Characterisation and Technological Procedures for Recycling and Reuse of Flotation Tailings from the Rudnik Mine in Serbia

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Introduction

This study is part of the REASONING project, which develops methods to recycle and valorize flotation tailings from the Rudnik Mine, advancing circular economy principles in mining waste management.

Focus:

On the Rudnik flotation tailings, which contain more than 11 million tonnes of material accumulated over decades of zinc, lead, and copper extraction and processing (Fig. 1).

Team:

The project involves researchers from six Serbian institutions and RWTH Aachen University (Germany) and is funded by the PRIZMA programme of the Science Fund of the Republic of Serbia.

Objectives:

(i) characterise tailings mineralogically and geochemically, (ii) develop technologies for efficient recovery of metals and non-metallic materials, and (iii) assess potential as secondary raw materials.

Project Workflow: From Sampling to Valorisation

The project workflow starts with sampling and multidisciplinary investigations, progresses through the development of technological methods, and ends with industrial- scale testing.

Sampling

- It starts with drilling and sampling boreholes that extend through the tailings deposit to the bedrock.
- Physico-chemical parameters—including pH, redox potential, conductivity, resistivity, dissolved oxygen, total dissolved solids, and temperature—are monitored seasonally using piezometers.

Mineralogical & Geochemical Characterisation

- Employ microscopy, SEM/EDS, XRD, Raman spectroscopy, and ICP-OES to analyse mineral associations.
- The primary and secondary mineral phases are studied, while magnetic susceptibility measurements at close intervals help detect and characterise potential local zones of metal enrichment.

Electrochemical Separation

- Involve theoretical modelling using PHREEQC and PhreePlot to determine optimal pathways for electrochemical deposition.
- Experiments commence with synthetic mine water and later employ real leach solutions from tailings.
- Initial tests will be applied on synthetic solutions via a trial-and-error approach.

Technological Procedures for Tailings Valorization

- Processing targets metals (Zn, Pb, Cu) and non-metallic materials.
- The process includes leaching (H_2SO_4/NaOH, oxidants, ultrasound, pre-rinsing), clay removal (sieving, washing, desilting), magnetic separation, gravity concentration of the non-magnetic fraction, and sulfide flotation.

Initial Results

Preliminary analyses indicate that the Rudnik flotation tailings consist of fine-grained material (-0.40 to 0.00 mm) primarily composed of aluminosilicates, oxides, carbonates, and sulfides such as arsenopyrite, pyrite, pyrrhotite, sphalerite, galena, and chalcopyrite (Figs. 2–5).

Figure 1. Landscape of the Rudnik Mine flotation tailings with the ore deposit in the background.

Figure 2. Two types of tailings material: brown, surface-derived and oxidized, and gray, unoxidized, from a drill core.

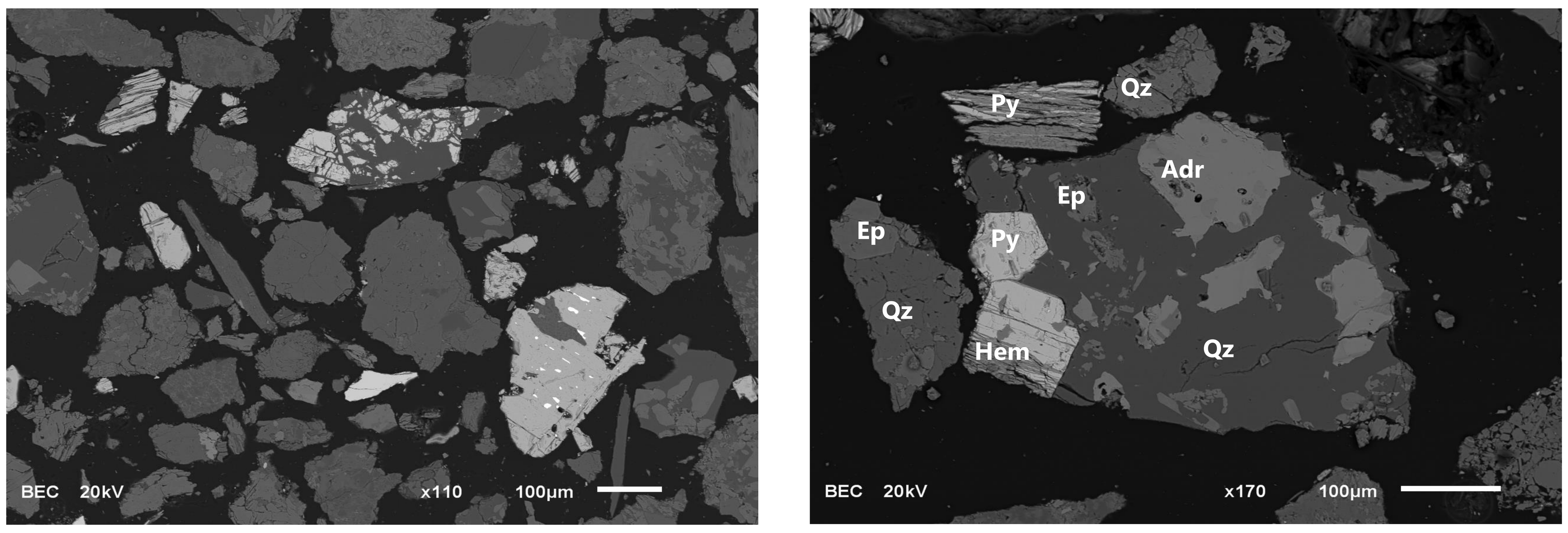

Figure 3. Photomicrographs (backscattered electron images) of tailings from the Rudnik deposit. The images show a variety of mineral grains of different sizes and morphologies, including primary rock-forming minerals (darker grains) and ore minerals (lighter grains), as well as secondary alteration products. Minerals occur either as individual grains or as complex intergrowths. Abbreviations: Adr – andradite, Ep – epidote, Py – pyrite, Hem – hematite, Qz – quartz.

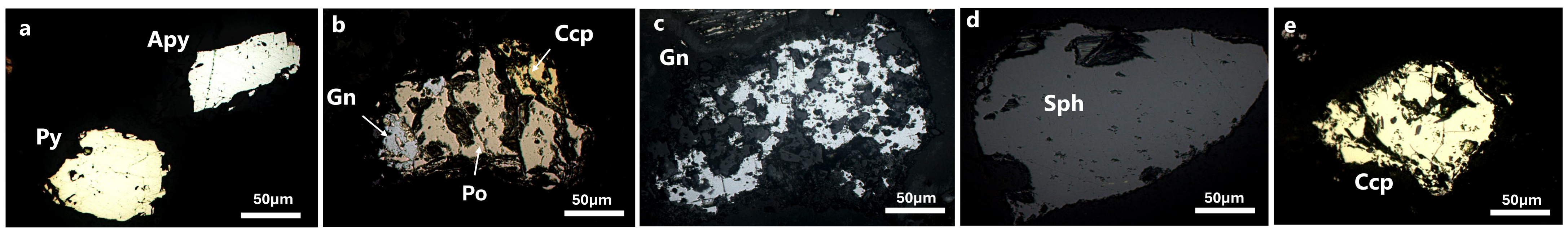

Figure 4. Photomicrographs (reflected light) of tailings from the Rudnik mine. (a) Pyrite and arsenopyrite grains dominate among the sulfide minerals as individual grains, (b-e) while other sulfides, such as pyrrhotite, galena, sphalerite, and chalcopyrite, appear as composite intergrowths reflecting their paragenetic relationships within the ore or as individual grains. Abbreviations: Apy – arsenopyrte, Ccp – chalcopyrite, Gn – galena, Hem – hematite, Po – pyrrhotite, Py – pyrite, Sp – sphalerite.

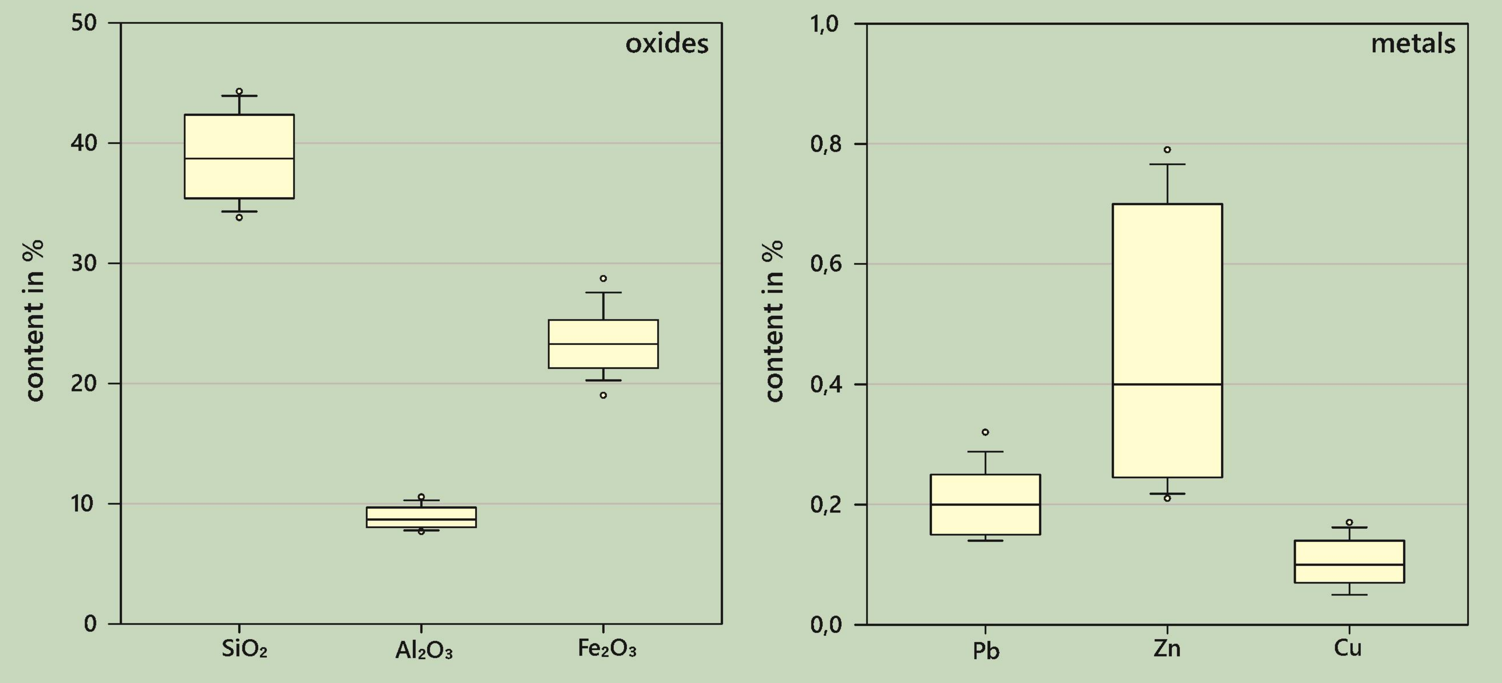

Figure 5. Box plot of main oxides (SiO_2, Al_2O_3, Fe_2O_3) and metals (Pb, Zn, Cu) in the tailings.

The bulk composition is dominated by SiO_2, Fe_2O_3 and Al_2O_3 highlighting the prevalence of silicate, oxide, and aluminosilicate phases.
Trace metals of economic interest are present, including Zn, Pb, and Cu, with localized concentrations of Ag and Bi.

Conclusion & Future Work

- Mineralogical and geochemical characterization confirms that the tailings contain recoverable metals and mineral phases, highlighting their potential as secondary raw materials.
- Processing methods demonstrated strong potential for metal extraction.
- Treated tailings also show promise for reuse in construction applications.
- Future work will focus on optimizing processing parameters, scaling up to pilot-scale operations, and assessing the environmental and economic feasibility of large-scale valorization.

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