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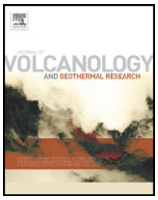

Short communication

First evidence of hydromagmatism at Colima volcano (Mexico)

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ABSTRACT

Here we report for the first time evidences of hydromagmatism at Colima volcano (western sector of Trans-Mexican Volcanic Belt). The studied location exposes 9 m of fine ash deposits dated at around 15 cal kyr BP by ^{14}C measurement on organic matter collected at the very base of the stratigraphic succession. The ash deposits rest directly on the top of a debris avalanche deposit. The morphology and grain size distribution of ash samples from the basal part of the stratigraphic succession testify for an explosive magma–water interaction, which produced finely bedded layers with blocky fragments characterized by adhering particles, quenching cracks and chemical pitting. The availability of ground water was hypothesized to be in close relationship with the amelioration of climate conditions at the end of the Last Glacial period, with rising temperatures that induced melting of glaciers and snow previously accumulated on the volcano summit slopes. This recognition demonstrates how, even a "dry" volcano like Colima, can experience hydromagmatism under adequate climatic conditions.

1. Introduction

Hydromagmatic pyroclasts are the product of explosive magma/water interaction, which produces thermo-hydraulic fragmentation commonly referred as molten fuel–coolant interaction (MFCI) (Zimanowski et al., 1997; Büttner et al., 2006). The general term hydromagmatism, or hydrovolcanism encompasses all environments where the water can encounter the magma, such as deep to shallow subaqueous, littoral, phreatic, and sub-glacial (Sheridan and Wohletz, 1983; Wohletz, 1983). Hydromagmatic eruptions (here intended as a general term indicating eruptions in which magma–water interaction drives the fragmentation process) are usually responsible for fine ash generation, which is dispersed as fallout deposits (Dellino and Kyriakopoulos, 2003; Folch et al., 2012; Langmann et al., 2012) and/or pyroclastic density currents (PDCs; Sulpizio et al., 2008; Dellino et al., 2011). Fine ash is also found in deposits of magmatic-driven fragmentation eruptions (Zimanowski et al., 2003), but microscopic analysis could discriminate between magmatic and hydromagmatic processes (Heiken and Wohletz, 1986). In particular, the study of fine ash by specifically designed grain size analysis and microscopic investigation at the SEM provides valuable information on the mechanism of hydromagmatic eruptions (Dellino and Kyriakopoulos, 2003). The size distribution of hydromagmatic pyroclasts is strongly controlled by efficiency of thermo-hydraulic explosions and by the physical and chemical properties of magma including its composition and presence and size of bubbles and crystals. All these factors influence the fragmentation processes, which controls the eruption mechanisms and, at the very end, the dispersal mechanisms and the deposit types.

Colima volcano, located in western Mexico (Fig. 1), has been always considered as a "dry" volcano, in the sense that its explosive eruptions are inferred to be dominated by magmatic fragmentation (Macias, 2005; Bonasía et al., 2011), and no description of any hydromagmatic deposits has been provided in literature to date. In this paper we report, for the first time, the description of a hydromagmatic succession exposed in the Montegrande ravine in the southeastern sector of the volcano edifice. These deposits have a minimum age of ca. 15,000 cal yr BP obtained from ^{14}C measurement of organic matter collected at the very base of the studied stratigraphic succession [average value between ^{14}C 13,585 ± 135 (16,577–16,893 cal yr BP, 1 sigma; cal. II sigma 16,165–17,044) and 12,460 ± 70 (cal. I sigma 14,231–14,750; cal. II sigma 14,151–15,031)] (Roverato et al., 2011), and provide the geological evidence that Colima volcano had also experienced explosive magma/water interaction processes during its eruptive history.

2. Geological framework

Colima volcano is the southernmost and youngest eruptive center of the Colima Volcanic Complex (CVC) an andesitic complex located in the western part of the Trans Mexican Volcanic Belt (TMVB). The TMVB is a continental volcanic arc extending across central Mexico associated with the subduction of the Cocos and Rivera plates beneath the North American plate (Ferrari et al., 1994; Bandy et al., 2005) (Fig. 1). The CVC stands within the Central Colima Graben and rises 4255 m above the sea level on top of Cretaceous limestones, Late Miocene–Pleistocene volcanic rocks, and Pliocene–Holocene lacustrine

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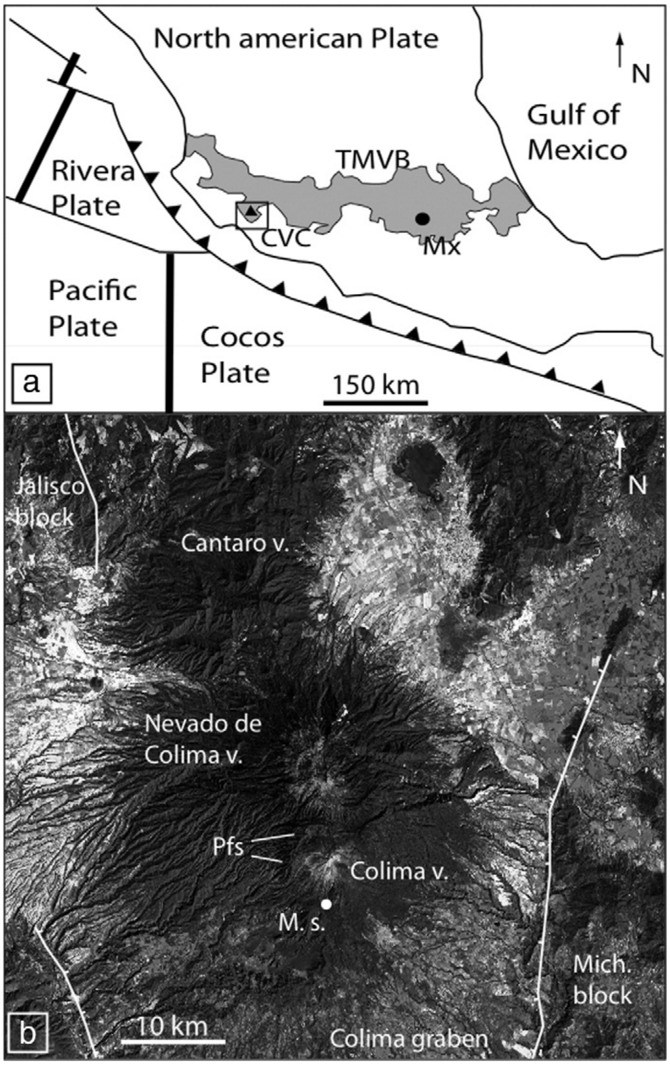

Fig. 1. Location map of the Trans-Mexican Volcanic Belt (TMVB); CVC: Colima Volcanic Complex; PFS: Paleofuego scarp; MX: Mexico City (a). Aster image showing the location of the Jalisco and Michoacan blocks and the Colima Volcanic Complex in the Colima Graben; Pfs: Paleofuego scarp; M.s. Montegrande sequence (b).

sediments, alluvium, and colluvium (Allan, 1985; Allan et al., 1991; Norini et al., 2010). This volcanic complex is a N–S chain that consists of three main andesitic stratovolcanoes (Cantaro, Nevado de Colima and Colima volcano) whose activity started at about 1.7 Ma ago and migrated southward (Robin et al., 1987; Luhr and Prestegaard, 1988; Cortes et al., 2005). The Colima volcano consists of the recent and active cone, Fuego de Colima, which was built inside the >23,000 yr old Paleofuego scarp (Roverato et al., 2011) originated by a southward sector collapse that produced a ~10 km^3 debris avalanche deposit (Luhr and Prestegaard, 1985, 1988). The Fuego de Colima is one of the most active volcanoes in the world nowadays, with Merapi- and Soufriere-type dome collapses, Vulcanian and Plinian explosive eruptions, and extrusion of lava flows and domes (Macias, 2005; Saucedo et al., 2005). The activity of the Colima volcano included also several sector collapses, and lahars/debris flows associated, which occurred in the Upper Pleistocene and Holocene, that inundated the surrounding plain down to the Pacific coast over a distance of 120 km from the active volcanic vent (Robin et al., 1987; Luhr and Prestegaard, 1988; Stoopes and Sheridan, 1992; Komorowski et al., 1997; Capra et al., 2002; Cortes et al., 2010; Roverato et al., 2011).

3. Analytical methodology

Macroscopic and microscopic characteristics of particles from the study succession were analyzed through grain-size and scanning electron microscope (SEM) images. The samples were sieved using two different methods. The classes between -3 and 4ϕ (8 mm to 63 μm) were dry sieved at 1ϕ interval, while the finer classes ($>4\phi$; <63 μm) were analyzed using a Laser Particle Sizer (LPS) photosedimentograph-Analysette 20 at the Centro de Geociencias-UNAM (Campus Juriquilla, Queretaro, Mexico). Finally to obtain the complete range of clast size (from -3 to 9ϕ), all the results were normalized and merged. In order to characterize the particle surface features, microscopic analysis was performed using a SEM (sizes between 3 and 4ϕ, 125–63 μm). This grain size class provides the best information on fragmentation mechanisms representative for the thermo-kinetic energy transfer processes acting during an explosive volcano eruption (Wohletz, 1983; Zimanowski et al., 2003). The SEM images were obtained from a JEOL-35C Tractor Northern SEM operated under 15 kV acceleration at Centro de Geociencias-UNAM (Campus Juriquilla, Queretaro, Mexico).

4. The Montegrande succession

The ca. 9 m thick Montegrande succession (64,4611.06 O; 2,152,068.82 N) crops out at 6 km from the present day vent of the volcano, and rests directly on top of the irregular surface of the Tonila debris avalanche deposit (T-DAD; Roverato et al., 2011) (Fig. 2a). Only the first 2 m of the exposure was accessible for detailed description and sampling, and consists of fine to very fine, light-brown to yellowish-reddish, usually massive, ash layers. Grain-size data on the fine ash samples (Fig. 2b) show a prevalent unimodal distribution, and SEM image analysis reveals that the ash particles are mostly composed of juvenile glass, with subordinate lithic fragments and a few loose crystals. Juvenile particles show blocky morphology (Fig. 3b, d, e) with very low to moderate vesicularity. The bubbles are mainly spherical to sub-spherical, separated by thick glass walls (Fig. 3a). Other typical hydromagmatic features are the peculiar stepped surface (Fig. 3d) related to the brittle-mode fragmentation that occurs during the explosive magma–water interaction (Büttner et al., 1999, 2002; Dellino and Kyriakopoulos, 2003; Zimanowski et al., 2003). Sub-rounded clasts (Fig. 3f) are also present, testifying the free air ductile fragmentation regime (Büttner et al., 2002). Some particles show pitting surfaces due to contact with acidic fluids during transportation in the eruptive cloud (Fig. 3c). Most particles show low content in Na in their surficial parts (EDS analyses).

5. Discussion and conclusive remarks

Grain-size and SEM image analysis demonstrates how the fine pyroclastic fragments from the basal portion of the Montegrande succession were generated from hydromagmatic fragmentation. The hydromagmatic character of this ca. 15,000 cal yr BP old succession is related to the interaction of an ascending magma body with water, which triggered the explosive eruption style. Around 15,000 cal yr BP the Colima volcano and the surrounding area experienced the termination of the Late Glacial Period (LGP, 18,000–15,000 cal yr BP; Caballero et al., 2010; Vázques-Selem and Heine, 2011), which was characterized by deglaciation phases and very humid environment (Vázques-Selem and Heine, 2011). Roverato et al. (2011) reported that the volcano edifice was probably seasonally ice-capped during the LGP due to the migration of the altitudinal limit of permanent snow to lower altitudes. The snow/ice melting of the summit glacier and the humid environment suggest that the volcano edifice was partially water saturated at that time. It means that water was present at superficial levels as well as at depth in the volcanic edifice. Based on these considerations, we can speculate that the water available in the volcanic edifice favored the explosive interaction with the rising magma, triggering