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Journal of Volcanology and Geothermal Research 136 (2004) 297–302

Journal of volcanology and geothermal research

www.elsevier.com/locate/jvolgeores

Short communication

Observations of eruptive activity at Santiaguito volcano, Guatemala

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Received 5 May 2004

Abstract

The study of active vent dynamics is hindered by the difficulty of directly observing features and processes during eruptive periods. Here, we describe some recent observations of the summit dome activity of Santiaguito volcano, Guatemala, from the vantage point of its parent, Santa María. We have taken 12 h of digital video of activity over a 3-year period, which includes 28 eruptions and numerous smaller gas exhalations. Santiaguito persistently extrudes a dacitic lava flow, and produces strombolian eruptions on the order of every 0.5 to 2 h; we have documented many of these eruptions as emitting from a ring-shaped set of fractures in the dome surface. The ring has apparently grown from 70 m diameter in 2002 to 120 m in 2004, which could reflect an increasing conduit opening. Eruptions typically consist of 30–60 s of vigorous emissions; measurements of emission exit velocities have ranged from 5 to 30 m/s. The observed ash bursts, correlated with measured extrusion rates, suggest an incremental plug flow through the conduit. Bubble generation and shearing at the conduit boundaries produce the ring-shaped ash and gas pulses. Continued field studies from this unique observation site may help relate summit emission characteristics to conduit geometry and eruption processes.

Keywords: Santiaguito volcano; conduit flow; strombolian eruptions; volcanology

1. Introduction

The understanding of volcanic eruption dynamics is challenging, because direct observations are typically dangerous or impractical, and most of the action occurs at depth. Modeling (e.g., Melnik and Sparks, 2002) and experimental (e.g., Mader et al., 2004) studies often provide the most robust evaluations, because it is relatively easy to modify conditions and thus derive information about dynamic and evolving processes which cannot be directly observed or measured. However, the effectiveness of these studies depends on knowledge of boundary conditions either from direct observation of eruptions themselves, or indirect evaluations of deposits.

Conduit systems are generally depicted, and modeled numerically, as consisting of a magma body at some depth with a cylindrical-shaped zone through which the magma rises to the surface. The ascending magma is composed of differing proportions of solid + fluid + gas phases, with conditions changing during ascent due to changes in pressure and composition. Bubble nucleation, growth, deformation, and fragmentation are important aspects of the models, and form the basis for many current research directions (e.g., Mader et al., 2004 and papers within).

Yet, it is also known that simplifying assumptions of discrete, stable conduit boundaries are unrealistic

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doi:10.1016/j.jvolgeores.2004.06.001

even for a single event, much less a series or cycle of eruptions (Jaupart, 2000).

How can field observations help? There are many potentially important field observations which could be of use to current theoretical and laboratory studies (e.g., Jaupart, 2000; Barmin et al., 2002; Melnik and Sparks, 2002; Gonnermann and Manga, 2003; Mangan et al., 2004; Speiler et al., 2004): information about the conduit shape and size; the stability of the conduit during an eruption, and over longer time periods; the "leakiness" of a conduit, with respect to location of summit emissions; and the rates and composition of emissions.

Few volcanoes allow regular, unobstructed observation of the summit activity during eruptive episodes. However, Santa María volcano (3772 m asl) and the related Santiaguito dome (2500 m) are uniquely situated to provide such a view. The devastating 1902 eruption of Santa María volcano erupted roughly 5–10 km^3 of dacite, removing much of the southwestern portion of the previously symmetrical cone, but preserving the summit. A repose period followed until 1922, when lava extrusion began in the 1902 crater, forming the Santiaguito dome at a point below the Santa María summit. Extrusive activity has continued unsteadily since 1922. The actual location of active venting has migrated somewhat from the central Caliente vent over the past 80 years along three westward-trending lateral vents. The present activity is focused on the Caliente vent, active since 1977 (Rose, 1987). It currently feeds a slowly advancing dacitic lava flow, with strombolian eruptions every 0.5 to 2 h producing a range of pyroclastic flows, block and ash flows, and ashfalls. During the rainy season, these materials deposited on Santiaguito's flanks are remobilized as lahars, often with destructive consequences for agriculture and transportation.

2. Methods

From the summit of Santa Maria, there is a clear view to the Santiaguito dome, approximately 2.5 km to the southwest. There are no recent topographic maps of the region. Using a pair of airphotos taken in January 2000 by the Bolivian Air Force and a stereoscope, we were able to measure the apparent distances from Santa Maria to Santiaguito summits, and the diameter of the Santiaguito summit crater. Comparing these measurements to topographic maps gives a summit crater diameter of approximately 180 m ($\pm$ 25 m).

We are developing an archive of digital video observations of the crater and activity from our annual field excursions (Bluth and Rose, 2002), beginning from January 2002 (Table 1). The duration of the video is constrained by light levels, with a 0600 local time typically as a start, and until daily meteorological cloud formation obscures the view (anywhere from 0900 to 1100). Activity generally consists of strombolian ash and steam eruptions, with minor gas exhalations also occurring between events. The eruptions vary in timing, and often occur in pairs separated by a few minutes repose. Fumaroles are present on the upper flanks, and also occur in various and changing locations within the summit crater.

Table 1
Video archive of Santiaguito volcanic activity

Date	Observation site	Observation period (local time)	Notes
January 11, 2002	Santa María summit	0627–0823	5 eruptions, 13 exhalations
January 9, 2003	El Brujo vent[a]	0610–1037	11 eruptions, 23 exhalations
January 11, 2003	Santa María summit	0545–0851	6 eruptions, 7 exhalations
January 15, 2004	Santa María summit	0619–0915	6 eruptions, 8 exhalations

[a] Approximately 1.5 km W of the active Caliente vent, at about 150 m lower elevation; thus, there is no direct observation of the dome surface from this location.

3. Observations and discussion

Fig. 1 shows a sequence of images taken from a typical Santiaguito eruption (chosen for its clarity). This sequence of images illustrates several key features.

3.1. "Ring"-shaped emission pattern

Fig. 1a–d shows the emissions emanating from a ring-shaped pattern of fractures. The emissions initiate

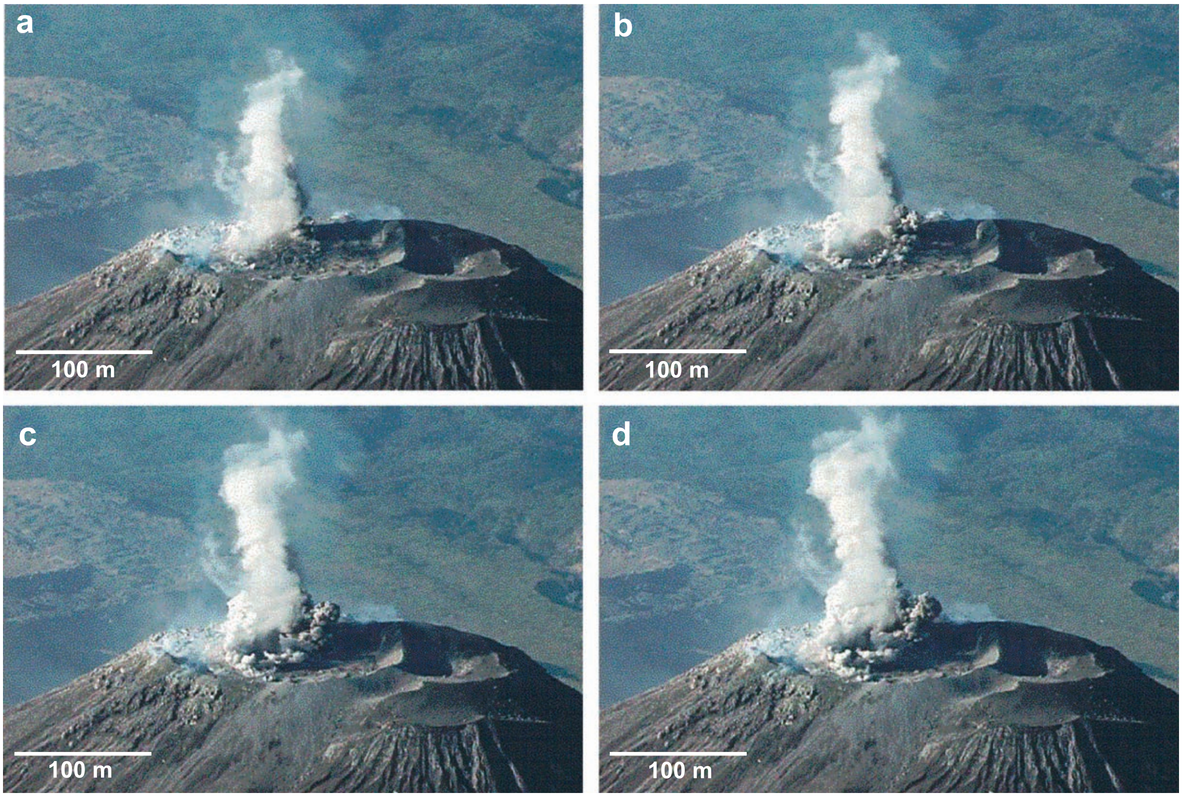

Fig. 1. (a–d) A time-sequence of a typical strombolian eruption at Santiaguito volcano, Guatemala. The photos are 1 s apart, and show the emissions emanating from a ring-shaped pattern within the summit dome. The ring diameter is approximately 70 m. View is towards the south; note the block-lava flow in the background.

at the circumference of the ring; overall, roughly 50% of the observed eruptions displayed this pattern. The eruptions are not purely confined to the ring; in some larger events, explosions are initiated in the ring, then migrate outwards. Note also that the emissions do not occur simultaneously around the ring. We have observed emissions from virtually the whole summit region during the set of eruptions, but never all at once. The ring diameter in Fig. 1 is estimated to be 70 m. It appears that the diameter has increased over time, with the 2003 ring measuring 90–100 m in diameter and the 2004 ring at about 120 m diameter.

This ring-shaped pattern of emissions is consistent with the cartoon model of a cylindrical conduit, perhaps with a conical widening at the summit. Shear-induced magma fragmentation, releasing gases particularly at the conduit wall boundaries has been hypothesized as typical of open-system degassing (e.g., Gonnermann and Manga, 2003). Monitoring the size of the conduit may be important for understanding the explosivity or eruption potential in active systems. Conduit diameter makes a significant different in eruption modeling studies; Barmin et al. (2002) used a diameter of 20 m, while Gonnermann and Manga (2003) and Mangan et al. (2004) assumed diameters of 40 and 50 m, respectively. For comparison, during its highly active period in 1997, the conduit at Soufriere Hills Volcano, Montserrat was estimated at 50–60 m diameter (Watts et al., 2002).

3.2. Eruption characteristics

The eruptions last for approximately 30–60 s of vigorous emissions, often followed by several minutes of gas fuming. The main components of the events are steam and fine ash. In one event, ballistics were observed of approximately 1 m in diameter, with the bombs landing down the flanks. Measurements of emission speed range from 5 to 30 m/s, with most occurring at about 10 m/s. The optimal sites for making these exit velocity measurements were perpendicular to our viewing angle, to minimize distortion from the emissions traveling either towards or away from our line of sight. Terminal plume heights varied from several hundred meters above the vent, to 1200+ m (i.e., above eye level from our Santa María vantage point). Studies of the eruption dynamics of some of these events in 2003 were made by Johnson et al. (2004).

Similar observations were recorded for the repetitive vulcanian eruptions of Soufriere Hills Volcano in 1997 (Druitt et al., 2002). Video monitoring suggested exit velocities of 40 to 140 m/s, with typically slower "jets" at the start of the eruption, and increasing about 10 s later in the eruption.

3.3. Inter-eruption observations

Between eruptive episodes, periods of white, steam emissions (termed "exhalations" here) can be observed, either as discrete puffs (lasting tens of seconds), or as long-lasting (up to 10 min) of small, continuous emissions from various locations within the summit crater. Constant degassing can be observed from numerous flank fumaroles, and occasionally through cracks in the summit surface. The

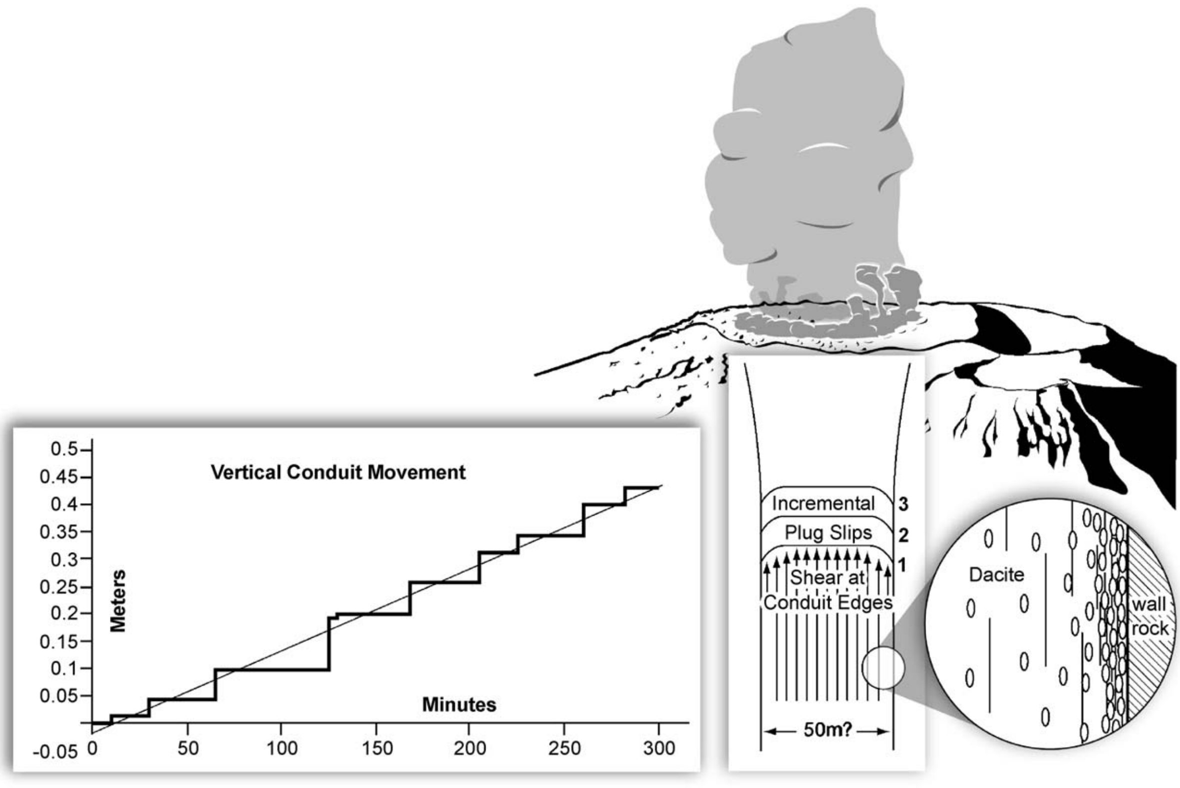

Fig. 2. Hypothetical scheme for the conduit processes at Santiaguito, based on surface observations. The plug flow extrusion of dacite comes through a cylindrical conduit that moves incrementally. In this representation, we show the rate of movement that would be associated with an average extrusion rate of 0.2 m^3/s, through a 50-m diameter conduit. The stepwise vertical conduit movement is compensated by surface flow to the south from the vent (into the page). The drawing here incorporates the incremental movement surfaces of the conduit (1, 2 and 3) which are exaggerated in the vertical scale (they are only a few centimeters in dimension). The detail at lower right envisions bubble formation preferentially along abundant slip surfaces near the conduit edge, which gives rise to the ring-shaped ash pulses. The set of fractures above the conduit may widen in a funnel-like fashion as shown here.

flank fumaroles appear unaffected by any eruptive activity (observed emitting even during eruptions), but within the summit the emissions often change locations, spontaneously initiating, then terminating over time.

3.4. A hypothetical conduit model

Fig. 2 depicts the incremental movement of plug flow extrusion of dacite through a cylindrical conduit, consistent with our video observations and measurements. Most of the shearing of dacite occurs near the conduit walls where bubbles preferentially form, which give rise to ash bursts. We assume a rate of movement that would be associated with an average extrusion rate of 0.2 m^3/s through a conduit 50 m in diameter. This is the low extrusion rate that prevails most of the time at Santiaguito, based on field and remote sensing observations (Harris et al., 2002, 2003). During accelerated extrusion periods, the rate increases by as much as an order of magnitude (Barmin et al., 2002). The stepwise vertical conduit movement is resolved by the surface extrusion of a block lava flow to the south (away in the schematic view drawn).

4. Ongoing work

Santa Maria volcano provides an excellent perspective for observations of summit eruption dynamics at Santiaguito volcano. We have multiple years of observations from which to study changes in emission geometry and timing, exit velocities, and many other pertinent details of emissions types and fates, and plan to continue these observations. We have collected samples of ash which fell from activity at the Caliente vent and lava samples from the ongoing lava dome extrusions. It will be important to evaluate our observations in detail over a multi-year period, in order to link our eruption observations with ongoing activity, for example, combining ring diameter evolution to extrusion rates and sulfur degassing fluxes. Seismic data will also help in understanding of the plug flow dynamics. The lava flow extrusion rates have been declining during this time period (2002–2004); the observed increase in conduit diameter may thus reflect a "sinking" of the cone-shaped structure at the top of the feeder conduit and give us additional clues as to the future activity of this persistently erupting system.

Acknowledgements

We thank our Guatemalan colleagues, Oto Matías and Rudiger Escobar, for field support and discussions, and both the INSIVUMEH and CONRED agencies for their continuing support of field studies. Partial funding for this work came from NSF Grant EAR 0118587 from the International-Americas Program.

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