

Resilience of deep aquifer microbial communities to seasonal hydrologic variability as determined by online gas monitoring

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Understanding microbial life in extreme environments is critical for assessing biogeochemical cycles on Earth. In deep terrestrial aquifers, microbial communities persist under extreme hydrological conditions, but their response to hydrological fluctuations remains poorly understood. Here, we investigate microbial resilience in the geothermal system of Lavey-les-Bains, Switzerland, where deep aquifer water interacts with a seasonally variable amount of near-surface groundwater.

Using long-term online gas monitoring, stable water isotopes, CH₄ isotopic composition and microbial DNA analyses, we show that while seasonal variations strongly influence groundwater mixing, microbial communities remain largely stable over time. Despite high hydrological connectivity between 200-500m, microbial composition shows distinct depth-dependent structuring. Intermediate depths (200-300m) are dominated by sulfur-disproportionating *Dissulfurispira* and *Micrarchaeota*, whereas deeper zones (500m) host sulfate- and iron-reducing taxa such as *Thermales* and *Bathyarchaeota*. This decoupling of microbial diversity from seasonal hydrological variation suggests that intrinsic environmental factors, particularly temperature, exert greater control over the structure of deep aquifer microbiomes than fluctuating water sources.

Our results argue for the resilience of subsurface microbial life to environmental perturbations and demonstrate the value of continuous gas monitoring in resolving biogeochemical dynamics in geothermal systems. This study provides insights into microbial survival strategies in extreme environments, with implications for deep carbon cycling, geothermal resource potential, and biosignature detection in subsurface ecosystems.