https://doi.org/10.5194/egusphere-egu2020-18437

FRIEDRICH-SCHILLER-UNIVERSITÄT JENA

AquaDiva

Exploring the hydrogeological functioning and microbial habitats of the deep hillslope aeration zone in limestone-mudrock alternations




Robert Lehmann[1], Cassandre Sara Lazar[2], Kirsten Küsel[3], and Kai Uwe Totsche[1*]

[1] Institute of Geosciences, Department of Hydrogeology, Friedrich-Schiller-Universität, Jena, Germany
[2] Département des Sciences Biologiques, Université du Québec à Montréal, Montreal, Canada
[3] Institute of Biodiversity, Aquatic Geomicrobiology, Friedrich-Schiller-Universität, Jena, Germany

*Contact: kai.totsche@uni-jena.de

The aeration zone beneath topographic heights

https://doi.org/10.5194/egusphere-egu2020-18437

The aeration zone beneath topographic groundwater recharge areas, comprising variably water-saturated soil, regolith and bedrock is a typically large but hardly explored compartment of the Critical Zone.

Fluid and matter exchange within the deep aeration zone, the dynamics of its diverse microbial dwellers and their contribution for subsurface matter cycling and groundwater quality are widely unknown.

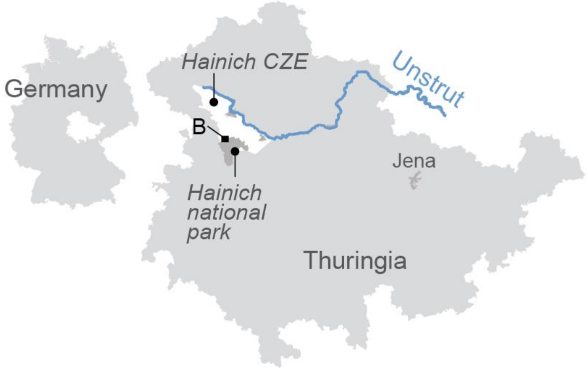
https://doi.org/10.5194/egusphere-egu2020-18437

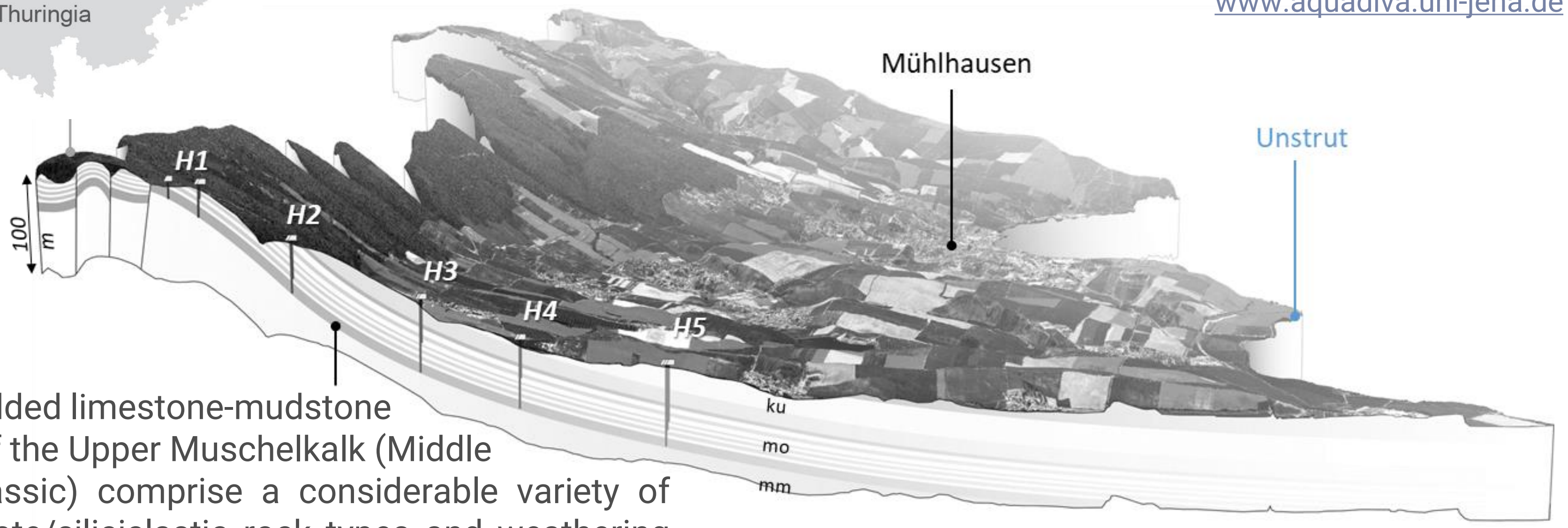
The Hainich Critical Zone Exploratory

The Hainich Critical Zone Exploratory (Collaborative Research Center AquaDiva, Küsel et al., 2016) uniquely accesses the Critical Zone, ranging from the unmanaged (national park) and managed surface (forest, pasture, cropland) to used groundwater resources in the widely-distributed setting of alternating mixed carbonate-/siliciclastic bedrock. Our continually developed platform welcomes international researchers for joining CZ research that focuses on the subsurface biogeosphere, their controls and functions. We accessed the subsurface of a (sub-)regional groundwater flow system by lysimeters, aeration zone collectors, and multi-level monitoring wells, etc., along a hillslope transect, down to 90 m bgl.

Critical Zone

www.aquadiva.uni-jena.de

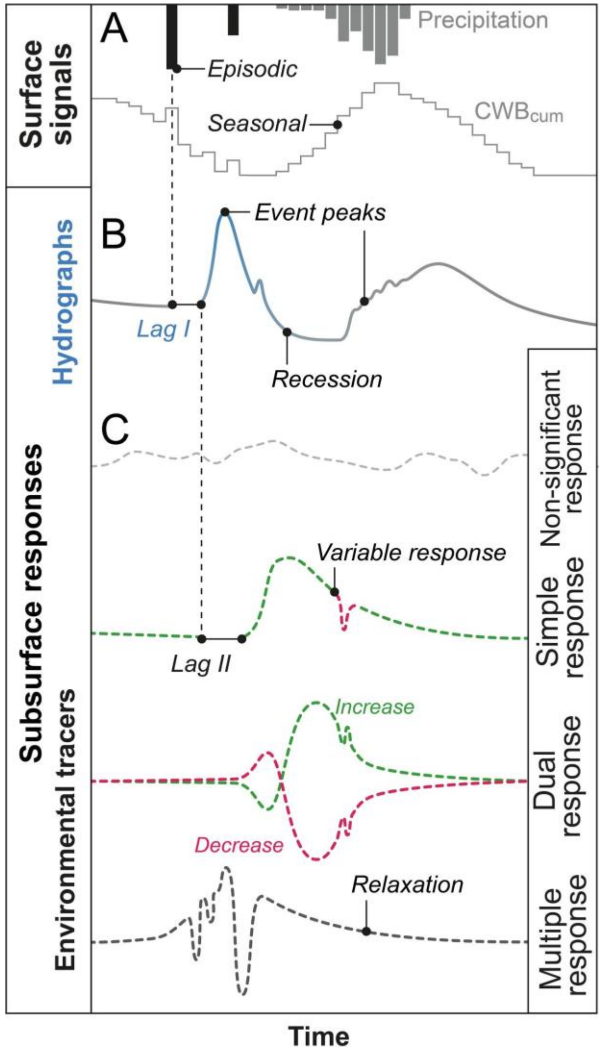




The thin-bedded limestone-mudstone alternations of the Upper Muschelkalk (Middle Germanic Triassic) comprise a considerable variety of mixed carbonate/siliciclastic rock types and weathering stages (see Kohlhepp et al. 2017, Lazar et al. 2019).

https://doi.org/10.5194/egusphere-egu2020-18437

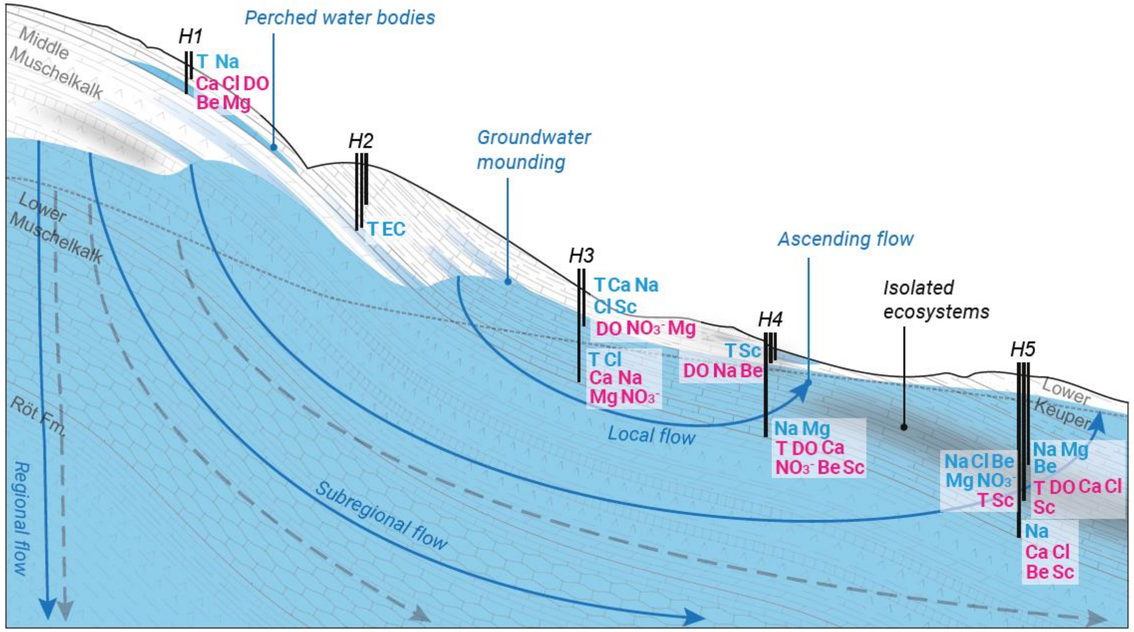
Multi-directional fluid flow dynamics in hillslope terrain



▲ Classification of subsurface responses to signals of surface and/or subsurface origin (from Lehmann and Totsche 2020)

Lehmann, R. and Totsche, K. U. 2020. Multi-directional flow dynamics shape groundwater quality in sloping bedrock strata. Journal of Hydrology 580, 124291.
DOI: https://doi.org/10.1016/j.jhydrol.2019.124291

◀ We analyzed 8-year time series of surface conditions (vegetation period, precipitation; surface signals), subsurface temperatures, multi-depth hydraulic heads and fluctuating non-conservative environmental tracers in groundwater samples (subsurface responses).



◀ Conceptualized flow regime along the eastern Hainich hillslope (cross section, 10x exaggerated, modified from Lehmann and Totsche 2020). The fluctuation of environmental tracers as responses to head fluctuations were used to trace flow directions and cross-stratal exchange. On the catchment scale, the responses strongly differ due to conditions like authigenic sources, diminishing signals with increasing flow paths, etc.
Decreasing signals with rising heads are marked blue; red marks increases. Inferred flow patterns reflect conditions during water level highstands (winter/spring, in blue; grey: average conditions).

Multi-directional fluid flow dynamics in hillslope terrain

https://doi.org/10.5194/egusphere-egu2020-18437

Lehmann, R. and Totsche, K. U. 2020. Multi-directional flow dynamics shape groundwater quality in sloping bedrock strata. Journal of Hydrology 580, 124291.
DOI: https://doi.org/10.1016/j.jhydrol.2019.124291

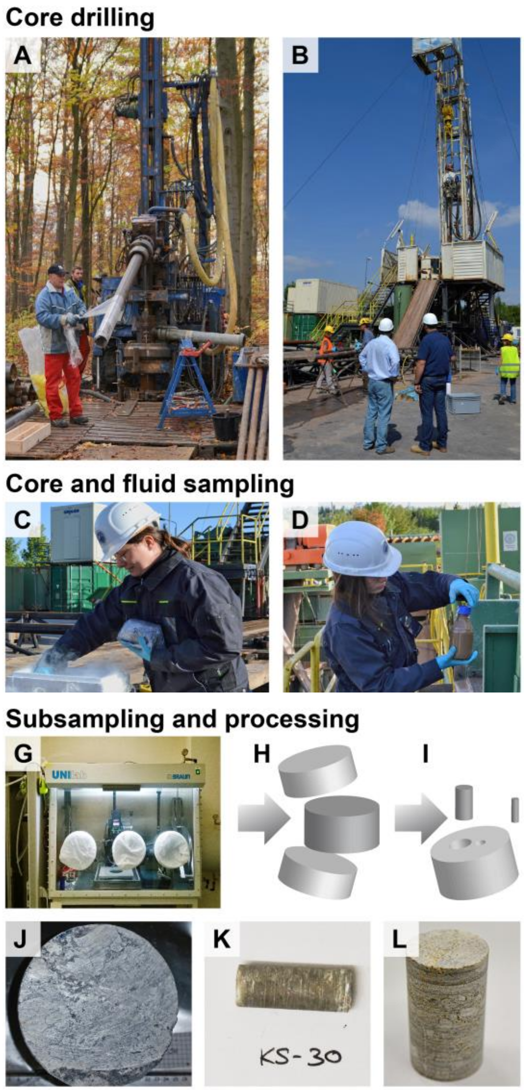
◂ The Hainich ridge harbors a typically large aeration zone. The hillslope configuration of sloping limestone-mudstone alternations, including their weathering state, facilitates multi-storey perched groundwater that fluctuates due to seasonal and episodic forcing (e.g. heavy rain, snowmelts). Weathered and dense argillaceous strata facilitate stratiform flow and localized recharge to the phreatic zone that cause groundwater mounding in winter/spring. Mounding that boosts shallow (local) flow routes, was evident from head measurements and indirectly from transient flow patterns that were inferred from multi-tracer fluctuation.

On a sub-regional scale, a large set of environmental tracers, including authigenic signals was required to explore the cross-stratal exchange through low-permeability strata and the transient flow patterns that shape the groundwater quality and the nutritional supply of ecosystems. For instance, we found aeration zone-loading of waters, that bypass argillaceous, oxygen deficient overburden and cause, for instance, oxygen and nitrate input to the main aquifer by seasonally ascending flow. Thus, the hillslope interplay of aeration/phreatic zone fluid flow can overcome the isolating or protective cover of argillaceous strata and increase the intrinsic groundwater vulnerability.

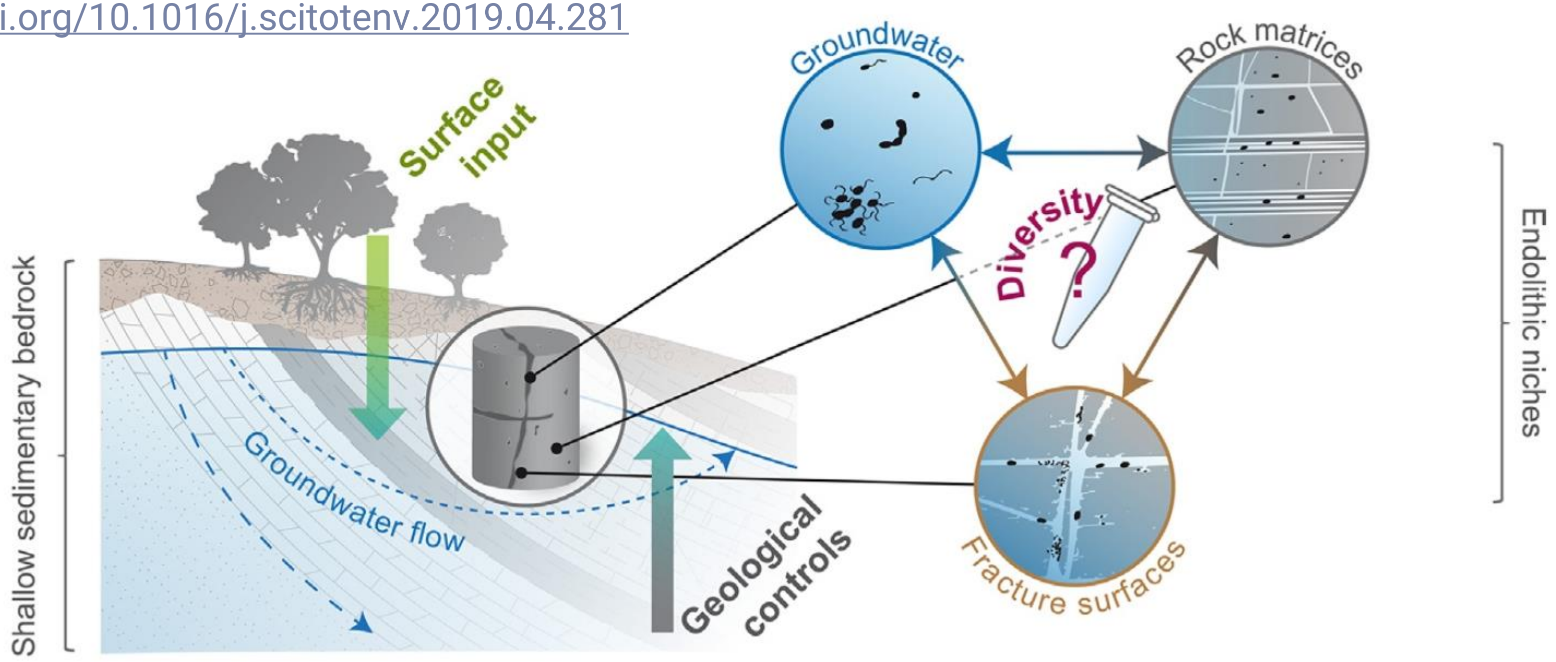
- The hillslope aeration zone is an important regulator of catchment-scale water flow
- Large sets of environmental tracers (incl. authigenic signals), are required
  (I) to explore cross-compartment exchange in mixed lithologies, and thus
  (II) to determine the hydrogeological functions of argillaceous strata
- The interplay of aeration/phreatic zone fluid flow dynamics is a strong factor of ecosystem compartmentalization (e.g. by surface connection and nutritinal supply)

https://doi.org/10.5194/egusphere-egu2020-18437

Endolithic habitats and bacterial diversity in LMA



Lazar, C.S., Lehmann, R., Stoll, W., Rosenberger, J., Totsche, K.U., Küsel, K. 2019. The endolithic bacterial diversity of shallow bedrock ecosystems. Science of the Total Environment 679, 35-44. DOI: https://doi.org/10.1016/j.scitotenv.2019.04.281

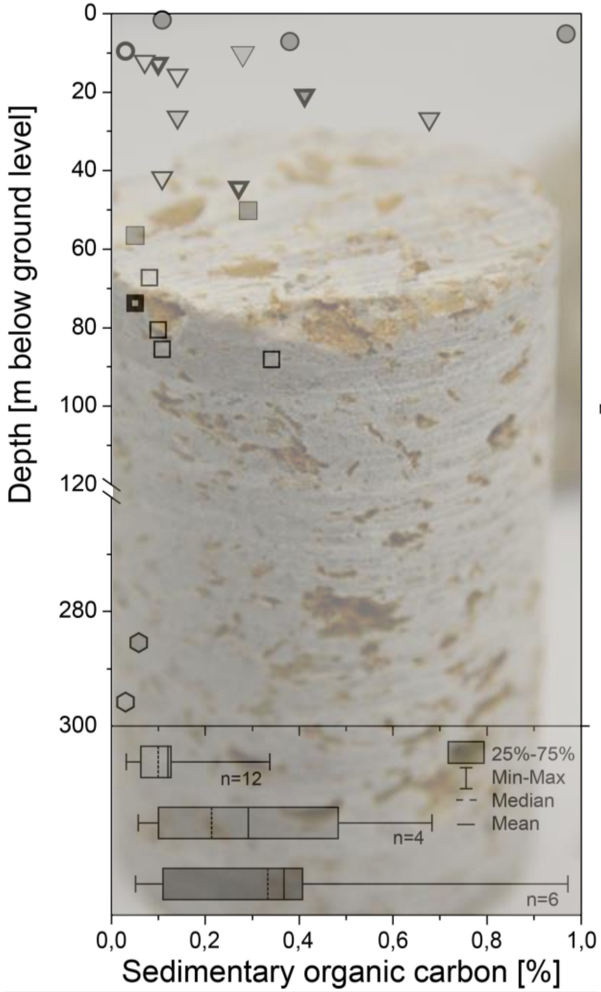


▲ Sedimentary bedrock such as the investigated limestone-mudstone alternations (LMA) harbors diverse habitats within fractures and even tight rock matrices. Their dwellers contribute to biogeochemical cycling (e.g. mineralization of organic compounds, denitrification) and functions of the Critical Zone, like provision of readily drinkable water. Nutritional requirements of microorganisms can be met by surface-sourced input as well as by sedimentary sources, thus requiring careful interdisciplinary exploration (from Lazar et al. 2019).

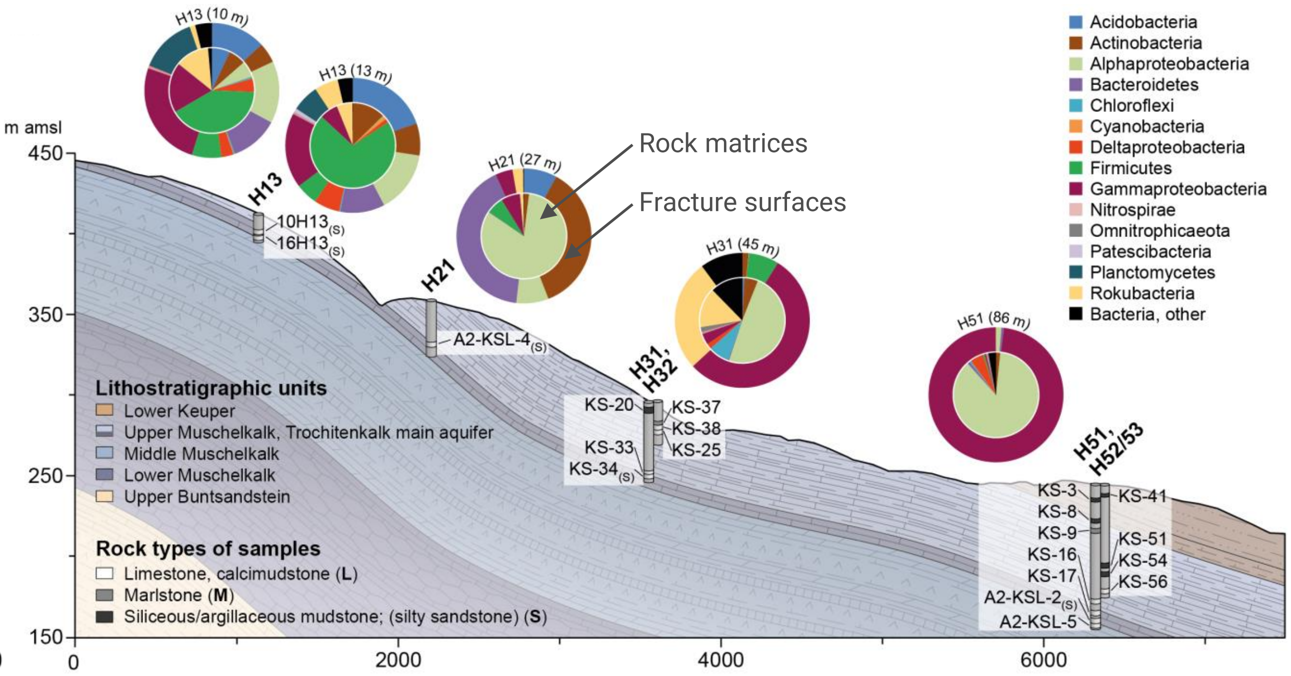
▲ Sampling and processing steps of the limestone/mudstone samples of the Hainich CZE and the INFLUINS deep drilling (from Lazar et al. 2019)

Endolithic habitats and bacterial diversity in LMA

https://doi.org/10.5194/egusphere-egu2020-18437



▲ Along the Hainich hillslope, mixed carbonate-siliciclastic rock was found to provide diverse habitat conditions (rock types, organic carbon content, weathering states, pore sizes, oxicity, saturation, etc.)(from Lazar et al. 2019).



◄ Exemplary taxonomic affiliations of the bacterial 16S rRNA gene reads (phylum level) from the Trochitenkalk formation. Typically, bacterial communities differ between fracture surfaces and groundwater-suspended communities. ~30% of matrix-inhabiting phyla were found at fracture surfaces (>40% in groundwater). Contrastingly, <12% of groundwater-suspended phyla were found in tight matrices. Oligotrophic heterotrophs dominate bacterial communities in isolated habitats. Shallow weathered rock is inhabited by destruents of labile OC, whereas chemolithoautotrophy increases in isolated habitats along increasing groundwater flow paths.

- Bacterial patterns differ between habitats of high- and low-bulk rock permeability
- Depth and matrix permeability are minor controls of endolithic diversity
- Surface input or isolation control endolithic bacterial communities in LMA

References

Kohlhepp, B., Lehmann, R., Seeber, P., Küsel, K., Trumbore, S. E., Totsche, K. U. 2017. Aquifer configuration and geostructural links control the groundwater quality in thin-bedded carbonate-siliciclastic alternations of the Hainich CZE, central Germany. Hydrology and Earth System Sciences 21(12), 6091-6116.
DOI: https://doi.org/10.5194/hess-21-6091-2017

Küsel, K., Totsche, K. U., Trumbore, S. E., Lehmann, R., Steinhäuser, C., and Herrmann, M. 2016. How Deep Can Surface Signals Be Traced in the Critical Zone? Merging Biodiversity with Biogeochemistry Research in a Central German Muschelkalk Landscape. Front. Earth Sci., 32, 1–18,
DOI: https://doi.org/10.3389/feart.2016.00032

Lazar, C.S., Lehmann, R., Stoll, W., Rosenberger, J., Totsche, K.U., Küsel, K. 2019. The endolithic bacterial diversity of shallow bedrock ecosystems. Science of the Total Environment 679, 35-44.
DOI: https://doi.org/10.1016/j.scitotenv.2019.04.281

Lehmann, R. and Totsche, K. U. 2020. Multi-directional flow dynamics shape groundwater quality in sloping bedrock strata. Journal of Hydrology 580, 124291.
DOI: https://doi.org/10.1016/j.jhydrol.2019.124291

Further literature:
http://www.aquadiva.uni-jena.de/Publications.html

https://doi.org/10.5194/egusphere-egu2020-18437

Thank you for your attention!

We kindly acknowledge:

DFG Deutsche Forschungsgemeinschaft

FRIEDRICH-SCHILLER-UNIVERSITÄT JENA

www.aquadiva.uni-jena.de

www.hydro.uni-jena.de

Follow me on ResearchGate