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Constraining the degassing processes of Popocatépetl Volcano, Mexico: A vesicle size distribution and glass geochemistry study

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ABSTRACT

The explosive activity of Popocatépetl Volcano is a threat to the surrounding densely populated areas and it is therefore important to recognize indicators of change in eruptive style (explosive to dome building) within a short period of time. In this study we present results of vesicle size distributions (VSDs) and compositional analysis of matrix glass from juvenile clasts from five of the main plinian eruptions of Popocatépetl (*ca.* 23–1.2 ka), the 2001 small eruption during partial dome collapse and four eruptions during 1997 (May 11th and June 14th, 15th and 30th). Major element analysis of matrix glass (WDS-EPMA) allows the estimation of the depth from which the erupted magma went into disequilibrium (between crystals and melt), by calculating the equilibrium pressure using the quartz–albite–orthoclase ternary system of Blundy and Cashman (2001). Quantitative interpretation of texture in juvenile (pumice or scoria) clasts via VSD analysis using CSD software was used to link physical changes experienced by magma during ascent, with conditions responsible for eruptions. The extent and style of vesiculation in juvenile clasts is also related to eruption style and duration and has specifically allowed the recognition of changes in vesicular texture that represent variations from explosive to dome building activity (Mangan and Sisson, 2000; Adams et al., 2006). This study highlights a more complicated story in terms of magma storage, than that previously accepted for the Popocatépetl volcanic system and is an important contribution to ongoing research at the volcano.

1. Introduction

Large active volcanoes situated near densely populated regions not only represent major hazards that can be monitored and studied using their current eruptive products, but also often contain a wealth of information about their past eruptive activity locked up in their volcano-stratigraphy. Popocatépetl displays constant degassing activity and therefore also provides a valuable data-set on its current behavior.

The modern cone of Popocatépetl has experienced explosive and effusive activity dating back to *ca.* 19 kyr (Siebe et al., 1996, 1999; Siebe and Macias, 2004; Schaaf et al., 2005). Historically Popocatépetl has had a major eruptive phase every 1000–3000 yr (Siebe et al., 1996). Recently, after a period of quiescence lasting several decades, Popocatépetl began a new phase of activity, erupting explosively and effusively in late 1994. During this period, mirroring historical activity, explosive products from Popocatépetl reached Mexico City and Puebla metropolitan areas (respectively 60 km NW and 40 km E of the crater; Fig. 1). Therefore, recognition of changes in eruptive behavior is critical for rapid evaluation of hazards at Popocatépetl. To this extent the information preserved in the erupted juvenile clasts, which span 19 kyr to present, may also contain valuable information when compared to the recent and current erupted deposits of Popocatépetl.

A series of suggestions up to present have been put forward in an attempt to explain the most recent degassing and eruptive behavior at Popocatépetl in comparison with pre-1994 activity as open-vent degassing (Burton et al., 2007). As discussed in Roberge et al. (2009), recent activity at Popocatépetl displays open-vent degassing that leads to the separation of large volumes of rising volatiles from the magma, the accepted method for this process is that convection is required to allow for the rise of gassy-magma and then the sinking of subsequent dense degassed magma within the most shallow parts of the volcanic conduit (Kazahaya et al., 1994; Stevenson and Blake, 1998; Witter et al., 2005). However, recent work by Roberge et al. (2009) has identified that instead deep-degassing beneath open-vent volcanoes can explain the observed flux of volatiles and eruptive activity at Popocatépetl. Understanding the degassing process at this volcano therefore is critical to understanding the eruptive hazard.

Textural analysis of igneous rocks can provide valuable quantitative information about a rocks evolution and therefore magmatic processes (Higgins, 2000, 2002, 2006; Jerram and Higgins, 2007). The interpretation of texture in juvenile clasts erupted during magmatic

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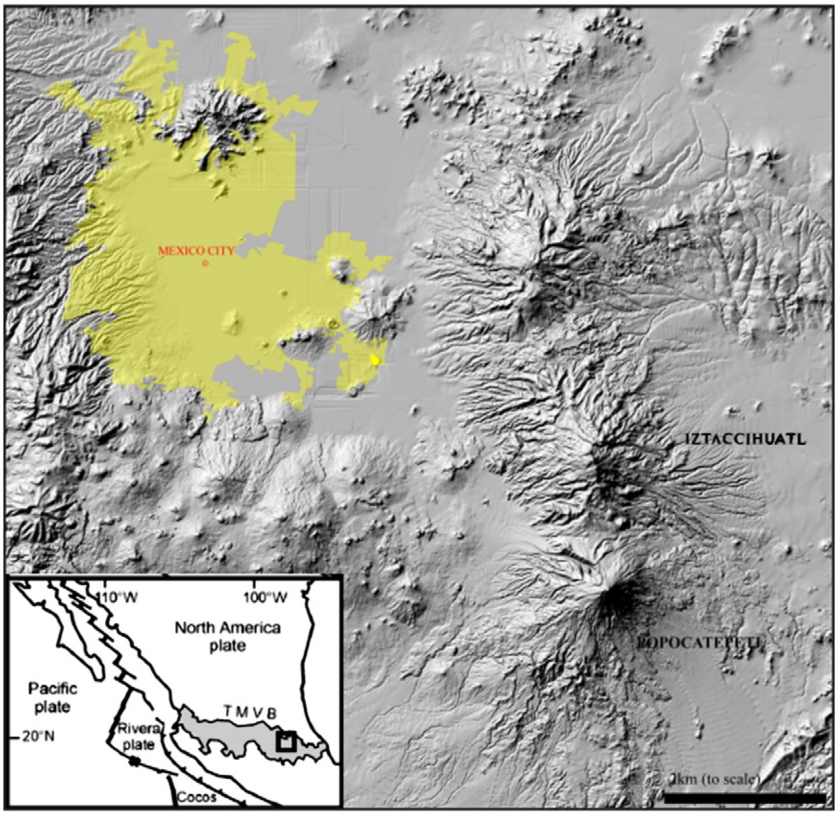

Fig. 1. Map of the Trans-Mexican Volcanic Belt (TMVB) including the location of Popocatépetl with relation to surrounding populated areas.

eruptions is one way that can be used to link physical changes experienced by magma during ascent, with conditions responsible for eruptions (Cashman and McConnell, 2005). The extent and style of vesiculation, for example, can be related to eruption style and duration (Cashman and Mangan, 1994). Furthermore, extensive crystallization and variations in degassing (changing volatile ratios and volumes in the melt) lead to viscosity changes in the magma which control the transition from explosive to effusive volcanism (Woods and Koyaguchi, 1994; Scandone et al., 2007). One approach therefore to the investigation of change in the eruptive behavior of Popocatépetl is to combine information on the juvenile melt (glass) erupted, as this can provide a proxy for viscosity and depth of magma origin (Blundy and Cashman, 2001), with the distribution of vesicle texture which constrains vesicle nucleation events and growth processes. If changes in eruptive behavior can be constrained using these relatively simple proxies then they may prove a powerful tool to help on-going interpretations of the eruptive products from Popocatépetl, and transferred for use at other active volcanic systems.

In this work we present results of vesicle size distributions (VSDs) and compositional analysis of matrix glass from juvenile clasts from the five of the plinian eruptions of Popocatépetl (*ca.* 19–1.2 ka), from the 2001 small eruption flow caused by dome collapse and from four eruptions during 1997 (May 11th and June 14th, 15th and 30th). Discussion is aimed at the changes in VSD results and magma disequilibrium depths defined by matrix glass chemistry of juvenile clasts that reflect magma ascent variations throughout the stratigraphic window sampled (Fig. 2) and thus constrain a model for the variations in the degassing processes of Popocatépetl.

2. Geological setting and eruptive activity at Popocatépetl

Popocatépetl is located on the volcanic front of the central part of the Trans Mexican Volcanic Belt (TMVB; Fig. 1). Magma generation beneath the TMVB is generally believed to be related to the complex subduction of the oceanic Cocos Plate (Demant, 1978). The history of Popocatépetl is divided into a series of cone building periods and catastrophic cone collapse. The last collapse prior to the formation of the modern cone has been dated and described in detail by Siebe et al. (1995a) as *ca.* 23 kyr BP. This cone has been called Ventorillo (Espinasa-Perena and Martin-Del Pozzo, 2006) and its collapse formed the Upper Tlayecac avalanche deposit and Tochimilco pumice (called the White pumice in Schaaf et al., 2005). This deposit and those formed prior to it was initially described by Robin and Boudal (1987 and 1988) with a more recent description within Espinasa-Perena and Martin-Del Pozzo (2006).

The current dome of Popocatépetl was initially built by lavas that are andesitic–dacitic in composition (Robin, 1984). At least seven plinian eruptions have occurred since and between those plinian eruptions were “mild” vulcanian eruptions (Siebe et al., 1996, 1999; Panfil et al., 1999). In other work, up to 12 Plinian eruptions have been identified (Espinasa-Perena and Martin-Del Pozzo, 2006 and references therin) but in this study our work is based upon the stratigraphy and nomenclature identified by Schaaf et al. (2005; Fig. 2).

The volcano reawakened on December 21, 1994 after ~70 years of dormancy. The first eruptive stage (December 1994–March 1996) consisted of vulcanian explosions that cleared the conduit system. Explosions were frequent during December 1994 and January 1995, after this eruption, frequency reduced and ceased by August 1995 (De la Cruz-Reyna et al., 1995). Eruptive activity resumed in March 1996, alternating between effusive (dome building) and explosive events, and in January 1997, a new dome formed in the crater. This dome was partially destroyed by the eruption of 11 May 1997 (Delgado-Granados et al., 2008). Activity then continued to increase in May and June until 30 June 1997, when an 8 km-high eruption cloud produced ash fall on Mexico City, 67 km northwest of Popocatépetl. Following this eruption, a new dome formed, and since then eruptive activity has maintained the same style, with variations in magnitude of explosivity, effusion rate, and lava dome volume.