Santiaguito in Guatemala during the 20th century

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Abstract. The Santiaguito volcano, which was active for past 83 years, has produced soda- rich, calc alkalic dacite lava. The volcanic activity has consisted in of endogenous extrusion, block- lava flows, Merapi type block and ash flows, vertical pyroclastics eruptions and lahars. The typical Eruption consists of 30- 60 s of vigorous emission. Bubble generation and shearing at the conduit boundaries produce the ring- shaped ash and gas pulses. Four lateral vents were developed, but the present activity is located at the Caliente vent.

1) Introduction

Thirty to forty thousand years of basaltic andesite volcanism at Santa Maria Volcano built the remarkably symmetrical composite cone (volume of 20 km³), which constitutes the most prominent physiographic feature of the area (Rose and others, 1977b). In 1902, one of the largest eruption ever mentioned in history emitted approximately 5 km³ of dacite in a period of 19 hours. After this event in 1902 a dormancy of 20 years followed. In 1922 a new lava extrusion began in the centre the crater created in 1902. The dome is called Santiaguito. It's building a dacite dome complex ~ 1200 m below and ~ 2500 SW of the Santa Maria complex (Rose, 1987). From 1922 to 1972 there were four periods of rapid extrusion separated by periods of little magma production. In last 80 years, 4 vents with a lateral extent of ~ 1,5 km have contributed ~ 1,1 km³ to the construction of the ~ 500 m edifice (Rose, 1987; Harris et al., 2003). Extrusive activity has continued unsteadily since 1922. The present activity is focused on the Caliente vent, active since 1977 (Rose, 1987).

The volcanic activity has consisted of endogenous extrusion, block flow lava, Merapi- type block and ash flows, vertical pyroclastic eruptions, and lahars. Santiaguito's magma is similar to the 1902 dacite, but slightly more mafic (Rose 1987). The ascending magma is composed of differing proportions of solid + fluid

+ gas phases, with conditions changing during ascent due to changes in pressure and compositions. It currently feeds a slowly advancing dacite lava flow, with small volcanian to strombolian eruption every 0, 5 to 2 h producing a range of pyroclastic flows, block and ash flows, and ash falls (Bluth; Rose, 2004). A bias in favour of vulcanian is that the magma leads to very explosive eruptions. During rainy season, these materials deposits on Santiaguito’s slope are evolving into lahars, often with destructive consequences for agriculture.
The highland tropical- monsoon climate coastal slope gives Santiaguito frequently fog. For this reason, it makes difficult to observe without a specific expedition.

1. Activity since 1922

During the last 80 years four vents are formed: Caliente, La Mitad, El Monje and El Brujo (Figure 1). The Santiaguito has constructed in six 3- 5- year spurts of extrusion, which were spaced at 10- 12- years intervals (Rose 1987). Some characterises in the erupted cycle are the cycle lasts from 6 to 15 years and a short 3- 5- years spurt of high extrusion is interspersed with a longer period of low extrusion (Rose 1987).

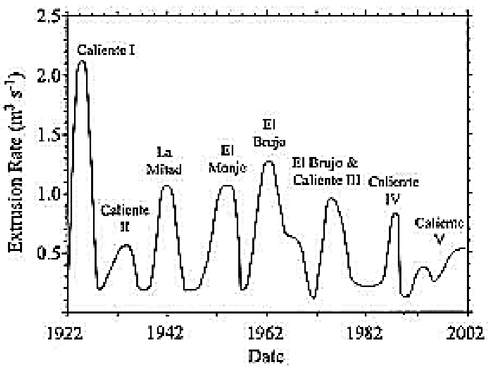

Figure 1: Estimated variation in extrusion rate since 1922 showing the eight main extrusion cycles during the period 1922-2002 (changed after Rose 1987).

During the eruptive spurts La Mitad from 1939- 1942, El Monje from 1949-1955 and the El Brujo from 1959- 1963 are developed. They are located along a west- trending line from the Caliente vent, which is formed in 1922. The La Mitad, El Monje and El Brujo have a short lived character, because of their inconsistent. After Rose 1987, the Caliente vent is the principal or central vent at Santiaguito where the magma rises from the depth, because of the location within the 1902 explosion crater.

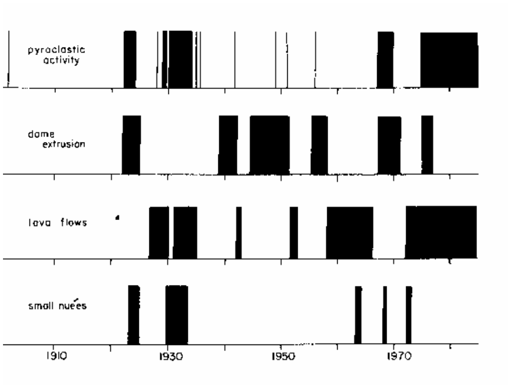

Figure 2: Schematic representation of the timing of different types of activity at Santiaguito (changed after Rose 1987).

After 1975 the rate of lava extrusion declined, but did not stop. The lava- flow activity at the El Brujo vent stopped and exogenous dome extrusion began. Roughly 1977 the activity ceased at the El Brujo. Since 1977, the Caliente vent is active. Almost all of the observation from Rose (1987) demonstrates the occurrence of vertical pyroclastic eruption from the Caliente vent. The eruption happened at intervals of 30 minutes to several hours, are generally a few minutes in length. They produce very fine- grained ash, occasionally produce accretionary lapilli, and sometimes eject bread- crust bombs of up to 1 m in diameter (Rose 1987). Each year the ash fall arrived at inhabitants areas. These eruption emit very little SO_2 and are accompanied by an engine- like noise.

The volcanic activity has consisted in of endogenous extrusion, block- lava flows, Merapi type block and ash flows, vertical pyroclastics eruptions, lahars and small nuées (Figure 2). The location of the Caliente vent is in the centre of the 1902 explosion crater, a location which is consistent with its being the locus of magma rise from depth. This crater location is also likely to funnel meteoric water to the magma column, because the crater obtained heavy rainfall, is not drained by rivers, and has a porous, composite cone structure (Rose 1987). The ash has a fine overall grain size. The morphology of the ash particles suggests a phreatomagmatic origin (Heiken, 1972, 1974). The Santiaguito dome is considered a low SO_2 emitter for instant 120 tones/ day, but it is one of Guatemala’s most dangerous volcanoes (Rodrigues et al. 2004). Furthermore, the low SO_2 concentration of the clouds from the eruption is consistent with the idea from Rose 1987. He interprets these eruptions as phreatomagmatic, but new work highlighting suggests unsteady flow in the conduit of volcanian flows (Barmin et al. 2000).

The periods of continuous degassing or fuming occur on different time scales from the sporadic ash explosion and consequently a wide range of SO2 emission was measured. This makes it difficult to determine the volcano’s background fluxes. It is hard to calculate the volume of ash produced by these eruptions, because the ash is dispersed widely in very thin beds. A cone of debris has been build to a thickness of 50 m around the vent. The debris covers the rough talus surface of the summit of the dome with a smooth carapace (Rose 1987).

In 1984, the active extrusion has displaced from the El Brujo vent back to Caliente. The significance of this shift is not clear (Rose 1987). The shifting represent the closing of the El Brujo vent, like the La Mitad vent in the early 1940s and at the El Monje vent in the 1950s (Figure 1). The regeneration of the Caliente vent, and its continuation since then, could be an important signal that the activity of the Santiaguito will shift completely back to the east side of the complex. If true, this shift is important to the volcanic hazard assessment (Rose 1987).

3. Observation of eruptive activity

3. 1. "Ring"- shaped emission pattern

Figure 3 shows the emissions emanating from a ring- shaped pattern within the summit dome. Approximately 50% of the observed eruption began in the circumference of the ring (Bluth, Rose 2004). In some larger events the explosions are initiated in the ring and migrate outwards. Also the emission does not take place simultaneously around the ring. The ring diameter in Figure 2 is roughly 70 m. In course of the time the ring diameter is increased, because the 2003 ring measured 90- 100 m in diameter the 2004 ring about 120 m in diameter (Bluth, Rose 2004).

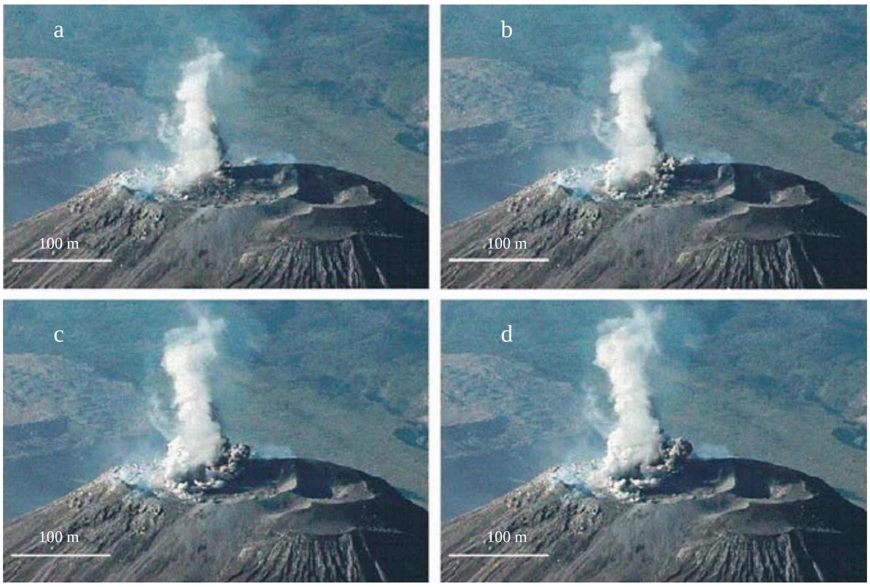

Figure 3: Typical eruption at Santiaguito volcano. The photos are 1 s apart, and show the ring pattern within the summit dome (modified after Bluth et al. 2004).

3. 2. Eruption characteristics

The eruptions take nearly 30- 60 s of intense emission and there are often followed by several minutes of gas fuming (Bluth and Rose 2004). The main components of the event are steam and fine ash and in some events bombs were observed with approximately 1 m in diameter. These bombs are landing down the flank. The emission speed is range from 5 to 30 m/s, but the most occurring at about 10 m/s. The plume heights varied from several hundred meters above the vent, to 1200+m.

3. 3. Inter- eruption observation

Between the eruption events there are periods of white, steam emission (termed “exhalation” here). The exhalation occur as discrete puffs which lasting tens of seconds, or as long- lasting which is up to 10 min of small, continuous emissions from various locations within the summit crater. From numerous flank fumaroles constant degassing can be observed, also occasionally through cracks in the summit surface. But flank fumaroles seem unaffected by any eruptive activity. But inside the summit emission often change locations (Bluth, Rose 2004).

3.4. A hypothetical conduit model

Figure 4 describes the gradual movement of plug flow extrusion of dacite through a cylindrical conduit. Most of the shearing of dacite occurs near the conduit walls where bubbles preferentially form, which give rise to ash bursts. Bluth and Rose (2004) suppose 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 dominates most of time at Santiaguito volcano, based on field and distal observation (Harris et al. 2002). The stepwise vertical conduit movement is resolved by the surface extrusion of a block lava flow (Bluth and Rose 2004)

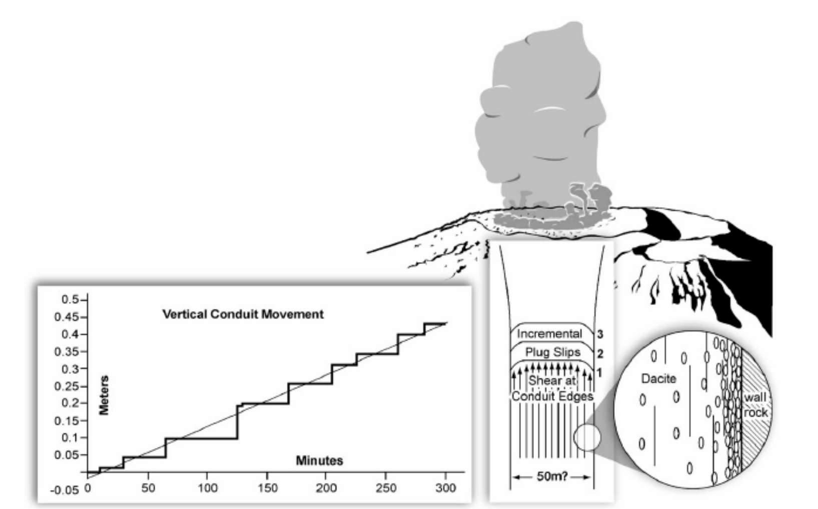

Figure 4: Hypothetical scheme for the conduit activity at Santiaguito (changed after Bluth and Rose 2004).

4. Surface temperature at Santiaguito lava dome

Sahetapy- Engel et al. (2004) used an infrared thermometer and digital video camera to observed and document short-term evolution of surface brightness temperature and morphology at Santiaguito lava dome. All measurements and observations were made from the summit of Volcano Santa Maria, 2, 5 km away from target area. The targeted area is situated in the NW sector of the summit that was showing the most activity at the initial time of the observation period. The thermometer dataset presents 40- 70 minute- long cooling cycles, each defined by a cooling curve that is both initiated and terminated by rapid increased in temperature due to regular ash venting.

The data collection was from 4:22 AM until 8:39 AM on January 11; 2002, continuous brightness temperature measurement were collected using a single-channel IR thermometer at 2 s sampling rate. These are integrated brightness temperature of surface that may or may not be thermally homogenous. They do not represent the absolute temperature of the surface because Sahetapy- Engel et al. (2004) did not take into account emission or atmospheric effects.

Four complete cooling cycles (Figure 4) in between 42 and 72 minutes long can be distinguished from the dataset of the IR thermometer (Sahetapy- Engel et al. 2004). Digital video footage is available for the entire duration of cooling cycle 4, allowing linkage of thermal signatures to specific events.

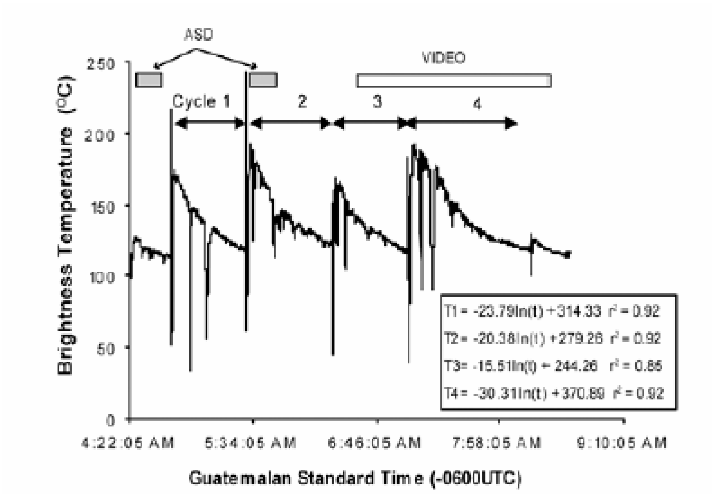

Figure 4: IR thermometer dataset showing the cyclic variations of temperature with time. Four cooling cycles are distinguished, refers as cycles 1- 4 (modified after Sahetapy- Engel et al. 2004)

Figure 5 demonstrate a summary of the video observed events during cooling cycle 4. The temperature spike at the onset of the cycle agree with the relatively energetic ash- rich plume emission event (Figure 5 (mark i)). A ~ 30 minute- long period of intermittent emission of light- colored gas- rich, low- energy plumes from a vent within the observation area occurred mid- cycle (Figure 5 (mark ii)). Two isolated exhalation of light- colored plumes occur toward the end of the cycle but fail to register any thermal signature in the dataset (Figure 5 (mark iii)). The absent of thermal signature suggests that the two plumes nay be roughly at the same temperature as the dome surface.

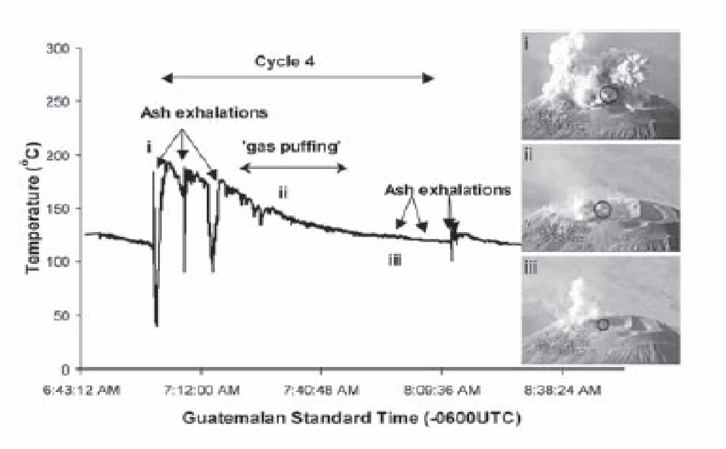

Figure 5: IR temperature measurement for the thermal cycle 4 with associated physical events observed from digital footage. Three capture images show: (i) ash eruption at the initiation of the cycle, (ii) mid- cycle semi continuous gas puffing and (iii) small plumes with no thermal signature (changed after Sahetapy- Engel et al. 2004)

Using the IR thermometer dataset and video observation, Sahetapy- Engel et al. (2004) recognize that each cooling cycle is initiated and terminated by a thermal resurfacing event which is temporally synchronous with the periodic ash eruptions.

5. Block lava flows

Constant effusive activity from four distinct vents (El Caliente, La Mitad, El Monje, and El Brujo) has construct a ~ 1 km³ complex of overlapping domes and block flows in the centre of the 1902 crater. Since 1958, activity has been characterized by an increasing prominence of block flow, as opposed to dome emplacement. Beginning in 1975, the cone around the Caliente was refracting to the south, and al block- lava flow began to emerge. This lava flow remains as a coherent unit for about 400 m south of the vent, at which point the slope over which it is flowing greatly steepness. Here the flow front continually overstepping, developing rock falls of incandescent lava and/ or block and ash flows (Rose 1987). This type of action is called "Merapi- Type" (Williams and McBirney, 1979)

Thick, slow- moving block- lava flows are combined with extrusive activity in dacite systems, where lava- core depressurization during flow front collapse develops dangerous block- and- ash flows.

The block- lava flow surface consist of a thick (1, 9- 3, 4 m), cool (40- 111°C) crust of meter size, subangular blocks (Harris et al 2002). Santiaguito block- flow surface are consisting of angular to rounded dacite blocks, similar in form to the rubble- like surfaces that cover the dome units within the complex.

Harris et al. (2002) divided the flow into three thermally distinguishable sections: proximal, medial- distal, and toe (Figure 4).

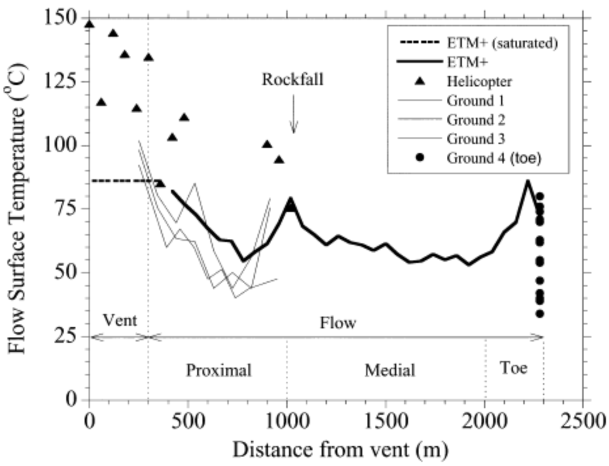

Figure 6: Down- flow surface- temperature profile from helicopter, ground- based and temperature measurements (modified after Harris et al. 2002)

The proximal flow section is characterized by relatively high surface temperature. The medial- distal section is defined by relatively low temperature and is it extends from the point at which the flow reaches the base of the dome.
The flow toe includes the flow front and is characterized by an increase in temperature. The flow had a width of ~ 200 m and a flow- front perimeter and high of ~ 260 m and 18- 30 m (Harris et al. 2002). The flow surface consisted of a blocky crust with temperature of 34- 80 °C and 56- 86 °C (Harris et al. 2002). Thinner, hotter surface crusts are characterized by two processes: avalanching of surface crust at the flow- front perimeter to expose hotter surface and spreading and thinning the flow across the toe section (Harris et al. 2002).

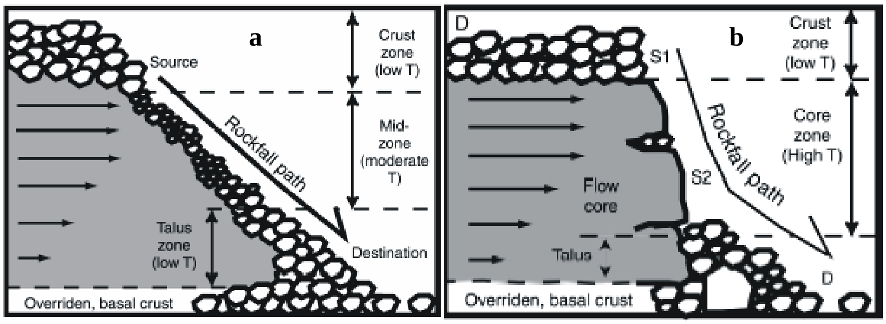

Figure 8: a, b) Cartoons showing a cross section through the flow. Arrow lengths in block flow are proportional to velocity. b) Plug flow results in collapse of the upper flow front (modified after Harris et al. (2002)).

Harris et al. (2002) observed two simultaneous mechanisms: (1) flow front oversteepening and collapse to cause caterpillar- track- type advance and pushing aside of frontal crust and (2) forward extrusion of the flow core through the frontal crust. Vertically, the plug dominates the top half of the flow, creating an upper high- velocity collapsing zone and a lower- velocity basal shear zone. In this case, higher velocities at the flow top will result in oversteepening and subsequent instability and collapse of the upper zone (Figure8).
In the south of Santiaguito, there are laharic depositions which correlate with the monsoon rain. For example, in July and August of 1983 a lahar affected the town of El Palmar, 10 km south and 1900 below Santiaguito (Rose 1987).

7. References

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