

## Gold and silver distribution in Chodak gold-beneficiation tailings

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**Abstract:** This study investigates the distribution, granulometric characteristics, and mineralogical composition of precious metals in technogenic waste generated by the Chodak gold beneficiation plant. Samples collected from different depth intervals were examined using chemical, granulometric, and mineralogical analytical methods. The results showed that gold concentrations ranged from 0.60 to 1.68 g/t, while silver concentrations varied from 4.35 to 28.89 g/t. The highest concentrations of both Au and Ag were identified in sample 4a. Granulometric analysis demonstrated that the waste is predominantly composed of fine particles, with the  $-0.071$  mm fraction constituting the major proportion of the material. Mineralogical investigations identified pyrite, arsenopyrite, chalcopyrite, sphalerite, magnetite, hematite, and iron hydroxides. Gold occurs as finely dispersed particles and in association with sulfide minerals. The findings confirm the potential of Chodak tailings as a secondary source of precious metals and provide a basis for developing effective recovery technologies.

**Keywords:** Gold tailings, technogenic waste, gold recovery, silver, mineralogical composition, granulometric analysis.

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### INTRODUCTION

The increasing demand for precious metals and the depletion of high-grade primary ore resources have intensified interest in the processing of technogenic mineral wastes generated by mining and metallurgical industries. Gold-processing wastes, including tailings and other accumulated residues, may contain significant amounts of gold, silver and associated valuable components that were not completely recovered during the initial beneficiation process [4]. Therefore, the reprocessing of such wastes is considered an important approach for the efficient utilization of mineral resources, reduction of accumulated industrial waste and improvement of the environmental sustainability of mining operations.

The Chodak gold-bearing deposit is one of the mineralized areas where significant quantities of technogenic waste have been accumulated as a result of ore extraction and beneficiation. The wastes generated during gold beneficiation contain a complex association of metallic and non-metallic minerals. According to the investigated materials, gold in the Chodak beneficiation wastes occurs in both free and bound forms. Free gold is mainly represented by finely dispersed particles, while a considerable part of gold is associated with sulfide and oxide minerals [9]. Silver is also present in the waste and occurs in association with sulfide minerals and other mineral phases. Such a complex distribution of valuable components makes their recovery technically challenging and requires a detailed study of the material composition of the waste [5].

Mineralogical investigations indicate the presence of pyrite, arsenopyrite, chalcopyrite, sphalerite, magnetite, hematite, iron hydroxides and other mineral phases in the studied material. Gold-bearing mineral associations are closely related to sulfide minerals, particularly pyrite and arsenopyrite, while oxidation processes result in the formation of iron hydroxides and secondary mineral phases [7]. The particle-size distribution of the waste also plays an important role in the recovery of precious metals, since gold and silver are distributed unevenly among different size fractions. The analytical results demonstrate variations in the concentrations of Au and Ag depending on sampling depth and granulometric fraction, indicating the heterogeneous nature of the technogenic material [10].

A comprehensive characterization of the chemical, granulometric and mineralogical composition of gold-processing wastes is therefore essential for selecting an appropriate recovery technology. The identification of the forms of occurrence and distribution of gold and associated valuable metals provides the basis for determining the optimal combination of beneficiation, hydrometallurgical and other processing methods. In particular, the presence of finely disseminated and mineral-bound gold requires technological approaches capable of liberating and selectively recovering valuable components from complex mineral associations [2].

The objective of this study is to investigate the material composition and distribution of valuable metals in technogenic wastes from the Chodak gold beneficiation plant and to evaluate their potential as a secondary source of precious metals. Particular attention is given to the distribution of gold and silver in different depth intervals and granulometric fractions, as well as to the mineralogical associations controlling their occurrence [12]. The obtained results are intended to provide a scientific basis for developing an effective technological approach for the additional recovery of gold and associated valuable components from accumulated Chodak beneficiation wastes.

## RESEARCH METHODOLOGY

The study was conducted using technogenic waste samples collected from different depth intervals of the Chodak gold beneficiation plant tailings. Samples were taken from the surface and deeper layers, including 1–2.5, 4.0–5.5 and 6.0–7.0 m depths. The samples were subjected to chemical, granulometric and mineralogical analyses to determine the distribution and occurrence forms of precious metals.

The chemical composition of the samples was determined with particular attention to gold (Au) and silver (Ag), while palladium (Pd) and platinum (Pt) were also considered. Granulometric analysis was performed by separating the material into different particle-size fractions and determining the mass percentage of each fraction. Mineralogical investigations were used to identify the main sulfide

and oxide minerals and their association with gold-bearing phases. The principal research methods are summarized in Table 1.

**Table 1. Research methods used for characterization of Chodak technogenic waste**

| No. | Research method        | Main parameters determined                             | Purpose                                                 |
|-----|------------------------|--------------------------------------------------------|---------------------------------------------------------|
| 1   | Sampling               | Depth and sampling layer                               | Obtaining representative waste samples                  |
| 2   | Chemical analysis      | Au, Ag, Pd, Pt                                         | Determining precious-metal concentrations               |
| 3   | Granulometric analysis | Particle-size distribution, %                          | Establishing metal distribution by size fraction        |
| 4   | Mineralogical analysis | Pyrite, arsenopyrite, chalcopyrite, sphalerite, oxides | Determining mineral associations of valuable components |
| 5   | Comparative analysis   | Au and Ag distribution                                 | Evaluating the recovery potential of the waste          |

The obtained analytical results were compared according to sampling depth, particle-size fraction and mineralogical composition. This integrated approach was used to assess the distribution of precious metals in the technogenic waste and to determine its potential as a secondary source of gold and associated valuable components [1].

## RESULTS

The chemical and mineralogical investigations of the Chodak gold-processing plant tailings revealed a heterogeneous distribution of precious metals within the technogenic material. The concentrations of gold and silver varied considerably depending on the sampling location and depth. The analytical results obtained for samples collected from different depths are presented in Table 2.

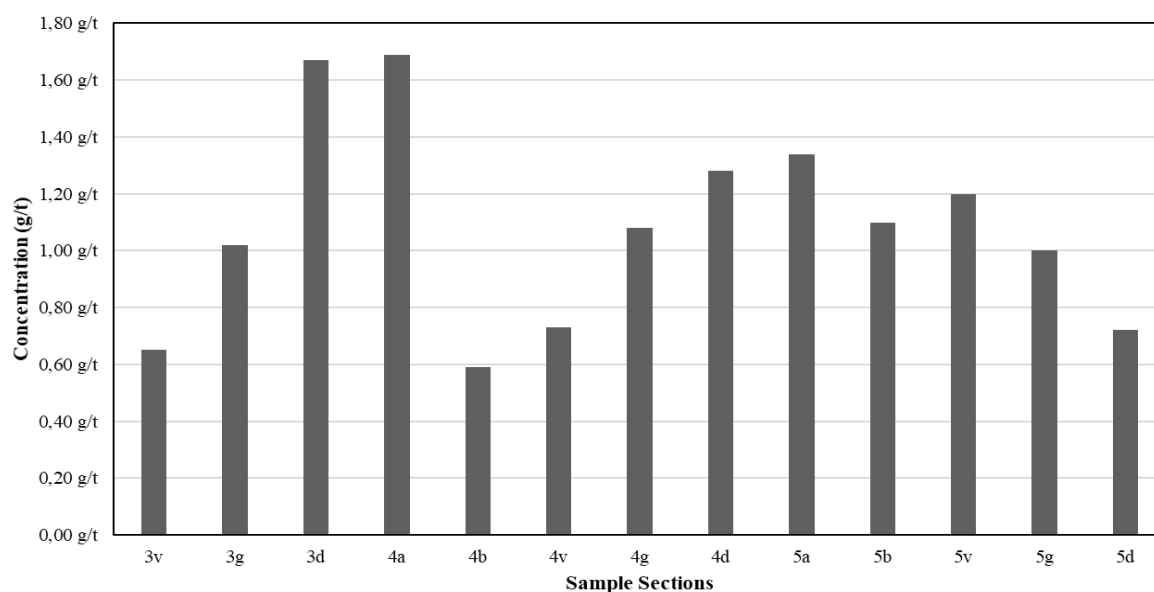
**Table 2. Gold and silver concentrations in samples collected from different depths**

| Sample | Au, g/t | Ag, g/t |
|--------|---------|---------|
| 1      | 0.66    | 4.35    |
| 2      | 1.02    | 7.78    |
| 3      | 1.66    | 6.45    |
| 4      | 1.68    | 28.89   |
| 5      | 0.60    | 20.44   |
| 6      | 0.74    | 9.87    |
| 7      | 1.08    | 4.58    |
| 8      | 1.28    | 6.01    |
| 9      | 1.34    | 12.65   |
| 10     | 1.10    | 6.32    |
| 11     | 1.20    | 6.22    |
| 12     | 1.00    | 5.32    |
| 13     | 0.72    | 4.87    |

The results show that the gold concentration ranged from 0.60 to 1.68 g/t, whereas the silver concentration varied from 4.35 to 28.89 g/t. The highest gold content was recorded in sample 4a (1.68 g/t), followed closely by sample 3d (1.66 g/t). The maximum silver concentration was also observed in sample 4a, reaching 28.89 g/t. A relatively high silver concentration was additionally detected in sample 4b (20.44 g/t).

### Gold concentration in Chodak tailings samples

Au concentrations measured in samples collected from different sections and depths of the technogenic waste.

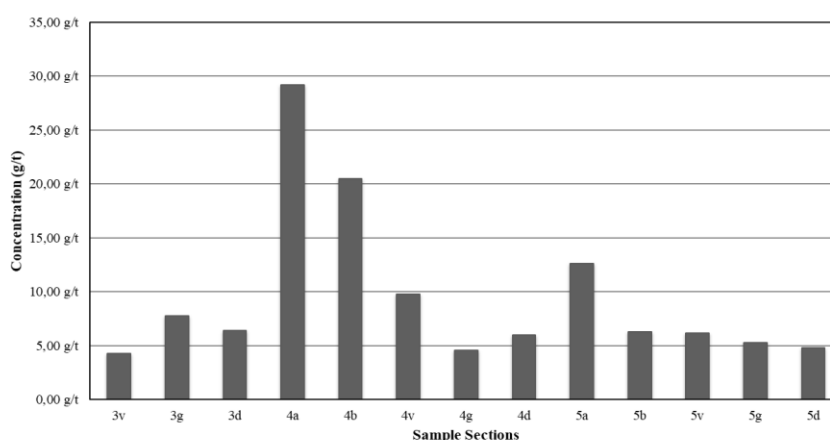


**Figure 1. Distribution of gold concentration in samples from different sections of the Chodak tailings**

The distribution of silver demonstrates a more pronounced variation than that of gold. The maximum Ag content of 28.89 g/t was measured in sample 4a, while sample 4b contained 20.44 g/t. In contrast, the lowest silver concentration was found in sample 3v (4.35 g/t). This indicates that silver is distributed particularly unevenly within the investigated technogenic material.

### Silver concentration in Chodak tailings samples

Ag concentrations measured in samples collected from different sections and depths of the technogenic waste.



**Figure 2. Distribution of silver concentration in samples from different sections of the Chodak tailings**

### Granulometric distribution of precious metals

Granulometric analysis showed that the investigated waste consists predominantly of fine particles. In the upper layer (1–2.5 m), the unground material was dominated by the  $-0.071$  mm fraction, accounting for 84.2% of the sample. In the ground material from the same layer, this fraction increased to 85%. A similar predominance of fine material was observed in the middle and lower layers.

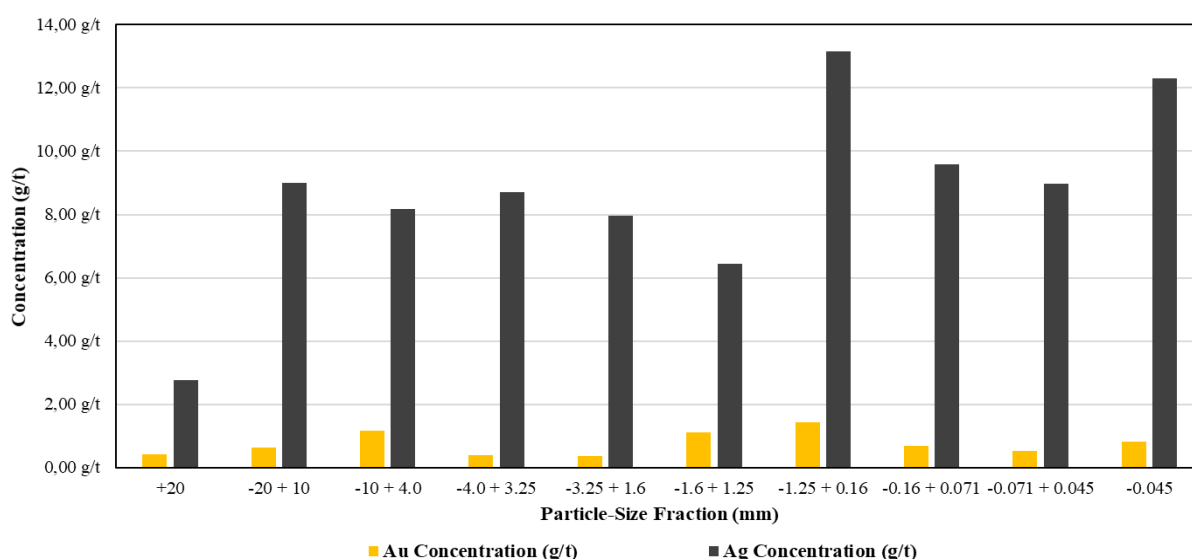
**Table 3. Granulometric composition of the investigated technogenic waste**

| Sampling layer                    | Dominant fraction, mm | Content, % |
|-----------------------------------|-----------------------|------------|
| Upper layer, 1–2.5 m, unground    | $-0.071$              | 16.84      |
| Upper layer, 1–2.5 m, ground      | $-0.071$              | 85.00      |
| Middle layer, 4.0–5.5 m, unground | $-0.071$              | 87.00      |
| Middle layer, 4.0–5.5 m, ground   | $-0.071$              | 87.00      |
| Lower layer, 6.0–7.0 m            | $-0.071$              | 85.30      |

The granulometric data demonstrate that the tailings are strongly enriched in fine material. The prevalence of particles smaller than  $0.071$  mm is important for the recovery of precious metals because finely dispersed gold may occur either as liberated particles or in close association with sulfide and oxide minerals.

### Gold and silver distribution by particle-size fraction

Au and Ag concentrations measured in individual granulometric fractions of the Chodak technogenic waste.



**Figure 3. Distribution of Au and Ag concentrations among different particle-size fractions**

The results indicate that the distribution of gold and silver is not directly proportional to particle size. Elevated concentrations occur in both intermediate and fine fractions, suggesting that valuable components are present in different mineralogical forms. The enrichment of Au and Ag in fine fractions is consistent with the presence of finely disseminated and mineral-bound precious metals.

#### Mineralogical characteristics

Mineralogical examination identified pyrite, arsenopyrite, chalcopyrite, sphalerite, magnetite, hematite and iron hydroxides, including goethite and hydrogoethite. Gold was observed both as finely dispersed free particles and in association with sulfide minerals. Arsenopyrite and pyrite were identified as important mineral phases associated with gold occurrence. Oxidation-zone minerals, including iron hydroxides, were also observed.

### CONCLUSION

The results of the study demonstrate that the technogenic wastes of the Chodak gold beneficiation plant contain significant residual concentrations of precious metals, particularly gold and silver. The Au concentration in the investigated samples ranged from 0.60 to 1.68 g/t, while Ag varied from 4.35 to 28.89 g/t. The highest concentrations of both metals were recorded in sample 4a. Granulometric analysis showed that the waste is predominantly composed of fine particles, with the  $-0.071$  mm fraction representing the major portion of the material. The distribution of Au and Ag among the particle-size fractions was heterogeneous, indicating that precious metals occur in different mineralogical associations and forms.

Mineralogical investigations identified pyrite, arsenopyrite, chalcopyrite, sphalerite, magnetite, hematite and iron hydroxides as the principal mineral phases, with gold occurring both as finely dispersed particles and in association with sulfide minerals. The combination of chemical, granulometric and mineralogical results confirms the presence of recoverable precious-metal components in the accumulated Chodak technogenic waste. These findings provide a basis for further investigation and selection of appropriate beneficiation and hydrometallurgical methods aimed at recovering residual gold and silver and improving the utilization of technogenic mineral resources.

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