Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.35604

Fe-Si-organic matter facilitated transformation of Pb bearing colloids along soil-rivers in a smelter contaminated environment

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Understanding Pb transport from soil to river systems is critical in smelter-contaminated areas, where surficial soils are significantly enriched in Pb. Along the soil–river continuum, changes in pH, redox, and organic ligands destabilize colloids and drive Pb re-partitioning, thereby controlling its mobility and reactivity. These processes were studied around the Pb-smelter in Trail, British Columbia, Canada, located along the Columbia River, a major drinking water source in the northwestern United States. Here, the colloidal transition from soils to surface waters was examined using batch leaching experiments with simulated rainwater and water samples from creeks and the Columbia River. Samples were sequentially filtered (0.45 and 0.02 μm), and colloids were characterized using chemical analyses and transmission electron microscopy to assess compositional and morphological changes.

Soil leachate samples exhibit low Fe/DOC and Si/DOC ratios. Under mildly acidic conditions, Pb partitioning is primarily controlled by organic matter (OM)-Pb complexes, stabilized by electrostatic and steric interactions. The presence of Pb in organo–Fe complexes (TEM) further supports the role of organic ligands in maintaining colloidal stability and enhancing Pb mobility in soil leachates.

During the transition into well-oxygenated creek and river water, Fe/DOC and Si/DOC ratios increase sharply, and pH approaches neutrality. These conditions favor Fe oxidation and the polymerization of Fe–Si phases, leading to predominantly inorganic colloids. Concurrently, the pronounced decrease in dissolved Pb indicates a shift in Pb speciation from organic complexes to adsorption and/or co-precipitation onto Fe–Si phases. Lower DOC concentrations, near-zero zeta potential, and inorganic polymer formation under circumneutral conditions reduce colloidal stability and promote aggregation. The reduced proportion of Pb in the finer size fraction is consistent with its incorporation into larger inorganic aggregates.

Our study reveals that the dynamics among Pb, OM, and Fe-Si phases strongly control the transformation of colloidal Pb, controlling its dissolved fraction. Geochemically driven Pb-bearing colloidal transition from soil to rivers is both a shift in the dominant colloidal type from organic to inorganic colloids and an increase in size. These observations indicate that the otherwise immobile element Pb is readily mobilized from contaminated soils into the Columbia River.