

Supplementary Information 1 for

Multidisciplinary monitoring of mud volcanoes: a new perspective on fluids and seismicity link from the Salse di Nirano (Italy)

E. Ferrari¹, A. L. Rizzo^{2,1}, G. Capelli Ghioldi³, A. Sciarra⁴, G. Tamburello³, F. Viveiros⁵, S. Lovati¹ and M. Massa¹

¹ National Institute of Geophysics and Volcanology (INGV), Milano, Italy.

² Department of Earth and Environmental Sciences, University of Milano-Bicocca, Milano, Italy.

³ National Institute of Geophysics and Volcanology (INGV), Bologna, Italy.

⁴ National Institute of Geophysics and Volcanology (INGV), Roma 1, Italy.

⁵ Instituto de Vulcanologia e Avaliação de Riscos, Universidade dos Açores, Portugal.

Corresponding author: elisa.ferrari@ingv.it

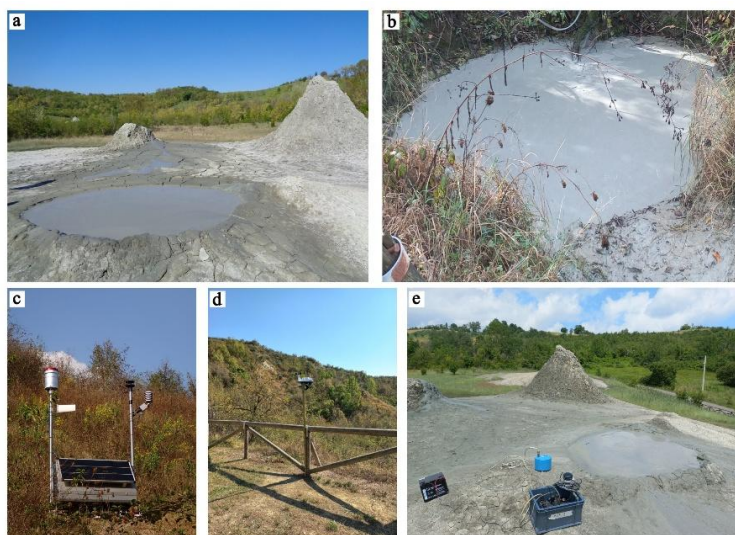


Fig. S1 (a) Monitored La Giunta mud pool. (b) Monitored F mud pool. (c) Permanent soil CO₂ flux station integrated with meteorological and soil sensors. (d) Meteorological station. (e) Setting of temporary seismic measurements close to La Giunta mud pool

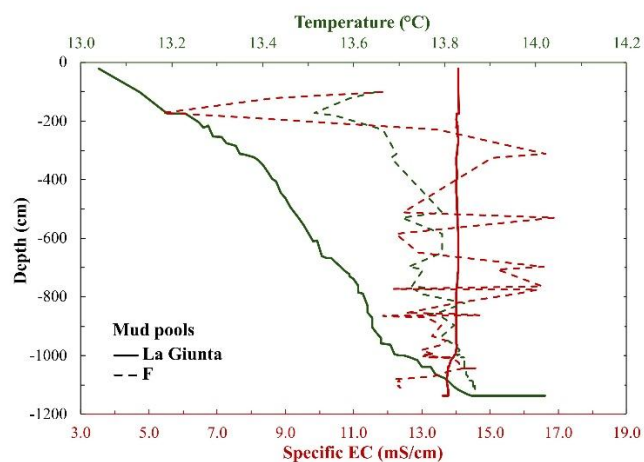


Fig. S2 Temperature (dark green) and specific electrical conductivity EC (red) vertical profiles of La Giunta (solid line) and F (dashed line) mud pools.

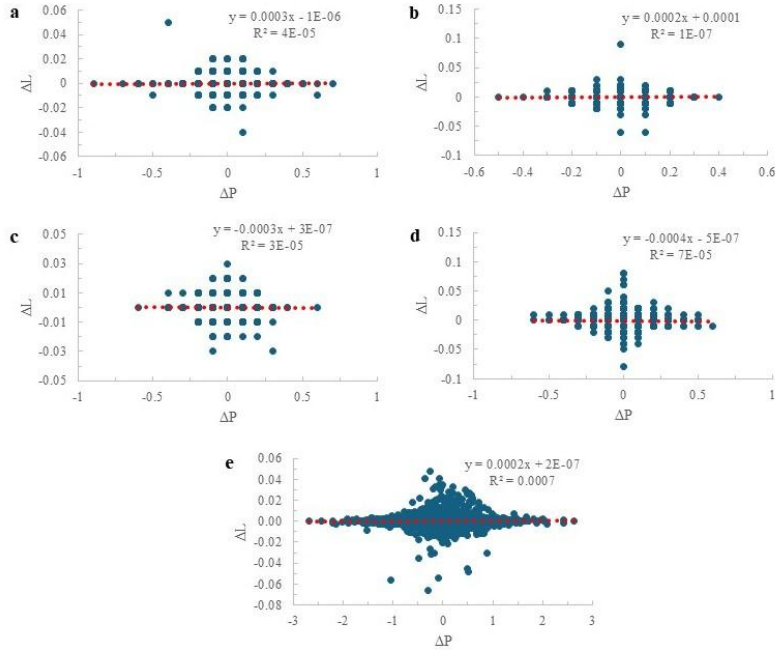


Fig. S3 ΔP - ΔL plots for the estimation of barometric efficiency of La Giunta (**a, b, c, d** corresponding to La Giunta A, B, C, D intervals, respectively) and F (**e**) mud pools. ΔP is calculated as $P(t)-P(t+1)$, where P is the atmospheric pressure and t the time; ΔL is calculated as $L(t+1)-L(t)$, where L is the mud level. The red dotted line represents the linear trend curve calculated for each plot. The associated equation and R^2 are displayed

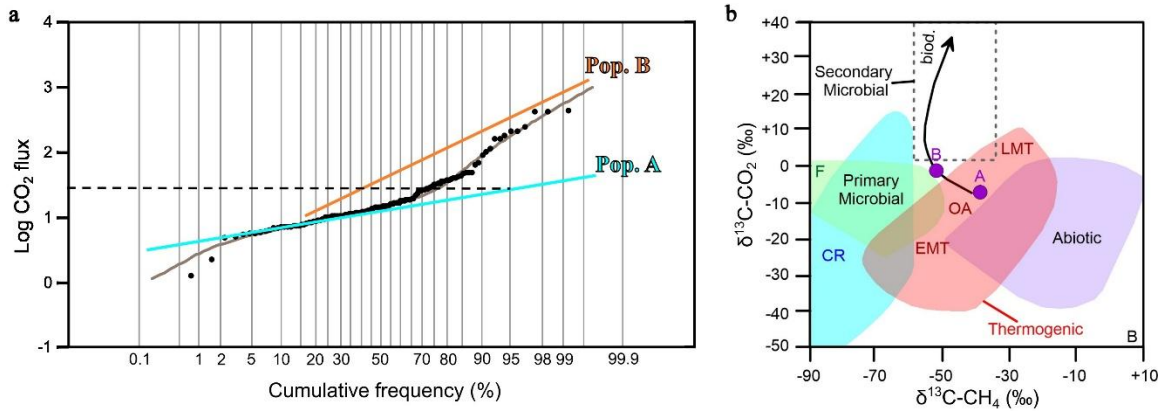


Fig. S4 (a) Probability plot of soil CO_2 flux measured during the July 2023 survey. Population A and B are highlighted in light blue and orange, respectively. **(b)** Genetic diagram of $\delta^{13}C-CH_4$ vs. $\delta^{13}C-CO_2$ (after Milkov & Etiope, 2018) for soil gases sampled at location A and B (please, refer to Figure 1). CR: CO_2

reduction. F: fermentation. EMT: early mature thermogenic gas. OA: oil-associated thermogenic gas. LMT: late mature thermogenic gas. The black arrow indicates biodegradation path

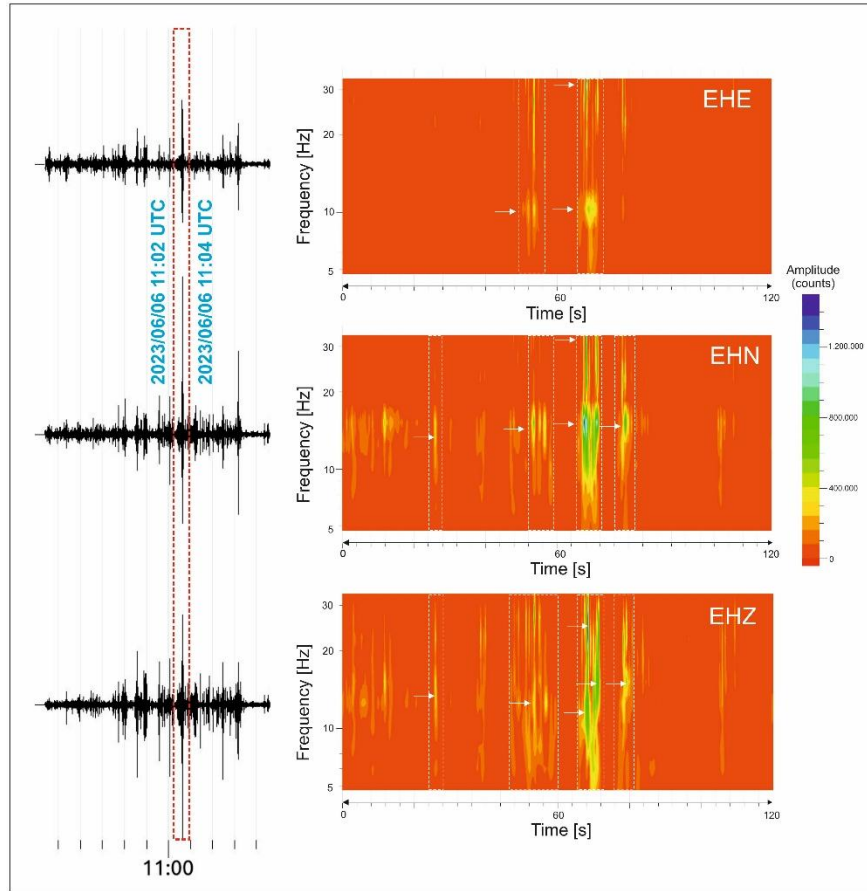


Fig. S5 Seismograms recorded on June 6, 2023, during the temporary measure performed few meters close to La Giunta mud pool during a heavy episode of bubble emissions (10 minutes around 11.00 a.m., UTC). From top to bottom the East-West, the North-South and the vertical component of motion. On the right the

correspondent FFT spectrograms are reported for two minutes of signals (red box on the left panels), filtered in the interval 5-35 Hz

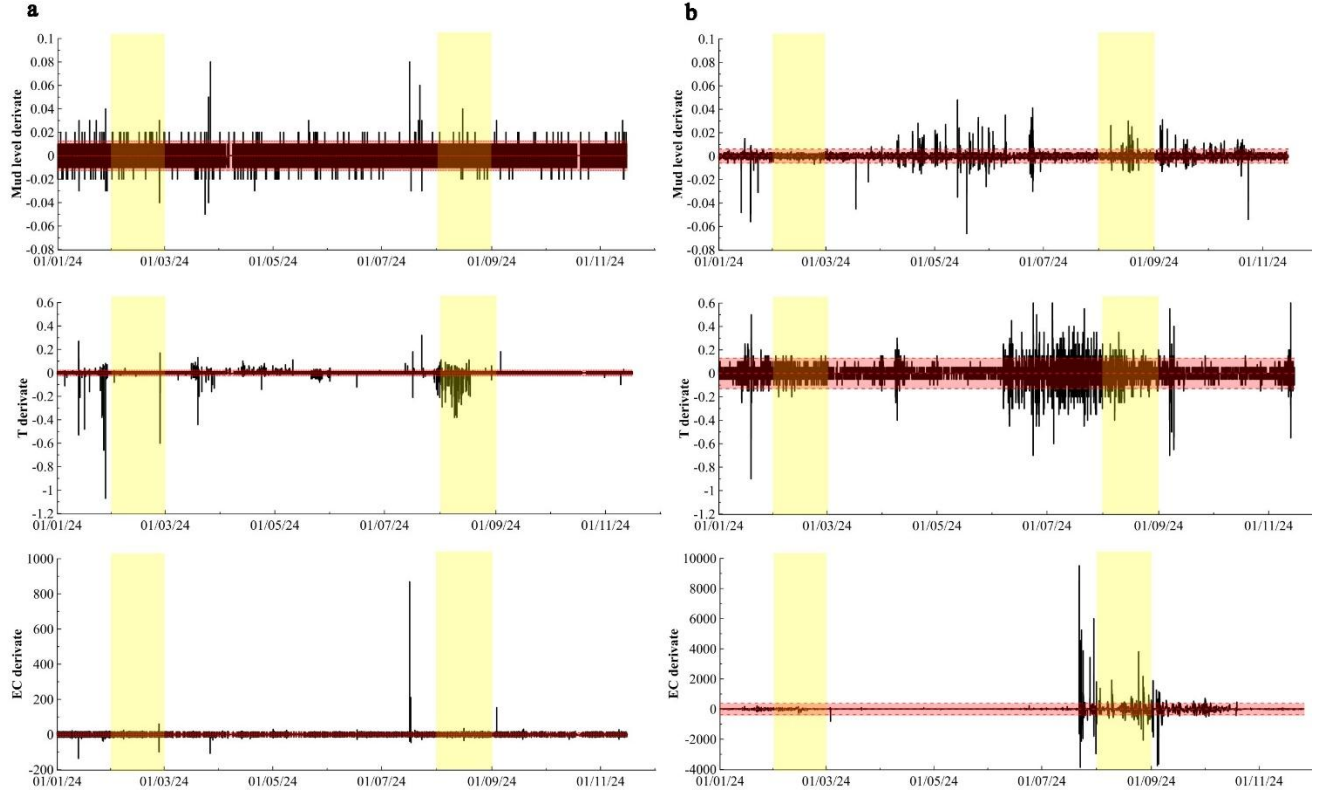


Fig. S6 First derivate of mud level, temperature and specific EC (black) for La Giunta (**a**) and F (**b**) 2024 time-series. First derivates are already cleaned up of atmospheric effects (e.g., changes related to rainfall). Light red boxes represent $\pm 4\sigma$ (La Giunta data) or $\pm 2\sigma$ (F data) confidence intervals. Light yellow rectangles represent the two main seismic swarms occurred during this period: (i) February to March swarm occurred in the North Western Apennines (within 50 km from Nirano) characterized by a maximum local magnitude of 4.2; (ii) August to September swarm occurred within 30 km from Salse di Nirano and characterized by maximum magnitude of 3.0