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Insights on tellurium and cobalt biogeochemical cycling from micro- and nano-analytical techniques

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Understanding processes that drive natural cycling of under-studied critical raw materials such as tellurium (Te) and cobalt (Co) is important as humanity uses an every larger range of commodities to drive the green energy transition. Critical raw materials are found in many deposit types, usually as minor elements (for instance, both Co and Te are found in different types of copper deposit). Their behaviour in outcropping zones of deposits is relevant both for exploration & mining areas and for understanding mobility around recycling facilities where processing of critical raw material-containing products occurs. A combination of micro- and nano-analytical work has been used to explore Te and Co behaviour in surface environments where the elements are naturally enriched. Single particle inductively coupled plasma mass spectrometry (SP ICPMS) was used to detect elemental nanoparticulate phases, 16S rRNA genomic sequencing to characterise the identity of microbes in soils overlying the outcrops and (for Co) growth media incubated with the soils and (for Te) sediments incubated with soluble Te and microbial cultures. X-ray fluorescence microscopy (XFM) was used to map high-resolution trace element geochemistry, X-ray Absorption Near Edge Spectroscopy (XANES) to trace the oxidation state of the element of interest and scanning electron microscopy to view the mineral transitions from primary to secondary textures. The detection of nanoparticles (native tellurium and manganese-cobalt oxides) in both proximal and distal soils around Te-rich and Co-rich outcrops respectively, provide strong evidence for dynamic Te and Co cycling in surface environments. Bacteria detected in the soils high (>100 ppm) in Te and Co include genera known to have high metal tolerance and ability to transform metal(loid)s. Electron microscopy images show secondary (oxidised supergene) minerals fringing primary (hypogene) minerals such as native tellurium and tellurides (for Te) and sulfides and sulfarsenides (for Co), with synthetic analogues experimentally generated for Te showing similar textures to natural weathering environments. Cobalt and tellurium are both mobile in surface environments based on evidence of nanoparticle cycling, demonstrating the importance of (1) analysing for nanoparticulate phases in terrestrial environments; and (2) not assuming oxidation state homogeneity when studying critical raw materials.