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High level triggers for explosive mafic volcanism: Albano Maar, Italy

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A B S T R A C T

Colli Albani is a quiescent caldera complex located within the Roman Magmatic Province (RMP), Italy. The recent Via dei Laghi phreatomagmatic eruptions led to the formation of nested maars. Albano Maar is the largest and has erupted seven times between ca 69–33 ka. The highly explosive nature of the Albano Maar eruptions is at odds with the predominant relatively mafic ($SiO_2 = 48–52$ wt.%) foiditic ($K_2O = 9$ wt.%) composition of the magma. The deposits have been previously interpreted as phreatomagmatic, however they contain large amounts (up to 30%vol) of deep seated xenoliths, skarns and all pre-volcanic subsurface units. All of the xenoliths have been excavated from depths of up to 6 km, rather than being limited to the depth at which magma and water interaction is likely to have occurred, suggesting an alternative trigger for eruption. High precision geochemical glass and mineral data of fresh juvenile (magmatic) clasts from the small volume explosive deposits indicate that the magmas have evolved along one of two evolutionary paths towards foidite or phonolite. The foiditic melts record ca. 50% mixing between the most primitive magma and Ca-rich melt, late stage prior to eruption. A major result of our study is finding that the generation of Ca-rich melts via assimilation of limestone, may provide storage for significant amounts of CO_2 that can be released during a mixing event with silicate magma. Differences in melt evolution are inferred as having been controlled by variations in storage conditions: residence time and magma volume.

1. Introduction

The volcanic products of the Colli Albani Volcanic District, including the most recently erupted magmas from Albano Maar, are defined as alkali-rich and silica undersaturated (mainly >7 wt.% K_2O, <50 wt.% SiO_2; tephrites to tephri-phonolites and K-foidites; Boari et al., 2009; Conticelli et al., 2010; De Benedetti et al., 2008; Freda et al., 2006, 2011; Gaeta et al., 2006, 2011; Giordano et al., 2006; Marra et al., 2003; Palladino et al., 2001; Trigila et al., 1995). Foiditic compositions have been found elsewhere worldwide i.e. Mt Vulture in Italy (D'Orazio et al., 2007), and at Eifel, Germany and Ngorangoro, Tanzania (Mollel and Swisher, 2011; Shaw and Woodland, 2012 and the references therein). These compositions are typically erupted during low volume, effusive activity, often associated with carbonatitic magmatism. In contrast, products of Albano Maar are highly-fragmented, reflecting intense explosive activity, usually related to phreatomagmatism (Giordano and CARG Team, 2010; Giordano et al., 2002 and the references therein).

The Colli Albani Volcanic District magmas, like those erupted elsewhere in the RMP, originate from a heterogeneous, metasomatised, phlogopite-rich mantle under high XCO_2 caused by the decarbonation of subducted pelagic sediments rich in carbonate (Boari et al., 2009; Chiarabba et al., 2010; Chiodini and Frondini, 2001; Conticelli et al., 2010). The most recent activity at Colli Albani (<355 ka) is associated with small volume eruptions of magmas characterised by some degree of assimilation of Mesozoic carbonate in the shallow magma plumbing system (1–6 km in depth; Boari et al., 2009; Di Rocco et al., 2012). Experimental work suggests that carbonate enhances the fractionation of Ca-rich clinopyroxene and suppresses the crystallisation of plagioclase feldspar and phlogopite in parental phono-tephrite melts, this effect is enhanced at elevated carbonate concentrations and therefore melts may evolve along different pathways depending on the degree of carbonate assimilation (Freda et al., 2008; Gaeta et al., 2009; Iacono Marziano et al., 2007, 2008; Mollo et al., 2010; Trigila et al., 1995). Part of the aim of this study was to compare the different compositions produced under the specific experimental conditions, with the large natural glass geochemical dataset presented herein, and thus investigate the evolution of these magmas both within and between eruptions.

A long-standing question regarding maar-diatreme mafic volcanism, including kimberlite volcanism, is the relative importance of magmatic CO_2 and H_2O and external H_2O in promoting the fragmentation and the explosivity of low viscosity magmas (Lorenz, 1986; Russell et al.,

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2012). However, while the shape of the glass shards can be used as evidence in support of magma–water interaction (Büttner et al., 1999; Pardo et al., 2009; Wohletz, 1986) and evidence for low emplacement temperatures (e.g. Porreca et al., 2008), the contribution of magmatic volatiles to explosivity of maar-diatremes is more difficult to assess, making it an area of significant scientific interest.

Here we present micron-scale major (WDS-EMPA) and trace (LA-ICP-MS) element glass data for juvenile volcanic clasts from the last four of the seven known eruptions of Albano Maar (Units IV–VII; Table 1). The resultant geochemical dataset provides a new and larger range of juvenile magma compositions erupted at Albano Maar that has been published previously (De Benedetti et al., 2008; Freda et al., 2006; Gaeta et al., 2011; Giaccio et al., 2009) and provides additional information on the geochemistry, and spatial and temporal variability of Albano Maar magmas. The glass data is used to further constrain the evolution of Albano Maar magmas and gain insight into: (1) the relative roles of fractionation and crustal contamination on Albano Maar magma compositions; and (2) influences on explosivity and dispersal of Albano Maar tephra.

2. Geological background

The Colli Albani Volcanic District is a complex, overlapping volcanic edifice (Fig. 1; Giordano and CARG Team, 2010; Giordano et al., 2006), which developed along the Tyrrhenian margin of Italy within an extensional regime during the middle to late Pleistocene and through the Holocene (Avanzinelli et al., 2008, 2009; Rosenbaum and Lister, 2004). The Colli Albani Volcanic District is located in a densely populated area south of Rome, therefore understanding of its volcanic history and potential hazard is of critical importance. It has been active since ca. 600 ka with the early formation of a large caldera complex due to the eruption of intermediate to large volume ignimbrites, followed by post-caldera activity (<355 ka), accompanied by a significant reduction of the average eruption rate over time (Giordano and CARG Team, 2010; Giordano et al., 2006). Albano Maar is the locus of the most recent activity at the Colli Albani Volcanic District and has erupted at least 7 times between ca. 69 ka and 33 ka (De Benedetti et al., 2008; Freda et al., 2006; Funiciello et al., 2003; Gaeta et al., 2011; Giaccio et al., 2009; Giordano and CARG Team, 2010; Giordano et al., 2002, 2006; Marra et al., 2003), forming a nested maar-diatreme complex. The maar-complex is aligned NNW–SSE and N–S, parallel to earlier effusive activity and linking it with the central Colli Albani Volcanic District (Anzidei et al., 2008; Boari et al., 2009; De Benedetti et al., 2008; Freda et al., 2006; Gaeta et al., 2011; Giordano et al., 2006). Until recently, the Colli Albani Volcanic District, was considered to be quiescent and incapable of further activity (De Rita et al., 1995; Karner et al., 2001). This view has recently been challenged on the basis of emerging young ages for these deposits (De Benedetti et al., 2008; Freda et al., 2006; Funiciello et al., 2003), occurrence of frequent seismic swarms and ground deformation (Chiarabba et al., 1997), and ongoing CO_2 emission in the Albano area, as indicated by CO_2 oversaturated groundwater (Anzidei et al., 2008; Chiodini and Frondini, 2001). This CO_2 emission may have also been the cause of a series of Lake Albano overturns and lahars, some as young as ca. 5.8 ± 0.1 ka ^{14}C, whose deposits (Fig. 1) are referred to as the Tavolato formation (De Benedetti et al., 2008; Funiciello et al., 2003).

Sedimentary xenoliths and seismic tomography indicate that the shallow crust below the Colli Albani Volcanic District consists of Mesozoic carbonate basement at a depth of 1–6 km, overlain by Pliocene sediments (reviewed in Chiarabba et al., 2010; Danese and Mattei, 2010). Modelling of seismic data indicate that remains of the solidified main magma reservoir are located below the carbonate basement of the volcano edifice (>6 km depth, Chiarabba et al., 2010 and the references therein). This is in agreement with petrologic data by Boari et al. (2009), which indicate that the early caldera history at Colli Albani (>355 ka) is associated with a main magma reservoir located below 6 km depth, with no evidence of interaction with the shallow carbonates. A shallowing of the plumbing system is instead evident for the post-caldera stage (<355 ka), when a series of smaller volume reservoirs interacted with the shallow carbonates (Boari et al., 2009; Di Rocco et al., 2012). Recent seismic unrest appears to be linked to inflation of a magma source in the central-western area beneath the Via Dei Laghi maars (Anzidei et al., 2008; Chiarabba et al., 1997 and the references therein). 3D wave velocity models suggest it may be due to new magma accumulating (Bianchi et al., 2008; Chiarabba et al., 1997, 2010). This influx of new magma into the carbonate basement and resulting decarbonation reactions could be the cause of the current large CO_2 out fluxes (Carapezza and Tarchini, 2007; Chiodini and Frondini, 2001) and points towards potential hazard created by this volcano in the future.

Table 1
Proximal and distal sample descriptions.

Sample	Unit	Clast type	Age (ka)	Location/depth of tephra	% ves[#]	% cryst[#]	Modal percentages of main phases of clasts/shards[⁎]	Modal percentages of unit components[α]	Emplacement mechanisms
10AH07Sc1	VII	Proximal pumice	*33 ± 4*[*]	Within the surge	40	60	lc: 70%; gl: 21%; cpx: 7%; ap: 2%	JC: 90%; L: 2%; EP: 4%; Met. C:2%; MC + MI: 2%	Fall and flow
AH07B				50 cm above?	25	80	gl: 38%; lc: 31%; cpx: 28%; mt: 3%		
AH07A				Base of unit within 15 cm of a/the thick pumice rich layer	35	76	gl: 45.5%; 35.5% lc; x: 10%; bi: 8.5%; cpx: 1%		
10AH062	VI		–	Basal breccia	40	75	lc: 41%; gl: 40%; cpx: 10%; x: 7%; mt: 1%; ap: 1%	JC: 80%; L: 2%; EP: 10% SC: 2%; Met. C:2%; MC + MI: 4%	Base surge and ballistic fallout
AH05	V		*36 ± 3–40 ± 6*[*]	Basal breccia	40–50	75	lc: 70%; gl: 20%; cpx: 8%; mt: 2%	JC: 1%; L: 60%; EP: 20% SC: 5%; Met. C: 9%; MC + MI: 5%	Pyroclastic density current
10AH042	IV		*40 ± 6*[*]	1 m above base	30	80	san: 40%; phl: 20%; cpx: 15%; lc: 11%; gl: 10%; mt: 2%; ap: 2%	JC: 15%; L: 30%; EP: 5% SC: 20%; Met. C: 5%; MC + MI: 25%	Base surge and ballistic fallout
10AH041				Base	40	60	cpx: 48%; gl: 24%; lc: 14%; phl: 12%; mt: 2%		
TGOmis	I[€]	Magmatic intrusive	*68.9 ± 0.2*[*]	Basal breccia	–	–	lc: 45%; cpx: 42%; ca: 6%; ap: 5; gl: 2%	–	–
10AH05cum	V[€]		*36 ± 3–40 ± 6*[*]	Basal breccia	–	–	cpx: 75%; phl: 11%; lc: 7%; ca: 4%; ap: 2%; gl: 1%	–	–

*Gaeta et al. (2011) ($^{39}Ar/^{40}Ar$ ages); ⁎Clinopyroxene (cpx), Phlogopite (phl), Leucite (lc), Sanidine (San), Kspar (kf), Biotite (bi), Apatite (ap), Magnetite (mt), Glass (gl), Calcite (ca); #Data collected by eye and point counting and is therefore subjective; αDe Benedetti et al. (2010); abbreviations: Juvenile clasts (JC), lavas (L), sedimentary clasts (SC), magmatic cumulates and magmatic intrusives (MC + MI), metamorphosed clasts (Met. C), earlier pyroclastics (EP). €Although the intrusive clasts are found in a specific unit, they have not been compared specifically to the glass from this unit as we cannot be confident as to their eruptive origin.