



MeMoVolc consensual document: a review of cross-disciplinary approaches to characterizing small explosive magmatic eruptions

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Lucia Gurioli, D. Andronico, Patrick Bachèlery, Hélène Balcone-Boissard, Jean Battaglia, et al.. MeMoVolc consensual document: a review of cross-disciplinary approaches to characterizing small explosive magmatic eruptions. Bulletin of Volcanology, 2015, 77, pp.49. 10.1007/s00445-015-0935-x . hal-01170133

HAL Id: hal-01170133

<https://uca.hal.science/hal-01170133>

Submitted on 17 Nov 2021

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MeMoVolc consensual document: a review of cross-disciplinary approaches to characterizing small explosive magmatic eruptions

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Abstract A workshop entitled “*Tracking and understanding volcanic emissions through cross-disciplinary integration: A textural working group.*” was held at the Université Blaise Pascal (Clermont-Ferrand, France) on the 6-7 November 2012. This workshop was supported by the European Science Foundation (ESF). The main objective of the workshop was to

establish an initial advisory group to begin to define measurements, methods, formats and standards to be applied in the integration of geophysical, physical and textural data collected during volcanic eruptions. This would homogenize procedures to be applied and integrated during both past and ongoing events. The workshop comprised a total of 35 scientists from six countries (France, Italy, Great Britain, Germany, Switzerland and Iceland). The four main aims were to discuss and define:

- Standards, precision and measurement protocols for textural analysis
- Identification of textural, field deposit, chemistry and geophysical parameters that can best be measured and combined
- The best delivery formats so that data can be shared between, and easily used by different groups;
- Multi-disciplinary sampling and measurement routines currently used, and measurement standards applied, by each community

The group agreed that community-wide, cross-disciplinary integration, centered on defining those measurements and formats that can be best combined, is an attainable and key global focus. Consequently, we prepared this paper to present our initial conclusions and recommendations, along with a review of the current state of the art in this field that supported our discussions.

Introduction

A major goal of modern volcanology is to relate conditions of magma ascent to the resulting eruption style using information preserved in volcanic deposits. Because it is impossible to directly observe magma ascent, vesiculation and fragmentation, one way to obtain quantitative information on magma-ascent dynamics is through textural quantification of the sampled particles. Textural quantification involves full description of the vesicle and crystal properties of erupted products (e.g., Sparks 1978; Sparks and Brazier 1982; Whitham and Sparks 1986; Houghton and Wilson 1989; Marsh 1988, 1998; Cashman and Marsh 1988, Toramaru 1989, 1990; Cashman and Mangan 1994; Higgins 2000; 2006; Blower et al. 2002; Burgisser and Gardner 2005; Shea et al. 2010a; Rust and Cashman 2011; Baker et al. 2012 and references therein). Magma viscosity, ascent rate, vesiculation processes, fragmentation style and explosion dynamics all imprint characteristic and measurable properties on the textures of volcanic particles, as shown by theoretical and experimental studies (e.g., Rust and

Cashman 2011; Gonnerman and Houghton 2012; Degruyter et al. 2012; Nguyen et al. 2013 and references therein). The main assumption is that most of the pyroclast properties are acquired during ascent in the conduit, with few changes occurring after fragmentation or in the atmosphere, if the pyroclasts are lapilli size or smaller (e.g., Houghton and Wilson 1989; Nguyen et al. 2013). Specifically, the textural parameters of the pyroclastic components can yield insights into the dynamics of explosive eruptions, as reviewed in Table 1.

However, the physical characteristics of individual pyroclasts must not be considered in isolation from detailed studies of (i) the deposits from which they were collected, (ii) their chemical properties, (iii) geophysical signatures of the related explosive event, or (iv) petrological and/or analogue experiments. Indeed, attempts to understand eruption dynamics have been increasingly coupled to traditional fieldwork and geophysical measurements made synchronously with sample collection. In 2004, a special issue of the *Journal of Volcanology and Geothermal Research* (Volume 137) focused on multidisciplinary approaches, proposing “simultaneous collection of multiple geophysical data sets, such as seismic, infrasonic, thermal and deformation data, as well as sampling of ejecta and detailed mapping”. The argument was that “complete constraint of a volcanic system is not possible using one data set, so that an integrated multiparametric approach involving simultaneous collection of multiple geophysical and petrological data sets will increase our ability to reach tightly constrained and confident conclusions regarding the mechanics and dynamics of volcanic systems and eruptions” (Harris et al. 2004). Since 2004, numerous studies have borne these predictions out, combining textural data with:

- i. Field deposits (e.g., Polacci et al. 2006a; Rust and Cashman 2007; 2011; Mattsson 2010);
- ii. Petrological data (e.g., Larsen 2008; Shea et al. 2009; 2010b; Burgisser et al. 2010; Bai et al. 2011);
- iii. Chemical analyses (e.g., Piochi et al. 2005, 2008; Shimano and Nakada 2006; Noguchi et al. 2006; Costantini et al. 2010; Schipper et al. 2010a; b; c; 2011; 2012; 2013; Balcone-Boissard et al. 2010, 2011, 2012; Shea et al. 2012; 2014)
- iv. Geophysical measurements (e.g., Burton et al. 2007; Gurioli et al. 2008, 2013; 2014; Polacci et al. 2009b; Andronico et al. 2008; 2009a; 2009b; 2013a, 2013b; Miwa et al. 2009; Miwa and Toramaru 2013; Colò et al. 2010; Landi et al. 2011; Pistolesi et al. 2011; Leduc et al. 2015)

Together, these studies have delivered complete pictures of explosive eruptions and their dynamics (Fig. 1).

Despite this progress, we remain far from establishing the best protocols for sampling pyroclasts and for correlating and comparing the many parameters that can be measured using individual clasts and field deposits. Only a few papers address some of these issues (e.g., Bonadonna et al 2013; Engwell et al. 2013; Klawon et al. 2014). In addition, no study has yet attempted to correlate all derivable textural parameters with the full range of multidisciplinary data available. To partially resolve these issues, a working group funded by the European Science Foundation, through the MeMoVolc program (<http://www.memovolc.fr/>), was set up. The group was composed of experts actively working on integration of textural, deposit and geophysical data, equally balanced between four theme areas: (i) particle-texture studies, (ii) deposit analysis, (iii) chemistry and (iv) geophysics. The priorities of the meeting were discussion and definition of:

- Improved standards, precision and measurement protocols needed by the particle-texture studies.
- Best practices for particle-texture studies in order to have comparable datasets from different types of eruptions.
- Parameters obtained from particle-texture, deposit, geochemical and geophysical data that need to be measured, and the best delivery format if each discipline's output is to be of use to all workers.
- Multi-disciplinary sampling and measurement routines, as well as measurement standards.

The core communal issues to be explored were agreed on:

1. What are the best sampling and measurement strategies for the quantification of pyroclast textural features, and what are their precision and uncertainty?
2. What are the best sampling and measurement strategies for pyroclastic deposits to allow textural characterization of their particles?
3. How can we link chemistry and particle-texture properties?
4. How can we link geophysical data and the particle-texture quantification?
5. What is the best multi-disciplinary strategy for combining output from each field in a meaningful way?

The paper reviews these topics in the light of a workshop consensus. Because of the time constraints and the complexity of the arguments, the paper focuses only on the study of explosive subaerial magmatic eruptions that generate sustained columns or fountains, and the associated fallout deposits (Fig. 1). Further workshop or working groups should be organized

to synthesise and integrate all work in progress, and already completed, in the areas of phreatic, phreatomagmatic and submarine explosions, as well as pyroclastic density current and lava flow deposits (Table 1).

The final objective of this paper is to ensure that data collected in the field and laboratory can be shared effectively and ingested in a multi-disciplinary sense into experiments, modeling and monitoring. In the longer term, the objective is to publish and update standards, as well as to propose, support and organize field meetings to test integrated collection methodologies. The ultimate aim is to increase the number of open-access data-bases of standard and community-accepted quality, thereby increasing resources available for cross-disciplinary correlations.

Sampling of pyroclasts and quantification of their textural features

(i) Representative samples

Pyroclasts reflect degassing of the parent magma, from the conduit to the plume. Part of the textural signature is assumed to reflect the fragmentation (or explosion) zone. Consequently, texture can be used as an indicator of magma properties (composition, porosity, connectivity, permeability, vesicle and crystal content, size, shape and distribution) at that time (Table 1). This assumption has two requirements:

- i. The textural signature that was quenched immediately at the fragmentation level can be distinguished from the textural effects of post-fragmentation processes, including microlite formation and bubble nucleation, expansion, collapse, coalescence and Ostwald ripening that will change clast vesicularity or vesicle size and shapes once the pyroclast has been formed (e.g., Thomas et al. 1994; Cashman et al. 1994; Herd and Pinkerton 1997; Larsen and Gardner 2000; Gurioli et al. 2008; Costantini et al. 2010; Stovall et al. 2011, 2012). The time window for post-fragmentation changes depends on magma composition, viscosity and fragmentation depth.
- ii. Because clast density is also a function of clast size (Houghton and Wilson 1989), only clasts of similar sizes must be used in order to avoid non-uniform grain-size effects on textural parameters.

We thus recommend choosing samples that are representative of the studied explosion, or unit, in terms of:

- i. Timing: This requires sampling of narrow stratigraphic intervals (Houghton and Wilson 1989) in which juvenile clasts of similar dimensions can be assumed to represent those parts of the magma fragmented at a particular time (n.b. conduit processes can change over short timescales);
- ii. Distribution: This requires selection of more than one outcrop for each event;
- iii. Degree of fragmentation: This requires selection of a sampling methods that is appropriate for the the full range of grain sizes in the deposit;
- iv. Componentry: If the juvenile fraction is heterogeneous, then sampling should be done based on preliminary componentry analysis of the clasts analyzed (e.g., Wright et al. 2011, Eychenne et al 2015)

In previous studies, only clast sizes of 16-32 mm, i.e. coarse lapilli (White and Houghton 2006) have been considered for textural purposes. Such clasts were considered to be large enough to be easily sampled and studied, while being fully representative of the density variation of the majority of erupted pyroclasts and unaffected by significant post-fragmentation phenomena (Houghton and Wilson 1989). These requirements are not always met. In basaltic magma, post-fragmentation effects can be a complication even for these sizes (e.g., Cashman et al. 1994; Szramek et al. 2006; Costantini et al. 2010; Gurioli et al. 2008; Pioli et al. 2014; Pistolesi et al. 2008; 2011; Stovall et al. 2011; 2012). In these cases, the challenge is to identify, quantify and remove post-fragmentation effects in order to isolate textures preserved across the fragmentation zone. For example, the original shapes of vesicles may be reconstructed by de-coalescing large vesicles using the presence of broken, or partially retracted, glassy septa.

However, if we study an ash-dominated or a bomb-dominated event, particle-texture analyses must be performed on the fine or coarse juvenile fragments, respectively. Ash size particles (<2 mm) have been investigated recently in terms of vesicle and crystal size distributions (Taddeucci et al. 2002, 2004; Cioni et al. 2008; D’Oriano et al. 2011a, b; Miwa et al. 2009; 2013; Miwa and Toramaro 2013; Proussevitch et al. 2011; Genareau et al. 2012; 2013; Colucci et al. 2013, Schipper et al. 2013), and an extensive work has been done in the last 40 years in characterizing ash morphology and deposit componentry (Table 1). For the ash fraction, post-fragmentation expansion can be excluded (e.g., Proussevitch et al. 2011; Genareau et al. 2012; 2013; Colucci et al. 2013). Consequently, analyses allow comparison between morphological and textural features of clasts sampled in proximal and distal areas. Ash particles can record most of the information related to magma ascent dynamics (e.g., decompression-driven microlite crystallization) and fragmentation (Cioni et al. 2008;

D’Oriano et al. 2005; D’Oriano et al. 2011a, b; Proussevitch et al. 2011; Genareau et al. 2012; 2013; Colucci et al. 2013). Advantages of studying ash are that it can also be statistically more representative of the variability of the magma properties and is less affected by density-driven settling within the plume. However, ash fragments record only small-scale vesicularity. The integration of observations made on the external shapes of clasts may give information about the presence and importance of a coarser vesicularity which drives magma fragmentation (e.g., Proussevitch et al. 2011; Genareau et al. 2012; 2013; Colucci et al. 2013). However, they cannot provide complete information about the abundance and size of the full vesicle population, if the magma included bubbles larger than the ash particles. Furthermore, ash particles are not suitable for permeability studies, as they are often smaller than the bubbles forming the permeability network. However, the presence of coalesced vesicles in a preferred direction, and an abundance of ash clasts with an elongate shape, have been interpreted as an indication of the development of a permeable bubble network (D’Oriano et al. 2011a).

Bombs may provide a plethora of information regarding pre-eruptive degassing and ascent rate (e.g. Hoblitt and Harmon 1993; Wright et al. 2007), timing and degree of thermal interaction of magma with wall-rock material prior to ejection (Rosseel et al. 2006; Sottili et al. 2009; 2010), post-fragmentation changes due to bubble growth, coalescence or shape changes (e.g. Herd and Pinkerton 1997, Shin et al. 2005) and mingling between stagnant and fresh magma (Gurioli et al. 2014; Leduc et al. 2015).

(ii) Bulk measurements of particle characteristics

The fastest and most straightforward textural measurement of individual pyroclasts is density (vesicularity), which provides basic information on processes related to gas exsolution and escape (Houghton and Wilson 1989). The densities of lapilli and small bombs can be determined by comparing their weights in water and air following the Archimedes principle. Clasts can be made impermeable with silicone waterproofing spray, by immersion in cellulose acetate, or by using ParafilmTM wax. This technique is fairly rapid and yields large arrays of data with a reproducibility within 10-30 kg m⁻³ and accuracy within 30 kg m⁻³ (Barker et al. 2012). Quicker, more timely and precise, density measurements can now be performed using a commercial envelope-density measurement device (<http://www.micromeritics.com/Product-Showcase/GeoPyc-1360-Envelope-Density-Analyzer.aspx>). Following the same principles, a battery-powered device has been used to vacuum-seal pumice or scoria in plastic bags in the field (Kueppers et al. 2005).

For pyroclasts characterized by fine vesiculation (with largest vesicles smaller than 2-3 mm), the density can be measured with the glass-bead method (Nakamura et al. 2008) that allows the calculation of the density as well as the volume of an object of irregular size. For large bombs (from 15 to 40 cm in diameter), a "natural waterproofing" effect was exploited (Gurioli et al. 2013). Extensive tests showed that decimetric size bombs collected at Stromboli acquired a "natural waterproofing" from their quenched margins and thus could be weighed in water without waterproofing. This represents an easy, precise and fast strategy for large bombs.

The derived density distributions, coupled with external morphology variation, can be used as filters to select a few clasts, representative of the low, modal and high density values, from each subpopulation observed (e.g., Shea et al. 2010a). Selected clasts are then used for textural quantification.

Other bulk particle-texture measurements include vesicle connectivity, permeability (Klug and Cashman 1996; Klug et al. 2002; Formenti and Druitt 2003; Rust and Cashman 2004; and references in Table 1) and electrical conductivity (Le Pennec et al. 2001; Bernard et al. 2007; Wright et al. 2009; Wright and Cashman 2014). The connectivity measurements are mostly performed using gas-displacement helium pycnometers, and they deliver first-order information on the outgassing capacity (i.e., potential for gas loss) of the magma near fragmentation (Klug et al. 2002; Formenti and Druitt 2003; Giachetti et al. 2010; Shea et al. 2011; 2012). Permeability controls the rate at which magma outgases during decompression. Several methods exist for permeability measurements in volcanology. Rust and Cashman (2004) used a commercial permeameter to perform systematic steady-state gas-flow experiments using porous samples, and the relationship between flow rate and pressure gradient was determined. They also introduced the Forchheimer equation into volcanology, which is a modified form of Darcy's law that includes the inertial effect of gas flow, and specified the importance of this effect in volcanic degassing processes. Mueller et al. (2005) used gas-pressure decay with time after sudden decompression in a fragmentation bomb for the permeability measurements, without measuring gas-flow rate. A falling head permeameter developed by Burbié and Zinszner (1985) has also been used to measure the permeability of volcanic porous materials (Jouniaux et al. 2000; Bernard et al. 2007). Recently, a low-cost gas permeameter was developed (Takeuchi and Nakashima, 2005) and improved (Takeuchi et al., 2008), to measure permeability of natural samples and experimental products. Finally, electrical conductivity measures how well a material transports electric charge. Rocks, in general, are poor conductors, whereas ionic fluids are good conductors. Therefore a

measurement of conduction through fluid-saturated rocks provides information about the connected pore pathway through the sample. Although the influence of pathway tortuosity and pore shape on permeability is useful for numerical simulations on gas percolation, it has been the object of only a few studies (Table 1).

(iii) Comparison between 2D and 3D particle-texture measurements

Two different methods are currently available for extracting vesicle and crystal sizes, shapes and distributions in pyroclasts. The first is by conversion of 2D data from a planar surface (such as a thin section or photograph) to 3D data through stereology. The second method derives 3D data directly from X-ray tomographic reconstructions and visualization of clast textures without the need of stereological conversions (Song et al. 2001; Shin et al. 2005; Polacci et al. 2006b; 2008; 2009a, b; 2010; Degruyter et al. 2010b; Gualda et al. 2010; Giachetti et al. 2011; Baker et al. 2012), using computer software especially developed for geo-textural purposes (e.g. Ketcham and Carlson 2001; Ketcham 2005; Friese et al. 2013). Other 3D methods include serial sectioning (e.g. Bryon et al. 1995), serial focusing with optical microscope (Manga 1998), serial grinding (e.g., Marschallinger 1998a, b, c; Mock and Jerram 2005), and constructing digital elevation models of individual ash grains to calculate vesicle volume (Proussevitch et al. 2011). Two-D and 3D observations have different limitations and potential, and the two methods are becoming complementary, not competitive (e.g., Giachetti et al. 2011; Baker et al. 2011).

2D method

Standard procedures for the 2D method have been recently published for vesicles (Shea et al. 2010a) and crystals (Higgins 2000; 2006). Two-D techniques can yield high-quality data and account for both vesicle and crystal sizes in the sample and can be applied to particles ranging in size from bombs (e.g., Gurioli et al. 2014, Leduc et al. 2015) to ash (Miwa et al. 2009; 2013; Miwa and Toramaru 2013). These measurements are best used when there is a broad size distribution to be measured. The main limitation of the method is that is based on the assumption of spherical shape of the textural objects, following Sahagian and Proussevitch (1998). When this conversion is simply obtained by dividing the number of vesicles per unit area by the median value of diameter of each size class (Cheng and Lemlich 1983), no shape assumption is made. However, the 3D conversion is more precise when a shape is defined. Empirical corrections are commonly used for crystal analyses (Higgins 2000 and 2006), but

for vesicles, whose shapes are less uniform, they risk introducing systematic, uncontrolled errors in the data (Sahagian and Proussevitch 1998; Proussevitch et al. 2007a; 2007b).

3D method

X-ray-computed microtomography is the only available high-resolution, non-invasive 3D technique that allows reconstruction, visualization and processing of samples. Data acquisition is generally relatively straightforward, and several scales can be examined and combined, ranging from centimeters to <1 micron, depending on the resolution (Giachetti et al. 2011). In addition, the so-called ‘local area’ tomography technique (e.g., Lak et al. 2008) enables high resolutions to be attained, even with samples larger than the field of view of the camera. However, 3D quantification of textures can also be labor intensive, depending on the size of the volume that needs to be analyzed and on the textural parameters required. The results show the internal structures of samples, highlighting how objects and apertures are linked together. This information provides an excellent suite of data for studies of vesicle size, shape and distribution, collapse, deformation, coalescence, permeability, and tortuosity, as well as for determining crystal volume, size and distribution and visualizing crystal aggregates in 3D (Polacci et al. 2009a, b; 2012; Bai et al. 2010, 2011; Degruyter et al. 2010a, b; Zandomeneghi et al. 2010; Gualda 2010a, b; Baker et al. 2012; Castro et al. 2012; Okumura et al. 2013). Vesicles with complex shapes are easily identified, while in a 2D section they might be interpreted as two or more vesicles, thus biasing vesicle size distribution (VSD) and vesicle number density (N_v) (e.g. Giachetti et al. 2011). The 3D method is particularly effective for determining N_v if the study is focused on a specific size range; vesicle number densities over a wide range of sizes is achieved with nested studies in which a series of scans are done at different sizes and resolutions (e.g. Giachetti et al. 2011; Pardo et al. 2014b). However, the resolution of the reconstruction is still critical. Klug et al. (2002) showed that vesicle walls may be as thin as 0.1 μm . To achieve this sort of spatial resolution using tomography requires very small samples. When the attained resolution is 5-15 μm , thin vesicle walls are not resolved.

There is currently no unique protocol for 3D measurements of different types of pyroclastic (or lava) samples; however the SYRMEP group of the Elettra Synchrotron Light Source (Trieste, Italy), together with researchers at McGill University of Montreal and INGV Pisa (M. Polacci), are developing protocols for volcanic samples of different vesicularities and crystallinities.

(iv) Crystal size distribution

Crystal size distribution (CSD) is a well-established tool for interpreting the physical processes and environmental variables that drive differentiation and crystallization in magma chambers and conduits (e.g., Marsh 1988; Cashman and Marsh 1988; Cashman 1992; Hammer et al. 1999; Cashman and McConnell 2005; Armienti 2008; also see references in Table 1). CSD, coupled with vesicle distribution data, yield deeper insights into the physical processes operating in the conduit (e.g., Gurioli et al. 2005; D’Oriano et al. 2005; Piochi et al. 2005; 2008; Noguchi et al. 2006; Giachetti et al. 2010; D’Oriano et al. 2011a; Vinkler et al. 2012). The CSD method has been well tested and widely applied (Table 1), so that it is now quite straightforward to quantify CSD (Higgins 2000; 2006; and references in Table 1).

However, we must keep in mind that crystals are commonly anisotropic, and therefore shape cannot be ignored. Most studies use the Higgins technique to account for shape. However, the Higgins method assumes that all crystals are the same shape. This is clearly not true, as small crystals are often more anisotropic than large crystals. Treating all crystals in the same way can introduce artifacts (see Castro et al. 2003). In addition, there are still resolution issues for microlites, as well as problems in both back-scattered electron (BSE) and cathode ray tube (CRT) analyses when the crystals have a density (Z number) near that of the glass. Several methods can be used to facilitate the extraction and quantification of crystals. CSDs of larger crystals (phenocrysts, antecrysts, etc.) can be measured from transmitted light microscopy images of thin sections and analyzed with digital image analysis to automate and hence speed up the quantification process (e.g., Armienti et al. 1994; Launeau et al. 1994; Lumbreras and Serrat 1996; Goodchild and Fueten 1998; Launeau and Cruden 1998; De Keyser 1999; Heilbronner 2000; Armienti and Tarquini 2002; Boorman et al. 2004). Tarquini and Favalli (2010) used a slide scanner to acquire input imagery in transmitted light from thin sections and GIS software to analyze the data.

Crystals can also be identified using a scanner and a polarizing filter placed at different angles (Pioli et al. 2014). Three pictures are then combined, and their correlation allows the individual grains to be classified by their characteristic orientation. To measure smaller crystals (microphenocrysts and microlites), a scanning electron microscope is commonly used in backscattered electron (BSE) mode (Cashman 1992; Hammer et al. 1999; Cashman and McConnell 2005; Nakamura 2006; Ishibashi and Sato 2007; Salisbury et al. 2008; Blundy and Cashman 2008; Wright et al. 2012). Development of rapid x-ray mapping techniques now allows CSD analysis of x-ray element maps, which provide information on crystal

compositions, textures (crystal size, orientation, shape) and modes of minerals (e.g., Muir et al. 2012; Leduc et al. 2015). Another new technique uses an electron backscatter diffraction detector (EBSD) attached to the SEM to obtain crystal orientations, which can provide insights into shearing, accumulation and degassing processes (Prior 1999; Prior et al. 1999; Hammer et al. 2010). Chemical mapping is now routinely and widely used (e.g., Leduc et al. 2015). In contrast, EBSD is more difficult to use and interpreting the data is harder than the chemical maps. As described in the references cited, it produces a wealth of information on various minerals, although the monocline structure of the feldspar can be problematic.

Crystal size distribution can also be obtained directly in 3D via X-ray computed microtomography. Using this approach, it is possible to obtain the total crystal volume, as well as the crystal volume of each mineral phase present: crystallinity, crystal size and crystal shape (e.g., Zandomeneghi et al. 2010; Voltolini et al. 2011). Again, resolution can be a problem. First, crystals may span a large size range, which requires imaging at several different resolutions (e.g., Pamukcu et al. 2010; 2012). Additionally, as in BSE analysis, the compositional similarity between some crystal phases, such as alkali feldspars, and silicic matrix glass can make automated analysis challenging (e.g., Baker et al. 2012). However, excellent results can be obtained by working in phase-contrast tomographic mode (Polacci et al. 2010), and applying a procedure known as phase retrieval to the reconstructed sample volumes (Arzilli et al. 2013).

(v) Errors in particle-texture analyses

Uncertainties in textural analysis are due to several factors. Any textural parameter, such as porosity or crystal size, has intrinsic measurement errors. These are linked to the apparatus used and are generally easy to quantify using standards. A good practice, when a new method is introduced, is to assess its intrinsic error with synthetic samples of well-known particles, having textural components (e.g. crystals, vesicles/voids) with known size and distribution (e.g., see review of Rust and Cashman 2004 for permeability, and Baker et al. 2011 for 3D data from X-ray microtomography). Another type of uncertainty is linked to natural variability, which is generally approached by using the concept of Representative Elementary Volume (REV, Bear 1972). Parameters measured in small, neighboring, regions within a sample have a large variability. As the analyzed regions become larger, this variability decreases until a steady value is reached at the REV size. One complication is that the REV should be significantly smaller than the sample (not guaranteed for ash, or even lapilli,

particles), and that some parameters have an REV at the deposit scale, which means that many clasts have to be analyzed. If the sample location is such that eruptive parameters were steady during deposition, application of REV at the deposit scale allows analysis of magma at the point of fragmentation in the conduit. Taking porosity as an example, one 2D SEM image will yield one porosity measurement with a typically small (~1 %) intrinsic error due to thresholding of the grayscale values that represent vesicles. Several 2D images of the same sample taken at different locations and/or different resolutions (larger than the REV) typically yield larger (~10 %) uncertainties that are caused by small-scale spatial heterogeneity. Finally, if we assume that – or if we have a – very well sorted deposit, then the density distribution of all clasts at that location indicates the variability of porosity at the conduit scale, which can be quite large (e.g., Houghton and Wilson 1998). The situation is more complex with poorly sorted deposits in which particles range from bombs through lapilli to ash.

Raw data in terms of size (area, long axis, short axis, perimeter) and orientation of crystals and vesicles yield negligible intrinsic errors, because they are computed with programs on 2D binary images with high resolution ($>10^6$ pixels). In this phase, the uncertainty is due to the image clean-up process, which is generally unquantified (because it takes too long to have four people complete the task independently and then take the average for every image).

The greatest source of intrinsic error here is thresholding, which is set by the operator (Baker et al. 2011). When converting 2D data to a 3D projection, however, the error depends on the stereological model used (i.e. particle shapes have to be assumed, Cashman 1988) and is thus harder to estimate.

Most 2D textural parameters have well-established techniques and protocols to quantify intrinsic errors, including:

- VSD (Toramaru 1990; Mangan et al. 1993; Klug and Cashman 1994; 1996; Klug et al. 2002; Adams et al. 2006b; Shea et al. 2010a),
- CSD (Higgins 2006), fabric indicators (Launeau et al. 1990),
- vesicle shape (Moitra et al. 2013),
- clast shape (Marshall 1987; Capaccioni and Sarocchi 1996; Dellino and Liotino 2002; Riley et al. 2003; Ersoy et al. 2006).

However, conversion from 2D to 3D distributions introduces errors linked to stereological assumptions. The Cheng and Lemlich (1983) method does not involve assumptions of object shape, but it does not take into account a truncation effect (e.g. Pickering et al. 1995). Truncation is related to the sensitivity of the measurement process; smaller objects are

increasingly difficult to detect. On the other hand, large-scale truncation occurs under several circumstances related to sample-size (volume and area) limitations. The Sahagian and Proussevitch (1998) conversion assumes spherical shapes and corrects for the cut effect (this being the effect induced by rarely cutting a spherical object through its exact center). Giachetti et al. (2011) found that N_v obtained by 2D and 3D methods for the same lapilli agreed within 15 %, and that VSD were also very similar. They recommended the Cheng and Lemlich (1983) method for 2D vesicle analysis, as the Sahagian and Proussevitch (1998) method may generate negative values for some size classes.

In terms of parameters that we can derive from textural analyses, decompression rate is probably one of the most important to quantify due to its implications for eruption dynamics. To achieve this, microlite shape, N_v and size distribution have been used in combination with experimental data for low-mass flux and effusive eruptions (Couch et al. 2003; Cashman and McConnell 2005; Szramek et al. 2006; Clarke et al. 2007; Martel 2012; Wright et al. 2012). Martel et al. (2006) consider this approach to be highly reliable, because different generations of microlites (nucleated pre-eruptively in the reservoir or syn-eruptively in the conduit) can be distinguished on the basis of chemical composition. Decompression rates deduced from N_v (e.g., Toramaru 2006), however, tend to be maximum estimates, because there could be more nucleation events during ascent that add to the signature left by decompression. Maximum decompression rates associated with the final, rapid, stages of ascent could be calculated directly from the smallest bubbles formed during the final fragmentation event (Giachetti et al. 2010; Shea et al. 2011; 2012). Another developing method is to use chemical gradients of volatiles in melt inclusions in crystal embayments to infer rise rates (Ferguson et al. 2013).

However, the relationships between bubble shape, nucleation, coalescence, deformation and/or fragmentation are not well established yet.

Quantification and sampling of pyroclastic deposits for the textural characterization of their components

(i) Preliminary field studies and sampling strategy

Field-based studies of pyroclastic deposits aim to relate both the whole-deposit characteristics (thickness and grain size) and the physical properties of the constituent particles to the eruption conditions. Particle-texture studies are time consuming, especially when they provide complete size distributions of the vesicle and crystal population. For these measurements, the

choice of a limited number of “representative” clasts selected for the analysis is critical, particularly when using these data to model eruption processes and their variability in time and space. Obtaining such clasts requires a cautious sampling strategy with well-defined scientific goals during field work. These studies are best performed only on well-documented deposits, supported by a robust stratigraphic reconstruction and correlation, as well as an accurate compositional stratigraphic framework. When not familiar with the deposit, a preliminary survey at different locations is useful to evaluate the significance of the outcrops used for detailed analysis. Well-defined sublayers (or units) should be identified in the deposit on the basis of clear, unequivocal lithologic and sedimentologic features and cross-correlated over the whole dispersal area of the deposit. Stratigraphic data are critical for placing each studied layer within an appropriate temporal framework within the stratigraphic sequence.

Pyroclasts can be collected after the eruption, from fall deposits of old (unobserved) or recent (observed) eruptions, for which sampling is done preferably within hours to days of the event (e.g., Gurioli et al. 2008; 2013). Sampling may also take place during eruptive activity, with samples collected using sampling device placed inside the fallout field. Three simple collection methods that can be applied to active fallout, as currently used, are: (1) the hand collection method involves collecting (and quenching) bombs or lapilli as they fall out of the plume by people standing in the active fallout field (e.g., Lautze and Houghton, 2007, 2008; Gurioli et al. 2014); (2) the “clean surface” strategy, whereby plastic sheets are laid out close to the vent, or a preexisting surface is cleaned before the eruption. In both cases the pyroclasts falling in a known area are collected (e.g., Rose et al. 2008; Andronico et al. 2009a; 2013a and b; Eychenne et al. 2012; Houghton et al. 2013, Harris et al. 2013b, Schipper et al. 2013); (3) the bucket strategy, in which a large number of buckets are distributed across a discrete area of fallout for a certain period of time (e.g., Yoshimoto et al. 2005; Swanson et al. 2009; Bustillos and Mothes 2010). When possible, the aims are to collect a sufficient number of samples to estimate the magnitude of the event through the mass load per unit area; and to obtain a sufficient number of clasts for chemical and textural characterization. Other promising methods are just coming on-line, such as automatic ash sampling collectors (e.g., Bernard 2013; Shimano et al. 2013, Marchetti et al. 2013).

(ii) Definition of essential, basic physical properties of the deposit to the study

Most particle and deposit texture studies aim at characterizing magma heterogeneity and ascent dynamics, and at understanding the fragmentation process, beginning with the size,

morphology and componentry of the particles (Table 1). Clasts selected for particle-texture analysis are usually sampled in a deposit at a single location (reference section). Lateral variability across the deposit is filtered by transport and sedimentation processes, which primarily depend on eruption intensity, along with related plume dynamics and other dynamic effects such as wind direction and velocity and rainfall. Therefore, clast properties can differ both in time (from the base to the top of a vertical sequence) and in space (from the main axis of dispersal to lateral outcrops at the edge of the fallout zone across the cloud, and from proximal to distal sites). Volcanic plumes (and clouds) are thus complex systems, the properties of which do not vary linearly with the main eruption parameters. They are also affected by external variables, such as wind direction and velocity. The external variables add additional complexity to the clast-type distribution. For this reason, the deposit should be preliminarily characterized at least in terms of stratigraphy, dispersal, thickness variation and volume before more detailed study is initiated (e.g., Fisher and Schmincke 1984; Cas and Wright 1987; Thordarson et al. 2009; Cioni et al. 2011). Estimation of plume height, eruption duration, volume and magma eruption rate can then also be derived for past eruptions from such analyses (e.g., Carey and Sparks 1986; Pyle 1989; Fierstein and Nathenson 1992; Sparks et al. 1997; Bonadonna et al. 1998; Freundt and Rosi 1998; Bonadonna and Costa 2012; Fagents et al. 2013).

(iii) Selecting the outcrop

There are three basic criteria for sample outcrop selection. First: minimize the effect of wind dispersal. Outcrops located along the main dispersal axis are preferred to lateral exposures, unless the effect of wind is the target of study. If wind direction or eruption intensity changes during different phases of the same eruption, it is more appropriate to sample each tephra layer at different 'equivalent' locations rather than to collect all samples at a single type outcrop. If sampling is restricted to a single location, the inferred dispersal pattern and distance from the main dispersal axis of each layer should be noted and taken into account when analyzing clast variability among different layers.

A second criterion for selecting the outcrop is that clear textural variations among the juvenile clasts, in terms of color, general morphology, vesicularity, vesicle shape, and crystallinity should be evaluated in the preliminary field survey, so that any lateral and vertical variability within the deposit is already defined following field reconnaissance. This

ensures that, when clast types are chosen in the laboratory, the main textural types are easily identified and separated.

The third criterion for outcrop selection, if one of the goals of the study is quantification of the proportion of distinct textural clast types, is to remember that sedimentation from the volcanic plume is affected by clast density, shape and size (Bonadonna et al. 1998; Pfeiffer et al. 2005; Barsotti et al. 2008; Eychenne et al. 2013, and references therein). This is especially relevant when a single explosion produces a juvenile population with a wide range of textural and other physical features: their relative proportions within the deposit can vary laterally in the deposit as well as with distance from the vent. Thus, at any single site, the sample is not necessarily representative of the abundance within the eruption mixture. This is especially true in the case of small plumes and mid-intensity eruptions (e.g., Rose et al. 2008; Cioni et al. 2008; 2011; D’Oriano et al. 2011a; Andronico et al. 2013a and references therein). While the textural features of the different clast types can be studied at a single outcrop, the relative proportions between clast types need to be determined across the whole deposit by integrating componentry data on samples collected at outcrops at differing azimuths and distances from the source.

(iv) Sampling

After identification of the outcrops where the deposit shows the best and most complete exposure, a suitable approach is random collection of a statistically relevant number of clasts from a single layer. Several techniques can be used, ranging from sieving in the field to find the dominant clast size (for coarse clasts), or sampling the bulk deposit for later clast selection in the laboratory (for small clasts). In the case of fine-grained deposits, it can be useful to apply sampling techniques that preserve structural and textural characteristics of the whole deposit. Samples can be retrieved using tubes or boxes manually pressed into the deposits, or carefully carved out and surround-wrapped deposit blocks. In situ and/or laboratory impregnation techniques of deposits exist for a broad range of grain sizes and compositions (Bouma 1969), some of which are applicable to fragile or loose volcanic deposits (e.g. Fiske et al 2009). The applicability of such techniques to fine-to-medium grained volcanic deposits should be tested, since they would allow both 2D (e.g., X-ray radiography and thin section analysis) and 3D analysis (X-ray tomography and anisotropy of magnetic susceptibility) to be applied to deposits, rather than single pyroclasts; these, techniques are frequently used for hard rocks (e.g., Lanza and Meloni 2006).

The number of samples should be defined depending on the purpose of the study. Fixing the number of samples per stratigraphic layer based on the layer characteristics (e.g., extent of zoning/fluctuations in grain-size, componentry, etc.) for characterizing eruption dynamics, or focusing on the layer thickness for conduit dynamic characterizations, are two examples of such pre-selection decisions. Before selecting clasts, basic grain-size studies (when the bulk deposit is collected) on each sampled layer (median and sorting of grain-size distribution) and componentry analysis should be carried out to ensure effective sub-sampling for textural studies. Following White and Houghton (2006) componentry analysis is the subdivision of the sample into three broad components: juvenile, non-juvenile particles and composite clasts. The juvenile components are vesicular or dense fragments, as well as crystals, that represent the primary magma involved in the eruption; non-juvenile material includes accessory and accidental fragments, as well as crystals, that predate the eruption from which they are deposited. Finally, the composite clasts are mechanical mixtures of juvenile and non-juvenile (and/or recycled juvenile) clasts. More-detailed componentry can subdivide the juvenile and non-juvenile materials into subpopulations that have important dynamic meanings (e.g., Eychenne et al. 2015).

Finally, after choosing the size intervals of the clasts for physical and textural measurements (i.e., bulk and solid density, vesicularity, microtextures, permeability), it is useful to compare the grain-size distribution of each interval with the total grain-size distribution of the sampled layers, especially when the grain-size distribution is highly variable within the sampled stratigraphy. This strategy allows checking of sample representativeness. For example, sampling may be from (i) bimodal or complex multimodal distributions, or (ii) anomalous, poorly sorted deposits. In the second case, sampling should avoid features that can be indicative of contamination from other sources, such as ballistic components, elutriated ash from pyroclastic density currents or from reworking (e.g., Fierstein et al. 1997, Eychenne et al. 2012). It is useful, whenever possible, to show variance, or invariance, of the textural features by comparing data collected in the selected size class with textural data for different size classes. This should, at least, be carried out for a few selected samples.

How to link petrological, geochemistry and textural quantifications

(1) Initial parameters and conduit processes

611 Geochemical and petrological analysis of pyroclastic products can constrain the initial
612 conditions in the shallow crustal holding chamber through to the surface via the conduit
613 system (Fig. 1). In transit through this system, the textural features are imprinted on the
614 pyroclasts quenched upon eruption. The geochemical and petrologic analysis can help:

- 615 • Define pre-eruptive P-T storage conditions from mineral-melt equilibria or
616 disequilibria (e.g., Rutherford et al. 1985; Scaillet and Evans 1999; Pichavant et al.
617 2002; Blundy and Cashman 2008; Schipper et al. 2010b);
- 618 • Assess initial viscosity, temperature, melt composition and volatile budget, including
619 input of gases from deeper sources (e.g., Wallace 2001; Blundy and Cashman 2008;
620 Métrich et al. 2010);
- 621 • Define the evolution of volatile contents (specifically Cl, F, S, H₂O, CO₂) using
622 electron probe, ion probe (SIMS), Raman and FTIR in melt inclusions and host
623 minerals, while combining results with vesiculation studies and gas release
624 measurements (e.g., Wallace 2005; Métrich and Wallace 2008, Schipper et al. 2010c).
625 In such a way we can determine whether the magma was saturated, over-saturated or
626 under-saturated at a certain depth, and how these conditions affect vesiculation in the
627 conduit (e.g., Anderson 1991; Hurwitz and Navon 1994; Dixon 1997; Roggensack et
628 al. 1997; Schipper et al. 2012);
- 629 • Measure residual volatiles in glasses and bulk-rock samples to reveal how degassed
630 the magma is (Newman et al. 1988; Villemant and Boudon 1998; Shea et al. 2014);
- 631 • Provide variable diffusion of stable elements (⁶Li, ⁷Li, H/D, ¹⁰B, ¹¹B) or radiogenic
632 isotopes (²¹⁰Pb-²²⁶Ra), which are used as tracers for melt degassing and interaction
633 with hydrothermal fluids (e.g., Berlo et al. 2004; Kent et al. 2007; Humphreys et al.
634 2008b; Schiavi et al. 2010; Berlo and Turner 2010; Vlastélic et al. 2011);
- 635 • Measure mineral diffusion profiles and derive pre-eruptive residence times, ascent
636 rates and cooling rates (e.g., Kahl et al. 2011);
- 637 • Provide crystal shapes, zoning schemes, and dissolution stages, while determining
638 which magmatic process and physical parameters control crystal shape/zoning (e.g.,
639 Hammer and Rutherford 2002; Rutherford and Devine 2003; Blundy et al. 2006; Costa
640 et al. 2008; Streck 2008);

641 In addition, laboratory petrological investigations can provide:

- Experimental observations on phase equilibria (mineral-melt-vapor), crystallization paths and liquid line of descent (e.g., Hammer and Rutherford 2002; Couch et al. 2003; Blundy et al. 2006; Hammer 2008);
- Calibration of decompression rates. While this has been carried out for rhyolitic systems (e.g., Mourtada-Bonnefoi and Laporte 2002, 2004; Mangan and Sisson 2005; Gardner 2007; Cichy et al. 2011; Cluzel et al. 2008) and phonolitic systems (e.g., Larsen 2008; Shea et al. 2010b), there are ongoing studies on basaltic systems (Bai et al. 2008; Lesne et al. 2011; Pichavant et al. 2013);
- Diffusion coefficients of relevant chemical elements, including volatiles, to improve kinetic modeling (Dohmen et al. 2007; Chakraborty 2008);
- Relationships between crystal morphologies, cooling rates and degree of undercooling (e.g., growth of crystals with hopper and swallow tail shapes experiencing rapid late-stage crystallization; Faure et al. 2003, 2007);
- Surface flux of volatiles (i.e. what leaves the system; see reviews by Fischer 2008; Pyle and Mather 2009) compared with melt inclusion data (i.e. what is in the system initially; e.g., Le Voyer et al. 2010; Rose-Koga et al. 2012; Schiavi et al. 2012).

2) Where geochemistry can help textural study

Measurements of volatile contents in quenched, phenocryst-hosted melt inclusions provide estimates of initial (shallow crustal) values (e.g., Kent 2008). These are minimum estimates, because H₂O can leak from melt inclusions during ascent by intracrystalline diffusion as the far-field environment of the crystal evolves (Chen et al. 2011, 2013). Melt inclusion volatile contents can be inverted to equivalent saturation pressures using multi-species (e.g., H₂O-CO₂; H₂O-Cl) solubility laws (using, for example, VOLATILCALC, Newman and Lowenstern 2002; MELTS, Ghiorso and Sack 1995; Asimow and Ghiorso 1998). These, in turn, can be used to calculate total pressures (and hence depth) by assuming volatile saturation, or minimum pressures if the sample is under-saturated in volatiles. Progressive closure of melt inclusion networks in growing phenocrysts can result in zone-dependent melt inclusion volatile contents that record the evolution of pressure conditions as magmas migrate from depth (Blundy and Cashman 2008, and references therein). Combining major element and volatile compositions of the melt with phenocryst contents allows calculation of initial magma physical properties (viscosity, density, surface tension, and others). Derivations of

such parameters are necessary for modeling magma ascent, vesiculation and groundmass crystallization.

Pre-ascent storage conditions can also be inferred from phase-equilibria studies of natural compositions. Comparison of natural and experimental phase abundances and compositions, combined with constraints of volatile content (from melt inclusions) and temperature (from e.g., Fe-Ti oxides) allows estimation of total pressure if the degree of volatile saturation is established through use of mixed-volatile experiments (Pichavant et al. 2007; Cadoux et al. 2014).

Residual volatile content (e.g., H₂O, CO₂, SO₂, Cl, F) measured in the glass or directly from gases emitted at the vent can be correlated with textures (e.g., Piochi et al. 2005; 2008; Schipper et al. 2010a; Balcone-Boissard et al. 2011, 2012; Shea et al. 2012, 2014; Burton et al. 2007; Polacci et al. 2009b; Miwa and Toramaru 2013). The residual volatile contents can also be compared with pre-eruptive volatile contents obtained from melt inclusion to evaluate both the extent and efficiency of syn-eruptive degassing (e.g., Shimano and Nakada 2006; Noguchi et al. 2006, Métrich et al. 2001; 2010). Residual water content or Cl content (when Cl partitions into a H₂O vapor phase, so that it can thus be used as an indicator of degassing processes; Balcone-Boissard et al. 2010) is typically plotted against V_g/V_l , where V_g is the volume of vesicles corrected for phenocrysts and V_l is the volume of melt and microlites (Villemant and Boudon 1998, Balcone-Boissard et al. 2011, 2012). An important issue is to assess the extent of post-eruption hydration. Recently, thermal gravimetric studies have proved to be quite effective in allowing this correction based on oxygen or hydrogen isotopic compositions (e.g., Giachetti and Gonnerman 2013; Shea et al. 2014). Studies of hydrogen isotopes, correlated with SEM glass textures, permit distinction of magmatic water from meteoric water generated by re-hydration (Kyser and O'Neil 1984). Hydration can also be assessed from the ratio of water species (molecular H₂O vs. OH) in residual glass, as determined by FTIR data or Raman analyses (Hammer et al. 1999; Le Losq et al. 2012).

Ascent and decompression in the conduit can result in chemical changes that can be quantified by a range of microbeam analytical techniques (e.g., EPMA, LA-ICPMS, FTIR, μ -Raman). As the pressure drops, H₂O will migrate out of melt inclusions and crystals (Le Voyer et al 2010; Hamada et al 2010), and light elements (Li, B) will try to re-establish equilibrium between crystals, host melt and any vapor or brine phase present (Berlo et al. 2004). At the same time, H₂O and CO₂ migrating out of melt inclusions will become apparent as re-entrant tubes at the edges of crystals (Liu et al. 2007; Humphreys et al. 2008a). Each of these processes will establish diffusive gradients frozen into the pyroclast that can be

measured and modelled using experimentally determined kinetic laws to infer decompression rates during ascent (e.g. Gonnermann and Manga 2013). These decompression rates can then be compared with values derived from other approaches, including those based on analyses of microlite sizes and shapes, vesicle number densities, and hornblende-breakdown reactions (e.g., Martel 2012; Cluzel et al. 2008; Giachetti et al 2010; Shea et al. 2011).

3) Contentious points

Care needs to be taken when converting decompression rate to magma ascent rate, and especially when comparing decompression rates obtained using different methods. Pressure gradients in conduits are highly nonlinear due to the strong effect of dissolved H₂O on magma viscosity, particularly at low H₂O contents (Gonnermann and Manga 2013). Moreover, different processes will likely record different decompression rates, according to the time available for the process to take place. For example, microlite growth is relatively slow, so that microlite size and shape distributions are likely to record an average decompression rate during ascent (Martel 2012). Bubble nucleation and growth, on the other hand, can occur very rapidly, so that N_v may record just the peak decompression rate immediately beneath the fragmentation zone (Cluzel et al. 2008; Giachetti et al 2010). Comparison of rate calculations from different methods therefore requires caution. However, integration of decompression rates as obtained from different textural and chemical characterizations, when combined with mass eruption rate estimation from deposit analysis or direct observations, can provide quantitative insights into the processes involved in magma ascent from the deep source to the surface.

Another outstanding issue is the role of dense clasts. That is, did they originate (i) from magma quenched at depth prior vesiculation, (ii) by vesicle collapse in an originally vesicular clast, (iii) from volatile-poor magma or from recycling? It is important to provide a correct interpretation, because the three conclusions relate to very different mechanisms. In several eruptions it has been found that the densest clasts were depleted in water through syneruptive bubble collapse and coalescence (Rust and Cashman 2007; Piochi et al. 2008, Shea et al. 2014). In Plinian eruptions at Vesuvius (Pompeii and Avellino), the densest clasts have been interpreted as magma that lost water during transition from closed-to open-system degassing (Balcone-Boissard et al. 2011; 2012). Water depletion can also result from syn-eruptive processes, such as clast recycling at magmatic temperature (Gurioli et al. 2014) and intrinsic magmatic redox conditions, as shown by the experiments of D’Oriano et al. (2012). No study

has yet have demonstrated that dense clasts retain all of their original gas and were quenched at great pressure.

Another key question is whether the measured compositions (including volatile content) of bulk rock, glass, or minerals represent equilibrium or disequilibrium processes, and if equilibrium or disequilibrium conditions pertain to local subsystems or to the whole magmatic body under investigation (see for example Pichavant et al. 2007). Chemical species with different diffusivities, for example, record equilibrium or non-equilibrium conditions in the same sample (e.g. De Campos et al. 2008; Schipper et al. 2012). Equilibrium kinetics is also composition-dependent, because it is dictated in part by melt viscosity which is itself related to viscosity. This issue will generally affect silicic to intermediate magmas more than basaltic magmas. However, we note that even for basaltic systems crystal-fluid-bubble magma mixtures can achieve apparent viscosities that range over six orders of magnitude, up to 10^6 Pa s (e.g., Gurioli et al. 2014), depending on the degree of cooling, degassing and crystallization. Such rheological variation even within a single composition, and its effect on eruption mechanisms, deserves increased attention.

How to link the geophysical data with pyroclast textural quantification

A wide array of remote sensing and geophysical approaches can be used to parameterize an explosive event, both within and outside the conduit (Fig. 1). Geophysical signals are generated by fluid and gas flow in the magma-filled part of the conduit and during fragmentation. Magma-gas ascent dynamics and conduit conditions extracted from geophysical data for this part of the system are particularly difficult to validate because the system cannot be directly observed. They are thus effectively “invisible” to direct observation. Measurements outside the conduit can be made of the emitted mixture of gas and particles as it (i) exits the vent, (ii) ascends above the vent as a plume, and then (iii) drifts away from the vent as the cloud. Models and dynamic parameters extracted for geophysical and remote sensing data outside the conduit are a little easier to validate because they can be directly observed.

The invisible part of the system is the realm of studies using seismic, pressure (infrasonic), and deformation data. All three data sets have long been shown capable of detecting the geophysical signature of explosive events spanning weakly explosive Hawaiian-to-Strombolian through Plinian events. Seismic data sets are available, for example, for gas-pistoning events, puffing, fountains, and strombolian eruptions at mafic systems (e.g.,

Goldstein and Chouet 1994; Ripepe et al. 1996; Sciotto et al. 2011; Ripepe and Braun 1994), as well as for events that generate somewhat larger plumes during silicic eruptions, as at Santiaguito, Soufriere Hills, and Redoubt. Associated pressure impulses (typically recorded by infrasound and barometers) have long been recorded for such energetic events, famous examples including the pressure response to the 1883 eruption of Krakatoa and the 1967 caldera-forming eruption of Fernandina (Simkin and Howard 1970). Magma-gas ascent has also been shown to generate rapid, but recordable, deformation signals detected by tiltmeters (Aoyama and Oshima 2008; Genco and Ripepe 2010; Iguchi et al. 2008; Zobin et al 2007).

Velocities, masses and size distributions of particles leaving the vent have typically been measured by visible and thermal video (e.g., Chouet et al. 1974; Ripepe et al. 1993; Harris et al. 2012; Delle Donne and Ripepe 2012; Taddeucci et al. 2012; Bombrun et al. 2014; Gaudin et al., 2014a, b) and Doppler radar (e.g., Dubosclard et al 1999; Hort and Seyfried 1998; Vöge et al 2005; Gouhier and Donnadieu 2008; 2011; Gerst et al 2013). Infrasonic array methods are also available to locate the emission in x,y space (Ripepe and Marchetti 2002). Plume front velocities, density and entrainment rates have also been successfully tracked using visible and thermal cameras, as well as radiometers, for a few stronger, ash-rich, buoyant plumes at Stromboli, Santiaguito and Eyjafjallajökull (Patrick 2007; Sahetapy-Engel and Harris 2009; Bjornsson et al. 2013; Valade et al. 2014); See Chapter 9 of Harris (2013) for review.

Satellite remote sensing has long been used to track and measure properties of the eruption cloud as it drifts and disperses. These data are available for all cloud sizes, from those associated with small Strombolian and fountaining events (e.g., Heiken and Pitts 1975; Dehn et al. 2000; 2002) to sub-Plinian and Plinian events (e.g., Holasek and Self 1995; Koyaguchi and Tokuno 1993; Holasek et al. 1996). Cloud dispersion dynamics are especially well revealed by geostationary satellite data with nominal imaging of one image every 15 minutes and higher. Basic cloud properties that can be measured by satellite data include cloud dimensions, drift velocity and height (e.g., Robock and Matson 1982; Denniss et al. 1998; Aloisi et al. 2002; Zakšek et al 2013). Prata (1989) and Wen and Rose (1994) introduced a method to potentially extract particle size distribution and mass from “split window” (10-12 μm) thermal data. While specially modified ground-based thermal cameras were adapted to extract ash particle size and plume mass (Prata and Bernardo 2009), newly available technology such as LiDAR and PLUDIX were shown of value in detecting, tracking and measuring fine particles in the Eyjafjallajökull cloud (e.g., Bonadonna et al. 2011). Disdrometers and ash collectors, however, currently show greater potential for measuring

particle size and terminal velocity (Marchetti et al. 2013; Shimano et al. 2013) than PLUDIX, which was designed more for meteorological applications (Caracciolo et al. 2006; Prodi et al. 2011).

For the gas content of the cloud, satellite-based sensors such as TOMS, AIRS, OMI, MODIS, GOME and IASI have been used to obtain the SO₂ content in the far field, once the gas cloud has decoupled from the ash cloud (e.g., Krueger et al. 1990; Carn et al. 2003; 2005; Watson et al. 2004; Yang et al. 2007; Thomas et al. 2011; Rix et al. 2012; Walker et al. 2012). Ground-based sensors, such as COSPEC, FLYSPEC and DOAS (e.g., Caltabiano et al. 1994; Horton et al. 2005; Oppenheimer et al. 2011), have been used to measure SO₂ fluxes relatively close to the source; see Williams-Jones et al (2008) for full review. These approaches have been recently supplemented by SO₂ camera systems, which allow 2D images of SO₂ concentrations to be collected at ~1 Hz rates (Mori and Burton 2006). Such studies have, though, tended to focus on passive degassing and gas-puffing systems, because the presence of ash interferes with UV-light transmission on which the technique relies, making measurements problematic. Recently, SO₂ cameras have been used to measure the gas masses and fluxes involved in discrete explosive events (Mori and Burton 2009; Holland et al 2011; Barnie et al. 2014).

However, none of these remote sensing techniques directly collects or makes contact with the magma or particles they measure. Thus the need exists for quality ground-truth data to validate particle velocities and sizes extracted from what is, basically, an electronic response, as well as to test the assumptions and models used to convert received “power” to a more meaningful and useful parameter (such as mass). At the same time, any single data set can be inverted to support a conduit or plume dynamic model; but results need to fall within constraints provided by ground-truth data. In this case, ground truth is provided by analyses of the magma and particles themselves to extract parameters such as magma temperature, chemistry, density, crystallinity and vesicle content, as well as vesicle shape and size and particle density, size, shape and roughness. Magma ascent, explosion-source and fragmentation models based on geophysical data likewise need to be consistent with independent measurements made for physical volcanology for the same processes if they are to be valid. We explore below these needs, mostly focusing on weakly explosive, basaltic cases, the usual targets because they provide a reliable and easy-to-measure source for testing new technology, methods and algorithms for ground-based geophysical enquiry.

The basic need: Realistic assumptions and validation

The basic response of a remote sensing instrument is a voltage which, through calibration, can be converted at higher level physical value, such as spectral radiant intensity or power. The conversion of this value to higher level and more volcanologically useful parameters (such as particle-size distribution, mass flux or plume density) requires an increasingly complex system of assumption stacking. Thus, to adequately reduce geophysical data, a number of input parameters are required and many assumptions need to be made, all of which can be provided by the physical volcanological community. Data sets from this community, especially if provided simultaneously with geophysical data collection during an active event, or provided as a library typical of that event, can also be used to “ground truth” or check the precision and reality of the geophysically applied input or generated output.

Seismic signals that accompany explosions are primarily short period (SP; high frequency > 1 Hz) signals which are typically termed “explosion quakes”. These usually have high amplitudes and mostly include frequencies up to a few hertz, with a possible higher frequency acoustic phase (McNutt 1986, Mori et al. 1989, Braun and Ripepe, 1993). Below these frequencies, short period (SP) signals are often hidden by very-long period (VLP) components with much lower amplitudes (Neuberg et al. 1994; Kaneshima et al. 1996). In spite of an enormous amount of work, it remains unclear as to how we can explain the VLP seismic component, which itself is only one part of the seismic signal. It also remains unclear as to whether, and/or how, SP and VLP components are related to the magnitude and intensity of an explosion, although attempts have been made using tremor (Brodsky et al. 1999; Nishimura and McNutt 2008; Prejean and Brodsky 2011). Clearly, better coupling with the physical volcanology community could help narrow down much uncertainty and allow progress towards better models to untangle the seismic signal associated with discrete explosive events.

Delay times in the arrival of seismic, infrasonic and thermal signals have been commonly used to assess the depth at which various physical processes occur in explosive basaltic systems (e.g., Ripepe and Braun 1994; Ripepe et al. 2001; 2002; Harris and Ripepe 2007). However, the sound speed in the conduit needs to be assumed if, for example, the thermal-infrasound delay is to be used to obtain the fragmentation depth. This will vary strongly with conditions in the empty portion of the conduit, including mixture density, gas-to-particle ratio, and temperature of the mixture through which the sound is propagating. Thus we need to know these variables if we are to provide a realistic sound speed value and hence infer a plausible depth. We thus need to constrain two fundamental parameters to strengthen geophysical modelling of the shallow explosion mechanism and depth. First, the magma crystal and bubble content (as well as size, shape and distribution), plus fluid chemistry and

temperature, are needed to define magma rheology properties and bubble ascent dynamics. Second, the exact proportions and character of the mixture of gas and particles that ascends the final section of the conduit to exit the vent and feed the emission must be known.

Velocities, mass fluxes and particle size distributions (PSDs) for lapilli through bomb-size particles have been derived from high spatial and temporal resolution video data obtained using both near-infrared and thermal cameras (Chouet et al. 1974; Ripepe et al. 1993; Harris et al. 2012; Delle Donne and Ripepe 2012; Bombrun et al. 2014).

Generally, these studies have focused on Stromboli. For such camera data, the lower limit of a particle size that can be extracted is limited by pixel size. This is typically about one centimeter in dimension, depending on the detector's instantaneous field of view and distance to the target (Harris 2013). A pixel-mixture model can be applied to obtain the size of a sub-pixel particle, but it needs to assume a temperature for the particle and then uses the pixel-integrated temperature to solve for the pixel portion occupied by that particle (Harris et al. 2013a). Symmetry then needs to be assumed to convert from particle area to particle volume, and a density needs to be assumed to derive particle mass (Bombrun et al. 2014). For ash-rich plumes, methods have been applied to extract total plume mass and air entrainment properties from ascent dynamics of buoyant thermals (Wilson and Self 1980; Patrick 2007; Valade et al. 2014). However, all methods need particle shape, particle density, plume density and/or size distribution data to: (i) determine whether the input assumptions are valid; and (ii) ground truth the remote-sensing-data-derived size and mass data (Harris et al. 2013a and b). The advantage is, if a validated method can be developed, particle size distribution, mass and mass flux data for the plume leaving the vent can potentially be provided multiple times per second using camera data (e.g., Taddeucci et al. 2012; Bombrun et al. 2014).

Deducing the erupted mass from Doppler radar data requires the assumption of a particle size distribution for the eruption. Because this distribution is unknown, an average particle size can be constrained from the Doppler radar measurement, typically using the eruption velocities themselves deduced from either terminal fall velocities (Hort et al 2003) or by discriminating between lapilli (larger than a few millimeters or 1 cm, depending on the radar wavelength) and fine ash particles (<1 mm) using their temporal velocity evolution (Valade and Donnadieu 2011). Both methods can be used to obtain an estimate for the erupted mass of ballistics. We thus need to know whether the constrained average particle size can be used for mass calculation, whether the assumption is a good approximation, and what the difference between the derived value and true value is.

The radar is able to measure particles of all sizes, provided enough particles are available to return a signal. The relationship between particle size and number of particles required for a signal that exceeds the noise level is not linear, however. It also depends on the radar wavelength and the distance between the radar and target. The smaller the radar wavelength, and/or the smaller the distance between the radar and target, the smaller the number of fine particles needed for a return signal. For particles <1 mm, halving the particle size increases the number of required particles by a factor of 64. Doubling the size of particles to >1 cm means that only 1/4 of the number of particles is needed to return the same signal amplitude. In addition, radar can measure at points (gates) across the entire plume thickness. Currently, radar's best role is to provide radial velocity measurements, with well-stated limits as to the particle size to which these data relate, through the entire plume thickness.

Questions, points and issues

The main question from the geophysical community to the textural community is: “*What does the magma look like at the point of fragmentation?*” Geophysical analysts need to know everything possible about the fragments physically in order to reduce and model the data correctly. To help with this, we concluded that:

- Measurements of basic geophysical parameters (such as seismic energy, acoustic energy, energy partitioning, spectral radiance, and radar power) are the most straightforward to consider for correlations with parameters derived from physical volcanology.
- Multi-disciplinary correlations lead to improved understanding of explosion dynamics, and only a complete set of measurements can enable a complete and well-constrained understanding of the system (e.g., Gurioli et al. 2013; 2014; Leduc et al 2015).
- A wealth of textural and geophysical data exist for Strombolian events, and some data for larger events. They have been used to define the characteristic geophysical and textural signatures that allow distinguishing each event type (e.g. Patrick et al. 2007; Leduc et al 2015). Focus on such relatively low energy events is appropriate, because they are frequent and approachable (Harris and Ripepe 2007).
- There is an unfortunate, but understandable, lack of multi-disciplinary data for larger (Vulcanian-to-Plinian) events; because they are rare. With multi-disciplinary approaches becoming more routine, this situation is improving.

Thermal and SO₂ sensor arrays are becoming increasingly common components of permanent monitoring arrays at many persistently active sites (Harris 2013). However, such technology

will probably never be installed on every potentially active volcano, all of which give seismic and pressure signals detectable by distant stations. From a practical point of view, it is more realistic to push forward with operational correlations between seismic-infrasonic metrics and deposit and particle textural deliverables to understand the ongoing progression of global volcanic events. In doing so, we must remember that many geophysical signals tend to be time-averages (e.g., tremor amplitude). We need to consider, however, geophysical measurements that describe single, discrete explosions if we are to reasonably compare the data with textural variations between many individual emission events, or emission phases, that characterize the total eruption total energy is one prime example (e.g., Marchetti et al 2009).

We are at an exciting point in our ability to track and understand explosive volcanic emissions through true cross-disciplinary integration of deposit, geochemical, textural and geophysical data. Studies are increasingly bringing together multiple approaches in the field (e.g., Rosi et al. 2006), in the laboratory (Clarke et al. 2009), at large-scale experiments (Sonder et al. 2013) and during field deployments (Harris et al. 2013b). As a community, we appear to be converging on the correct, multi-disciplinary approach. We are at the beginning of a new age, one which links particle texture to seismology (Miwa et al. 2009; Miwa and Toramaru 2013; Gurioli et al. 2014; Leduc et al. 2015) and infrasound (Colò et al. 2010, Landi et al. 2011); as well as petrology to geophysics (Saunders et al. 2012; Martí et al. 2013). Continuation of this trajectory can be aided by further support for pan-disciplinary workshops, meetings and working groups, the objectives of which are to totally understand the system and to constrain measurements with the least uncertainty.

Questions, needs and recommendations

Tables 2–4 summarize the main results from the previous discussions. Table 2 is the summary of major conclusions to date from cross-disciplinary approaches. Table 3 suggests improvements to methods to facilitate cross-disciplinary approaches. Finally, Table 4 groups outstanding questions that might be addressed if the recommended methods are used.

The list of key issues and questions defined allows us to distil the following community-wide points and initiatives as priorities:

1. We need to define, and adhere to, standard sampling, data collection, experimental and methodological procedures to allow full integration of the four disciplines;

2. In doing this, we need to understand each other's needs, and then follow each other's well-recognized sampling etiquette in order to work together as a truly integrated team;
3. We should aim to collate all data and measurements that can be provided by each discipline at some central host site and evaluate whether we need more from each field;
4. Quantification and statement of the precision of the measurements must always be made, and a set of standards must be produced to allow data quality control has to be followed;
5. The community needs to explore and discuss the best means to improve the quality of the measurements and the amount of data available;
6. Guidelines should be agreed on regarding essential key parameters that need to be extracted, versus those that are less important. Common standards need to be established that allow these key parameters to be shared by all groups;
7. Central to this is creation of an open access data bank to support essential geophysical, deposit, textural and geochemical data integration and sharing. This means creation of a repository of data grouped by eruptive style and/or geographic location into which members can make deposits and withdrawals;
8. All of this should ideally be integrated into a GIS platform to allow for easy cross-correlation and comparison of different types of parameters.

DynVolc: an integrated database

Inspired by this effort, a database – DynVolc (Dynamics of Volcanoes) – is now operative at <http://wwwobs.univ-bpclermont.fr/SO/televolc/dynvolc/index.php>. This database is part of an observation system within the services provided by Observatoire de Physique du Globe de Clermont-Ferrand (OPGC). It is an attempt to provide an integrated and accessible library for all multi-disciplinary data sets for explosive eruptive events. This database is an integrated collection of data from physical and geophysical observations of dynamic volcanic processes.

DynVolc database spans the full range of explosive and effusive activity. Its intent is to provide a library of standards for eruptive styles, for each of which the data base provides:

- field data (i.e., results of field mapping, outcrop and sample descriptions)
- key deposit features (thickness, areal dispersion, sedimentary structure, grain size)
- clast characterization (componentry, morphology, density, porosity, permeability)

- clast texture (connectivity, vesicle and crystal size and size distributions)
- chemical analyses of samples (bulk and glass chemistry)
- associated geophysical measurements (e.g., fragmentation depth, ejection and ascent velocity, fragment and gas mass, seismic and acoustic energies)

Integration of these data allows improved, better constrained, insights into the dynamics driving each eruptive style. It also allows improved definition of the rheological and degassing conditions associated with each activity style. At the same time it provides a library of key physical parameters that need to be assumed by geophysical data reduction methods, as well as during model-based enquiry.

Central to this initiative will be the transformation of this database into a communal databank, involving a web-based GIS platform to allow huge amounts of cross-correlation and comparison between parameters relating to different processes and cross-correlation of different datasets obtained for the same eruption. It is intended as an open database into which anyone can input, and withdraw, citable cross-disciplinary information for scientific analysis. At the same time, through this library, we can provide cross-community time series, baseline and monitoring data for the full range volcanic activity.

Acknowledgements

L Gurioli thanks the MeMoVolc, European Science Foundation grant (ref. n. 4253). G Valentine D Swanson and the editor, J White are thanked for their constructive reviews. This research was financed by the French Government Laboratory of Excellence initiative no ANR-10-LABX-0006, the Région Auvergne, and the European Regional Development Fund. This is Laboratory of Excellence ClerVolc contribution number XXX

References

- Adams NK, Houghton BF, Hildreth W (2006a) Abrupt transitions during sustained explosive eruptions: examples from the 1912 eruption of Novarupta, Alaska. *Bull Volcanol* 69:189–206
- Adams NK, Houghton BF, Fagents S, Hildreth W (2006b) The transition from explosive to effusive eruptive regime: The example of the 1912 Novarupta eruption, Alaska. *GSA Bulletin* 118 (5/6):620–634. doi: 10.1130/B25768.1

1045 Alfano F, Bonadonna C, Volentik ACM, Connor CB, Watt SFL, Pyle DM, Connor LJ (2011)
 1046 Tephra stratigraphy and eruptive volume of the May, 2008, Chaiten eruption, Chile. *Bull*
 1047 *Volcanol* 73 (5):613–630
 1048
 1049 Alfano F, Bonadonna C, Gurioli L (2012) Insights on rhyolitic eruption dynamic from textural
 1050 analysis: the example of the May Chaitén eruption (Chile). *Bull Volcanol* 74(9):2095-2108. doi
 1051 10.1007/s00445-012-0648-3
 1052
 1053 Aloisi M, D’Agostino M, Dean KG, Mostaccio A and Neri G (2002). Satellite analysis and
 1054 PUFF simulation of the eruptive cloud generated by the Mount Etna paroxysm of 22 July
 1055 1998. *J Geophys Res* 107(B12): 2373. doi: 10.1029/2001JB000630
 1056
 1057 Anderson AT (1991) Hourglass inclusions: theory and application to the Bishop Rhyolitic
 1058 Tuff. *Am Min* 76:530-547
 1059
 1060 Andronico D, Corsaro RA, Cristaldi A, Polacci M (2008) Characterizing high energy
 1061 explosive eruptions at Stromboli volcano using multidisciplinary data: an example from the 9
 1062 January 2005 explosion. *J Volcanol Geotherm Res* 176:541–550.
 1063 doi:10.1016/j.jvolgeores.2008.05.011
 1064
 1065 Andronico D, Scollo S, Cristaldi A, Ferrari F (2009a), Monitoring ash emission episodes at
 1066 Mt. Etna: The 16 November 2006 case study. *J Volcanol Geotherm Res* 180 (2–4):123–134.
 1067 doi:10.1016/j.jvolgeores.2008.10.019
 1068
 1069 Andronico D, Cristaldi A, Del Carlo P, Taddeucci J (2009b) Shifting styles of basaltic
 1070 explosive activity during the 2002-03 eruption of Mt Etna, Italy. *J Volcanol Geotherm Res*
 1071 180(2-4):110-122. doi:10.1016/j.jvolgeores.2008.07.026
 1072
 1073 Andronico D, Lo Castro MD, Sciotto M, Spina L (2013a) The 2010 ash emissions at the
 1074 summit craters of Mt Etna: Relationship with seismo-acoustic signals. *J Geophys Res* 118:51–
 1075 70. doi:10.1029/2012JB009895
 1076

1077 Andronico D, Taddeucci J, Cristaldi A, Miraglia L; Scarlato P, Gaeta M (2013b) The 15
 1078 March 2007 paroxysm of Stromboli: video-image analysis, and textural and compositional
 1079 features of the erupted deposit. *Bull Volcanol* 75:733. doi 10.1007/s00445-013-0733-2
 1080

1081 Aoyama H and Oshima H (2008) Tilt change recorded by broadband seismometer prior to
 1082 small phreatic explosion of Meakan-dake volcano, Hokkaido, Japan. *Geophys Res Lett* 35.
 1083 doi:10.1029/2007GL032988
 1084

1085 Armienti P (2008) Decryption of igneous textures: crystal size distribution tools. *Rev Mineral*
 1086 *Geochem* 69:623-649
 1087

1088 Armienti P, Tarquini S (2002) Power law olivine crystal size distributions in lithospheric
 1089 mantle xenoliths. *Lithos* 65:273–285
 1090

1091 Armienti P, Pareschi M, Innocenti F, Pompilio M (1994) Effects of magma storage and ascent
 1092 on the kinetics of crystal growth. The case of the 1991-92 Mt.Etna eruption. *Contrib Mineral*
 1093 *Petr* 115:402–414
 1094

1095 Arzilli F, Voltolini M, Mancini L, Cicconi MR, Giuli G, Carroll MR (2013) Spherulites in
 1096 trachytic melts. *Mineral Mag* 77(5):622
 1097

1098 Asimow PD, Ghiorso MS (1998) Algorithmic modifications extending MELTS to calculate
 1099 subsolidus phase relations. *Am Mineral* 83:1127–1131
 1100

1101 Bai L, Baker DR, Rivers M (2008) Experimental study of bubble growth in Stromboli basalt
 1102 melts at 1 atmosphere. *Earth Planet Sci Lett* 267:533–547. doi:10.1016/j.epsl.2007.11.063
 1103

1104 Bai L, Baker DR, Hill RJ (2010) Permeability of vesicular Stromboli basaltic glass: Lattice
 1105 Boltzmann simulations and laboratory measurements. *J Geophys Res* 115:B07201.
 1106 doi:10.1029/2009JB007047
 1107

1108 Bai L, Baker DR, Polacci M, Hill RJ (2011) In-situ degassing study on crystal-bearing
 1109 Stromboli basaltic magmas: implications for Stromboli explosions. *Geophys Res Lett*
 1110 38:L17309. doi.org/10.1029/2011GL048540

1111

1112 Baker DR, Polacci M, LaRue A (2011) A study on the reproducibility of counting vesicles in
 1113 volcanic rocks. *Geosphere* 7:70-78

1114

1115 Baker DR, Mancini L, Polacci M, Higgins MD, GAR. Gualda, R.J. Hill, M.L. Rivers (2012)
 1116 An introduction to the application of X-ray microtomography to the three-dimensional study
 1117 of igneous rocks. *Lithos* 148:262-276

1118

1119 Balcone-Boissard H, Villemant B, Boudon G (2010) Behavior of halogens during the
 1120 degassing of felsic magma. *Geochem Geophys Geosyst* 11(9):477–485.
 1121 doi:10.1002/2010GC003028

1122

1123 Balcone-Boissard H, Boudon G, Villemant B (2011) Textural and geochemical constraints on
 1124 eruptive style of the 79AD eruption at Vesuvius. *Bull Volcanol.* doi 10.1007/s00445-010-
 1125 0409-0

1126 Balcone-Boissard H, Boudon G, Ucciani G, Villemant B, Cioni R, Civetta L, Orsi G (2012).
 1127 Magma degassing and eruption dynamics of the Avellino Pumice Plinian eruption of Somma-
 1128 Vesuvius (Italy). Comparison with the Pompeii eruption. *Earth Planet Sci Lett* 331-332:257-
 1129 268. doi: 10.1016/j.epsl.2012.03.011

1130

1131 Barsotti S, Neri A, Scire JS (2008). The VOL-CALPUFF model for atmospheric ash
 1132 dispersal: 1. Approach and physical formulation. *J Geophys Res* 113:B03208.
 1133 doi:10.1029/2006JB004623

1134

1135 Barker SJ, Rotella MD, Wilson CJN, Wright IC, Wysoczanski RJ (2012) Contrasting
 1136 pyroclast density spectra from subaerial and submarine silicic eruptions in the Kermadec arc:
 1137 implications for eruption processes and dredge sampling *Bull Volcanol* 74:1425–1443.
 1138 doi:10.1007/s00445-012-0604-2

1139

1140 Barrie T, Bombrun M, Burton MR, Harris A and Sawyer G (2014) Quantification of gas and
 1141 solid emissions during Strombolian explosions using simultaneous sulphur dioxide and
 1142 infrared camera observations. *J Volcanol Geotherm Res*
 1143 <http://dx.doi.org/10.1016/j.jvolgeores.2014.10.003>

1144

1145 Bear J (1972) Dynamics of fluids in porous media. Dover, New York

1146

1147 Belien IB, Cashman KV, Rempel AW (2010), Gas accumulation in particle-rich suspensions

1148 and implications for bubble populations in crystal-rich magma. *Earth Planet Sci Lett* 297(1-

1149 2):133-140. doi:10.1016/j.epsl.2010.06.014

1150

1151 Berlo K, Turner S (2010) ^{210}Pb - ^{226}Ra disequilibria in volcanic rocks. *Earth Planet Sci Lett*

1152 (Frontiers) 296:155-164

1153

1154 Berlo K, Blundy J, Turner S, Cashman K, Hawkesworth C, Black S (2004) Geochemical

1155 precursors to volcanic activity at Mount St. Helens, USA. *Science* 306:1167-1169

1156

1157 Bernard B (2013) Home-made ashmeter: a low-cost, high-efficiency solution to improve

1158 tephra field-data collection for contemporary explosive eruptions. *J Appl Volcanol* 2:1

1159

1160 Bernard ML, Zamora M, Geraud Y, Boudon G (2007) Transport properties of pyroclastic

1161 rocks from Montagne Pele'e volcano (Martinique, Lesser Antilles). *J Geophys Res*

1162 112:B05205.doi.org/10.1029/2006JB004385

1163

1164 Bindeman IN (2003) Crystal sizes in evolving silicic magma chambers. *Geology* 31:367-370

1165

1166 Bjornsson H, Magnusson S, Arason P and Petersen GN (2013) Velocities in the plume of the

1167 2010 Eyjafjallajökull eruption. *J Geophys Res Atmos* 118:698–711 doi:10.1002/jgrd.50876

1168

1169 Blower JD (2001a) Factors controlling permeability-porosity relationships in magma. *Bull*

1170 *Volcanol* 63:497–504

1171

1172 Blower JD (2001b) A three-dimensional network model of permeability in vesicular material.

1173 *Comp Geosci* 27:115–119

1174

1175 Blower JD, Keating JP, Mader HM, Phillips JC (2001) Inferring volcanic degassing processes

1176 from bubble size distributions. *Geophys Res Lett* 28(2):347–350

1177

1178 Blower JD, Keating JP, Mader HM, Phillips JC (2002) The evolution of bubble size
1179 distributions in volcanic eruptions. *J Volcanol Geother Res* 120:1–23.
1180 [http://dx.doi.org/10.1016/S0377-0273\(02\)00404-3](http://dx.doi.org/10.1016/S0377-0273(02)00404-3)
1181

1182 Blundy J, Cashman KV (2008) Petrologic reconstruction of magmatic system variables and
1183 processes. *Rev Mineral Geochem* 69:179–239.
1184

1185 Blundy J, Cashman K, Humphreys M (2006) Magma heating by decompression-driven
1186 crystallization beneath andesite volcanoes. *Nature* 443:76-80
1187

1188 Bombrun M, Barra V, Harris A (2014) Algorithm for particle detection and parameterization
1189 in high-frame-rate thermal video. *J Appl Remote Sens* 8(1):083549.
1190 doi:10.1117/1.JRS.8.083549
1191

1192 Bonadonna C, Costa A (2012) Estimating the volume of tephra deposits: A new simple
1193 strategy. *Geology* 40 (5):415–418. doi:10.1130/G32769.1
1194

1195 Bonadonna C, Ernst GGJ, Sparks RSJ (1998) Thickness variations and volume estimates of
1196 tephra fall deposits: the importance of particle Reynolds number. *J Volcanol Geotherm Res*
1197 81:173–187
1198

1199 Bonadonna C, Genco R, Gouhier M, Pistolesi M, Cioni R, Alfano F, Hoskuldsson A, Ripepe
1200 M (2011) Tephra sedimentation during the 2010 Eyjafjallajökull eruption (Iceland) from
1201 deposit, radar, and satellite observations. *J Geophys Res* 116(B12202).
1202 doi:10.1029/2011JB008462
1203

1204 Boorman S, Boudreau AE, Kruger FJ (2004) The lower zone–critical zone transition of the
1205 Bushveld complex: a quantitative textural study. *J Petrol* 45:1209–1235
1206

1207 Bouma AH (1969) *Methods for the study of sedimentary structures*. Jhon Wiley and Sons,
1208 New York, p 458
1209

1210 Bouvet de Maisonneuve C, Bachmann O, Burgisser A (2009) Characterization of juvenile
 1211 pyroclasts from the Kos Plateau Tuff (Aegean Arc): insights into the eruptive dynamics of a
 1212 large rhyolitic eruption. *Bull Volcanol* 71:643-658
 1213
 1214 Braun T, Ripepe M (1993) Interaction of seismic and air waves as recorded at Stromboli
 1215 volcano. *Geophys Res Lett* 20(1):65–68
 1216
 1217 Brodsky E, Kanamori H, Sturtevant B (1999) A seismically constrained mass discharge rate
 1218 for the initiation of the May 18, 1980 Mount St. Helens eruption. *J Geophys Res* 104:29,387–
 1219 29,400
 1220
 1221 Bryon DN, Atherton MP, Hunter RH (1995) The interpretation of granitic textures from serial
 1222 thin sectioning, image analysis and three-dimensional reconstruction. *Miner Magaz* 59:203-
 1223 211
 1224
 1225 Burbié T, Zinszner B (1985) Hydraulic and acoustic properties as a function of porosity in
 1226 Fontainebleau sandstone. *J Geophys Res* 90:11524–11532
 1227
 1228 Burgisser A, Gardner JE (2005) Experimental constraints on degassing and permeability in
 1229 volcanic conduit flow. *Bull Volcanol* 67:42–56
 1230
 1231 Burgisser A, Poussineau S, Arbaret L, Druitt TH, Giachetti T, Bourdier JL (2010) Pre-
 1232 explosive conduit conditions of the 1997 Vulcanian explosions at Soufrière Hills Volcano
 1233 (Montserrat): I. pressure and vesicularity distributions. *J Volcanol Geotherm Res* 194 (1–
 1234 3):27–41. doi:10.1016/j.jvolgeores.2010.01.008
 1235
 1236 Burton MR, Mader HM, Polacci M (2007) The role of gas percolation in quiescent degassing
 1237 of persistently active volcanoes. *Earth Planet Sci Lett* 264:46–60.
 1238 doi:10.1016/j.epsl.2007.08.028
 1239
 1240 Bustillos J, Mothes P (2010) Ash falls at Tungurahua volcano: implementation of systematic
 1241 ash collection for quantifying accumulated volumes, *Cities On Volcanoes abstract volume*,
 1242 Tenerife. Canary Island, Spain, May 31 – June 4 2010, 2.7-O-07
 1243

1244 Büttner R, Dellino P, Zimanowski B (1999) Identifying magma–water interaction from the
 1245 surface features of ash particles. *Nature* 401:688– 690
 1246

1247 Büttner R, Dellino P, La Volpe L, Lorenz V, Zimanowsky B (2002) Thermohydraulic
 1248 explosions in phreatomagmatic eruptions as evidenced by the comparison between pyroclasts
 1249 and products from Molten Fuel Interaction experiments. *J Geophys Res* 107 (B11):2277.
 1250 doi:10.1029/2001JB000511.
 1251

1252 Cadoux A, Scaillet B, Druitt TH, Deloule E (2014). Magma storage conditions of large
 1253 Plinian eruptions of Santorini Volcano (Greece). *J Petrology* 55(6):1129-1171.
 1254 doi:10.1093/petrology/egu021
 1255

1256 Caltabiano T, Roman R and Budetta G (1994) SO₂ flux measurements at Mount Etna (Sicily).
 1257 *J Geophys Res* 99:12 809 – 12 819
 1258

1259 Capaccioni B, Sarocchi D (1996) Computer-assisted image analysis on clast shape fabric from
 1260 the Orvieto-Bagnoregio ignimbrite (Vulsini District, central Italy): implications on the
 1261 emplacement mechanisms. *J Volcanol Geotherm Res* 70(1–2):75-90. doi: 10.1016/0377-
 1262 0273(95)00049-6
 1263

1264 Caracciolo C, Prodia F, Uijlenhoet R (2006) Comparison between Pludix and impact/optical
 1265 disdrometers during rainfall measurement campaigns. *Atmos Res* 82(1-2):137–163
 1266

1267 Carey RJ, Houghton BF, Thordarson T (2009) Abrupt shifts between wet and dry phases of
 1268 the 1875 eruption of Askja Volcano: microscopic evidence for macroscopic dynamics. *J*
 1269 *Volcanol Geotherm Res* 184:256–270
 1270

1271 Carey RJ, Manga M, Degruyter W, Swanson D, Houghton B, Orr T, Patrick M (2012)
 1272 Externally triggered renewed bubble nucleation in basaltic magma: The 12 October 2008
 1273 eruption at Halema‘uma‘u Overlook vent, Kīlauea, Hawai‘i, USA. *J Geophys Res*
 1274 117:B11202. doi:10.1029/2012JB009496
 1275

1276 Carey RJ, Manga M, Degruyter W, Gonnermann H, Swanson D, Houghton B, Orr T, Patrick
 1277 M (2013) Convection in a volcanic conduit recorded by bubbles. *Geology* 41(4):395–398

1278

1279 Carey S, Sparks RSJ (1986) Quantitative models of the fallout and dispersal of tephra from
 1280 volcanic eruption columns. *Bull Volcanol* 48:109–125. doi:10.1007/BF01046546

1281

1282 Carey S, Maria A, Sigurdsson H (2000) Use of fractal analysis for discrimination of particles
 1283 from primary and reworked jökulhlaup deposits in SE Iceland. *J Volcanol Geotherm Res*
 1284 104:65–80

1285

1286 Carn SA, Krueger AJ, Bluth GJS, Schaefer SJ, Krotkov NA, Watson IM, Datta S (2003)
 1287 Volcanic eruption detection by the Total Ozone Mapping Spectrometer (TOMS) instruments:
 1288 a 22-year record of sulfur dioxide and ash emissions. In: *Volcanic Degassing* (eds. C
 1289 Oppenheimer, DM Pyle and J Barclay), Geological Society, London, Special Publications,
 1290 213, pp.177-202.

1291

1292 Carn SA, Strow LL, de Souza-Machado S, Edmonds Y, Hannon S (2005) Quantifying
 1293 tropospheric volcanic emissions with AIRS: the 2002 eruption of Mt. Etna (Italy). *Geophys*
 1294 *Res Lett* 32(2):L02301. doi:10.1029/2004GL021034

1295

1296 Cas RAF, Wright JV (1987) *Volcanic successions: modern and ancient*. Allen & Unwin,
 1297 London, 528p

1298

1299 Cashman KV (1988) Crystallization of Mount St. Helens 1980–1986 dacite: A quantitative
 1300 textural approach. *Bull Volcanol* 50(3):194-209. doi:10.1007/BF01079682

1301

1302 Cashman KV (1992) Groundmass crystallization of Mount St. Helens dacite, 1980-1986: A
 1303 tool for interpreting shallow magmatic processes. *Contrib Mineral Petrol* 109:431-449

1304

1305 Cashman KV (1993). Relationship between plagioclase crystallization and cooling rate in
 1306 basaltic melts. *Contrib Mineral Petr* 113:126-142

1307

1308 Cashman KV, Mangan MT (1994) Physical aspects of magmatic degassing II. Constraints on
 1309 vesiculation processes from textural studies of eruptive products. In: M. Carroll (Editor),
 1310 *Volatiles in Magmas*. Mineral Sot Am Washington, DC, pp. 447-478

1311

1312 Cashman KV, Marsh BD (1988) Crystal size distribution (CSD) in rocks and the kinetics and
 1313 dynamics of crystallization II. Makaopuhi lava lake. *Contrib Mineral Petrol* 99:292–305
 1314

1315 Cashman KV, McConnell S (2005) Transitions from explosive to effusive activity – the
 1316 summer 1980 eruptions of Mount St. Helens. *Bull Volcanol* 68:57-75
 1317

1318 Cashman KV, Mangan MT, Newman S (1994) Surface degassing and modifications to vesicle
 1319 size distributions in Kilauea basalt. *J Volcanol Geotherm Res* 61:45-68
 1320

1321 Castro JM, Cashman KV, Manga M (2003) A technique for measuring 3D crystal-size
 1322 distributions of prismatic microlites in obsidian. *Am Mineral* 88:1230-1240
 1323

1324 Castro JM, Burgisser A, Shipper CI, Mancini S (2012) Mechanisms of bubble coalescence in
 1325 silicic magmas. *Bull Volcanol* 74:2339-2352
 1326

1327 Chakraborty S (2008) Diffusion in solid silicates: A tool to track timescales of processes
 1328 comes of age. *Annu Rev Earth Planet Sci* 36 (1):153-190
 1329

1330 Chen Y, Provost A, Schiano P, Cluzel N (2011) The rate of water loss from olivine-hosted
 1331 melt inclusions. *Contrib Mineral Petrol* 162:625-636
 1332

1333 Chen Y, Provost A, Schiano P, Cluzel N (2013) Magma ascent rate and initial water
 1334 concentration inferred from diffusive water loss from olivine-hosted melt inclusions. *Contrib*
 1335 *Mineral Petrol* 165:525-541
 1336

1337 Cheng HC, Lemlich R (1983) Errors in the measurement of bubble-size distribution in foam.
 1338 *Ind. Eng Chem Fundam* 22:105–109
 1339

1340 Chouet B, Hamisevicz N, McGetchin TR (1974) Photoballistics of volcanic jet activity at
 1341 Stromboli, Italy. *J Geophys Res* 79:4961–4976
 1342

1343 Cichy SB, Botcharnikov RE, Holtz F, Behrens H (2011) Vesiculation and microlite
1344 crystallization induced by decompression: a case study of the 1991-1995 Mt Unzen eruption
1345 (Japan). *J Petrol* 52:1469-1492
1346

1347 Cigolini C, Laiolo M, Bertolino S (2008) Probing Stromboli volcano from the mantle to
1348 paroxysmal eruptions. In: Annen C, Zellmer GF (eds) *Dynamics of crustal magma transfer,*
1349 *storage and differentiation.* Geological Society, London, special publication, vol 304.
1350 Geological Society, London, pp 33–70
1351

1352 Cimorelli C, Di Traglia F, Taddeucci J (2010) Basaltic scoria textures from a zoned conduit as
1353 precursors to violent Strombolian activity. *Geology* 38(5): 439-442
1354

1355 Cioni R, D’Orsano C, Bertagnini A (2008) Fingerprinting ash deposits of small scale eruptions
1356 by their physical and textural features. *J Volcanol Geotherm Res* 177:277–287
1357

1358 Cioni R, Bertagnini A, Andronico D, Cole PD, Mundula F (2011) The 512 AD eruption of
1359 Vesuvius: complex dynamics of a small scale subplinian event. *Bull Volcanol* 73 (7):789-810.
1360 doi:10.1007/s00445-011-0454-3
1361

1362 Clarke AB, Stephens S, Teasdale R, Sparks RSJ, Diller K (2007) Petrologic constraints on the
1363 decompression history of magma prior to Vulcanian explosions at the Soufrière Hills volcano,
1364 Montserrat. *J Volcanol Geotherm Res* 161:261-274
1365

1366 Clarke AB, Phillips JC, Chojnicki KN (2009) An investigation of Vulcanian eruption
1367 dynamics using laboratory analogue experiments and scaling analysis. In: *Studies in*
1368 *Volcanology: The Legacy of George Walker,* Thordason T, Self S, Larsen G, Rowland SK,
1369 Höskuldsson Á (eds) *IAVCEI Special Publications in Volcanology* 2: 155-166.
1370

1371 Cluzel N, Laporte D, Provost A (2008) Kinetics of heterogeneous bubble nucleation in
1372 rhyolitic melts: implications for the number density of bubbles in volcanic conduits and for
1373 pumice textures. *Contrib Mineral Petrol* 156:745-763
1374

1375 Colò L, Ripepe M, Baker DR, Polacci M (2010), Magma vesiculation and infrasonic activity
1376 at Stromboli open conduit volcano. *Earth Planet Sc Lett* 292 (3–4)
1377

1378 Colucci S, Palladino DM, Mulukutla GK, Proussevitch AA (2013) 3-D reconstruction of ash
1379 vesicularity: Insight into the origin of ash-rich explosive eruptions. *J Volcanol Geotherm Res*
1380 255:98-107
1381

1382 Costa F, Cohmen R, Chakraborty S (2008) Time scales of magmatic processes from modeling
1383 the zoning patterns of crystals. In Putirka KD, Tepley FJ (Eds) *Minerals, inclusions and*
1384 *volcanic processes*. *Rev Mineral Geochem* 69:545-594
1385

1386 Costantini L, Houghton BF, Bonadonna C (2010) Constraints on eruption dynamics of
1387 basaltic explosive activity derived from chemical and microtextural study: the example of the
1388 Fontana Lapilli Plinian eruption, Nicaragua. *J Volcanol Geother Res* 189 (3–4):207–224.
1389 doi:10.1016/j.jvolgeores.2009.11.008
1390

1391 Couch S, Sparks RSJ, Carroll MR (2003) The kinetics of degassing-induced crystallization at
1392 Soufrière Hills Volcano, Montserrat. *J Petrol* 44(8):1477–1502
1393

1394 De Campos CP, Dingwell DB, Perugini D, et al. (2008) Heterogeneities in magma chambers:
1395 Insights from the behavior of major and minor elements during mixing experiments with
1396 natural alkaline melts. *Chem Geol* 256:131–145. doi: 10.1016/j.chemgeo.2008.06.034
1397

1398 De Keyser TL (1999) Digital scanning of thin sections and peels. *J Sedim Res* 69:962–964
1399

1400 Degruyter W, Bachmann O, Burgisser A (2010a) Controls on magma permeability in the
1401 volcanic conduit during the climactic phase of the Kos Plateau Tuff eruption (Aegean Arc).
1402 *Bull Volcanol* 72:63–74. doi: 10.1007/s00445-009-0302-x
1403

1404 Degruyter W, Burgisser A, Bachmann O, Malaspina O (2010b) Synchrotron X-ray
1405 microtomography and lattice Boltzmann simulations of gas flow through volcanic pumices.
1406 *Geosphere* 6:470–481
1407

1408 Degruyter W, Bachmann O, Burgisser A, Manga M (2012) The effects of outgassing on the
 1409 transition between effusive and explosive silicic eruptions. *Earth Planet Sc Lett* 349-350:161-
 1410 170
 1411
 1412 Dehn J, Dean K, Engle K (2000) Thermal monitoring of North Pacific volcanoes from space.
 1413 *Geology* 28(8):755-758
 1414
 1415 Dehn J, Dean KG, Engle K, Izbekov P (2002) Thermal precursors in satellite images of the
 1416 1999 eruption of Shishaldin volcano. *Bull Volcanol* 64:525-545
 1417
 1418 Delle Donne D, Ripepe M (2012) High-frame rate thermal imagery of Strombolian
 1419 explosions: Implications for explosive and infrasonic source dynamics. *J Geophys Res*
 1420 117(B12). doi: 10.1029/2011JB008987
 1421
 1422 Dellino P, La Volpe L (1996a) Image processing analysis in reconstructing fragmentation and
 1423 transportation mechanisms of pyroclastic deposits. the case of Monte Pilato-Rocche Rosse
 1424 eruptions, Lipari (Aeolian Islands, Italy). *J Volcanol Geotherm Res* 71:13–29
 1425
 1426 Dellino P, La Volpe L (1996b) Cluster analysis on ash particles morphology features to
 1427 discriminate fragmentation dynamics in explosive eruptions. *Acta Vulcanologica* 1:31–39
 1428
 1429 Dellino P, Liotino G (2002) The fractal and multifractal dimension of volcanic ash particles
 1430 contour: a test study on the utility and volcanological relevance *J Volcanol Geotherm Res* 113
 1431 (1–2):1-18. doi:10.1016/S0377-0273(01)00247-5
 1432
 1433 Dellino P, Isaia R, La Volpe L, Orsi G (2001) Statistical analysis of textural data from
 1434 complex pyroclastic sequences: implications for fragmentation processes of the Agnano-
 1435 Monte Spina Tephra (4.1 ka), Phlegraean Fields, southern Italy. *Bull Volcanol* 63:443–461
 1436
 1437 Dellino P, Mele D, Bonasia R, Braia G, La Volpe L, Sulpizio R (2005) The analysis of the
 1438 influence of pumice shape on its terminal velocity. *J Geophys Res* 32:L21306.
 1439 doi:10.1029/2005GL023954
 1440

1441 Dellino P, Mele D, Sulpizio R, La Volpe L, Braia G (2012) A method for the calculation of
 1442 the impact parameters of dilute pyroclastic density currents based on deposit particle
 1443 characteristics. *J Geophys Res* 113 (B7). doi 10.1029/2007JB005365
 1444
 1445 Denniss AM, Harris AJL, Rothery DA, Francis PW, Carlton RW (1998) Satellite observations
 1446 of the April 1993 eruption of Lascar volcano. *Int J Remote Sensing* 19(5):801-821
 1447
 1448 Dixon JE (1997) Degassing of alkali basalts. *Am Min* 82:368-378
 1449
 1450 Dohmen R, Becker H-W, Chakraborty S (2007) Fe–Mg diffusion in olivine I: experimental
 1451 determination between 700 and 1,200°C as a function of composition, crystal orientation and
 1452 oxygen fugacity. *Phys Chem* 34:389–407. doi: 10.1007/s00269-007-0157-7
 1453
 1454 D’Oriano C, Poggianti E, Bertagnini A, Cioni R, Landi P, Polacci M, Rosi M (2005) Changes
 1455 in eruptive styles during the A.D. 1538 Monte Nuovo eruption (Phleagrean Fields, Italy): the
 1456 role of syneruptive crystallization. *Bull Volcanol* 67:601–621
 1457
 1458 D’Oriano C, Cioni R, Bertagnini A, Andronico D, Cole PD (2011a) Dynamics of ash-
 1459 dominated eruptions at Vesuvius: the post-512 AD AS1a event. *Bull Volcanol* 73 (6):699-
 1460 715. doi:10.1007/s00445-010-0432-1
 1461
 1462 D’Oriano C, Bertagnini A, Pompilio M (2011b) Ash erupted during normal activity at
 1463 Stromboli (Aeolian Islands, Italy) raises questions on how the feeding system works. *Bull*
 1464 *Volcanol* 73:471-477
 1465
 1466 D’Oriano C, Pompilio M, Bertagnini A, Cioni R, Pichavant M (2012) Effects of experimental
 1467 reheating of natural basaltic ash at different temperatures and redox conditions. *Contrib*
 1468 *Mineral Petrol*. doi: 10.1007/s00410-012-0839-0
 1469
 1470 Dubosclard G, Cordesses R, Allard P, Hervier C, Coltelli C, Kornprobst J (1999) First testing
 1471 of a volcano Doppler radar (Voldorad) at Mount Etna, Italy. *Geophys Rese Lett* 26(22):3389–
 1472 3392
 1473

1474 Eichelberger JC, Carrigan CR, Westrich HR, Price RH (1986) Non-explosive silicic
 1475 volcanism. *Nature* 323:598–602
 1476

1477 Engwell SL, Sparks RSJ, Aspinall WP (2013) Quantifying uncertainties in the measurement
 1478 of tephra fall thickness. *J Applied Volcanol* 2:5. doi:10.1186/2191-5040-2-5.
 1479

1480 Ersoy O, Chinga G, Aydar E, Gourgaud A, Cubuku HE, Ulusoy I (2006) Texture
 1481 discrimination of volcanic ashes from different fragmentation mechanisms: A case study,
 1482 Mount Nemrut stratovolcano, eastern Turkey. *Comput Geosci* 32:936-946
 1483

1484 Eychenne J, Le Pennec JL, Troncoso L, Gouhier M, Nedelec JM (2012) Causes and
 1485 consequences of bimodal grainsize distribution of tephra fall deposited during the August
 1486 2006 Tungurahua eruption (Ecuador). *Bull Volcanol* 74:187–205. doi: 10.1007/s00445-011-
 1487 0517-5
 1488

1489 Eychenne J, Le Pennec JL, Ramón P, Yepes H (2013) Dynamics of explosive paroxysms at
 1490 open-vent andesitic systems: High-resolution mass distribution analyses of the 2006
 1491 Tungurahua fall deposit (Ecuador). *Earth Planet Sci Lett* 361:343-355. doi: 10.10-
 1492 16/j.epsl.2012.11.002
 1493

1494 Eychenne J, Houghton BF, Swanson DA, Carey RJ, Swavely L (2015) Dynamics of an open
 1495 basaltic magma system: The 2008 activity of the Halema‘uma‘u Overlook vent, Kīlauea
 1496 Caldera. *Earth Planet Sci Lett* 409:49-60
 1497

1498 Fagents SA, Gregg TKP, Lopes RMC (2013) Modeling Volcanic Processes. The Physics and
 1499 Mathematics of Volcanism. Cambridge University Press
 1500

1501 Faure F, Trolliard G, Nicollet C, Montel J-M (2003) A developmental model of olivine
 1502 morphology as a function of the cooling rate and the degree of undercooling. *Contrib Mineral*
 1503 *Petrol* 145 (2):251–263. doi: 10.1007/s00410-003-0449-y
 1504

1505 Faure F, Schiano P, Trolliard G, Nicollet C, Soulestin B (2007) Textural evolution of
 1506 polyhedral olivine experiencing rapid cooling rates. *Contrib Mineral Petrol* 153:405-416
 1507

1508 Ferguson DJ; Plank TA; Hauri EH; Houghton BF; Gonnermann HM; Swanson DA; Blaser
 1509 AP (2013) Comparing eruptions of varying intensity at Kilauea via melt inclusion analysis.
 1510 American Geophysical Union, Fall Meeting 2013, abstract #V33F-07
 1511
 1512 Fierstein J, Nathenson M (1992) Another look at the calculation of fallout tephra volumes.
 1513 Bull Volcanol 54:156–167
 1514
 1515 Fierstein J, Houghton BF, Wilson CJN, Hildreth W (1997) Complexities of plinian fall
 1516 deposition at vent: an example from the 1912 Novarupta eruption (Alaska). J Volcanol
 1517 Geotherm Res 76:215–227
 1518
 1519 Fischer TP (2008) Fluxes of volatiles (H₂O, CO₂, N₂, Cl, F) from arc volcanoes. Geochem J
 1520 42:21–38. doi: 10.2343/geochemj.42.21
 1521
 1522 Fisher RV, Schmincke H-U (1984) Pyroclastic rocks. Springer, Berlin Heidelberg New York
 1523
 1524 Fiske RS, Rose TR, Swanson D, Champion D, McGeehin J (2009) Kulanaokuaiki Tephra (ca.
 1525 A.D. 400–1000): Newly recognized evidence for highly explosive eruptions at Kīlauea
 1526 Volcano, Hawai‘i." GSA Bull 121:712-728
 1527
 1528 Formenti Y, Druitt TH (2003) Vesicle connectivity in pyroclasts and implications for the
 1529 fluidisation of fountain-collapse pyroclastic flows, Montserrat (West Indies). Earth Planet Sci
 1530 Lett 214:561–574
 1531
 1532 Freundt A, Rosi M (1998) From Magma to Tephra. Elsevier, New York
 1533
 1534 Frieese K-I, Cichy SB, Wolter F-E, Botcharnikov RE (2013). Analysis of tomographic mineral
 1535 data using YaDiV – Overview and practical case study. Comput Geosci 56:92-103
 1536
 1537 Gaonac’h H, Lovejoy S, Stix J, Schertzer D (1996a) A scaling growth model for bubbles in
 1538 basaltic flows. Earth Planet Sci Lett 139:395–409
 1539
 1540 Gaonac’h H, Stix J, Lovejoy S (1996b) Scaling effects on vesicles shape, size and
 1541 heterogeneity of lavas from Mount Etna. J Volcanol Geotherm Res 74:131–153

1542

1543 Gaonac'h H, Lovejoy S, Schertzer D (2003) Percolating magmas and explosive volcanism.
 1544 Geophys Res Lett 30. doi:10.1029/2002GL0116022

1545

1546 Gaonac'h H, Lovejoy S, Schertzer D (2005) Scaling vesicle distributions and volcanic
 1547 eruptions. Bull Volcanol 67(4):350–357

1548

1549 Gardner JE (2007) Heterogeneous bubble nucleation in highly viscous silicate melts during
 1550 instantaneous decompression from high pressure. Chem Geol 236:1-12

1551 Gaudin D, Moroni M, Taddeucci J, Scarlato P, Shindler L. (2014a) Pyroclast Tracking
 1552 Velocimetry: A particle tracking velocimetry-based tool for the study of Strombolian
 1553 explosive eruptions. J Geophys Res Solid Earth 119:5369–5383. Doi:10.1002/2014JB011095

1554 Gaudin D, Taddeucci J, Scarlato P, Moroni M, Freda C, Gaeta M, Palladino DM (2014b)
 1555 Pyroclast Tracking Velocimetry illuminates bomb ejection and explosion dynamics at
 1556 Stromboli (Italy) and Yasur (Vanuatu) volcanoes. J Geophys Res Solid Earth 119:5384–5397.
 1557 doi:10.1002/2014JB011096

1558

1559 Genareau K, Proussevitch AA, Durant AJ, Mulukutla GK, Sahagian DL (2012) Sizing up the
 1560 bubbles that produce very fine ash during explosive volcanic eruptions. Geophys Res Lett
 1561 39:(L15306).

1562

1563 Genareau K, Mulukutla GK, Proussevitch AA, Durant AJ, Rose WI, Sahagian DL (2013) The
 1564 size range of bubbles that produce ash during explosive volcanic eruptions. J Appl Volcanol
 1565 2:4. doi:10.1186/2191-5040-2-4

1566

1567 Genco R, Ripepe M (2010) Inflation-deflation cycles revealed by tilt and seismic records at
 1568 Stromboli volcano. Geophys Res Lett 37. doi: 10.1029/2010GL042925

1569

1570 Gerst A, Hort M, Aster RC, Johnson JB, Kyle PR (2013) The first second of volcanic
 1571 eruptions from the Erebus volcano lava lake, Antarctica—Energies, pressures, seismology,
 1572 and infrasound. J Geophys Res 118:3318–3340. doi:10.1002/jgrb.50234

1573

1574 Ghiorso MS, Sack RO (1995) Chemical mass transfer in magmatic processes. IV. A revised
 1575 and internally consistent thermodynamic model for the interpolation and extrapolation of
 1576 liquid-solid equilibria in magmatic systems at elevated temperatures and pressures. *Contrib*
 1577 *Mineral Petrol* 119:197–212
 1578
 1579 Giachetti T, Gonnermann HM (2013). Water in pumices: rehydration or incomplete degassing?
 1580 *Earth Planet Sci Lett* 369-370:317-332
 1581
 1582 Giachetti T, Druitt TH, Burgisser A, Arbaret L, Galven C (2010) Bubble nucleation and
 1583 growth during the 1997 Vulcanian explosions of Soufrière Hills Volcano, Montserrat. *J*
 1584 *Volcanol Geotherm Res* 193 (3–4):215–231. doi:10.1016/j.jvolgeores.2010.04.001
 1585
 1586 Giachetti T, Burgisser A, Arbaret L, Druitt TH, Kelfoun K (2011) Quantitative textural
 1587 analysis of Vulcanian pyroclasts (Montserrat) using multi-scale X-ray computed
 1588 microtomography: comparison with results from 2D image analysis. *Bull Volcanol* 73
 1589 (9):1295-1309. doi:10.1007/s00445-011-0472-1
 1590
 1591 Goldstein P, Chouet B (1994) Array measurements and modeling of sources of shallow
 1592 volcanic tremor at Kilauea Volcano, Hawaii. *J Geophys Res* 99(B2):2637–2652
 1593
 1594 Gonnermann HM, Houghton BF (2012) Magma degassing and fragmentation during the
 1595 Plinian eruption of Novarupta, Alaska, 1912. *Geochem Geophys Geosyst* 13:Q10009. doi: 10
 1596 .1029 /2012GC004273
 1597
 1598 Gonnermann HM, Manga M (2013) Dynamics of magma ascent in the volcanic conduit. In
 1599 *Modelling volcanic processes: the physics and mathematics of volcanism*, ed. By S. Fagents,
 1600 T.K.P. Gregg, R.M.C. Lopes. Cambridge University Press, New York, pp. 55-84
 1601
 1602 Goodchild JS, Fueten F (1998) Edge detection in petrographic images using the rotating
 1603 polarizer stage. *Comput Geosci* 24:745–751
 1604
 1605 Gouhier M, Donnadieu F (2008) Mass estimations of ejecta from Strombolian explosions by
 1606 inversion of Doppler radar measurements. *J Geophys Res* 113:B10202.
 1607 doi:10.1029/2007JB005383

1608

1609 Gouhier M, Donnadieu F (2011) Systematic retrieval of ejecta velocities and gas fluxes at
 1610 Etna volcano using L-Band Doppler radar. *Bull Volcanol* 73(9):1139-1145.
 1611 doi:10.1007/s00445-011-0500-1

1612

1613 Gualda GAR (2006) Crystal size distributions derived from 3D datasets: sample size versus
 1614 uncertainties. *J Petrol* 47(6):1245-1254

1615

1616 Gualda GAR, Rivers M (2006) Quantitative 3D petrography using X- ray tomography:
 1617 application to Bishop Tuff pumice clasts. *J Volcanol Geotherm Res* 154(1–2):48–62

1618

1619 Gualda GAR, Baker DR, Polacci M (2010a) Introduction: Advances in 3D imaging and
 1620 analysis of Geomaterials, *Geosphere*, special issue "Advances in 3D Imaging and Analysis of
 1621 Geomaterials" 6-5:468-469. doi:10.1130/GES00639.1

1622

1623 Gualda GAR, Pamukcu AS, Claiborne LL, Rivers ML (2010b) Quantitative 3D petrography
 1624 using X-ray tomography 3: documenting accessory phases with differential absorption
 1625 tomography. *Geosphere* 6(6):782–792

1626

1627 Gurioli L, Houghton B, Cashman K, Cioni R (2005) Complex changes in eruption dynamics
 1628 and the transition between Plinian and phreatomagmatic activity during the 79AD eruption of
 1629 Vesuvius. *Bull Volcanol* 67:144-159 doi: 10.1007/s00445-004-0368-4

1630

1631 Gurioli L, Harris AJL, Houghton BF, Polacci M, Ripepe M (2008) Textural and geophysical
 1632 characterization of explosive basaltic activity at Villarrica volcano. *J Geophys Res*
 1633 113:B08206. doi:10.1029/2007JB005328

1634

1635 Gurioli L, Harris AJL, Colò L, Bernard J, Favalli M, Ripepe M, Andronico D (2013)
 1636 Classification, landing distribution and associated flight parameters for a bomb field emplaced
 1637 during a single major explosion at Stromboli, Italy. *Geology* 41 (5):559–562. doi
 1638 10.1130/G33967.1

1639

1640 Gurioli L, Colò L, Bollasina AJ, Harris AJL, Whittington A, Ripepe M (2014) Dynamics of
1641 strombolian explosions: inferences from inferences from field and laboratory studies of
1642 erupted bombs from Stromboli volcano. *J Geophys Res* 119. doi:10.1002/2013JB010355
1643

1644 Hamada M, Laporte D, Cluzel N, Koga KT (2010) Simulating bubble number density of
1645 rhyolitic pumices from Plinian eruptions: constraints from fast decompression experiments.
1646 *Bull Volcanol* 72:735-746
1647

1648 Hammer JE (2008). Experimental studies of the kinetics and energetics of magma
1649 crystallization. *Rev Mineral Geochem* 69:9-59
1650

1651 Hammer JE, Rutherford MJ (2002) An experimental study of the kinetics of decompression-
1652 induced crystallization in silicic melt. *J Geophys Res* 107(B1). doi:10.1029/2001JB000281
1653

1654 Hammer JE, Cashman KV, Hoblitt RP, Newman S (1999) Degassing and microlite
1655 crystallization during pre-climactic events of the 1991 eruption of Mt. Pinatubo, Philippines.
1656 *Bull Volcanol* 60:355–380
1657

1658 Hammer JE, Sharp TG, Wessel P (2010) Heterogeneous nucleation and epitaxial crystal
1659 growth of magmatic minerals. *Geology* 38: 367-370.
1660

1661 Harris A (2013) *Thermal Remote Sensing of Active Volcanoes: A User's Manual*, Cambridge
1662 University Press: 728 p.
1663

1664 Harris AJL, Ripepe M (2007) Synergy of multiple geophysical approaches to unravel
1665 explosive eruption conduit and source dynamics – A case study from Stromboli. *Chemie der*
1666 *Erde* 67: 1-35.
1667

1668 Harris AJL, Ripepe M, Hort M (2004) Foreward. *J Volcanol Geotherm Res* 137(1-3):vii– viii.
1669 doi:10.1016/S0377-0273(04)00276-8
1670

1671 Harris AJL, Ripepe M, Hughes EE (2012) Detailed analysis of particle launch velocities, size
1672 distributions and gas densities during normal explosions at Stromboli. *J Volcanol Geotherm*
1673 *Res* 231-232:109-131

1674

1675 Harris AJL, Delle Donne D, Dehn J, Ripepe M, Worden K (2013a) Volcanic plume and bomb
 1676 field masses from thermal infrared camera imagery. *Earth Planet Sci Lett* 365:77-85. doi:
 1677 10.1016/j.epsl.2013.01.004

1678

1679 Harris AJL, Battaglia J, Donnadieu F, Gurioli L, Kelfoun K, Labazuy P, Sawyer G, Valade S,
 1680 Bombun M, Barra V, Delle Donne D, Lacanna G (2013b) Full bandwidth remote sensing for
 1681 total parameterization of volcanic plumes. *EOS* 94 (37):321-322

1682

1683 Heiken G and Pitts DE (1975) Identification of eruption clouds with the landsat satellites. *Bull*
 1684 *Volcanol* 39(2):255-265

1685

1686 Heiken G, Wohletz KH (1985) Volcanic ash, University of California Press, Berkeley, Ca,
 1687 USA

1688

1689 Heilbronner R (2000) Automatic grain boundary detection and grain size analysis using
 1690 polarization micrographs or orientation images. *J Struct Geol* 22:969–981

1691

1692 Herd R, Pinkerton H (1997) Bubble coalescence in basaltic lava: its impact on the evolution
 1693 of bubble populations. *J Volcanol Geotherm Res* 75:137–157

1694

1695 Higgins MD (2000) Measurement of crystal size distributions *Am Mineral* 85:1105–1116

1696

1697 Higgins MD (2002a) A crystal size-distribution study of the Kiglapait layered mafic intrusion,
 1698 Labrador, Canada: Evidence for textural coarsening. *Contrib Mineral Petr* 144:314-330

1699

1700 Higgins MD (2002b) Closure in crystal size distributions (CSD), verification of CSD
 1701 calculations, and the significance of CSD fans. *Am Mineral* 87:171-175

1702

1703 Higgins MD (2006) Quantitative textural measurements in igneous and metamorphic
 1704 petrology. Cambridge University Press, Cambridge

1705

1706 Higgins MD (2011) Textural coarsening in igneous rocks. *Int Geol Rev* 53:354–376

1707

1708 Hoblitt RP, Harmon RS (1993) Bimodal density distribution of cryptodome dacite from the
 1709 1980 Mount St. Helens, Washington. *Bull Volcanol* 55:421– 437
 1710
 1711 Holasek RE, Self S (1995) GOES weather satellite observations and measurements of the
 1712 May 18, 1980, Mount St. Helens eruption. *J Geophys Res* 100(B5):8469-8487
 1713
 1714 Holasek RE, Self S, Woods AW (1996) Satellite observations and interpretation of the 1991
 1715 Mount Pinatubo eruption plumes. *J Geophys Res* 101(B12):27635-27655
 1716
 1717 Holland ASP, Watson M, Phillips JC, Caricchi L, Dalton MP (2011) Degassing processes
 1718 during lava dome growth: Insights from Santiaguito lava dome, Guatemala. *J Volcanol*
 1719 *Geotherm Res* 202(1–2):153-166
 1720
 1721 Hort M, Seyfried R, Vöge M (2003) Radar Doppler velocimetry of volcanic eruptions:
 1722 Theoretical considerations and quantitative documentation of changes in eruptive behaviour at
 1723 Stromboli volcano, Italy. *Geophys J Int* 154:515-532
 1724
 1725 Hort M, Seyfried R (1998) Volcanic eruption velocities measured with a micro radar.
 1726 *Geophys Res Lett* 25:113–116
 1727
 1728 Horton K, Williams-Jones G, Garbeil H, Elias T, Sutton AJ, Mougini-Mark P, Porter JN,
 1729 Clegg S (2005) Real-time measurement of volcanic SO₂ emissions: validation of a new UV
 1730 correlation spectrometer (FLYSPEC). *Bull Volcanol*: doi 10.1007/s00445-005-0014-9
 1731
 1732 Houghton BF, Wilson CJN (1989) A vesicularity index for pyroclastic deposits. *Bull*
 1733 *Volcanol* 51:451–462. doi:10.1007/BF01078811
 1734
 1735 Houghton BF, Carey RJ, Cashman KV, Wilson CJN, Hobden BJ, Hammer JE (2010) Diverse
 1736 patterns of ascent, degassing, and eruption of rhyolite magma during the 1.8 ka Taupo
 1737 eruption, New Zealand: Evidence from clast vesicularity, *J Volcanol Geotherm Res* 195:31–
 1738 47
 1739

1740 Houghton BF, Swanson DA, Rausch J, Carey RJ, Fagents SA, Orr TR (2013) Pushing the
 1741 Volcanic Explosivity Index to its limit and beyond: Constraints from exceptionally weak
 1742 explosive eruptions at Kīlauea in 2008. *Geology* 41(6):627–630
 1743

1744 Humphreys MCS, Menand T, Blundy JD, Klimm K (2008a) Magma ascent rates in explosive
 1745 eruptions: constraints from H₂O diffusion in melt inclusions. *Earth Planet Sci Lett* 270:25-40
 1746

1747 Humphreys MC, Blundy JD, Sparks RSJ (2008b) Shallow-level decompression crystallization
 1748 and deep magma supply at Shiveluch volcano. *Contrib Mineral Petrol* 155:45-61
 1749

1750 Hurwitz S, Navon O (1994) Bubble nucleation in rhyolitic melts: experiments at high
 1751 pressure, temperature, and water content. *Earth Planet Sci Lett* 122:267-280
 1752

1753 Iguchi M, Yakiwara H, Tameguri T, Hendrasto M, Hirabayashi J (2008) Mechanism of
 1754 explosive eruption revealed by geophysical observations at the Sakurajima, Suwanosejima
 1755 and Semeru volcanoes. *J Volcanol Geotherm Res* 178(1):1-9
 1756

1757 Innocenti S, Andreastuti S, Furman T, del Marmol M-A, Voight B (2013) The pre-eruption
 1758 conditions for explosive eruptions at Merapi volcano as revealed by crystal texture and
 1759 mineralogy. *J Volcanol Geother Res* doi.org/10.1016/j.jvolgeores.2012.12.028
 1760

1761 Ishibashi H, Sato H (2007) Viscosity measurements of subliquidus magmas: alkali olivine
 1762 basalt from the Higashi-Matsuura district, Southwest Japan. *J Volcanol Geotherm Res*
 1763 160:223–238
 1764

1765 Jerram DA, Cheadle MJ, Philpotts AR (2003) Quantifying the building blocks of igneous
 1766 rocks: are clustered crystal frameworks the foundation? *J Petrol* 44:2033–2051
 1767

1768 Jouniaux L, Bernard ML, Zamora M, Pozzi JP (2000) Streaming potential in volcanic rocks
 1769 from Mount Pelée. *J Geophys Res* 105:8391–8401
 1770

1771 Kahl M, Chakraborty S, Costa F, Pompilio M (2011) Dynamic plumbing system beneath
 1772 volcanoes revealed by kinetic modeling, and the connection to monitoring data: An example
 1773 from Mt. Etna. *Earth Planet Sc Lett* 308:11–22. doi: 10.1016/j.epsl.2011.05.008

1774

1775 Kaneshima S, Kawakatsu H, Matsubayashi H, Sudo Y, Tsutsui T, Ohminato T, Ito H, Uhira
 1776 K, Yamasato H, Oikawa J, Takeo M, Iidaka T (1996) Mechanism of phreatic eruptions at Aso
 1777 Volcano inferred from near-field broadband seismic observations. *Science* 273(5275):643-645
 1778

1779 Kennedy B, Spieler O, Scheu B, Kueppers U, Taddeucci J, Dingwell DB (2005) Conduit
 1780 implosion during Vulcanian eruptions. *Geology* 33:581-584. doi: 10.1130/G21488.1
 1781

1782 Kent AJR (2008) Melt inclusions in basaltic and related volcanic rocks. *Rev Mineral*
 1783 *Geochem* 69: 273-331
 1784

1785 Kent AJR, Blundy J, Cashman K, Cooper KM, Donnelly C. et al. (2007) Vapor transfer prior
 1786 to the October 2004 eruption of Mount St. Helens, Washington. *Geology* 35: 231–234
 1787

1788 Ketcham RA (2005) Computational methods for quantitative analysis of three-dimensional
 1789 features in geological specimens. *Geosphere* 1:32-41
 1790

1791 Ketcham RA, Carlson WD (2001) Acquisition, optimization and interpretation of X-ray
 1792 computed tomographic imagery: applications to the geosciences. *Comput Geosci* 27:381–400
 1793

1794 Klawonn M, Houghton BF, Swanson DA, Fagents SA, Wessel P, Wolfe CJ (2014)
 1795 Constraining explosive volcanism: subjective choices during estimates of eruption magnitude.
 1796 *Bull Volcanol* 76:793. doi: 10.1007/s00445-013-0793-3
 1797

1798 Klug C, Cashman KV (1994) Vesiculation of May 18, 1980, Mount St. Helens magma.
 1799 *Geology* 22:468–472
 1800

1801 Klug C, Cashman KV (1996) Permeability development in vesiculating magmas: implications
 1802 for fragmentation. *Bull Volcanol* 58:87–100
 1803

1804 Klug C, Cashman KV, Bacon CR (2002) Structure and physical characteristics of pumice
 1805 from the climatic eruption of Mount Mazama (Crater Lake), Oregon. *Bull Volcanol* 64:486–
 1806 501
 1807

1808 Koyaguchi T, Tokuno M (1993) Origin of the giant eruption cloud of Pinatubo, June 15,
1809 1991. *J Volcanol Geotherm Res* 55:85-96
1810

1811 Krueger AJ, Walter LS, Doiron SD (1990) TOMS measurement of sulfur dioxide emitted
1812 during the 1985 Nevado del Ruiz eruptions. *J Volcanol Geotherm Res* 41:7-15
1813

1814 Kueppers U, Scheu B, Spieler O, Dingwell DB (2005) Field-based density measurements as
1815 tool to identify pre-eruption dome structure: set-up and first results from Unzen volcano,
1816 Japan. *J Volcanol Geotherm Res* 141:65–75
1817

1818 Kueppers U, Scheu B, Spieler O, Dingwell DB (2006) Fragmentation efficiency of explosive
1819 volcanic eruptions: A study of experimentally generated pyroclasts. *J Volcanol Geotherm Res*
1820 153(1–2):125-135
1821

1822 Kyser TK, O’Neil JR (1984) Hydrogen isotope systematic of submarine basalts. *Geochim*
1823 *Cosmochim Acta* 48:2123–2133
1824

1825 Lak M, Néraudeau D, Nel A, Cloetens P, Perrichot V, Tafforeau P (2008) Phase contrast X-
1826 ray synchrotron imaging: opening access to fossil inclusions in opaque amber. *Microsc*
1827 *Microanal* 14(3):251–259
1828

1829 Landi P, Marchetti E, La Felice S, Ripepe M, Rosi M (2011) Integrated petrochemical and
1830 geophysical data reveals thermal distribution of the feeding conduits at Stromboli volcano,
1831 Italy. *Geophys Res Lett* 38:L08305
1832

1833 Lanza R, Meloni A (2006) The Earth’s magnetism: an introduction for geologists. 278 pp.
1834 Berlin, Heidelberg, New York: Springer-Verlag
1835

1836 Larsen JF (2008) Heterogeneous bubble nucleation and disequilibrium H₂O exsolution in
1837 Vesuvius K-phonolite melts. *J Volcanol Geotherm Res* 275:278–288
1838

1839 Larsen JF, Gardner JE (2000) Experimental constraints on bubble interactions in rhyolite
1840 melts: implications for vesicle size distributions. *Earth Planet Sci Lett* 180:201–214
1841

1842 LaRue A, Baker DR, Polacci M, Allard P, Sodini N (2013), Can vesicle size distributions
 1843 assess eruption intensity during volcanic activity? *J Geophys Res-Solid Earth* 4:373–80.
 1844 doi:10.5194/se-4-373-2013
 1845

1846 Laumonier M, Arbaret L, Burgisser A, Champallier R (2011) Porosity redistribution enhanced
 1847 by strain localization in crystal-rich magmas. *Geology* 39:715–718.
 1848 <http://dx.doi.org/10.1130/G31803.1>
 1849

1850 Launeau P, Cruden AR (1998) Magmatic fabric acquisition mechanisms in a syenite: results
 1851 of a combined anisotropy of magnetic susceptibility and image analysis study. *J Geophys Res*
 1852 103:5067–5089
 1853

1854 Launeau P, Bouchez JL, Benn K (1990) Shape preferred orientation of object populations:
 1855 Automatic analysis of digitized images. *Tectonophysics* 180:201-211
 1856

1857 Launeau P, Cruden AR, Bouchez JL (1994) Mineral recognition in digital images of rocks: a
 1858 new approach using multichannel classification. *Can Mineral* 32:919–933
 1859

1860 Lautze NC, Houghton BF (2005) Physical mingling of magma and complex eruption
 1861 dynamics in the shallow conduit at Stromboli volcano, Italy. *Geology* 33:425–428.
 1862

1863 Lautze NC, Houghton BF (2007) Linking variable explosion style and magma textures during
 1864 2002 at Stromboli volcano, Italy. *Bull Volcanol* 69:445–460
 1865

1866 Lautze NC, Houghton BF (2008) Single explosions at Stromboli in 2002: use of clast
 1867 microtextures to map physical diversity across a fragmentation zone. *J Volcanol Geotherm*
 1868 *Res* 170:262–268
 1869

1870 Lautze N, Taddeucci J, Andronico D, Cannata C, Tornetta L, Scarlato P, Houghton B, Lo
 1871 Castro D (2012) SEM-based methods for the analysis of basaltic ash from weak explosive
 1872 activity at Etna in 2006 and the 2007 eruptive crisis at Stromboli. *Phys Chem Earth* 45–
 1873 46:113–127. doi:10.1016/j.pce.2011.02.001
 1874

1875 Lautze N, Taddeucci J, Andronico D, Houghton B, Niemeijer A, Scarlato P (2013) Insights
1876 into explosion dynamics and the production of ash at Stromboli from samples collected in real
1877 time, October 2009. *Geol S Am S* 498:125-139
1878

1879 Lavallée Y, Varley N, Alatorre-Ibargüengoitia MA, Hess KU, Mueller S, Richard D, Scheu
1880 B, Spieler O, Dingwell DB (2012) Magmatic architecture of dome-building eruptions at
1881 Volcán de Colima, Mexico. *Bull Volcanol* 74:249-260
1882

1883 Leduc L, Gurioli L, Harris AJL, Colò L, Rose-Koga E Dynamics of a gas-dominated
1884 strombolian explosion. *Bull Volcanol* 77:8. doi: 10.1007/s00445-014-0888-5.
1885

1886 Le Losq C, Neuville DR, Moretti R, Roux J (2012) Determination of water content in silicate
1887 glasses using Raman spectrometry: Implications for the study of explosive volcanism. *Am*
1888 *Mineral* 97:779-790
1889

1890 Le Pennec JL, Hermitte D, Isya D, Pezard P, Coulon C, Cochemé J-J, Mulyadi E, Ollagnier
1891 F, Revest C (2001). Electrical conductivity and pore-space topology of Merapi lavas:
1892 implication for the degassing of porphyritic andesite magmas. *Geophys Res Lett*
1893 28(22):4283–4286
1894

1895 Le Voyer M, Rose-Koga EF, Shimizu N, Grove TL, Schiano P (2010) Two contrasting H₂O-
1896 rich components in primary melt inclusions from Mount Shasta. *J Petrol* 5(7):1571–1595. doi:
1897 10.1093/petrology/egq030
1898

1899 Lesne P, Kohn SC, Blundy J, Witham F, Botcharnikov RE, Behrens H. (2011). Experimental
1900 simulation of closed-system degassing in the system basalt-H₂O-CO₂-S-Cl. *J Petrol* 52:1737-
1901 1762
1902

1903 Liu Y, Anderson AT, Wilson CJN (2007) Melt pockets in phenocrysts and decompression
1904 rates of silicic magmas before fragmentation. *J Geophys Res* 112. doi:10.1029/2006JB004500
1905

1906 Lovejoy S, Gaonac’h H, Schertzer D (2004) Bubble distributions, and dynamics: the
1907 expansion-coalescence equation. *J Geophys Res* 109:B11203. doi:10.1029/2003JB002823
1908

1909 Lumbreras F, Serrat J (1996) Segmentation of petrographical images of marbles. *Comput*
1910 *Geosci* 22:547–558
1911

1912 Magee C, O’Driscoll B, Chambers AD (2010) Crystallization and textural evolution of a
1913 closed-system magma chamber: insights from a crystal size distribution study of the Lilloise
1914 layered intrusion, east Greenland. *Geol Mag* 147:363–379
1915

1916 Manga M. (1998) Orientation distribution of microlites in obsidian. *J Volcanol Geother Res*
1917 86:107–115
1918

1919 Mangan M (1990) Crystal size distribution systematics and the determination of magma
1920 storage times: The 1959 eruption of Kilauea volcano, Hawaii. *J Volcanol Geother Res*
1921 44:295–302
1922

1923 Mangan MT, Cashman, KV (1996) The structure of basaltic scoria and reticulite and
1924 inferences for vesiculation, foam formation, and fragmentation in lava fountains. *J Volcanol*
1925 *Geotherm Res* 73:1-18
1926

1927 Mangan M, Sisson T (2000) Delayed, disequilibrium degassing in rhyolite magma:
1928 decompression experiments and implications for explosive volcanism. *Earth Planet Sci Lett*
1929 183:441–55
1930

1931 Mangan M, Sisson T (2005). Evolution of melt-vapor surface tension in silicic volcanic
1932 systems: Experiments with hydrous melts. *J Geophys Res* 110:B01202. doi:
1933 10.1029/2004JB003215
1934

1935 Mangan MT, Cashman KV, Newman S (1993) Vesiculation of basaltic magma during
1936 eruption. *Geology* 21:157–160
1937

1938 Marchetti E, Ripepe M, Harris AJL, Delle Donne D (2009) Tracing the differences between
1939 Vulcanian and Strombolian explosions using infrasonic and thermal radiation energy. *Earth*
1940 *Planet Sci Lett* 279:273–281
1941

1942 Marchetti E, Poggi P, Bonadonna C, Pistolesi M, Hoskuldsson A (2013) Towards real-time
1943 measurements of tephra fallout grain-size distribution. MeMoVolc Meeting, Geneve
1944 Switzerland, January 2014
1945

1946 Maria A, Carey S (2002) Using fractal analysis to quantitatively characterize the shapes of
1947 volcanic particles. *J Geophys Res* 107:(B11):2283. doi:10.1029/2001JB000822
1948

1949 Maria A, Carey S (2007) Quantitative discrimination of magma fragmentation and pyroclastic
1950 transport processes using the fractal spectrum technique. *J Volcanol Geotherm Res* 161:234–
1951 246
1952

1953 Marsh BD (1988) Crystal size distribution (CSD) in rocks and the kinetics and dynamics of
1954 crystallization: I. Theory. *Contrib Mineral Petrol* 99:277– 291
1955

1956 Marsh BD (1998) On the interpretation of crystal size distributions in magmatic systems. *J*
1957 *Petrol* 39:553–599
1958

1959 Marsh BD (2007) Crystallization of silicate magmas deciphered using crystal size
1960 distributions. *J Am Ceramic Society* 90:746-757
1961

1962 Marshall JR (1987) *Clastic particles: Scanning electron microscopy and shape analysis of*
1963 *sedimentary and volcanic clasts*, Van Nostrand Reinhold Company, New York, 346 p.
1964

1965 Marschallinger R (1998a) A method for three-dimensional reconstruction of macroscopic
1966 features in geological materials. *Comput Geosc* 24:875-883
1967

1968 Marschallinger R (1998b) Correction of geometric errors associated with the 3-D
1969 reconstruction of geological materials by precision serial lapping. *Mineral Mag* 62:783-792
1970

1971 Marschallinger R (1998c) 3-D reconstruction and volume modelling of the grain fabric of
1972 geological materials. *Phys Chem Earth* 23:267-271
1973

1974 Martel C (2012) Eruption Dynamics inferred from microlite crystallization experiments:
 1975 application to Plinian and dome-forming eruptions of Mt. Pelée (Martinique, Lesser Antilles).
 1976 J Petrol 53:699-725
 1977
 1978 Martel C, Radadi Ali A, Poussineau S, Gourgaud A, Pichavant M (2006) Basalt-inherited
 1979 microlites in silicic magmas: evidence from Mt. Pelée (Martinique, F.W.I.). Geology 34:905–
 1980 908
 1981
 1982 Marti J, Soriano C, Dingwell DB (1999) Tube pumices as strain markers of the ductile-brittle
 1983 transition during magma fragmentation. Nature 402(6762):650–653
 1984
 1985 Martí J, Castro A, Rodríguez C, Costa F, Carrasquilla S, Pedreira R, Bolos X (2013)
 1986 Correlation of magma evolution and geophysical monitoring during the 2011–2012 El Hierro
 1987 (Canary Islands) submarine eruption. J Petrology 54(7):1349-1373.
 1988 doi:10.1093/petrology/egt014.
 1989
 1990 Mattsson HB (2010) Textural variation in juvenile pyroclasts from an emergent, Surteyan-
 1991 type, volcanic eruption: The Capelas tuff cone, São Miguel (Azores). J Volcanol Geoth Res
 1992 189:81–91
 1993
 1994 McNutt SR (1986) Observations and analysis of B-type earthquakes, explosions, and volcanic
 1995 tremor at Pavlof Volcano, Alaska. Bull Seis Soc Amer 76:153-175
 1996
 1997 Mele D, Dellino P, Sulpizio R, Braia G (2011) A systematic investigation on the
 1998 aerodynamics of ash particles, J Volcanol Geotherm Res 203:1–11.
 1999 doi:10.1016/j.jvolgeores.2011.04.004
 2000
 2001 Melnik O, Sparks RSJ (2002) Dynamics of magma ascent and lava extrusion at Soufrière
 2002 Hills Volcano, Montserrat. In: Druitt, T., Kokelaar, B. (Eds.), The Eruption of Soufrière Hills
 2003 Volcano, Montserrat, from 1995 to 1999. The Geological Society of London, pp. 153–171.
 2004
 2005 Métrich N, Bertagnini A, Landi P, Rosi M (2001), Crystallization driven by decompression
 2006 and water loss at Stromboli volcano (Aeolian Islands, Italy). J Petrol 42:1471–1490.
 2007 doi:10.1093/petrology/42.8.1471

2008

2009 Métrich N, Wallace PJ (2008) Volatile abundances in basaltic magmas and their degassing
 2010 paths tracked by melt inclusions. In Putirka KD, Tepley FJ (Eds) Minerals, inclusions and
 2011 volcanic processes Rev Mineral Geochem 69:363-402

2012

2013 Métrich N, Bertagnini A, Di Muro A (2010) Conditions of magma storage, degassing and
 2014 ascent at Stromboli: new insights into the volcano plumbing system with inferences on the
 2015 eruptive dynamics. J Petrol 51(3):603-626

2016

2017 Miwa T, Toramaru A (2013) Conduit process in vulcanian eruptions at Sakurajima volcano,
 2018 Japan: Inference from comparison of volcanic ash with pressure wave and seismic data. Bull
 2019 Volcanol 75:685

2020

2021 Miwa T, Toramaru A, Iguchi M (2009) Correlations of volcanic ash texture with explosion
 2022 earthquakes from vulcanian eruptions at Sakurajima volcano, Japan. J Volcanol Geotherm
 2023 Res 184(3–4):473–486

2024

2025 Miwa T, Geshi N, Shinohara H (2013) Temporal variation in volcanic ash texture during a
 2026 vulcanian eruption at the Sakurajima volcano, Japan. J Volcanol Geotherm Res 260:80-89

2027

2028 Mock A, Jerram DA (2005) Crystal size distributions (CSD) in three dimensions: Insights
 2029 from the 3D reconstruction of a highly porphyritic rhyolite: J Petrol 46:1525–1541. doi:
 2030 10.1093/petrology/egi024

2031

2032 Mock A, Jerram DA, Breitzkreuz C (2003) Using quantitative textural analysis to understand
 2033 the emplacement of shallow-level rhyolitic laccoliths a case study from the Halle volcanic
 2034 complex, Germany. J Petrol 44:833-849

2035

2036 Moitra P, Gonnermann HM, Houghton BF, Giachetti T (2013) Relating vesicle shapes in
 2037 pyroclasts to eruption styles. Bull Volcanol 75:691. doi 10.1007/s00445-013-0691-8

2038

2039 Morgan DJ, Jerram DA, Chertkoff DG, Davidson JP, Pearson DG, Kronz A, Nowell GM
 2040 (2007) Combining CSD and isotopic microanalysis: magma supply and mixing processes at
 2041 Stromboli volcano, Aeolian islands, Italy. Earth Planet Sci Lett 260(3–4):419–431

2042

2043 Mori T, Burton M (2006) The SO₂ camera: a simple, fast and cheap method for groundbased
 2044 imaging of SO₂ in volcanic plumes. *Geophys Res Lett* 33(L24804):
 2045 doi:10.1029/2006GL027916

2046

2047 Mori T, Burton M (2009) Quantification of the gas mass emitted during single explosions on
 2048 Stromboli with the SO₂ imaging camera. *J Volcanol Geotherm Res* 188:395–400.
 2049 doi:10.1016/j.jvolgeores.2009.10.005

2050

2051 Mori J, Patia H, McKee C, Itikarai I, Lowenstein P, De Saint Ours P, Talai B (1989)
 2052 Seismicity associated with eruptive activity at Langila volcano, Papua New Guinea. *J*
 2053 *Volcanol Geotherm Res* 38(3–4):243–255

2054

2055 Mourtada-Bonnefoi CC, Laporte D (2002) Homogenous bubble nucleation in rhyolitic
 2056 magmas: An experimental study on the effect of H₂O and CO₂. *J Geophys Res* 107:B4. doi:
 2057 10.1029/2001JB000290

2058

2059 Mourtada-Bonnefoi CC, Laporte D (2004) Kinetics of bubble nucleation in a rhyolitic melt:
 2060 an experimental study of the effect of ascent rate. *Earth Planet Sci Lett* 218:521–537

2061

2062 Mueller S, Melnik O, Spieler O, Scheu B, Dingwell DB (2005) Permeability and degassing of
 2063 dome lavas undergoing rapid decompression: An experimental determination *Bull Volcanol*
 2064 67(6):526–538. doi:10.1007/s00445-004-0392-4

2065

2066 Mueller S, Scheu B, Spieler O, Dingwell DB (2008) Permeability control on magma
 2067 fragmentation. *Geology* 36(5):399–402. doi:10.1130/G24605A.1

2068

2069 Mueller S, Scheu B, Kueppers U, Spieker O, Richard D, Dingwell DB (2011) The porosity of
 2070 pyroclasts as an indicator of volcanic explosivity. *J Volcanol Geotherm Res* 203:168–174

2071

2072 Muir DD, Blundy JD, Rust AC (2012) Multiphase petrography of volcanic rocks using
 2073 element maps: a method applied to Mount St. Helens, 1980–2005 *Bull Volcanol* 74:1101–
 2074 1120

2075

2076 Murtagh RM, White JDL (2013) Pyroclast characteristics of a subaqueous to emergent
 2077 Surtseyan eruption, Black Point volcano, California. *J Volcanol Geotherm Res* 267:75-91
 2078
 2079 Murtagh RM, White JDL, Sohn YK (2011) Pyroclast textures of the Ilchulbong ‘wet’ tuff
 2080 cone, Jeju Island, South Korea. *J Volcanol Geotherm Res* 201:385-396.
 2081
 2082 Nakamura K (2006) Textures of plagioclase microlite and vesicles within volcanic products
 2083 of the 1914–1915 eruptions of Sakurajima Volcano, Kyushu, Japan. *J Mineral Petrol Sci*
 2084 101:178–198
 2085
 2086 Nakamura M, Otaki K, Takeuchi S (2008) Permeability and pore-connectivity variation of
 2087 pumices from a single pyroclastic flow eruption: Implications for partial fragmentation. *J*
 2088 *Volcanol Geotherm Res* 176:302–314
 2089
 2090 Németh K (2010) Volcanic glass textures, shape characteristics and compositions of
 2091 phreatomagmatic rock units from the Western Hungarian monogenetic volcanic fields and
 2092 their implications for magma fragmentation. *Cent Eur J Geosci* 2:399–419
 2093
 2094 Neuberg J, Luckett R, Ripepe M, Braun T (1994) Highlights from a seismic broadband array
 2095 on Stromboli volcano. *Geophys Res Lett* 21:749–752
 2096
 2097 Newman S, Lowenstern JB (2002) VolatileCalc: a silicate melt-H₂O-CO₂ solution model
 2098 written in Visual Basic for Excel. *Computers and Geosciences* 28(5):597-604
 2099
 2100 Newman S, Epstein S, Stolper E (1988) Water, carbon dioxide, and hydrogen isotopes in
 2101 glasses from the CA. 1340 A.D. eruption of the Mono Craters, California: constraints on
 2102 degassing phenomena and initial volatile content. *J Volcanol Geotherm Res* 35:75-96
 2103
 2104 Nguyen CT, Gonnermann HM, Chen Y, Huber C, Maiorano AA, Gouldstone A, Dufek J
 2105 (2013) Film drainage and the lifetime of bubbles. *Geochem Geophys Geosyst* 14:3616–3631
 2106
 2107 Nishimura T, McNutt SR (2008) Volcanic tremor during eruptions: temporal characteristics,
 2108 scaling and estimates of vent radius. *J Volcanol Geotherm Res* 178:10-18
 2109

2110 Noguchi S, Toramaru A, Shimano T (2006) Crystallization of microlites and degassing during
 2111 magma ascent: Constraints on the fluid mechanical behavior of magma during the Tenjo
 2112 Eruption on Kozu Island, Japan. *Bull Volcanol* 68:432–449. doi 10.1007/s00445-005-0019-4
 2113
 2114 Noguchi S, Toramaru A, Nakada S (2008) Relation between microlite textures and discharge
 2115 rate during the 1991–1995 eruptions at Unzen, Japan. *J Volcanol Geotherm Res* 175(1–
 2116 2):141–155
 2117
 2118 O’Driscoll B, Donaldson CH, Troll VR, Jerram DA, Emeleus CH (2007) An origin for
 2119 harrisitic and granular olivine in the rum layered suite, NW Scotland: a crystal size
 2120 distribution study. *J Petrol* 48(2):253–270
 2121
 2122 Okumura S, Nakamura M, Tsuchiyama A (2006) Shear-induced bubble coalescence in
 2123 rhyolitic melts with low vesicularity. *Geophys Res Lett* 33:L20316.
 2124 doi:10.1029/2006GL027347
 2125
 2126 Okumura S, Nakamura M, Tsuchiyama A, Nakano T, Uesugi K (2008) Evolution of bubble
 2127 microstructure in sheared rhyolite: Formation of a channel-like bubble network: *J Geophys*
 2128 *Res* 113:B07208. doi: 10.1029/2007JB005362
 2129
 2130 Okumura S, Nakamura M, Uesugi K, Nakano T, Fujioka T (2013) Coupled effect of magma
 2131 degassing and rheology on silicic volcanism. *Earth Planet Sci Lett* 362:163–170
 2132
 2133 Oppenheimer C, Scaillet B, Martin RS (2011) Sulfur degassing from volcanoes: source
 2134 conditions, surveillance, plume chemistry and impacts, *Rev Mineral Geochem* 73:363–421.
 2135 doi:10.2138/rmg.2011.73.13
 2136
 2137 Palladino DM, Taddeucci J (1998) The basal ash deposit of the Sovana Eruption (Vulsini
 2138 Volcanoes, central Italy): the product of a dilute pyroclastic density current. *J Volcanol*
 2139 *Geotherm Res* 87:233–254
 2140
 2141 Pamukcu AS, Gualda GAR (2010) Quantitative 3D petrography using X-ray tomography 2:
 2142 combining information at various resolutions. *Geosphere* 6:775–781.
 2143 doi.org/10.1130/GES00565.1

2144

2145 Pamukcu AS, Gualda GAR, Anderson AT (2012) Crystallization stages of the Bishop Tuff
 2146 magma body recorded in crystal textures in pumice clasts. *J Petrol* 63:589–609

2147

2148 Pardo N et al (2014a) Perils in distinguishing phreatic from phreatomagmatic ash; insights
 2149 into the eruption mechanisms of the 6 August 2012 Mt. Tongariro eruption, New Zealand. *J*
 2150 *Volcanol Geotherm Res* <http://dx.doi.org/10.1016/j.jvolgeores.2014.05.001>

2151

2152 Pardo N, Cronin SJ, Wright HMN, Schipper IC, Smith I, Stewart B (2014b) Pyroclast textural
 2153 variation as an indicator of eruption column steadiness in andesitic Plinian eruptions at Mt.
 2154 Ruapehu. *Bull Volcanol* 76:822

2155

2156 Patrick MR (2007) Dynamics of Strombolian ash plumes from thermal video: motion,
 2157 morphology, and air entrainment. *J Geophys Res* 112:B06202. doi:10.1029/2006JB004387.

2158

2159 Perugini D, Poli G, Properini N (2002) Morphometric analysis of magmatic enclaves: a tool
 2160 for understanding magma vesiculation and ascent. *Lithos* 61:225–235

2161

2162 Perugini D, Valentini L, Poli G (2007) Insights into magma chamber processes from the
 2163 analysis of size distribution of enclaves in lava flows: a case study from Vulcano Island
 2164 (Southern Italy). *J Volcanol Geotherm Res* 166:193–203

2165

2166 Perugini D, Speziali A, Caricchi L, Kueppers U (2011) Application of fractal fragmentation
 2167 theory to natural pyroclastic deposits: Insights into volcanic explosivity of the Valentano
 2168 scoria cone (Italy). *J Volcanol Geotherm Res* 202(3-4):200-210

2169

2170 Pfeiffer T, Costa A, Macedonio G (2005) A model for the numerical simulation of tephra fall
 2171 deposits. *J Volcanol Geotherm Res* 140:273–294

2172

2173 Pickering G, Bull JM Sanderson DJ (1995) Sampling power-law distributions:
 2174 Tectonophysics. 248:1–20. doi:10.1016/0040-1951(95)00030-Q

2175

2176 Pichavant M, Martel C, Bourdier JL, Scaillet B (2002) Physical conditions, structure, and
 2177 dynamics of a zoned magma chamber: Mount Pelée (Martinique, Lesser Antilles Arc). *J*
 2178 *Geophys Res* 107. doi:10.1029/2001JB000315
 2179
 2180 Pichavant M, Costa F, Burgisser A, et al. (2007) Equilibration scales in silicic to intermediate
 2181 magmas: implications for experimental studies. *J Petrol* 48:1955–1972. doi:
 2182 10.1093/petrology/egm045
 2183
 2184 Pichavant M, Carlo I, Rotolo SG, et al. (2013) Generation of CO₂-rich melts during basalt
 2185 magma ascent and degassing. *Contrib Mineral Petr*. doi: 10.1007/s00410-013-0890-5
 2186
 2187 Piochi M, Mastrolorenzo G, Pappalardo L (2005) Magma ascent and eruptive processes from
 2188 textural and compositional features of Monte Nuovo pyroclastic products, Campi Flegrei,
 2189 Italy. *Bull Volcanol* 67:663–678
 2190
 2191 Piochi M, Polacci M, De Astis G, Zanetti A, Mangiacapra A, Vannucci R, Giordano D (2008)
 2192 Texture and composition from pumices and scoriae of the Campi Flegrei caldera (Italy):
 2193 Implications on the dynamics of explosive eruptions. *Geochem Geophys Geosyst* 9:Q03013.
 2194 doi:10.1029/2007GC001746
 2195
 2196 Pioli L, Erlund E, Johnson E, Cashman K, Wallace P, Rosi M, Delgado Granados H (2008)
 2197 Explosive dynamics of violent strombolian eruptions: the eruption of Parícutin volcano 1943–
 2198 1952 (Mexico). *Earth Planet Sci Lett* 271:359–368
 2199
 2200 Pioli L, Pistolesi M, Rosi M (2014) Transient explosions at open-vent volcanoes: the case of
 2201 Stromboli (Italy). *Geology* 42:863–866
 2202
 2203 Pistolesi M, Rosi M, Pioli L, Renzulli A, Bertagnini A, Andronico D (2008), The paroxysmal
 2204 explosion and its deposits, in *The Stromboli Volcano: An Integrated Study of the 2002–2003*
 2205 *Eruption*, *Geophys. Monogr. Ser.* vol. 182, edited by S. Calvari et al. pp. 317–329, AGU,
 2206 Washington, D. C. doi:10.1029/182GM26
 2207

2208 Pistolesi M, Delle Donne D, Pioli L, Rosi M, Ripepe M (2011) The 15 March 2007 explosive
 2209 crisis at Stromboli volcano, Italy: assessing physical parameters through a multidisciplinary
 2210 approach. *J Geophys Res* 116(B12). doi: 958 10.1029/2011JB008527
 2211
 2212 Platz T, Cronin SJ, Cashman KV, Stewart RB, Smith IEM (2007) Transition from effusive to
 2213 explosive phases in andesite eruptions — A case-study from the AD1655 eruption of Mt.
 2214 Taranaki, New Zealand. *J Volcanol Geotherm Res* 161:15-34
 2215
 2216 Polacci M, P Papale, M Rosi (2001) Textural heterogeneities in pumices from the climatic
 2217 eruption of Mount Pinatubo, 15 June 1991, and implications for magma ascent dynamics. *Bull*
 2218 *Volcanol* 63:83–97
 2219
 2220 Polacci M, Pioli L, Rosi M (2003) The Plinian phase of the Campanian Ignimbrite eruption
 2221 (Phlegrean Fields, Italy): evidence from density measurements and textural characterization of
 2222 pumice. *Bull Volcanol* 65:418–432
 2223
 2224 Polacci M, Corsaro R, Andronico D (2006a) Coupled textural and compositional
 2225 characterization of basaltic scoria: Insights into the transition from Strombolian to fire
 2226 fountain activity at Mount Etna, Italy. *Geology* 34(3):201–204. doi:10.1130/G223181.1
 2227
 2228 Polacci M, Baker DR, Mancini L, Tromba G, Zanini F (2006b) Three-dimensional
 2229 investigation of volcanic textures by X-ray microtomography and implications for conduit
 2230 processes. *Geophys Res Lett* 33(13):L13312. doi:10.1029/2006GL026241
 2231
 2232 Polacci M, Baker DR, Bai L, Mancini L (2008) Large vesicles record pathways of degassing
 2233 at basaltic volcanoes. *Bull Volcanol* 70:1023–1029. doi:10.1007/s00445-007-0184-8
 2234
 2235 Polacci M, Baker DR, Mancini L, Favretto S, Hill RJ (2009a) Vesiculation in magmas from
 2236 Stromboli and implications for normal Strombolian activity and paroxysmal explosions in
 2237 basaltic systems. *J Geophys Res* 114:B01206. doi.org/10.1029/2008JB005672
 2238
 2239 Polacci M, Burton MR, La Spina A, Murè F, Favretto S, Zanini F (2009b) The role of syn-
 2240 eruptive vesiculation on explosive basaltic activity at Mt. Etna, Italy. *J Volcanol Geotherm*
 2241 *Res* 179:265–269

2242

2243 Polacci M, Mancini L, Baker DR (2010) The contribution of synchrotron X-ray computed
 2244 microtomography to understanding volcanic processes. *J Synchrotron Radiation* 17:215–221
 2245

2246 Polacci M, Baker DR, La Rue A, Mancini L (2012) Degassing behaviour of vesiculated
 2247 basaltic magmas: an example from Ambrym volcano, Vanuatu Arc, and comparison to
 2248 Stromboli, Aeolian Islands, Italy. *J Volcanol Geotherm Res* 233-234:55-64. doi:
 2249 10.1016/j.jvolgeores.2012.04.019
 2250

2251 Polacci M, Bouvet de Maisonneuve C, Giordano D, Piochi M, Mancini L, Degruyter W,
 2252 Bachmann O (2014) Permeability measurements of Campi Flegrei pyroclastic products: An
 2253 example from the Campanian Ignimbrite and Monte Nuovo eruptions. *J Volcanol Geotherm*
 2254 *Res* 272:16-22
 2255

2256 Prata AJ (1989) Infrared radiative transfer calculations for volcanic ash clouds. *Geophys Res*
 2257 *Lett* 15(11):1293–1296
 2258

2259 Prata AJ, Bernardo C (2009) Retrieval of volcanic ash particle size, mass and optical depth
 2260 from a ground-based thermal infrared camera. *J Volcanol Geotherm Res* 186:91–107
 2261

2262 Prejean SG, Brodsky EE (2011) Volcanic plume height measured by seismic waves based on a
 2263 mechanical model. *J Geophys Res Solid Earth* 116(B1. doi:10.1029/2010JB007620
 2264

2265 Prior DJ (1999) Problems in determining the orientations of crystal misorientation axes, for
 2266 small angular misorientations, using electron backscatter diffraction in the SEM. *J Microsc*
 2267 *195*:217–225
 2268

2269 Prior DJ, Boyle AP, Brenker F, Cheadle MC, Day A, Lopez G, Peruzzo L, Potts GJ, Reddy S,
 2270 Spiess R, Timms NE, Trimby P, Wheeler J, Zetterström L (1999) The application of electron
 2271 backscatter diffraction and orientation contrast imaging in the SEM to textural problems in
 2272 rocks. *Am Mineral* 84:1741–1759
 2273

2274 Prodi F, Caracciolo D, Adderio LP, Gnuffi M, Lanzinger E (2011) Comparative investigation
 2275 of Pludix disdrometer capability as Present Weather Sensor (PWS) during the Wasserkuppe
 2276 campaign. *Atmos Res* 99(1):162–173
 2277

2278 Proussevitch AA, Sahagian DL, Tsentalovich EP (2007a) Statistical analysis of bubble and
 2279 crystal size distributions: formulations and procedures. *J Volcanol Geotherm Res* 164:95–111
 2280

2281 Proussevitch AA, Sahagian DL, Carlson W (2007b) Statistical analysis of bubble and crystal
 2282 size distributions: application to Colorado Plateau basalts. *J Volcanol Geotherm Res* 164:112–
 2283 126
 2284

2285 Proussevitch AA, Mulukutla GK, Sahagian DL (2011) A new 3D method of measuring bubble
 2286 size distributions from vesicle fragments preserved on surfaces of volcanic ash particles.
 2287 *Geosphere* 7:1–8
 2288

2289 Pyle M (1989) The thickness, volume and grainsize of tephra fall deposits. *Bull Volcanol*
 2290 51:1–15
 2291

2292 Pyle DM, Mather TA (2009) Halogens in igneous processes and their fluxes to the atmosphere
 2293 and oceans from volcanic activity: A review. *Chem Geol* 263(1-4):110–121. doi:
 2294 10.1016/j.chemgeo.2008.11.013
 2295

2296 Riley CM, Rose WI, Bluth GJS (2003) Quantitative shape measurements of distal volcanic
 2297 ash. *J Geophys Res* 108:B10. doi: 10.1029/2001JB000818
 2298

2299 Ripepe M, Braun T (1994) Air-wave phases in strombolian explosion-quake seismograms: a
 2300 possible indicator for the magma level? *Acta Vulcanol* 5:201–206
 2301

2302 Ripepe M, Marchetti E (2002) Array tracking of infrasonic sources at Stromboli volcano.
 2303 *Geophys Res Lett* 29 (22):2076
 2304

2305 Ripepe M, Ciliberto S, Della Schiava M (2001) Time constraints for modeling source
 2306 dynamics of volcanic explosions at Stromboli. *J Geophys Res* 106(B5):8713–8727
 2307

2308 Ripepe M, Harris AJL, Carniel R (2002). Thermal, seismic and infrasonic evidences of
 2309 variable degassing rates at Stromboli volcano. *J Volcanol Geotherm Res* 118:285–297
 2310
 2311 Ripepe M, Poggi P, Braun T, Gordeev E (1996) Infrasonic waves and volcanic tremor at
 2312 Stromboli. *Geophys Res Lett* 23:181–184
 2313
 2314 Ripepe M, Rossi M, Saccorotti G (1993) Image processing of explosive activity at Stromboli.
 2315 *J Volcanol Geotherm Res* 54:335–351
 2316
 2317 Rix M, Valks P, Hao N, Loyola D, Schlager H, Huntrieser H, Flemming J, Koehler U,
 2318 Schumann U, Inness A (2012) Volcanic SO₂, BrO and plume height estimations using
 2319 GOME-2 satellite measurements during the eruption of Eyjafjallajökull in May 2010. *J*
 2320 *Geophys Res* 117:D00U19. doi:10.1029/2011JD016718
 2321
 2322 Robock A, Matson M (1982) Circumglobal transport of the El Chichon volcanic dust cloud.
 2323 *Science* 221:195-197
 2324
 2325 Roggensack K, hervig RL, McKnight SB, Williams SN (1997) Explosive basaltic volcanism
 2326 from Cerro Negro volcano: influence of volatiles on eruptive style. *Science* 277:1639-1642
 2327
 2328 Rose WI, Self S, Murrow PJ, Bonadonna C, Durant AJ, Ernst GGJ (2008) Nature and
 2329 significance of small volume fall deposits at composite volcanoes: Insights from the October
 2330 14, 1974 Fuego eruption, Guatemala. *Bull Volcanol* 70(9):1043–1067
 2331
 2332 Rose-Koga EF, Koga K, Schiano P, Le Voyer M (2012) Mantle source heterogeneity for South
 2333 Tyrrhenian magmas revealed by Pb isotopes and halogen contents of olivine-hosted melt
 2334 inclusions. *Chem Geol* 334:266-279
 2335
 2336 Rosseel JB, White JDL, Houghton BF (2006) Complex bombs of phreatomagmatic eruptions:
 2337 role of agglomeration and welding in vents of the 1886 Rotomahana eruption, Tarawera, New
 2338 Zealand. *J Geophys Res* 111:B12205. doi:10.1029/2005JB004073
 2339

2340 Rosi M, Bertagnini A, Harris AJL, Pioli L, Pistolesi M, Ripepe M (2006) A case history of
 2341 paroxysmal explosion at Stromboli: Timing and dynamics of the April 5, 2003 event. *Earth*
 2342 *Planet Sci Lett* 243:594–606
 2343

2344 Rotella MD, Wilson CJN, Barker SJ, Wright IC (2013) Novel origins of highly vesicular
 2345 pumice in a distinctive non-explosive submarine eruptive style. *Nature Geosci* 6:129–132
 2346

2347 Rotella MD, Wilson CJN, Barker SJ, Cashman KV, Houghton BF, Wright IC (2013) Bubble
 2348 development in explosive silicic eruptions: insights from pyroclast vesicularity textures from
 2349 Raoul volcano (Kermadec arc). *Bull Volcanol* 76:826
 2350

2351 Rust AC, Cashman KV (2004) Permeability of vesicular silicic magma: inertial and hysteresis
 2352 effects. *Earth Planet Sci Lett* 228:93–107, [http://dx.doi.org/ 10.1016/j.epsl.2004.09.025](http://dx.doi.org/10.1016/j.epsl.2004.09.025)
 2353

2354 Rust AC, Cashman KV (2007) Multiple origins of pyroclastic obsidian and implications for
 2355 changes in the dynamics of the 1300 BP eruption of Newberry Volcano, OR. *Bull Volcanol*
 2356 69:825-845
 2357

2358 Rust AC, Cashman KV (2011) Permeability controls on expansion and size distributions of
 2359 pyroclasts. *J Geophys Res* 116:B11202
 2360

2361 Rust AC, Manga M, Cashman KV (2003) Determining flow type, shear rate and shear stress
 2362 in magmas from bubble shapes and orientations. *J Volcanol Geotherm Res* 122:111–132
 2363

2364 Ruth D, Calder E (2014) Plate tephra: Preserved bubble walls from large slug bursts during
 2365 violent Strombolian eruptions. *Geology* 42(1):11–14, doi:10.1130/G34859.1
 2366

2367 Rutherford MJ, Hill PM (1993) Magma ascent rates from amphibole breakdown: an
 2368 experimental study applied to the 1980–1986 Mount St. Helens eruptions. *J Geophys Res*
 2369 98:19667–19685
 2370

2371 Rutherford MJ, Devine JD (2003) Magmatic conditions and magma ascent as indicated by
 2372 hornblende phase equilibria and reactions in the 1995-2002 Soufrière Hills magma. *J Petrol*
 2373 44:1433-1454

2374

2375 Rutherford MJ, Sigurdsson H, Carey S, Davis A (1985) The May 18, 1980 eruption of Mount
 2376 St. Helens, 1. Melt compositions and experimental phase equilibria. *J Geophys Res* 90:2929-
 2377 2947

2378

2379 Saar MO, Manga M (1999) Permeability-porosity relationship in vesicular basalts. *Geophys*
 2380 *Res Lett* 26(1):111–114

2381

2382 Sable JE, Houghton BF, Del Carlo P, Coltelli M (2006) Changing conditions of magma ascent
 2383 and fragmentation during the Etna 122 BC basaltic Plinian eruption: evidence from clast
 2384 microtextures. *J Volcanol Geotherm Res* 158:333–354

2385

2386 Sable JE, Houghton BF, Wilson CJN, Carey RJ (2009) Eruption mechanisms during the
 2387 climax of the Tarawera 1886 basaltic Plinian eruption inferred from microtextural
 2388 characteristics of the deposits, in *Studies in Volcanology: The Legacy of George Walker*,
 2389 *Spec. Publ. IAVCEI*, vol. 2, pp. 129–154, *Geol. Soc.*, London

2390

2391 Sahagian DL, Proussevitch AA (1998) 3D particle size distributions from 2D observations:
 2392 stereology for natural applications. *J Volcanol Geotherm Res* 84:173–196

2393

2394 Sahetapy-Engel ST, Harris AJL. (2009) Thermal-image-derived dynamics of vertical ash
 2395 plumes at Santiaguito volcano, Guatemala. *Bull Volcanol* 71:827-830. doi:10.1007/s00445-
 2396 009-0284-8

2397

2398 Salisbury MJ, Bohrsen WA, Clynne MA, Ramos FC, Hoskin P (2008) Multiple plagioclase
 2399 crystal populations identified by crystal size distribution and in situ chemical data:
 2400 implications for timescales of magma chamber processes associated with the 1915 eruption of
 2401 Lassen Peak, CA. *J Petrol* 49:1755–1780

2402

2403 Saunders K, Blundy J, Dohmen R, Cashman (2012) Linking petrology and seismology at an
 2404 active volcano. *Science* 336(6084):1023-1027. doi:10.1126/science.1220066

2405

2406 Scaillet B, Evans BW (1999) The 15 June 1991 eruption of Mount Pinatubo. I. Phase
 2407 equilibria and pre-eruption P - T - fO_2 - fH_2O conditions of the dacite magma. *J Petrol* 40(3):381-
 2408 411
 2409
 2410 Schiavi F, Kobayashi K, Moriguti T, et al. (2010) Degassing, crystallization and eruption
 2411 dynamics at Stromboli: trace element and lithium isotopic evidence from 2003 ashes. *Contrib*
 2412 *Mineral Petr* 159:541–561
 2413
 2414 Schiavi F, Kobayashi K, Nakamura E, et al. (2012) Trace element and Pb–B–Li isotope
 2415 systematics of olivine-hosted melt inclusions: insights into source metasomatism beneath
 2416 Stromboli (southern Italy). *Contrib Mineral Petrol* 163:1011-1031
 2417
 2418 Schipper CI, White JDL, Houghton BF (2010a) Syn- and post-fragmentation textures in
 2419 submarine pyroclasts from Loihi Seamount, Hawaii. *J Volcanol Geotherm Res* 191:93–106.
 2420 doi:10.1016/j.jvolgeores.2010.01.002
 2421
 2422 Schipper CI, White JDL, Houghton BF, Shimizu N, Stewart RB (2010b) Explosive submarine
 2423 eruptions driven by volatile-coupled degassing at Lo`ihi Seamount, Hawai`i. *Earth Planet Sci*
 2424 *Lett* 295(3-4):497-510
 2425
 2426 Schipper CI, White JDL, Houghton BF, Shimizu N, Stewart RB (2010c) "Poseidic" explosive
 2427 eruptions at Loihi Seamount, Hawaii. *Geology* 38(4):291-294
 2428
 2429 Schipper CI, White JDL, Houghton BF (2011) Textural, geochemical, and volatile evidence
 2430 for a Strombolian-like eruption sequence at Lō`ihi Seamount, Hawai`i. *J Volcanol Geotherm*
 2431 *Res* 207:16–32
 2432
 2433 Schipper CI, White JDL, Nichols ARL, Burgisser A, Hellebrand E, Murtagh RM (2012)
 2434 Incipient melt segregation as preserved in subaqueous pyroclasts. *Geology* 40(4):355-358
 2435
 2436 Schipper CI, Castro JM, Tuffen H, James MR, How P (2013) Shallow vent architecture during
 2437 hybrid explosive-effusive activity at Cordón Caulle (Chile, 2011-12): evidence from direct
 2438 observations and pyroclast textures. *J Volcanol Geotherm Res* 262:25–37
 2439

2440 Sciotto M, Cannata A, Di Grazia G, Gresta S, Privitera E, Spina L (2011) Seismoacoustic
 2441 investigations of paroxysmal activity at Mt. Etna volcano: New insights into the 16 November
 2442 2006 eruption. *J Geophys Res* 116. doi: 10.1029/2010JB008138
 2443

2444 Shea T, Larsen JF, Gurioli L, Hammer JE, Houghton BF, Cioni R (2009) Leucite crystals:
 2445 surviving witnesses of magmatic processes preceding the 79 AD eruption at Vesuvius, Italy.
 2446 *Earth Planet Sci Lett* 281:88–98
 2447

2448 Shea T, Houghton BF, Gurioli L, Cashman KV, Hammer JE, Hobden B (2010a) Textural
 2449 studies of vesicles in volcanic rocks: an integrated methodology. *J Volcanol Geotherm Res*
 2450 190:271–289
 2451

2452 Shea T, Gurioli L, Larsen JF, Houghton BF, Hammer JE, Cashman KV (2010b) Linking
 2453 experimental and natural vesicle textures in Vesuvius 79 AD white pumice. *J Volcanol*
 2454 *Geotherm Res* 192:69–84
 2455

2456 Shea T, Gurioli L, Houghton BF, Cashman KV, Cioni R (2011) Column collapse and
 2457 generation of pyroclastic density currents during the A.D. 79 eruption of Vesuvius: the role of
 2458 pyroclast density. *Geology* 39:695–698
 2459

2460 Shea T, Gurioli L, Houghton BF (2012) Transitions between fall phases and pyroclastic
 2461 density currents during the AD 79 eruption at Vesuvius: building a transient conduit model
 2462 from the textural and volatile record. *Bull Volcanol* 74:2363–2381. doi 10.1007/s00445-012-
 2463 0668-z
 2464

2465 Shea T, Hellebrand E, Gurioli L, Hugh T (2014) Conduit- to localized-scale degassing during
 2466 Plinian eruptions: Insights from major element and volatile (Cl and H₂O) analysis within
 2467 Vesuvius AD79 pumice. *J Petrol.* doi:10.1093/petrology/egt069
 2468

2469 Sheridan MF, Marshall JR (1983) Interpretation of pyroclast surface features using SEM
 2470 images. *J Volcanol Geotherm Res* 16:153–159
 2471

2472 Sheridan MF, Marshall JR (1987) Comparative charts for quantitative analysis of grain-
 2473 textural elements on pyroclasts, in *Clastic Particles: Scanning Electron Microscopy And*

2474 Shape Analysis Of Sedimentary And Volcanic Particles, edited by J. R. Marshall, Van
 2475 Nostrand Reinhold Company, New York
 2476

2477 Shimano T, Nakada S (2006) Vesiculation path of ascending magma in the 1983 and the 2000
 2478 eruptions of Miyakejima volcano, Japan. Bull Volcanol 68:549–566. doi: 10.1007/s00445-
 2479 005-0029-2
 2480

2481 Shimano T, Nishimura T, Chiga N, Shibasaki Y, Iguchi M, Miki D and Yokoo A (2013)
 2482 Development of an automatic volcanic ash sampling apparatus for active volcanoes. Bull
 2483 Volcanol 75:73. doi: 10.1007/s00445-013-0773-7
 2484

2485 Shin H, Lindquist WB, Sahagian DL, Song S-R (2005) Analysis of the vesicular structure of
 2486 basalts. Comput Geosci 31(4):473–487. doi:10.1016/j.cageo.2004.10.013
 2487

2488 Simakin AG, Bindeman IN (2008). Evolution of crystal sizes in the series of dissolution and
 2489 precipitation events in open magma systems. J Volcanol Geotherm Res 17:997-1010
 2490

2491 Simkin T, Howard KA (1970) Caldera Collapse in the Galápagos Islands, 1968 The largest
 2492 known collapse since 1912 followed a flank eruption and explosive volcanism within the
 2493 caldera. Science 169(3944):429-437
 2494

2495 Sonder I, Graettinger A, Valentine G (2013) Large-scale blast experiments examine
 2496 subsurface explosions. EOS Trans AGU 94(39):337–338. doi:10.1002/2013EO390002
 2497

2498 Song SR, Jones KW, Lindquist WB, Dowd BA, Sahagian DL (2001) Synchrotron X-ray
 2499 computed microtomography: studies on vesiculated basaltic rocks. Bull Volcanol 63(4):252–
 2500 263. doi:10.1007/s004450100141
 2501

2502 Sottili G, Taddeucci J, Palladino DM, Gaeta M, Scarlato P, Ventura G (2009) Subsurface
 2503 dynamics and eruptive styles of maars in the Colli Albani Volcanic District, Central Italy. J
 2504 Volcanol Geotherm Res 180:189-202
 2505

2506 Sottili G, Taddeucci J, Palladino DM (2010) Constraints on magma–wall rock thermal
 2507 interaction during explosive eruptions from textural analysis of cored bombs. *J Volcanol*
 2508 *Geotherm Res* 192:27-34
 2509
 2510 Sparks RSJ (1978) The dynamics of bubble formation and growth in magmas. *J Volcanol*
 2511 *Geotherm Res* 3:1–37. doi:10.1016/0377-0273(78)90002-1
 2512
 2513 Sparks RSJ, Brazier S (1982) New evidence for degassing processes during explosive
 2514 eruptions. *Nature* 295:218–220
 2515
 2516 Sparks RSJ, Burski MI, Carey SN, Gilbert JS, Glaze LS, Sigurdsson H, Woods AW (1997)
 2517 *Volcanic Plume*. John Wiley & Sons, New York
 2518
 2519 Spillar V, Dolejs D (2013) Calculation of time-dependent nucleation and growth rates from
 2520 quantitative textural data: inversion of crystal size distribution. *J Petrol.*
 2521 doi:10.1093/petrology/egs091
 2522
 2523 Stovall WK, Houghton BF, Gonnermann HM, Fagents S.A, Swanson DA (2011) Eruption
 2524 dynamics of Hawaiian-style fountains: The case study of episode 1 of the Kīlauea Iki 1959
 2525 eruption. *Bull Volcanol* 73:511–529. doi:10.1007/s00445-010-0426-z
 2526
 2527 Stovall WK, Houghton BF, Hammer JE, Fagents SA, Swanson DA (2012) Vesiculation of
 2528 high fountaining Hawaiian eruptions: Episodes 15 and 16 of 1959 Kīlauea Iki. *Bull Volcanol*
 2529 74:441–455. doi:10.1007/s00445-011-0531-7
 2530
 2531 Streck MJ (2008) Mineral textures and zoning as evidence for open system processes. In
 2532 Putirka KD, Tepley FJ (Eds) *Minerals, inclusions and volcanic processes*. *Rev Mineral*
 2533 *Geochem* 69:595-622
 2534
 2535 Suzuki Y, Nakada S (2001) Timing of vesiculation and crystallization during magma ascent -
 2536 Example of the phreatomagmatic phase in Usu 2000 eruption. *Bull Earthq Res Inst* 76:253-
 2537 268
 2538

2539 Suzuki Y, Nakada S (2002) Vesiculation and magma ascent process in the Usu 2000 eruption,
 2540 inferred from texture and size distribution of bubbles. *Bull Volcanol Soc Japan* 47:675-688
 2541

2542 Swanson DA, Wooten K, Orr T (2009) Buckets of ash track tephra flux from Halema'uma'u
 2543 crater, Hawaii. *Eos Trans AGU* 90:427–428. doi:10.1029/2009EO460003
 2544

2545 Szramek L, Gardner JE, Larsen J. (2006) Degassing and microlite crystallization of basaltic
 2546 andesite magma erupting at Arenal Volcano, Costa Rica. *J Volcanol Geotherm Res* 157:182-
 2547 201
 2548

2549 Taddeucci J, Pompilio M, Scarlato P (2002) Monitoring the explosive activity of the July–
 2550 August 2001 eruption of Mt. Etna (Italy) by ash characterization. *Geophys Res Lett*
 2551 29(8):1029–1032. doi:10.1029/2001GL014372
 2552

2553 Taddeucci J, Pompilio M, Scarlato P (2004) Conduit processes during the July–August 2001
 2554 explosive activity of Mt. Etna (Italy): inferences from glass chemistry and crystal size
 2555 distribution of ash particles. *J Volcanol Geotherm Res* 137:33–54
 2556

2557 Taddeucci J, Scarlato P, Capponi A, Del Bello E, Cimarelli C, Palladino D, Kueppers U
 2558 (2012) High-speed imaging of Strombolian explosions: The ejection velocity of pyroclasts.
 2559 *Geophys Res Lett* 39(2)
 2560

2561 Takeuchi S, Nakashima S (2005) A new simple gas permeameter for permeability
 2562 measurement of small samples of volcanic eruptive material and experimental run products
 2563 (in Japanese with English abstract). *Bull Volcanol Soc Jpn* 50:1–8
 2564

2565 Takeuchi S, Nakashima S, Akihiko Tomiya A (2008) Permeability measurements of natural
 2566 and experimental volcanic materials with a simple permeameter: toward an understanding of
 2567 magmatic degassing processes. *J Volcanol Geotherm Res* 177:329–339.
 2568 <http://dx.doi.org/10.1016/j.jvolgeores.2008.05.010>.
 2569

2570 Tarquini S, Favalli M (2010) A microscopic information system (MIS) for petrographic
 2571 analysis. *Comput Geosci* 36:665–674
 2572

2573 Thomas N, Jaupart C, Vergnolle S (1994) On the vesicularity of pumice. *J Geophys Res*
 2574 99:15633–15644
 2575
 2576 Thomas HE, Watson IM, Carn SA, Alfredo AJ, Prata F, Realmuto VJ (2011) A comparison of
 2577 AIRS, MODIS and OMI sulphur dioxide retrievals in volcanic clouds. *Geomatics, Nat*
 2578 *Hazards Risk* 2(3):217-232
 2579
 2580 Thordarson T, Self S, Larsen G, Rowland SK, Hoskuldsson A (2009) *Studies in Volcanology:*
 2581 *the Legacy of George Walker*. *GSL Special Publication*
 2582
 2583 Toramaru A (1989) Vesiculation process and bubble size distribution in ascending magmas
 2584 with constant velocities. *J Geophys Res* 94(1):523–17,542. doi:10.1029/JB094iB12p17523
 2585
 2586 Toramaru A (1990) Measurement of bubble size distributions in vesiculated rocks with
 2587 implications for quantitative estimates of eruption processes. *J Volcanol Geotherm Res* 43:71–
 2588 90
 2589
 2590 Toramaru A (2006) BND (bubble number density) decompression rate meter for explosive
 2591 volcanic eruptions *J Volcanol Geotherm Res* 154:303-316
 2592
 2593 Toramaru A, Noguchi S, Oyoshihara S, Tsune A (2008) MND (microlite number density)
 2594 water exsolution rate meter. *J Volcanol Geotherm Res* 175(1–2):156–167
 2595
 2596 Tsukui M, Suzuki Y (1995) Vesiculation of basaltic magma: magmatic versus
 2597 phreatomagmatic eruption in 1983 eruption of Miyakejima. *Bull Volcanol Soc Jpn* 40, 395–
 2598 399
 2599
 2600 Valade S, Donnadieu F (2011) Ballistics and ash plumes discriminated by Doppler radar.
 2601 *Geophys Res Lett* 38:L22301. doi:10.1029/2011GL049415
 2602
 2603 Valade SA, Harris AJL, Cerminara M (2014) Plume Ascent Tracker: Interactive Matlab
 2604 software for analysis of ascending plumes in image data. *Comput Geosci* 66:132–144. doi:
 2605 10.1016/j.cageo.2013.12.015
 2606

2607 Villemant B, Boudon G (1998) Transition between dome-forming and plinian eruptive styles:
 2608 H₂O and CL degassing behaviour. *Nature* 392:65-69
 2609
 2610 Vinkler AP, Cashman K, Giordano G, Groppelli G (2012) Evolution of the mafic Villa Senni
 2611 caldera-forming eruption at Colli Albani volcano, Italy, indicated by textural analysis of
 2612 juvenile fragments. *J Volcanol Geotherm Res* 235-236:37–54
 2613
 2614 Vlastélic I, Staudacher T, Bachèlery P, Télouk P, Neuville D, Benbakkar M (2011) lithium
 2615 isotope fractionation during magma degassing: constraints from silicic differentiates and
 2616 natural gas condensates from Piton de la Fournaise volcano (Réunion Island). *Chem Geol*
 2617 284:26-34
 2618
 2619 Voltolini M, Zandomeneghi D, Mancini L, Polacci M (2011) Texture analysis of volcanic rock
 2620 samples: Quantitative study of crystals and vesicles shape preferred orientation from X-ray
 2621 microtomography data. *J Volcanol Geot Res* 202:83–95
 2622
 2623 Vöge M, Hort M, Seyfried R (2005) Monitoring volcano eruptions and lava domes with
 2624 Doppler radar. *EOS Trans AGU* 86:537-541
 2625
 2626 Walker JC, Carboni E, Dudhia A, Grainger RG (2012) Improved detection of sulphur dioxide
 2627 in volcanic plumes using satellite-based hyperspectral infrared measurements: Application to
 2628 the Eyjafjallajökull 2010 eruption. *J Geophys Res* 117:D00U16. doi:10.1029/2011JD016810
 2629
 2630 Wallace PJ (2001) Volcanic SO₂ emissions and the abundance and distribution of exsolved gas
 2631 in magma bodies. *J Volcanol Geotherm Res* 108:85-106
 2632
 2633 Wallace PJ (2005) Volatiles in subduction zone magmas: concentrations and fluxes based on
 2634 melt inclusion and volcanic gas data. *J Volcanol Geotherm Res* 140:217-240
 2635
 2636 Watson IM, Realmuto VJ, Rose WI, Prata AJ, Bluth GJS, Gu Y, Bader CE, Yu T (2004)
 2637 Thermal infrared remote sensing of volcanic emissions using the moderate resolution imaging
 2638 spectroradiometer. *J Volcanol Geotherm Res* 135:75–89
 2639

2640 Wen S, Rose WI (1994) Retrieval of sizes and total masses of particles in volcanic clouds
 2641 using AVHRR bands 4 and 5. *J Geophys Res: Atmospheres* 99(D3):5421–5431
 2642

2643 White JDL, Houghton BF (2006) Primary volcanoclastic rocks. *Geology* 34:677-680.
 2644 doi:10.1130/G22346.1
 2645

2646 Whitham AG, Sparks RSJ (1986) Pumice. *Bull Volcanol* 48:209–223
 2647

2648 Wilhelm S, Worner, G (1996) Crystal size distribution in Jurassic Ferrar flows and sills
 2649 (Victoria Land, Antarctica): Evidence for processes of cooling, nucleation, and crystallisation.
 2650 *Contrib Mineral Petr* 125:1-15
 2651

2652 Williams-Jones G, Stix J, Hickson C (2008) The COSPEC cookbook. *IAVCEI: Methods in*
 2653 *Volcanology I*: 233 p.
 2654

2655 Wilson L, Huang TC (1979) The influence of shape on the atmospheric settling velocity of
 2656 volcanic ash particles. *Earth Planet Sci Lett* 44:311–324
 2657

2658 Wilson L, Self S (1980) Volcanic explosion clouds: density, temperature and particle content
 2659 estimates from cloud motion. *J Geophys Res* 85:2567-2572
 2660

2661 Wright HMN, Weinberg R (2009) Strain localization in vesicular magma: Implications for
 2662 rheology and fragmentation. *Geology* 37:1023–1026. doi:10.1130/G30199A.1
 2663

2664 Wright HMN, Cashman KV (2014) Compaction and gas loss in welded pyroclastic deposits
 2665 as revealed by porosity, permeability, and electrical conductivity measurements of the Shevlin
 2666 Park Tuff. *GSA Bulletin* 126(1/2):234–247. doi: 10.1130/B30668.1
 2667

2668 Wright HMN, Roberts JJ, Cashman KV (2006) Permeability of anisotropic tube pumice:
 2669 model calculations and measurements. *Geophys Res Lett* 33:L17316.
 2670 doi.org/10.1016/j.epsl.2009.01.023
 2671

2672 Wright HMN, Cashman KV, Rosi M, Cioni R (2007) Breadcrust bombs as indicators of
 2673 Vulcanian eruption dynamics at Guagua Pichincha volcano. Ecuador. *Bull Volcanol* 69: 281–
 2674 300
 2675

2676 Wright HMN, Cashman KV, Gottesfeld EH, Roberts JJ (2009) Pore structure of volcanic
 2677 clasts: Measurements of permeability and electrical conductivity. *Earth Planet Sci Lett*
 2678 280:93–104. doi.org/10.1016/j.epsl.2009.01.023
 2679

2680 Wright HMN, Folkes CB, Cas RAF, Cashman KV (2011) Heterogeneous pumice populations
 2681 in the 2.08-Ma Cerro Galán Ignimbrite: implications for magma recharge and ascent
 2682 preceding a large-volume silicic eruption. *Bull Volcanol* 73:1513–1533
 2683

2684 Wright HMN, Cashman KV, Mothes PA, Hall ML, Ruiz AG, Le Pennec J-L (2012) Estimating
 2685 rates of decompression from textures of erupted ash particles produced by 1999-2006
 2686 eruptions of Tungurahua Volcano, Ecuador. *Geology* 40:619-622. doi:10.1130/G32948
 2687

2688 Wohletz K (1983) Mechanisms of hydrovolcanic pyroclast formation: grain size, scanning
 2689 electron microscopy, and experimental studies. *J Volcanol Geother Res* 17:31–63
 2690

2691 Wohletz K (1986) Explosive magma–water interactions: thermodynamics, explosion
 2692 mechanisms, and field studies. *Bull Volcanol* 48:245–264
 2693

2694 Wohletz K (1987) Chemical and textural surface features of pyroclasts from hydrovolcanic
 2695 eruption sequences. In: Marsall, J.R. (Ed.), *Clastic Particles*. Van Nostrand Reinhold Co, New
 2696 York, N.Y., pp. 79–97
 2697

2698 Yang K, Krotkov NA, Krueger AJ, Carn SA, Bhartia PK, Levelt PF (2007) Retrieval of large
 2699 volcanic SO₂ columns from the Aura Ozone Monitoring Instrument (OMI): comparison and
 2700 limitations. *J Geophys Res* 112:D24S43. doi:10.1029/2007JD008825
 2701

2702 Yamada K, Emori H, Nakazawa K (2008) Time-evolution of bubble formation in a viscous
 2703 liquid. *Earth Planets Space* 60:1–19
 2704

- 2705 Yokoyama T, Takeuchi S (2009) Porosimetry of vesicular volcanic products by a water-
 2706 expulsion method and the relationship of pore characteristics to permeability. *J Geophys Res*
 2707 114:B02201. <http://dx.doi.org/10.1029/2008JB005758>.
 2708
- 2709 Yoshimoto M, Shimano T, Nakada S, Koyama E, Tsuji H, Iida A, Kurokawa M, Okayama Y,
 2710 Nonaka M, Kaneko T, Hoshizumi H, Ishizuka Y, Furukawa R, Nogami K, Onizawa S, Niihori
 2711 K, Sugimoto T, Nagai M (2005) Mass estimation and characteristics of ejecta from the 2004
 2712 eruption of Asama volcano. *Bull Volcanol, Soc Jpn* 50:519–533 (In Japanese with English
 2713 abstract)
 2714
- 2715 Zandomeneghi D, Voltolini M, Mancini L, F. Brun, D. Dreossi, M. Polacci (2010)
 2716 Quantitative analysis of X-ray microtomography images of geomaterials: Application to
 2717 volcanic rocks, *Geosphere*, special issue "Advances in 3D Imaging and Analysis of
 2718 Geomaterials" 6:793-804. doi:10.1130/GES00561.1.
 2719
- 2720 Zakšek K, Hort M, Zaletelj J, Langmann B (2013) Monitoring volcanic ash cloud top height
 2721 through simultaneous retrieval of optical data from polar orbiting and geostationary satellites.
 2722 *Atmos Chem Phys* 13(5):2589-2606
 2723
- 2724 Zimanowski B, Wohletz K, Dellino P, Buttner R (2003) The volcanic ash problem *J. Volcanol.*
 2725 *Geotherm. Res.* 122:1-5
 2726
- 2727 Zobin VM, Santiago-Jiménez H, Ramírez-Ruiz JJ, Reyes-Dávila GA, Bretón-González M,
 2728 Navarro-Ochoa C (2007) Quantification of volcanic explosions from tilt records: Volcán de
 2729 Colima, México. *J Volcanol Geotherm Res* 166(2):117-124
 2730

2731 **Figure captions**

2732

2733 **Figure 1** Diagrammatic illustration showing a volcanic strombolian conduit (modified from
 2734 Harris and Ripepe 2007), and the list of a few parameters that can be measured through the
 2735 deposit (D), the texture of the pyroclasts (T), the geochemistry (G) and the geophysics (G)
 2736 methods for small, magmatic explosions.

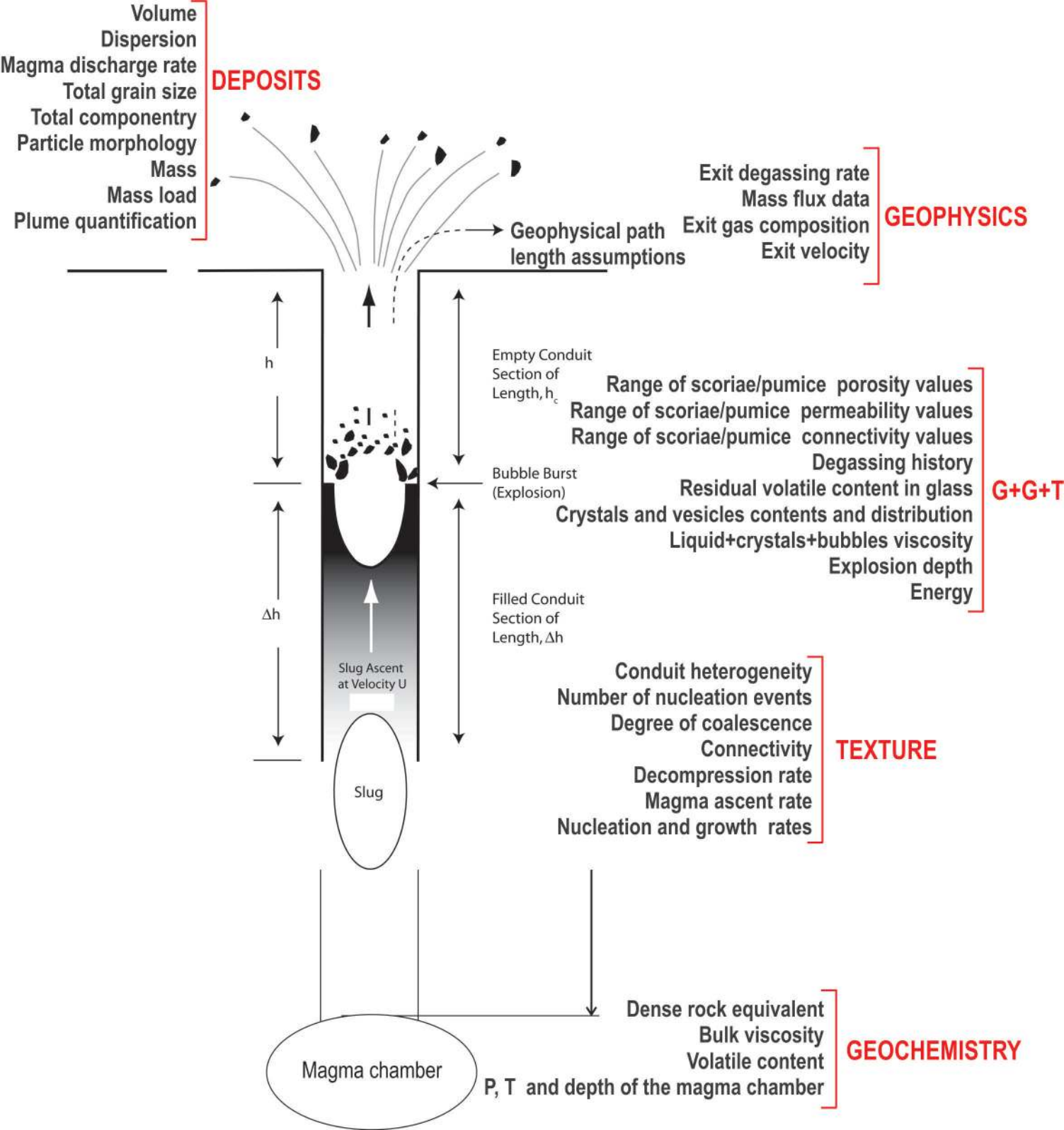


Table 1 Quantification of explosive dynamics from textural parameters of the pyroclast components

<i>Textural parameters</i>	<i>Quantification</i>		<i>References</i>
Clast shape, morphology and size	Discriminate between different fragmentation mechanisms		Wohletz 1983; 1986; 1987; Heiken and Wohletz 1985; Sheridan and Marshall 1983; 1987; Dellino and La Volpe 1996a; b; Palladino and Taddeucci 1998; Büttner et al. 1999; 2002; Kueppers et al. 2006; Dellino et al. 2001; 2012; Zimanowski et al. 2003 Németh 2010 Pardo et al. 2014a
	Conduit stratigraphy and processes		Taddeucci et al. 2002; D’Oriano et al. 2005; Cioni et al. 2011; Perugini et al. 2011; Andronico et al. 2009b; 2013a; Lautze et al. 2012; 2013; Perugini et al. 2002; 2007
	State of the magma at the fragmentation		Carey et al. 2000; Dellino and Liotino 2002; Maria and Carey 2002; 2007; D’Oriano et al. 2011; Ruth and Calder 2014
	Link between vesicularity and particle morphology, and particle morphology with cloud dispersal and sedimentation		Wilson and Huang 1979; Dellino et al. 2005; Mattsson 2010 Alfano et al. 2011; Mele et al. 2011
Clast density and vesicularity	Lateral variability of magma within the conduit		Houghton and Wilson 1989; Kennedy et al. 2005; Kueppers et al. 2005; Mueller et al. 2011; Barker et al. 2012
	Dense juvenile	Presence of outgassed magma	Sable et al. 2006; Lautze and Houghton 2005; 2007; 2008; Polacci et al. 2008; 2009a; b; 2012; Gurioli et al. 2005; 2014; Shea et al. 2011; 2012; 2014; Cimarelli et al. 2010
		Presence of a plug	Hoblitt and Harmon 1993; D’Oriano et al. 2005; Sable et al. 2009; Adams et al. 2006a; 2006b; Giachetti et al. 2010; Barker et al. 2012; Lavallée et al. 2012
Clast permeability and connectivity	Degassing history experienced by the magma		Eichelberger et al. 1986; Klug and Cashman 1996; Saar and Manga 1999; Jouniaux et al. 2000; Blower 2001a, b; Klug et al. 2002; Melnik and Sparks 2002; Rust and Cashman 2004; 2011; Mueller et al. 2005; 2008; Wright et al. 2006; 2007; 2009; Plats et al. 2007; Bernard et al. 2007; Takeuchi et al. 2008; Nakamura et al. 2008; Bouvet de Maisonneuve et al. 2009; Yokoyama and Takeuchi 2009; Bai et al. 2010; 2011; Degruyter et al. 2010a; 2010b; 2012

		Vinkler et al. 2012; Polacci et al. 2012; 2014; Nguyen et al. 2014; Pioli et al. 2008; Formenti and Druitt 2003; Giachetti et al. 2010; Shea et al. 2011; 2012
Clast conductivity	Input parameters for numerical percolation simulations	Le Pennec et al; 2001; Bernard et al. 2007; Wright et al. 2009; Wright et Cashman 2014
Vesicle shape and size	Bubble coalescence, ripening or collapse signatures	Klug and Cashman 1996; Mangan and Cashmann 1996; Gurioli et al. 2005; Shin et al. 2005; Sable et al. 2006; Polacci et al. 2008; Castro et al. 2012
	Shear conditions in the conduit Convection in the conduit	Marti et al. 1999; Polacci et al. 2001; 2003; Rust et al. 2003; Okumura et al. 2006; 2008; Bouvet de Maisonneuve et al. 2009; Wright and Weinberg 2009; Laumonier et al. 2011; Shea et al. 2011; 2012 Carey et al. 2013
	Eruptive style	Moitra et al. 2013
Vesicle size distributions (VSDs)	Vesicle nucleation processes and growth in magmas	Klug and Cashman 1994; Shea et al 2010a; LaRue et al. 2013, and references therein
	Total number of nucleation, coalescence or ripening events	Gaonac'h et al. 1996a; b Klug and Cashman 1996; Herd and Pinkerton 1997; Blower et al. 2001; 2002; Gaonac'h et al. 2003; 2005; Lovejoy et al. 2004, Yamada et al. 2008; Bai et al. 2008; Costantini et al. 2010
	Post-fragmentation evolution as indicator of : i) fountaining mechanisms ii) transportation and dispersal of the pyroclasts in submarine environment	Polacci et al; 2006a; Gurioli et al; 2008; Stovall et al. 2011; 2012; Schipper et al. 2010a, b, c; 2011; 2012; Rotella et al. 2013; 2014
Vesicle Number density (Nv)	Link with magma mass eruption rate (MER), link with column height	Polacci et al. 2006b; Toramaru 2006; Gurioli et al. 2008; Carey et al. 2009; Houghton et al. 2010; Rust and Cashman 2011; Alfano et al. 2012
	Magma decompression rate	Mangan and Sisson 2000; Suzuki and Nakada 2001; 2002; Toramaru 2006; Cluzel et al. 2008; Shea et al. 2010b; 2011; 2012; Wright et al. 2012
	Phreatomagmatic fragmentation	Tsukui and Suzuki 1995; Suzuki, Nakada 2001, 2002; Shimano and Nakada 2006; Mattsson 2010; Murtagh et al. 2011; Murtagh and White 2013
	Link vesicularity with external trigger mechanisms (crystallinity, pressure changes)	Belien et al. 2010; Carey et al. 2012; Gurioli et al. 2014

Crystal size distribution (CSD)	Crystal size (mean, modal, and maximum crystal size), crystallization kinetics (nucleation and growth rates), annealing, crystal accumulation, and fractionation	Cashman and Marsh, 1988; Marsh 1988; 1998; 2007; Cashman 1993; Armienti et al. 1994; Higgins 2000; 2002a;b; 2006; 2011; Wilhelm and Worner, 1996; Bindeman 2003; Gualda 2006; Gualda and Rivers 2006; Mock et al. 2003; Simakin and Bindeman, 2008; Spillar and Dolejs 2013
	Magma ascent rate	Cashman 1992; Rutherford and Hill 1993; Rutherford and Devine 2003; Noguchi et al. 2008; D'Oriano et al. 2011
	Pre-eruptive decompression paths	Hammer et al. 1999; Szramek et al. 2006; Clarke et al. 2007; Innocenti et al. 2013
	Magma storage conditions prior to eruption and residence times	Mangan 1990; O'Driscoll et al. 2007; Cigolini et al. 2008; Simakin and Bindeman 2008; Magee et al. 2010; Shea et al. 2009
	Water exsolution rate meter	Toramaru et al. 2008
	Magma mixing	Morgan et al. 2007; Jerram et al. 2003
Crystal+Vesicle size and percentage	Three phases magma rheology, fluid mechanical behavior of magma	Gurioli et al. 2014; Noguchi et al. 2006