Bull Volcanol (2011) 73:471–477
DOI 10.1007/s00445-010-0425-0

SHORT SCIENTIFIC COMMUNICATION

Ash erupted during normal activity at Stromboli (Aeolian Islands, Italy) raises questions on how the feeding system works

Claudia D'Oriano · Antonella Bertagnini · Massimo Pompilio

Received: 25 August 2010 / Accepted: 17 October 2010 / Published online: 17 November 2010

Abstract Ash fallout collected during 4 days of sampling at Stromboli confirms that a crystal-rich (HP) degassed magma erupts during the Strombolian explosions that are characteristic of the normal activity of this volcano. We identified 3 different types of juvenile ash fragments (fluidal, spongy and dense), which formed through different mechanisms of fragmentation of the low-viscosity, physically heterogeneous (in terms of the size and spatial distribution of bubbles) shoshonitic magma. A small amount (less than 3 vol%) of volatile-rich magma with low porphyricity (LP), erupted as highly vesicular ash fragments, has been collected, together with the HP magma, during normal strombolian explosions. Laboratory experiments and the morphological, textural and compositional investigations of ash fragments reveal that the LP ash is fresh and not recycled from the last paroxysm (15 March 2007). We suggest that small droplets of LP magma are dragged to the surface by the time-variable but persistent supply of deep derived CO_2-rich gas bubbles. This coupled ascent of bubbles and LP melts is transient and does not perturb the dynamics of the HP magma within the shallow reservoir. This finding provides a new perspective on how the Stromboli volcano works and has important implications for monitoring strategies.

Editorial responsibility: J.D.L. White

C. D'Oriano (✉) · A. Bertagnini · M. Pompilio
Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Pisa,
Via della Faggiola 32,
56126, Pisa, Italy
e-mail: doriano@pi.ingv.it

Keywords Stromboli · Strombolian activity · Ash · Paroxysms · Clast morphology · Glass chemistry · Bubble ascent

Introduction

Normal activity at Stromboli consists of continuous, "passive" streaming of gas from the crater area and active degassing ("puffing") of small, discrete bursts of gas every 1–2 s, punctuated by mild explosions at a frequency of about 13 events/h (Ripepe et al. 2008). Explosions can be dominated by coarse ballistic particles (Type 1 eruptions of Patrick et al. 2007) or consist of an optically opaque ash-rich plume with (Type 2a) or without (Type 2b) large numbers of coarse ejecta and gas thrust (Type 2 eruptions).

Such explosions tap a crystal-rich, degassed magma residing within the upper part of the plumbing system. Typical products are dark, low-vesicular scoriae rich in millimeter-sized crystals (50 vol %) of plagioclase, pyroxene and olivine (magma with High Porphyricity–HP) (Bertagnini et al. 2008).

More violent explosive sequences occur sporadically. The most powerful eruptions among these throw incandescent bombs and meter-sized ballistic lithic blocks up to several kilometers from the craters, sometimes affecting inhabited areas. These paroxysms also produce wind-advected lapilli that fall on the flanks of the volcano down to the sea. Such larger explosive events are related to the ascent and violent emission of volatile-rich, nearly aphyric magma erupted as golden pumices (magma with Low Porphyricity-LP).

At Stromboli, as for other volcanoes, the texture and composition of volcanic products closely reflect magmatic and eruptive processes (Taddeucci et al. 2002; Cioni et al. 2008; Houghton and Gonnermann 2008). The ability to systematically sample freshly erupted bombs is strongly controlled by the access to the summit during explosive activity. In contrast, fine tephra is easily collected even at a distance and is a good proxy for the state of the magmatic system, providing useful information on ongoing magmatic and volcanic processes and heralding shifts between eruptive styles. The only critical limitation is that fine tephra cannot provide information on vesicle and crystal populations coarser than the clast size. In addition in a volcano characterised by persistent activity, weathering, alteration and recycling within the crater or in the upper part of the conduit can mask primary magmatic information. To address this issue, we initiated a study on the textural and compositional features of ash erupted at Stromboli during normal explosive activity in order to define its characteristic features and identify which are the juvenile components and which primary magmatic signatures are preserved.

Sampling and methods

Ash sampling was carried out for 4 days on the summit of Stromboli in September 2008. Ash erupted during 18 distinct explosions was collected in the Pizzo area (Fig. 1). Collected ash mainly represents the products of type-2a and -2b explosions, as type-1 explosions produced only coarse ejecta which fell close to the vents. Wind speeds during sampling were low, thus the collected ash samples can be considered fully representative of fallout material produced by volcanic explosions and not recycled from the ground.

After a preliminary examination of all the samples, 5 specimens representative of activity at two different craters (SW and NE) on three different days were selected for detailed characterisation following the analytical procedure proposed by Cioni et al. (2008). After sieving, about 30 juvenile fragments in the 0.5–1 mm size range were randomly hand-picked from each studied sample and then mounted with double-sided adhesive tape on a glass slide. Single ash fragments were examined and photographed under a Scanning Electron Microscope (SEM) to classify clast types on the basis of their external morphology and shape. Glass slides were then embedded in epoxy resin, sectioned and polished for textural (crystal and vesicle size, shape and contents) and compositional analyses of the groundmass (glasses and minerals). Major elements in glasses were determined at INGV-Rome with a Jeol-JXA8200 EMP equipped with five wavelength-dispersive spectrometers, using 15 kV accelerating voltage and 10 nA beam current. Analyses were performed with a defocused electron beam of 5 µm and a counting time of 5 s on background and 15 s on peak. Glasses were also analysed using EDAX DX4 EDS spectrometer linked to Philips XL30 SEM at the DST-Pisa, at an accelerating voltage of 20 kV, beam current of 0.1 nA in raster mode using 5× 5 µm windows. The analytical error is less than 5 wt%.

Texture and components

A classification of products erupted during normal Strombolian activity at Stromboli was proposed by Lautze and Houghton (2005, 2007) based on analysis of lapilli-sized scoriae. These authors identified three different types of juvenile ejecta on the basis of bubble and crystal contents. The present study identified at least five different types of ash fragments, which in part correspond to those described by Lautze and Houghton (2007). The following is a description of the different types of ash, here listed in order of abundance:

a. Fluidal (10–62 vol%). Particles are characterized by smooth, glassy external surfaces varying in shape from equant to tear-shaped. The groundmass consists of honey-coloured, variably vesicular glass with rare microphenocrysts. Vesicles are elongate following the external shape of the clast. Pele's hairs fall in this category (Fig. 2);
b. Spongy (28–50 vol%). These clasts are generally equant. The rough, curved external surface of the clasts was generally produced by the rupture of randomly oriented spherical-ovoid bubbles of the same size; the groundmass consists of honey-coloured glass containing rare microphenocrysts.
c. Dense (7–30 vol%). Fragments are equant and angular, and are characterised by the presence of a few large bubbles with thick walls. The groundmass is glassy and contains a few microphenocrysts.
d. "Recycled"(3–14 vol%). Clasts in this broad category have external shapes comparable to those of clasts in the previously described ash types, but their external surfaces are less shiny. SEM observation revealed the presence of oxides and pyroxene crystallites growing on the external surface. The groundmass varies from hypocrystalline to holocrystalline. Some grains appear cryptocrystalline under the optical microscope due to the great abundance of oxide microlites.
e. Lithics (2–7 vol%). The overall shape varies from angular to sub-rounded. These clasts sometimes show a red, oxidised external surface or a greyish, dull appearance. The groundmass varies from glassy with incipient palagonitization (red-orange glass) to crystal-rich (up to holocrystalline).

Fig. 1 A) Map of Italy showing the location of Stromboli and the morphology of Stromboli Island; B) Digital elevation model of the Stromboli summit (courtesy of M. Marsella) showing the crater terrace in 2009 and the collection points (red stars); C) Photo of the crater terrace as it appeared during ash collection in September 2008; D) Typical ash-rich explosion (Type 2a) from the SW crater in September 2008

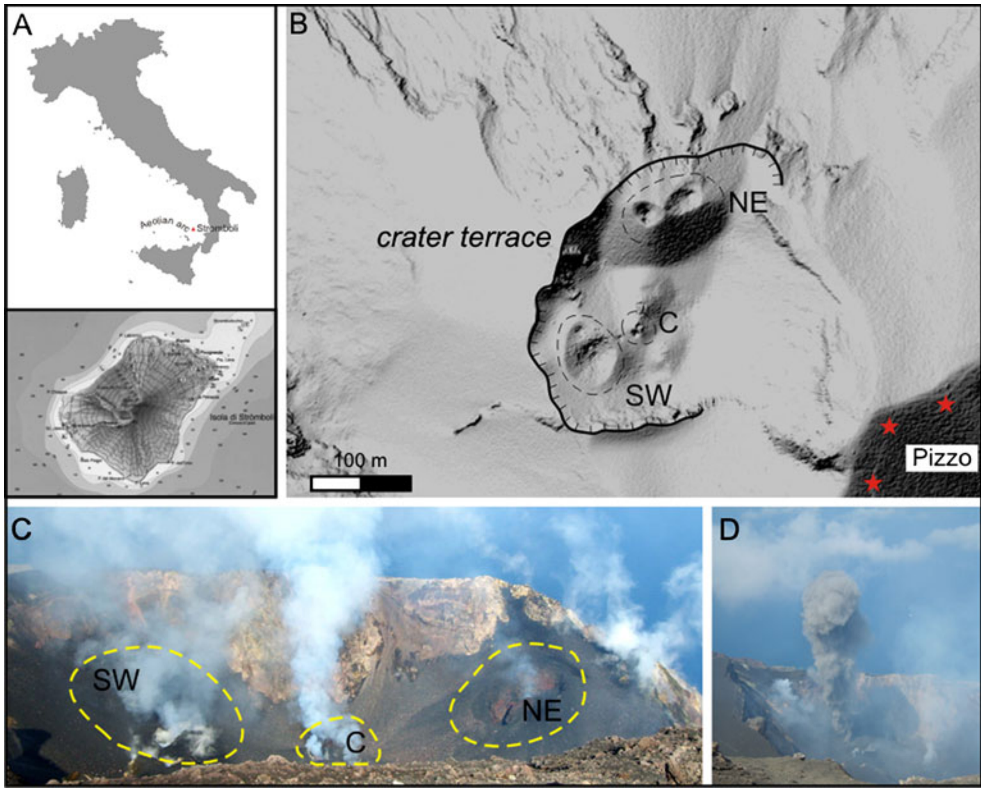

Fig. 2 Stereomicroscopic, back-scattered and secondary images, respectively, of the different types of juvenile ash collected in September 2008. Bars correspond to 100 μm

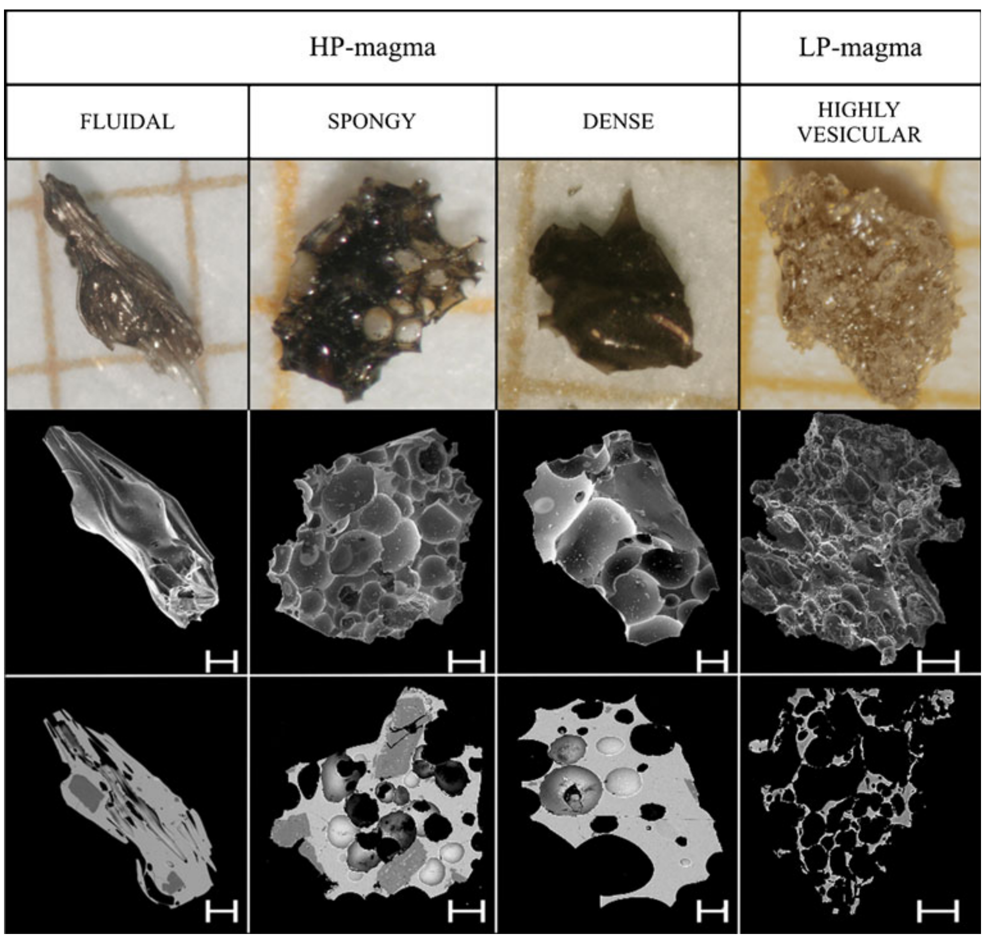

Table 1 Major elements concentration in glasses of fluidal, spongy, dense and highly vesicular ash

Type	fluidal	fluidal	fluidal	fluidal	fluidal	fluidal	fluidal	spongy	spongy	spongy	spongy	spongy	dense	dense	dense	dense
Sample#_Clast#	EST4_2	EST4_11	EST4_12	EST1_30	EST1_18	EST1_20	EST1_2	EST14_22	EST14_6	EST1_27	EST1_25	EST1_5	EST14_19	EST14_4	EST14_9	EST1_31
SiO_2	52.96	53.1	53.08	53.01	53.29	52.91	53.07	52.98	52.95	52.99	53.17	53.26	54.93	53.69	53.15	53.16
TiO_2	2.00	1.76	1.77	1.71	1.68	1.73	1.66	1.77	1.74	1.93	1.77	1.60	1.90	1.68	1.72	1.75
Al_2O_3	16.04	15.93	15.82	16.05	15.84	16.03	15.97	15.8	15.80	15.90	16.05	15.75	16.36	16.08	16.00	16.06
FeO	9.76	9.66	9.81	9.94	9.86	9.75	9.95	9.71	9.84	9.79	9.82	9.97	10.14	9.69	9.65	9.77
MnO	0.32	bdl	0.16	0.09	0.10	0.16	0.18	0.12	0.07	0.11	bdl	0.19	0.07	0.09	0.15	0.26
MgO	3.50	3.45	3.54	3.46	3.53	3.57	3.53	3.52	3.61	3.57	3.63	3.55	3.80	3.50	3.63	3.61
CaO	7.44	7.53	7.41	7.41	7.41	7.47	7.44	7.40	7.67	7.38	7.59	7.39	7.29	7.18	7.49	7.23
Na_2O	3.32	3.50	3.59	3.23	3.36	3.40	3.33	3.14	3.43	3.43	3.16	3.36	1.37	3.09	3.21	3.32
K_2O	4.13	4.29	4.16	4.25	4.15	4.20	4.21	4.67	4.30	4.24	4.04	4.32	3.37	4.20	4.20	4.21
P_2O_5	0.41	0.56	0.57	0.64	0.60	0.56	0.55	0.76	0.44	0.46	0.57	0.49	0.55	0.65	0.64	0.51
S	0.03	0.04	bdl	0.06	0.02	0.02	bdl	bdl	bdl	0.03	0.05	bdl	0.06	0.02	0.02	bdl
Cl	0.08	0.18	0.10	0.15	0.16	0.21	0.11	0.13	0.14	0.17	0.14	0.11	0.16	0.13	0.14	0.12
total	99.99	100	100.01	100	100	100.01	100	100	99.99	100	99.42	99.99	100	100	100	100
Type	dense	dense	dense	dense	highly vesicular	highly vesicular	highly vesicular	highly vesicular	highly vesicular	highly vesicular	highly vesicular	highly vesicular	highly vesicular	highly vesicular	highly vesicular	
Sample#_Clast#	EST1_17	EST1_17	EST14_25	EST1_4	EST8_1	EST8_2	EST8_3	EST15_1	EST15_2	EST15_3	EST15_4	EST3_1	EST3_2	ESt3_3	EST3_4	
SiO_2	52.70	52.42	53.00	52.81	49.19	48.01	49.59	48.64	49.56	48.22	48.87	49.40	48.48	49.31	49.20	
TiO_2	1.84	1.59	1.85	1.87	0.83	0.88	1.24	0.96	1.01	0.80	0.77	0.76	1.06	1.07	1.02	
Al_2O_3	15.73	15.76	16.09	15.93	16.69	16.75	16.85	17.52	17.28	17.48	17.74	17.90	17.76	17.84	17.40	
FeO	9.45	10.04	9.88	10.00	7.27	7.66	7.71	7.94	8.10	8.05	8.25	7.98	8.27	8.16	8.20	
MnO	0.24	bdl	0.12	0.14	0.15	0.16	0.20	0.17	0.19	0.22	0.19	0.13	0.18	0.24	0.08	
MgO	3.32	3.58	3.63	3.57	6.53	6.37	5.60	6.50	6.40	6.35	6.40	6.25	6.10	6.11	6.19	
CaO	6.91	6.6	7.55	7.56	12.21	12.05	10.96	11.92	11.89	12.28	12.30	11.85	11.74	11.92	11.94	
Na_2O	3.93	3.87	2.88	3.00	2.63	2.65	2.76	2.68	2.45	2.35	2.42	2.36	2.49	2.40	2.48	
K_2O	5.26	5.44	4.21	4.28	2.14	2.32	2.48	1.90	1.94	1.96	1.95	2.13	2.07	2.02	2.01	
P_2O_5	0.50	0.50	0.59	0.60	0.63	0.60	0.73	0.60	0.57	0.47	0.60	0.54	0.65	0.49	0.60	
S	bdl	bdl	bdl	0.04	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
Cl	0.12	0.19	0.19	0.21	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	
total	100	99.99	99.99	100.01	98.26	97.45	98.13	98.82	99.40	98.19	99.48	99.30	98.79	99.57	99.11	

bdl below detection limit, *nd* not determined

f. Highly vesicular (0–3 vol%). Fragments have a pumice-like appearance; the external shape of clasts is similar to that of the spongy components. The vesicles vary in size and have very thin walls. The groundmass consists of light coloured (under the microscope) glass and lacks microlites.

Glass composition

Textural features suggest that clasts belonging to categories A–C and F underwent fast cooling (quenching) after fragmentation; they therefore provide a snapshot of the magma at the top of the conduits that feeds the Strombolian explosions. For this reason, only microlite-free matrix glasses were analysed, and their compositions (Table 1) were compared with those of glasses in bombs and lapilli erupted during the last 20 years (Fig. 3). Figure 3 shows that glasses analysed in fluidal, spongy and dense clasts overlap the compositional fields of the glasses in the products of normal activity and in the HP products erupted during paroxysms (e.g. 5 April 2003). In particular, glasses in the dense clasts show the lowest CaO/Al_2O_3 values, possibly reflecting a small amount of microlite crystallisation (feldspars). Conversely, highly vesicular shards plot in and extend the compositional field of glasses analysed in the LP products of paroxysms occurring after 2003.

The composition of glass in the highly vesicular clasts almost matches that of the glassy ash erupted from the summit craters before and after the 5 April 2003 paroxysm (Schiavi et al. 2009), although the latter is slightly more evolved.

Neither fluidal, spongy or dense clasts, nor highly vesicular shards show intermediate compositions such as those measured by Landi et al. (2008b) and Andronico et al. (2008) in the products of the "intermediate" explosion occurred on 9 January 2005.

Compositional data indicate that clasts A–C are on the whole fully representative of the common HP magma stored in the shallow portion of the plumbing system and involved in normal Strombolian explosions. Sampled highly vesicular clasts unequivocally represent the LP magma, until now recorded only in paroxysms (with the exception of the unusual ash explosion that predated the 5 April 2003 paroxysms; Schiavi et al. 2009).

Discussion and conclusions

The texture and composition of HP clasts confirm that the HP magma is, on the whole, chemically homogeneous and that textural and slight compositional differences are linked to both the inhomogeneous distribution of bubbles in the very shallow part of the conduit (~10 m) and the mechanism of magma fragmentation (ductile or brittle) and quenching, which is in turn controlled by rheological parameters such as temperature and viscosity. This is in agreement with the previous study by Lautze and Houghton (2007), who showed that the presence of different lapilli-sized scoriae was related to small-scale fluctuations in magma properties resulting from a combination of ongoing vesicle migration and growth, and mingling between mature degassed magmas and new ascending melts.

The identification of highly vesicular clasts in the sampled ash provides evidence for the first time that parcels of LP magma may be present within the conduit during normal Strombolian activity also.

To exclude the possibility that the highly vesicular clasts derived from recycling of products erupted during the paroxysm which preceded our sampling (15 March 2007), we carried out some laboratory experiments in which natural LP ashes were exposed to high (700–1000°C) temperatures and variable oxidising conditions (in air or in vacuum). These experiments expand upon those performed in the field by Spadaro et al. (2002), who investigated the effects of exposing fresh basaltic glasses to the gases (H_2O with minor abundances of SO_2, CO_2, HCl and HF) in one of the Etnean active craters at low temperatures (<10°C). Spadaro et al. showed that the morphological and chemical

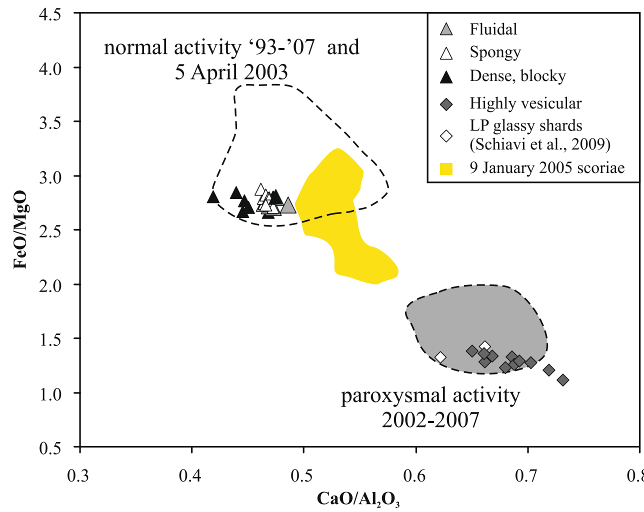

Fig. 3 CaO/Al_2O_3 vs FeO/MgO in matrix glasses of: the ash collected during the sampling experiment (triangles); LP glassy shards analysed by Schiavi et al. 2009 (diamond). Dashed area comprises the composition of matrix glass in the scoriae erupted during the intense 9 January 2005 explosion (Landi et al. 2008b; Andronico et al. 2008). Gray field: composition of matrix glass in pumices derived from LP-magma erupted during paroxysmal activity occurred after 2003 (Landi et al. 2006; 2008a; Métrich et al. 2010); white field: composition of matrix glass in scoriae derived from HP-magma and lava erupted during normal activity since 1993 (Landi et al. 2006; 2008a)

transformation of basaltic glasses becomes significant within a few hours of exposure to volcanic gases, whereas our experiments reveal that high temperatures (1000°C) give rise to extensive groundmass crystallisation and incipient sintering after just 1 hour. Similarly, exposure to lower temperatures (700–750°C) induces the discoloration of clasts: their surface becomes orange-red (in air) or dull grey (under a vacuum).

Since the highly vesicular fragments in our samples have distinctive shiny surfaces and show no evidence of groundmass recrystallization or sintering, we conclude that they represent a fresh, newly erupted LP magma.

This new finding provides important insight into how the feeding system of the volcano works and raises two main questions:

i) is this a sporadic occurrence or a normal feature of persistent activity?
ii) how do volatile-rich parcels of deep magma rise through a crystal-rich body without significant mixing?

After the finding of an LP component in our samples, we carried out a preliminary, though not systematic, survey of ash sampled in the last 20 years during normal Strombolian activity. This has revealed, in some cases the occurrence of few highly vesicular LP-like clasts; however, the lack of a rigorous protocol for ash collection, as adopted during our sampling, does not allow us to exclude that pyroclasts were reworked by the wind during past sampling.

Parcels of LP magma not erupted during a paroxysm were also observed in the products of the discrete explosions occurring in March 2003, when the shallow plumbing system was reactivated after the crater collapse at the end of December 2002. These LP juvenile ashes were investigated in-situ by Schiavi et al. (2009), who proposed that they heralded the arrival of the large volume of LP magma erupted during the 5 April 2003 paroxysm.

In 2008 there was no paroxysm, and summit activity provided no evidence of the upwelling of a deep-seated magma (e.g. no lava overflow or increase in the number and intensity of explosions). The first LP pumices erupted during an explosive episode only 8 months later (Cristaldi 2009).

Assuming that there is no new significant input of magma, we suggest that these LP parcels are associated with small, deep bubble plumes that reach the surface without significantly interacting with the upper convective HP magma body. In this situation, bubble trails and LP melts behave locally as closed systems, reaching a buoyancy threshold that favours their ascent. This is in agreement with both the time-variable but persistent supply of CO_2-rich gas bubbles from depth, as recently revealed by geochemical monitoring (Aiuppa et al. 2010a) during normal Strombolian activity, and the deep provenance of some gas slugs (Burton et al. 2007). We believe that this coupled ascent of bubble trails and LP melts is transient, very small in volume and does not perturb the dynamics of the HP magma within the reservoir. A similar process but involving larger quantities of both gases and LP magma leads to extensive HP-LP syn-eruptive mingling, possibly producing a paroxysm.

In order to assess the abundance of LP ash component and their persistence over time during normal Strombolian activity, this preliminary set of data should be expanded by further systematic and accurate sampling and investigation. In conclusion, special attention should be paid to compare products erupted during the normal state of activity with those emitted in periods in which geophysical and geochemical anomalies highlight perturbations in the steady-state of the volcano (e.g. prior to the 2007 paroxysm, Aiuppa et al. 2010b). This information would provide new insight into how the Stromboli volcano works, with important implications for monitoring strategies.

Acknowledgments We are indebted to A. Aiuppa for constructive criticisms and to B.F. Houghton for the stimulating review and his noble forgiving character. We thanks M. Marsella for providing digital elevation model of Stromboli and A. Cavallo for technical assistance in EMP analyses. C.D. was funded by MIUR project: Advancing Interdisciplinary Research Platform on Volcanoes and Earthquakes (AIRPLANE). This work was supported by the Project V2-Paroxysm 2007–2009 INGV-DPC agreement.

References

Aiuppa A, Bertagnini A, Métrich N, Moretti R, Di Muro A, Liuzzo M, Tamburello G (2010a) A model of degassing for Stromboli volcano. Earth Planet Sci Lett 295:195–204

Aiuppa A, Burton M, Caltabiano T, Giudice G, Guerrieri S, Liuzzo M, Murè F, Salerno G (2010b) Unusually large magmatic CO2 gas emissions prior to a basaltic paroxysm. Geophys Res Lett. doi:10.1029/2010GL043837

Andronico D, Corsaro RA, Cristaldi A, Polacci M (2008) Characterizing high energy explosive eruptions at Stromboli volcano using multidisciplinary data: an example from the 9 January 2005 explosion. J Volcanol Geotherm Res 176:541–550

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, Inguaggiato S, Puglisi G, Ripepe M, Rosi M (eds) The Stromboli Volcano: An Integrated Study of the 2002–2003 Eruption: American Geophysical Union Monograph Series n. 182

Burton M, Allard P, Muré F, La Spina A (2007) Magmatic gas composition reveals the source depth of slug-driven strombolian explosive activity. Science 317:227–230

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

Cristaldi A (2009) Rapporto sull'evento esplosivo dello Stromboli del giorno 03/05/2009 ripreso dalle telecamere di sorveglianza. Internal report n° UFVG2009/018, INGV, Sezione di Catania, Italy, at http://www.ct.ingv.it/Report

Houghton BF, Gonnermann HM (2008) Basaltic explosive volcanism: constraints from deposits and models. Chem Erde 68:117–140

Landi P, Francalanci L, Pompilio M, Rosi M, Corsaro RA, Petrone CM, Nardini I, Miraglia L (2006) The December 2002–July 2003 effusive event at Stromboli volcano, Italy: insights into the shallow plumbing system by petrochemical studies. J Volcanol Geotherm Res 155:263–284

Landi P, Corsaro RA, Francalanci L, Civetta L, Miraglia L, Pompilio M, Tesoro R (2008a) Magma dynamics during the 2007 Stromboli eruption (Aeolian Islands. Italy): Mineralogical, geochemical and isotopic data. J Volcanol Geotherm Res 182:255–268

Landi P, Métrich N, Bertagnini A, Rosi M (2008b) Recycling and "re-hydration" of degassed magma inducing transient dissolution/crystallization events at Stromboli (Italy). J Volcanol Geotherm Res 174:325–336

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

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

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. J Petrol 3:603–626

Patrick MR, Harris AJL, Ripepe M, Dehn J, Rothery DA, Calvari S (2007) Strombolian explosive styles and source conditions: insights from thermal (FLIR) video. Bull Volcanol 69:769–784

Ripepe M, Delle Donne D, Harris A, Marchetti E, Ulivieri G (2008) Dynamics of Strombolian activity. In: Calvari S, Inguaggiato S, Puglisi G, Ripepe M, Rosi M (eds) The Stromboli Volcano: An Integrated Study of the 2002–2003 Eruption: American Geophysical Union Monograph Series n. 182

Schiavi F, Kobayashi K, Moriguti T, Nakamura E, Pompilio M, Tiepolo M, Vannucci R (2009) Degassing, crystallization and eruption dynamics at Stromboli: trace element and lithium isotopic evidence from 2003 ashes. Contrib Mineral Petrol. doi:10.1007/s00410-009-0441-2

Spadaro FR, Lefèvre RA, Ausset P (2002) Experimental rapid alteration of basaltic glass: implications for the origins of atmospheric particulates. Geology 30:671–674

Taddeucci J, Pompilio M, Scarlato P (2002) Monitoring the explosive activity of the July–August 2001 eruption of Mt. Etna (Italy) by ash characterization. Geophys Res Lett. doi:10.1029/2001GL014372