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Earthquake Hydrology and seismic detection capability of deep pressure devices within the Gran Sasso aquifer (central Italy)

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This study investigates the potential of hydroseismograms for seismic monitoring and understanding earthquake physics, utilizing high-frequency pore pressure measurements within the Gran Sasso Aquifer (GSA) in central Italy. Hydroseismograms, obtained from a hydraulic pressure device (HPD) installed in deep, horizontal wells intersecting a major fault network within the GSA, are compared with seismic records from the nearby GIGS station to assess the HPD's earthquake detection capabilities. This unique setting, combined with the HPD's high-frequency (20 Hz) data acquisition system, offers a sensitive method for monitoring both seismic activity and pore pressure anomalies. The GSA's fractured-karst geology and its location within a high seismic hazard zone in Italy, along with the presence of the Italian Institute of Nuclear Physics (INFN) underground laboratory (UL), create an ideal environment for studying deep, saturated aquifer-earthquake interactions, minimizing interference from shallow hydrological processes. The UL houses two horizontal boreholes, named S13 (190 m) and S14 (175 m), equipped with the HPD. Approximately 250 meters from S13, the INGV seismic station GIGS, part of the GINGER experiment, uses two broadband seismometers for continuous microseismic monitoring and global seismicity recording. The research analyzes long-term, high-frequency pore pressure data from the GSA, aiming to further understand the complex relationship between groundwater and seismic activity. The primary objective of the joint analysis of well and seismic data, spanning from May 1, 2015, to December 31, 2023 (with ongoing monitoring), is to identify and correlate earthquake occurrence with hydraulic pressure variations detected by the HPDs in S13 and S14. A statistical inferential approach was used to evaluate HPD sensitivity, comparing the number of HPD-detected events with those recorded by GIGS (1068 events) across different magnitudes and epicentral distances. Statistical analysis demonstrates the HPD's significantly enhanced sensitivity compared to previous studies. The HPD detected 148 of the 1068 events recorded by GIGS (a 13.9% overall success rate), with this detection probability strongly influenced by earthquake magnitude and epicentral distance. Mainly for far events, the identified detection threshold significantly exceeds the "hard" detection limit for typical aquifers defined by Montgomery and Manga (2003) based on the Dobrovolski et al. (1979) criterion, a limit below which they found no

detections in a large dataset.

This finding warrants further investigation into the not yet fully understood mechanisms of hydroseismic detection. This study, covering data from May 2015 to December 2023, reveals the potential of HPDs installed in carbonate rock boreholes for seismic monitoring. The GSA hydrogeological and seismotectonic conditions provide an optimal environment for HPD deployment for both medium-to-long-term and high-frequency pore pressure monitoring. The strategic borehole locations intersecting the main fault network offer a unique opportunity to study the complex interplay between hydrological processes and seismic activity. Ongoing HPD monitoring will further explore their potential as a valuable tool for future seismic studies and contribute to the advancement of earthquake science, with implications for seismic hazard assessment and early warning systems.

References

Montgomery, D. R., & Manga, M. 2003. Streamflow and water well responses to earthquakes. Science, 300(5628), 2047-2049.