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Short communication

# The grain size dependency of vesicular particle shapes strongly affects the drag of particles. First results from microtomography investigations of Campi Flegrei fallout deposits

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ABSTRACT

Acknowledging the grain size dependency of shape is important in volcanology, in particular when dealing with tephra produced and emplaced during and after explosive volcanic eruptions. A systematic measurement of the tridimensional shape of vesicular pyroclasts of Campi Flegrei fallout deposits (Agnano-Monte Spina, Astroni 6 and Averno 2 eruptions) varying in size from 8.00 to 0.016 mm has been carried out by means of X-Ray Microtomography. Data show that particle shape changes with size, especially for juvenile vesicular clasts, since it is dependent on the distribution and size of vesicles that contour the external clast outline. Two drag laws that include sphericity in the formula were used for estimating the dependency of settling velocity on shape. Results demonstrate that it is not appropriate to assume a size-independent shape for vesicular particles, in contrast with the approach commonly employed when simulating the ash dispersion in the atmosphere.


## 1. Introduction

Pyroclastic particles injected into the atmosphere during explosive eruptions represent a serious threat to human beings, infrastructures and activities from a proximal to global scales (Blong, 1984; Casadevall, 1994; Horwell and Baxter, 2006; Bonadonna et al., 2012; Wilson et al., 2012, 2014). The transportability of pyroclastic particles in the atmosphere is a function of their aerodynamic behavior, which is influenced by both fluid and particle properties. The latter include density, size and shape, which together control the aerodynamic drag and the settling velocity of particles. In particular, much effort has been made recently to establish appropriate and accurate shape descriptors, by means of a combination of 1D and 2D parameters (Sneed and Folk, 1958; Wilson and Huang, 1979; Haider and Levenspiel, 1989; Swamee and Ojha, 1991; Ganser, 1993; Rodrigue et al., 1994; Chien, 1994; Taylor, 2002; Tran-Cong et al., 2004; Dellino et al., 2005; Pfeiffer et al., 2005; Loth, 2008; Hölzer and Sommerfeld, 2008; Bagheri and Bonadonna, 2016; Dioguardi et al., 2017a). These methods, unfortunately, do not take completely into account the complex 3D outline of volcanic particles (Baker et al., 2012), which are characterized by surface irregularities at a wide range of scales (from μm to mm). More recently, the application of X-Ray micro-computed tomography (X-ray micro-CT) to measure the shape of irregular particles has allowed a significant advance in this field (Ersoy et al., 2010; Rausch et al., 2015; Vonlanthen et al., 2015; Bagheri et al., 2015). Dioguardi et al. (2017b) proposed new 3D shape descriptors, namely 3D sphericity $\Phi_{3D}$ and 3D Fractal dimension $D_{3D}$, obtained by analyses on volcanic ash and lapilli particles. The two tridimensional parameters were included in ad hoc developed shape-dependent drag formulas that resulted in a good predictability of settling velocities of irregular shape pyroclasts. In particular, $\Phi_{3D}$ differs from the sphericity usually found in the literature in that the particle surface area is directly measured with the only limitation of the instrument resolution and computing requirements (e.g. Ganser, 1993; Dellino et al., 2005; Bagheri and Bonadonna, 2016), thus avoiding the rough approximation to the surface area of smooth shapes.

The usual approach in multiphase flow modelling in volcanology is to assume a size-independent particle shape (e.g. Folch et al., 2008; Dellino et al., 2008; Alfano et al., 2011; Bonadonna et al., 2012; Sulpizio et al., 2012; Devenish, 2013; Dioguardi et al., 2014; Dioguardi and Dellino, 2014; Beckett et al., 2015; de' Michieli Vitturi et al., 2015; Doronzo et al., 2015; Cerminara et al., 2016; Costa et al., 2016). The validity of this assumption depends on the type of pyroclastic particles. Explosive volcanic eruptions are known to generate variably types of particles as a result of magma fragmentation processes. These range from juvenile vesicular pumices to different types of crystals and lithic fragments. While the assumption of a size-independent shape for crystal and lithic fragments look reasonable, it does not apply to highly vesicular juvenile particles, whose outline is characterized by the walls

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of broken gas bubbles of different size. The shape of a particle is, in this case, controlled by the relationship between particle size and the mean vesicle size (Wohletz, 1983; Dellino and La Volpe, 1996; Riley et al., 2003; Mele et al., 2011; Liu et al., 2015). Unfortunately, there is not a systematic study that quantified the size-dependent 3-dimensional shape of volcanic particles from lapilli down to fine ash, which is relevant for the transportation and deposition processes of explosive eruptions.

In this paper, the dependency of full, 3-dimensional, particle shape on grainsize is investigated in conjunction with the vesicle-size distribution. In order to investigate dependency, the highly vesicular pumices of Campi Flegrei fallout deposits were used. As shape descriptor, we used sphericity, which is one of the most widely used parameter in drag laws (Wilson and Huang, 1979; Haider and Levenspiel, 1989; Swamee and Ojha, 1991; Ganser, 1993; Chien, 1994; Pfeiffer et al., 2005; Hölzer and Sommerfeld, 2008; Dioguardi et al., 2017b). The 3D sphericity $\Phi_{3D}$ of juvenile particles ranging from 8 to 0.016 mm in size was measured with an X-Ray micro-CT scanner. In order to assess the influence of the size-dependent shape on the aerodynamic behavior of particles, 3D sphericity data were used inside the drag laws of Ganser (1993) and Dioguardi et al. (2017b), the former being most widely used shape-dependent drag law in volcanology (e.g. Costa et al., 2006; Folch et al., 2009; Alfano et al., 2011; Beckett et al., 2015), the latter being the first shape-dependent drag law to make use of the tridimensional descriptor of sphericity.

## 2. Materials

Particles were sampled from fall deposits of the Agnano-Monte Spina, Astroni 6 and Averno 2 eruptions at Campi Flegrei (Italy), which were considered as representative of the large (Agnano-Monte Spina), intermediate (Astroni 6) and small scale (Averno 2) events since 5 ka at Campi Flegrei Caldera (Orsi et al., 2004, 2009; Costa et al., 2009).

The sample of Agnano-Monte Spina eruption (4.5 ka, Smith et al., 2011) was collected from the sub-Member B1 Plinian fall deposit (de Vita et al., 1999). It is the product of deposition from a pulsating column that reached a height of about 23 km, and which dispersed the pyroclastic material eastward (de Vita et al., 1999). The highly vesicular, alkali-trachytic pumices have been sampled 4 km downwind from the vent.

The sample of Astroni eruption particles comes from fall deposits of Unit 6 (4.2 ka; Isaia et al., 2004; Smith et al., 2011). The highly vesicular, alkali-trachytic pumices are from the basal pumice layer and were sampled at 1.5 km east from the vent. The maximum column height is estimated to have been about 14 km and the dispersion of tephra was towards the east.

The sampled particles from the Averno 2 eruption (4.3 ka, Isaia et al., 2009; Smith et al., 2011) came from sub-member A2 fall deposits (Di Vito et al., 2011). Those deposits were emplaced during the first magmatic phase of the eruption, which generated columns reaching a maximum height of 10 km. The highly vesicular, peralkaline alkali-trachytic pumices were sampled at 1.3 km from the vent.

## 3. X-ray microtomography analysis

In order to assess the possible variation of 3D particle shape with size, 30 juvenile particles were selected from the size range between −3 ϕ (8 mm) and 5 ϕ (0.032 mm), i.e.: 8.00, 4.00, 2.00, 1.00, 0.50, 0.25, 0.125, 0.063 and 0.032 mm. For the Averno 2 eruption, particles in the size fraction 0.016 mm were also examined. Particles were cleaned by ultrasonic bath and mounted around a wood or graphite rod holder (Fig. 1) using vinyl glue. The holders' materials were chosen because of their low X-ray attenuation coefficients, which allowed them to be easily discriminated from the particles. The wood (diameter 2 mm, height 70 mm) and the graphite (diameter 0.5 mm, height 40 mm) rod holders were used for particles of grain fractions from 8 mm to 2 mm and from 1 mm to 0.016 mm, respectively.

X-ray imaging was carried out with a Bruker SkyScan 1172 high-resolution μX-CT scanner. The system is equipped with a polychromatic micro focus X-ray tube. The pixel size was chosen as to achieve a constant particle volume of 46,000 voxels/particle, in order to obtain size-independent parameters (Dellino and La Volpe, 1996; Mele et al., 2011; Dioguardi et al., 2017b). The resolution allowed the representation of both coarse and small features with a significant number of voxels (including vesicles), as already discussed in previous papers (Dellino and La Volpe, 1996; Mele et al., 2011; Dioguardi et al.,

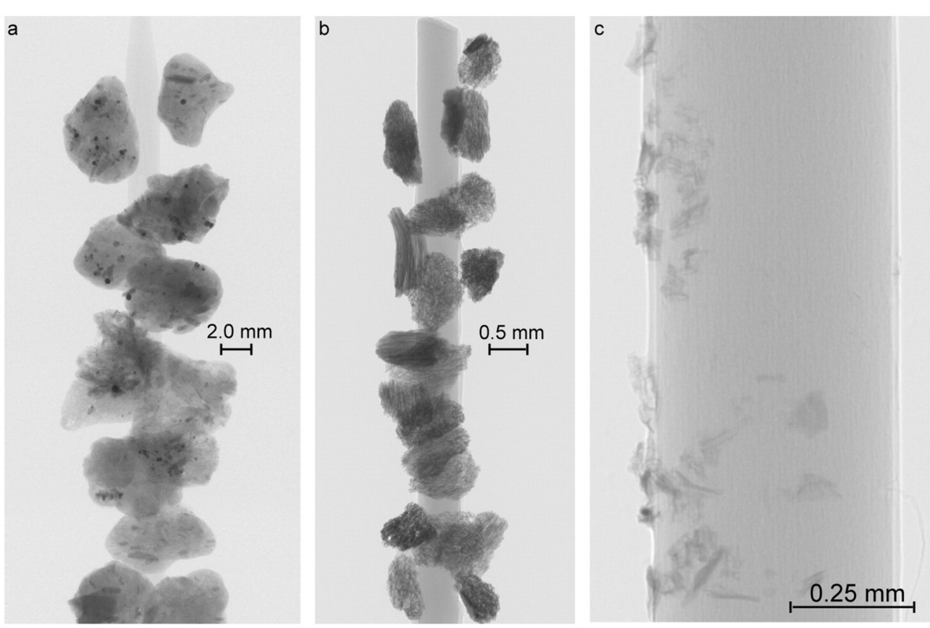


**Fig. 1.** X-Ray projection images of scanned pyroclastic particles of: (a) 4.00 mm size, (b) 0.50 mm size and (c) 0.064 mm size.