Research Networking Programmes

Short Visit Grant ☐ or Exchange Visit Grant ☒

(please tick the relevant box)

Scientific Report

Proposal title: Quantitative assessment of lava flow hazard at Pico Island, Portuguese Azores

Proponent Institution: Istituto Nazionale di Geofisica e Vulcanologia (INGV), Osservatorio Etneo, Sezione di Catania, Italy

Host Institution: Centro de Vulcanologia e Avaliação de Riscos Geológicos (CVARG), Universidade dos Açores, Portugal

Key Personel: Annalisa Cappello (Research Fellow at INGV-Catania)

Application reference N°: 4258

1) Purpose of the visit

The purpose of the visit was the development of the lava flow hazard map at Pico Island, in the Azores archipelago. The methodology used, successfully tested at Etna volcano [*Del Negro et al.,* 2013], is based on the following steps: (i) computation of the spatiotemporal probability map of future vent opening, (ii) characterization of the expected eruptions, (iii) execution of lava flow simulations by the MAGFLOW model, and (iv) computation of lava flow invasion probability. The methodology was applied to Pico Island, which was built by a succession of eruptions of fluid basaltic lava flows, as at Etna, to identify areas most likely to be invaded in the future by eruptive products. The lava flow hazard map may help local authorities to mitigate the volcanic risk, making the necessary decisions to deal with ongoing eruptions and to plan long-term land use.

2) Description of the work carried out during the visit

Pico Island is the youngest island of the Azores archipelago. It is characterized by two main morpho-tectonic units: the stratovolcano of Pico Mountain (2351 m a.s.l.) on the western sector, which is the highest mountain of the Mid-Atlantic Ridge, and the "Planalto da Achada" fissure zone that extends along the central part of the island from its eastern termination to Pico Mountain (Figure 1).

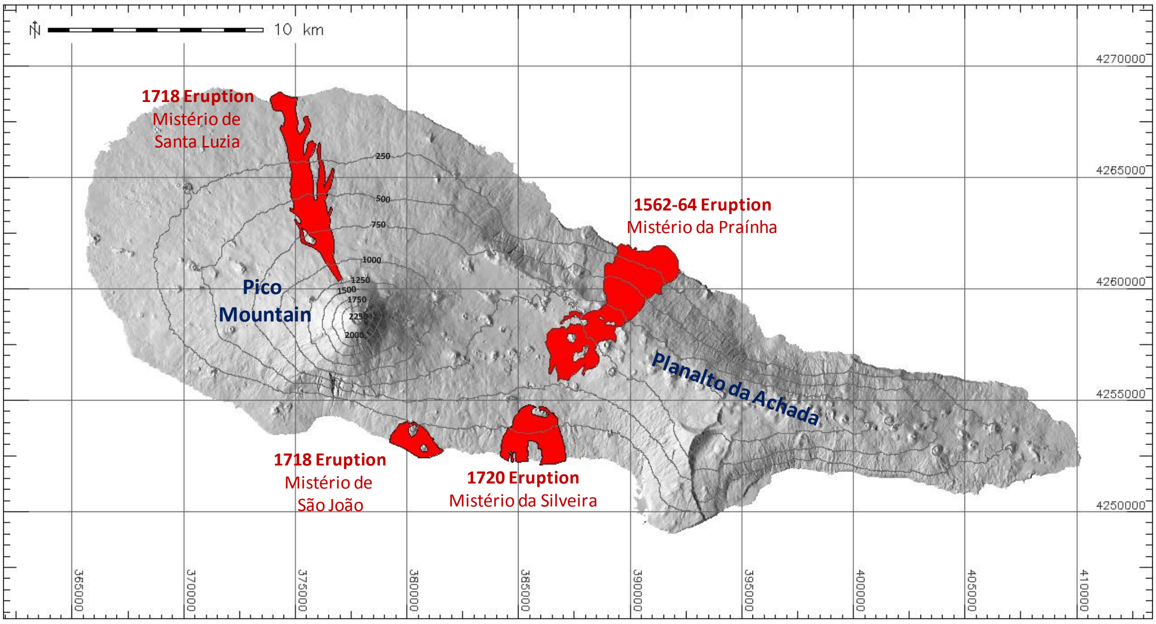

Figure 1 – Main morpho-tectonic units of Pico island – Pico Mountain and "Planalto da Achada" – and the lava flow fields of the recorded historical eruptions. Coordinates are in UTM – WGS84 (zone 26N).

The most recent volcanic activity took place both in the Pico Mountain flank vents and the "Planalto da Achada" fissure zone [*Nunes,* 1999]. The first eruption of Pico is recorded in 1562 (Mistério da Praínha), with the lava flow run to the northern slope of the island. Other two flank eruptions, one to the north (Mistério de Santa Luzia) and one to the south (Mistério de São João), occurred in 1718. The last documented eruption was in 1720 (Mistério da Silveira) on the south of the mountain (Figure 1).
The first activity carried out at the CVARG was the simulations of the historical eruptions of Pico to calibrate the MAGFLOW model and define the possible eruptive future scenarios. Then, the lava flow hazard map was developed as follows:

- *Computation of the spatiotemporal probability map of future vent opening*

The computation of the spatiotemporal probability map of future vent opening was based on the analysis of the spatial distribution of volcanic and geological structures, and on the eruption frequency within a time window. These data are generally inferred by field measurements (if available), literature data, geological maps, orthophotos, aerial photographs, and all historical information of the island. At Pico, the spatiotemporal probability map was built by considering the locations of eruptive fissures identified using the geological map and the aerial photographs, and a constant eruption frequency. A 250-m spaced grid of potential vents $v_i(x,y)$ was defined over the whole island and a spatial probability was calculated with the formula of the Gaussian kernel. The smoothing factor was estimated using the Least Squares Cross-Validation [*Cappello et al.,* 2012; 2013; *Bartolini et al.,* 2013]. Finally the spatiotemporal probability map for future opening was calculated as:

$$p_a(v_i, \Delta t) = 1 - \exp(-\lambda_{xy} \Delta x \Delta y \lambda_t \Delta t) \quad (1)$$

where λ_{xy} is the spatial probability of vent opening and λ_t is the annual rate calculated considering the number of historical eruptions occurred in the last 450 years. Thereby p_a specifies the probability of activation of each potential vent $v_i(x,y)$, i.e. the probability that at least one eruption will occur in the unit area ΔxΔy (250 m × 250 m) within the considered Δt time period (500 years).

- *Characterization of the expected eruptions*

The characterization of the expected eruptions exploits the knowledge of data related to the historical effusive eruptions. On the basis of information about eruption duration and the lava flow volume, two different eruptive classes were identified, one for Pico Mountain and one for the "Planalto da Achada" fissure zone.

- *Execution of lava flow simulations by the MAGFLOW model*

The numerical simulations were performed using MAGFLOW cellular automaton model, which has been successfully used to simulate lava flow paths during effusive eruptions and paroxysmal events [*Vicari et al.,* 2007; 2009; 2011b; *Hérault et al.,* 2009; *Ganci et al.,* 2012], and to produce hazard maps of lava flow invasion [*Cappello et al.,* 2011a; 2011b; *Vicari et al.,* 2011a]. MAGFLOW is based on a two-dimensional structure with cells described by five scalar quantities: ground elevation, lava thickness, heat quantity, temperature, and amount of solidified lava. The system evolution is purely local, with each cell evolving according to its present status and the status of its eight immediate neighbors. The ground elevation is provided by the Digital Elevation Model (DEM). Lava thickness varies according to lava influx between source cells and any neighboring cells. Lava flux between cells is determined according to the height difference in the lava using a steady-state solution for the one-dimensional Navier-Stokes equation for Bingham fluids, coupled with a simplified heat transfer model [*Vicari et al.,* 2007; *Bilotta et al.,* 2012]. Rheological properties are modeled using a variable viscosity relationship by *Giordano and Dingwell* [2003], parameterized in terms of temperature and water content [*Del Negro et al.,* 2008].
To determine the lava flow emplacement, MAGFLOW requires several input parameters, among these: the digital representation of the topography, the physical properties of the lava, an estimate of the effusion rate, and the location of the eruptive vent. As digital representation of the topography, a 10-m resolution DEM of Pico Island was used. The physical parameters arose from the petrological and chemical properties of the erupted lavas [*V. Zanon*, personal communication; *Métrich et al.,* 2013; *Zanon and*

Frezzotti, 2013]. The effusion rate was considered as a bell-shaped curve [Vicari et al., 2007], reaching the peak after a 1/6 of the entire time of simulation and then gradually decreasing until the end of the eruption. The locations of the eruptive vents were the nodes of the 250-m spaced grid of potential vents, from which a simulation was executed, depending on the locations of vent at the central volcano or the fissure zone.

- *Computation of lava flow invasion probability*

Finally the lava flow invasion hazard map was compiled by considering the probability of activation p_a and the overlaps of the simulated lava flows:

$$Haz(x, y, \Delta t) = 1 - \prod_{i=1}^{M} (1 - p_a(v_i, \Delta t)) \qquad (2)$$

where M is the number of MAGFLOW simulations emitted by vent v_i invading the point (x,y), and $p_a(v_i, \Delta t)$ is the spatiotemporal probability of opening for vent v_i in the next Δt years. Thus $Haz(x,y,\Delta t)$ is the probability of point (x,y) to be affected by at least a lava flow in the next Δt years.

3) Description of the main results obtained

The main results obtained within the exchange visit at the CVARG are:

- the collection of information regarding historical eruptions of Pico Island, including geological, physical, chemical and volcano-structural data;
- the spatiotemporal probability map of future vent opening in Pico Island, which was built by considering the location of eruptive fissures;
- the hazard map by lava flow inundation, which was compiled by considering the spatiotemporal probability of future vent opening and the overlaps of MAGFLOW numerical simulations.

4) Future collaboration with host institution

The aim of the exchange visit to the CVARG was to strengthen the scientific cooperation between the Volcanology Research Group of the CVARG and the INGV of Catania. The visit undoubtedly enhanced the knowledge on Pico Island, producing extremely promising scientific results that will soon lead to the publications of joint scientific papers. The visit has also given the chance to plan common research activities and projects in the next years.

5) Projected publications / articles resulting or to result from the grant

A co-authored INGV-CVARG publication about the hazard map by lava flow inundation at Pico Island is in preparation. It is also expected that other works born from the collaboration between INGV and CVARG will be published in the next future. Obviously ESF will be duly acknowledged in all publications and communications.

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