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Adventive hydrothermal circulation on Stromboli volcano (Aeolian Islands, Italy) revealed by geophysical and geochemical approaches: Implications for general fluid flow models on volcanoes

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ABSTRACT

On March 15th 2007 a paroxysmal explosion occurred at the Stromboli volcano. This event generated a large amount of products, mostly lithic blocks, some of which impacted the ground as far as down to 200 m a.s.l., about 1.5 km far away from the active vents. Two days after the explosion, a new vapour emission was discovered on the north-eastern flank of the volcanic edifice, at 560 m a.s.l., just above the area called "Nel Cannestrà". This new vapour emission was due to a block impact. In order to investigate the block impact area to understand the appearance of the vapour emission, we conducted on May 2008 a multidisciplinary study involving Electrical Resistivity Tomography (ERT), Ground Penetrating Radar (GPR), Self-Potential (SP), CO_2 soil diffuse degassing and soil temperature surveys. This complementary data set revealed the presence of an anomalous conductive body, probably related to a shallow hydrothermal level, at about 10–15 m depth, more or less parallel to the topography. It is the first time that such a hydrothermal fluid flow, with a temperature close to the water boiling point (76 °C) has been evidenced at Stromboli at this low elevation on the flank of the edifice. The ERT results suggest a possible link between (1) the main central hydrothermal system of Stromboli, located just above the plumbing system feeding the active vents, with a maximum of subsurface soil temperature close to 90 °C and limited by the NeoStromboli summit crater boundary and (2) the investigated area of Nel Cannestrà, at ~500 m a.s.l., a buried eruptive fissure active 9 ka ago. In parallel, SP and CO_2 soil diffuse degassing measurements suggest in this sector at slightly lower elevation from the block impact crater a magmatic and hydrothermal fluid rising system along the N41° regional fault. A complementary ERT profile, on May 2009, carried out from the NeoStromboli crater boundary down to the block impact crater displayed a flank fluid flow apparently connected to a deeper system. The concept of shallow hydrothermal level have been compared to similar ERT results recently obtained on Mount Etna and La Fossa cone of Vulcano. This information needs to be taken into account in general fluid flow models on volcanoes. In particular, peripheral thermal waters (as those bordering the north-eastern coast of Stromboli) could be contaminated by hydrothermal and magmatic fluids coming from regional faults but also from the summit.

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1. Introduction

Stromboli volcano is located in the northern part of the Aeolian archipelago in the Tyrrhenian Sea. During the last millennium, Stromboli has been characterized by a permanent mild explosive activity (Rosi et al., 2000) sometimes interrupted by paroxysmal events producing ballistics that damaged also the inhabited lower part of the island. Since 1900, seventeen paroxysmal events have been evidenced. Fifteen paroxysms were recorded between 1906 and 1954 (Barberi et al., 1993). The two last paroxysms occurred on April 5th 2003 (Bonaccorso et al., 2003; Calvari et al., 2005; Calvari et al., 2006) and March 15th 2007 (Patanè et al., 2007; Carapezza et al., 2008; Neri and Lanzafame, 2008; Barberi et al., 2009; Rizzo et al., 2009). During the last event on March 15th 2007, several blocks of metric size impacted also the flanks of the volcano at an elevation of ~500 m a.s.l. The impact of one of those blocks, located at an elevation of 560 m a.s.l., just above the northern part of the island called "Nel Cannestrà", triggered a new vapour emission zone, which was first observed on March 17th 2007 (Fig. 1a). In the same area is located the Nel Cannestrà eruptive fissure active 9 ka ago (S. Calvari, pers. comm.), and aligned with the N41° regional fault (Fig. 1b) of several tens of km long crossing the Aeolian archipelago. This sector is also a preferential CO_2 degassing area where a permanent CO_2 flux monitoring station has been installed in 2007 (Carapezza et al., 2008).

In the last decade, several geophysical and geochemical campaigns of measurements were carried out on Stromboli Island in order to delineate the hydrothermal circulation (Finizola et al., 2002, 2003; Revil et al., 2004; Finizola et al., 2006, 2009). At the scale of the Island, the lateral extension of the hydrothermal system of Stromboli seems to be well controlled by the NeoStromboli crater boundary ("NEO STR" in Fig. 1b) down to the investigated depth ~215 m of the electrical resistivity tomographies performed to date (see Finizola et al., 2006).

During the last two eruptive crises of Stromboli (in 2002–2003 and in 2007), extensive surveys were performed to look for gas geochemical precursors before the onset of the eruption and the paroxysmal activity (Carapezza et al., 2004; Inguaggiato and Rizzo, 2004; Capasso et al., 2005; Carapezza et al., 2008; Rizzo et al., 2009). These surveys focused on different areas: the summit where the flux of CO_2 from the soil was monitored, as well as Rina Grande (675 m a.s.l.) and Nel Cannestrà (525 m a.s.l.) areas, and along the north-eastern coast where dissolved gases (CO_2, H_2, and He) in thermal waters were analysed. For both eruptive crises, gas anomalies were clearly identified. It is interesting to note that precursors in the thermal waters (dissolved CO_2 amount) appeared about five months before the 2002 eruption onset while high anomalous values of the flux of the CO_2 were recorded at the crater rim only one week before the 2002 eruption onset (Carapezza et al., 2004). These results suggested that a direct magmatic gas contamination rose in the thermal waters located on the north-eastern coast of Stromboli. Such hypothesis is also supported by the He isotopic ratios of the thermal waters that were significantly higher (R/Ra closer to the magmatic end-member) than the summit fumaroles (Inguaggiato and Rizzo, 2004; Capasso et al., 2005; Rizzo et al., 2009). Dissolved gases in the thermal waters of Stromboli are now considered to be a good precursor for the ascent of magma.

In the present paper, we focus on area characterized by vapour emission first observed on March 17th 2007 and associated with a block impact crater. This active fluid flow area, of about 80 m² (an

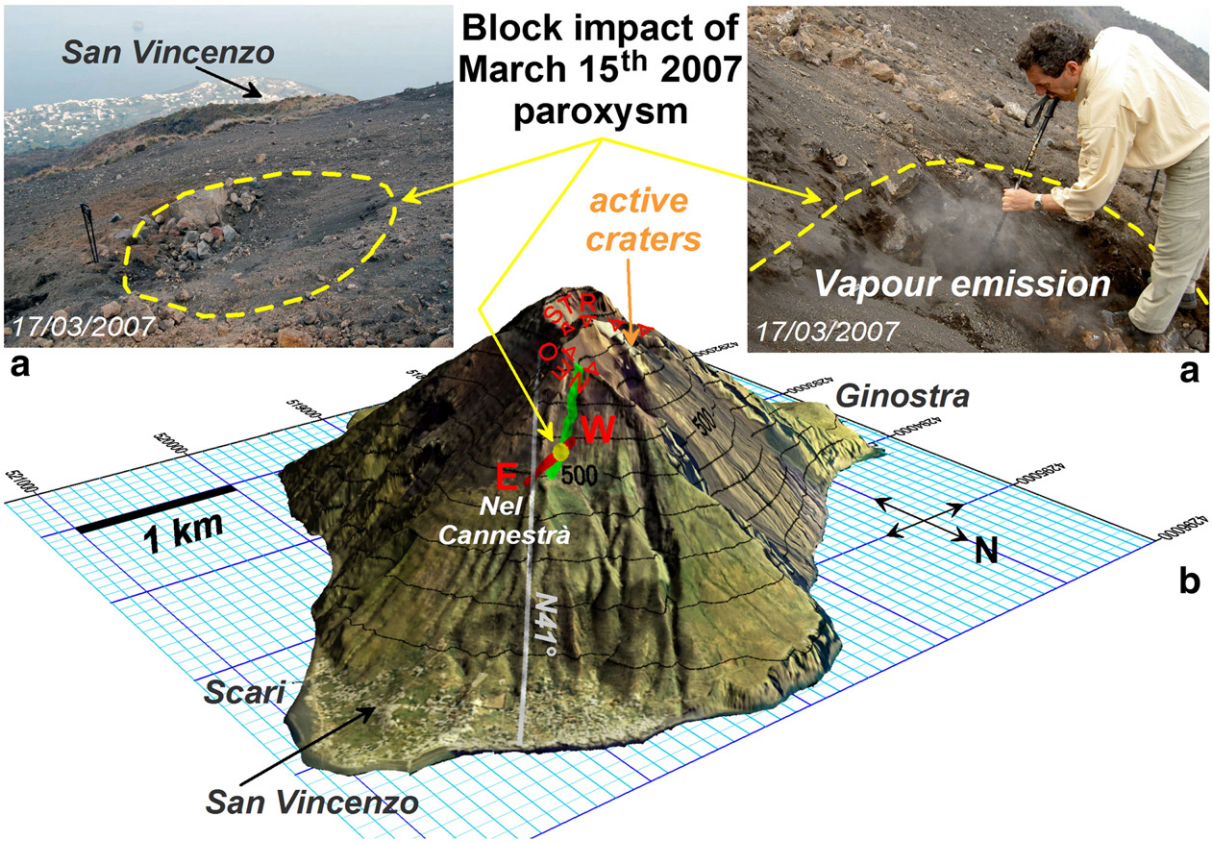

Fig. 1. a: Pictures of the block impact crater that occurred during the March 15th, 2007 paroxysm at Stromboli volcano. The picture on the left is a courtesy from M. Rosi. b: Orthophoto of Stromboli volcano (Marsella et al., 2009) superimposed with a digital elevation model of the edifice. The red W–E line corresponds to the profile performed in May 2008 using resistivity tomography, georadar, temperature, self-potential, and CO_2 flux measurements. The green line corresponds to the resistivity profile performed in May 2009. The grey line represents the N41° regional fault (Finizola et al., 2002). The black lines correspond to the isoaltitude with a spacing of 100 m. The label "NEO STR" stands for NeoStromboli crater boundary. The coordinates are in UTM(m)-WGS84.