Recovering critical and economic metals (In, Sn, Zn, Cu) from mine waste debris and weathered outcrops in the Zn-Fe skarn belt of the Iglesiente-Sulcis region (SW Sardinia): the case of the historical Perda Niedda mining area

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Perda Niedda is a historical, poorly known mining area, close to the Arenas-Tiny mine site near Iglesias in SW Sardinia. Mineralization at Perda Niedda consists of several Fe-Zn-rich skarn occurrences developed in the Cambrian Gonnesa limestones over the Oridda monzogranite stock, satellite to the 289 Ma Mt. Linas pluton. Perda Niedda is actually part of a late-Variscan skarn system stretching across the Iglesiente-Sulcis region. Recent studies defined the features of the skarn mineralization: magnetite-sphalerite-fluorite-cassiterite enrichments are associated with retrograde silicate assemblages which deeply replaced prograde skarn facies dominated by andraditic garnet. Critical metals In and Sn are concentrated in cassiterite and Fe-sphalerite (with chalcopyrite disease), and also hosted in widespread garnets and magnetite, as revealed by EPMA and in-situ LA-ICPMS analyses. Twenty samples from several mine dumps and variably mineralized weathered outcrops were collected to verify the fate of In, Sn and associated metals Zn and Cu during weathering. Powdered samples were analyzed by XRD, prior to and after acid attack with aqua regia ($HCl+HNO_3$) aimed at dissolving metals from soluble mineral phases. The resulting solutions were analyzed by Microwave Plasma Atomic Emission Spectrometer (MP-AES). The XRD analyses provided qualitative evaluation of secondary minerals, like Fe- (goethite, lepidochrocite-pharmacosiderite) and Mn-Zn-Fe hydroxides (pyrochroite, chalcophanite), compared to primary minerals (magnetite, cassiterite and andradite) in the starting materials and residues. The solutions from mineralized gossans and weathered mine dump debris recorded high Zn (up to 1 wt.%), Cu (up to 0.7 wt.%) and notable In (0.1 wt.%) contents likely released from Fe-Mn-Zn hydroxide crusts, while the coupled low Sn (280 ppm) might be due to release from magnetite only, because of cassiterite insolubility. Interesting results derived from analyses of poorly mineralized samples still preserving abundant prograde andradite, soluble into HCl (https://www.mindat.org/article.php/553/Solubility+Data+on+646+Common+and+Not+So+Common+Minerals). Their solutions from acid attack provided remarkable Sn contents, up to 0.26 wt.%, with Zn+Cu (up to 2 wt.%) and In (up to 140 ppm). Such pilot study suggests various features involving weathering of mineralized skarns and their economic potential. The first one is the control of the primary minerals in the mobility of valuable metals, in particular In and Sn, when distributed between soluble (sphalerite-magnetite) and insoluble (cassiterite) phases. The second feature regards the role of secondary minerals in efficiently capturing metals liberated during weathering, thereby generating metal-enriched gossans. Last but not least, the role of soluble prograde Ca-garnets acting as initial reservoirs for metals like Sn and In, directly emanated by the granite magma after emplacement, as well as a further potential ore mineral.