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Coupled thoron, radon, and microbial tracers of seismically induced groundwater flow changes

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Natural radioactive gases such as thoron (^{220}Rn) and radon (^{222}Rn) are widely used as useful tracers for detecting stress induced changes in groundwater systems associated with seismic activity. However, gas anomalies alone are often difficult to interpret because they can also be influenced by hydrological forcing and site specific transport processes. Here we test the hypothesis that integrating groundwater microbial community dynamics with thoron and radon measurements can overcome these limitations and provide a more robust indicator of seismically induced fluid system changes. We conducted continuous monitoring of thoron and radon in groundwater wells before, during, and after the 2017 Mw 5.5 Pohang earthquake (South Korea), together with physicochemical parameters (temperature, pH, electrical conductivity) and 16S rRNA gene sequencing. Distinct thoron and radon anomalies were observed in association with co-seismic and post-seismic microseismicity. Short lived thoron spikes showed high temporal sensitivity to rapid stress perturbations near active faults, whereas radon anomalies reflected longer range permeability enhancement and fluid mixing. Time series and cross correlation analyses indicate that gas anomalies correlate more with seismic energy release than with hydrological variability. Concurrently, microbial communities displayed the shifts during periods of elevated thoron and radon, with increased relative abundance of stress tolerant and chemoautotrophic taxa. Integrated analysis reveals coupled hydro-bio-geochemical signatures that improve discrimination of seismic forcing from background variability compared to gas tracers alone. Our results demonstrate that combining gaseous tracers with microbial ecological indicators provides a robust framework for assessing transient groundwater flow dynamics associated with seismic activity.

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