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Amplified biogeochemical cycling during permafrost thaw drives mobilization of hazardous metal(loid)s

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Permafrost thaw intensifies water-mineral-microbe interactions, altering all the key governing variables that control metal(loid) mobility and transport. This keynote presentation will highlight how these amplified interactions have translated to dramatic shifts in water quality in cold regions within the last decade. A key area of concern is intensified sulfide-mineral oxidation, which has been reported in mountainous and cold regions across several continents. Our observations in headwater streams of the Yukon and Mackenzie river basins in Canada over the last 6 years capture precipitous declines in streamwater pH coupled with orders-of-magnitude increases in metal and metalloid (Al, As, Cd, Co, Cu, Fe, Mn, Ni, Se, Zn) concentrations—reaching levels acutely toxic to aquatic life. These results corroborate substantial interdecadal increase in sulfate export and “rusting” in major Arctic rivers. A parallel outcome of permafrost degradation is mobilization of redox-sensitive metal(loid)s Fe, Mn, As, and U associated with rapid anaerobic biodegradation of labile organic matter that is typical of water-saturated organic-rich permafrost soils. We have constrained speciation of these metal(loid)s in permafrost using synchrotron X-ray absorption and X-ray fluorescence measurements. Our laboratory batch and column experiments show that permafrost soils can be primed for mobilization of these metal(loid)s upon thaw, either through direct metal-organic carbon interactions or through indirect redox-driven carbon cycling. This collective body of knowledge indicates that permafrost hosts a substantial pool of reactive metal(loid)s that re-enter active biogeochemical and hydrological cycling during thaw. We highlight future research needs to constrain the fate of metals during transient geochemical conditions arising after permafrost degradation and to identify landscape-scale vulnerabilities of a warming cryosphere.