

## Mining waste as an exploration tool and secondary resource

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**Abstract** There is today no overall information about how much mining waste there is in Sweden and what it contains. This project focused on samples from waste rock, tailings and slag from the historical mining region Bergslagen, Sweden. Modern dissolution and analytical methods were used in order to determine approximately 50 elements in the samples. Modern analytical data for the historical mining waste is useful as an exploration tool and can provide information about remaining or new resources underground. Results show that there is a potential for recovery of critical elements from mining waste as well as dealing with environmental problems.

**Key words** tailings, slag, trace elements, environment

### Introduction

There is today no accurate information about how much mining waste there is in Sweden. Nor is there a clear idea about the content in the mining waste deposits. A lot of the waste was produced several hundred years ago and data about element content is scarce or of unknown quality. Some preliminary studies indicate, however, that there are very large volumes that potentially are available for recovery as a secondary resource. The mining waste is readily accessible above ground, thus saving a lot of energy compared to underground or open pit mining. This can in fact to some extent compensate for the lower metal concentrations in the mining waste compared to the ores.

Modern analytical data for the historical mining waste is also useful as an exploration tool and can provide information about remaining or new resources underground.

A major problem with historical mining waste is that it is often present in fairly small amounts in several locations. The geographical dispersion and the relatively small amount at each location together with the fact that the mining waste often has lower metal concentrations than present ore makes an ordinary concentrator out of the question. However, a strategically located flexible concentrator could be a feasible solution. This type of concentrator could also make it profitable to exploit smaller ores in the area. An alternative to a centralized concentrator is a mobile facility moving from mining waste site to mining waste site in order to extract elements from the waste.

A mobile facility could also be used for reclamation of mining waste where extraction of metals (for instance Ag) could add additional funds for the reclamation projects.

This project focused on collecting samples from waste rock, tailings and slag from the historical mining region Bergslagen, Sweden. Modern dissolution and analytical methods were

used in order to determine approximately 50 elements (including rare elements such as germanium, tungsten, indium and REE), in the samples.



**Figure 1.** Sampled mining waste sites.

Sampled areas in Bergslagen (fig. 1) were Bastnäs and Korphyttefältet at Riddarhyttan, Håkansboda at Stråssa, Ljusnarsbergsfältet and Gladhammar as well as smaller sample sets from Venafältet, Kälfallet (Riddarhyttan), Hästfältet (Norberg), Malmkärra (Norberg) and Persgruvan (Riddarhyttan). Slags were sampled at Lienshyttan and Gamla Kop-

parverket in Riddarhyttan and tailings were sampled at Persgruvan, Källfallet (Riddarhyttan) and Mårsätter.

## Methods

### Identification of objects for sampling

Each mining area has been divided into smaller objects prior to sampling. Care has been taken in order to divide the area into objects with roughly the same properties (with regards to origin, age, grain size, mineralogy, vegetation, age etc.).

Position has been determined for every object using hand held GPS (accuracy 3 m). Size of each object has been determined using a combination of GPS and on the ground measuring.

### Waste rock sampling

Primary elemental distribution in the primary geological deposit have not been investigated. From experience it is known that element distribution is uneven depending on primary geological features. One of the theories is that mining and transportation of the material to the waste pile has introduced “smearing” and blending of the elemental distribution, meaning that sampling of waste in theory has a slightly higher possibility to indicate occurrence of interesting elements than sampling of primary rocks, from outcrop or drill core.

Sampling of waste rock was performed by “randomly” chipping pieces from waste rock pieces using a hammer. For every sampling point at least 25 separate pieces were pooled into a sample. On average every sample was around 5 L (3.7 kg) containing around 35 pieces (n = 213).

At some objects replicate samples have been collected in order to study the representativeness of the sampling technique used.

Total amount of material in the sampled piles have been estimated to about 200 000 metric tons.

### Slag sampling

It was assumed that historical slags are more homogenous in composition than the geological material as even conditions during smelting was a prerequisite for good quality. Sampling of slag has been performed using a lower sampling density compared to waste rock. Focus has instead been to investigate whether elements have been enriched in the slag during the process. No chipping was performed; instead whole pieces of slag were collected directly from the waste deposit.

Total amount of material in the sampled slags have been estimated to about 150 000 metric tons.

## Tailings sampling

Tailings have been sampled at Källfallsgruvan, Mårsätter and at Vena. Samples have been retrieved using a small shovel or a hand held auger. Samples are from below the apparently oxidized upper layers of the tailings.

Average size for the tailings samples (n 21) were around 0.37 kg as they are considered to be more homogenous compared to the waste rock and slag samples.

Total amount of material in the sampled tailings have been estimated to about 75 000 metric tons.

## Analytical methods

Samples were analysed for major and trace elements by MS Analytical. Sample pulps were fused by borate flux in a high temperature controlled muffle furnace and the resulting beads were dissolved in dilute mineral acids. Major oxides were determined by inductively coupled plasma-optical emission spectroscopy (ICP-OES) and refractory trace elements were determined by inductively coupled plasma-mass spectroscopy (ICP-MS). Other trace elements were determined by inductively coupled plasma-optical emission spectroscopy (ICP-OES) following aqua regia digestion. Total sulphur and carbon were determined by a Leco Carbon and Sulphur analyser. Ore grade samples (Ag, Cu, Pb and Zn) were quantified by ICP-OES following 4-acid digestion. Analytical quality was monitored with method blanks, duplicates and certified reference materials and/or in-house verified reference materials.

## Statistical methods

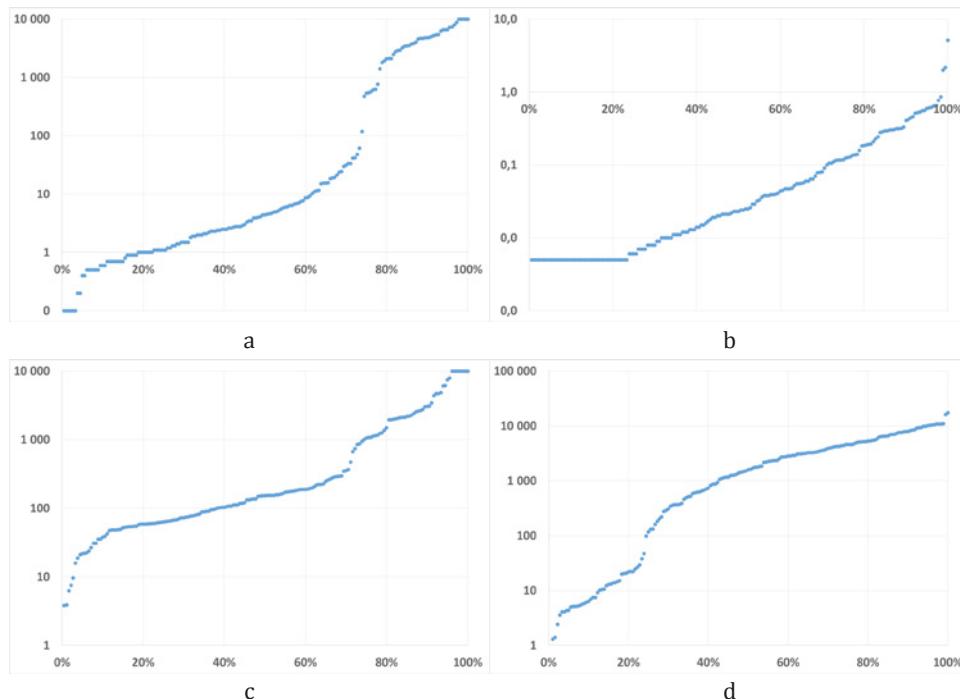
Principal component analysis (PCA) was performed on log-transformed and auto scaled data using the software The Unscrambler (Camo ASA).

## Results and discussion

A lot of data has been produced during the project and this paper will only be able to provide a small selection of data. Arsenic, gold, cerium and copper were chosen to illustrate the results. Table 1 and fig. 2 show the cumulative concentrations for the selected elements.

**Table 1** Statistical distribution of the selected elements (mg/kg dw).

	As	Au	Ce	Cu
10 <sup>th</sup> perc	0.60	0.005	37.8	6.30
25 <sup>th</sup> perc	1.10	0.006	63.5	118
Median	4.40	0.020	153	1 590
75 <sup>th</sup> perc	540	0.118	1 060	4 610
90 <sup>th</sup> perc	4 800	0.409	3 070	7 900



**Figure 2.** Concentrations of arsenic (a), gold (b) cerium (c) and copper (d) (mg/kg dw) in all 180 samples.

### Riddarhyttfältet

Gold has been reported historically from Bastnäs (Cronstedt 1781 and Ihre and Sädbom 1986). 51 new waste rock samples (196 kg) from Bastnäsfältet, showed elevated gold concentrations in 23 of 51 samples (highest concentration 5.11 mg/kg dw).

As expected rare earth elements were also found in significantly elevated concentrations (several of the first REE minerals ever were identified at this field site by Jöns Jakob Berzelius and colleges around 1803). Several samples exceed 1 000 mg/kg dw for Pr and 10 000 mg/kg dw for Ce and La.

Dividing the REE into LREE and HREE the Bastnäs field site has significantly higher concentrations compared to all the other sites. Average LREE concentrations are 7 470 mg/kg dw (La, Ce, Pr, Nd, Pm, Sm, Eu and Gd) with the highest concentration at 30 200 mg/kg dw. Also HREE (Tb, Dy, Ho, Er, Th, Yb and Lu) concentrations are unusually high with an average of 86 mg/kg dw and highest concentration at 319 mg/kg dw.

Co concentrations were expected to be higher at the site; with average concentrations at 141 mg/kg dw and highest concentration at 1 740 mg/kg dw. Three samples at Bastnäs had anomalous concentrations of Mo (409, 410 and 652 mg/kg dw). Ge concentrations within

the project were found to be highest at Bastnäs, but still at fairly low concentrations (average 1.55 mg/kg dw and highest 7.54 mg/kg dw). Bi found at a maximum of 3 050 mg/kg dw, but most often below 5 mg/kg dw. From an environmental perspective total sulphur concentrations were found to be at an average 0.23 % and As at 45 mg/kg dw (highest concentration 2 110 mg/kg dw).

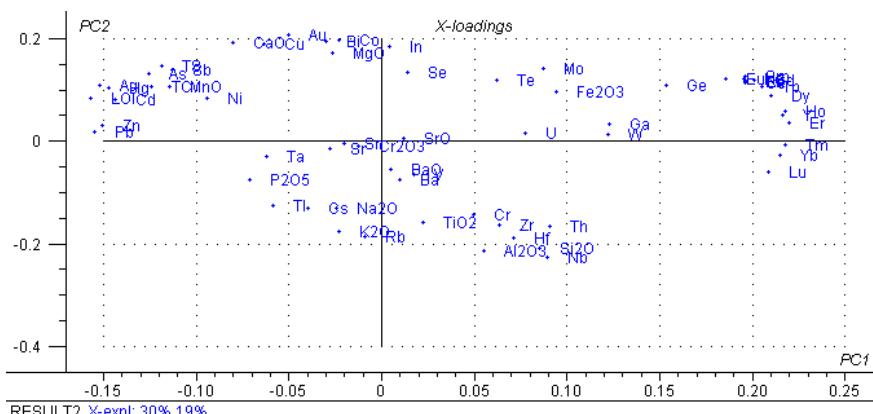
### Håkansbodafältet

At Håkansbodafältet 41 samples were taken (204 kg). Matrix is rich in carbonates with average 21.3 % CaO, 14 % MgO and 4.64 % total C. Copper concentrations are high at the site (average 7 250 mg/kg dw) as well as Co (average 382 mg/kg dw), As (average 1 470 mg/kg dw including four samples in excess of 10 000 mg/kg dw) and Sb (average 143 mg/kg dw).

### Exploration Sampling

Sampling at sites Bastnäs, Riddarhyttan and Håkansboda essentially confirmed historical data, although we now have a somewhat better picture of the distribution and degree of elemental distribution variation in the areas. As mentioned in the introduction other areas were sampled on a, by purpose, less systematic way. One area; Stripåsen (fig. 1), was selected for sampling purely on its REE-exploration potential being geographically located along the trend of REE-occurrences that occur diagonally across the Bergslagen area from Nora in the south to Norberg (Andersson et al. 2004). Stripåsen is a small old copper mine that has no recorded REE-mineralogy.

Our 4 randomly selected samples (totalling 20 kg) from Stripåsen mine in Hästefältet, Norberg, resulted in 1 640 mg/kg dw Ce, with top result: 2 390 mg/kg dw and 3 070 mg/kg dw, respectively. 5.03 mg/kg dw Hf, 1 140 mg/kg dw La with top result 1 680 and 2 160 mg/kg dw, respectively (the same sample was highest in Ce). Cu content was on average 5 020 mg/kg dw with peak 7 260 mg/kg dw and Mo in average 241 mg/kg dw. As far as is known, neither Ce nor La is previously reported from Stripåsen and the association Fe-Cu-REE found both in Stripåsen and the Bastnäs area may be worth exploring further.

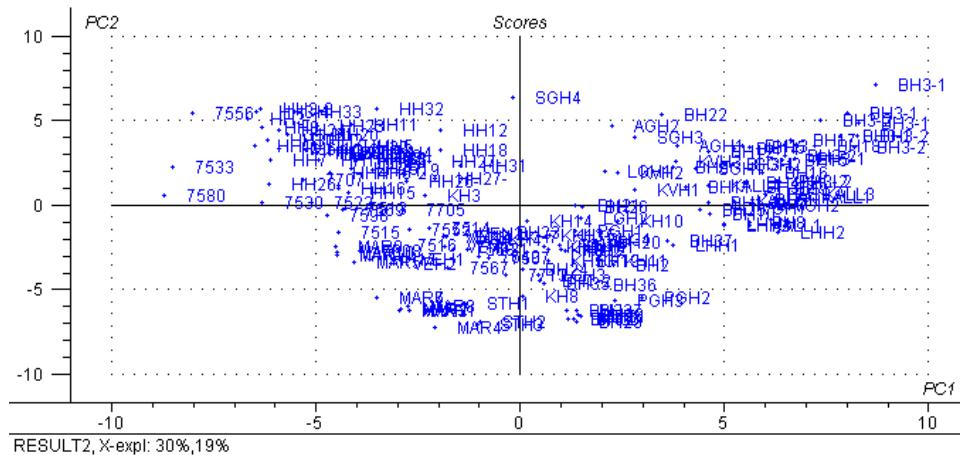


**Figure 3.** Loadings plot for performed principal component analysis (PCA). First two principal components explain 49% of the variation of the data.

## Principal component analysis

Principal component analysis was performed on all collected data in order to determine potential relationships between different elements.

Results are found in Fig. 3 and Fig. 4. From the PCA it is apparent that sulphide associated elements such as Pb, Zn, Cd, Hg and Ag are found close together alongside total sulphide and LOI. It is also quite clear that the mineralization's containing sulphides are very different from the mineralization's containing REE. Au is found close to Cu.



**Figure 4.** Score plot for performed principal component analysis (PCA).

## Conclusions

Preliminary results from sampling and extensive analysis of mining waste in south central Sweden confirm that historically reported occurrences can have anomalously high concentrations of valuable elements. Some anomalies may be suitable for recovery, others may indicate a resource still below ground and some may pose a threat to the environment or human health.

Our limited trial with waste sampling has confirmed several historical occurrences of REE, gold and copper, and has also identified at least one, new occurrence of REE.

The results indicate that there is a great potential for exploration and possibly also recovery of critical elements from mining waste, and quite likely, some environmental problems may be resolved at the same time as valuable components are extracted.

### **Acknowledgements**

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