GSA DATA REPOSITORY 2015319

"Hydrothermal fluid flow disruptions evidenced by sub-surface changes in heat transfer modality: the La Fossa cone of Vulcano case study"

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Supplementary material

This file includes text and figures that are divided into three data repository items:

Data repository Item DR1: Configuration of the temperature monitoring stations.

Data repository Item DR2: Characterization of seismicity related to fluid dynamics within the hydrothermal system of La Fossa cone of Vulcano.

Data repository Item DR3: Description of heat transfer at shallow depth and equations of conductive and convective heat transfer.

Data Repository Item DR1

Configuration of the temperature monitoring stations

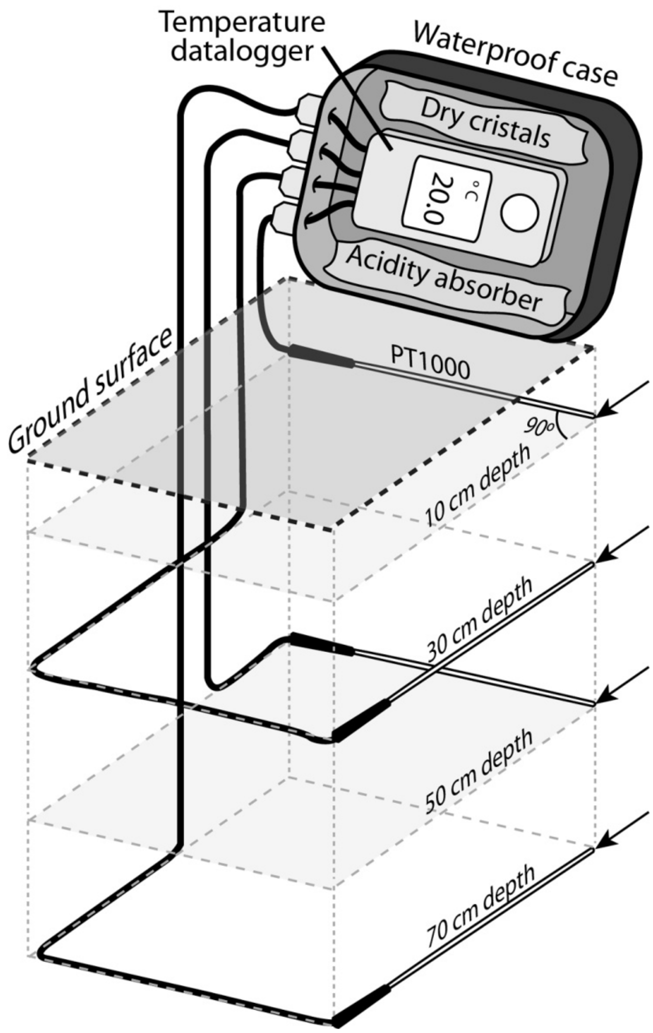

Figure DR1. Sketch of the temperature monitoring stations. The temperature data logger of Gran Cratere (GC) and Punte Nere (PN) sites, with the four PT1000 sensors have been installed at 10, 30, 50, and 70 cm depth into the soil following this geometry. The four arrows indicate the location of the temperature measurements at depth.

Data Repository Item DR2

Characterization of seismicity related to fluid dynamics within the of La Fossa cone of Vulcano.

Alparone et al. (2010) grouped the seismicity related to the hydrothermal system of la Fossa cone into three classes: long period (HB and MX), monochromatic events (MC and tornillos) and high frequency (HF) events. They affect a small volume of Vulcano Island (about 0.5 km^3) located below La Fossa Crater at depths ranging ca. between 0.1 and 1.1 km b.s.l. (Alparone et al., 2010; Milluzzo et al., 2010).

Long period and monochromatic events are characterized by narrow spectrum with sharp dominant spectral peaks, ranging between 2 and 8 Hz, and high degree of waveform similarity, suggesting stationary, nondestructive processes (resonance of hydrothermal fluid-filled cracks or conduits, simply fluid flow inside them).

Focusing on HF events, their main features are a frequency content ranging from 5 to 25 Hz (similar to volcano-tectonic events) and the low degree of waveform similarity, suggesting fracturing processes of moderate competent rocks surrounding the hydrothermal system (Montalto, 1994; Alparone et al., 2010).

Data Repository Item DR3

Description of heat transfer at shallow depth (<1m) and equations of conductive and convective heat transfer

Hydrothermal systems constitute efficient heat exchangers between the magma and the surface, acting as a buffer that transfers thermal energy through water vaporization.

For many high temperature hydrothermal systems, the thermal power drained by convection is of the same order of magnitude of the energy lost by conductive and radiative transfer (Hochstein and Browne, 2000). In most cases, the top of the convective cells does not reach the surface causing the formation of sub-fumarolic zones (Aubert, 1999). In case of a weak hydrothermal activity, the shallow subsurface (<1m) can be subdivided into three zones (Fig.DR3a):

(1) From the deepest zone to depth Z_2 (boiling point of water), the water vapor flow corresponds to the ascent of vapor created by vaporization of meteoric water in the deep layers, where the temperature reaches and exceeds the boiling temperature of water. In this area the latent heat (Q) produced by condensation of bi-phase water vapor flow is nearly zero.

(2) From Z_2 to Z_1, vapor flow is lowered by the condensation which is assumed to be nearly complete at Z_1 (flow rate is equal to zero at Z_1). The condensation creates an increase of liquid water content in the ground. This depth interval of condensation also corresponds to the area where heat transferred by water vapor is totally released as latent heat through condensation.

(3) From Z_1 to the surface, the heat transfer is solely conductive and the latent heat produced by condensation of bi-phase water vapor flow is nearly zero.

Based on this subdivision of the ground, Z_1 appears as a main transition zone between a pure conductive heat transfer above Z_1, and an increasing mixing of the ratio between convective versus conductive heat transfer below Z_1.

In case of a disruption in the hydrothermal activity, the condensation layer will vary in depth. For instance, the higher is the pressure into the hydrothermal system, the closer to the surface will be the energy drained by the hydrothermal fluids as well as the condensation area

(Fig.DR3b,c). Thus, sub-fumarolic zones can evolve to fumarolic areas at the surface, allowing part of the water vapor to condense in the atmosphere (Finizola et al., 2009). As described above, the condensation area is also controlling the heat transfer mechanism (conductive or convective).

Using a mere physical approach, in a porous medium with vapor, heat is diffused both by convective and conductive transfer. The complete equation governing heat transfer is (Aubert, 1999):

$$\delta^2 T/ \delta Z^2 + Q/\lambda + (\delta T/\delta Z)\, C_v\, \rho\, (V/ \lambda) = 0, \quad (1)$$

where T is the soil temperature, Q is the heat quantity produced by condensation of vapor per unit volume of the medium, λ is the thermal conductivity, ρ is the vapor density, C_v is the specific heat of the vapor, V is the vapor ascent velocity, and Z is the depth. For flux values lower than about 100 $W.m^{-2}$ the third term of eq.(1) is negligible.

In the area above the condensation level (Z_1 in Fig. DR3), the heat transfer is purely conductive, Q is equal to zero and thus:

$$\delta^2 T/ \delta Z^2=0. \quad (2)$$

In other words, $\delta T/ \delta Z$ = Cte, which means that the temperature gradient is linear as a function of depth in the pure conductive area, as illustrated in Fig. DR3. Therefore, at a constant depth, the linearity of the temperature gradient appears as a direct indicator of the ratio between the conductive/convective heat transfers. Consequently, the control of this linearity, through the coefficient of determination R^2, gives direct information on the disruptions occurring inside the hydrothermal system.

Concerning the physics of heat transfer, only temperature gradient can easily discriminate the two heat transfer processes: conductive transfer corresponds to linear temperature gradient, while convective transfer is associated with non-linear temperature gradient (see the blue curves in Fig. DR3). We used this feature to quantify the ratio of these two processes of heat transfer.

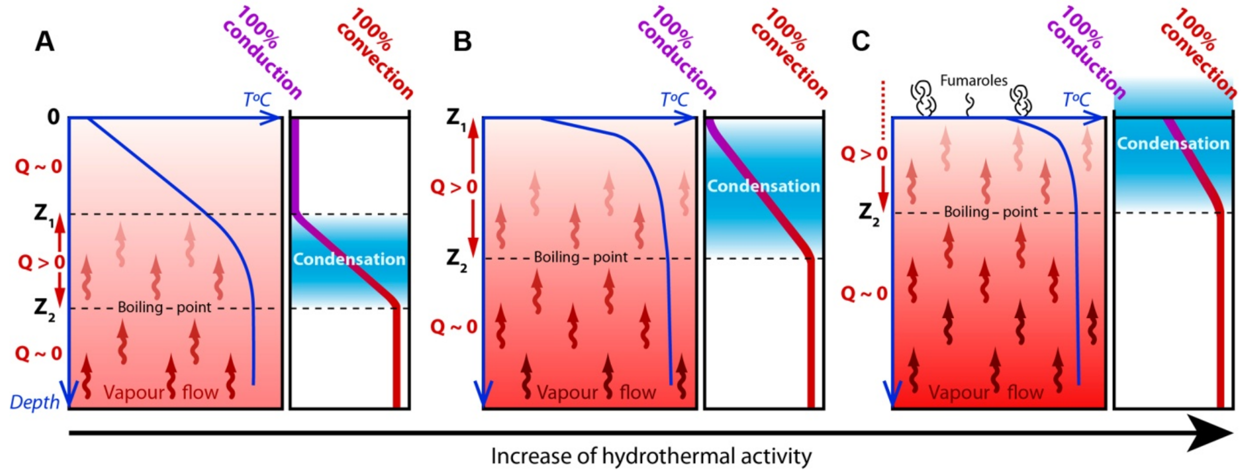

Figure DR3. Sketch of three stages of shallow hydrothermal activity (<1m). The increase in the intensity of the hydrothermal fluid flow is responsible of a decrease in depth of the condensation area and changes in the heat transfer mode from conductive to convective. "Q" stands for the latent heat produced by condensation of bi-phase water vapor flow. "Z_2" corresponds to the depth of the boiling point of water. "Z_1" is the depth where the condensation of water vapor is assumed to be nearly complete (the flow rate is equal to zero).

REFERENCES CITED

Alparone, S., Cannata, A., Gambino, S., Gresta, S., Milluzzo, V., and Montalto, P., 2010, Time-space variation of volcano-seismic events at La Fossa (Vulcano, Aeolian Islands, Italy): new insights into seismic sources in a hydrothermal system: Bulletin of Volcanology, v. 72-7, p. 803-816, doi: 10.1007/s00445-010-0367-6.

Aubert, M., 1999, Practical evaluation of steady heat discharge from dormant active volcanoes: case study of Vulcarolo fissure (Mount Etna, Italy): Journal of Volcanology and Geothermal Research, v. 92, p. 413-429, doi:10.1016/S0377-0273(99)00088-8.

Finizola A., Aubert, M., Revil, A., Schütze, C., and Sortino, F., 2009, Importance of structural history in the summit area of Stromboli during the 2002–2003 eruptive crisis inferred from temperature, soil CO_2, self-potential, and electrical resistivity tomography: Journal of Volcanology and Geothermal Research, v. 183, p. 213–227, doi:10.1016/j.jvolgeores.2009.04.002.

Hochstein, M.P., and Browne, P.R.L., 2000, Surface manifestations of geothermal systems with volcanic heat sources, *in* Sigurdsson, H., Houghton, B., McNutt, S.R., Rymer, H., and Stix, J., eds., Encyclopedia of Volcanoes, Academic Press, London, p. 835-855.

Milluzzo, V., Cannata, A., Alparone, S., Gambino, S., Hellweg, M., Montalto, P., Cammarata, L., Dilibero, I.S., Gresta, S., Liotta, M., and Paonita, A., 2010, Tornillos at Vulcano: clues to the dynamics of the hydrothermal system: Journal of Volcanology and Geothermal Research, v. 198, p. 377–393, doi:10.1016/j.jvolgeores.2010.09.022.

Montalto, A., 1994, Seismic events at Vulcano (Italy) during 1988–1992, Journal of Volcanology and Geothermal Research, v. 60 (3-4), p. 193-206, doi:10.1016/0377-0273(94)90051-5.