for fragmentation and particles-substrate collisions. The sensors should be constrained in the laboratory first.
- GPS antennas incorporated in a resistant shell to mimic a particle, placed in area that can potentially be the source of future flows.
- Cameras.
- Load sensors to measure the impact on structures.
- Nano-particles to act as tracers.
- Hall-effect sensors, to measure velocities and local acceleration within the flow (to be positioned similar to the GPS antennas above).
- Satellite retrievals.

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