Geochemical Loading Rates from Open Pit Walls at the Åkerberg and Laver Mine Sites in Relation to Pit Lake Water Quality

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Abstract

Minewall stations were used to estimate geochemical loading rates of mine walls contributing to the element concentrations of the Laver and Åkerberg pit lakes, and portable XRF measurements were used to estimate pit wall element concentrations. Statistically significant differences of the geochemical loading rates were found for Ag, Cd, Cu, Pb and Zn which were higher at the Laver mine site. Portable XRF measurements suggest that the Cu, Pb and Zn concentrations of the mine walls also are higher at the Laver mine site. Compared to pit lake surface water concentrations the geochemical loading rates were relatively small.

Keywords: Pit Lake, Subarctic, Open Pit, Metal Leaching, Minewall Station

Introduction

There are many environmental issues that can arise due to mining, where poor water quality of pit lakes is one. Pit lakes have the potential to negatively impact ecosystems, humans, and water bodies. The water quality of pit lakes will depend on several factors where leaching from pit walls above the water surface is one. The quantity of elements that are released from pit walls are hard to estimate, and many methods are based on laboratory tests rather than field tests. Results can therefore differ from reality.

Minewall stations can be used as an inexpensive method to estimate geochemical loading rates of mine walls, which can be expressed in mg/m^2/week (Morin and Hutt 2004). Together with the total reactive surface area these rates can be used to calculate the environmental impact on pit lakes (Mend, 1995). In this study we used a total of 12 Minewall stations, installed at two old mine sites where pit lakes are present to estimate geochemical loading rates. Loadings were compared to handheld XRF measurements on pit walls, measured element concentrations in the pit lakes, and the estimated residence times of the pit lakes.

Eight stations were installed at the Laver mine site which was a low-grade Cu mine where some of the ore minerals were chalcopyrite, pyrrhotite, galena, sphalerite and arsenopyrite. It was mined between 1936 and 1946 (Ödman 1943). Four stations were installed at the Åkerberg mine site, where the ore consisted of quartz veins hosted in gabbro containing gold and silver. The ore contained very little sulfides and the mine was in operation between 1991 and 2003 (Billström *et al.* 2012).

The aims of the study were to investigate 1) if differences in geochemical loading rates could be seen for the two mine sites, 2) if there were similarities between portable XRF data and the geochemical loading rates, and 3) estimate the contribution from mine walls to the total element content found in the pit lakes.

Methods

Minewall stations

Minewall stations were installed at relatively flat mine walls, with as few cracks as possible, and their surface areas varied from 0.11-0.42 m^2. For some stations the frame consisted of T-molding, attached to the mine walls with silicone, while some had a frame made from a transparent plastic sheet. A transparent plastic sheet was also used to construct the covers which were attached to the frame with binder clips and tape (Figure 1). Sampling of the stations was conducted by spraying the surface area with 200 mL of deionized water that was collected at the lower end of the sloping bottom edge of the frame, that served as a canal for the water. The time between sampling events as well as the surface area of the Minewall stations can be found in Table 1. The samples were sent to ALS Scandinavia AB where they were analyzed using Inductively Coupled Plasma-Sector Field Mass Spectrometry (ICP-SMS) with an accuracy of ±20 % to determine element concentrations.

Portable XRF

For each Minewall station 20 portable XRF measurements were taken in situ. A 4 x 5 measuring grid was distributed on the surface by dividing the length of the left and right edges of the station by six, before five lines were drawn across the stations based on this spacing. The lengths of the lines were then divided by five to find the spacing for four points of measurement along each line. A measurement time of 15 s together with the Mining+ setting on the Olympus Innov-X DELTA XRF analyzer was used.

Results and discussion

The average composition based on the XRF measurements are shown in Table 2 and the average geochemical loading rate of each Minewall station together with the average geochemical loading rate of each mine site is shown in Table 3. The data from Table 3 is also illustrated in Figure 2 where comparisons of the geochemical loading rates for the Laver and Åkerberg mine sites are illustrated.

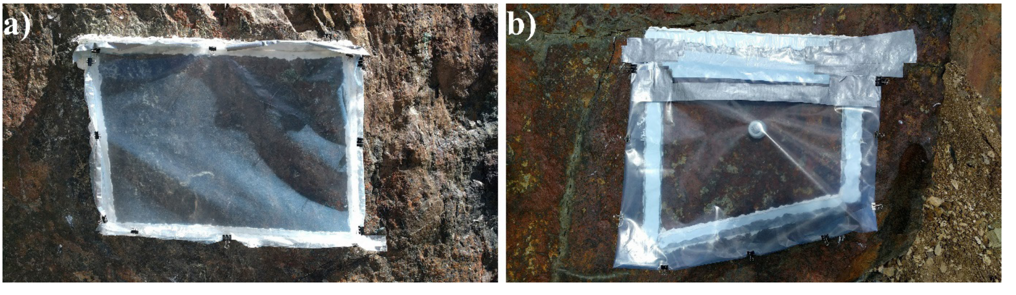

Figure 1 *a) Minewall station at the Laver pit lake including T-molding. b) Minewall station at the Åkerberg pit lake without T-molding. Figure from Paulsson (2021).*

Table 1 *Total active dates, sampling dates, leaching days between each sampling events and surface area for minewall stations at the Laver and Åkerberg mine sites. Data from Paulsson (2021).*

Minewall station	Active dates	Sampled	Leaching days	Surface area (m^2)
Laver 1 (2017)	9/6 – 7/9	7/9, 3/11	90	0.33
Laver 2 (2017)	9/6 – 3/11	7/9, 3/11	90 + 57	0.11
Laver 3 (2017)	9/6 – 3/11	7/9, 3/11	90 + 57	0.15
Laver 4 (2017)	9/6 – 3/11	7/9, 3/11	90 + 57	0.13
Åkerberg 1 (2017)	30/6 – 3/11	7/9, 3/11	69 + 57	0.12
Åkerberg 2 (2017)	30/6 – 3/11	7/9, 3/11	69 + 57	0.11
Åkerberg 3 (2017)	30/6 – 3/11	7/9, 3/11	69 + 57	0.22
Åkerberg 4 (2017)	30/6 – 3/11	7/9, 3/11	69 + 57	0.15
Åkerberg 5 (2018)	-	-	-	-
Åkerberg 6 (2018)	10/7 – 15/8	15/8	36	0.42
Åkerberg 7 (2018)	10/7 – 5/10	15/8, 5/10	36 + 51	0.22
Åkerberg 8 (2018)	10/7 – 5/10	15/8, 5/10	36 + 51	0.18

Table 2 Average element composition of the Minewall stations based on XRF measurements.

	Ag (%)	Al (%)	As (%)	Cd (%)	Co (%)	Cu (%)	Fe (%)	Ni (%)	Pb (%)	S (%)	Zn (%)
Åkerberg 1	0.02	5.6	0.04	0.03	-	-	13.3	0.009	-	0.02	0.011
Åkerberg 2	0.02	7.7	-	0.03	-	-	9.0	0.001	0.0001	0.05	-
Åkerberg 3	0.01	3.2	0.04	0.03	-	0.133	15.8	0.005	0.0008	2.81	0.001
Åkerberg 4	0.02	6.1	-	0.03	-	0.001	11.9	0.001	-	0.44	0.001
Åkerberg 5	0.02	5.2	0.01	0.03	-	0.009	10.9	0.004	0.0002	0.07	0.001
Åkerberg 6	0.01	4.2	0.03	0.03	-	-	12.1	0.001	0.0002	0.14	0.01
Åkerberg 7	0.01	4.4	0.05	0.03	0.006	0.004	11.8	0.003	0.0006	0.12	0.014
Åkerberg 8	0.02	7.3	-	0.03	-	-	9.8	0.003	-	-	-
Average Å	0.02	5.5	0.02	0.03	0.001	0.018	11.8	0.003	0.0002	0.46	0.005
Laver 1	0.01	7.9	0.17	0.02	0.024	2.532	13.9	0.006	0.0371	0.63	0.273
Laver 2	0.02	4.0	0.12	0.02	-	0.128	5.1	0.001	0.0261	0.78	0.057
Laver 3	0.02	7.0	-	0.03	-	0.097	7.5	0.003	0.0064	0.14	0.068
Laver 4	0.02	5.7	-	0.03	-	0.021	3.5	0.005	0.0143	0.08	0.014
Average L	0.02	6.2	0.07	0.03	0.006	0.694	7.5	0.04	0.021	0.41	0.103

Table 3 Average measured geochemical loading rates for the Minewall stations expressed as µg/m²/week.

	Ag (µg/m²/week)	Al (µg/m²/week)	As (µg/m²/week)	Au (µg/m²/week)	Cd (µg/m²/week)	Co (µg/m²/week)	Cu (µg/m²/week)	Fe (µg/m²/week)	Ni (µg/m²/week)	Pb (µg/m²/week)	S (µg/m²/week)	Zn (µg/m²/week)
Åkerberg 1	-	1.9	0.13	0.0012	0.002	0.29	0.3	0.9	0.5	-	127	0.6
Åkerberg 2	0.0004	2.1	0.02	0.0004	0.003	0.03	0.4	1.7	0.4	0.02	54	0.3
Åkerberg 3	0.0002	62.9	0.02	0.0016	0.002	0.30	2.0	110.4	1.5	0.02	526	1.1
Åkerberg 4	0.0002	70.8	0.02	0.0017	0.003	0.06	0.2	68.5	0.5	0.04	971	0.9
Åkerberg 6	0.0002	10.1	0.20	-	0.002	0.04	0.7	6.0	0.2	0.01	126	0.5
Åkerberg 7	0.0003	16.5	0.14	0.0059	0.002	0.05	0.5	8.4	0.3	0.05	167	0.8
Åkerberg 8	0.0003	3.9	0.04	0.0006	0.003	0.04	0.5	3.9	0.2	0.08	136	0.6
Average Å	0.0002	24.0	0.08	0.0016	0.002	0.11	0.6	28.5	0.5	0.03	301	0.7
Laver 1	0.0004	0.9	0.03	0.0004	0.199	1.9	58.6	1.0	0.5	0.43	719	49.7
Laver 2	0.0039	4.0	0.04	0.0005	0.149	0.06	7.3	9.5	0.6	0.25	151	27.9
Laver 3	0.0023	2.8	0.01	0.0004	0.187	0.11	11.0	1.5	0.3	0.19	73	39.2
Laver 4	0.0021	13.9	0.01	0.0003	0.911	0.67	12.6	7.3	0.5	0.91	342	211.5
Average L	0.0022	5.4	0.02	0.0004	0.361	0.68	22.4	4.8	0.5	0.44	321	82.1

The data suggests that there is a difference in geochemical loading rates for the two mine sites. Particularly for the elements Ag, Cd, Cu, Pb and Zn which had higher geochemical loading rates at the Laver mine site and for which the differences between Laver and Åkerberg were statistically significant based on an unpaired T-test where the P-values were <0.05. These elements are also found in ore minerals occurring at the Laver mine site. This suggests that the Minewall stations could be useful for estimating geochemical loading

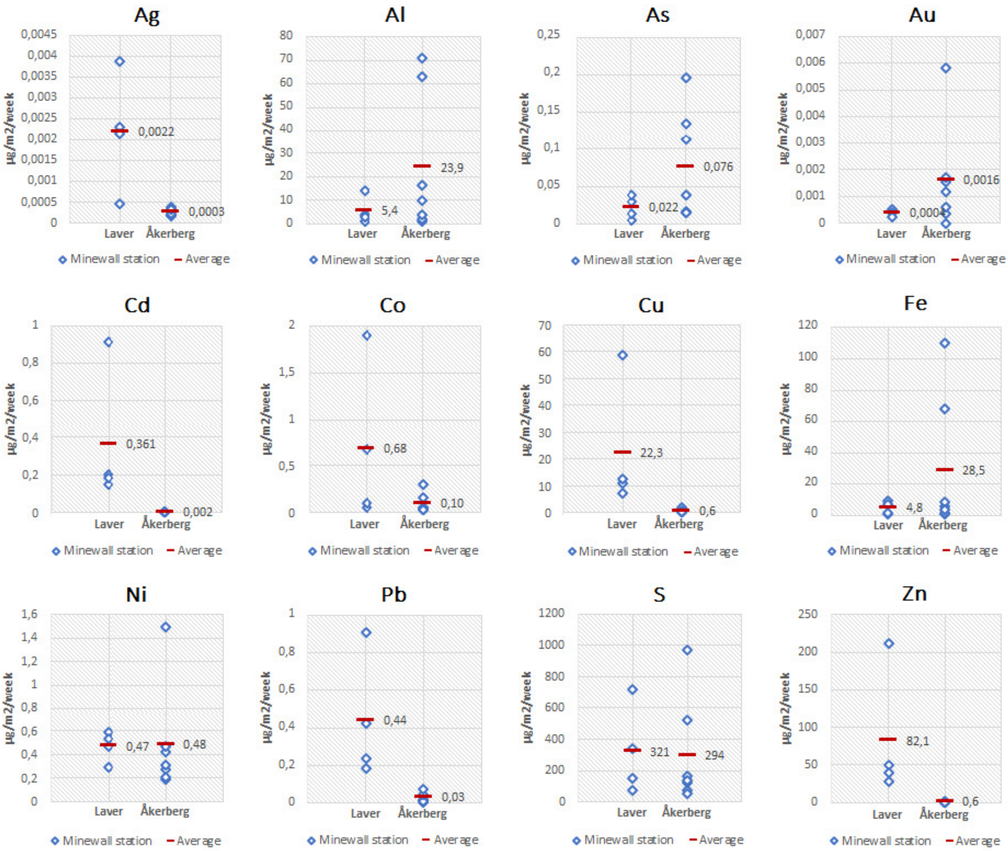

Figure 2 Comparison of geochemical loading rates (µg/m²/week) from Minewall stations at the Laver and Åkerberg mine sites. From Paulsson (2021).

rates at mine sites that were closed many years ago. The data could e.g., be used as input in predictive modelling of pit lake water quality. According to Figure 2 there might be differences for other elements such as Al, As, Au, Co, and Fe as well. Of the elements that showed a statistically significant difference between the two mine sites the concentrations are higher for Cu, Pb and Zn, while no difference in concentration can be seen for Ag or Cd, based on XRF measurements. This could potentially be due to differences in weathering rates for the various minerals at the Laver mine site, but it could also be because the XRF measurements are not completely reliable. The Ag concentrations are lower than the other elements of this group which potentially could have influenced the results since lower concentrations could be closer to the detection limit of the XRF. A determination of the rock geochemistry through chemical analysis would therefore be an important addition to the results of the study. There are also substantial differences in the geochemical loading rates of Minewall stations installed at the same mine site (Table 3) and data from many stations is therefore necessary to get reliable results.

Total yearly geochemical loading rates for the pit lakes (Table 4) can be estimated from Minewall station data and a low and high estimate of total reactive surface area (for further details see Paulsson (2021)). These yearly loading rates were divided by filtered surface water concentrations of the pit lakes to get an approximation of how large the yearly contribution of the mine walls are compared to the total element concentrations of the pit lakes in % (Table 5).

As can be seen from the data the yearly input is small for most elements for both the low and high estimate of the total reactive

Table 4 Leaching rates from the Minewall Stations expressed as yearly total input to the Laver (L) and Åkerberg (Å) pit lake in µg/L/year for a low and a high estimate of total reactive surface area. From Paulsson (2021).

	Ag (µg/L/ year)	Al (µg/L/ year)	As (µg/L/ year)	Au (µg/L/ year)	Cd (µg/L/ year)	Co (µg/L/ year)	Cu (µg/L/ year)	Fe (µg/L/ year)	Ni (µg/L/ year)	Pb (µg/L/ year)	S (µg/L/ year)	Zn (µg/L/ year)
L low	2.3E-05	5.7E-02	2.0E-04	3.6E-06	3.6E-03	4.8E-03	1.6E-01	5.1E-02	4.4E-03	4.2E-03	2.5	8.2E-01
L High	1.4E-04	3.4E-01	1.2E-03	2.2E-05	2.2E-02	2.9E-02	9.7E-01	3.0E-01	2.6E-02	2.5E-02	15	4.9
Å low	5.6E-06	5.3E-01	1.4E-03	3.6E-05	5.3E-05	2.1E-03	1.3E-02	6.4E-01	1.1E-02	6.5E-04	6.4	1.4E-02
Å high	3.3E-05	3.13	8.4E-03	2.2E-04	3.2E-04	1.2E-02	8.0E-02	3.8	6.3E-02	3.9E-03	38	8.2E-02

Table 5 Estimated yearly input to the Laver (L) and Åkerberg (Å) pit lake expressed as % of their filtered (<0.2 µm) surface water concentrations for a low and a high estimate of total reactive surface area.

	Ag (%)	Al (%)	As (%)	Au (%)	Cd (%)	Co (%)	Cu (%)	Fe (%)	Ni (%)	Pb (%)	S(%)	Zn (%)
L low	0.1	0.3	0.01	1.8	0.2	1.0	0.1	0.3	0.3	0.6	0.1	0.2
L high	0.8	2.1	0.1	11.0	1.2	6.1	0.9	1.5	1.9	3.7	0.7	1.4
Å low	1.3	4.4	0.005	3.6	0.1	0.3	0.9	17.2	0.2	3.8	0.1	0.1
Å high	7.9	25.7	0.03	22.0	0.6	1.7	5.3	101.9	1.0	22.9	0.3	0.4

surface area, and at both mine sites. However, the Åkerberg loading rates are substantially higher for the elements Ag, Al, Au, Cu, Fe and Pb which all are above 5% for the high estimate of the total reactive surface area. A potential explanation for this is that the Åkerberg mine was closed as late as 2003, while the Laver mine closed in 1946. Leaching from the pit walls at Åkerberg may therefore still be more active. The residence times for the epilimnions of the Laver and Åkerberg pit lakes have been estimated to 5.3-5.9 and 2.8-4.9 years respectively (Paulsson and Widerlund (2020)). This could mean that the change in contribution from the mine walls to the element concentrations in the pit lakes would be relatively larger at the Laver mine site if the residence times were considered.

Conclusions

Differences in geochemical loading rates could be observed for the two mine sites related to their geology, and statistically significant differences were found for the elements Ag, Cd, Cu, Pb and Zn. The results suggest that a relatively small portion of the element content in the pit lakes comes from pit wall leaching and that other sources are larger contributors.

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References

Billström, K., Mattson, B., Söderlund, U., Årebäck, H. & Broman, C. (2012). Geology and Age Constraints on the Origin of the Intrusion-Related, Sheeted Vein-Type Åkerberg Gold Deposit, Skellefte District, Sweden. Minerals, 2, 385-416. https://doi.org/10.3390/min2040385

MEND (Mine Environment Neutral Drainage Program). 1995. MINEWALL 2.0. Series of four reports (Literature Review, User's Guide, Application of MINEWALL to Three Minesites, and Programmer's Notes and Source Code) plus one diskette. Canadian Mine Environment Neutral Drainage (MEND) Reports 1.15.2.

Morin, K. A. & Hutt, N. M. (2004). The minewall approach for estimating the geochemical effects of mine walls on pit lakes. Pit Lakes, 16-18.

Ödman, O. H. (1943). Geology of the copper deposit at Laver, N Sweden. Sveriges geologiska undersökning, C 452.

Paulsson, O. (2021). Pit lake water quality and hydrology: Insights from case studies and modelling of pit lakes in northern Sweden (Doctoral dissertation, Luleå University of Technology).

Paulsson, O., & Widerlund, A. (2020). Pit lake oxygen and hydrogen isotopic composition in subarctic Sweden: A comparison to the local meteoric water line. Applied Geochemistry, 118, 104611.