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Effects of remote earthquakes at the Nirano Mud Volcanic Field: insights from geophysical studies

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Mud volcanoes are often characterized by elevated fluid pressures that deviate from hydrostatic conditions. This near-critical state makes mud volcanoes particularly sensitive to external perturbations and an ideal natural laboratory to test the effects of dynamic stress generated by remote seismic events.

The Pede-Apennines Thrust, northern Italy, is characterized by several mud volcanic systems aligned along a narrow WNW-ESE trending band that runs sub-parallel to this part of the Apennine chain. We use the Nirano Mud Volcanic System as a natural laboratory to test if and how distant earthquakes may affect such geological systems.

We first characterized the subsurface with a geoelectrical study and measurements of spontaneous potential. Next, we deployed a broadband seismic station (Trillium 240s equipped with a three-channel Reftek130 data-logger) inside the Nirano Mud Volcanic System to understand the typical seismic signal generated at depth. Seismic records show a background noise below 2 s period, sometimes interrupted by periods of repeated rhythmic high-frequency pulses that last from several minutes to hours. During such a period, each high-frequency pulse lasts approximately 20 s and individual pulses are separated by intervals of low frequency noise lasting from 40 s to 180 s. We identify such periods of high frequency (rhythmic) signals irregularly throughout our dataset, with no distinction between day or night hours.

In the late June 2013 the aftershocks of the M5.3 Garfagnana earthquake (21st of June 2013) were still ongoing and we recorded a M4.4 event on the 30th of June, approximately 60 km from our station. The earthquake, dominated by frequencies between 1 Hz and 2 Hz, caused a maximum vertical and horizontal displacement at the surface of 0.7 mm and 0.48 mm, respectively. Before the earthquake, the frequency band between 10 Hz and 20 Hz was dominated by weaker signals while after the earthquake the same frequency band was characterized by much more intense signals. The excitement of these higher frequencies lasted for less than 20 minutes with possibly few locally induced microseismic events towards the end of this period.

The measured response of the Nirano Mud Volcanic Field to the M4.4 earthquake ($\sim$60 km far) falls outside the empirical magnitude-vs-distance plot based on historical and qualitative data. We suggest that new quantitative data based on geophysical methods should be used to review the dynamic triggering threshold currently used for dynamic triggering studies of mud volcanic systems.