Minerals Engineering xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Minerals Engineering

journal homepage: www.elsevier.com/locate/mineng

Recovery potential of flotation tailings assessed by spatial modelling of automated mineralogy data

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ARTICLE INFO

Keywords:
Re-mining
Remining
Tailing
3D modelling
Mine waste
Recycling
Zero waste approach
MLA
Mineral liberation analysis
Processing
Re-processing
Reprocessing
Remediation
Tin recovery
Tin
Erzgebirge
Altenberg
Spatial modelling
Automated mineralogy
Cassiterite
TSF
Tailing storage facility
Geometallurgy

ABSTRACT

The extraction of ore minerals from fine-grained flotation tailings is a commercially interesting but technologically challenging endeavor that needs to be supported by a full technical and economic feasibility study. A novel approach to such an assessment is introduced here. It is illustrated by the example of a historic tailing storage facility containing on average 0.2 wt% of Sn as cassiterite. Mineral processing test work identified flotation as a suitable technology route to recover this cassiterite. The viability of flotation was attributed to three material parameters, namely grade, liberation and particle size of cassiterite. These parameters were quantified for a set of ten exploration drill cores by chemical assay and mineral liberation analysis. For each of the three relevant parameters a suitable weighting function was defined that was applied to the entire data set. The data was then geo-referenced and combined to construct a 3D model illustrating a depreciated grade, i.e., the amount of cassiterite-bound tin that can realistically be recovered from the tailings. Results of the case study illustrate the importance of combining chemical grade data with quantitative mineralogical and microfabric information in any effort to objectively assess the residual value contained in industrial tailings or any other residue considered for re-processing.

1. Introduction

Fine-grained residues hosted by industrial tailing storage facilities (TSFs) often contain significant amounts of minerals of commercial interest (Macri et al., 2015; Louwrens et al., 2015). Such valuable fractions may either comprise residual amounts of those minerals that were the primary target of industrial exploitation but that escaped previous beneficiation processes – or they may represent minerals that were previously not considered of commercial interest. TSFs should thus be regarded as low-grade ore deposits of anthropogenic origin. This is of particular relevance to regions that have an extensive record of industrial mining, such as many areas of Europe. Exploitation of TSFs will make at least some contribution to meet the demand for metals and minerals of European industry and it is the second pillow of the European Raw Materials Initiative to foster the supply of such materials from European sources (EU Commission, 2008, 2011). The drivers for research on TSFs in Europe, however, can never be reduced to resource exploitation, but need to integrate concerns of environmental impact and sustainable rehabilitation of affected landscapes.

Anthropogenic ore deposits such as TSFs are readily exposed at surface, have a well-defined tonnage and the raw material is already crushed and milled –factors that will reduce financial risk and

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http://dx.doi.org/10.1016/j.mineng.2017.09.008
Received 27 April 2017; Received in revised form 27 August 2017; Accepted 16 September 2017

development time (Büttner et al., 2016) The fine-grained nature of the raw material may be beneficial as less energy will be required for exploitation and comminution, but it may also have considerable detrimental effects, as currently available (physical) beneficiation processes struggle to be highly selective for very fine-grained particles. For historic TSFs this detriment is usually less problematic than for modern TSFs. Former beneficiation processes were less effective than the state of the art technologies, it can thus be expected that historic tailings contains still higher concentrations of target minerals in suitable particle size fractions. The resource potential of TSFs may indeed be significant, but any exploitation will require quantification by a thorough technical and economic feasibility study.

It is important to stress here that every TSF has its own depositional history and it will have its own, unique internal structure and composition. Relevant factors that will define the composition of the tailings include the primary characteristics of the ore processed, the processing technology applied as well as the method of tailings deposition (Redwan et al., 2012). Every TSF will thus require exploration and technical feasibility studies similar in detail to those commonly applied to primary ore deposits. Feasibility studies will depend heavily on a sound understanding of relevant material characteristics, including grade, particle and mineral grain size, liberation and deportment. Furthermore, the spatial distribution of such characteristics within the volume of any investigated TSF needs to be well understood as TSF's cannot be regarded being of uniform composition. The latter task is of particular relevance because well-known spatial approaches to resource modeling (Kriging, etc.) should not be used, given that the assumption of stationarity is in general not appropriate for tailings.

It is thus important to collate a comprehensive dataset for feasibility studies to lower the risk of investment prior to embarking into commercial tailings reclamation. In this study, an innovative approach to the definition of the resource potential of a TSF is presented in a case where a physical beneficiation process (flotation) could be applied to extract residual amounts of Sn (as cassiterite, SnO_2) from a silicate-rich residue. Results were obtained as part of a publically funded research project aimed to quantify the resource potential of large TSF's from historic mining operations in Saxony/Germany (Büttner et al., 2016; Büttner and Gutzmer, 2016).

2. Study area

The TSF "Tiefenbachhalde" in Altenberg/Saxony was established in 1952 by Volkseigener Betrieb (VEB) Zinnerz Altenberg. Tailings originated by processing of ores from the Altenberg Sn deposit, a world-class greisen deposit located in the Eastern Erzgebirge, Saxony, Germany (Weinhold, 2002). A 60 m high tailing dam wall was constructed in a steep valley to establish the Tiefenbachhalde. Two small streams (Tiefenbach and Schwarzwasser) were captured and canalized in tunnels that run below the TSF. The TSF was in active use between 1953 and 1966 as storage facility for the residues of density separation processes generated during cassiterite concentrate production. The surface area of the Tiefenbachhalde measures nearly 350 meters from west to east and 600 m from north to south. Being placed into a natural valley the thickness of the TSF varies greatly, locally exceeding 30 m. Two schematic cross sections of the TSF are shown in Fig. 1. In the literature the total volume of the tailings deposited has been reported as 1.95 Mio m^3 (Weinhold, 2002 and references therein). Even average particle sizes as well as average mineralogical and chemical composition of the tailings material contained in the Tiefenbachhalde have been reported (Weinhold, 2002 and references therein) (Table 1). Of particular relevance to the present study is the notion that only 50% of the Sn contained in the ore from the Altenberg deposit was recovered – with on average 0.22 wt% Sn lost to flotation tailings (Weinhold, 2002 and references therein). There is no conclusive information in literature concerning the deportment of Sn, particle sizes of Sn-bearing minerals and their liberation in the Tiefenbachhalde.

3. Methods

In a first step, all available historic data were compiled. Site visits were undertaken to identify suitable drill locations. Two drilling campaigns were executed; the first one to obtain a single drill core that was used to explore tailings characteristics and suitable beneficiation routes. The second campaign yielded nine additional cores that provided insight into the spatial distribution of tangible compositional attributes for the resource potential model that was constructed using simple yet robust linear interpolation methods.

3.1. Drilling, sampling and sample preparation

The surface of the Tiefenbachhalde has been modified considerably subsequent to its closure in 1966. The surface was covered with soil, cohesive material, construction waste and an asphalt layer mainly in the southern half of the TSF (BIUG GmbH, 2013). Therefore, suitable drill sites could only be selected on the northern half of the TSF and it was not possible to set up a regular drill grid pattern. Instead, it was decided to drill along three main lines in irregular distances, in order to constrain possible variations in the material composition in different spatial ranges (Fig. 2).

The first drill hole was placed near the center of the TSF using a liner drilling method whereas the other nine holes were realized by an ultrasonic drilling technology. In the absence of a basal sealing layer each drill core reached the topsoil immediately underlying the tailings material, assuring that the total thickness of the tailings at each drill point could be accurately constrained. Core samples were collected in all cases in plastic liners of one meter length and a diameter of 11 cm.

Drilled material was exposed by cutting a window along the whole length of the plastic liners. The cores were then photographed, logged and channel sampled. The tailing material was found to be uniform in macroscopic appearance. It was thus decided to always combine two meters of drill core material into one sample, generating a total of 92 samples for analysis. The samples were air dried, because no changes by oxidation where expected as primary ores were virtually devoid of sulfides. The dry samples were carefully de-agglomerated by hand with an agate mortar. Each sample was split by a Quantachrome rotary powder sample splitter (Sieving Riffler™) until there was an adequate amount for preparation of polished grain mounts. These were used for Mineral Liberation Analysis (MLA). Aliquots of samples were used for wet sieve analysis and laser granulometry, and also for further grinding to analytical fineness for chemical assaying.

3.2. Surveying of tailings and data preparation for 3D modelling

3.2.1. Topography

A historic topographic map of Altenberg (1:25.000; 1912; in Gauss-Kruger Germany, zone 4) was digitized and used as pre-mining reference. The current topography was obtained via a drone-borne photogrammetric survey using a fixed wing system equipped with a standard RGB camera and GPS. Resulting nadir, geotagged aerial images (ground resolution of 3.88 cm) were deployed to calculate a Digital Surface Model (DSM), ground resolution of 15.55 cm/px) using Structure-from-Motion (SfM) photogrammetry workflow implemented in Agisoft Photoscan. Further, an orthomosaic (3.88 cm/px resolution) was calculated from the images. The computed total XYZ error is given with 1.12 px (or ~16cm).

3.2.2. Drill hole location

Locations of drill holes were surveyed using a Global Navigation Satellite System (GNSS; Trimble R4-2) with a local base station (Trimble R5) setup. Surveyed points were base-line corrected to achieve precise location within ± 2 cm. As reference system WGS84/UTM zone 33N with the GRS80 ellipsoid was chosen.