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ScienceDirect
Journal of Volcanology and Geothermal Research 173 (2008) 1–14
Journal of volcanology and geothermal research
www.elsevier.com/locate/jvolgeores

Research paper

Thermal, seismic and infrasound observations of persistent explosive activity and conduit dynamics at Santiaguito lava dome, Guatemala

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Received 28 December 2006; accepted 25 November 2007
Available online 5 January 2008

Abstract

In January 2003 we deployed a seismo-acoustic array along with thermal sensors to define the dynamics and source characteristics of persistent, intermittent explosive activity at the Santiaguito lava dome, Guatemala. Seismic and acoustic waveforms accompanying thermal transients (i.e. the thermal signature produced by the vertical ash plumes) allowed discrimination of 35 explosions from minor degassing events during the 15.5 h observation period. Characteristics of thermal transients along with elastic and thermal energy flux from the explosive ash emissions allowed for a standardized measurement of eruption intensity, duration, frequency and repose interval. Using the thermal data we calculated a range of minimum exit velocities of 16–76 m/s and convective rise rates of 9–26 m/s to heights of 100 and 600 m above the vent. Source depths for the explosions were calculated using the thermo-acoustic delay, indicating a source 100–620 m below the vent. The intensity of the explosions, based on thermal amplitude and proxies for elastic energy released is not dependent on repose interval or depth. The data support the notion for shear-induced fragmentation at the conduit walls due to stick–slip movement of the upper, degassed, part of the magma column as a source mechanism. Loci of explosion depths suggest that this operates within a 500 m thick dacite plug in the uppermost portion of the conduit.

Keywords: Santiaguito; lava dome; conduit dynamics; thermal; infrasound

1. Introduction

Intermittent small-to-moderate-sized explosions (Volcanic Explosivity Index (VEI) of 2 are commonly observed at volcanoes which are characterized by persistent eruptive activity (Francis, 1993). This type of activity has persisted at the dacite lava dome complex of Santiaguito, Guatemala, since 1977, where repeated low energy explosions sending ash plumes to 1–4 km occur at a rate of approximately 1 event every 30 min (Rose, 1987). The intensity and frequency of explosions at Santiaguito are similar to the explosions observed at Stromboli, Italy, and have led previous workers to (incorrectly) classify these explosions as Strombolian or Strombolian-type eruptions (Bluth and Rose, 2004). The characteristic of the ash plumes produced by these explosions, however, more resembles that of weak vulcanian eruptions.

Similar styles of repetitive, low-intensity explosions at both basaltic (e.g. Stromboli) and silicic (e.g. Karymsky in Russia and Arenal in Costa Rica) volcanoes have been observed to generate both seismic and acoustic energy in the infrasonic range from an explosion source within the conduit. Integrating seismic and acoustic observations of these explosions have provided insights into the source mechanism of the explosions within the conduit (e.g. Braun and Ripepe, 1993; Vergniolle and Brandeis, 1996; Johnson et al., 1998; Chouet et al., 1999; Hagerty et al., 2000). Seismo-acoustic studies of such explosions at basaltic system such as Stromboli, Etna and Erebus suggest that bursting of discrete gas slugs at the magma free surface within the conduit as a source mechanism for generating low-intensity repetitive explosions (e.g. Blackburn et al., 1976; Braun and Ripepe, 1993; Ripepe and Braun, 1994; Vergniolle and Brandeis, 1994; Vergniolle and Brandeis, 1996; Chouet et al., 1999; Ripepe et al., 2002). At silicic volcanic systems such as Santiaguito, higher magma viscosity prevents formation of large discrete gas slugs. In addition, the conduit is typically

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0377-0273/$ - see front matter
doi:10.1016/j.jvolgeores.2007.11.026

capped by some form of obstruction, such as a dome or a lava plug, making a simple model involving bubble bursting at the free surface improbable. Rose (1987) and Sanchez-Bennet et al. (1992) suggested that, given the catchment-like geometry of Santa María and Santiaguito volcanic setting, explosions at Santiaguito may be phreato-magmatic. Johnson et al. (1998) proposed that similar repetitive explosions at Karymsky (analogous to Santiaguito explosions) are the result of cycles of gas buildup and release beneath an obstruction within the conduit. Recent dynamic conduit flow models ((Gonnermann and Manga, 2003) have led to a newer interpretation for the explosions at Santiaguito, and other similar systems, with the explosions resulting from shear-induced fragmentation due to intermittent rise of the dacite plug (Bluth and Rose, 2004).

To define and understand the conduit and eruption dynamics involved in the repeated explosive emissions at Santiaguito, a network of thermal, seismic and acoustic sensors was deployed in January 2003 to record the signals associated with the explosive events. The objectives of our study were twofold. First, to quantify the properties of the explosions, thereby providing a simple and consistent way for defining their character. The second was to gain insights into the subsurface source mechanism and conduit dynamics that generate such repeated, mildly explosive events at silicic systems.

Preliminary analysis and review of the data set was presented by Johnson et al. (2004). Johnson et al. (2004) selected 18 explosions from the data set and calculated exit and buoyant velocities using the thermal signal arrivals at two stacked thermal sensors. They also calculated cumulative seismic, acoustic and thermal energy released from these explosions and found positive correlation between thermal energy and buoyant rise rates. This study builds on and expands this preliminary study, and recalculates some of the initially given values. Johnson et al. (2004) considered just a section of the data set (18 explosions). Here we analyze all 35 explosions within the data set. We also fully detail and classify the thermal waveforms, while extracting new parameters, such as explosion intensity and duration, as well as velocity. In addition, we extend the Johnson et al. (2004) calculations for plume rise rates and cumulative released energy to examine how total energy released by each explosion is partitioned between thermal, seismic and acoustic energy. This allows us to determine whether all explosion types are generated by the same source mechanism. Finally, we carry out a new analysis that uses the delay between the arrivals of the thermal signal at sensors aimed at different heights above the vent to calculate the ascent velocity of the plumes. Following Ripepe et al. (2002) we use these velocities, along with the delay between thermal and acoustic arrivals, to determine the explosion source depth. These results are used to assess the applicability of a variety source models to describe the intermittent explosions at Santiaguito.

2. Background: Activity and vent structure at Santiaguito

Santiaguito is a dacite lava dome complex that formed within the explosion 1902 explosion crater on the southwestern flank of Santa María (Rose, 1972, 1987). Since 1922, eight cycles of lava extrusion from the central El Caliente vent and three lateral vents (La Mitad, El Monje and El Brujo) have formed a ~1.1 km^3 dome complex (Rose, 1987; Harris et al., 2003). Since 1977 the locus of volcanic activity has been at the primary El Caliente vent (Rose, 1987); the location of the initial extrusive activity during 1922–1939 (Rose, 1972). Since this time, intermittent explosions producing vertical ash plumes, typically reaching heights of ~1 to 2 km above the vent, has been the prominent type of activity (Rose, 1987; Fig. 1) along with extrusion of silicic lava flows (Rose, 1987; Harris et al., 2003, 2004).

Regular visual observations of these explosions are made by staff at the Santiaguito Volcano Observatory (OVSAN) of the Instituto Nacional de Vulcanologia, Meteorologia e Hidrologia (INSIVUMEH). In addition, a few snap-shot observations of the explosions have been made, each of a few hours in duration (Rose, 1987; Sanchez-Bennet et al., 1992; Bluth and Rose, 2004; Johnson et al., 2004; Sahetapy-Engel et al., 2004). However lack of geophysical monitoring capabilities and frequent cloud cover severely limit the amount of observations available for complete analysis. From visual observations made during 1999–2004, the frequency of the explosions is of the order of 1 to 2 events per hour but with occasional clusters of explosions occurring over a few minutes. The explosions generate vertical ash plumes which rise up to 3 km above the vent, but more typically ~1 km or less. Larger explosions are capable of feeding plumes that rise up to 4 km and generate small pyroclastic flows (Fig. 2.1). Bluth and Rose (2004) observed that the plumes generated by the explosions rise from a series of vents which form a ring around the 180 m-wide summit crater. They proposed that the ring-like configuration of the emission points was the surface expression of the flared top of the conduit. Source mechanisms for these explosions have not been explored in great detail but magma–water interaction (Rose, 1987; Sanchez-Bennet et al., 1992) and shear-induced fragmentation along the conduit walls due to unsteady flow (Bluth and Rose, 2004) have been proposed as potential mechanisms.

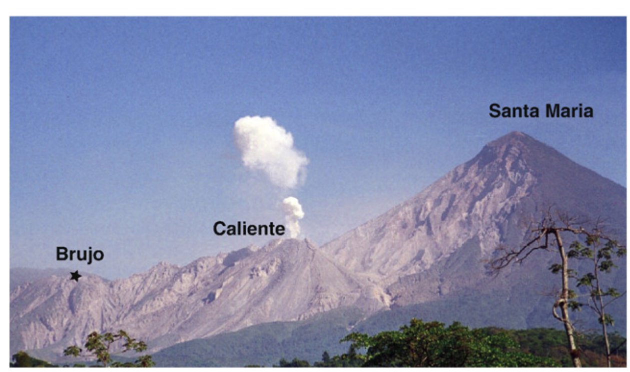

Fig. 1. Vertical ash plume from an explosion at the active Caliente vent of the Santiaguito lava dome complex, Guatemala. Image shows starting plume from ongoing emission, and detached thermal from an emission a few minutes prior. Santa Maria peak and scarp from the 1902 eruption of Santa Maria is visible to the right of Caliente vent. Deployment site was on top of Brujo dome, 1600 m west of Caliente vent (denoted by a black star).