Recovery of Critical Raw Materials from Abandoned Mine Wastes: Some Potential Case Studies in Northwest Italy

*materials proceedings*

*Proceeding Paper*

# Recovery of Critical Raw Materials from Abandoned Mine Wastes: Some Potential Case Studies in Northwest Italy †

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† Presented at the 2nd International Conference on Raw Materials and Circular Economy "RawMat2023", Athens, Greece, 28 August–2 September 2023.

**Abstract:** Critical and Strategic Raw Materials European Union's policies are targeting the production of fundamental raw materials from internal sources, fostering the recovery of relevant quantities of materials from the existing mining facilities in Europe. Northwest Italy was an important mining area until the mid-1900s, as reported by the Italian inventory of closed mining waste storage facilities, referring to 92 mining waste facilities. Three sites were chosen to better define their historical and bibliographical framework. The selected sites comprise the Traversella Mine (Piedmont), Libiola Mine (Liguria) and Herin Mine (Aosta Valley). Currently, there are relevant amounts of abandoned mining waste in the surrounding areas of these closed mines. The potential recovery of the residual valuable fraction of these materials could be crucial for both critical raw materials' recovery and environmental valorization of the involved territories.

**Keywords:** critical raw materials; mining waste; raw materials recovery

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**Citation:** Baldassarre, G.; Fiorucci, A.; Marini, P. Recovery of Critical Raw Materials from Abandoned Mine Wastes: Some Potential Case Studies in Northwest Italy. *Mater. Proc.* **2023**, *15*, 77. https://doi.org/10.3390/materproc2023015077

Academic Editors: Antonios Peppas, Christos Roumpos, Charalampos Vasilatos and Anthimos Xenidis

Published: 5 February 2024



## 1. Introduction

In recent years, the growing demand for raw materials resulted in continuous economic and supply risk assessments from European Union Institutions. Accordingly, EU Policies have evolved to feed the increasing domestic industrial and economic need for raw materials. In March 2023, the European Commission published a new policy guideline for the raw material sector, the so-called "Raw Materials Act" [1]. The framework presented an updated Critical and Strategic Raw Materials list and a group of actions aimed at producing such materials from internal sources, fostering the recovery of relevant quantities of minerals from existing mining facilities among Partner Countries' territories. This general aspect is also needed to achieve the ambitious goals set by the 2050 Long-Term Strategy for Climate Neutrality [2] and the European Green Deal [3].

The Italian mining industry has an important tradition in terms of the variety of commodities produced during the recent century. Nevertheless, most of the actual Italian production of raw materials is focused on industrial minerals, ornamental stones and construction materials, while there are no mining operations for metals [4]. These factual backgrounds left plenty of abandoned sites within the mining districts of the country.

According to the European Directive 2006/21/CE, the Italian Institute for Environmental Protection and Research, ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale), in 2012, started to conduct a census for the determination of a national inventory of closed waste storage facilities, including abandoned structures which have severe negative effects on the environment, or which can pose a serious threat to human health or the environment [5]. The last two updates of the census were published by ISPRA in 2017 and 2022 [6,7]. In 2017, the report stated that the number of abandoned mining waste facilities in the regions of Northwest Italy including Piedmont, Aosta Valley and Liguria was, respectively, 57, 25 and 10, accounting for 92 sites [6]. The last updated report, published in December 2022, reported a different number of total sites for the same areas, accounting for 82 localities, considering the communication collected from the local regional authorities [7].

The purpose of this study is to describe the actual conditions of three selected sites and provide a review of the geological setting, the type and quantity of commodities exploited during the activity of these mines and the state-of-the-art published works regarding the characterization of the existing mining waste. In this way, a set of actions for the definition of further research is needed to evaluate the possibility of developing focused studies for the recovery of CRM and other valuable minerals from the selected sites and, as a consequence, their environmental restoration.

## 2. Bibliographic Background

According to the ISPRA reports [5–7], several potential case studies can be considered in Italy. The selection of one site for each aforementioned region was made according to a set of conditions that can be outlined as follows:

1. Historical importance of the site;
2. Commodity extracted;
3. Availability of published scientific data;
4. Accessibility of the site for field investigation.

### *2.1. Traversella-Brosso Mine District, Piedmont*

The Traversella-Brosso mine district is situated about 55 km North of Turin, Piedmont, on the eastern side of the Chiusella Valley (Figure 1). The deposit is defined as a polymetallic Fe-Cu-W—with accessory Mo, As, Sb, Bi, Au and U—pyro-metasomatic deposit occurring in the metamorphic aureole generated at the contact between an intrusive body and the metamorphic rocks of the Sesia-Lanzo geological unit [8]. The ore body is considered a "skarn" deposit in which the mineralized veins are hosted in mica-schist, gneiss and layers of carbonate rocks [9].

The deposit was exploited starting from the Roman period and the Middle Ages, when mainly magnetite, such as iron ore, was mined with chaotic and artisanal methods, causing several stability problems to the rock mass. This activity was mainly used to deliver raw materials for the essential economy of local communities. During the XVIII century, the Traversella-Brosso district started to be exploited with industrial and planned operations. It brought a thriving production of the magnetite resource, accounting for about 340,000 metric tons of ore extracted between 1723 and 1824. Furthermore, from the 1930s, other types of ore minerals were exploited, such as scheelite, chalcopyrite and uraninite, thanks to the implementation of innovative technologies in the mineral processing plants [9,10]. During the final years of production, the mines produced 100 tons per day of iron ore, containing 40–50 ppm of scheelite and 2–3 ppm of uraninite [10]. The amount of Light Rare Earth Elements (LREEs, including Y, La, Ce, Pr, Nd and Sm) and Heavy Rare Earths Elements (HREEs, including Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu), measured in the scheelite exploited in Traversella, was 1036 ppm (min 101 ppm, max 2125 ppm) and 144 ppm (min 30 ppm, max 208 ppm), respectively, as reported by Matteucci [11]. The mining activity ceased in 1971 due to economic difficulties in the exploitation of the orebodies [9,10].

ISPRA underlined the presence of waste rock piles potentially containing As, Cd, Co, Mn, Ni, Pb, Cu, V, Fe and W in the areas near the former mine adits and processing plants. Furthermore, ISPRA classified this mining waste as having a medium/high ecological and sanitary risk [6,7]. Some references to dumping areas are also reported in the minor works published in journals of mineral collectors [12]. Moreover, no published data are available regarding the volumes or quantities of material present in these mining dump areas.

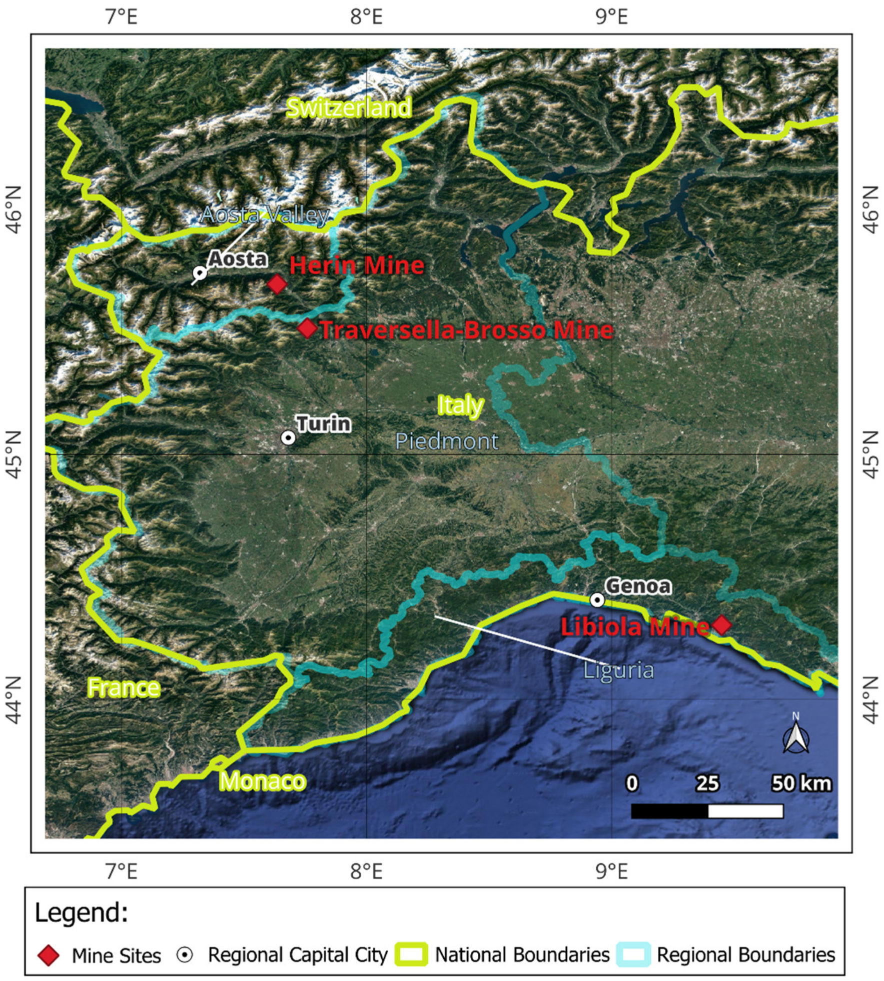


**Figure 1.** Location of the examined mine sites.

*2.2. Libiola Mine, Liguria*

The Libiola mine is located about 8 km northeast of the town of Sestri Levante, Liguria (Figure 1), within the Gromolo Creek basin [13]. This Fe-Cu ore deposit may be considered as a strata-bound volcanic massive sulfide (VMS), characterized by massive lens-shaped, stockwork veins and disseminated mineralization mainly associated with pillow basalts, basaltic breccia and serpentinite rocks [14]. Pyrite and chalcopyrite are reported as primary minerals; secondary minerals are represented by sphalerite, pyrrhotite, marcasite, hematite, mackinawite, magnetite, cubanite and gold, while quartz and carbonates are defined as accessory gangue minerals [13–15].

The mine was a well-known source of copper since the Bronze Age and the Roman period [14]. Modern exploitation activities started to develop in the 1840s when the local government financed the industrial-scale exploitation of the Libiola deposit [14]. This mine reached its peak production during the 20th century with historical records accounting for about 35,000 metric tons of iron and copper minerals in the year 1905 [15]. The mine was first closed in 1955 and then abandoned in 1962 [14]. Libiola is considered one the most important copper mines in Italy, producing about 1 Mt of Fe-Cu ore with an average grade of 5–10% of copper during its lifespan [15].

According to the literature accessed, the mine was exploited with three open-pits and with a 30 km long network of underground excavations. Mine wastes were dumped in five major piles near tunnel adits and surficial exploitation areas [16,17]. Furthermore, tailings from processing operations were not stocked in ponds but in small dumps [13–15]. Today, these waste rock dumps cover an area of 500,000 m$^2$ and contain both mineralized materials (pyrite and chalcopyrite) and gangue rocks (basalts and serpentinites), which are heterogeneously distributed in vertical and horizontal directions according to the former excavation techniques used during operations [14,15]. The abandoned mine and its dumped materials present relevant environmental pollution problems due to Acid Mine Drainage (AMD), affecting soils and water streams [13–19].

Some authors characterized the dumped materials using qualitative and quantitative methodologies for mineralogical and geochemical determinations [13,14,16]. Surface sampling campaigns were completed, and these efforts showed the presence of about 50% of gangue minerals (serpentine, plagioclase, magnetite, chlorite, augite, clay minerals, albite, quartz), 8% of primary sulfides (pyrite and chalcopyrite), about 40% of secondary minerals (Fe-oxyhydroxides and Fe-oxides, generated from the weathering of primary and sulfide minerals) and about 2% of other mineral species [16]. Geochemical analyses showed the presence of 10 mg/kg of copper and relevant heavy metals concentration in the material collected from the dump bodies [13]. Marescotti et al. [16] also proposed a geostatistical distribution model for mapping the distribution of the main pollutants and minerals on the surface of mining waste heaps. No relevant experimental data are present in the literature regarding a precise spatial and volumetric distribution of these materials in the case study area.

### *2.3. Herin Mine, Aosta Valley*

The Herin Mine is located 70 km north of Turin in the municipality of Champdepraz Aosta Valley Region (Figure 1). This Fe-Cu deposit belongs to the Zermatt-Sass ophiolitic system and it is hosted in greenschists (chloriteschists and micaschists) interlayered with quartzites. Sulfide mineralization occurs with massive or disseminated textural patterns [20,21].

The first documented information regarding the mining activities in Herin dates back to the 18th century, and it remarkably contributed to the regional copper and pyrite production until the activity ceased in 1955 [22,23]. The exploitation was developed mainly with underground excavation methods; the exploitation plan was not well-organized due to several stops in production and ownership changes during the years. The mine produced relevant quantities of commodities between the late 1880s and 1910s, accounting for 2820 tons of Cu in 1884 and about 11,000 tons of ore in 1915 [20,23]. Before the final closure of the mine, some exploration campaigns were carried out [23]. As a result, in 1948, the resources were estimated at 29,000 tons indicated and 50,000 tons inferred, with a 2.5% Cu grade [23]. Fantone et al. [20,21] stated that the Herin pyrites and chalcopyrites are characterized by a Ni-Co anomaly, reporting high concentrations of Co and Ni in the analyzed samples.

In 2017, the ISPRA reported the Herin abandoned mine in its inventory, underlining that the potential presence of As, Cd, Mn, Ni and Cu in the mining dumps is associated with a medium/high risk of environmental pollution [6]. No relevant scientific work has been developed in recent years regarding the actual state of the mining dumps surrounding the mining adits, according to the published data available in the literature.

## 3. Discussion

This work provides a historical and industrial literature review of three selected Italian mines whose extractive activity produced large amounts of mining waste. The potential dimension of the mine waste quantities could be extrapolated from the volume of extracted ore reported on historical industrial and scientific documents rather than photogrammetric surveys or filed inspections. Some of the commodities exploited in these locations are considered in the EU Critical Raw Materials List [1].

An official census of abandoned mining facilities was published by the ISPRA [6,7], while the detailed information about the volumes, tonnages and detailed content of SRM or CRM is scarcely available for the selected sites. Table 1 shows a recap of the main features investigated for the selected sites.

This information was reviewed to depict the current state of three mining sites, which were chosen according to their industrial importance and accessibility. As a result, an assessment of the geological setting, the amounts of commodities produced and the available information on the presence of mining waste was proposed. By doing so, it should be emphasized that investigations of the actual status of mining waste dump areas in the studied sites are present, mainly concerning mineralogical features. New analysis of CRM content should be taken into consideration to complete an improved investigation of the selected case study areas. Additionally, the information on the tonnages and volumes of the waste present in these areas should be implemented as a priority by future initiatives to demonstrate the effectiveness of their recovery potential.

**Table 1.** Main features regarding mine waste facilities for the analyzed potential case studies.

| Site | Municipality, Province, Region | Reported Commodities | Information on Mining Dumps |
|---|---|---|---|
| Traversella-Brosso Mine | Traversella, Turin, Piedmont<br>Brosso, Turin, Piedmont | Fe [1], W, Mo, U, REE [2] | ISPRA [6,7]<br>Minor works [12] |
| Libiola Mine | Sestri Levante, Genoa, Liguria | Fe [3], Cu | ISPRA [6,7]<br>Marescotti et al. [13,16]<br>Buccheri et al. [14] |
| Herin Mine | Champdepraz, Aosta, Aosta Valley | Fe [3], Cu, Ni, Co | ISPRA [6] |

[1] Magnetite Ore. [2] LREE and HREE, not exploited during industrial operations. [3] Pyrite Ore.

Continued efforts are needed to define research actions devoted to the characterization and quantification of the existing waste dumps in Northwest Italy. In conclusion, technical feasibility studies should be oriented to the recovery of these valuable raw materials from secondary sources.

**Author Contributions:** Conceptualization, G.B. and P.M.; methodology, G.B.; validation, A.F. and P.M.; investigation, G.B., A.F. and P.M.; resources, P.M. and A.F.; data curation, G.B.; writing—original draft preparation, G.B.; writing—review and editing, A.F. and P.M.; visualization, G.B.; supervision, P.M.; project administration, P.M.; funding acquisition, P.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the European Union NextGenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR)—MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.3—D.D. 1551.11-10-2022, PE00000004).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** This contribution used publicly accessible data available in the referenced sources.

**Acknowledgments:** This study was carried out within the MICS (Made in Italy—Circular and Sustainable) Extended Partnership and received funding from the European Union NextGenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR)—MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.3—D.D. 1551.11-10-2022, PE00000004). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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