

Lichen-substratum interactions in severe environment polluted by heavy metals

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Heavy metal pollution is a worldwide problem. The use of native organisms for assessment and monitoring of polluted sites is an approach that could contribute to a reduction on costs and secondary environmental impacts. Because several fruticose lichens occur even in areas highly polluted by heavy metals, lichens may meet the requirements. Therefore, interactions between lichens and substrata is an important key to determine the behavior of heavy metals in surface environment polluted by heavy metals.

Although, no studies have investigated interactions of fruticose lichens and the corresponding substrata comprehensively from the aspect of biogeochemical behavior of heavy metals. Therefore, several fruticose lichens, including *Stereocaulon exutum* and several *Cladonia* Spp., from contaminated abandoned mine sites and the corresponding substrata were investigated (1) to determine the behavior of heavy metals during the weathering of slag mediated by *S. exutum*, (2) to determine the distribution of the heavy metals in the thalli of *S. exutum*, and (3) to determine the correlations between the heavy metal concentrations of lichens and those of the corresponding substrata.

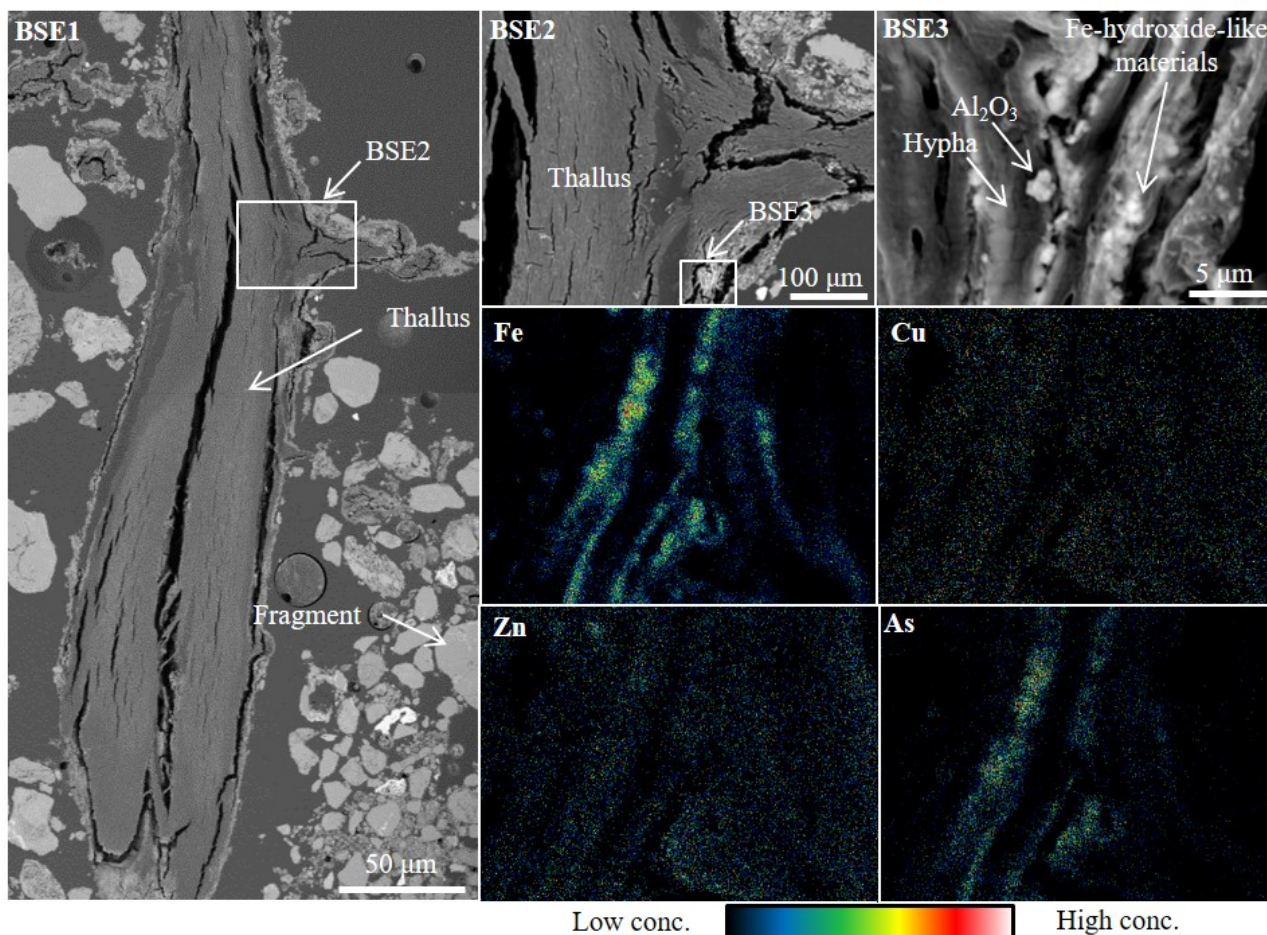
The slag that is a substratum of *S. exutum* consists primarily of willemite, fayalite, and/or magnetite and contains matte drops, which are mainly Cu-metals, -alloys, and -sulfides. The willemite and matte drops are ultimately converted to Fe-hydroxides during the weathering process. In addition to abiotic weathering, the heavy metals are dissolved during the biotic weathering by substances from the lichen and hyphal penetration. The dissolved heavy metals are absorbed into the lichen thalli. Absorbed Cu and Zn are distributed within the cells of hyphae, whereas Fe and As are distributed on the surface of hyphae. Fe-hydroxide-like materials are occur on the surface of hyphae (Fig).

Based on previous studies, cations in thalli are distributed into four fractions, e.g. the intercellular and surface, ion exchange site, intercellular, and residual fractions. Although the form of the ions was not identified in this study, the distribution of elements in the hyphal cells may indicated the possible absorption of ions into the cytoplasm through ion exchange sites from external solutions. For the Fe and As concentrated on the surface of hyphae as Fe-hydroxide-like materials, this distribution could be explained by elemental precipitation or the formation of compounds on the hyphae.

The concentrations of Cu, Zn, As, and Pb of *Cladonia* Spp. thalli were positively correlated with those of the corresponding substrata. Distribution maps of the average heavy metal concentrations of the lichens and the corresponding substrata were made to determine the practical applications of the lichens as a biomarker. The maps for the distribution of Cu, Zn, and As in the lichens had very similar distributions to those of the corresponding substrata at the scale of all study sites in southwest Japan. Therefore, a large-scale analysis of lichens with many samples successfully detected the distribution of heavy metal pollution of soil.

In conclusion, *C. ladonia* Spp. lichens can be used in practical applications for biomonitoring and assessment of heavy metal pollution of soil. Because lichen is a pioneer organism in polluted areas by heavy metals worldwide, the investigation of interactions between lichens and substrata could contribute to determine the elemental cycle between biosphere and lithosphere during natural recovery process of polluted areas.

Keywords: abandoned mine site, weathering of slag, fruticose lichen, absorption of heavy metals, biomarker



Back-scattered electron images and elemental maps of the medulla inside the cortex of thallus (Sueoka *et al.*, 2015).