Artificial juvenile pyroclasts from wet and dry “eruptions”: impact of magma composition on grain sizes and particle shapes

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Abstract

Juvenile pyroclasts come in a range of sizes, shapes, surface features and internal textures (e.g., for basalt, sideromelane versus tachylite). These parameters are influenced by how magma deforms, fragments and cools, which is controlled by factors such as magma viscosity, surface tension, crystallinity, volatile content, and interaction with external water, including Molten Fuel Coolant Interactions (MFCI) and less explosive interactions.

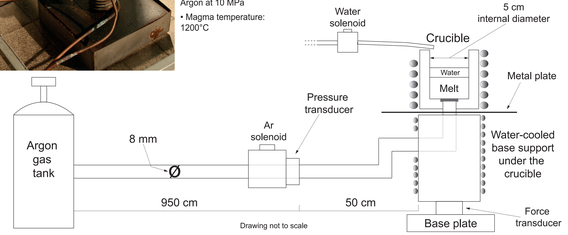
To understand how both silica content and interaction with external water impact on magma fragmentation and the resulting juvenile pyroclasts, a series of laboratory scale experiments were performed at the Physikalisch Vulkanologisches Labor in Würzburg (Germany). In each run, 200 g of volcanic rock was re-melted to 1200°C within 1 hour using an induction furnace. The melt was fragmented and expelled from the steel crucible through the use of compressed argon injected from the base; this is known informally as a “dry blowout”. In wet blowouts, a layer of liquid water was added on top of the magma just before the start of deformation. Dry and wet blowouts were performed on three melt compositions ranging from olivine-melilitite (ultramafic) to basaltic trachy-andesite (intermediate); these three compositions have approximately the same equilibrium viscosity for low shear rates at 1200°C. Dry blowouts are somewhat comparable to fire fountains in nature.

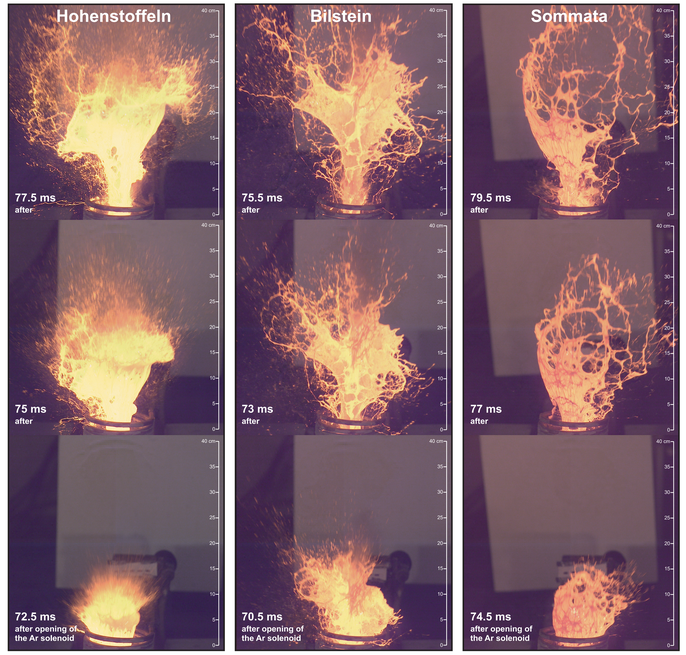
The artificial pyroclasts were collected and hand-sieved in order to obtain grain-size distribution, then different size fractions examined under the binocular microscope. Particles in the 0ϕ size fraction were assigned to different classes based on shapes and other visual features. Major differences in the particle shapes were observed between the three dry blowouts, despite using the same experimental conditions, comparable magma surface tensions, and equilibrium viscosities. Therefore, instantaneous viscosity and non-Newtonian behaviour probably plays a role in controlling particle shapes in lava fountains and other eruptive styles.

Experiment set-up

Exp. parameters

- Mass of volcanic material: 200 g, granulated
- Water volume (wet blow-out only): 100 ml
- Driving pressure: 500 cm³ Argon at 10 MPa
- Magma temperature: 1200°C

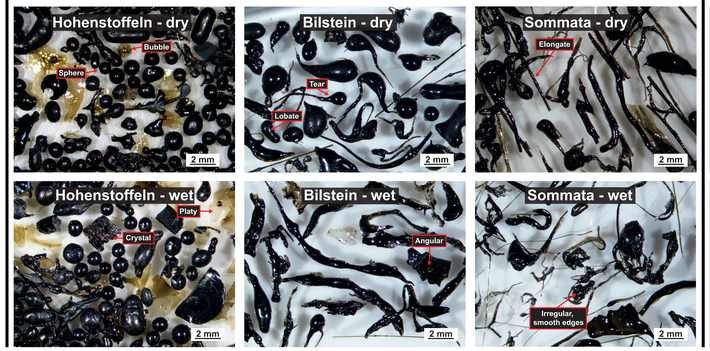




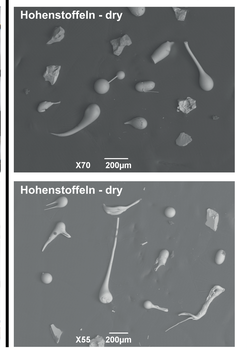
Methods

- Dry hand-sieving of each sample, separating the single size fractions up to 4ϕ (63 μm)
- Observation of all size fractions at the binocular microscope
- 0ϕ (1 mm) fraction selected for i) particle shape analysis and counting at the binocular; ii) internal features in thin sections
- 4ϕ (63 μm) fraction selected for surface features study and geochemistry at SEM-EDS

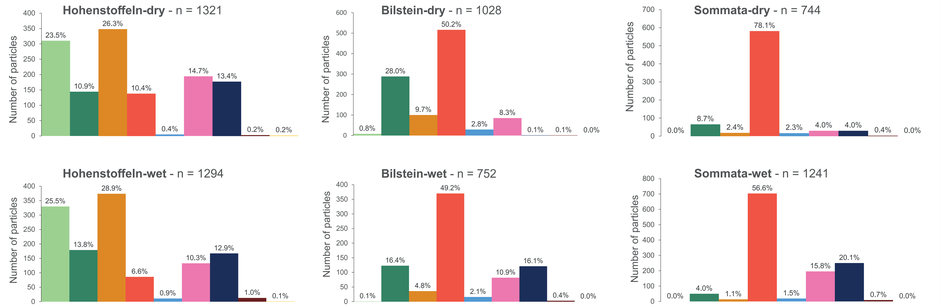
Particle shape - binocular (0ϕ)



Particle shape - SEM (4ϕ)



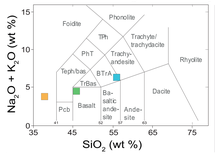
Particle shape proportions (0ϕ)

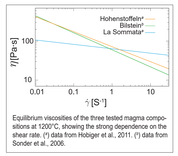


Legend

- Spheres
- Lobate/Ovoid
- Tears
- Angular/Blocky, sharp edges
- Elongate
- Irregulars, smooth edges
- Platy/"Wings"/ "Folded glass"
- Bubbles
- Crystals

Geochemistry and equivalent viscosity

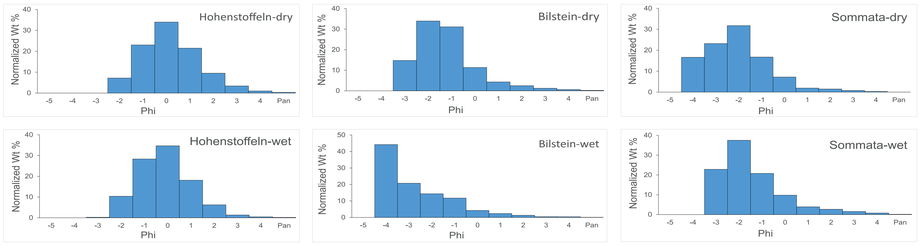




Equilibrium viscosities of the three tested magma compositions at 1200°C, showing the strong dependence on the shear rate. (*) data from Hobiger et al., 2011. (†) data from Sonder et al., 2006.

Composition	Area	Information and age	SiO_2 (wt %)	$Na_2O + K_2O$ (wt %)	Equilibrium viscosity (Pa·s)
Olivine-melilitite	Baden-Württemberg, Germany	Hohenstoffeln lava lake (Miocene, 15 Ma)	38.1	3.89	73
Alkaline basalt	Bilstein, Brilon, Germany	Continental lava flows (mid-Devonian, ??)	45.3	4.52	50
Basaltic trachy-andesite	Vulcano, Italy	La Sommata scoria cone (Pleistocene, 99 - 20 ka)	54.4	6.16	64

Grain-size distribution of the artificial pyroclasts



Discussion and preliminary conclusions

- Three magma compositions with similar equilibrium viscosities were tested under the same experimental conditions
- Important differences in particle shapes were observed, for the dry blowouts:
  - The ultramafic magma produced mostly spheres, lobate clasts and tears
  - The intermediate magma produced mostly elongate particles
  - The mafic magma produced particles with transitional characteristics
- Experimental results on ink jets (Shimozuru, 1994) linked the production of Pele’s hairs versus Pele’s tears as dependent on several parameters such as magma viscosity (η), magma and air density (ρ_m, ρ), droplet velocity (v) and surface tension (σ), all represented by *Pele number* (*Pe*), defined by $Pe = \rho \cdot v \cdot \eta / \rho_a \cdot \sigma$. Pele’s hair are produced by larger (*Pe*) and Pele’s tears for smaller (*Pe*) (Shimozuru, 1994)
- The parameters defining *Pele number* initially appear to be the same for all dry blowouts, so identical particles would be expected regardless of magma composition. But this erroneously assumes that equilibrium viscosity of the magma is the relevant parameter
- Yet instantaneous viscosity, which is directly applicable to what happens in the crucible and air during the experiments, is thought to be much lower for ultramafic melts due to their non-Newtonian behavior (shear thinning). This allows the reshaping of the ultramafic melt drops to configurations such as spheres and tears
- In contrast, Newtonian behavior shown by our intermediate magma leads to a clear prevalence of elongated fragments under the same experimental conditions
- Finally, fast interaction of the melt with water during the wet runs seems to have a role in the formation of platy particles, which appear for the mafic and intermediate compositions.
- **In summary, non-Newtonian behavior probably has a major influence in controlling particle shapes in lava fountains and other eruptive styles**

References

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