Tracing mine water inflows, deriving dewatering measures for an open pit and a first trial to adapt the approach for underground mines

David Hagedorn[1], Nils Hoth[1]

[1] Technische Universität Bergakademie Freiberg, Gustav-Zeuner-Straße 1A, 09599 Freiberg, Germany, Nils.Hoth@mabb.tu-freiberg.de, David.Hagedorn@mabb.tu-freiberg.de

Abstract Within the first part of this paper, an overview is given about the initial approach to trace mine water inflows to their sources, which we presented at IMWA 2016. Recent results of further investigations are described. Furthermore, the procedure for the realization of actual dewatering measures is described. Within the second half of this paper, a trial to adapt our approach for an underground mine is described. Additionally, the later section gives an overview about the results of the adapted approach. In the end it is summarized in which conditions the approach works best.

Key words Dewatering, hard rock open pit, cut and fill, local hydrogeology, flow path interpretation

Introduction and review

Increasing production rates in open pit and underground mines nowadays lead to a deeper and more extensive development of mines. Greater depths may lead to increasing hydraulic heads and significantly increased water inflows. As a consequence, wet mining conditions occur, which in turn lead to a reduced production efficiency and safety risks. To reduce the inflows and their effects, companies have to implement dewatering systems. A good understanding of the local hydrogeology and water flow paths is the basis for the implementation of effective dewatering measures.

At last year's IMWA, we presented our approach to trace water inflows into BOLIDEN's Aitik open pit to derive suitable dewatering measures for the mine. Our approach for the sampling in Aitik was to sample different inflows into the mine, as well as natural and artificial surface waters from ponds, lakes, rivers and ditches in the vicinity of the mine. We evaluated the results of water sample analysis by identifying differences, similarities and connection between the waters. Based on the field parameters pH and Eh value, alkalinity, acidity and electrical conductivity, we grouped the samples. Based on this grouping, we developed different flow path suppositions of how different groups possibly could be interconnected. Following this, we used higher contents of Al, Cu and rare earth elements, which were typical for some waters, as trace elements to verify whether or not our flow path suppositions seemed reasonable. This methodology ruled out the influence of some artificial surface waters on the inflows in the major inflow zone of the pit and relate inflows on the hanging wall to runoff from waste rock dumps and infiltrated waters from the tailings. As a result, costs were saved for planned water management by discarding likely ineffective measures. The following description sums up the example we presented. Figure 1 shows an image of the sampling sites with the major inflow area of the pit.

There was a strong belief that the clarification ponds and a surface ditch (samples represented by the red dots) were leaky and connected to the inflows (represented by samples marked with green dots). Figure 2 shows that this relation seems very unlikely, as the surface waters have higher contents of Al, Cu and REE, while the inflows show lack of significant concentrations of these elements. Thus, an already planned and probably ineffective sealing of the ditch could be eliminated and costs were saved (Hagedorn et al 2016).

Further research and derived dewatering measures in Aitik

Based on the outcomes of our sample analysis, on site discussions took place with the local experts about the inflow characteristics and possible sources of the major inflows. These discussions lead to a new understanding of the inflow regime. Some of the inflowing waters showed a sulfidic, mouldy smell. Additionally it came up that the area on the surface used to be a bog area in pre-mining conditions and that the material on the waste rock dump on the surface is likely to produce such sulfidic runoffs. Based on these findings, a new conceptual model of the inflows was developed. We assumed that runoffs from the dump infiltrate to the first sedimentary layer, where they mix with the ground waters in this horizon, which are related to the old bog waters. Within the sedimentary layer, the waters infiltrate into an extensively fractured zone, which is related to the ore body. Within this zone, the waters sink down and enter the pit 200 meters below. To verify this supposition, it was decided to drill shallow wells in the area of the fractured zone. The wells were used for short pumping tests and water sampling for chemical analysis. Water levels were usually hit at depths about 80 meters below ground surface.

Pumping test results show that the closer the well is to the fractured zone, the well yield is higher. Historical reports and pumping tests on wells in this area support this outcome. Results of the chemical analysis are still pending, but it seems very likely that the sampled well waters will show similarities in elemental contents and behaviour. Longer pumping tests shall be executed in the near future, and longer term discharge from the wells may lead to visible reduction of the pore pressures at piezometers in the vicinity or even to visibly lower inflows. Based on the results, wells will be selected for continuous dewatering objectives. If the pumping trials are effective, our next aim for Aitik is to reduce the inflows in the hanging wall, which we assume to be related to the tailings and the runoffs from the waste rock dumps.

Adapting our approach for an underground mine

As our investigations lead to new insights in Aitik, BOLIDEN gave us the opportunity to adapt our approach for their underground mine Renström. Renström is located in the Boliden area in the Swedish province Västerbottens län. Renström started production in 1952 and produced 318 000 tons of ore in 2014. Main metals within the ore are zinc, copper, lead, silver and gold. With about 1400 m depth, Renström is the deepest mine in Sweden. Upwards mechanized cut and fill mining with hydraulic backfill is the main mining method applied in Renström. Within wider ore bodies, the technique of drift and fill with cement stabilised backfill is applied. To mine the sill pillars, vertical stoping with hydraulic backfill is applied. During the history of the mine backfill materials have included natural sand, tailings and waste rock. To visualize the conditions a little, Figure 3 shows a sketch of the lower part of Renström between the level 500 and 1400 m below the ground. (BOLIDEN 2016)

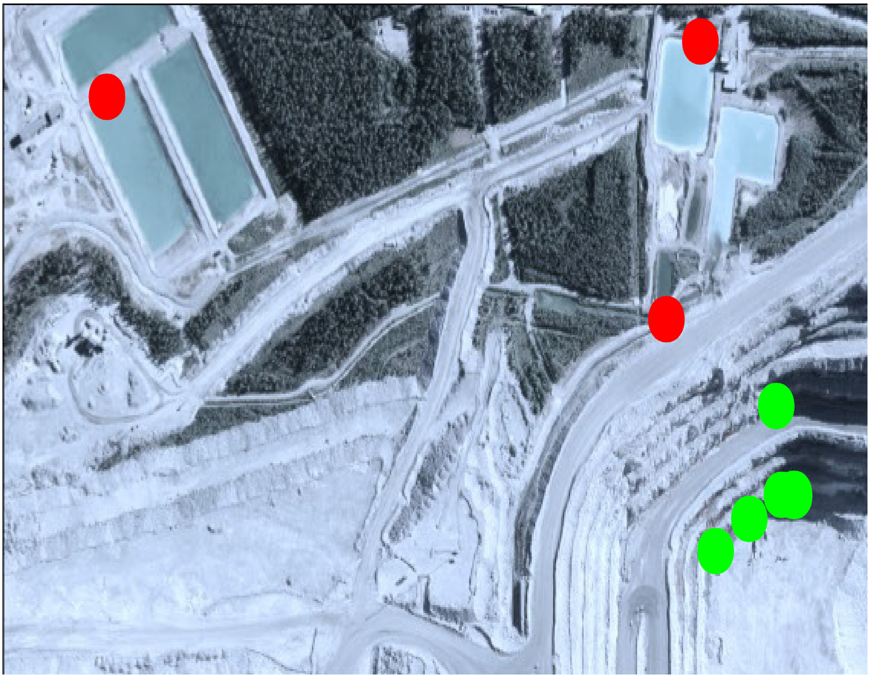

Figure 1 *Example for sample relation hypothesis. Red dots represent samples of possible sources and green dots represent samples from inflows, with local coordinates from Hagedorn et al. (2016)*

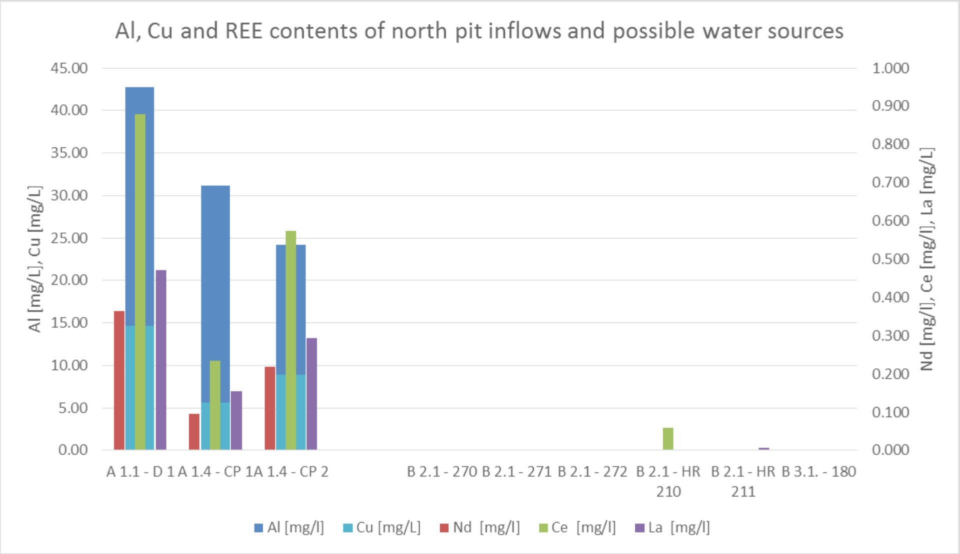

Figure 2 *Al, Cu, Nd, Ce, and La contents of sampled sources and inflows, from Hagedorn et al. (2016)*

Renström had problems with water inflows in the deeper part of the mine, where water flowed through the fractures of the sill pillars with pressures measured in drainage wells of about 5 bar. It is assumed that water from overlying, mined out areas leaks down through the sill pillars. Some fractured sill pillars have collapsed, which is a serious safety issue. Therefore, the mining had to be paused until the water pressure was reduced. As 20 % of the mine production comes from the sill pillar mining, the pausing has an impact on the production rate. To take suitable measures to avoid the water pressure above and within the sill pillars and to reduce the water inflows to the production area, it is necessary to identify the sources of the inflows. (Isaksson 2016)

As the possible flow regimes in underground mines are usually more complex and sources of inflows cannot be distinguished as sharply as in open pit mines, we had to adjust our sampling approach. We split the potential sources into surface waters, underground waters and other sources. Samples we assumed to be inflows were divided into samples from inflows from backfill drainage and from crosscuts. Of the total 29 samples, we took 6 surface water samples from lakes, a river and water treatment ponds, and the remaining samples were collected in different parts of the mine.

The grouping of samples based on the on-site measured field parameters pH and Eh value, alkalinity, acidity and electrical conductivity resulted in three major groups: natural surface waters, samples with similarities to natural surface waters, stronger mineralized samples with moderate alkalinity and low acidity and other samples. As most of the laboratory sample results showed similar characteristics and these samples could only be divided into two major groups, the development of flow path suppositions also became more challenging. For the flow path supposition development it is furthermore necessary to have a good conceptual understanding of the mine site. Old underground mines like Renström are usually quite complex, achieving a conceptual understanding for such a mine makes it even more ambitious to develop this flow path suppositions.

Unfortunately for our trace analysis, almost all of the waters showed a neutral to slightly alkaline pH values. As a consequence, the waters did not contain any typical Al, Cu, Nd, Ce and La contents, which we used as trace elements for certain Aitik mine waters. Because of these limitations and the big similarities between the sampled waters, the whole interpretation process needed to be based on a wider spectre of parameters and made the analysis more complex.

Results of Additional Water Analysis

Complete analysis with a wide range of elements, a TC/TN-analysis and an analysis of the stable isotopes ($_2$H/ $_{18}$O) have been carried out for all samples, and the results were used to derive new insights of the flow regime. As already mentioned, the sampled waters showed many similarities, which unfortunately continued in the additional analyses for the Renström samples.

Nevertheless, the measured parameters gave some useful hints and information. For instance, some samples indicate relations to surface waters, based on their low mineralization

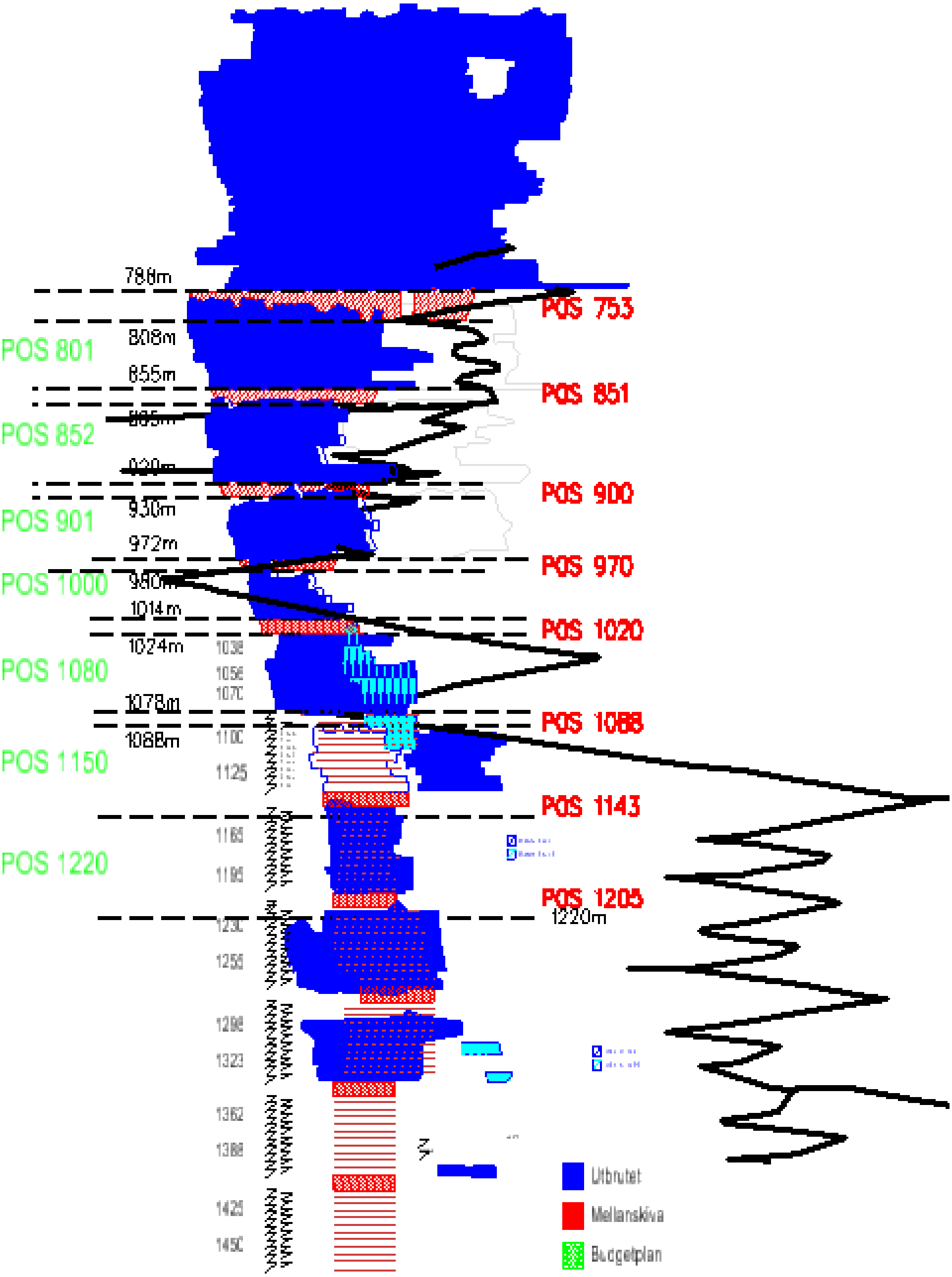

Figure 3 *Sketch of the lower part of Renström, blue areas are mined ore, red shaded areas are remaining sill pillars, black line shows the main ramp, from Isaksson (2016)*

and their isotope signature. Especially, quite high inflows from exploration wells for a future ore body showed very similar conditions to what we suspect to be near surface ground waters. Unfortunately it is unclear at this moment whether the waters are generated within the future ore body or within the section between well opening and ore body. We suggested further research on the origin of these waters resulting in a significant inflow and the relation to shallow groundwater may have a major influence on the efficiency of the mining of this ore body.

Some samples in the upper part of the Renström mine also show some indications for a relation to shallow groundwater, but they are not as distinct as for the waters from the exploration wells. They may also be connected to the basins of the service waters, which are used for drilling and other mine operations. Further isotopic measurements regarding the local seasonal variations of the isotopic composition in the area may lead to more reliable information.

For the deeper inflows, it gets a little trickier, as the waters are mineralized but very similar. What we can say so far is that the waters in the sumps and pump stations match with the inflowing waters. It is very likely that they are similar, and the waters in the sumps and pump stations represent the inflows as these have to be pumped out of the mine. But we cannot exclude that the basins from sumps and pump stations are connected to the inflows through fractures, as there are no in and output measurements for the basins. Of course, this seems unlikely, but so far we cannot rule it out. If the inflows are not interconnected with the basins they may origin from the waters which were used for the hydraulic backfill or deep groundwater, which enters the backfilled areas through pores or fractures. To derive further information about the origin of the waters in the backfilled areas, further analyses of parameters are necessary. For example, a sample from a deep well could provide information about the characteristics of the deep ground waters. Due to the long history of the mine, there are limited information about where which materials, binders and waters have been applied for the backfill. As these materials influence the water conditions, core logs from the backfilled areas could give further hints about the inflow origins. Furthermore, in and output data of the hydraulic backfill areas and their drainage could provide valuable information about the origin of the waters.

Furthermore, some Renström samples showed surprisingly elevated total inorganic carbon and total nitrogen. We are still looking for the sources. One idea is that it might be connected to the applied explosives.

Conclusions

What we can derive from the results in Aitik is that our approach to trace mine inflows to their sources by comparing their field parameters, elemental contents, isotopic signatures and TC/TN values worked well so far. Nevertheless, the final assessment needs to be based on the outcome of the derived dewatering measures, the results of first trials for the major inflow zone will be available in the near future. Further steps will then be to target other inflow zones.

What we learned from Renström is that our approach is limited, if the sources of waters and inflows are very similar to each other. The best starting situation requires clearly different waters within the investigation area. For example, acidic waters which contain typical REE contents. Nevertheless, we could identify hints for the origins of certain waters, too, but they are not as clear as in Aitik. Therefore, it is necessary to carry out further investigations. In this way, interpretation goes on and is not finalized yet. Further research could lead to a better understanding of the flow regime in Renström.

Another research goal is to increase the understanding of the local hydrogeology and actual flow paths in Aitik and Renström in order to provide further information for decision making for the implementation of further dewatering measures, with the higher aim of reducing the overall water inflows and increase the production efficiency and safety by establishing dryer mining conditions.

References

BOLIDEN (2016) Renström Visitor Presentation. Internal Document

Hagedorn D, Hoth N, Mwagalanyi H (2016) Dewatering challenges in an large scale production hard rock open pit in northern Sweden. Mining Meets Water – Conflicts and Solutions, IMWA 2016, (S. 503). Leipzig.

Isaksson M (2016) Renström water problem description and personal conversations