

# Use of green liquor dregs for reclamation of historical mining waste: suitable properties and results from a full-scale reclamation in 2017

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## Abstract

*Green liquor dreg (GLD) is a calcite dominated alkaline byproduct from the pulp and paper industry with high buffering capacity and thixotropic properties, making it suitable for treatment of acidic mining waste. In a comprehensive four-year study, GLD from 16 Swedish mills was characterised through multiple sampling campaigns, analysing elemental composition, buffering capacity, sequential leaching, and interactions with acid rock drainage. This dataset is now a robust foundation for understanding the variability of GLD between mills, offering key insights into which parameters are most critical for different mining waste applications.*

*Several small and medium sized tests have been performed, with good results, to determine the suitability and possible drawbacks when mixing GLD and acid mining waste. As a final confirmation of the technique approximately 4,500 tonnes of acid mining waste at Gladhammar, Sweden (pH 3.8, 96 mg/L copper and 21 mg/L cobalt) was slurry injected with 100 tonnes of GLD in 2017.*

*During injection, pH in the drainage from the area increased from 3.5 to around 10 due to excess GLD being washed out. One to two months after injection, pH was around 7.5 and concentrations of copper and cobalt was 38 and 4.9 mg/L, respectively. During 2024, pH was 8 and concentrations of copper and cobalt were 1.1 and 0.95 mg/l, respectively.*

*The challenge at Gladhammar was to reduce metal loads while allowing the waste rock piles to be accessible for mineral hunters and geoscientific studies in the future. With alkaline injections, areas with cultural, historical and geological values can be treated with low visual impact.*

*The full-scale reclamation at Gladhammar confirms that GLD can be used for reclamation of historical mining waste as pH increases and trace element concentrations decrease.*

**Keywords:** waste rock, acid rock drainage, alkaline waste products, geochemistry

## 1 Introduction

Green liquor dreg (GLD) is an alkaline waste product from pulp and paper production. Today there is no sustainable use for GLD, and it is therefore exempt from taxation in Sweden. At the same time there are several thousand abandoned and active mining sites that require treatment to prevent or neutralise acid rock drainage. GLD is potentially a good material to treat these mining sites.

Each year, about 300,000 tonnes of GLD is generated by the Swedish pulp and paper industry. As there is no sustainable use for GLD, the material is deposited at the mills' own landfill or used to cap the mills' own, or municipal household waste landfills (a demand which decreases as most landfills are covered). Even if there are no taxes for GLD disposal (at least not yet), the mills have high costs to operate their own landfills.

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The paper focuses on combining two large industry sectors in Sweden, namely the pulp and paper industry and the mining industry. The idea is to use the alkaline GLD produced by the pulp and paper industry to combat problems with acidic mining waste and acid rock drainage (ARD), which is a large problem for the mining industry.

Samples have been gathered and data have been produced for GLD from several of the pulp and paper mills in Sweden. A valuable database containing information about different properties relevant for mining waste reclamation have been created. The aim of this paper is to present different properties that demonstrate how GLD is suitable for acid waste rock reclamation.

## 2 Material and methods

### 2.1 Sampling

GLD from 16 Swedish mills was characterised through multiple sampling campaigns, analysing elemental composition, buffering capacity, sequential leaching, and interactions with ARD.

Sampling was performed up to five times for each mill between 2017 and 2019 to obtain representative samples covering different locations and different times of the year.

### 2.2 Elemental content

Elemental analysis on solid samples was performed on dried samples (dried at 105°C). Samples were analysed by MS Analytical AB in Vancouver, Canada, using the analytical method WRA-310 for elements.

### 2.3 Leaching of elements

Leaching was performed in two sequential steps at liquid/solid ratios (L/S) 2 and 8. Wet samples corresponding to 25 g dw were placed in 250 mL centrifuge bottles. 50 ml of ultrapure water (18.2 MΩ) was added and then the samples were shaken in an end-over-end shaker for 24 h ± 0.5 h. After shaking, all samples were centrifuged at 20,000 G for 20 minutes except samples from the Aspa mill, and the liquid phase poured off and saved. The Aspa mill samples were first centrifuged for 20 minutes in 20,000 G and thereafter centrifuged two additional times at 30,000 G for 30 minutes with the liquid phase poured off between each centrifugation. After phase separation, the solid phase remained in the bottle and an additional 200 ml ultrapure water was added and again shaken in an end-over-end shaker for 24 h ± 0.5 h and the same centrifugation process repeated to obtain the liquid phase. The liquid phase was analysed for pH, electrical conductivity, alkalinity and element concentrations. Elements were analysed with ICP-MS on an Agilent 7500cx, on samples filtered through a 0.2 µm filter.

Geochemical calculations were performed on the obtained solutions using the software PHREEQC to obtain information about possible solubility limiting solid phases for the leached elements.

### 2.4 Buffering capacity

Buffering capacity was determined by adding increasing amounts of hydrochloric acid (HCl) to a fixed amount of GLD. pH was measured several times up to six months to determine if the buffering capacity was available immediately or if there were some kinetic constraints.

### 2.5 Sequential leaching

Sequential leaching was performed on GLD for two reasons. It was partly performed to gain information about how different elements are associated to the matrix and partly to gain information about the leachability of trace elements during different chemical scenarios (i.e. during mixing with acid waste rock).

Leaching was performed on wet samples corresponding to 2 g dry weight. Leaching was performed in five steps based on a procedure by Tessier et al. (1979) modified by Karlsson et al. (1987). The acid leaching step

(step 3) was repeated separately with fresh samples corresponding to 1 g dry weight as the pH was not sufficiently low in the original leaching protocol. The repeated leaching step was named 3.1. The oxidation step (step 5) was performed twice on selected samples to make certain leaching was complete (Table 1).

**Table 1 Leaching steps used during the sequential leaching**

Step	Type	Leaching solution	Leaching time (h)	Temperature (°C)
1	Water soluble	20 ml MQ water	2	25
2	Ion exchangeable	20 ml 1 M NH <sub>4</sub> Ac at pH 7	1	25
3	Acid soluble	20 ml 1 M NH <sub>4</sub> Ac at pH 5	5	90
3.1	Acid soluble	20 ml 1 M NH <sub>4</sub> Ac at pH 5	5	90
4	Reducible	20 ml 0.043 M NH <sub>2</sub> OH-HCl in 25% HAc	5	90
5	Oxidisable	20 ml 0.02 M HNO <sub>3</sub> + 30% H <sub>2</sub> O <sub>2</sub>	3	85
6	Residual		3	85

After each leaching step the samples were centrifuged for 20 minutes at 12,000 rpm to separate the liquid phase from the solid phase. The liquid phase was decanted and analysed for elements. In the solution from the first leaching step (step 1), pH was measured in addition to element analysis.

## 2.6 Interaction with acid rock drainage

When GLD is used for stabilising acid waste rock, there is a risk that trace elements from the GLD will be leached as pH decreases. To determine the effects on trace element leaching from GLD at lowered pH, leaching was performed using different acid solutions. Three different GLDs were exposed to three different acid solutions. To determine the effects from pH alone, HCl was used. To increase the complexity, sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) was used to simulate an ARD. Finally, simulated ARD with high dissolved concentrations of dissolved iron a mixture between H<sub>2</sub>SO<sub>4</sub> and ferrous iron (Fe(II)) was used.

## 2.7 Full-scale reclamation

Gladhammar mine in southern Sweden commenced mining for copper and cobalt in the 15<sup>th</sup> century and continued until 1892. Mining resulted in waste rock containing copper, cobalt, lead, and arsenic. Initial reclamation was performed in 2011 and waste rock was mixed with lime and deposited under water in a nearby lake. The Gladhammar mining area is one of very few sites where the three minerals gladiolite (PbCuBi<sub>5</sub>S<sub>9</sub>), hammarite (Pb<sub>2</sub>Cu<sub>2</sub>Bi<sub>4</sub>S<sub>9</sub>), and Lindströmite (Pb<sub>3</sub>Cu<sub>3</sub>Bi<sub>7</sub>S<sub>15</sub>) are found and hence, authorities decided that some waste rock should be collected and preserved due to its high geoscientific value. Representative waste rock material was collected from eight areas representing the geology at the mine site (around 4,500 tonnes in total). The material was then rearranged into eight piles (Figure 1) on a geomembrane covered surface (1,000 m<sup>2</sup>) with a well collecting all leachates. Eventually, it became apparent that the piles had a large negative impact on the environment, with acidic pH and high concentrations of cationic trace elements like copper, cobalt, and nickel.



**Figure 1** Partial picture of two of the piles at Gladhammar. Stakes mark planned points for injection of green liquor dregs

Injection of GLD was performed to preserve the surface and neutralise the acidic pH. Slurry injection was done during the spring of 2017 at 99 points evenly spread over the area. In short, GLD was transported from Mönsterås pulp and paper facility and was tipped close to the waste pile. Slurry mixing was performed in batches (ca 1 tonne) using a plane mixer and pumping was performed using a slurry pump. Resistance was low and during normal conditions, pressure never exceeded 2 bars. A total of 63 tonnes of dry GLD was injected (Sartz et al. 2018). Sampling and analysis of water quality had started already when the waste rock was collected and is still ongoing.

### 3 Results and discussion

#### 3.1 Element content

When comparing the elemental concentrations to elemental concentrations in Swedish till, most trace elements and some major elements are not of any concern (Stahre et al. 2024). Elements of most concern are sulphur (S), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni) and zinc (Zn) (Table 2). High concentrations of these elements in GLD can be a problem when using GLD for mine site reclamation purposes, as the mine sites often already have high concentrations of these elements in the effluent. As shown in Table 2, leaching is, however, low, indicating a safe use at mining sites.

#### 3.2 Leaching of elements

Selected leaching results are found in Table 2. Leaching of sodium and potassium were as expected, very high at L/S 10. Ranging from 2,500 up to 129,000 mg/L for sodium and 200 to 17,600 mg/L for potassium. Sodium is not an element commonly accumulated in pulping wood but is added in large quantities during cooking. Potassium is accumulated from the wood but can also come from impurities in the cooking chemicals. When comparing the amount of leached sodium to the total amount of sodium in GLD an average

of 67% of the total amount in the GLD was leached. For potassium, the fraction leached averaged 72%. However, calcium, which was the most abundant element (not including organic material) in all except one mill sample, leached very little, resulting in an average calcium leaching fraction of  $\leq 0.7\%$ .

Chromium leaches generally less than 1 mg/kg but a few samples leached more, resulting in 1–8% leached. Nickel leached  $\leq 0.55$  mg/kg resulting in  $\leq 3.45\%$  leached. Copper leached on average 4 mg/kg (corresponding to a leached fraction of 2.2%). Zinc leaching was originally a concern as total zinc concentrations were high with an average of 2,300 mg/kg, but when looking at the leaching data for zinc, total leaching was on average 0.18%. Leaching for cadmium and lead were generally low, resulting in an average of 0.47% for cadmium and 1.84% for lead. For cadmium, most samples leached less than 1.2% with only two samples exceeding it, and for lead, most samples leached less than 5%, with also only two samples exceeding it. The sample with the highest leached concentration of cadmium was also the sample with the highest leached concentration of lead.

Trace elements leaching is thus fairly low and lowering of the alkaline pH when applied to acid mining waste will most likely decrease the leaching further as most elements have their solubility minima at circumneutral pH.

**Table 2 Minimum, average and maximum for both total and leached (L/S 10) concentrations (both as mg/kg and %). Please note that minimum and maximum total concentration samples are not necessarily the same as the min and max leached concentration samples**

	Na	K	Ca	Cd	Cu	Cr	Ni	Pb	Zn
Total, mg/kg min	9,050	498	49,200	1.0	33	17	7.0	3.0	226
Total, mg/kg average	53,200	4,810	213,000	9.0	244	132	76	20	2,310
Total, mg/kg max	162,000	25,800	383,000	33	622	418	257	85	6,030
Leached, mg/kg min	2,510	215	4.0	0.002	BDL*	0	0.02	0.00	0
Leached, mg/kg average	37,300	3,360	69	0.023	4.0	1	0.23	0.16	3
Leached, mg/kg max	129,000	17,600	854	0.097	59	16	0.55	0.55	25
Leached, % min	24.6	17.9	0.0	0.01	0.0	0.004	0.02	0.00	0.01
Leached, % average	66.7	71.8	0.0	0.47	2.2	0.8	0.67	1.84	0.18
Leached, % max	100	100	0.7	4.18	28.3	8.1	3.45	13.0	1.42

\*BDL = below detection limit

pH is not only influenced by soluble alkaline salts like caustic soda (NaOH) but also by the presence of less soluble salts like portlandite ( $\text{Ca}(\text{OH})_2$ ) and calcite ( $\text{CaCO}_3$ ). Electrical conductivity on the other hand is mostly dependent on the soluble salt content. Alkalinity is dependent on two parts; the biggest influence on the buffering capacity consists of easily soluble salts that are quickly washed out. The other part is a long-term buffering substance that is slow but capable of buffering large volumes of acid leachates (for instance calcite).

Sodium and potassium are present in GLD as easily soluble salts that are easily washed out. Sodium (and potassium to some extent) is strongly correlated to electrical conductivity and alkalinity, indicating that the sodium salts are in the form of soluble oxides/hydroxides that acts as the main short time buffer. Geochemical calculations indicate only natron ( $\text{Na}_2\text{CO}_3$ ) as solubility controlling phase at extremely high sodium concentrations. Calcium leaching is restricted by calcite solubility resulting in little effect on short time buffering capacity, however, in the long-term, the calcium minerals will affect the buffering capacity.

For nickel, copper, cadmium and lead there are some soluble salts present in the GLD but most of the elements are probably solubility controlled. Geochemical calculations indicated hydroxides as solubility controlling phases for at least copper and in some cases also for lead. Leaching of zinc is to some extent solubility controlled which is indicated by the fact that the soluble zinc concentrations are similar for both L/S 2 and L/S 8.

Decreasing pH will, for most elements, decrease the leached concentrations as the concentrations of soluble hydroxy complexes will be lower at neutral pH compared to a highly alkaline pH.

It is likely that in the long-term perspective, sodium and potassium content in GLD are washed out. Calcium in calcite remains, giving GLD a long-term buffering capacity that is not washed out which is good for applications related to acid neutralisation. Zinc – that is of concern for both landfilling and in applications towards mining waste reclamation – is not as problematic as indicated by the total metal concentrations. For the other trace elements, it is likely that there will be a first flush effect due to soluble salts dissipating and after that, leaching is controlled by the amount of water flowing through the system. As it takes a long time to achieve a leaching rate of L/S 10, it is probable that the actual leaching will be lower. When comparing the leached concentrations from GLD with concentrations from mining waste, there is an environmental benefit even if the GLD is not entirely inert.

### 3.3 Buffering capacity

Results from the long-term buffering capacity tests are presented below. Samples having all lines relatively close to each other indicate that the total buffering capacity is available immediately and there are no kinetic constraints (for instance Karlsborg [Figure 2], Skutskär, Gruvön, Frövi, Östrand and Vallvik). A major part of the buffering capacity is most likely calcite. Samples having increased buffering capacity with time (for instance Billingsfors, Munksund [Figure 3] and Väja) indicate that the total buffering capacity is not immediately available. This might be due to occluded buffering minerals or less soluble buffering minerals compared to calcite. Samples with a great variation between different acid addition (Aspa [Figure 4] and Gävle) are due to the occasional presence of small grains of limestone grit.

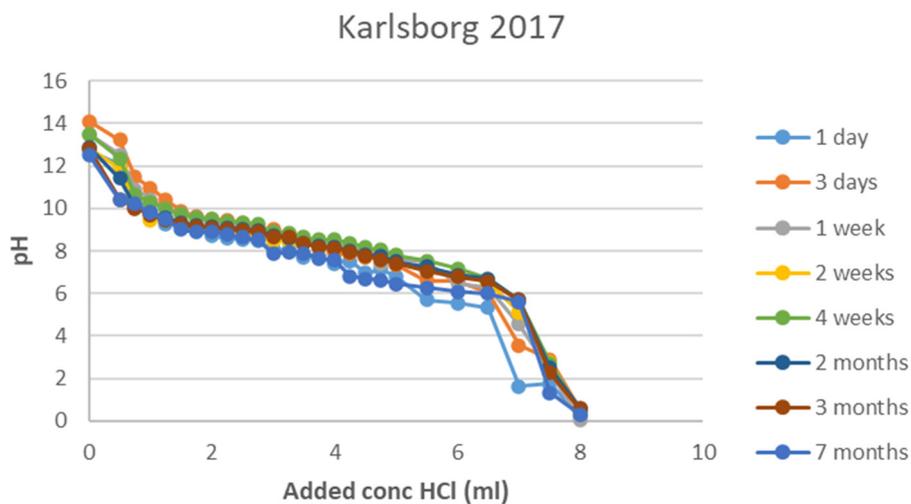
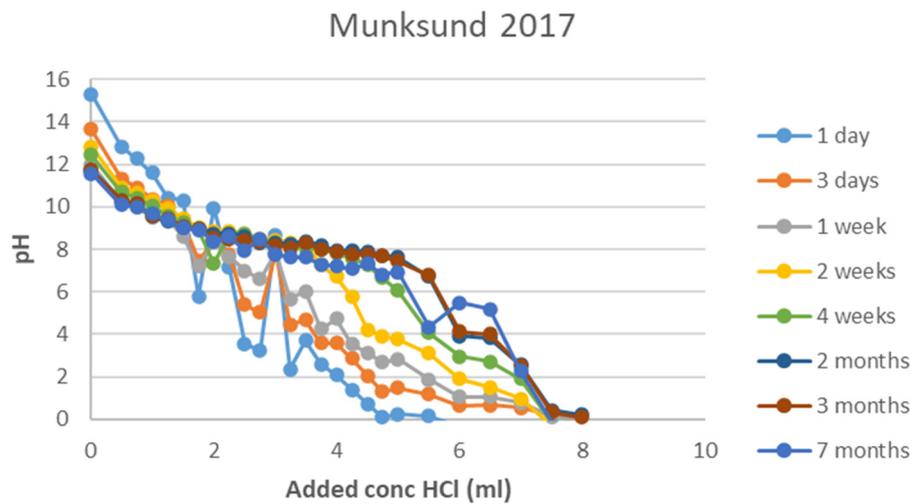
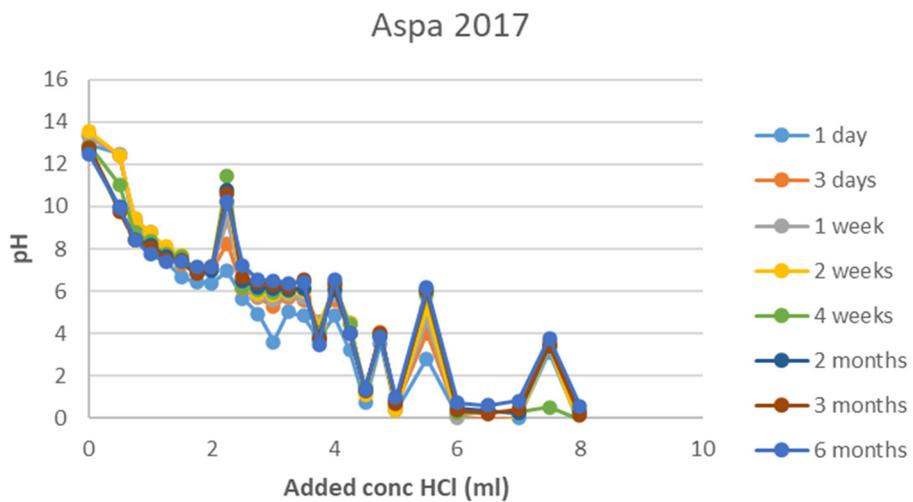


Figure 2 Long-term buffering (three months) capacity for Karlsborg. pH versus added HCl (ml)



**Figure 3** Long-term buffering (three months) capacity for Munksund. pH versus added HCl (ml)

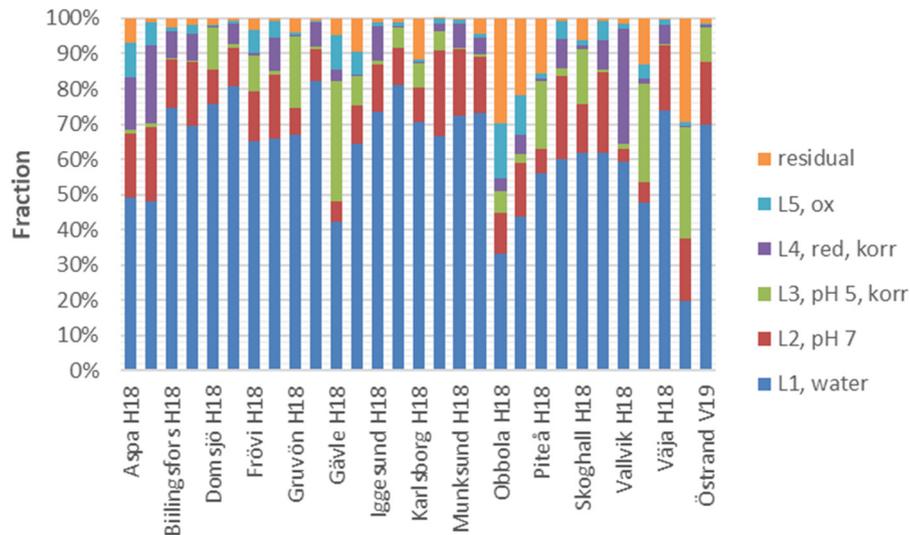


**Figure 4** Long-term buffering (three months) capacity for Aspa. pH versus added HCl (ml)

### 3.4 Sequential leaching

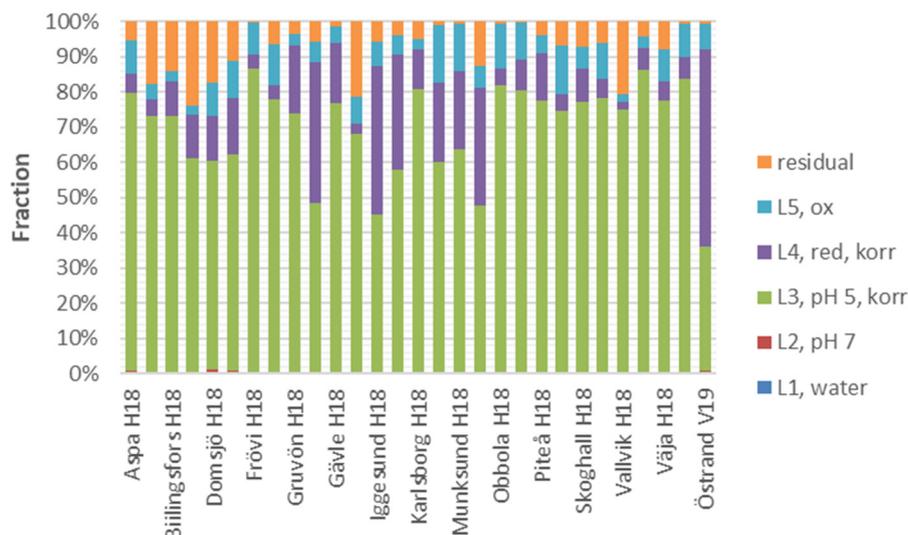
Sequential leaching was performed to determine the association strength different elements have to the GLD and their potential altered leaching during changed chemistry (changed pH or redox for instance). Sodium, calcium, lead and zinc were chosen to illustrate some different behaviours.

Sodium is mainly easily leached as indicated by Figure 5. Around 80–90% is water soluble or ion exchangeable. This is expected as sodium is mainly found as NaOH in GLD. All samples behave in a similar fashion when it comes to sodium leaching.



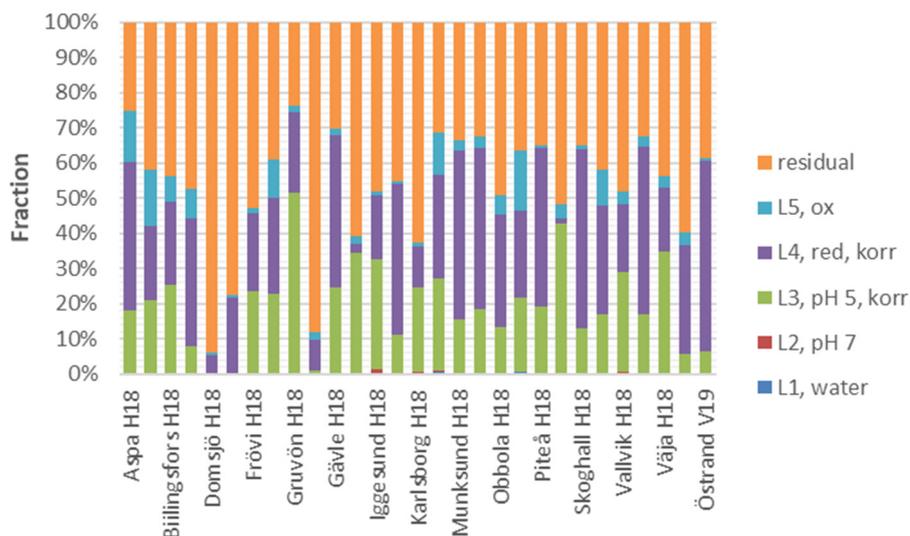
**Figure 5 Sequential leaching for sodium for the different mills. L1 water soluble (blue), L2 ion exchangeable (red), L3 acid soluble (green), L4 reducing conditions (purple), L5 oxidising conditions (light blue), and residual fraction (orange)**

Calcium (Figure 6) on the other hand is mainly found as  $\text{CaCO}_3$  and is therefore mainly (around 80%) leached during the acid soluble step (L3). The residual fraction is most likely insoluble residues from the calcination. Also, for calcium, the solid speciation is similar for all samples.



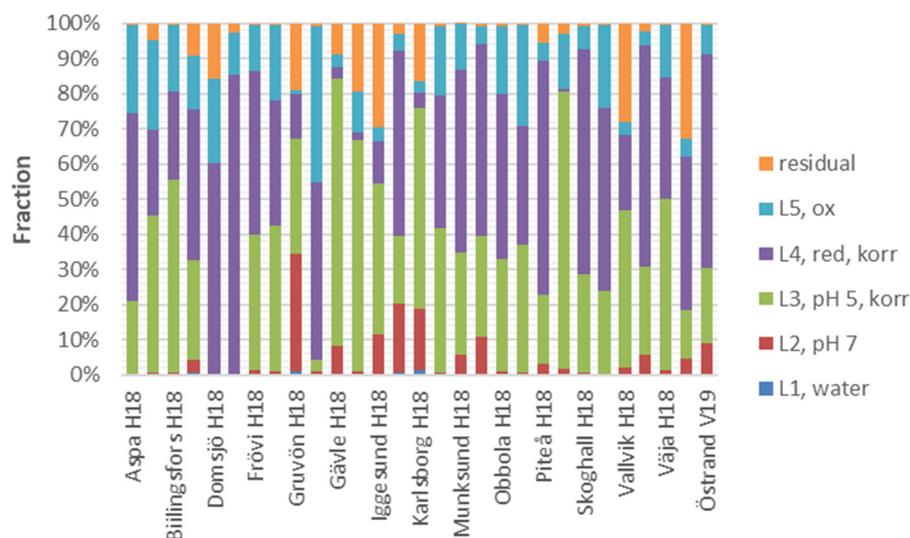
**Figure 6 Sequential leaching for calcium for the different mills. L1 water soluble (blue), L2 ion exchangeable (red), L3 acid soluble (green), L4 reducing conditions (purple), L5 oxidising conditions (light blue), and residual fraction (orange)**

Lead (Figure 7) is more strongly associated with the matrix with a small fraction released during low pH, a significant fraction released during reducing conditions, and around 40% found in the residual phase. Lead leached during low pH is probably found as cerussite ( $\text{PbCO}_3$ ), while lead leached during reducing conditions is probably associated with iron oxyhydroxide phases. Also for lead the solid speciation is similar for all samples.



**Figure 7 Sequential leaching for lead for the different mills. L1 water soluble (blue), L2 ion exchangeable (red), L3 acid soluble (green), L4 reducing conditions (purple), L5 oxidising conditions (light blue), and residual fraction (orange)**

Zinc (Figure 8) is more easily leached than lead with even a small fraction being ion exchangeable in GLD from some mills. The greatest fractions of zinc are released during lowered pH and reducing conditions. A small fraction is also released during oxidising conditions indicating an association with organic matter.

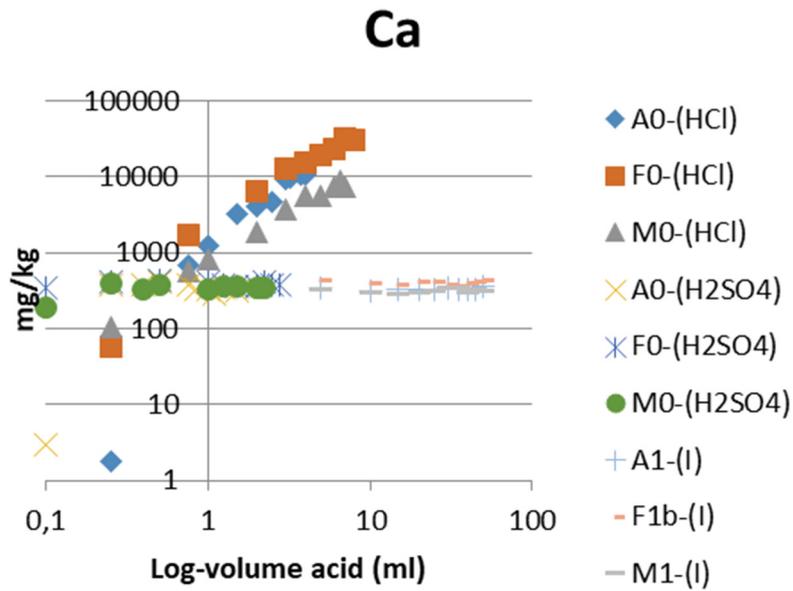


**Figure 8 Sequential leaching for zinc for the different mills. L1 water soluble (blue), L2 ion exchangeable (red), L3 acid soluble (green), L4 reducing conditions (purple), L5 oxidising conditions (light blue), and residual fraction (orange)**

### 3.5 Interaction with acid rock drainage

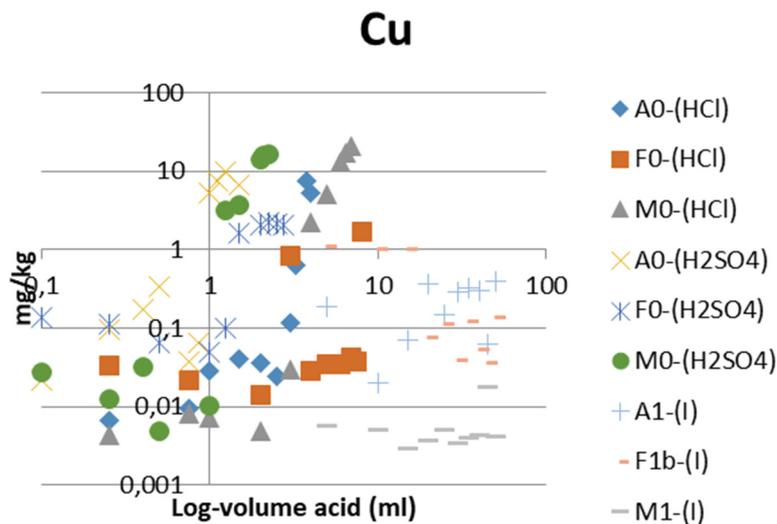
Results from leaching of GLD from Aspa (A), Frövi (F) and Metsä (M) with three different acid solutions (HCl, H<sub>2</sub>SO<sub>4</sub> and H<sub>2</sub>SO<sub>4</sub>/Fe(II)) are illustrated with the elements calcium, copper, zinc and lead in the figures below.

Calcium leaching (Figure 9) increases with increased addition of HCl (lower pH). However, when adding H<sub>2</sub>SO<sub>4</sub> instead the leached calcium concentrations are fairly stable. This is because the high added sulphate concentrations form gypsum (CaSO<sub>4</sub>) that has a very low solubility. H<sub>2</sub>SO<sub>4</sub> is a much more suitable leaching solution when looking at ARD from mine sites since they contain high sulphate concentrations at low pH. Adding Fe(II) during leaching does not alter the leaching for calcium.

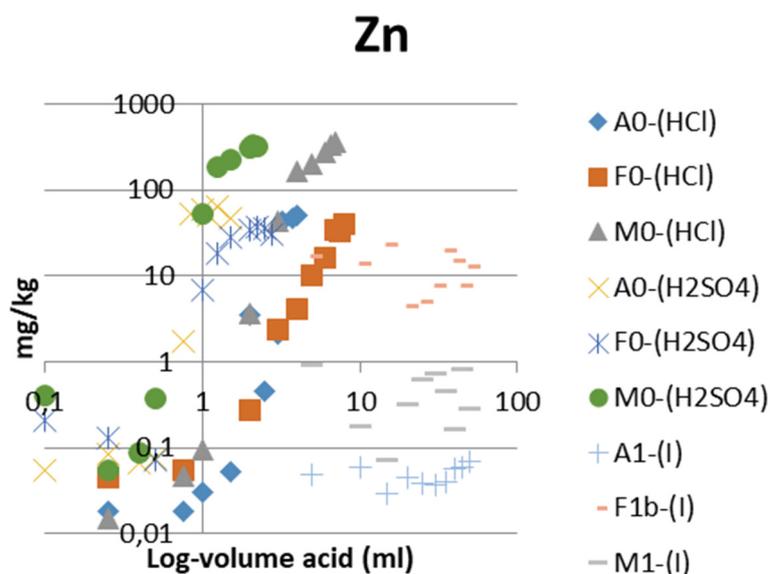


**Figure 9 Leaching of calcium from GLD (A = Aspa, F = Frövi and M = Metsä) with HCl, H<sub>2</sub>SO<sub>4</sub> and H<sub>2</sub>SO<sub>4</sub>/Fe(II)-solution**

Copper (Figure 10) and zinc (Figure 11) leaching increases with increased addition of both HCl and H<sub>2</sub>SO<sub>4</sub> (lower pH). Secondary sulphate minerals are thus not important for copper and zinc leaching. However, when adding Fe(II) to the leaching with H<sub>2</sub>SO<sub>4</sub>, the copper concentrations decrease with approximately one order of magnitude. This is likely because the ferrous iron is being oxidised and precipitated as ferric hydroxide in contact with the highly alkaline GLD. Formed iron oxyhydroxides will act as a good sorbent for divalent cations like copper and zinc.



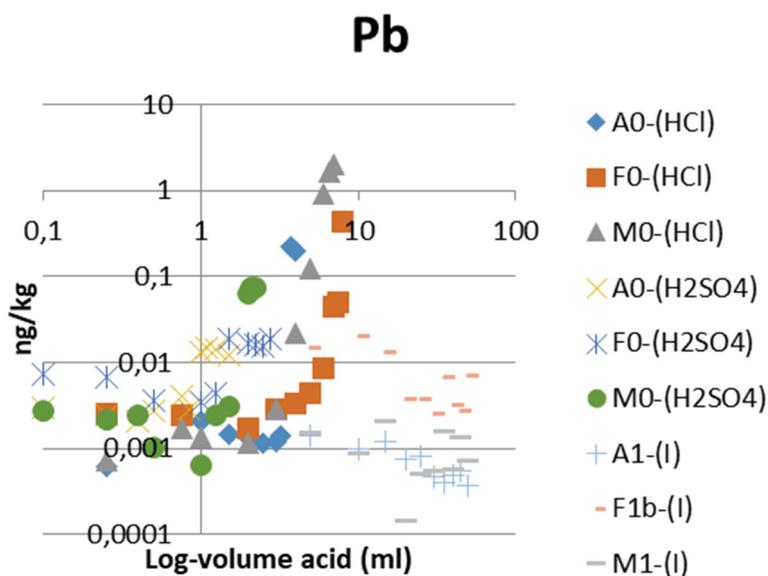
**Figure 10 Leaching of copper from GLD (A = Aspa, F = Frövi and M = Metsä) with HCl, H<sub>2</sub>SO<sub>4</sub> and H<sub>2</sub>SO<sub>4</sub>/Fe(II)-solution**



**Figure 11 Leaching of zinc from GLD (A = Aspa, F = Frövi and M = Metsä) with HCl, H<sub>2</sub>SO<sub>4</sub> and H<sub>2</sub>SO<sub>4</sub>/Fe(II)-solution**

Lead leaching (Figure 12) increases with increased addition of HCl (lower pH). However, when adding H<sub>2</sub>SO<sub>4</sub> instead the leached concentrations are much lower. This is because the high added sulphate concentrations form anglesite (PbSO<sub>4</sub>) that has a very low solubility. H<sub>2</sub>SO<sub>4</sub> is a much more suitable leaching solution when looking at ARD from mine sites since they contain high sulphate concentrations at low pH. Adding Fe(II) will decrease the leached lead concentration even further as lead is also being adsorbed to the formed iron oxyhydroxides.

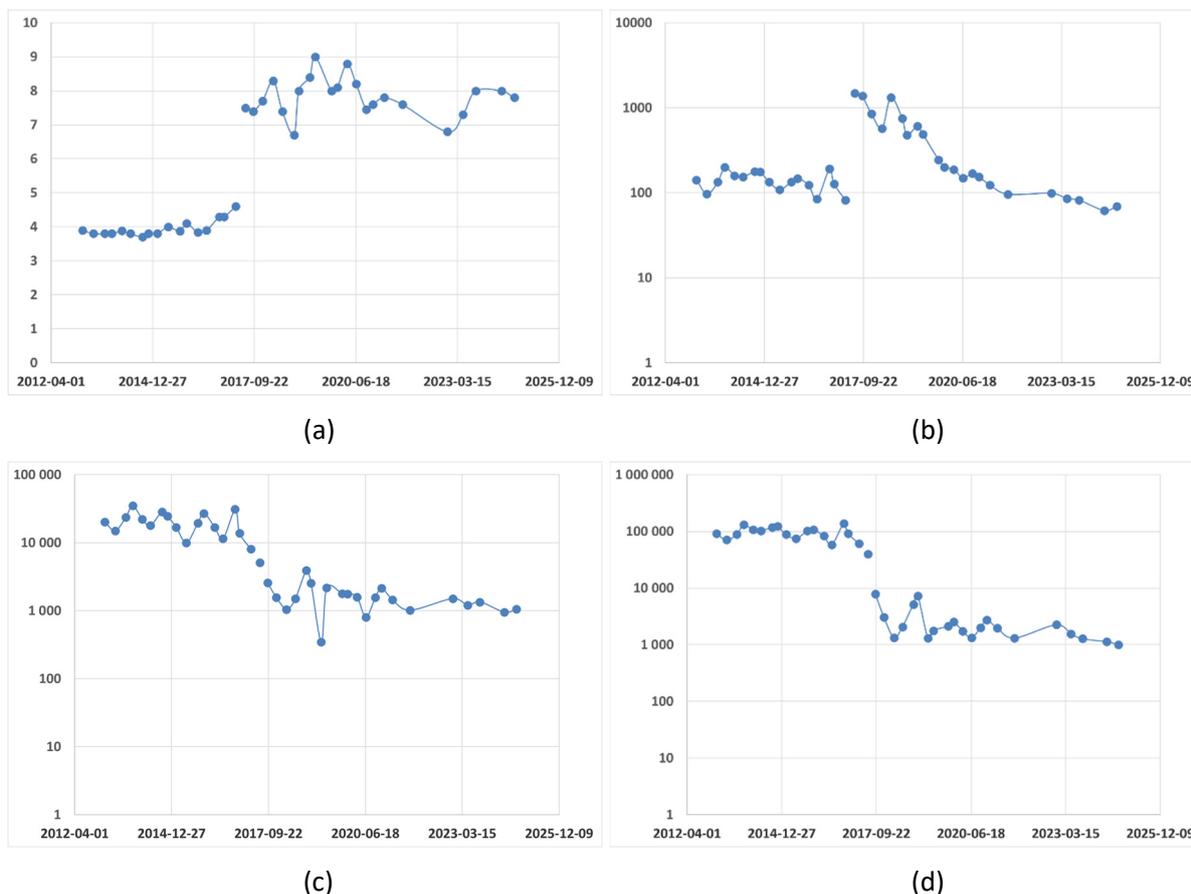
Element leaching from GLD during decreased pH are substantially lower when a leaching solution similar to ARD is being used (that is H<sub>2</sub>SO<sub>4</sub> or H<sub>2</sub>SO<sub>4</sub>/Fe(II)). It is thus important to determine the actual leachability during the conditions being expected at the actual site for use.



**Figure 12 Leaching of lead from GLD (A = Aspa, F = Frövi and M = Metsä) with HCl, H<sub>2</sub>SO<sub>4</sub> and H<sub>2</sub>SO<sub>4</sub>/Fe(II)-solution**

### 3.6 Full-scale reclamation

During GLD injection into the waste rock, pH at the drainage sampling point increased from 3.5 to above 10 due to a slight excess of GLD being washed out initially. One to two months after injection, pH was around 7.5 and concentrations of copper and cobalt were 38 and 4.9 mg/L, respectively (Figure 13).



**Figure 13 Results from the full-scale reclamation illustrated by selected parameters. (a) pH; (b) Sulphur (mg/l); (c) Cobalt ( $\mu\text{g/l}$ ); (d) Copper ( $\mu\text{g/l}$ ). Injection was performed during spring 2017**

Follow-up measurements of leachates from the waste pile indicate a clear increase in pH (from 3.8 to 8.3) in late 2017, and markedly decreased levels of cadmium (93%), cobalt (94%), copper (98%), nickel (95%), lead (99%), and zinc (97%). Increased concentrations have been noticed for iron and sulphate which may be because of acidic secondary minerals that were dissolved as pH increased. As iron started to precipitate again as oxidised iron, these levels have decreased again. At the second and third sampling after injection, there were significantly decreased levels of iron.

In 2024, cadmium concentrations were still 96% lower compared to before the reclamation while cobalt was 92% lower, copper 97% lower, lead 98% lower and zinc 96% lower.

Oxyanions have, contrary to the cationic trace elements, increased somewhat in the drainage. Arsenic has, for instance, increased from, on average, 0.47  $\mu\text{g/l}$  before reclamation to 33  $\mu\text{g/l}$  after reclamation. Also, molybdenum and vanadium concentrations have increased due to the increase in pH.

## 4 Conclusion

GLD is an alkaline byproduct from the production of pulp and paper. It mainly consists of calcite, organic matter and non-process elements. Trace element total concentrations are somewhat higher compared to natural background, but leachability is low.

Laboratory studies also indicate that GLD trace element leaching is lower when GLD is mixed with ARD compared to traditional leaching tests. This is mainly due to precipitation of low solubility sulphate minerals and secondary iron oxyhydroxide minerals acting as good sorbents. This supports the conclusion that GLD is very suitable for mining waste reclamations.

Buffering capacity is also generally very good with high concentrations of calcite. In general, the present buffering is easily available even though some of the samples contained buffering minerals with lower solubility. From a reclamation perspective, however, buffering availability within 3–6 months is still very good.

Solid speciation of GLD indicate that major cations are more easily leached compared to the trace elements. Sodium leaching is very high (water soluble and ion exchangeable) while calcium leaching is much lower (gypsum precipitation). Trace elements such as Pb and Zn are, according to the sequential leaching results, more prone to be mobile during lowered pH and reducing conditions. However, according to leaching with H<sub>2</sub>SO<sub>4</sub> and H<sub>2</sub>SO<sub>4</sub>/Fe(II) other immobilising mechanisms will trap the trace elements in a real-world setting.

In conclusion, GLD is well suited to be used for treatment of acidic mining waste instead of being landfilled in non-hazardous and hazardous landfills. This is a big step towards solving two big waste problems in Sweden; the problem of cheap reclamation of many small old orphan sulfidic as well as modern mining sites, and the problem of how to dispose of GLD at a large-scale and reasonable cost.

The Gladhammar reclamation was performed as planned and without any major technical problems. Injection of GLD slurry increased pH in the leachates from around 3.8 to around 8.3. Concentrations of cobalt and copper were reduced by 94 and 98%, respectively. The appearance of the waste rock did not change, which means that the waste pile is still accessible for mineral hunters and geoscientific research. To summarise, the reclamation worked very well, and the concentrations of the main problematic elements has decreased considerably.

With alkaline injections, areas with cultural, historical and geological values can be treated with low visual impact and remnants can be left with appearances intact. The pilot study has shown that GLD can be used for full-scale applications and that it increases pH and decreases trace element concentrations without any negative side effects.

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