Bioaccumulation of metals by lichens: Uptake of aqueous uranium by *Peltigera membranacea* as a function of time and pH

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ABSTRACT

Uranium sorption experiments were carried out at ~25 °C using natural samples of the lichen *Peltigera membranacea*. Thalli were incubated in solutions containing 100 ppm U for up to 24 h at pH values from 2 to 10. Equilibrium sorption was not observed at less than ~6 h under any pH condition. U sorption was strongest in the pH range 4–5, with maximum sorption occurring at a pH of 4.5 and an incubation time of 24 h. Maximum U uptake by *P. membranacea* averaged ~42 000 ppm, or ~4.2 wt% U. This appears to represent the highest concentration of biosorbed U, relative to solution U activity, of any lichen reported to date. Investigation of post-experimental lichen tissues using electron probe microanalysis (EPM) reveals that U uptake is spatially heterogeneous within the lichen body, and that U attains very high local concentrations on scattered areas of the upper cortex. Energy dispersive spectroscopic (EDS) analysis reveals that strong U uptake correlates with P signal intensity, suggesting involvement of biomass-derived phosphate ligands or surface functional groups in the uptake process.

INTRODUCTION

The threat of environmental pollution from the release and dispersal of uranium and related radionuclides into the biosphere has stimulated extensive research focusing on the geochemical properties of radionuclides and the interaction of U minerals and dissolved species with biological systems. The strong tendency of U to form stable aqueous complexes and precipitates with organic ligands and compounds is well known (e.g., Nash et al. 1981; Turner et al. 1993; Landais 1993; Read et al. 1993; Jamet et al. 1993) and indicates that U-biotic interactions could play an important role in radionuclide cycling at the Earth’s surface. This hypothesis is supported by recent work elucidating the profound influence exerted by microbial communities on element cycling in the biosphere.

Experimental and field studies by Mann and Fyfe (1985), Milodowski et al. (1990), Lovely et al. (1991), and Macaskie et al. (1992) demonstrate that algae and bacteria can facilitate the precipitation of solid U phases directly from solution, through adsorption of aqueous U onto bacterial cell walls and subsequent nucleation of hydrous uranyl phases (Macaskie et al. 1992) or through U adsorption followed by reduction of U(VI) to relatively insoluble U(IV) at the cell wall interface (Lovely et al. 1991). Clearly, the effects of bioaccumulation by bacteria or fungi must be acknowledged in attempts to understand radionuclide cycling and dispersal. Many basidiomycete fungi are efficient accumulators of radionuclides and may form mycorrhizae with vascular plants. Such symbiotic relationships can lead to radionuclide uptake by the vascular plant hosts (Shaw and Bell 1994). Herbivorous grazing of bioaccumulating lichenized fungi in arctic and subarctic habitats can promote radionuclide cycling into higher trophic levels, resulting in widespread distribution of toxic metals from originally localized sources (Sheard 1986a, 1986b; Thomas et al. 1994).

In terrestrial environments, fungi can exist in a free-living state, as symbioses, e.g., with vascular plant roots (mycorrhizae), or else forming intimate associations with green algae or cyanobacteria. This latter type of association comprises the lichens, or lichenized fungi. Lichens are highly diverse and successful organisms, occurring in extreme environments worldwide in all major ecosystems apart from the deep sea and forming the dominant biomass in Arctic and Antarctic regions. Indeed, lichen-dominated vegetation covers approximately 8% of the Earth’s land surface, giving them a globally important role in plant ecology and carbon, nitrogen, and phosphorus cycling (e.g., Nash 1996; Knops et al. 1991). However, the role of lichens in micronutrient and trace metal cycling in many settings remains largely unquantified.

Lichens lack roots, a protective outer cuticle, are long-lived and depend on sorption of nutrient elements often