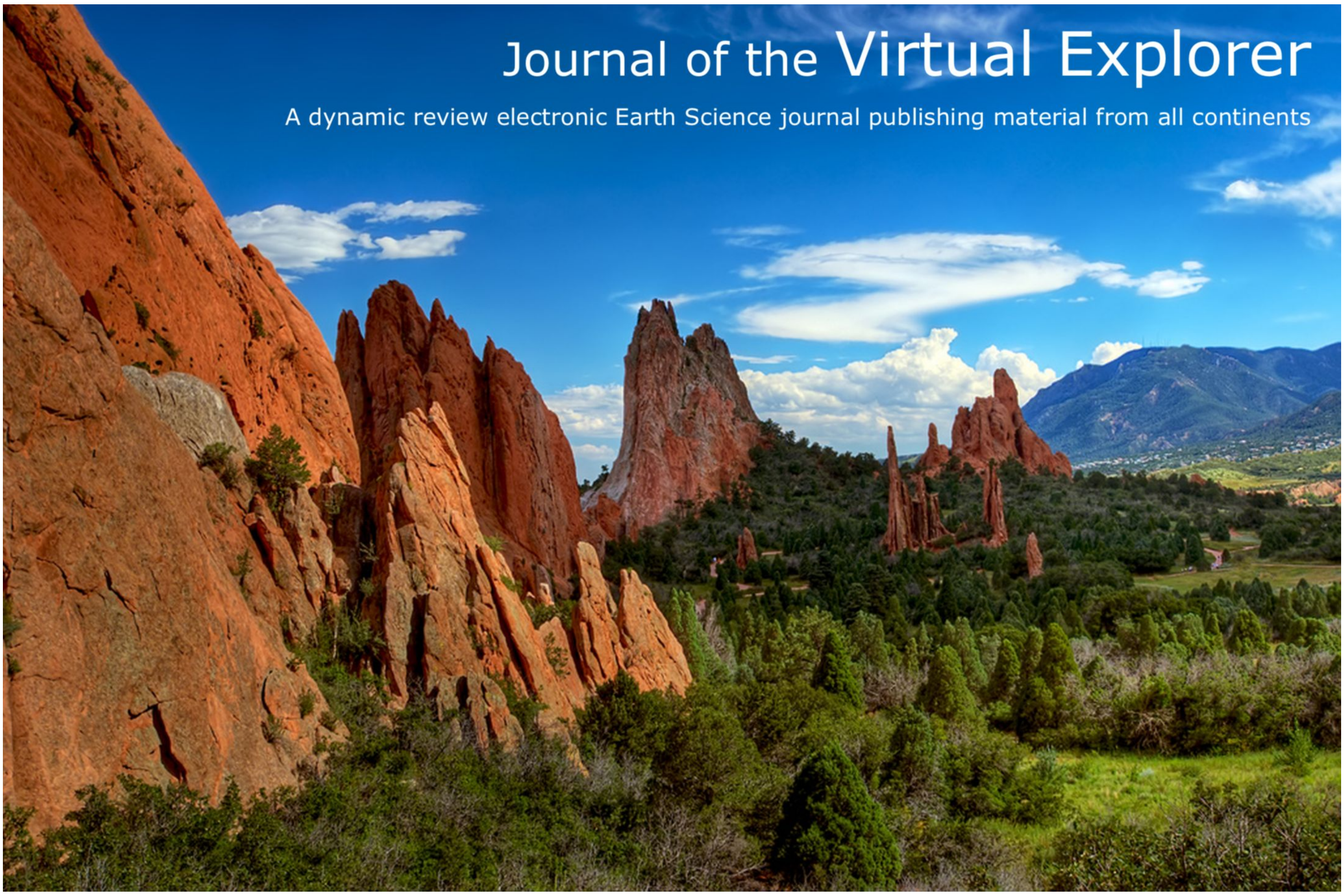


Past and present mid-intensity explosive eruptions of Italian volcanoes and their impact on human activity

Raffaello Cioni, Antonella Bertagnini, Claudia D'Oriano, Massimo Pompilio

Journal of the Virtual Explorer, Electronic Edition, ISSN 1441-8142, volume **36**, paper 26
In: (Eds.) Marco Beltrando, Angelo Peccerillo, Massimo Mattei, Sandro Conticelli, and Carlo Doglioni, The Geology of Italy: tectonics and life along plate margins, 2010.

Past and present mid-intensity explosive eruptions of Italian volcanoes and their impact on human activity

Raffaello Cioni
Dip.to Scienze Terra, Via Trentino 51, 09127 Cagliari, Italy.; Istituto Nazionale Geofisica e Vulcanologia, sez. di Pisa, Via della Faggiola 32, 56126, Pisa, Italy. *Email: rcioni@unica.it*

Antonella Bertagnini
Istituto Nazionale Geofisica e Vulcanologia, sez. di Pisa, Via della Faggiola 32, 56126, Pisa, Italy.

Claudia D'Oriano
Istituto Nazionale Geofisica e Vulcanologia, sez. di Pisa, Via della Faggiola 32, 56126, Pisa, Italy

Massimo Pompilio
Istituto Nazionale Geofisica e Vulcanologia, sez. di Pisa, Via della Faggiola 32, 56126, Pisa, Italy

Abstract: Active Italian volcanoes are characterized by a large variability of eruptive mechanisms, from quiet lava effusions to catastrophic ignimbritic eruptions. The impact of volcanic activity, and in particular of explosive activity, is clearly related to the intensity and magnitude of the eruptions, varying from an incidental interference with everyday life up to devastating consequences on civilizations. While the largest events have usually monopolized the interest of volcanologists and historians, the modalities and impact of mid intensity eruptions have not been investigated in so much detail. In addition, the frequency of occurrence of mid intensity eruptions is by far higher than that of the largest events, so making their study of primary importance for the assessment of the impact of volcanic activity on environment and human life.

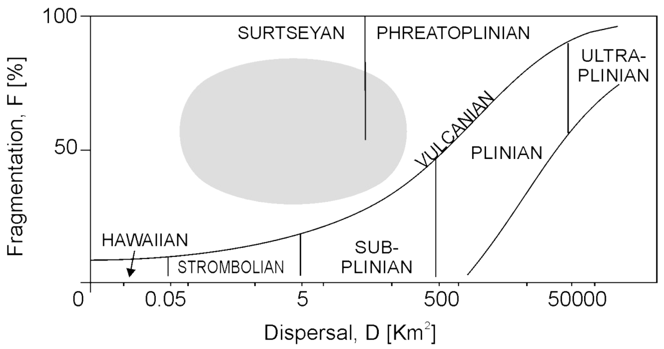
In this paper, case histories of mid-intensity explosive activity at Mt. Vesuvius, Phlegrean Fields, Mt. Etna and Stromboli are presented in order to introduce and discuss the hazard and impact related to this type of activity.

Citation: 2010. Past and present mid-intensity explosive eruptions of Italian volcanoes and their impact on human activity. In: (Eds.) Marco Beltrando, Angelo Peccerillo, Massimo Mattei, Sandro Conticelli, and Carlo Doglioni, *Journal of the Virtual Explorer*, volume **36**, paper 26, doi: 10.3809/jvirtex.2010.00229

Introduction

Explosive activity at volcanoes is characterized by ejection into the atmosphere products derived from the fragmentation of magma and preexisting rocks. Dispersal and fragmentation of the products have been used to classify the eruption style, with the most dispersed and fragmented products being related to the most intense events (Walker, 1973; Fig. 1). While many fields of the resulting classification diagram have been largely explored in past years, eruptions with deposits characterized by intermediate dispersal have not been studied in large detail (shaded area in Fig. 1).

Figure 1. Classification diagram of explosive volcanic eruptions



Classification diagram of explosive volcanic eruptions based on the amount of magma fragmentation (F) and dispersal (D) of tephra. The shaded area corresponds to deposits of mid-intensity eruptions, characterized by intermediate dispersal and efficient magma fragmentation.

These deposits can vary from thick accumulations of lapilli-sized material to very fine ash beds. While in the past two decades fine-grained deposits have been generally interpreted as the result of the explosive interaction between external fluids and magma, the direct observations of the phenomena clearly demonstrated that ash production is instead very often related to primary fragmentation driven by magmatic degassing.

As a matter of fact, in nature we observe the occurrence of eruptions characterized by largely contrasting fragmentation of the products, associated to a similar dispersal. This suggests the possibility that mid-intensity eruptions cannot be explained by simply referring to a single modality of magma ascent and fragmentation, like for example in the case of the models explaining dynamics of low intensity, basaltic activity or Plinian-like, silicic activity. Rather, different eruption processes have to be devised, each corresponding to a different type of eruption style (and corresponding products and deposits) observed.

Recent observations of volcanic crises all around the world have confirmed that mid-intensity explosive activity is associated with a large range of eruptive styles and magma compositions, suggesting that the dynamics of magma degassing, fragmentation and tephra dispersal can be largely variable.

Even though the hazard implications of mid-intensity eruptions are clearly lower than those associated with pumice and ash deposition related to the large Plinian or sub Plinian events (Santacroce, 1987), they assume however an important role in the definition of the scenario for short-term, mid-magnitude, expected events at a large number of volcanoes worldwide.

In addition, ash-dominated events can produce a strong environmental impact and affect wide areas up to thousands of kilometres from their source due to the large dispersal of ash plumes.

The fallout of only a few millimeters of volcanic ash may cause serious temporary pollution in pasture-lands and in water supply systems, increasing water acidity through the leaching of the volatile components (essentially chlorine and sulfur) (Blong, 1984). Moreover, the potential for the inhalation of volcanic ash as a hazard to human respiratory health has become increasingly apparent (Baxter et al 1999; Bernstein *et al.* 1986; Rojas-Ramos *et al.* 2001; Horwell *et al.* 2003). Also the socio-economical impact of such small-size, ash producing eruptions can be impressive. The 1995–1996 Vulcanian eruptions of Mt. Ruapehu, New Zealand (Johnston *et al.* 2000), or the 1994 eruption of Rabaul Caldera (Papua-New Guinea) may provide an up-to-date picture of the problem. During these eruptions, only a few millimeters of ash caused very high economic costs, with damage to hydroelectric power facilities, the interruption of air and road traffic, and water and grass contamination (Johnston *et al.* 2000). The implications of ash emission on air traffic have been discussed in recent papers (Bursik *et al.* 2009; Papp *et al.* 2005) and have been recently brought to world attention during the eruption (still in progress at the moment of writing this paper) of the volcano Eyjafjallajökull (Southern Iceland) which shut down air travel in Europe for several days.

The past and more recent activity of Italian volcanoes is dotted with this type of activity, which, also due to the very intense population of the area since pre-historical times, has had a strong impact on human life. The paper deals with the general problems related to this class of explosive activity and presents a large case history from several volcanoes.

Main features of mid-intensity eruptions

Eruption styles and classification

The products of explosive activity are characterized by the constant occurrence of fallout deposits, so that classification of past explosive eruptions is based on their dispersal and fragmentation. Dispersal index (D) and fragmentation index (F) allow a classification of different eruptive styles on the basis of their position on the binary plot D/F (Walker, 1973; Fig. 1). In this classification scheme the following eruptive styles are included: Hawaiian, Strombolian, sub-Plinian, Plinian, Vulcanian, Surtseyan or Phreato-Plinian. While there is a general positive correlation between dispersal, fragmentation and eruption intensity, a large variability of styles corresponds to eruptions characterized by intermediate D and F. These mid-intensity eruptions can so vary between prolonged, unsteady fountaining of scoria and ash with formation of low level convecting columns (generically identified as Violent Strombolian eruptions), to violent, repeated outbursts of highly viscous, silicic magma (Vulcanian explosions), to prolonged phases of ash emission which generate sustained, low-level, ash-charged plumes (ash emission activity), to cone-forming explosive activity dominated by poorly dispersed pyroclastic density currents alternated with unsteady convective columns. The dynamics of these eruptions is dominated by the generation of discontinuous to unsteadily fed eruption columns, which result in the deposition of stratified pyroclastic fallout beds.

Grain size of the deposits is largely variable, from coarse-grained, massive beds of scoria-like clasts, to complex alternation of lapilli and ash beds, to massive or thinly laminated sequences of fine ash. Dispersal of the products often shows multilobed to roughly circular distribution, confirming that deposition occurred over prolonged periods possibly subjected to a variable, low level, wind field. Pyroclastic density currents are generally associated with Vulcanian or cone-building activity, while it has been rarely observed in Violent Strombolian activity (Arrighi *et al.* 2001; Behncke *et al.* 2008). The related deposits vary from small-volume, massive, topographically controlled block and ash deposits, to radially dispersed, cross-stratified, surge-like beds. Dispersal is generally restricted to a maximum runout between hundred of meters and 2-3 kilometers.

Hydromagmatic activity, intended as the result of syn-eruptive interaction between magma and external water, can contribute to enhance the explosivity of this mid-intensity eruptions, but its role has been probably often overestimated in the reconstruction of past activity. The main characteristics of hydromagmtic deposits have been universally considered the presence of abundant fine-grained products derived by the enhanced fragmentation of magma driven by the explosive expansion of vaporized water. The existence of different types of eruptions with deposits of intermediate Dispersal Index and Fragmentation Index (Violent Strombolian and Vulcanian eruptions) was interpreted as the result of magma-water interaction on otherwise poorly fragmented materials. However, recent observations of the deposits and the dynamics of these eruptions (Montserrat, Merapi, Unzen, Paricutin) have clearly shown very minor, if any, contribution of external water to explosivity. In addition, increasing evidence is growing that at several volcanoes prolonged phases of magma degassing and ash production and dispersal result in deposits with similar dispersal and fragmentation characteristics.

This large spectrum of activity characterized by mid intensity explosivity and dispersal is well represented in past and present activity at Italian volcanoes as illustrated by some selected examples in the following sections.

Compositional, textural and morphological features of the products as a key to interpret eruptive dynamics

One of the main aspects of mid-intensity eruptions is that their products span a very large range of compositions, from the poorly evolved melts typical of most of the Violent Strombolian events, to the mildy or highly evolved magmas typical of Vulcanian outbursts. Conversely, monogenetic, tuff ring to tuff cone-building activity spans the whole compositional spectrum of typical silicatic melts.

Studies on volatile content of this type of eruptions indicate that magma generally have water concentration in the range 2-4 wt%, together with variable amounts of CO_2, S, Cl, and F, mainly as a function of the overall magma composition. High CO_2 concentration (up to 2000-3000 ppm) has been observed in some melt inclusion from mafic minerals especially associated with violent Strombolian eruptions (Marianelli *et al.* 2005; Métrich and Rutherford, 1998).

Several studies have also shown that during an eruption, juvenile products largely heterogeneous in terms of clast morphology and internal texture, and in some cases also of composition, can be erupted. In recent years, textural characterization of the clasts (i.e. content, shape and size distribution of vesicles and crystals) joined the most classical studies of clast morphology summarized above (Cioni *et al.* 2008). Crystal content of the groundmass, as well as vesicle content and shapes, can be considered as proxies for describing the modalities of syn-eruption magma degassing. In fact, syn-eruptive crystallization of groundmass microlites is often forced by degassing, which induces an increase in the liquidus temperature of the magma favoring crystal nucleation and growth (Cashman, 1988, 1990; Cashman and Blundy, 2000).

The detailed study of these deposits has also revealed that this variability can be very often observed within a single stratigraphic level, among the products erupted at a same moment during the eruption. An analogue large variability of the juvenile material is not so clear in high-intensity eruptions, so that this feature can be considered characteristic of mid-intensity explosive activity. This variability in the juvenile material has been interpreted in terms of inhomogeneities in the modality and dynamics of magma degassing and crystallization immediately before or during the eruption. These can lead to large syn-eruptive variations of the melt rheology due to summatory effects of the increase of crystal content in a progressively degassed an silica enriched residual melt. This effect is generally not very large in the case of basaltic melts, but can be very important for intermediate to highly evolved magmas.

Several concurring processes can be responsible for the large variability observed in the textural features of the juvenile material;

- magma ascent occurs through narrow conduits, slowing down the final rise to the surface of viscous magmas and promoting syn-eruptve degassing or cooling and crystallization. This occurs unhomogeneously throughout the magma, and local differences in the conditions of ascent rate and related degassing and cooling rates result in distinct textural features of the products. This process is especially important in silicic, high viscous magmas;

- rapid magma ascent of basaltic, low viscosity melts along small conduits can instead develop a parabolic, Poisseuille-like velocity profile, with high velocity in the central portion of the conduit and very low velocity at the margins, so creating an annular region of high velocity gradient which trigger important horizontal heterogeneities in vesicle and crystal contents, resulting at fragmentation in clasts with largely different physical features;

- syn-eruption recycling of juvenile fragments can be particularly important in these eruptions. In this case, pieces of magma fragmented in an eruptive pulse can escape atmospheric dispersal, falling down in the vent and being recycled by the following eruptive pulses. The characterization of this type of clasts is of fundamental importance to identify the true juvenile material erupted in a given phase of the eruption (those clasts generated by the primary fragmentation of the magma effectively involved in a given phase of the eruption) and to outline differences in the magmatic input rate within the conduit (Houghton and Smith, 1993);

- magma interaction with hydrothermal fluids or external water (Andronico *et al.* 2001; Barberi *et al.* 1989; Bertagnini and Landi, 1996; Bertagnini *et al.* 1991; Dzurisin *et al.* 1995; McPhie *et al.* 1990).

Until now, textural features of clasts (shapes, surface morphology, occurrence of secondary minerals, abundance, size and shape of vesicles and microlites) observed by optical and electron scanning microscopes have been empirically related to the above processes occurring in the volcanic conduits, but only few experiments have been conducted in order to test these relationships and to infer quantitatively relevant physical parameters (Büttner *et al.* 2002; De Rosa, 1999; Dellino *et al.* 2001; Zimanowski *et al.* 2003).

Between the experimental investigations already performed, most have focused on processes of magma water interaction (Büttner *et al.* 2002; Zimanowski *et al.* 1991), or on mechanisms of vesiculation and fragmentation on silicic explosive eruptions (Alidibirov and Dingwell, 2000; Cashman and Mangan, 1994; Dingwell, 1998; Mangan *et al.* 2004; Martel *et al.* 2001; Navon *et al.* 1998; Scheu *et al.* 2008). Similarly, a general knowledge of phase equilibria controlling the crystallizations and melts evolutions can be acquired for most of common magmas on the basis of experiments of thermodynamic modeling (Di Carlo *et al.* 2006; Grove and Juster, 1989; Métrich and Rutherford, 1998; Pompilio *et al.* 1998; Sisson and Grove, 1993; Trigila *et al.* 1990). Recent experiments have also further investigated relationships between microlite crystallization and decompression/degassing processes in magmas with different compositions and volatiles contents (Barclay *et al.* 1998; Blundy and Cashman, 2001, 2005; Blundy *et al.* 2006; Cashman, 1992; Cottrell *et al.* 1999; Hammer and Rutherford, 2002, 2003; Rutherford and Devine, 2003). These experiments have also shown that a large part of the crystallization occurs in a temperature or pressure range of few tens of degree and that an accurate prediction of relevant parameters (e.g. T or P of crystallization, nucleation and/or growth rates) is possible only if natural and experimental charges are close in composition. Finally, experiments on reheating and recycling of fine tephra are totally lacking.

Mid-intensity eruptions at Italian volcanoes: case histories

Mount Somma-Vesuvius

About 18 ka ago the mainly effusive activity which built Mt Somma changed to largely explosive. Since then, the Somma-Vesuvius volcanic complex (Fig. 2a) has shown many different styles of volcanic activity ranging from high-magnitude Plinian eruptions (four in the time interval between 18 ka ago and 79 AD) to low-intensity Strombolian and effusive activity.

On the whole, the magnitude of the eruptions has been roughly decreasing with time, while, after the Plinian event of Avellino (3.9 ka BP), the frequency increased.

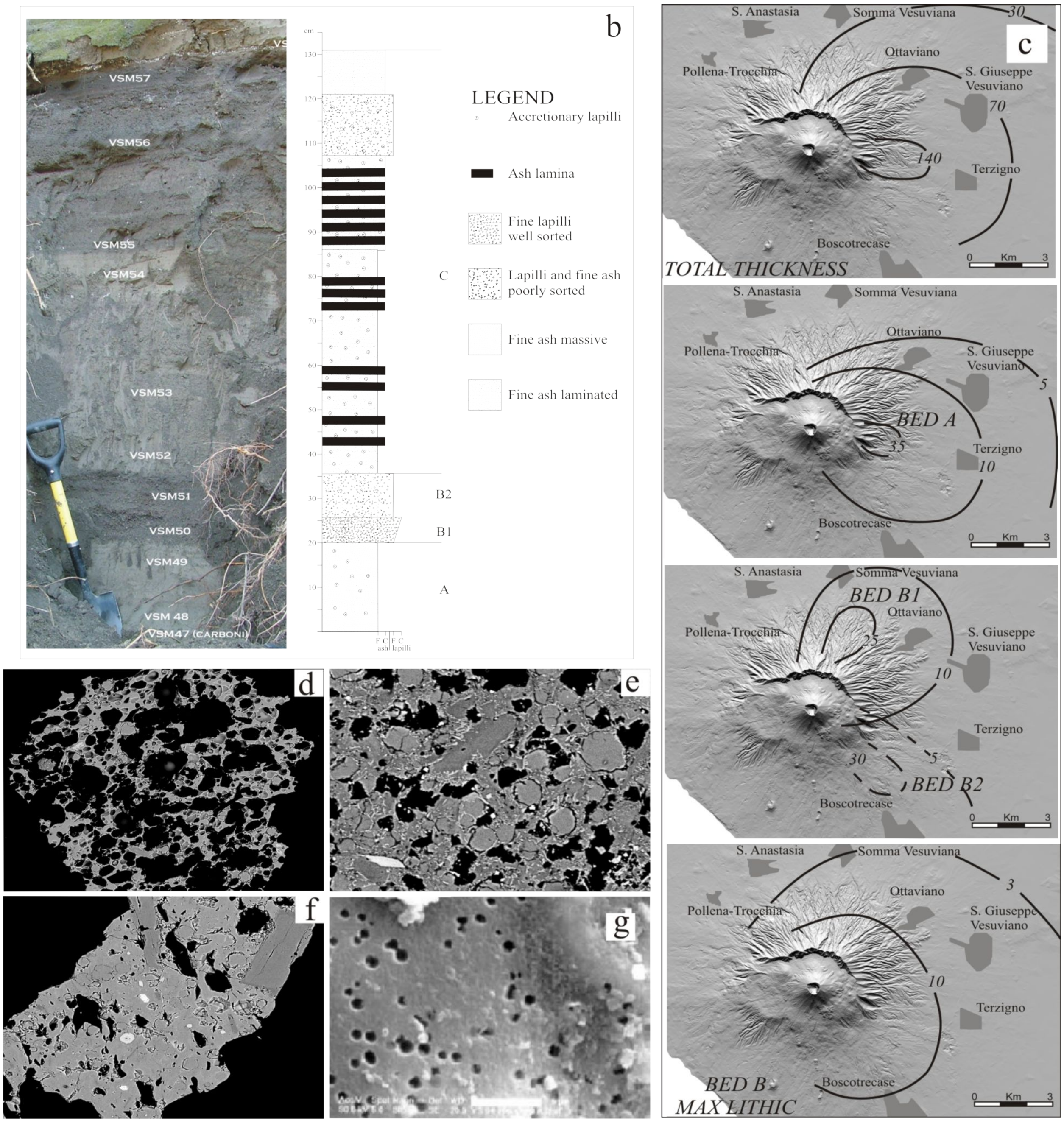
After the Avellino eruption, the occurrence of repeated mid-intensity explosive events is recorded by thick sequences of laminated to stratified ash deposits interlayered with minor massive lapilli beds. Periods dominated by prolonged ash emission activity alternated with Violent Strombolian eruptions characterized the volcano activity between higher intensity, Plinian and sub-Plinian events (i.e. the Plinian eruptions of Avellino and Pompeii, the AD 472 and 1631 sub-Plinian eruptions). Several explosive-effusive, polyphased eruptions - classified as Violent Strombolian from the style of their paroxysmal phase - also punctuated the last 300 years of activity of Vesuvius (1638 -1944).

In the following paragraphs we present the eruptive period between the Avellino and Pompeii eruptions focusing on AP3 eruption (according to Andronico and Cioni, 2002). The Violent Strombolian eruption occurred in April 1906 is taken as representative of this class of events.

Figure 2a. 3D perspective view of Vesuvius cone and its neighbours

(http://ipf.ov.ingv.it/viste_en.html - Osservatorio Vesuviano).

Figure 2b-g. Summarizing table for the AP3 eruption at Vesuvius



b) stratigraphic succession and schematic section at S. Pietro Quarry outcrop, located at about 3 Km eastward from the eruption vent; c) isopach maps (cm) of the deposits (modified from Andronico and Cioni, 2002), showing the total thickness (top), the Bed B1 and B2 (middle), and maximum lithic from Bed B areal distributions (bottom), used for the Mass Discharge Rate calculations; d, e, f) SEM Backscattered (BSE) images of different types of clasts: d) light, glassy, vesicular pumice; e) dense, highly crystallized, poorly vesicular scoria; f) poorly vesicular, crystal-poor, glassy fragments; d) pitting on the external surface of a clast.

1. Eruptive period between Avellino and Pompeii Plinian eruptions

Between the deposition of the Avellino Pumice (3500 year BP) and Pompeii Pumice (79 AD) Plinian eruptions, a complex sequences of fallout, massive to thinly stratified, scoria-bearing lapilli layers and ash events were deposited, reaching a maximum thickness in proximal area of about 800 cm. Thin paleosols, humified layers, and primary erosive unconformities generally separate the deposits of different eruptions. At least 6 main events were recognized (identified using the abbreviation "AP") followed by a progressive number (Andronico and Cioni, 2002). The first two events (AP1-AP2) were vent eruptions located 3 km west of the present crater of Vesuvius, in correspondence of the Piano delle Ginestre area as in the earlier Avellino eruption. Their stratigraphic features and clast characteristics suggest they were generated by a sub-Plinian to phreato-Plinian activity. Following these two eruptions, the stratigraphic succession records the deposition of four main eruptions (AP3–AP6 members) and at least two minor events (AP3 α and AP4 α members) totalling more than 4 m in thickness on the south-eastern slopes of the volcano. The succession consists of a monotonous sequence of fallout deposits largely represented by accretionary lapilli, massive to laminated ash, alternated with only minor lapilli beds. The AP3-AP6 succession was interpreted as mixed, violent Strombolian to Vulcanian events (Andronico and Cioni, 2002). The dispersal of these deposits indicates a shift in the position of the eruptive vent from Piano delle Ginestre to the area of the present crater. Along the eruptive sequence, the mean composition of the ejected material changes from tephritic phonolites to phonolites (AP1-AP2) to tephri-phonolite (AP3), with a progressive and continuous shift toward less evolved terms with time. This compositional variation shows a strong correlation with vent position and eruption style, reflecting in a lowering of melt viscosity, which can favour the lower intensity observed for the AP3–AP6 eruptions (Andronico and Cioni, 2002).

AP3 eruption

AP3 deposit consists of a fallout sequence mainly formed by ash beds and minor scoria layers. It has been subdivided into three main beds, based on colours changes and grain size of the products (Fig. 2b). The base is represented by an accretionary lapilli-rich, normally graded, vesiculated ash layer (Bed A). It is formed by massive, light-colored, fine ash and minor coarse ash laminations. In a few outcrops, this bed directly rests on a discontinuous, humified layer containing small, charred, vegetal remains. The transition toward the overlying Bed B is marked by a change in colour, corresponding to an abrupt change in the microscopic texture of juvenile shards. Bed B is an ubiquitous, coarse-grained fall deposit. Two main units are recognized. Unit B1 consists of a massive layer formed by light green-coloured, sometimes banded, scoria. Unit B2 is formed by an alternation of thin layers of dark, poorly vesicular, ash-coated lapilli and cohesive fine ash. At the top, a complex sequence of fine-grained, faintly laminated, accretionary lapilli-bearing, ash layers is present (Bed C). It represents the thickest bed (up to 1 m) of the AP3 member, possibly deposited by repeated eruptive pulses. It is very difficult to correlate the different layers forming Bed C because of their variable main direction of dispersal. In distal outcrops, up to about 14 Km from the vent, the deposit consists of three layers, correlated with A, B, C beds of the proximal section. At the base, bed A consists of 5 cm thick, massive layer, formed by light ash. Bed B is a 4 cm thick, well sorted, lapilli-bearing layer. At top, bed C consists of a 15 cm thick, accretionary lapilli-bearing layer, at the top of which are 6 cm of lapilli deposit. The total volume estimation of the whole AP3 deposit resulted 1.5 x 10^8 m^3. Andronico and Cioni (2002) estimated the peak magma discharge rates (MDR) from isopleth maps of the maximum lithics in AP3 Bed (Fig. 2c). They found that the measured clast dimensions were close to the lower range of applicability for the method. The inferred peak MDR was of 3×10^6 kg s^{-1} (Wilson and Walker, 1987), corresponding to column heights of about 10 km. MDR values are one order of magnitude lower than those of most known Plinian and sub-Plinian events of Vesuvius (Carey and Sigurdsson, 1987; Rolandi *et al.* 1993a, 1993b; Rosi *et al.* 1993). Using the method proposed by Carey and Sparks (1986), Andronico and Cioni (2002) also calculated values of maximum column height of around 12 km, and a tropopause wind speed of ~15 m s^{-1}. These values correspond to MDR about two times larger than those calculated with the previous method. No MDR estimation was possible using these classical methods on the ash-rich beds always present in the different members.

The products of the AP3 eruption are mostly made of juvenile materials (pumice, scoria, accretionary lapilli and loose crystals) and in minor part, of lithic fragments which consist of altered leucite and pyroxene-bearing lavas and very rare skarn material. Juvenile fragments are largely heterogeneous showing a variability of the physical, textural, and, in some cases, compositional features. As a general rule ash fragments vary between two end members: a) light, glassy, vesicular pumice (Fig. 2d) and b) dense, highly crystallized, poorly vesicular scoria (Fig. 2e). All the intermediate terms between these types exist. In particular, poorly vesicular, crystal-poor, glassy fragments are well represented (Fig. 2f). The large amount of coalescing vesicles relative to the total vesicularity of fragments suggests an important role of permeability in magma degassing. In some cases the pumice-like portion of the magma includes or envelops the dense, dark portion. Juvenile material is characterized by a porfiritic index of 1-5%, with a mineralogical assemblage represented by rare, mm-sized phenocrysts of leucite, pyroxene and biotite set in a groundmass of leucite, plagioclase and pyroxene with variable glass.

The stratigraphic observation and clasts characterization allow identification in AP3 eruption two contrasting styles of activity, each repeated during the eruption at least two times: 1) emplacement of a ash-rich layers (this activity dominated both the first phase of the eruption and the central part of the eruption); and, 2) deposition of well sorted lapilli-rich layer, present in the lower part and at the top of the sequence.

1) Ash-rich layers - Deposits of this phase of the eruption consist of massive, centimeter thick, fine ash-rich layers and are characterized by features such as accretionary lapilli and vesiculated tuff, typical of deposition from a "wet" system. Juvenile clasts have blocky and platy external shapes with diffuse superficial pitting (Fig. 2g) and adhering of small particles, together with hydration and contraction cracks. Although different types of particles coexist within the same stratigraphic layer, the majority of the fragments (67% of Bed A, and 46% of Bed C) show a low sphericity external shape and smooth, not ragged external surface, while very angular fragments with irregular outlines are scarcely represented (5% in Bed A, and 20 % in Bed C). In addition, groundmass characterization of the ash evidenced the presence of poorly vesicular, poorly crystalline glassy fragments, together with dense, microlite-rich fragments in samples. These features have been associated with phreatomagmatic explosions in which the explosive vaporization of external water results in the fragmentation and quenching of the magma (Wholetz, 1986; Büttner *et al.* 1999, Morrissey *et al.* 2000; Andronico and Cioni, 2002; Taddeucci *et al.* 2002). The ubiquitous and large occurrence of moderately vesicular, glassy fragments, on the other hand, suggests that external water only acted to increase the intensity of a fragmentation process which was primarily driven by the gas bubbles explosions. According to this hypothesis, interaction of external water with the magma caused an increase of mixture pressure favoring the fragmentation of the poorly vesicular portions of the magma.

2) Lapilli-rich layers - Bed B, representative of violent Strombolian episodes consists of abundant scoria with large spherical to ovoid vesicles, separated by thick septa. The external surface of the clasts shows minor pitting and very minor occurrence of small adhering particles. The study of particle outlines revealed an increase of very angular fragments with bubble-wall-controlled contours (33 % in Bed B and 26 % in Bed C top). Groundmass analyses highlighted that moderately vesicular, glassy fragments represent the most abundant (more than 50%) type of ash emitted during these phases of activity, associated with dense, crystal-rich and moderately vesicular, crystal-rich fragments. These features are indicative of efficient magma degassing at fragmentation in fully magmatic Strombolian activity (Heiken and Wohletz, 1985). Moderately vesicular clasts with an almost completely crystalline groundmass are already present in these beds suggesting an extreme pressurization caused by microlite growth (Sparks, 1997; Gardner and *et al.* 1998). The last of these possibly represents the shattering of magma lining the external portions of the conduit, crystallized for the dual effects of degassing and cooling.

From crystal size distribution analysis of plagioclase microlite growth in the groundmass of the juvenile clasts it is possible to estimate the duration of the AP3 eruption (Cashman, 1988; Marsh 1988; 1998; Higgins 2000). Assuming that plagioclase grew at depth in the magma chamber/conduit and had a growth rate of 10^{-7}-10^{-8} mm s^{-1} (Fenn, 1977; Hammer *et al.* 1999; Cashman and Blundy, 2000), the residence time for magma (i.e. the duration of the eruption) result of 10-20 days (D'Oriano, PhD thesis, 2008).

2. Violent Strombolian eruptions

This kind of eruption is thought to be the most likely type in the next, short-term reactivation of the volcano (Marzocchi *et al.* 2004; Neri *et al.* 2008).

Eruptive dynamics, products and impact of violent Strombolian eruptions occurred in the last three centuries; in particular, the two last events (1906 and 1944) are well described in numerous contemporary accounts and scientific papers.

The paroxysmal phase of these eruptions (the violent strombolian phase) has a purely magmatic character and consists in up to some kilometers-high, quasi-steady lava fountains. Several episodes of lava fountaining, each lasting from tens of minutes to hours, can occur, and the total duration of this phase ranges from hours to days. Coarse grained scoria beds (up to 1 meter on the volcano slopes) are deposited. Heavy ballistic showers can reach towns at the foot of the volcano. This phase is often preceded by overflow from the crater or lava emission(s) from lateral vents. Intense lava effusions from lateral vents can also occur during the violent Strombolian phase and affect towns located on the volcano slopes.

The final part of the eruption lasts from hours to days. Quasi-steady eruptive columns several kilometers high can develop. Repeated explosions generate dense ash-plumes dispersed by low level winds. This activity has a phreatomagmatic character, possibly related to the involvement of fluids from shallow hydrothermal systems (Bertagnini *et al.* 1991; Cioni *et al.* 1992; Mastrolorenzo *et al.* 1993; Fulignati *et al.* 1996; Andronico *et al.* 1996). The waning stages are dominated by the emission of wet fine-ash.

Magmas feeding these eruptions range from tephrites to phonolitic tephrites. Volatile content in melt inclusions hosted in high-Mg olivines is high, exceeding 5 wt%. and points to the involvement of a deep-seated, volatile-rich magma, possibly residing in an mush column located at a depth of ≥ 8 km (Marianelli *et al.* 2005).

The 1906 eruption

The 1906 eruption lasted 18 days and was observed by many contemporary scientists, but the most exhaustive descriptions of the eruptive phenomena, nature, volume and impact of emitted products are due to Mercalli (1906), Perret (1924), Johnston Lavis (1909) and Sabatini (1906).

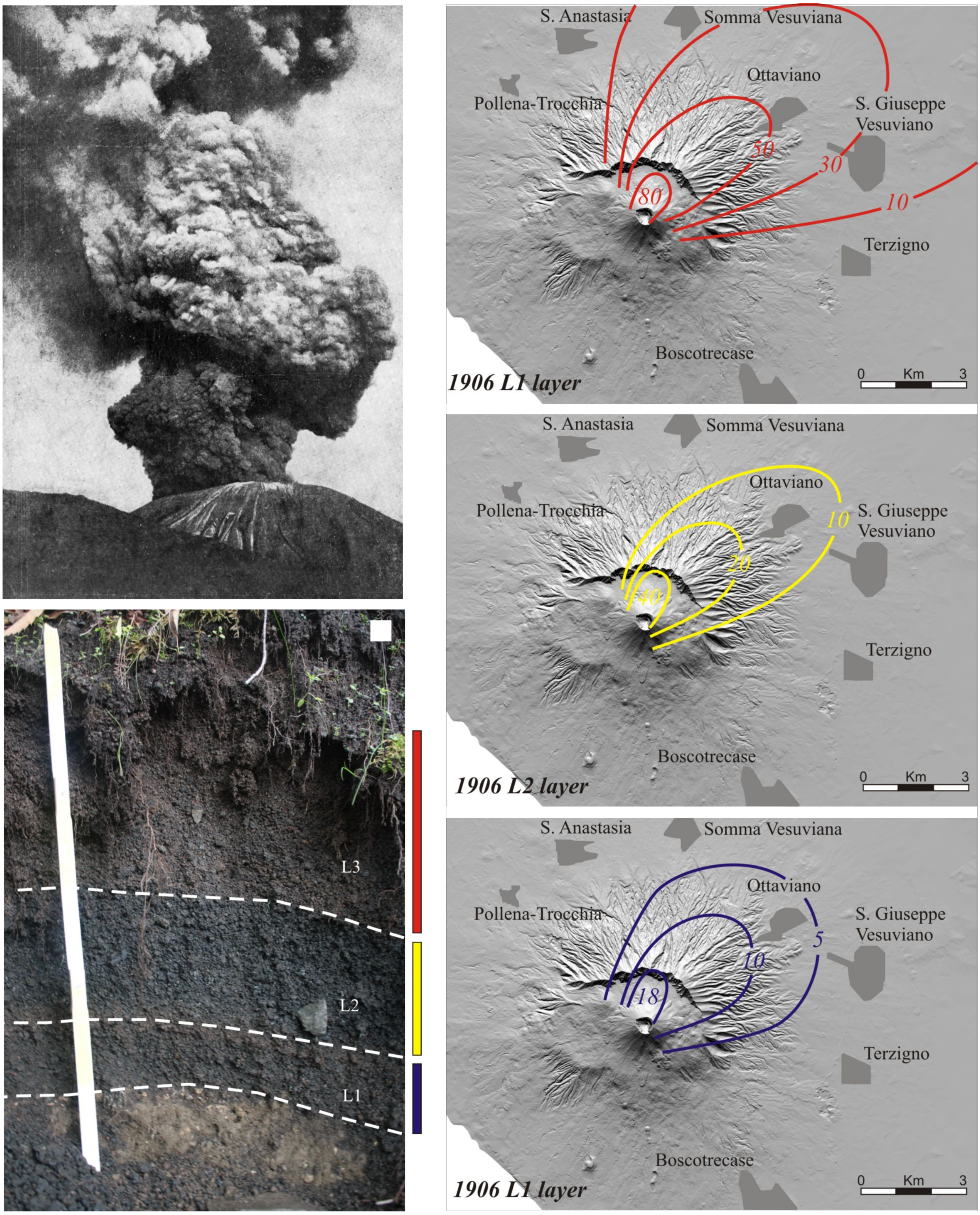
According to Perret (1924), the beginning of the eruption can be set at 5:30 am on 4 April with the opening of a radial fracture on the southern slope of the Vesuvius cone and the activation of an effusive vent at an elevation of about 1200 m. In the following three days, new vents opened both on the same radial fracture and farther east at elevations of about 600 and 800 m. The lava emission was limited to a narrow sector 30° wide (Sabatini, 1906). From the morning of 4 April the explosive activity at the crater progressively increased and ash-laden convective clouds rose up to 2-3 km. In the morning of 7 April a moderate decrease of the explosions was observed. After 6 April a maximum lowering of the sea level of 50 cm indicated the swelling of the volcano (Mercalli, 1906).

In the early afternoon of 7 April, the magma level quickly rose and a strong increase of the explosive activity began. In the evening, 1-2 km high incandescent jets closely followed one each other as to form a true persistent fire fountain (Mercalli, 1906). A strong resumption of the effusive activity occurred shortly after and lava flows reached the villages of Boscotrecase and Torre Annunziata. Around 11 pm the intensity of the explosions further increased up to a maximum between 1-3:30 am (Mercalli, 1906). In this time interval a heavy fallout of lapilli, bombs and blocks affected Ottaviano and other villages at the NE foot of the volcano. According to Mercalli, the explosive climax ended at 3:30 am when the upper portion of the Vesuvius opened “like the falling of the petals of a flower” (Perret, 1924). The unfolding of the cone marked a change in the eruptive style and the beginning of the “intermediate gas phase” of Perret and the “vulcanian phase” of Mercalli. The descriptions of the two volcanologists of the activity are somewhat different, possibly because they observed the eruptive phenomena from two different points of view (Mercalli from Naples and Perret from the Vesuvius Observatory, at 1.5 km from the crater). Perret describes a quasi-steady column, as a huge persistent geyser which, with recurring “crescendo-diminuendo” effects, attained a height of 13 km in the early afternoon of 8 April (Fig. 3a). According to Mercalli, during all the day of the 8th, the volcano was enveloped in an impenetrable cloud of reddish ash while 4-5 km high, cauliflower dark grey clouds rose at short intervals. Towards the evening the violence of the explosions began to decrease; however, not until 10 pm or later when the lapilli shower stopped at Ottaviano (Johnston-Lavis, 1909).

In the night between 8 and 9 April the explosive activity progressively weakened and the ejected material became finer and finer (Johnston-Lavis, 1909). During the whole day ash-laden clouds were drifted by wind towards SW. As a result, the whole area was plunged into a total darkness, while a reddish-grey pisolitic ash was falling (Mercalli, 1906).

In the following days the ash fallout continued with a general intensity decrease. By 13 April the ash had a reddish color then turned light grey, giving to the Vesuvius cone a peculiar snow-covered effect (Johnston-Lavis, 1909). On 21 April the eruption was effectively over, but in the following weeks several episodes of lahar generation extensively damaged the N and W sectors.

Figure 3. Summarizing table for the 1906 eruption at Vesuvius



a) 8 April eruption plume (photo of Perret, 1924); b) stratigraphic succession of the proximal deposit with indications of the different layers; c) isopach maps (cm) of the different layers (modified form Arrighi *et al.* 2001).

The fallout of coarse material chiefly affected the NE sector (Fig. 3b). In the village of Ottaviano, located at 6 km from the crater along the dispersal axis, the deposit attained an average thickness of 80 cm and was formed by two main beds: the lower layer (~20 cm) was mainly constituted by black vesicular scoria lapilli further subdivided in two layers by the presence of a reddish ash coating on the scoria clast (L1 and L2 in Fig.3c) while the upper one had a more abundant lithic component and a characteristic reddish-ash coating of the clasts (the cocoa-coloured lapilli of Johnston-Lavis, L3 in Fig. 3c).

The ash dispersal, strongly controlled by the dominant winds, was rather variable. Up to 20 cm of red ash was measured in Torre del Greco (6 km SW from the cone) and 15-20 cm near Ottaviano (Mercalli, 1906). Light ash fallout was reported in a ENE direction (1 cm in Apulia about 200 km distant) up to Montenegro, at about 400 km.

In the villages of Ottaviano and nearby San Giuseppe Vesuviano 216 people were killed and 112 injured by roof collapses. A further 11 people died and 30 were injured in the collapse of a shed in a market in Naples and around 34,000 people became refugees (Chester and Duncan, 2007).

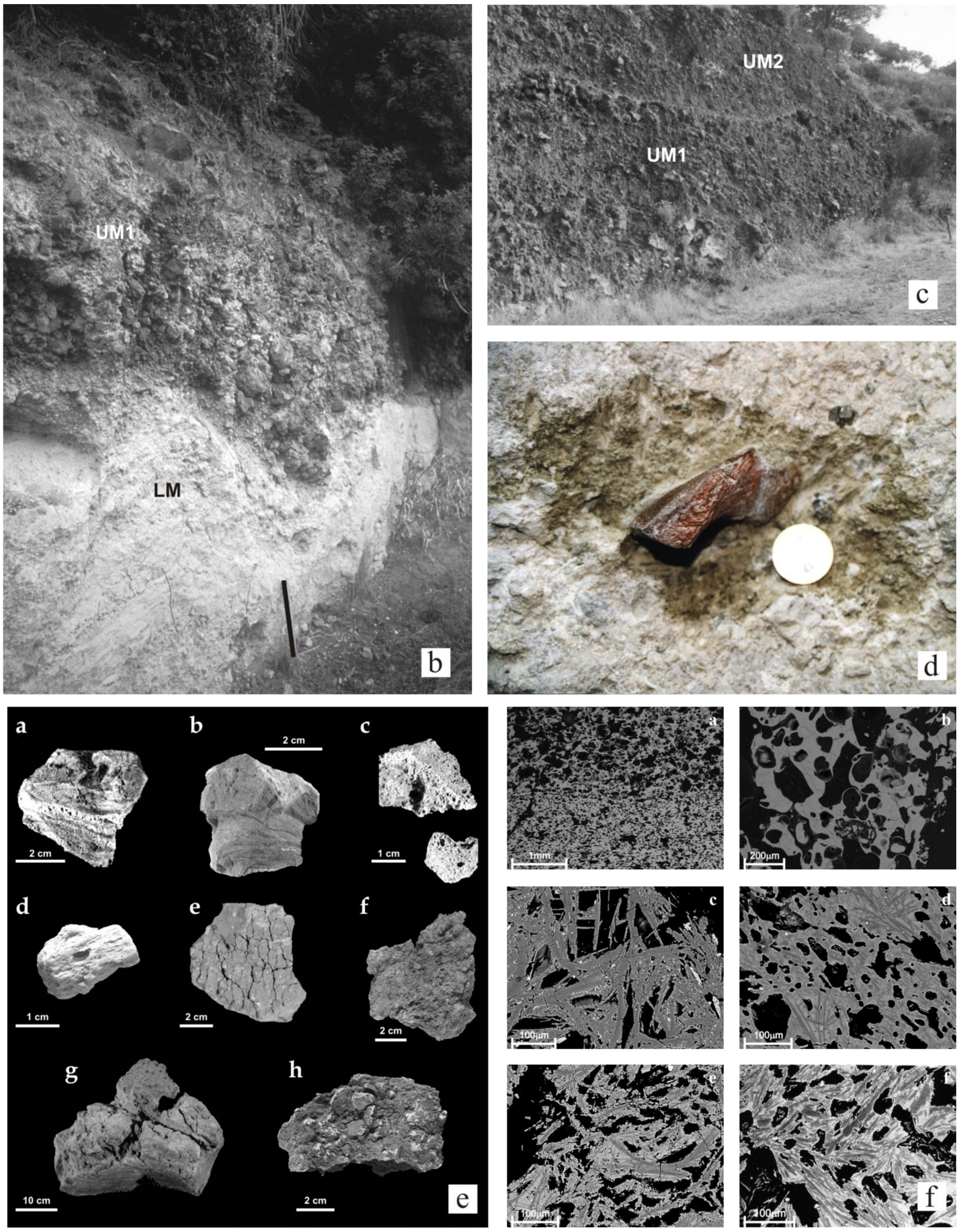
A minimum volume, varying from 5.7 x 10^6 m^3 (Sabatini, 1906) to 20 x 10^6 m^3 (Mercalli, 1906) was estimated for the lava flows. According to Sabatini (1906) the coarse fallout deposit had a volume of about 12.1 x 10^7 m^3 and the distal ash a minimum volume of 2.8 x 10^7 m^3. Mass discharge rates of 0.34-5.38 x 10^6 kg/s was calculated by Arrighi *et al.* (2001) on the basis of durations deduced by historical chronicles and field data.

Phlegrean Fields

The Phlegrean Fields is a 13 kilometres-wide caldera situated to the west of Naples (Italy) that resulted from two big collapses which occurred 35,000 and 12,000 years ago. Since the beginning of their activity (not precisely known, but around 60,000 years ago) they were characterized essentially by explosive eruptions and subordinately effusive activities (Orsi *et al.* 1996; Pappalardo *et al.* 1999), the products of which range in composition from latite to phonotrachyte. After the second caldera collapse the following eruptions were generated by vents located either inside the caldera or along its structural boundary. About 72 eruptions occurred in three epochs of volcanic activity between 12 and 9.5 ka, between 8.6 and 8.2 ka and between 4.8 and 3.8 ka (Di Vito *et al.* 1999). The volcanic activity was mostly explosive with phreatomagmatic phases generating tuff rings and tuff cones and subordinately effusive. The most recent eruption formed the Monte Nuovo tuff cone (Fig. 4a) in 1538 AD after a quiescence of about 3,000 years.

Figure 4a. Monte Nuovo cone and town of Lucrino at its feet.

Figure 4b-f. Summarizing table for the AP3 eruption at Vesuvius



b) field photographs of MtN proximal deposits (from D’Oriano *et al.*, 2005). Note the wavy, erosive contact between the Lower and Upper Members. Bar is 40 cm; c) Upper Member outcrop. The contact between UM1 and UM2 is evidenced by a change in the grain-size. Thickness of UM1 is about 2.50 m; d) fragment of manufactured product within the LM deposit; e) juvenile products of Lower Member (a, b, c, d) and Upper Member (e, f, g, h); a - banded pumice; b - banded pumice with obsidian-like texture; c - coarsely vesicular pumices; d - tube pumice; e - dense clast with superficial fractures; f - scoria-like clast; g - cauliflower bomb; h - agglutinated Clast (from D’Oriano *et al.*, 2005); f) SEM-BSE images showing groundmass textures of juvenile products from Lower (a, b) and Upper Member (c, d, e, f): a - microvesicular and coarsely vesicular bands in banded pumice clast; b - coarsely vesicular pumice clast; c - dense holocrystalline clast; d - dense glassy clast, e - scoria-like fragment and f - glassy scoria (from D’Oriano *et al.*, 2005).

The AD 1538 Monte Nuovo eruption

The AD 1538 Monte Nuovo (MtN) eruption is the most recent volcanic event of the Phlegrean Fields and the only one that occurred in historical times. It took place after 3.5 Ka of quiescence in the NW sector of the Phlegrean Fields caldera. Several contemporary eyewitness accounts (Del Nero, 1538; Delli Falconi, 1538; Marchesino, 1538; Porzio, 1551; Da Toledo, 1538) provide detailed information on precursors, timing and description of the eruptive phenomena. The MtN eruption was characterized by two main phases with contrasting eruptive styles. The deposits forming the body of the MtN cone consist of ash and pumice tephra; they are overlain by thin, dark-coloured, coarse-grained block and lapilli deposits. A wavy erosive surface separates these two units, called the Lower and Upper Member, respectively (Fig. 4b,c) (D'Oriano *et al.* 2005). The historical accounts of the event were thoroughly summarized by Parascandola (1946) and analysed in comparison with deposits by Rosi and Santacroce (1984) and Lirer *et al.* (1987).

The eruption started on Sunday 29 September around 8 pm from a vent near the village of Tripergole - 3 km west of Pozzuoli. During the first 2 days the activity was vigorous and consisted of quasi-continuous emission of ash-laden, black clouds which generated concurrent radially spreading pyroclastic density currents and a vertically rising convective column. During this phase the substantial involvement of groundwater in the eruption is suggested by the description of vapour-charged, white clouds and by the downwind fallout of muddy ash on the towns of Pozzuoli (~30 cm) and Naples (~2 cm), with fine ash dispersed to Calabria (~200 km SE). Wet deposition of the ash-rich deposits is evidenced by their incipient consolidation, occurrence of accretionary lapilli and mud coatings. After 2 days of activity the pyroclastic cone was almost entirely formed and an up 40 cm thick pumice raft was reported in the Bay of Pozzuoli. Activity had to be intense in the first 12 hours of the eruption because in this time span the cone was already largely formed (Del Nero 1538). The long-range ash dispersal reported by the chronicles (ash fallout up to a distance greater than 200 km) suggests strong convective power of the associated eruptive plume indicating a relatively high mass discharge rate. The first phase of the eruption corresponds to the first 2 days of activity (from 8 p.m. of 29 September to early afternoon of 1 October). The minimum volume of deposits emplaced in this phase is 3-6x10^7 m^3 based only on the volume of the cone. Considering that the construction of the cone was largely completed after 12 h of activity (Del Nero, 1538), the minimum value for the mass discharge rate results of about 10^6 kg s^{-1} (D'Oriano *et al.* 2005).

On the morning of Tuesday 1 October the activity declined and then stopped completely. At that time, Da Toledo climbed the cone up to the crater rim observing some "boiling" in the crater bottom accompanied by moderate launch of stones. Around 4 p.m. on Thursday 3 October a new strong explosion generated dark globular clouds which overran the sea for a few miles, along with a scattered shower of blocks. After two more days of pause a new explosion occurred in the afternoon of Sunday the 6th, killing 24 people who were attempting to climb the new cone. In addition to thick burial around the vent, devastation around the cone was substantial. Da Toledo (1538) reports of trees being uprooted and covered by ash (pyroclastic density current activity?) up to Grotte di Lucullo, which, according to Parascandola (1946), was near Miseno, about 5 km south of Monte Nuovo, in the area of Capo Miseno. Marchesino (1538) who visited Pozzuoli in the afternoon of October 4, reported that 90% of the edifices were found destroyed or severely damaged as a result of the combined effect of ash load and seismic shaking. The minimum volume of the Upper Member is between 1 and 4x10^6 m^3. The similar sedimentological features of UM2 and UM1 deposits suggest they were emplaced with similar dynamics during two independent events (D'Oriano *et al.* 2005).

Despite the identical K-phonolitic bulk rock composition of all MtN products (both LM and UM units), textures and microphenocryst compositions exhibit important differences. The juvenile material of LM member consists mostly of variable vesicular pumiceous lapilli and very subordinated cm-sized platy obsidian fragments. Foreign lithics account for less than 5 wt% of the deposit and are represented by fragments of the Neapolitan Yellow Tuff (Orsi *et al.* 1992). Chips of buildings and pottery from the pre-existing village of Tripergole as well as marine shells were also occasionally observed in the deposits (Fig. 4d). In LM, density is largely variable in each layer ranging from 400 to 2,000 kg m^{-3} throughout the sequence. This wide range reflects the large variability of clast morphological features. D'Oriano *et al.* (2005) recognized different clast types (Fig.4e, f): banded (42 vol

%), coarsely vesicular (42 vol%), tube (8 vol%), and microvesicular pumices (8 vol%). Tube pumices have the lowest density while microvesicular have the widest density range. Banded pumices typically display the alternation of yellow and grey bands differing in their vesicularity. The latter are identical to microvesicular pumices while the former have textures very similar to coarsely vesicular pumices. Dense, platy obsidian fragments of up to 1–2 cm are scattered throughout the upper half of the sequence, probably resulting from the shattering of obsidian-bearing banded pumices. Bombs and blocks are represented by coarsely vesicular pumices and banded pumices within the lower 2/3 of the deposit and by microvesicular pumices at the top of the sequence.

The analysed samples of UM1 show a narrower density range than LM, from 700–2,100 kg m^{-3}. The juvenile fragments are dark in colour, have heterogeneous textures and can be grouped into four main clast types: dense, scoria-like, transitional and glassy scoria. The first three clast types constitute UM1a and b (average frequency of 40, 37, 23%, respectively, of the analysed samples), while UM1c is only made up by glassy scoria. Transitional clasts include all fragments with morphological and textural characteristics between dense and scoria-like clasts. Most of them are agglutinated clasts formed by the welding of cm-sized, dense, blocky fragments and variably vesicular, irregularly shaped, scoria-like material. Some of the largest (m-sized) clasts have sets of parallel dm-long open cracks.

The large variability in density and clast and vesicle shapes of the LM juvenile fragments sheds some light into processes occurring in the volcanic conduit during the first phase of the eruption. Large density variations in juvenile material have been described both in purely magmatic eruptions (Gardner *et al.* 1998; Polacci *et al.* 2001; Rosi *et al.* 2004) and in deposits originated by magma/water interaction (Houghton and Wilson, 1989; Morrissey *et al.* 2000). The sedimentological and textural features of the LM deposits and the chronicle's accounts clearly indicate a prominent role of magma/water interaction during this phase of the eruption. Several lines of evidence, however, suggest that fragmentation was dominated by purely magmatic processes (mainly degassing and gas expansion). The contemporary occurrence of coarsely vesicular pumices, low-density, tube pumices and banded pumices reflects the disruption of a magma column characterized by a horizontal zonation of textural features. Banded pumices may originate in an outer collar-like region of the conduit, owing to mixing between melts with different viscosity (Freundt and Tait, 1986). The homogeneous magma composition suggests that differences in rheological properties were not produced by compositional variations but they should reflect a horizontal temperature gradient, with the cooler external region occupied by obsidian-bearing material which was physically mixed within the more fluidal rising magma. According to this conceptual model, coarsely vesicular pumices represent the central portion of the conduit.

Textures of the UM1 juvenile products suggest that they resulted from the disruption of a variably crystallized magma plug. Due to the short time (2 days) separating the two UM explosions from the preceding activity, we can assume quasi-closed system conditions for the degassing and crystallization history of the magma plug. Plug explosions occur as the response of a pressurization induced by a disequilibrium between volatile loss through permeable conduit walls and continuous gas accumulation in the inner crystal-rich part of the plug. When overpressure exceeded the tensile strength of the rigid, topmost part of the plug, blasting of this cap occurred, and gas hosted within the plug eventually expanded to lower pressure accelerating the fragments (Alidibirov 1994; Alidibirov and Dingwell 2000). The whole process can be envisaged as a layer-by-layer mechanical fragmentation due to an inward propagating decompressional wave. The process progressively dampened when the fragmentation front reached less viscous magma at the bottom of the plug. Crystallization due to massive cooling or to decompressional degassing enhances the volatile oversaturation, forcing gas exsolution and generating internal overpressure (Tait *et al.* 1989; Sparks, 1997). The sudden decompression of the partially crystallised and degassed magma body result in the emission of related to a Vulcanian style of activity (Morrissey and Mastin, 2000). The radial distribution of the pyroclastic flow deposits suggests they derive from the boiling-over of a dense cloud carrying a coarse mixture of plug fragments.

The shift from LM to UM activity can be attributed to a continuous decrease of the mass flux, triggering a feedback that contributed to decrease the frequency of the pulsatory activity. The decrease in the mass flux is a realistic hypothesis when considering that more than 90% of the total erupted volume was discharged during the first phase, implying an important decrease of the magma chamber overpressure (Folch and Marti, 1998). The shift between these two phases was also accomplished by a drastic change in the process of fragmentation. Fragmentation of magma during LM was dominated by conditions of rapid degassing during high magma ascent rate which promoted vesiculation and impeded crystal nucleation (Cashman and Blundy, 2000). On the other hand, the fragmentation of UM magma occurred under quasi-static conditions with the development of a highly crystalline, pressurized plug. The switch between the frequent explosions at the end of LM phase and the two distinct explosive events of UM may be related to non-linear variations of magma rheology. Viscosity of crystal-rich magmas shows a dramatic increase around a crystal content of 30–40% by volume (Lejeune and Richet, 1995). Overcoming of a crystal content threshold at the transition between LM and UM could have induced an important decrease of the magma ascent velocity favouring condition of magma crystallization along the conduit.

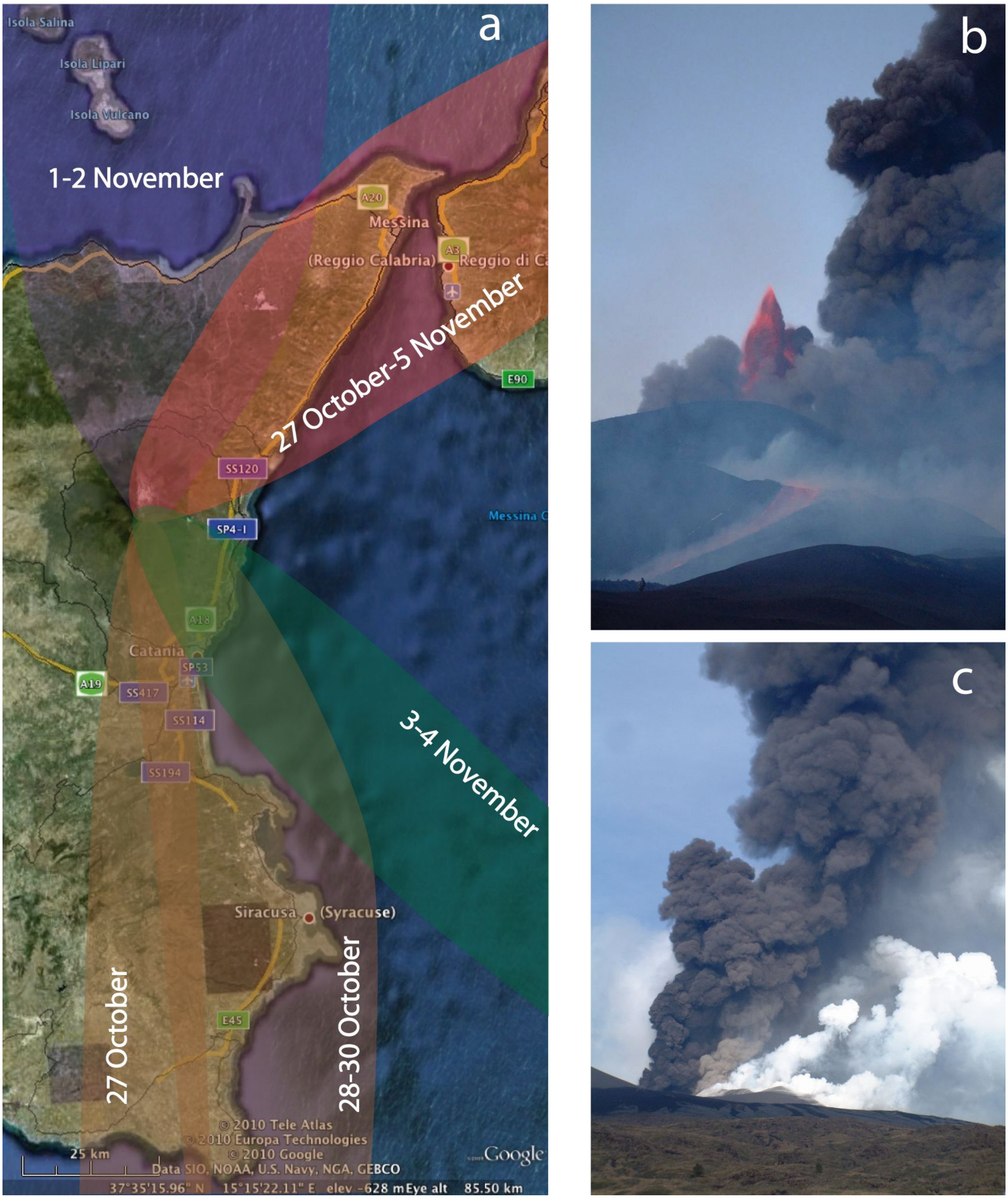
Mt. Etna

Mt Etna is mainly known for its persistent activity from its summit or from effusive eruptions originating from fissures on the flanks of the volcano. Tephra layers cropping extensively on the volcano flanks and adventives cones punctuating all the sectors of the volcano edifice witness an explosive activity of mid large intensity related to the recent activity of this volcano. The recent analysis of historical records of Branca and Del Carlo (2004) indicates that in the last four centuries at least 12 subplinan eruptions took place from that central crater while at least seven long-lasting, ash plume-forming explosive eruptions occurred from volcano flanks. Subplinan eruptions are generally impulsive, can last hours and produce several km-high eruptive columns and tephra fallout also of lapilli size at distances of several tens of kilometers. Explosive flank eruptions (Class B of Branca and Del Carlo, 2004) produce significant ash-plumes a few km-high from which a fallout of lapilli and ash extending for several tens of km from the volcano results. Though no casualties have been associated to this activity, these eruptions have had (in the past and also more recently) a significant impact on human activity and on the economy. We summarize here the main features of 2001 and 2002-3 eruptions, which are the most recent expressions of this flank-explosive activity. Such events have been and studied with modern methods and monitored with a large multidisplinary effort that include field survey, seismic, ground deformation, gas geochemistry, petrology, gravimetric an magnetic measurements and show large similarities.

The 2001 eruption

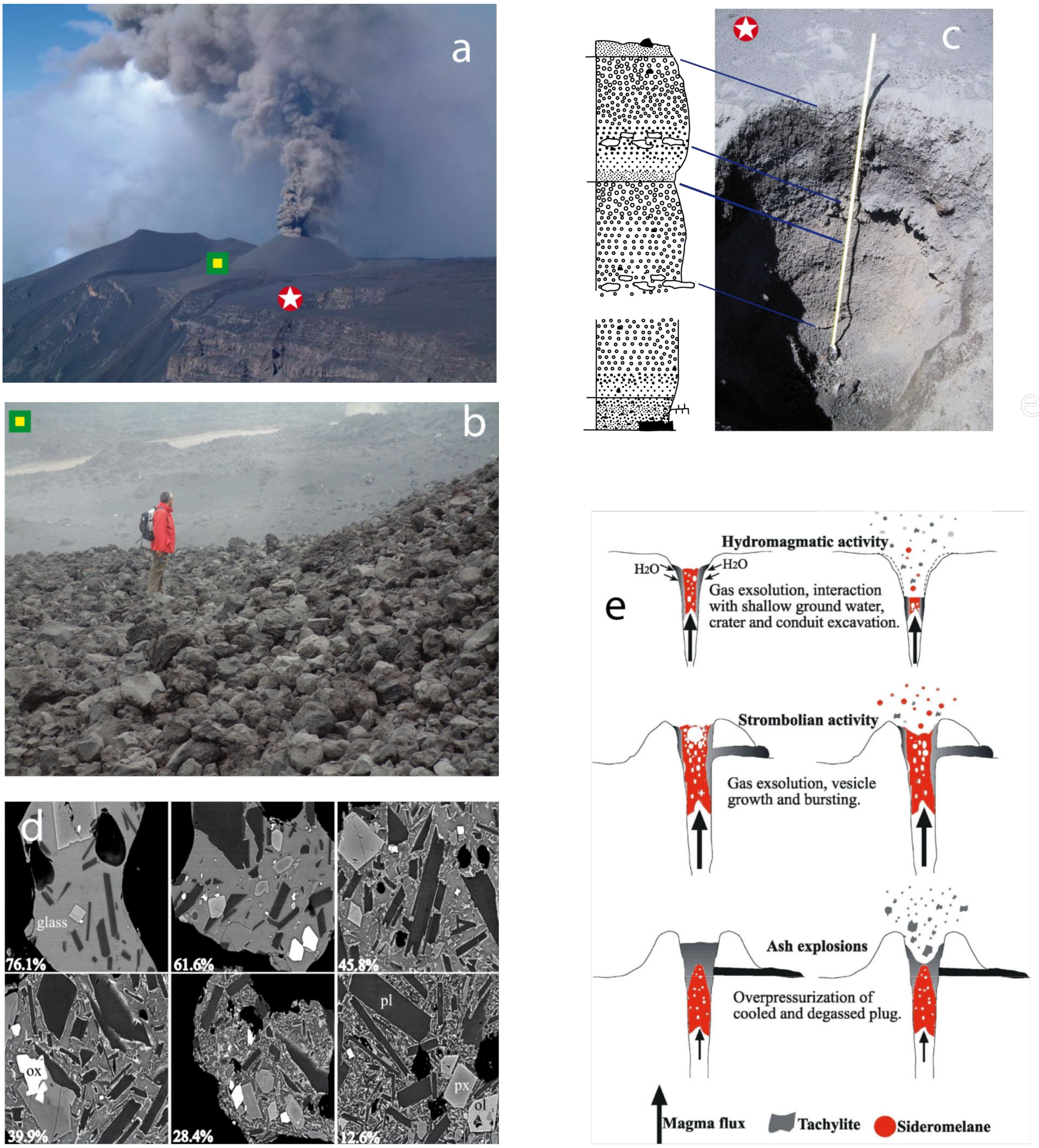
After eight years, and heralded by seismic swarms and geodetic, magnetic, and gravimetric anomalies, Mt. Etna resumed flank activity from 17 July - 9 August 2001. A complex system of eruptive fissures cut the NE and the S flanks of the volcano from 2900 to 2100 m elevation, producing extensive lava flows that buried infrastructure (mainly touristic) and forests down to 1035 m above sea level. Explosive activities of variable character took place from 18 July - 7 August in the form of hydromagmatic explosions, fire fountaining, Strombolian explosions and nearly sustained or pulsating ash explosions. Explosive vents were clustered in the southern reaches of the fissure system (at 2550 and 2100 m). Most of the tephra were erupted from a vent area at 2550 m elevation, forming a ≍100 m high scoria cone (Fig. 5b). Explosive activity at this vent area started with discrete, frequent hydromagmatic explosions and formed explosion craters. On July 24, activity shifted to Strombolian explosions and fire fountains forming, at first, two ill-defined and then one large scoria cone. In the final phase of the activity, from 1 - 5 August, the cone emitted pulsating tephra columns - initially continuous and gradually shifting to discrete explosions of decreasing frequency (order of minutes) and intensity (Fig. 5b). This activity deposited a thin blanket of ash that covered the cone and its surroundings, together with dense, non vesicular blocks. Possible small collapses of the ash column were also documented. During the entire eruption abundant ash was dispersed towards the S and E quadrant of the mountain by local winds causing the international airports of Catania and Reggio Calabria to be closed for some days. Lava flow from three emission points accompanied the explosive activity at 2550 vent in the period 25 July - 1 August (Fig. 5c).

Figure 5. 2001 and 2002 eruptions at Etna



a) Distribution of the ash plume during the early days of 2002-3 Etna eruption. (redrawn from Andronico et al. 2005 and 2009). b) Fire fountains and ash emission from 2800 a.s.l. cone on S fissures, during mid November 2002. Compare the cone height with images from the video recorded on 27 October 2002 from the same position showing the very beginning of the activity on this fissure system; c) Contemporaneous emission of ash and vapour from 2800 a.s.l. cone on S fissures, at the end of November 2002. Picture taken from SW flank.

Figure 6. Summarizing table for the 2001 and 2002 eruptions at Etna



a) Aerial photo of Laghetto cone taken from NE with vigorous ash production on 1 August 2001. Lava flows poured out at the foot of the cone are also evident: Symbol report location of outcrops reported in b) and c); b) Dense blocks deposits at the foot of the Laghetto cone. These blocke are related to the last phase of the activity; c) Ash fall proximal deposit related to the 2001 eruption from Laghetto cone. Succession includes from the bottom: 1) lithic rich crudely layered (10 cm thick) of mm to a few cm-sized ash; 2) Two well sorted graded fall layers (220 and 70 cm thick) of cm-sized scorias and dm-sized bombs; 3) 20-cm thick layer mostly made of a few mm to mm-sized ash. Bar is 2 m long.(Redrawn from Taddeucci et al., 2003); d) SEM-BSE images of ash showing a large range of glass abundance in percentage (white digits) (redrawn from Taddeucci et al 2004); e) Conduit processes during the different stages of 2001 eruption as inferred by textural and compositional study of Taddeucci el al 2004.

The variability of explosive activity and the intense monitoring of the summer 2001 Etna eruption provided an exhaustive data record, making this eruption a favourable case study for the transitions between different types of explosive basaltic activity. In particular, tephra were largely investigated under several point of view, including deposit composition, texture grain size, plume dispersal and transport, volume, ground distribution, etc. (Taddeucci *et al.* 2002; Taddeucci *et al.* 2004a, 2004b; Scollo *et al.* 2007). Monitoring of ash componentry and related physical and chemical properties of the magma emitted during eruption were also employed to interpret transitions between eruptive styles. In ash samples, the following components have been recognized (Taddeucci *et al.* 2002): i) gray-black, opaque tachylite clasts, not or poorly vesiculated, equant and often blocky in shape, appearing micro- to crypto-crystalline in thin section; ii) transparent, light to dark brown sideromelane glass, non-vesicular to highly vesicular, that exhibit variable shape and smoothed surface; iii) felsic (plagioclase) crystals and mafic (pyroxene and olivine) crystals; v) altered volcanic and sedimentary lithic clasts. Fine ash aggregates were also found in samples erupted on 19-21 July. Microlite content increases gradually from sideromelane to tachylite, and the two components often grade into one another (Fig. 6b).

Both proximal stratigraphy (studied on field after the eruption) and the daily distal ash records show that eruption products varied in time accordingly with the three activities observed at the vent. In stratigraphic columns (Fig. 5d) from bottom to top we observe: a basal deposit enriched in oxidized (mainly volcanic) lithics and blocky ash with occasional hydration cracks and ash aggregates; a thick middle zone dominated by vesicular, glassy pyroclasts, both scoria and ash; a thin top layer of poorly vesicular to unvesicular, microlite-rich, dense and blocky juvenile pyroclasts. Dense blocks are mostly found at the slope break at the base of the cone where they form a continuous belt likely created by rolling blocks that landed on the cone flanks. This deposit architecture indicates that dense blocks were erupted during the last phase when the cone had already formed. The juvenile origin of the blocks is clearly shown by the presence within them of sedimentary inclusions that mark other products of this eruption (Corsaro *et al.* 2007).

The observed features and stratigraphy of the eruption deposit, and the temporal trend of the activity, led Taddeucci *et al.* (2002) to the following inferences on the explosive processes during the three periods identified. First period: blocky shape of the ash particles, abundance of lithics, and the occurrence of aggregates and hydration cracks are typical of explosions caused by magma-water interaction (e.g. Büttner *et al.* 1999; Doubik and Hill, 1999), as well as the jets observed at the vent. When the eruption started, magma reached local water tables causing hydromagmatic explosions that widened the conduit and opened the new vents. Second period: vesicular sideromelane and fuse-like bombs that formed during Strombolian and continuous fire-fountaining activity are indicative of efficient magma degassing at fragmentation in fully magmatic activity (e.g., Heiken and Wohletz, 1985). As magma flux and pressure increased, water was cut off from the conduit and the activity becomes fully driven by magma degassing. Third period: the presence in the deposit of dense blocks and ash rich in poorly vesicular, microlite-rich tachylite implies fragmentation of a relatively cooled and degassed magma. The final part of the eruption involved the top of a largely degassed melt column, whose fragmentation was controlled by the concomitant increase of pore pressure and yield-strength of the cooling and crystallizing magma in a kind of small-scale, vulcanian-like eruptive mechanism (Nairn and Self, 1978; Self *et al.* 1979). Common aspects of the third phase with Vulcanian eruptions are the observed activity style, with continuous to discrete and cannon-like ash explosions (especially in the last days of activity) and the occasional occurrence of collapses of the denser parts of the ash column. Also the deposit shares features with Vulcanian ones - such as the thin ash fall layer together with large ballistic, dense blocks.

Crystal size distributions and textural investigations showed that sideromelane implies a simple crystallization history, probably due to single (or shorter) nucleation and microlite growth event, tachylite represents a subsequent, more complex crystallization stage of the magma in respect to sideromelane. During the 2001 flank eruption of Mt. Etna, the tachylite crystallization took place in increasing disequilibrium conditions, and, possibly, after a ~40°C temperature decrease.

Compositional, CSD, and vesiculation features of the ash particles indicate that tachylite-forming magma experienced a longer residence time in the upper conduit in respect to the sideromelane-forming one. Residence time is controlled by ascent velocity. The evolution of the explosive activity suggests that sideromelane formed by fragmentation of the central, microlite-poor, still vesicular, and hotter zone of magma flow where rising magma slugs transported magma at a relatively high velocity.

Conversely, tachylite formed by fragmentation of the microlite-rich, denser, and cooler magma formed by vesicle collapse in the peripheral zone of the magma flux. The relative abundance of sideromelane and tachylite ash particles in the eruption deposit records the evolution of velocity gradients in the rising magma flux. Both of these ash particle types erupted simultaneously (over a 24 hours time window) during the Strombolian activity, but sideromelane content in the ash gradually decreased as the eruption evolved until the final, pulsing ash explosions erupted only tachylite ash and dense blocks. In this view, the transition from Strombolian to small-scale, vulcanian-like pulsing ash explosions may result from the progressive development of the peripheral zone until it formed a rigid, permeable, fractured plug of degassed and crystallized magma at the top of the magma column (Fig. 5f). Fragmentation of the plug also produced dense blocks with irregular, sometimes altered surfaces, likely remnants of the permeable network of fractures left by cooling and vesicle escape and collapse. The increased development of the peripheral zone is a consequence of a decrease in the magma emission rate and the two processes jointly lead to the closure of the vent and the end of the eruption.

From the point of view of the hazard related to the ash, though with different eruptive mechanisms, strong ash production is related to the opening and closing stages of the eruption and are strictly related to the physical properties of the magma that increase the efficiency of the brittle fragmentation of the magma.

The 2002 eruption

On 26 October 2002 at 20:12 GMT, an earthquake swarm (Patanè, 2002; Acocella *et al.* 2003) preceded and accompanied the formation of eruptive fissures over the S and NE flanks of the volcano, marking the onset of the 2002-03 Etna eruption. A north-south, 1 km-long eruptive fissure opened on the upper southern flank of the volcano (2850-2600 m a.s.l.), between Torre del Filosofo and the old cable-car station partially destroyed during the 1983 eruption. Another NE oriented 4 km long fissure developed on N flank, from northern base of NEC (3010-2920 m a.s.l) down to 1900 m. Detailed eruption chronology together with compositional and gas geochemical data are reported in Andronico *et al.* (2005). North fissure system was active until 5 november producing fire fountains, Strombolian activity and lava flows. The southern fissure produced 100-300 m high fire fountains that soon evolved into an ash column up to about 5 km a.s.l. (see movie) that was blown south by the wind spreading on the Catania and other south eastern Sicily towns. Fine ash reached the Northern Africa and Greek islands (Dellino and Kyriakopulos, 2003). Eruptive activity at the S fissure lasted until 28 January 2003, showing several changes in the eruptive style and a two week pause in lava effusion. This kind of activity (tephra dispersal, nature and volume of the deposits) were reported in detail and evaluated by several papers (Andronico *et al.* 2008, Andronico *et al.* 2005; Andronico *et al.* 2009).

Figure Animation. Etna 2002 eruption

Please see online version for this animation.

Early days of the eruption were characterized by an alternation of lava fountains and phreatomagmatic explosions forming dense ash columns reaching an height of 4.2 km on the vents with mass eruption rates varying from 2.2 to 4.9 10^4 kgs^{-1} (Andronico *et al.* 2008). After that, ash-rich eruptions columns alternated to Strombolian explosions. The latter became dominant after end of December 2002. Ash fallout covered all sectors of the volcano with the exception of the western flank and extended southward up to Siracusa (80 km) and Ragusa (100 km) or northward up to Reggio Calabria (Fig. 5a). Ash fall concentration at the ground attained during the early days 18 kg/m^2 at Rifugio Sapienza (S flank, 1900 m.a.s.l.) several kilos (up to 6 kg/m^2 in Zafferana) in the mid-lower flanks and about 1 kg/m^2 at Catania. Ash plume and tephra strongly affected commercial flights (airports of Catania, Reggio Calabria and Sigonella), main roads, highways and cultivated areas.

As in the 2001 eruption, ash juvenile components (mostly tachylite and sideromelane, Andronico *et al.* 2009) show that the relative abundance of tachylite and sideromelane and the morphology of the particles show large variations. And in particular, sideromelane abundance increases with episodes of Strombolian activity.

With regard to eruptive mechanisms (also for the 2002 eruption), crystallization occurring in the topmost part of the conduit seems to have a strong control on the efficiency and the style of magma fragmentation, hindering gas segregation and leading toward a brittle regime that increases ash production, and contributing to determining the eruptive style at the vent.

Stromboli Island

The typical activity of Stromboli, for which the volcano is famous, consists of mild intermittent explosions, ejecting incandescent scoriae, magma lumps, ash and blocks to heights of a few tens to hundreds of meters. Most of the coarse ejecta falls back into the craters although some are expelled up to 200 m from the source vent.

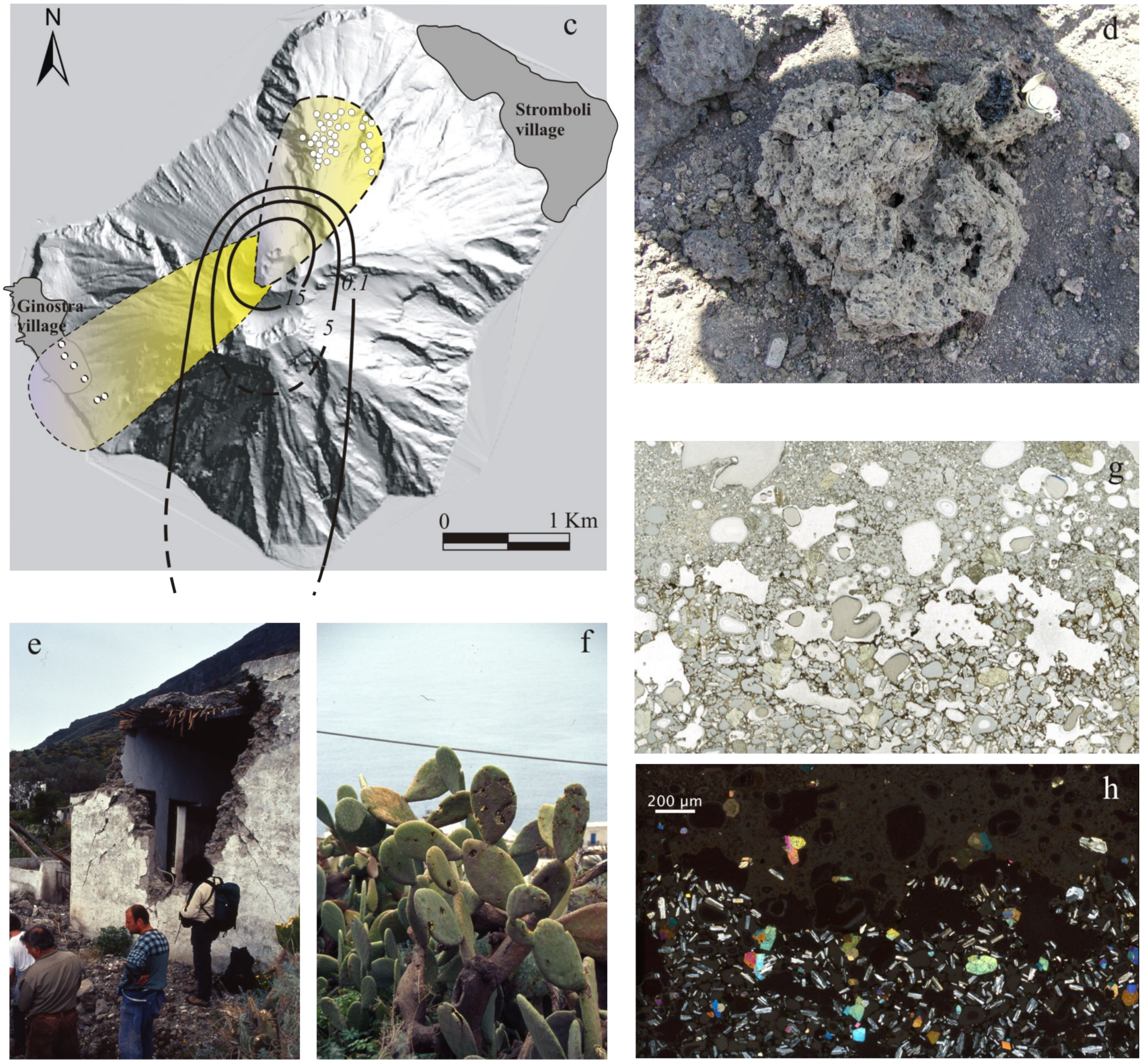
Figure 6a-b. 5 April 2003 paroxysm at Stromboli

a) Convective column generated during Phase 2 and co-ignimbritic clouds related to pyroclastic flow formation during Phase 3; b) ash plumes emitted during the late Phase 4 (pictures courtesy of S. Calvari).

Every 10-20 years during the past two centuries, lava effusions occurred either from the summit craters or from vents opened inside the Sciara del Fuoco - a collapse scar on the NW flank. Lava flowed onto the Sciara slope eventually reaching the sea and without causing concern to the population. Both mild Strombolian explosions and lava flows are fed by a highly porphyritic (HP), degassed HK-shoshonitic basalt residing in the shallow part of the feeding system.

The most violent and hazardous eruptive manifestations of the volcano are represented by the Strombolian paroxysms (Mercalli, 1907). They usually consist of sequences of explosive events lasting from a few minutes to days. Ballistic bombs and blocks are ejected up to a distance of a few kilometres from the craters, sometimes affecting the two villages on the coast. The impulsive emission of jets of gas and pyroclasts evolves into short-lived convective columns depositing ash, pumice lapilli and bombs on the volcano slopes up to the sea. Significant morphological modifications of the crater area and the formation of deep craters are also commonly observed (Bertagnini *et al.* 2008). The distinctive feature of paroxysms is the emission of a low porphyritic (LP), volatile-rich HK-basalt as highly inflated, light colored pumice. Pumice are variably mingled with the HP residing magma (Fig. 6 g, h) and unmingled HP scoriae are present as well. In the last 8 years the volcano has produced two lava effusions (December 2002 - July 2003 and February - April 2007, respectively) and two paroxysms (on 5 April 2003 and 15 March 2007, respectively) while the effusive eruptions were in progress.

Figure 6c-h. Summarizing table for the 5 April 2003 paroxysm at Stromboli



c) Mapped impact craters from larger ballistic blocks (yellow-colored areas indicate the higher concentrations of blocks) and isomass lines (values are in kg/m^2) of fallout deposit related to Phase 2 (modified from Pistolesi et al, 2008); d) Highly vesicular LP pumice bomb sampled at about 500 m from the crater area (picture courtesy of N. Métrich); e) house in Ginostra village damaged by a m-sized block ejected during Phase 2; f) shards of a block fragmented after impact and jabbed in prickly pears near Ginostra village; g) and h) optical microscope pictures (open-nicol and cross-nicol, respectively) of a mingled clast, highlighting the difference between the highly vesicular and nearly aphyric LP and crystal-rich HP magmas.

Strombolian paroxysms: the case of the 5 April 2003 eruption

The 5 April 2003 paroxysm was observed by several researchers present on the island and a detailed event chronology was reconstructed through data from thermal camera, digital photos and a thermo-acoustic-seismic array (Calvari *et al.* 2006; Ripepe and Harris, 2008; Harris *et al.* 2008). The integration of these data with field and laboratory analyses (Rosi *et al.* 2006; Pistolesi *et al.* 2008) provided a quantitative picture of the explosive dynamics, while geochemical, mineralogical and melt inclusions studies characterized nature, deep of provenance and ascent dynamics of the emitted magmas (Métrich *et al.* 2005; Francalanci *et al.* 2008). The paroxysm of 5 April 2003, the most violent of the past 50 years, had a total duration of about 373 s and progressed through four phases:

1) Eruption onset (~30 s). The eruption began with a weak emission of red ash to a height of a few tens of meters, from the NE and central craters. After 17 s the emission became more intense and cauliflower grey clouds rose from the NE crater.

2) Climactic explosion (~38 s). The second phase began with the emission of a rapidly expanding, dark-colored ash plume that was, seconds later, over taken by a second plume composed of multiple jets, comprising leading blocks with ashy contrails (Fig. 6a). The explosions involved simultaneously both SW and NE craters and fed an up to 4 km-high convective column. Meter-sized ballistic blocks were launched up to 1400 m above the craters and fell on the volcano flanks and on the village of Ginostra, at about 2 km from the vent (Fig. 6c, e, f). The areal distribution was strongly asymmetrical, in two narrow sectors oriented to NE and WSW respectively, such as in the large paroxysm of 11 September 1930.

The convective plume drifted southwards and the resulting fallout deposit consisted of variably expanded and mingled LP pumice clasts, HP scoriae and minor lithic fragments. Across the summit area, a moderately sorted, incipiently welded spatter deposit was emplaced, hot avalanche deposits limited to the crater area, resulted from sliding of fallout deposit accumulated on steep slopes.

The most of the pyroclastic material was emitted during this phase. From the isomass map (Fig. 6c) a total erupted mass of 1.1 – 1.4 x 10^8 kg was calculated, with erupted magma accounting for 0.8 – 1.1 x 10^8 kg. The average mass discharge rate was calculated in 2.8–3.6 × 10^6 kg/s, with a possible peak at 1.0-1.2 × 10^7 kg/s in the 10 s-long initial gas thrust. During this phase gas velocities peaked at 324 m/s when large blocks were ejected at velocities of up to 185 m/s. The overpressure needed to accelerate gas and blocks to this value was calculated at 3.8 MPa, one order of magnitude higher than the gas overpressure (~0.2 MPa) estimated for the mild explosions of the persistent Strombolian activity (Vergniolle and Brandeis, 1996).

3) Pyroclastic flow and smaller explosions (~75 s). This phase was dominated by the formation of a scoria flow and the concurrent rise of co-ignimbrite clouds (Fig. 6b), possibly accompanied by a series of explosions from the head of the dyke which was feeding the lava flow. The mass of the scoria flow deposit was estimated at about 1.0-1.3 x 10^7 kg. A 175 s long hiatus followed, characterized by low intensity pulses from the SW crater.

4) Terminating ash explosions (~87 s). Three main discrete explosions at SW crater emitted red colored, ash-laden plumes with maximum height of ~600 m.

Pumice (Fig. 6d) emitted during the paroxysm has a HK basaltic composition as their analogs erupted by the earlier paroxysms and similar mineralogical and textural features. It carries up to 15-20 vol% of crystals in a glassy groundmass. As verified in all previously studied eruptions, most of them are inherited from the shallow crystal-rich magma during syn-eruptive mingling or show resorption features indicating reactions between LP melts and cumulative body/crystal mush.

A few olivine crystals (Fo_{86-87}) host melt inclusions with a volatile content of 3.1 wt% (H_2O, CO_2, S, Cl), for which the total fluid pressure is evaluated between at about 200 MPa. It suggests that the paroxysm was initiated by the uprising of a small magma blob from a depth of about 8 km. The same depth has been estimated for the 15 March 2007 paroxysm (Métrich *et al.* 2010).

The H_2O and CO_2 evolution in melt inclusions in these recent paroxysms and earlier events indicate that they are related to the ascent of volatile-rich magma batches, under prevalently closed-system decompression conditions, from the storage zone lying at ~7-10 km depth. The low microlite content of the pumice suggests that decompression and ascent are fast enough to prevent crystal nucleation and growth (Bertagnini *et al.* 2003; Métrich *et al.* 2010).

Lessons from recent and past activity

The large case history discussed above for the recent and past activity at some active Italian volcanoes emphasizes the wide range of hazardous phenomena associated to the very large range of different eruption styles associated with mid-intensity eruptions. Similarly, the impact these eruptions can have on the territory is largely variable as a function of the eruptive dynamics, intensity, magnitude and product dispersal.

Fallout of pyroclastic material

Ballistic ejecta are generally considered those block- or bomb-sized fragments that follow a parabolic trajectory after expulsion with only a very minor interaction with local winds. Ballistic ejecta pose an important hazard especially for those low-to mid-intensity eruptions characterized by a very small amount of material expelled from the vent during each explosive outburst. Large explosive outbursts can also be associated with the ejection of ballistic clasts, but they are generally interspersed with a larger quantity of other falling material, so that the general hazard is mainly posed by the thick accumulation of pyroclasts non following ballistic trajectories.

The possibility of vent opening in densely inhabited areas (for example at Phlegrean Fields and Etna), including tourist sites at some areas (as for example at Etna and Stromboli) mean that ballistic ejecta are a serious hazard from Italian volcanoes. Casualties have recently occurred at these two volcanoes.

Hazards posed by fallout of pyroclastic material falling down from a convective columns are generally high, including in mid-intensity eruptions if the eruption vent is close to inhabited areas, and serious consequences have been associated with recent and past activity from Italian volcanoes. Effects of tephra fallout span a large range of possibilities - including possible damage to agriculture, buildings, health, transportation, power and water supply and waste water systems (http://volcanoes.usgs.gov/ash/). All but the first of these are more typical for Italian volcanoes due to the very close proximity of eruptive vents to largely inhabited areas.

Downwind fallout of coarse-grained material over large areas is mainly related with violent Strombolian eruptions, while ash-dominated fallout material can be both associated with violent Strombolian and Vulcanian activity. The last three centuries of Vesuvius activity have recurrently presented this problem over the whole volcano and especially in the eastern and southeastern adjacent sectors - up to distances of about 30-40 km due to the prevalent easterly direction of tropospheric winds. As a consequence, several violent Strombolian eruptions of the last two centuries (1872, 1906, 1944 eruptions) caused important damage to buildings in some of the villages at the foot of the volcano and especially in its eastern sector.

As clearly shown by the reported examples, mid-intensity eruptions are often associated with the production of large amounts of ash. This occurs both in eruptions characterized by phases of magma-water interaction (Vesuvius AP3 or the first phase of AD 1538 Monte Nuovo eruption at Phlegrean Fields) or during clearly magmatic activity (Etna 2001). During these eruptions ash is generally advected by low-level convective columns up to considerable distances (i.e. ash fallout is described up to 300 km south-east of Phlegrean Fields during the AD 1538 Monte Nuovo Eruption; satellite images show that ash plumes from the 2001-2002 Etna eruption were still visible over North Africa), mainly provoking damage to transportation, agriculture and water supply systems (Blong and McKee, 1995; http://volcanoes.usgs.gov/ash/). The recent eruptions of Etna caused, for example, the prolonged closure of the Catania and Reggio Calabria airports, and in the case of a northerly dispersal, could have caused a much larger economic damage over the whole Mediterranean area.

Generation of pyroclastic density currents

Pyroclastic density currents (PDC) represent one of the main sources of hazard associated with explosive volcanic activity. This type of phenomenon is typically associated with Plinian (s.l.) activity and only minor PDCs are sometimes associated with mid-intensity events like cone-forming and Vulcanian eruptions. The area swept by a PDC and its maximum runout are a function of eruption intensity, the less intense generally being able to produce dense PDCs which are strongly controlled by topography, have a reduced mobility and rapidly stop where the slope reduces. This is the case, for example, of some PDCs associated with violent Strombolian activity at Vesuvius (the 1822 eruption, Arrighi *et al.* 2001), of the glowing avalanches which formed along the Vesuvius slopes during the 1944 activity (Hazlett *et al.* 1991; Cole and Scarpati, 2010) or along the northeastern flank of Stromboli volcano during the 1930 eruption (Rittmann, 1931), or at the end of the 5 April 2003 paroxysm of Stromboli, only confined to the summit area (see above) and of the two block and ash flows generated during the Vulcanian phase 2 of the AD 1538 Monte Nuovo eruption. A short runout is also associated with dilute PDCs which can be generated during cone-forming (AD 1538 Monte Nuovo) and Vulcanian activity (1888-1890 eruption of La Fossa of Vulcano, Eolian Island, Frazzetta *et al.* 1983). Hazards associated to this type of activity are reduced, but are still relevant when eruptive vents are close to urbanized areas. Main hazards of this type of PDCs are mostly related to particle concentration and the temperature of the gas cloud mixture which can provoke asphyxiation and burns to humans or set fires in vegetated and urbanized areas. Expected dynamic pressure is less relevant as a source of hazard because of the generally small mass transported and the reduced velocity of the current.

Seismic activity and ground deformations

Deformation and seismic activity precedes, accompanies and follows eruptions, and it is not clearly related with its intensity (Mc Nutt, 1996; Sandri at al. 2004). Magnitude of earthquakes associated to volcanic activity is generally low (on average lower than 4) and it mainly impacts the restricted area of few kilometers around the vent. The common occurrence of seismic activity in swarms of hundreds to thousands of earthquakes of similar magnitude occurring in a very short time (days to hours) over the course of a volcanic crisis can have an important cumulative effect on structures, which are progressively weakened by the continuous ground shaking (Zuccaro *et al.* 2008). Important effects on buildings are also increased in some areas by the concomitant overloading by fallout tephra or by the effects of the lateral pressures exerted by eventual PDCs.

Similarly, large deformation in the form of vertical movements or extended fracturing is often restricted to the area closer to the vent and may have a strong impact on buildings. As a consequence, the final impact of an eruption crisis can be largely increased by this type of activity, as for example in the case of the AD 1538 Monte Nuovo eruption when the town of Pozzuoli was destroyed, in large measure, by the effects of deformation and seismic activity rather than by the reduced load of ash.

An extended network of fractures often forms during summit and lateral eruptions at Etna, causing local problems to communication and power infrastructures or buildings. The famous AD 1669 eruption of Monti Rossi opened a fracture system inside the village of Nicolosi, building a 200 m high cone in its outskirts (Corsaro *et al.* 1996).

Effusive activity

Violent Strombolian and Vulcanian eruptions are often associated with phases of lava effusion, whatever the composition of the magma involved. Paroxysmal explosive phases of these eruptions at Etna and Vesuvius are both preceded and/or accompanied by lava flows erupted from lateral vents or fissures. Vulcanian activity is generally associated with the slow extrusion of a lava plug (possibly occurred between the first and second phase of the AD 1538 Monte Nuovo eruption) or of a lava dome or coulée (as in the historical activity of La Fossa of Vulcano, Frazzetta *et al.* 1983). Also, eruptions characterized by continuous ash emission can be associated to lava effusion that, in the case of the AP3 eruption of Vesuvius, was possibly confined inside the caldera depression.

Impact of lava flow activity during mid-intensity, mixed explosive-effusive eruptions can be very large and, in some cases, can be comparable to damage (in terms for example of economical costs) related to the explosive part of the eruptions. During the recent activity of Vesuvius (1906 and 1944 eruptions) damage related to lava flow was huge, partially destroying the villages of Boscotrecase and San Sebastiano, respectively. Hazard from lava flow invasion should be so taken in account when dealing with the expected eruption scenario for his type of eruptions.

Conclusions

Impact on everyday life related to mid-intensity explosive activity can be incredibly large, and this type of activity poses major problems at Italian volcanoes - especially for those with eruptive vents near inhabited areas. The extensive case history presented in this paper gives account of the wide variability of eruptive processes involved in this class of eruption and of the spectrum of events which can occur at Italian volcanoes. Looking at the past history of the main Italian volcanoes, however, this spectrum can be even larger. Hazards posed by these eruptions are extremely variable - ranging from scattered ballistic fallout over proximal areas, to extensive ash fallout over very large areas, to the proximal dispersal of PDCs, to the possible emission of lava flows. Consequently, expected damage could be extremely high due to the high exposure and vulnerability of the affected areas.

A special feature of mid-intensity explosive eruptions, which heavily reflects in their impact on environment and everyday life, is the general long duration of these events. In fact, while large scale, catastrophic eruptions generally exhaust their destructive power within a few days, mid-intensity events can last for periods of weeks to several months, alternating phases of intense activity to periods of reduced activity. This behavior, together with the proximity of Italian volcanoes to largely inhabited areas, can produce a dreadful mix in terms of the response of population and authorities living under their shadow.

In the assessment of volcanic hazard and risk, both a long-term and a short-term perspective should be considered. Assessment over a long-term perspective should consider the whole range and probability of occurrence of possible hazards (and risks) related to each type of expected eruptions at a given volcano in a given point. The results can be very useful - especially for territorial planning. Planning the response to a volcanic event is a matter of short-term hazard (and risk) assessment. In this case, defining the eruption scenario in terms of the different types of activity, geographic area and their expected temporal evolution in the course of the eruption, is the basis for effective emergency management - immediately before, during and in the aftermath of an eruption. The study of the different types of eruptions that have occurred in the past for a given volcano like those described in this paper, both on the basis of geological information or of direct observations, is fundamental for this type of analysis.

References

Acocella, V., Neri, M. 2003. What makes flank eruptions? The 2001 Etna eruption and its possible triggering mechanisms. Bulletin of Volcanology 65, 517-529.

Alidibirov, M. 1994. A model for viscous magma fragmentation during volcanic blasts. Bulletin of Volcanology 56, 459–465.

Alidibirov, M, Dingwell, D.B. 2000. Three fragmentation mechanisms for highly viscous magma underrapid decompression. Journal of Volcanology and Geothermal Research 100, 413–421.

Andronico, D., Branca, S., Calvari, S., Burton, M., Caltabiano, T., Corsaro, R.A., Del Carlo, P., Garfi, G., Lodato, L., Miraglia, L., Muré, F., Neri, M., Pecora, E., Pompilio, M., Salerno, G., Spampinato, L. 2005. A multi-disciplinary study of the 2002-03 Etna eruption: insights into a complex plumbing system. Bulletin of Volcanology 67, 314-330.

Andronico, D., Branca, S., Del Carlo, P., 2001. The 18.7 ka phreatomagmatic flank eruption on Etna (Italy): relationship between eruptive activity and sedimentary basement setting. Terra Nova 13, 235-240.

Andronico, D., Cioni, R. 2002. Contrasting styles of Mount Vesuvius activity in the period between the Avellino and Pompeii Plinian eruptions, and some implications for assessment of future hazards. Bulletin of Volcanology 64, 372–391.

Andronico, D., Cioni, R., Marianelli, P., Santacroce, R. 1996. Introduction to Somma-Vesuvius, in Vesuvius Decade Volcano, Workshop handbook, edited by R. Santacroce et al., 1-49.

Andronico, D., Scollo, S., Cristaldi, A., Caruso, S. 2008. The 2002–03 Etna explosive activity: tephra dispersal and features of the deposit. Journal of Geophysical Research 113, 10.1029/2007JB005126.

Andronico, D., Scollo, S., Cristaldi, A., Ferrari, F. 2009. Monitoring ash emission episodes at Mt. Etna: The 16 November 2006 case study. Journal of Volcanology and Geothermal Research 180, 123-134.

Arrighi, S., Principe, C., Rosi, M. 2001. Violent strombolian and subplinian eruptions at Vesuvius during post-1631 activity. Bulletin of Volcanology 63, 126–150.

Barberi, F., Chelini, W., Marinelli, G., Martini, M. 1989. The gas cloud of Lake Nyos Cameroon, 1989. Results of the Italian technical mission. Journal of Volcanology and Geothermal Research 39, 125-134.

Barclay, I., Rutherford, M.I., Carroll, M.R. 1998. Experimental phase equilibria constraits on pre-eruptive storage conditions of the Soufrière Hills magma. Geophysical Research Letters 25, 3437-3440.

Baxter, P.J., Bonadonna, C., Dupree, R., Hards, V.L., Kohn, S:C., Murphy, M.D., Nichols, A., Nicholson, R.A:, Norton, G., Searl, A., Sparks, R.S:J, Vickers B.P. 1999. Cristobalite in Volcanic Ash of the Soufriere Hills Volcano, Montserrat, British West Indies. Science 283, 1142 – 1145.

Behncke, B., Calvari, S., Giammanco, S., Neri, M., Pinkerton, H. 2008. Pyroclastic density currents resulting from the interaction of basaltic magma with hydrothermally altered rock: an example from the 2006 summit eruptions of Mount Etna, Italy. Bulletin of Volcanology 70, 1249-1268.

Bernstein, R.S., Baxter, P.J., Falk, H., Ing, R., Foster, L., Frost, F. 1986. Immediate public health concerns and actions in volcanic eruptions: lessons from the Mount St. Helens eruptions, May 18-October 18, 1980. American Journal of Public Health. 76, 25-37.

Bertagnini, A., Landi, P. 1996. The Secche di Lazzaro pyroclastics of Stromboli volcano: a phreatomagmatic eruption related to the Sciara del Fuoco sector collapse. Bulletin of Volcanology 58, 239-245.

Bertagnini, A., Landi, P., Santacroce, R., Sbrana, A. 1991. The 1906 eruption of Vesuvius: from magmatic to phreatomagmatic actvity through the flashing of a shallow depth hydrothermal system. Bulletin of Volcanology 53, 517-532.

Bertagnini, A., Métrich, N., Francalanci, L., Landi, P., Tommasini, S., Conticelli, S. 2008. Volcanology and magma geochemistry of the present-day activity: constraints on the feeding system. In: Calvari S, Rosi M, Ripepe M (eds) Learning from Stromboli and its 2002–2003 eruptive crisis. AGU Geophysical Monograph 143, 19-37.

Bertagnini, A., Métrich, N., Landi, P., Rosi, M. 2003. Stromboli volcano (Aeolian Archipelago, Italy): An open window on the deep-feeding system of a steady state basaltic volcano . Journal of Geophysical Research 108, 10.1029/2002JB002146.

Blong, R.J., McKee, C. 1995, The Rabaul eruption 1994: destruction of a town: Natural Hazards Research Centre, Macquarie University, Australia, 52 p.

Blong, R.J. 1984. Volcanic hazards. Academic Press, Australia 1–424.

Blundy, J., Cashman, K. 2005. Rapid decompression-driven crystallization recorded by melt inclusions from Mount St Helens volcano. Geology 33, 793-796.

Blundy, J., Cashman, K., Humphreys, M., 2006. Magma heating by decompression-driven crystallisation beneath andesite volcanoes. Nature 443, 76-79.

Blundy, J.D., Cashman, K. 2001. Ascent-driven crystallization of dacite magmas at Mount St Helens, 1980-1986. Contribution to Mineralogy and Petrolology 140, 631-650.

Branca, S., Del Carlo, P. 2004. Eruptions of Mt. Etna during the past 3,200 years: a revised compilation integrating the historical and stratigraphic records. In: Bonaccorso, A., Calvari, S., Coltelli, M., Del Negro, C., Falsaperla, S. (eds) Mt. Etna: Volcano Laboratory. American Geophysical Union, Geophysical Monograph 143: 1-27.

Bursik, M.I., Kobs, S.E., Burns, A., Braitseva, O.A, Bazanova, L.I.,. Melekestsev, I.V, Kurbatov, A., Pieri, D.C. 2009. Volcanic plumes and wind: Jetstream interaction examples and implications for air traffic. Journal of Volcanology and Geothermal Research 186, 60-67.

Büttner, R., Dellino P., La Volpe L., Lorenz V., Zimanowski B., 2002. Thermohydraulic explosions in phreatomagmatic eruptions as evidenced by the comparison between pyroclasts and products from Molten Fuel Coolant Interaction experiments. Journal of Geophysical Research, vol. 107, NO. B11, 2277, 10.1029/2001JB000511.

Büttner, R., Dellino, P., Zimanowski, B. 1999. Identifying modes of magma/water interaction from the surface features of ash particles. Nature 401, 688-690.

Calvari, S., Spampanato, L., Lodato, L. 2006. “The 5 April 2003 vulcanian paroxysmal explosion at Stromboli volcano (Italy) from field observations and thermal data”. Journal of Geophysical Research 149, 160-175.

Carey, S., Sigurdsson, H. 1987. Temporal variations in column height and magma discharge rate during the 79 A.D. eruption of Vesuvius. Geological Society of American Bulletin 99, 303–314.

Carey, S., Sparks, R.S.J. 1986. Quantitative models of the fallout and dispersal of tephra from volcanic eruption columns. Bulletin of Volcanology. 48, 109–125.

Cashman, K.V. 1988. Crystallization of Mount St. Helens dacite: A quantitative textural approach. Bulletin of Volcanology 50, 194-209.

Cashman, K.V. 1990. Textural constraints on the kinetics of crystallization of igneous rocks. Reviews in Mineralogy 24, 259-314.

Cashman, K.V. 1992. Groundmass crystallization of Mount St. Helens dacite, 1980-1986: A tool for interpreting shallow magmatic processes. Contributions to Mineralogy and Petrology 109, 431-449.

Cashman, K.V., Blundy, J., 2000. Degassing and crystallization of ascending andesite and dacite. Philosophical Transactions of the Royal Society of London. 358, 1487–513.

Cashman, K.V., Mangan, M.T. 1994. Physical aspects of magmatic degassing II. Constraints on vesiculation processes from textural studies of eruptive products. Reviews in Mineralogy 30, 447-478.

Chester, D.K., Duncan, A.M. 2007. Lieutenant-Colonel Delmé-Radcliffe’s report on the 1906 eruption of Vesuvius, Italy. Journal of Volcanology and Geothermal Research 166, 204-216.

Cioni, R., D'Oriano, C., Bertagnini, A. 2008. Fingerprinting ash deposits of small scale eruptions by their physical and textural features . Journal of Volcanology and Geothermal Research 177, 277–287.

Cioni, R., Sbrana, A., Vecci, R. 1992. Morphologic features of juvenile pyroclasts from magmatic and phreatomagmatic deposits of Vesuvius. Journal of Volcanology and Geothermal Research 51, 61–78.

Cole, P.D., Scarpati, P. 2010. The 1944 eruption of Vesuvius, Italy: combining contemporary accounts and field studies for a new volcanological reconstruction. Geological Magazine 147, 391-415.

Corsaro, R.A., Miraglia, L., Pompilio, M. 2007. Petrologic evidence of a complex plumbing system feeding the July–August 2001 eruption of Mt. Etna, Sicily, Italy. Bulletin of Volcanology 69, 401-421.

Corsaro, R.A., Cristofolini, R., Patanè, L. 1996. The 1669 eruption at Mount Etna: Chronology, petrology and geochemistry, with inference on magma sources and ascent mechanisms. Bulletin of Volcanology 58, 348-358.

Cottrell, E., R.A., Miraglia, L., Pompilio, M. 2007. Petrologic evidence of a complex plumbing system feeding the July–August 2001 eruption of Mt. Etna, Sicily, Italy. Bulletin of Volcanology 69, 401-421.

D’Oriano, C. (2008). Dynamic of ash emission at Vesuvius. PhD thesis, 2008 http://veprints.unica.it/23/.

D’Oriano, C., Poggianti, E., Bertagnini, A., Cioni, R., Landi, P., Polacci, M., Rosi, M. 2005. Changes in eruptive style during the A.D. 1538 Monte Nuovo eruption (Phlegrean Fields, Italy): the role of syneruptive crystallization. Bulletin of Volcanology 67, 601- 621.

Da Toledo, P.G. 1538. Raginamento del terremoto, del Nuovo Monte, dall'aprimento di terra in Pozzolo nell'anno 1538 e della significazione di essi per Piero Giacomo Da Toledo. Napoli, Sultzbach, 1538.

De Rosa, R. 1999. Compositional modes in the ash fraction of some modern pyroclastic deposits: their determination and significance. Bulletin of Volcanology 61, 162–173.

Del Nero, F. 1538. Sul terremoto di Pozzuoli, dal quale ebbe origine la Montagna Nuova, nel 1538.

Delli Falconi, M.A. 1538. Dell'incendio di Pozzuoli nel DDXXXVIII, Napoli 1538.

Dellino, P., Isaia, R., La Volpe, L., Orsi, G.. 2001. Statistical analysis of textural data from complex pyroclastic sequences: implications for fragmentation processes of the Agnano-Monte Spina Tephra (4.1 ka), Phlegraean Fields, southern Italy. Bulletin of Volcanology 63, 443–461.

Dellino, P., Kyriakopoulos, K. 2003. Phreatomagmatic ash from the ongoing eruption of Etna reaching the Greek island of Cefalonia. Journal of Volcanology and Geothermal Research 126, 341-345.

Di Carlo, I., Pichavant, M., Rotolo, S., Scaillet, B. 2006. Experimental Crystallization of a High-K Arc Basalt: the Golden Pumice, Stromboli Volcano (Italy) Journal of Petrology, 1-27 10.1093/petrology/egl011.

Di Vito, M.A., Isaia, R., Orsi, G., Southon, J., de Vita, S., D'Antonio, M., Pappalardo, L., Piochi, M. 1999. Volcanism and deformation since 12,000 years at the Campi Flegrei caldera (Italy). Journal of Volcanology and Geothermal Research Volume 91, 221-246.

Dingwell., D. 1998; Recent experimental progress in the physical description of silic magma relavant to explosive volcanism. In: “The physics of explosive volcanic eruptions”. Gilbert, J:S. and Sparks, R.S.J. (eds). Cambridge Univeristy Press.

Doubik, P., Hill, B.E. 1999. Magmatic and hydromagmatic conduit development during the 1975 Tolbachik Eruption, Kamchatka, with implications for hazards assessment at Yucca Mountain, NV Journal of Volcanology and Geothermal Research 91, 43-64.

Dzurisin, D., Lockwood, J. P., Casadevall, T. J., Rubin, M. 1995. The Uwekahuna Ash Member of the Puna Basalt: Product of violent phreatomagmatic eruptions at Kilauea Volcano, Hawaii, between 2800 and 2100 14C years ago, Journal of Volcanology and Geothermal Research 66, 163–184.

Fenn, P.M. 1977. The nucleation and growth of alkali feldspars from hydrous melts. Canadian Mineralogist 15, 135–161.

Folch, A., Marti, J. 1998. The generation of overpressure in felsic magma chambers by replenishment. Earth and Planetary Science Letters 163, 301-314.

Francalanci, L., Bertagnini, A., Mètrich, N., Renzulli, A., Vannucci, R., Landi, P., Del Moro, S., Menna, M., Petrone, C.M., Cardini, I. 2008. Mineralogical, Geochemical and Isotopic Characterization of the Ejecta from the 5 April 2003 Paroxysm at Stromboli, Italy: inferences on the Eruptive Dynamics. In: “ Learning from Stromboli and its 2002-2003 Eruptive Crisis”, Calvari, S., Rosi, M., Ripepe M. (edts) Geophysical Monograph Series 182, American Geophysical Union, 331-345.

Frazzetta, G., La Volpe, L., Sheridan, M.F. 1983. Evolution of the Fossa Cone, Vulcano. Journal of Volcanology and Geothermal Research 17, 329-360.

Freundt, A., Tait SR 1986. The entrainment of high-viscosity magma into low-viscosity magma in erupting conduits. Bulletin of volcanology 48, 325-339.

Fulignati, P., Marianelli, P., Sbrana, A., Guido, L. 1996. The 1944 eruption: overall description. IAVCEI-CEI/CMVD Vesuvius Decade Volcano 1996 Workshop Handbook.

Gardner, C.A., Cashman, K.V., Neal, C.A. 1998. Tephra-fall deposits from the 1992 eruption of Crater Peak, Alaska: implications of clast textures for eruptive processes. Bulletin of Volcanology 59, 537–555.

Grove, T.L., Juster, T.C. 1989. Experimental investigations of low-Ca pyroxene stability and olivine-pyroxene-liquid equilibria at 1-atm in natural basaltic and andesitic liquids Contributions to Mineralogy and Petrology 103, 287-305.

Hammer, J.E., Cashman, K.V., Hoblitt, R.P., Newman, S. 1999. Degassing and microlite crystallization during pre-climactic events of the 1991 eruption of Mt. Pinatubo, Philippines. Bulletin of Volcanology 60, 355–380.

Hammer, J.E., Rutherford, M.J. 2002. An experimental study of the kinetics of decompression-induced crystallization in silicic melt. Journal of Geophysical Research 107, 10.1029/2001JB000281.

Hammer, J.E., Rutherford, M.J. 2003. Petrologic indicators of preeruption magma dynamics Geology 31, 79-82.

Harris, A.J.L., Ripepe, M., Calvari, S., Lodato, L., Spampinato, L. 2008. The 5 April 2003 explosion of Stromboli: timing of eruption dymanics using thermal data. In: “The Stromboli Volcano: An integrated study of the 2002-2003 eruption”. Geophysical Monograph Series 182, American Geophysical Union, 305-316.

Hazlett, RW., Buesh, D., Anderson, J.L., Elan, R., Scandone, R. 1991. Geology failure conditions and implications of seismogenic avalanches of the 1944 eruption at Vesuvius, Italy. Journal of Volcanology Geothermal Research 47, 249-264.

Heiken, G., Wohletz, K.H. 1985. Volcanic Ash. University of California Press, Berkeley, California, 245p.

Higgins, M.D. 2000. Measurement of Crystal Size Distributions. American Mineralogist. 85, 1105-1116.

Horwell, C.J., Sparks, R.S.J., Brewer, T.S., Llewellin, E.W., Williamson, B.J. 2003. Characterization of respirable volcanic ash from the Soufrière Hills volcano, Montserrat, with implications for human health hazards. Bulletin of Volcanology 65, 346–362.

Houghton, B.F., Smith, R.T. 1993. Recycling of magmatic clasts during explosive eruptions: Estimating the true juvenile content of phreatomagmatic volcanic deposits, Bulletin of Volcanology 55, 414– 420.

Houghton, B.F., Wilson, C.J.N. 1989. A vesicularity index for pyroclastic deposits. Bulletin of Volcanology 51, 451–462.

Johnston, D.M., Houghton, B.F., Neall, V.E., Ronan, K.R., Paton, D. 2000. Impact of the 1945 and 1995–96 Ruapehu eruptions, New Zealand: an example of increasing societal vulnerability. Geological Society of American Bulletin 112, 720–726.

Johnston-Lavis, H. J. 1909. The Mechanism of Volcanic Action, being the Opening Address to Section III (Vulcanology) of the International Geographical Congress. Geological Magazine 6, 433-443.

Lejeune, A.M., Richet, P. 1995. Rheology of crystal bearing silicate melts: An experimental study at high viscosities, Journal of Geophysical Research 100, 4215-4229.

Lirer, L., Rolandi, G., Di Vito, M, Mastrolorenzo, G 1987. L'eruzione del Monte Nuovo (1538) nei Campi Flegrei. Bollettino della Società Geologica Italiana 106, 447-460.

Mangan, M., Mastin, L., Sisson, T. 2004. Gas evolution in eruptive conduits: combining insights from high temperature and pressure decompression experiments with steady-state flow modeling. Journal of Volcanology and Geothermal Research, 129, 23-36.

Marchesino, F. 1538. Copia di una lettera di Napoli che contiene li stupendi, et gran pordigi apparsi sopra Pozzolo, Napoli 1538.

Marianelli, P., Sbrana, A., Métrich, N., Cecchetti, A. 2005. The deep feeding system of Vesuvius involved in recent violent strombolian eruptions. Geophysical Research Letters 32, L02306, 10.1029/2004GL021667.

Marsh, B.D. 1988. Crystal size distribution (CSD) in rocks and the kinetics and dynamics of crystallization I. Theory. Contributions to Mineralogy and Petrology 99, 277–291.

Marsh, B.D. 1998. On the Interpretation of Crystal Size Distributions in Magmatic Systems . Journal of Petrology 39, 553–599.

Martel, C., Dingwell, D.B., Spieler, O., Pichavant, M., Wilke, M. 2001. Experimental fragmentation of crystal- and vesicle-bearing silicic melts. Bulletin of Volcanology 63, 398–405.

Marzocchi, W., Sandri, S., Gasparini, P., Newhall, C:, Boschi, E. 2004. Quantifying probabilities of volcanic events: The example of volcanic hazard at Mount Vesuvius. Journal of Geophysical Research 109, B11201, 10.1029/2004JB003155.

Mastrolorenzo, G:, Munno, R:, Rolandi, G. 1993. Vesuvius 1906: a case study of a paroxysmal eruption and its relation to eruption cycles Journal of Volcanology and Geothermal Research 58, 217-237.

Mc Nutt, S.R. 1996. Seismic monitoring and eruption forecasting of volcanoes: a review of the state-of-the-art and case histories. In: Scarpa R, Tilling R (eds) Monitoring and mitigation of volcano hazards, Springer, Berlin Heidelberg New York, 99–146.

McPhie, J., Walker, G.P.L., Christiansen R.L. 1990. Phreatomagmatic and phreatic fall and surge deposits from explosions at Kilauea volcano, Hawaii, 1790 a.d.: Keanakakoi Ash Member Bulletin of Volcanology 52, 334-354.

Mercalli, G. 1906. La grande eruzione vesuviana cominciata il 4 aprile 1906. Memorie Pontificie dell' Accademia Romana e dei Nuovi Lincei 24, 1-34.

Mercalli, G. 1907. I vulcani attivi della terra. U. Hoepli Press, Milano, 1-422.

Métrich, N., Bertagnini, A., Di Muro, A. 2010. Conditions of Magma Storage, Degassing and Ascent at Stromboli: New Insights into the Volcano Plumbing System with Inferences on the Eruptive Dynamics. Journal of Petrology 51, 603-626.

Métrich, N., Bertagnini, A., Landi, P., Rosi, R., Belhadj O. 2005. Triggering mechanism at the origin of paroxysms at Stromboli (Aeolian Archipelago, Italy): The 5 April 2003 eruption. Geophysical Research Letters 32, L10305, 10.1029/2004GL022257, 2005.

Métrich, N., Rutherford, M.J. 1998. Low Pressure Crystallization Paths of H2O-Saturated Basaltic-Hawaiitic Melts from Mt Etna: Implications for Open-System Degassing of Basaltic Volcanoes - Thermochemical and dynamical inferences. Geochimica et Cosmochimica Acta 62, 1195-1205.

Morrissey, M.M., Mastin, L.G. 2000. Vulcanian eruptions. In: Sigurdsson H (ed) Encyclopedia of volcanoes. Academic, San Diego, 463-475.

Morrissey, M.M., Zimanowski, B., Wohletz, K., Büttner, R. 2000. Phreatomagmatic fragmentation. In: Sigurdsson H (ed) Encyclopedia of volcanoes. Academic, San Diego, 431-445.

Nairn, I.A., Self, S. 1978. Explosive eruptions and pyroclastic avalanches from Ngauruhoe in February 1975. Journal of Volcanology and Geothermal Research 3, 39-60.

Navon, O., Chekhmir, A., Lyakhovsky, V. 1998. Bubble growth in highly viscous melts: theory, experiments, and autoexplosivity of dome lavas Earth and Planetary Science Letters 160, 763-776.

Neri, A., Aspinall, W.P., Cioni, R., Bertagnini, A., Baxter, P.J., Zuccaro, G.., Andronico, D., Barsotti, S., Cole, P.D., Esposti Ongaro, T., Hincks, T.K., Macedonio, G., Papale, P., Rosi, M., Santacroce, R., Woo, G. 2008. Developing an Event Tree for probabilistic hazard and risk assessment at Vesuvius Journal of Volcanology and Geothermal Research 178, 397-415.

Orsi, G., D'Antonio, M., de Vita, S., Gallo, G. 1992. The Neapolitan Yellow tuff, a large-magnitude trachytic phreatoplinian eruption: eruptive dynamics, magma withdrawal and caldera collapse. Journal of Volcanology and Geothermal Research 53,275-287.

Orsi, G., De Vita, S., Di Vito, M. 1996. The restless, resurgent Campi Flegrei nested caldera (Italy): constraints on its evolution and configuration. Journal of Volcanology and Geothermal Research 74, 179-214.

Papp, K.R., Dean, K.G., Dehn, J. 2005. Predicting regions susceptible to high concentrations of airborne volcanic ash in the North Pacific region. Journal of Volcanology and Geothermal Research 148, 295-314.

Pappalardo, L., Civetta, L., D'Antonio, M., Deino, A., Di Vito, M., Orsi, G., Carandente, A., de Vita, S., Isaia, R., Piochi, M. 1999. Chemical and Sr-isotopical evolution of the Phlegraean magmatic system before the Campanian Ignimbrite and the Neapolitan Yellow Tuff eruptions. Journal of Volcanology and Geothermal Research 91, 141-166.

Parascandola, A. 1946. Il Monte Nuovo e il Lago Lucrino. Bollettino della Società dei Naturalisti in Napoli, vol. LV, 1944-1946.

Patanè, D., Chiarabba, C., Ornalla, C., De Gori, P., Moretti, M., Boschi, E. 2002. Tomographic images and 3D earthquake locations of the seismic swarm preceding the 2001 Mt. Etna eruption: Evidence for a dyke intrusion. Geophysical Research Letters 29, 10.1029/2001GL014391.

Perret, F.A. 1924. The Vesuvius eruption of 1906. Carnegie Institute Washington Publication 339, 151p.

Pistolesi, M., Rosi, M., Pioli, L., Renzulli, A., Bertagnini, A., Andronico, D. 2008. The paroxysmal event and its deposits. In: “The Stromboli Volcano: An integrated study of the 2002-2003 eruption”. Geophysical Monograph Series 182, American Geophysical Union., 317-316.

Polacci, M., Papale, P., Rosi, M. 2001. Textural heterogeneities in pumices from the climactic eruption of Mount Pinatubo, 15 June 1991, and implications for magma ascent dynamics. Bulletin of Volcanology 63, 83–97.

Pompilio, M., Trigila, R., Zanon, V. 1998. Melting experiments on Etnean lavas: the calibration of an emphirical geothermometer to estimate the eruptive temperature, Acta Vulcanologica 10, 67-75.

Porzio, S. 1551. De conflagrazione agri puteolani Simoni Portii Epistola. Napoli, Sultzbach, 1538, Floreantiae.

Ripepe, M., Harris, A.J.L. 2008. Dynamics of the 5 April 2003 explosive paroxysm observed at Stromboli by a near-vent thermal, seismic and infrasonic array. Geophysical Research Letters 35, L07306, 6 PP, 10.1029/2007GL032533.

Rittmann, A. 1931. Der Ausbruch des Stromboli am 11. September 1930. Zeitschrift für Vulkanologie 14, 47-77.

Rojas-Ramos, M., Catalan-Vazques, M., Martin-Del Pozzo, A.L., Garcia-Ojeda, E., Villalba-Caloca, J., Perez-Neria, J., 2001. A seven months prospective study of the respiratory effects of exposure to ash from Popocatepetl volcano, Mexico. Environmental Geochemistry and Health 23, 383–396.

Rolandi, G., Maraffi, S., Petrosino, P., Lirer, L. 1993a. The Ottaviano eruption of Somma-Vesuvio (8000 y. B.P.): a magmatic alternating fall and flow-forming eruption. Journal of Volcanology and Geothermal Research 58, 43-65.

Rolandi, G., Mastrolorenzo, G., Barrella, A.M., Borrelli, A., 1993b. The Avellino plinian eruption of Somma-Vesuvius (3760 y. B.P.): the progressive evolution from magmatic to hydromagmatic style. Journal of Volcanology and Geothermal Research 58, 67-88.

Rosi, M., Bertagnini, A., Harris, A.J.L., Pioli, L., Pistolesi, M., Ripepe M. 2006. A case history of paroxysmal explosion at Stromboli: Timing and dynamics of the April 5, 2003 event. Earth and Planetary Science Letters 243, 594–606.

Rosi, M., Landi, P., Polacci, M., Di Muro, A., Zandomeneghi, D. 2004. Role of conduit shear on ascent of the crystal-rich magma feeding the 800-year-b.p. Plinian eruption of Quilotoa Volcano (Ecuador). Bulletin of Volcanology 66, 307-321.

Rosi, M., Principe, C., Vecci, R.: 1993, The 1631 Vesuvius eruption. A reconstruction based on historical and stratigraphical data, Journal of Volcanology and Geothermal Research 58, 151–182.

Rosi, M., Santacroce, R., 1984. Volcanic hazard assessment in the Phlegraean Fields: a contribution based on stratigraphic and historical data. Bulletin of Volcanology 47, 359-370.

Rutherford, M.J., Devine, J. 2003. Magmatic Conditions and Magma Ascent as Indicated by Hornblende Phase Equilibria and Reactions in the 1995–2002 Soufrière Hills Magma. Journal of Petrology 44, 1433-1453.

Sabatini, V. 1906. L'eruzione vesuviana dell'Aprile 1906. Boll R Com Geol It 3.

Sandri, L., Marzocchi, W., Maccarelli, L. 2004. A new perspective in identifying the precursory patterns of eruptions. Bulletin of Volcanology 66, 263–275.

Santacroce, R. 1987. Somma Vesuvius. CNR Quaderni della Ricerca Scientifica 114, 251p.

Scheu, B., Kueppers, U., Mueller, S., Spieler, O., Dingwell, D.B. 2008. Experimental volcanology on eruptive products of Unzen volcano. Journal of Volcanology and Geothermal Research 175, 110-119.

Scollo, S., Del Carlo, P., Coltelli, M. 2007. Tephra fallout of 2001 Etna flank eruption: Analysis of the deposit and plume dispersion. Journal of Volcanology and Geothermal Research, 160, 147–164.

Self, S., Wilson, L., Nairm, I.A. 1979. Vulcanian eruption mechanisms. Nature 277, 440-443.

Sisson, T.W., Grove, T.L. 1993. Experimental investigations of the role of H2O in calc-alkaline differentiation and subduction zone magmatism. Contributions to Mineralogy and Petrology 113, 143-166.

Sparks, R.S.J. 1997. Causes and consequences of pressurization in lava dome eruptions. Earth and Planetary Science Letters. 150, 177–189.

Taddeucci, J., Pompilio, M., Scarlato, P. 2002. Monitoring the explosive activity of the July-August 2001 eruption of Mt. Etna (Italy) by ash characterization. Geophysical Research Letters 29, 10.1029/2001GL014372.

Taddeucci, J., Pompilio, M., Scarlato, P.G. 2004a. Conduit processes during the July–August 2001 explosive activity of Mt. Etna (Italy): inferences from glass chemistry and crystal size distribution of ash particles. Journal of Volcanology and Geothermal Research 137, 33-54.

Taddeucci, J., Spieler, O., Kennedy, B., Pompilio M., Dingwell, D.B., Scarlato, P. 2004b. Experimental and analytical modeling of basaltic ash explosions at Mount Etna, Italy, 2001. Journal of Geophysical Research 109, B08203, 10.1029/2003JB002952.

Tait, S.R., Vergniolle, S., Jaupart, C. 1989. Pressure, gas content and eruption periodicity of a shallow crystallizing magma chamber. Earth and Planetary Science Letters 92, 107–123.

Trigila, R., Spera, F.J., Aurisicchio, C. 1990. The 1983 Mount Etna eruption: thermochemical and dynamical inferences. Contribution to Mineralogy and Petrology 104, 594–608.

Vergniolle, S., Brandeis, G. 1996. Strombolian explosions 1. A large bubble breaking at the surface of a lava column as a source of sound, Journal of. Geophysical Research 101, 20433–20447.

Walker, G.P.L. 1973. Explosive volcanic eruptions – a new classification scheme. Geologische Rundschau 62, 431–446.

Wilson, L., Walker, G.P.L 1987. Explosive volcanic-eruptions, 6, Ejecta dispersal in plinian eruptions- The control of eruption conditions and atmospheric properties. Geophysical Journal of the Royal Astronomical Society 89, 657-679.

Wholetz, K.H. 1986. Mechanisms of hydrovolcanic pyroclast formation: grain-size, scanning electron microscopy, and experimental studies. Journal of Volcanology and Geothermal Research 17, 31–63.

Zimanowsky, B., Fröhlich, G., Lorenz, V. 1991. Quantitative experiments on phreatomagmatic explosions. Journal of Volcanology and Geothermal Research Volume 48, 341-358.

Zimanowsky, B., Wohletz, K.H., Dellino, P., Büttner, R. 2003. The volcanic ash problem. Journal of Volcanology and Geothermal Research 122, 1-5.

Zuccaro, G., Cacace, F., Spence, R.S., Baxter, P.J. 1999. Impact of explosive eruption scenarios at Vesuvius. Journal of Volcanology and Geothermal Research 178, 416–453.