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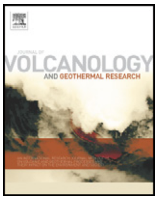

The 17 July 1999 block-and-ash flow (BAF) at Colima Volcano: New insights on volcanic granular flows from textural analysis

D. Sarocchi [a,*], R. Sulpizio [b,c], J.L. Macías [d], R. Saucedo [a]

[a] Instituto de Geología/Fac. Ingeniería UASLP, Dr. M. Nava No 5, Zona Universitaria 78240, San Luis Potosí, México
[b] CIRISIVU, c/o Dipartimento Geomineralogico, Universitá di Bari, via Orabona 4, 70125, Bari, Italy
[c] IDPA-Milan, Italy
[d] Departamento de Vulcanología, Instituto de Geofísica, Universidad Nacional Autónoma de México, Coyoacán 04510, D.F., México

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ABSTRACT

On July 17 1999, a strong explosion occurred at Colima Volcano (Mexico) that produced a 10 km high eruptive column. The partial column collapse originated a block-and-ash flow (BAF) that flowed to the south, along the San Antonio and Montegrande ravines, travelling 3.3 km from the volcano summit. The flow filled the ravines with a volume estimated at 7.9×10^5 m^3. The erosion of these deposits occurred between 1999 and 2002 (time of sampling), providing excellent longitudinal outcrops that allowed their detailed textural study. The study was carried out by means of quantitative textural analysis: (1) Rosiwal intersections, for carrying out vertical granulometric profiles; (2) total grain-size analysis, from -11 to $+9$ ϕ; and (3) Fourier and fractal analysis of the particle morphology. Grain size and morphometric parameters obtained with these methods were used to identify vertical and longitudinal variation patterns in the BAF deposit. The grain size variations allowed to infer the main particle segregation mechanisms that acted during transport and deposition of the studied BAFs. The two methods used for studying the particle shape morphologies yielded results with different accuracy and reliability. In particular, fractal analyses have been found to be the most effective in describing the particle support mechanisms that acted during transport and deposition of the studied BAFs.

The results highlight the importance of the information obtained by means of these techniques, and provide new insights in transportation and deposition mechanisms of BAFs.

1. Introduction

Gravity-driven flows in volcanic areas comprise some of the most complex and hazardous natural phenomena, and can occur either during explosive eruptions (i.e. column collapse, sector failure, and dome or lava flow failure) or during volcanic quiescence (i.e. slope instability, climatic events, and earthquakes). They include generation of pyroclastic density currents, debris avalanches, and volcaniclastic flows, which have different dynamics of transportation and emplacement (Reubi and Hernandez, 2000; Iverson and Vallance, 2001; Branney and Kokelaar, 2002; Sulpizio et al., 2007; Shea et al., 2008). Volcanic gravity driven flows can be described as a continuum between two end members, which are the solid particles and the fluid (water, gas or both; e.g. Branney and Kokelaar, 2002). Based on the relative ratio between the two end members the flows are classified as concentrated (high particle concentration) or diluted (prevalence of fluid fraction; e.g. Sulpizio and Dellino, 2008). The comprehension of the physics of these natural phenomena is far to be satisfactory (e.g. Iverson, 1997; Bursik et al., 2005; Sulpizio and Dellino, 2008), and this faces with the need of detailing their behaviour. Important clues for the physical constraints of flow behaviour come from the study of their deposits, which yield precious information about flow dynamics at time of deposition (Branney and Kokelaar, 2002; Sulpizio and Dellino, 2008).

Among volcanic gravity-driven flows the study of those characterised by high-particle concentration is exceedingly important, since they encompass some of the most destructive volcanic phenomena. In all these phenomena the same basic forces govern motion, but differing mixture compositions, initial and boundary conditions yield varied dynamics and deposits. Examples range from dry rock avalanches (Varnes, 1978; Hutchinson, 1988), in which pore fluid may play a negligible role, to liquid-saturated debris flows (e.g. Iverson, 1997) and gas-charged pyroclastic flows, in which fluids may enhance bulk mobility (e.g. Wilson, 1984; Druitt, 1998; Salatino, 2005).

These phenomena have a very hostile nature, and their direct observation is usually limited or impossible. Movies and photographs have sometimes captured volcanic gravity-flows (e.g. YouTube video, 2009, 2010), yielding important clues about their macro-scale behaviour. However, poor or little information has been obtained about the physics that governs their internal behaviour. In recent years important advancements came from laboratory and large scale

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[*] Corresponding author. Tel.: +52 444 8171039; fax: +52 444 8111741.
E-mail address: damiano.sarocchi@uaslp.mx (D. Sarocchi).

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experiments (e.g. Major, 1996; Dellino et al., 2007, 2010; Roche et al., 2008, 2010; Cagnoli and Romano, 2010), remote sensing (Terunuma et al., 2005; Liew et al., 2008), and numerical simulations (Patra et al., 2005; Charbonnier and Gertisser, 2009; Sulpizio et al., 2010), but field studies on real volcanic gravity-driven deposits remain an irreplaceable tool for obtaining crucial information about their behaviour. This is because a volcanic gravity-driven deposit records the physical processes that occurred at time of deposition (Branney and Kokelaar, 2002; Sulpizio and Dellino, 2008), and particle morphology can yield precious information about transportation regime (Capaccioni and Sarocchi, 1996; Dellino and Liotino, 2002; Maria and Carey, 2002; Sarocchi, 2007; Lukas et al., 2009; Manga et al., 2011).

This work deals with the detailed sedimentological and textural study of a special type of volcanic gravity-driven flows, named block-and-ash flows (BAFs). These flows belong to the solid-dominated end member of the pyroclastic density currents (Burgisser and Bergantz, 2002; Sulpizio and Dellino, 2008), are usually generated by small-volume collapses or explosions of domes (Sato et al., 1992), and are dominated by granular flow regime (Branney and Kokelaar, 2002).

BAFs and associated phenomena can cause great destruction (e.g. the eruption of Mt. Pelée in 1902 claimed for the life of 28,000 people; Fisher and Heiken, 1982). During the last 20 years at least four long-lasting eruptions produced BAFs: Unzen, 1991 (Nakada and Fujii, 1993; Yamamoto et al., 1993), Volcán de Colima 1991, 1998–99 and 2003–05 (Rodríguez-Elizarrás et al., 1991; Saucedo et al., 2002, 2004), Montserrat 1995–present day (Cole et al., 1998; Calder et al., 1999) and Merapi 2006 and 2010 (Camus et al., 2000; Bourdier and Abdurachman, 2001; Schwarzkopf et al., 2005), attracting the attention of the international volcanological community. This renewed interest generated a number of studies dealing with the genesis, classification, stratigraphy, and textures of BAF, and produced a significant enhancement in the comprehension of their behaviour (Rodríguez-Elizarrás et al., 1991; Sato et al., 1992; Carrasco-Núñez, 1999; Fujii and Nakada, 1999; Miyabuchi, 1999; Voight and Davis, 2000; Cole et al., 2002; Saucedo et al., 2002, 2004; Schwarzkopf et al., 2005; Charbonnier and Gertisser, 2009). Nevertheless, detailed studies of grain size, texture and grain morphology of BAFs are still poorly developed, due to the lack of suitable and efficient techniques of investigation. Indeed, there are very few outcrops well preserved and long enough and where the grain morphology changes can be detected with standard techniques (Fisher and Heiken, 1982; Boudon and Lajoie, 1989; Boudon et al., 1993; Taddeucci and Wohletz, 2001).

Here we present the study of a BAF deposit originated by the July 17th, 1999 dome explosion at Colima Volcano (the only one occurred that day; Fig. 1). This explosion, the largest in the 1998–1999 crises, produced a 10 km high column that, short time after, partially collapsed to the W, SW and S. The BAFs generated from the collapse engulfed the San Antonio and Montegrande ravines (Fig. 1; Saucedo et al., 2002). The BAF deposits were deeply eroded and incised in the following rainy seasons and, in 2002, a new 15 m-depth gully provided some hundred metres long exposure of the inner part of the BAF along the San Antonio ravine. Stratigraphic and quantitative

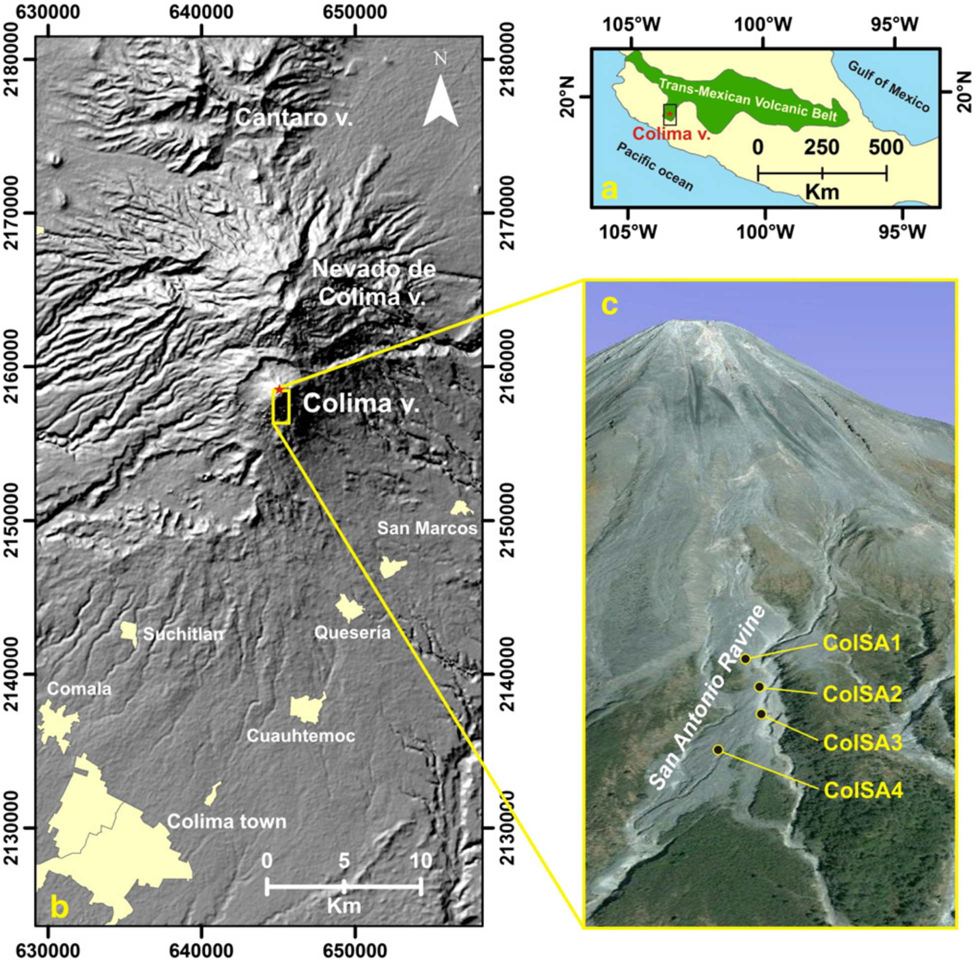

Fig. 1. a) Sketch map of the Trans-Mexican Volcanic Belt with the location of Colima Volcano. b) Digital Elevation Model of the Colima Volcano with highlighted San Antonio ravine area (UTM coordinates). c) Perspective view of San Antonio–Montegrande ravine with sampling locations. The image (Image from Google Earth TM) shows the ravine a few months after it was completely filled from the July 2003 block and ash flow. Distance between the first and the last outcrop is 400 m.