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Non-volatile vs volatile behaviours of halogens during the AD 79 plinian eruption of Mt. Vesuvius, Italy

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Abstract

Pre-eruptive conditions and degassing processes of the AD 79 plinian eruption of Mt. Vesuvius are constrained by systematic F and Cl measurements in melt inclusions and matrix glass of pumice clasts from a complete sequence of the pumice-fallout deposits. The entire 'white pumice' (WP) magma and the upper part of the 'grey pumice' (GP) magma were saturated relative to sub-critical fluids (a Cl-rich H_2O vapour phase and a brine), with a Cl melt content buffered at ~5300 ppm, and a mean H_2O content of ~5%. The majority of the GP magma was not fluid-saturated. From these results it can be estimated that the WP magma chamber had a low vertical extent (<500 m) and was located at a depth of ~7.5 km while the GP magma reservoir was located just beneath the WP one, but its vertical extent cannot be constrained. This is approximately two times deeper than previous estimates. H_2O degassing during the WP eruption followed a typical closed-system evolution, whereas GP clasts followed a more complex degassing path. Contrary to H_2O, Cl was not efficiently degassed during the plinian phase of the eruption.

This study shows that F and Cl behave as incompatible elements in fluid-undersaturated phonolitic melts. H_2O saturation is necessary for a significant partitioning of Cl into the fluid phase. However, Cl cannot be extracted in significant quantity from phonolitic melts during rapid H_2O degassing, e.g. during plinian eruptions, due to kinetics effects. Halogen contents are better preserved in volcanic glass (melt inclusions or matrix glass) than H_2O, therefore the combined analysis of both volatile species is required for reliable determination of pre-eruptive conditions and syn-eruptive degassing processes in magmas stored at shallow depths.

Keywords: Vesuvius; AD 79 plinian eruption; halogen behaviours; differentiation processes; magma degassing

1. Introduction

The eruptive style of explosive volcanic eruptions is principally determined by degassing processes, which are primarily controlled by the chemical and physical properties of the magma. H_2O, SO_2, CO_2 and halogens (F, Cl) represent the most important volatile components dissolved in magmas. Halogens are of particular interest because they behave as incompatible elements during melt differentiation and are controlled by their ability to partition into the fluid phase during shallow magma degassing (Villemant and Boudon, 1998; Villemant et al., 2003). Halogen distribution coefficients between aqueous fluids and melts vary over a wide range, largely as a function of melt composition as shown by experimental results (Kilinc and Burnham, 1972; Bureau et al., 2000; Signorelli and Carroll, 2000; Webster and De Vivo, 2002; Webster et al., 2003; Webster, 2004) and studies on natural systems (Villemant and Boudon, 1999). In addition, halogens are generally better preserved and easier to analyse than H_2O or CO_2 in volcanic glass (i.e. matrix glass and melt inclusions). An increasing number of high quality measurements of halogens in volcanic glass now exist. These cover a large variety of eruptive styles and magma compositions which exemplify a large variety of

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behaviours during magma differentiation and degassing, especially for highly silicic magmas. Phonolitic magma eruptions provide a particularly suitable material for such studies because their halogen contents are large and highly variable. In this work we reinvestigate the behaviour of water and halogens during the AD 79 eruption at Vesuvius which emitted tephri-phonolitic to phonolitic magmas during a sustained and mainly plinian activity. This famous eruption has already been subject to numerous studies; for instance, chronostratigraphy and sedimentology (Sigurdsson et al., 1985; Carey and Sigurdsson, 1987; Cioni et al., 1992), geochemistry and petrology including pre-eruptive conditions and magma degassing (Mues-Schumacher, 1994; Cioni et al., 1995; Cioni et al., 1998; Cioni et al., 1999; Signorelli et al., 1999; Signorelli and Capaccioni, 1999; Cioni, 2000; Webster et al., 2003), textures and vesiculation conditions (Gurioli et al., 2005), and numerical modelling of eruption dynamics (Papale and Dobran, 1993; Neri et al., 2002). Here we report new H_2O and halogen compositional data for melt inclusions and matrix glass. These results, combined with previous geochemical studies, provide new constraints on the pre-eruptive conditions of the AD 79 eruption and also on the factors controlling halogen behaviour during phonolitic magma differentiation and degassing.

2. Geological setting

2.1. Monte Somma–Vesuvius geological history

Mt. Somma–Vesuvius is a complex volcanic system, located in the Campanian Plain, Southern Italy, which is bordered by a Mesozoic carbonate platform. It is composed of the ancient Monte Somma stratovolcano, the activity of which ceased following a large caldera collapse, and the Vesuvius volcano (sensu stricto), which is located inside this caldera. The Monte Somma–Vesuvius volcanic system will be referred to as Vesuvius from now on. The onset of activity at Vesuvius occurred ~35 kyr ago. On the basis of chronostratigraphic and archeomagnetic studies, four distinct periods of activity are recognized (Raia et al., 2000; Principe et al., 2004) which display a large spectrum of volcanic activity, from effusive to large explosive eruptions. The principal explosive eruptions comprise four major plinian eruptions (Pomici di Base, ~20 000 BP; Mercato, ~9000 BP; Avellino, 3500 BP; Pompeii, AD 79) and numerous sub-plinian eruptions such as Pollena (472 AD) or the 1631 eruption. However, other plinian eruptions or different eruption dates are also recognized (e.g. Arno et al., 1987; Dobran, 1993; Rolandi et al., 1998; Cioni et al., 1999; Santacroce et al., 2003). Reported petrological data suggest that the magmatic system of Vesuvius is composed of a deep reservoir (10–20 km depth; Nunziata et al., 2006) from which magma batches rise and feed shallower magma chambers (typically 3–5 km; DeNatale et al., 1998; Lima et al., 2003; DeNatale et al., 2004; Civetta et al., 2004). Magma series ranging from silica undersaturated (K-basalt to K-trachyte) to highly silica undersaturated (K-tephrite to K-phonolite) have been recognized (Belkin et al., 1985; Joron et al., 1987; Cioni et al., 1992; Marianelli et al., 1995; Ayuso et al., 1998).

2.2. The AD 79 eruption

The AD 79 eruption of Vesuvius, also known as the "Pompeii eruption", has been previously described in detail (e.g. Sigurdsson et al., 1985; Cioni et al., 1992; Cioni et al., 1995). The eruption is commonly divided into three phases: an initial phreatomagmatic phase, followed by a plinian event which produced a thick pumice-fallout deposit and a final phase that was dominated by numerous collapse events. The pumice-fallout deposit displays a white to grey colour zoning, which is related to a change in the magma composition from phonolite to tephri-phonolite (Barberi et al., 1981; Joron et al., 1987). Hereafter "white pumice" (WP) and "grey pumice" (GP) refer to the two main pumice types, which are represented by six fallout units U1, U2, U3, U4 (WP) and U5, U6 (GP) (Fig. 1).

3. Sampling and analytical methods

This study focuses on the pumice-fallout deposits which represent 80% of the erupted magma from this eruption (Cioni et al., 1995). Surges and pyroclastic flow deposits (e.g. the eruptive units EU4 to EU8 described by Cioni et al., 1995) were not sampled. To achieve a detailed investigation of the degassing processes, a systematic and statistical sampling of a representative section of the pumice-fallout deposits was undertaken. Six fallout units, U1, U2, U3, U4 (U1234), U5 and U6 (U56) were sampled in a proximal 1 m thick section, at the Terzigno quarry, 6 km southeast of the present crater. Although this site which is located on a bearing of N140° from the crater, is not on the main dispersion axis (N160°) it provides an easily accessible and complete section of the AD 79 pumice-fallout deposits. At least 100 pumice clasts were collected from each unit sampled by sieving at ϕ 16 mm, to limit bias due to wind dispersion and to collect large fragments large enough for analysis. Each pumice clast was then washed and cut into three pieces for density measurements, chemical analyses and textural observations. On the basis of the density distribution histograms, at least three pumice clasts were selected from each unit for chemical analyses: one in the dominant density fraction and the two others from the high and low density fractions. For units U5 and U6, which have large density distributions, 10 and 8 clasts were selected, respectively. A piece of each selected clast was powdered in an agate mortar for chemical analyses and the remaining piece was polished for S.E.M. imaging, point analyses (EPMA) or used for mineral and groundmass separations.

— *Density and vesicularity*: The fragment was first weighted in air (M_a), before impregnation with molten paraffin to fill all open and connected vesicles. It was then re-weighed in air (M^i_a) and water (M^i_w). Density (d) and vesicularity are then calculated as follows:

$$d = M_a / \left(M^i_a - M^i_w\right)$$

$$\text{Vesicularity}(\%) = 100*(\text{DRE} - d)/\text{DRE}$$