Cement degradation and host rock alteration in nuclear waste disposal. Studies at the Grimsel Test Site

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Cement is a major component of the engineered barrier system in proposed underground repositories for low- and intermediate-level radioactive waste. Cement grouting of highly-conductive fractures in the vicinity of disposal sites for high-level waste is also planned. The interaction between the hyperalkaline solutions derived from the degradation of cement and the rocks hosting such repositories may change the physical and chemical properties of the host rocks.

The HPF project (Hyperalkaline Plume in Fractured Rock; ANDRA-FR-, DOE-USA-, JAEA-JP-, NAGRA-CH-, POSIVA-FI-, SKB-SE-) studied the alteration of a fractured granite due to the circulation of a synthetic high-pH solution [1,2,3,4]. Substantial changes in solution chemistry and a significant decrease in fracture permeability were observed both in the laboratory (core infiltration experiment; decimeter scale) and in the Grimsel Test Site (dipole flow along a fracture; meter scale), despite the relatively minor mineralogical alteration. Coupling of mineralogical alteration and permeability changes was incorporated into reactive transport modeling of the experiments.

The hydration and degradation of cement are being explicitly incorporated into the new LCS (Long-Term Cement Studies; JAEA-JP-, NAGRA-CH-, NDA-GB-, POSIVA-FI-) project at Grimsel. New laboratory and field experiments including a solid cement source are being designed. Reactive transport modeling of the hydration and degradation of cement, causing the formation of hyperalkaline solutions and the alteration of the host rock, will be an essential part of the experiment. Efforts are being made to incorporate the relevant processes into reactive transport modeling. Examples of these processes are the consumption of water by the hydration of clinker phases, C-S-H gel formation and dissolution, uptake of alkalies by C-S-H, and the role of sorption (ion exchange, surface complexation) in the propagation of the hyperalkaline plume.

[1] Mäder *et al.* (2006) *Jour. Geochem. Expl.* **90**, 68-94.
[2] Pfingsten & Soler (2003) *Jour. Cont. Hydrol.* **61**, 387-403.
[3] Pfingsten *et al.* (2006) *Jour. Geochem. Expl.* **90**, 95-113.
[4] Soler & Mäder (2007) *Appl. Geochem.* **22**, 17-29.

Prosopis juliflora and mycorrhizal fungi to revegetate arid acidic, metalliferous desert mine tailings

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Mine tailings, especially those found in arid environments are distributed into the environment primarily by wind and water erosion. Phytostabilization is a remediation technology that establishes a plant cover on tailings, without accumulation of metals into shoot material, thereby reducing the movement of tailings into the environment. One challenge is that tailings are difficult to revegetate due to low nutrients and organic carbon, low pH, and high metal(loid) concentrations. We examined the ability of a native plant *Prosopis juliflora* (mesquite) to grow in an acidic metalliferous tailings from the southwestern USA in association with arbuscular mycorrhizal fungi (AMF). Tailings were pH 4.5 with elevated lead (4,650 mg kg^{-1}) and zinc (1,500 mg kg^{-1}), essentially no organic carbon or nitrogen, and low numbers of neutrophilic heterotrophic bacteria (< 75 CFU/g dry tailings) [1,2]. A greenhouse experiment was performed to determine the effect of three AMF on mesquite biomass, AMF root colonization, and the accumulation of heavy metals in shoot tissues. The AMF used included two commercial inoculants (*Glomus intraradices* and a mix of *G. intraradices* and *G. deserticola*) and a native inoculum from a mesquite rhizosphere (morphotypes not identified). All tailings received a 10% (w/w) compost amendment which is slightly sub-optimal for plant growth in these tailings [1] and plants were harvested after 2 months. AMF inoculated plants showed increased dry biomass, up to 76%, and increased root length, up to 47%, ($p < 0.05$) compared to the uninoculated control. Root colonization by the three AMF inocula ranged from 38 to 78% indicating good infection rates. There was no significant difference in accumulation of Pb (up to 3.9 ± 0.8 mg kg^{-1}) and Zn (up to 111 ± 51 mg kg^{-1}) in mesquite shoot tissues of control and the inoculated plants ($p > 0.05$). The levels of heavy metals detected in the shoot do not exceed domestic animal toxicity limits for Pb (30 mg kg^{-1}) or Zn (500 mg kg^{-1}). In summary, AMF inoculation shows good potential to support plant growth in acidic metalliferous mine tailings at reduced compost concentrations.

[1] Mendez *et al.*, (2007). *J. Environ. Qual.* **36**: 245. [2] Grandlic *et al*. (2008). *Environ. Sci. Technol.* **42**: 2079