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A geochemical and geophysical investigation of the hydrothermal complex of Masaya volcano, Nicaragua

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ABSTRACT

Masaya volcano, Nicaragua, is a persistently active volcano characterized by continuous passive degassing for more than 150 years through the open vent of Santiago crater. This study applies self-potential, soil CO_2 and ground temperature measurements to highlight the existence of uprising fluids associated to diffuse degassing structures throughout the volcano. The diffuse degassing areas are organized in a semi-circular pattern and coincide with several visible and inferred surface volcanic structures (cones, fissure vents) and likely consist of a network of buried faults and dykes that respectively channel uprising flow and act as barrier to gravitational groundwater flow. Water depths have been estimated by multi-scale wavelet tomography of the self-potential data using wavelets from the Poisson kernel family. Compared to previous water flow models, our water depth estimates are shallower and mimic the topography, typically less than 150 m below the surface. Between 2006 and 2010, the depths of rising fluids along the survey profiles remained stable suggesting that hydrothermal activity is in a steady state. This stable activity correlates well with the consistency of the volcanic activity expressed at the surface by the continuously passive degassing.
When compared to previous structural models of the caldera floor, it appears that the diffuse degassing structures have an important effect on the path that shallow groundwater follows to reach the Laguna de Masaya in the eastern part of the caldera. The hydrogeological system is therefore more complex than previously published models and our new structural model implies that the flow of shallow groundwater must bypass the intrusions to reach the Laguna de Masaya. Furthermore, these diffuse degassing structures show clear evidence of activity and must be connected to a shallow magmatic or hydrothermal reservoir beneath the caldera. As such, the heat budget for Masaya must be significantly larger than previously estimated.

1. Introduction

Masaya volcano, Nicaragua (11.984°N, 86.161°W, 635 m), is a basaltic shield system consisting of a summit caldera (~11.5 × 6 km) hosting numerous cinder cones, pit craters and fissure vents (McBirney, 1956; Williams, 1983b; Rymer et al., 1998; Acocella, 2007; Harris, 2009) (Fig. 1). The summit caldera is the result of several collapse events (McBirney, 1956; Crenshaw et al., 1982), which are now covered by numerous lava flows that partially fill the caldera (Williams, 1983a; Walker et al., 1993). Since the pioneering work of McBirney (1956), several studies have supported the hypothesis of structural limits controlling the volcanic vent distribution (cinder cones and fissure vents) within the caldera (Williams, 1983a; Maciejewski, 1998), however, different models have been suggested to explain this distribution. Based on field observations, it appears that three of the fissure vents (e.g., the 1772 fissure vent; Fig. 1) have a similar orientation to the main regional Cofradrias fault (N5°E) (Williams, 1983a). Other volcanic structures are oriented differently, such as Masaya cone (N70°E), Nindiri cone (N54°E) and San Pedro fault (N48°E), which suggests a more complex structural influence on the shallow magmatic system (Fig. 1). Field observations suggest that the San Pedro fault (Fig. 2b) is in fact a fissure vent cutting through the west flank of Nindiri cone, starting at the top of San Pedro crater and stopping near Cerro Montozo cone (Fig. 1). On a smaller scale, Masaya and Nindiri cones show signs of collapse with the formation of pit craters (Santiago, San Pedro and San Fernando craters) and subsidence of Nindiri lava lake. Signs of normal faulting are present on the crater walls of Santiago, San Pedro and San Fernando craters (Rymer et al., 1998; Roche et al., 2001; Harris, 2009). Thus, at least in the south part of the caldera, fissure vents and pit craters may be connected at depth by both dykes and faults to a shallow magma chamber. In addition, a normal fault plane (NE–SW strike) associated with fumarolic activity, has been characterized by a previous geophysical study (magnetism and self-potential) across Comalito cone and the fissure vent on the north side of Masaya cone (Pearson, 2010). Earlier geophysical studies (Bouguer gravity mapping), aimed at

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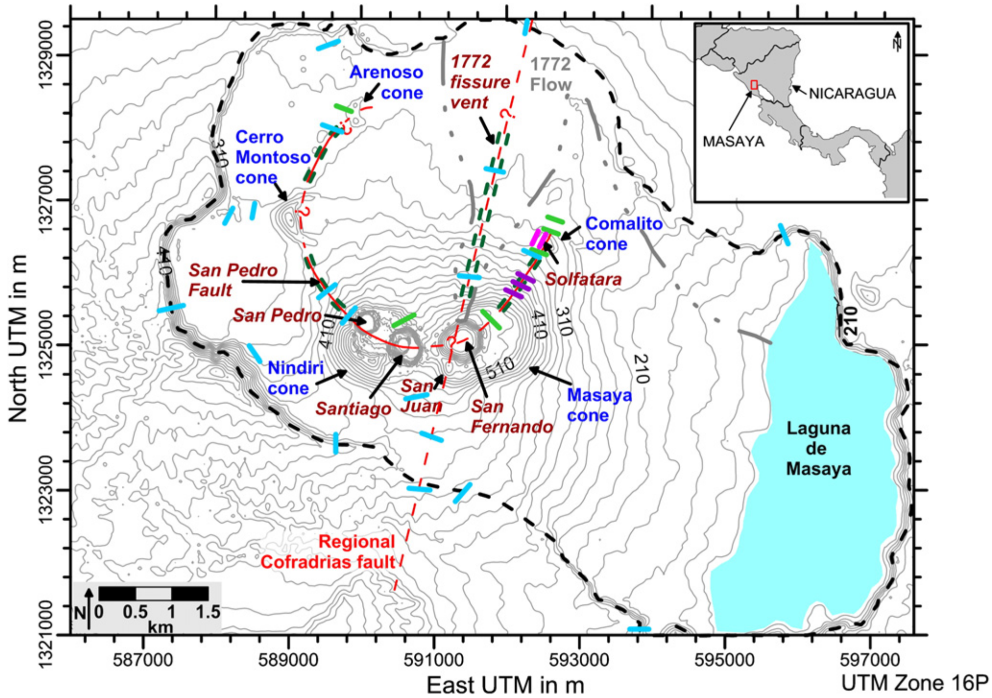

Fig. 1. Masaya caldera, Nicaragua with the post-caldera volcanic cones in blue. The crater names and ground structures are in red. The dark green dashed lines represent the fissure vent structures. Solid red lines are the inferred structure (Crenshaw et al., 1982; Harris, 2009) while the red dashed lines represent hypothetical structures (Crenshaw et al., 1982). The black dashed line is the inferred limit of the caldera. The grey dashed line represents the margins of the 1772 lava flow. Approximate location of previously published soil gas anomalies are represented in light blue (Crenshaw et al., 1982), light green (St-Amand, 1999), pink (Lewicki et al., 2003) and purple (Pearson, 2010).

determining the sources controlling these volcanic structures, were inconclusive due to small density contrasts between the rock formations and insufficient survey stations (Connor and Williams, 1990; Metaxian, 1994). One model suggests that the distribution of both fissure vents and cinder cones is controlled by the regional tensional stress associated to regional faults (Williams, 1983a), while another model suggests that the volcanic structures are associated to cone-sheets or ring-dykes that cut through the caldera (McBirney, 1956; Crenshaw et al., 1982; Maciejewski, 1998). While it is likely that regional faults influence the shallow magmatic system, it is also likely that more local effects, such as depth and shape of a magma chamber, play significant roles in the distribution of the volcanic vents.

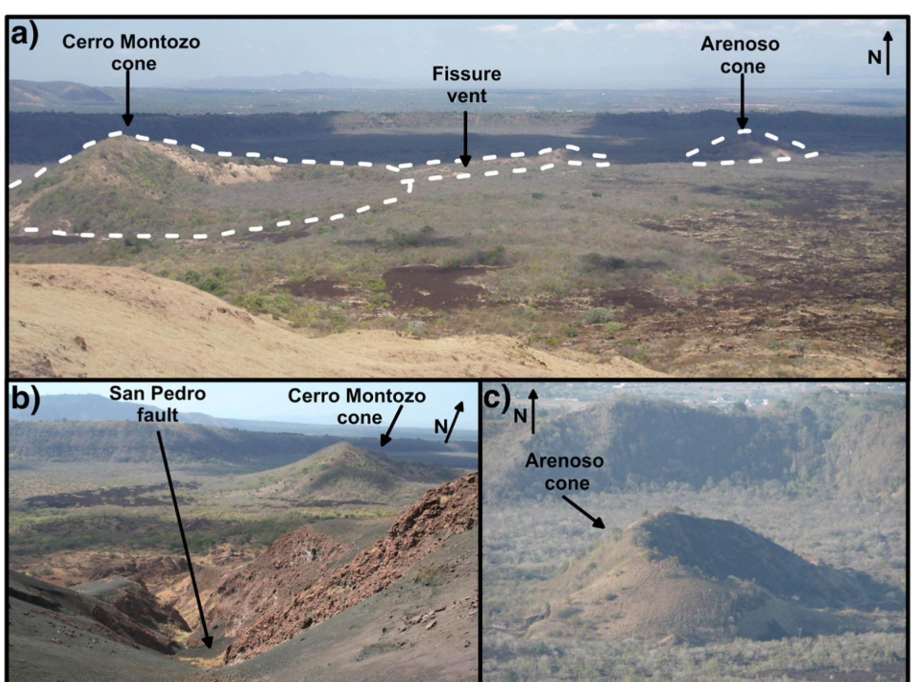

Fig. 2. Field photos showing the lineament of cinder cones and volcanic fissures. a) View of Cerro Montozo cone, Arenoso cone and one volcanic fissure. b) San Pedro fault cutting through Nindiri cone, connects San Pedro crater to Cerro Montoso cone. c) View of Arenoso cone, which is the furthest north of the volcanic cones within Masaya caldera.