Alteration and element mobility at microbe-mineral interfaces

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The *European Environment Agency* calculated in 2002 that remediation of heavy metal contaminated soils within the EU will cost 105 Mrd. US\$. These often large, heterogeneously and low contaminated areas may be prone to bioremediation techniques which would lower costs by a factor of up to 10. Using bioremediation, soil microorganisms like bacteria or fungi are involved in transfer of elements between the geosphere and the biosphere through the water phase. A potential use of plant biomass for alternative energy production may be a potent activity involving these landscapes not useable for food production because of metal contents. However, only if the molecular mechanisms of microbial interactions in soil and with the mineral components of heap remains as well as with plant roots in the soil are understood, a sustainable land management is feasible. Thus, this special issue focuses on research within a Research Training Group funded by the German Science Foundation on exactly this interdisciplinary research field between (hydro) geosciences, microbiology, mineralogy, and (geo) chemistry (www.gk-alteration.uni-jena.de).

To develop techniques for bioremediation, element cycling needs to be understood in detail. These include, e.g., microbially induced changes in physico-chemical parameters that, in turn, lead to mobilization of heavy metals during

weathering or their re-precipitation occurring in deeper soil or rock horizons also in saturated zones. The results of the collaborative research can then not only be used for bioremediation of heavy metal contaminated areas. They are, at the same time, prone to yield an understanding of fast formation of supergenic ore deposits close to the surface. Many such ore deposits are characterized by manganese and iron (hydro) oxide precipitation, which can be seen in field trials presented in this special issue not only for the partners within the Research Training Group, but also investigated by international cooperation partners of the group throughout Europe with scientists interested in similar processes (Fig. 1).

What basic principles can be learned from such interdisciplinary studies? In order to study the processes at the microbe-mineral interface, identification of microbes present is essential. A new method for fast identification of soil bacteria is presented here. The microbial community structure with regard to the lithology and the influence of metals on communities has been investigated at different sites in Europe. The microbial communities then are analyzed more specifically for the impact on mineralization processes which, as well as bacterial and fungal excretion of organic molecules, alter the stability of dissolved metal ions in water. Thus, the identification of resistance mechanisms of microbes and geochemical element cycles are tackled which participate in formation of minerals and hence may even be characterized as so far mostly overlooked reasons for the formation of ore bodies. Since biological processes and enzymatic activities speed up chemical reactions by several orders of magnitude, abiotic formation of ore bodies, especially in soil or near the surface may be reevaluated with this new result.

The second question addressed concerns the application of the basic principles identified: Is it possible to adjust

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Fig. 1 Precipitation of iron and manganese hydroxides from changing groundwater flow. The ions were mobilized from a former mining area and precipitated to form a bio-geo barrier co-precipitating other metals

techniques for remediation to allow for better management of contaminated areas? The uptake of metals into the biosphere is presented here with special emphasis on the mutual symbiosis between plants and fungi, the mycorrhiza. A method development will allow to study mycorrhiza with more convenient techniques *in vitro*. Analysis of specific transport proteins in the fungus allows to specifically address metal resistance and hence the potential use in metal delivery to the plant root by the symbiotic fungus. This ecotoxicology of metals in soil or water is specifically important for the ultimate application of the basic research results in phytoremediation in wetlands or on metal contaminated soils. Finally, a biomonitoring too is presented with dendroanalysis that allows to check remediation successes with low impact on the flora established on site. The examples include field trials that show that specifically the use of indigenous, autochthonous microbes is the preferable set-up. Here, the investigations relate back to the first part of basic investigations: only if the microbes applied can positively interact with the microflora present on site, a bioengineering of remediation processes is possible that will not be prone to yield stochastic results, which have been obtained in many earlier studies because of the disregarding of the hitherto unknown molecular principles governing soil communities.

Prof Dr Erika Kothe holds a chair for Microbial Communication at the Institute for Microbiology, Friedrich Schiller University of Jena, Germany. Her research interests are in fungal genetics, where signal exchange and pheromone response are studied with the model basidiomycete *Schizophyllum commune*, in the mutual symbiosis of ectomycorrhiza with special emphasis on host-fungus interactions and in bio-geo interactions, which encompasses research on heavy metal resistance in streptomycete bacteria.

The effects of heavy metal resistant strains on metal mobility and plant growth promotion are specifically included in this research topic. A test field site for inoculation with selected strains was established in 2004, and there, the impact of specifically streptomycetes on heavy metal uptake into plants or metal mobility with the percolating water is studied. She was coordinator of the Research Training Group “Alteration and element mobility at microbe-mineral interfaces” funded through the German Research Foundation from 2004 through 2015 (DFG-GRK 1257) featured in this special issue.

Prof Dr Georg Büchel holds a chair for Applied Geology at the Institute for Earth Sciences of the Friedrich Schiller University Jena, Germany. His research topics are Maar lakes in different climatic zones, from the tropics with a long-standing research project in Java, to the German Maar district Eifel and to the Ukinrek Maar in Alaska. Together with Prof. Kothe, he established the study program for BSc/MSc Biogeosciences at the Friedrich Schiller University Jena. This is related

to his research topic of bio-geo interactions with a focus on reactive transport of metals. For that, a test field site in the former uranium mining site near Jena was established which serves to study the processes in metal transport in the environment and into plant biomass. Specifically, the formation of reactive (bio) geological barriers, manganese and iron oxide formation and dissolution, and the potential of rare earth elements to follow reactive transport through fractionation patterns are the major research fields. He was co-coordinator of the Research Training Group “Alteration and element mobility at microbe-mineral interfaces” featured in this special issue.