SOME EXAMPLES FROM BOLIDEN'S PROGRAMME FOR MINE SITES RECLAMATION

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ABSTRACT

Since 1924, Boliden has been operating nearly 50 mines and 13 concentrators in Sweden and an additional 6 mines in other countries. In the last 10-15 years, substantial effort has been put into reclamation of closed sites. As a general principle, site specific solutions have been developed, aiming at walk away solutions. The techniques used are in most cases combinations of flooding and dry cover, but also innovations such as groundwater saturation have been introduced. Various methods to enhance the integrity of the reclaimed area by establishing sustainable vegetation have been applied. A significant step forward has been taken by using various waste fractions from the municipal society. Without exception, the results have surpassed the forecast. New ecosystems are developing, with a wide variety of species on reclaimed areas and fish populations are establishing in flooded tailings ponds. The challenge for the future will be to develop principles and methods for transferring reclaimed areas back to society. To accomplish such a process, innovative solutions for new land uses will be required. This calls for an approach that reaches beyond the strictly technical considerations. This paper will give a brief review of the principles and the programme for mine site reclamation and the technical considerations involved, focusing on the conditions in Sweden, where the majority of the sites in the reference list are found.

INTRODUCTION

Since the foundation of the company in 1924, Boliden has been operating nearly 50 mines and 13 concentrators in Sweden and an additional 6 mines in other countries. Today, 9 mines and four concentrators are in production in Sweden and Ireland, and new reserves are continuously being identified and developed. In the Skellefteå district, production is based on mining a sequence of small and medium sized ore bodies and ore treatment in a central concentrator. In the original Boliden and Kristineberg area, 30 mines and 3 mills have been in operation. Today, five mines and one mill are in production. Accordingly, 25 mines and 2 mills have been closed.

In the last 10 to 15 years, substantial effort has been put into reclamation of closed sites. The list of reclaimed sites in the Skellefteå district so far comprises 18 mines and a mill with tailings storage facilities. Mine sites have also been subject to reclamation in other parts of Sweden. Among these sites are the reclaimed Stekenjokk (Broman and Göransson 1994) and Saxberget (Lindvall & al 1997) mines, as well as the comprehensive decommissioning programme started at Aitik (Lindvall & al 1997), where reclamation activities are underway, co-ordinated within the ongoing production. Outside Sweden, the most significant reclamation project underway is Premier Gold, Northern BC, Canada. This mine was never in operation ~~in~~ under Boliden's management, but was a part of the package obtained when Boliden acquired Westmin Resources in 1998.

Boliden's policy for decommissioning is based on the philosophy that no enterprise lasts forever. The success of a technical solution is a product of its initial quality and the maintenance put into it. The solutions applied shall be self supporting and permanent, calling for a minimum of active stewardship from future generations. According to Boliden's judgement, this means the highest possible level of effort. In addition to the technical criteria, another requirement is sufficient protection of the remediated areas from improper land use.

MAIN TECHNICAL SOLUTIONS

Most existing mining sites have been subject to long-term operation, initially with limited consideration for environmental issues compared to today's standards. The conditions at the sites today, including their physical disposition, are governed by decisions made earlier, in many cases decades ago. For old sites, therefore, an emphasis on remediative rather than on preventive measures has to be applied.

Boliden´s reclamation activities started in 1954 with vegetation tests at an abandoned tailings pond in Laisvall, in the alpine region of Northern Sweden. The objective of the re-vegetation was to increase evapotranspiration and, as a result, reduce the amount of water to be treated before discharge to the receiving water body. Initially, reference sites were located outside Sweden where the main problems were fugitive dust generation and/or vegetation establishment on pyrite-containing material. Information from South Africa in the mid 1960's (SAIMM, vol 60) indicated that when a vegetation cover was established, the oxygen supply was reduced which resulted in elevated pH. Investigations at the tailings ponds in Boliden and Kristineberg in the late 1970's, led to the conclusion that water saturation of the material or water cover inhibited pyrite oxidation. (Göransson, 1973).

An obvious alternative was to use various kinds of covers. Such methods had been investigated under the auspices of a research project managed by the Swedish EPA. In the final report from that project (Naturvårdsverket, report 4202), alternatives such as water cover were only briefly mentioned. Examples from Norway, where a few mines had been practising continuous underwater disposal of tailings, had encouraging results.

The techniques eventually used to prevent sulphide oxidation, were, in most cases, flooding and dry cover, but also innovations such as groundwater saturation have been introduced. As examples of walk away, decommissioning solutions were generally lacking, most of the technology and methods had to be developed by Boliden in-house.

DESCRIPTION OF SOME TYPICAL RECLAMATION SITES IN SWEDEN

Stekenjokk

In Stekenjokk, in northern Sweden, a mine and a concentrator were in operation from 1976 to 1988. The ore contained sphalerite, chalcopyrite and pyrite. Zinc and copper concentrates were extracted and the pyrite deposited in a tailings pond.

The decommissioning of the mine site which included a central industrial area, a waste rock dump, a small open pit and a 110 ha combined tailings and clarification pond, was described in 1983 in a conceptual plan, and approved in 1985 by the Licensing Board. Detailed planning for the closure started in 1986 and the final decommissioning plan was approved in 1989.

Due to the high sulphur content, about 20% in both the waste rock and the tailings, the focus was on minimizing the ARD. The open pit could easily be filled with water and after removal or destruction of all the buildings, the industrial area could be covered with moraine. All sulphide-bearing waste rock could be used in construction activities in the tailings area.

Some pyrite-bearing tailings had been deposited above the water level during operation and undergone weathering. In order to stop or slow down further weathering, different technical measures were considered (Broman and Göransson 1994):

1. Flooding
2. Dry moraine covering
3. Pyrite flotation and separate pyrite deposition
4. Addition of buffering material

In the evaluation process, the main parameter was the environmental protection effect. Other important parameters were the time required for implementation, uncertainties in performance, practical limitations and costs. The estimated costs (1989 cost level) for the previously mentioned measures were 15, 120, 45 and 30 MSEK[1] (2, 15, 6 and 4 MUSD[2]). The cost for other measures at the site was calculated to be about 7 MSEK (1 MUSD).

Pyrite flotation and buffering were not feasible due to the short remaining operation time. A moraine cover was judged to be unrealistic due to the high cost. Also, the availability of borrow material in the area was limited and use of a moraine cover would require transportation over long distances. Moreover, a moraine cover was considered to be less efficient compared to flooding. The conclusion was therefore that flooding was the preferred alternative.

Before decommissioning could start, the following critical conditions had to be evaluated:

- Water balance including water availability for permanent flooding
- Weathering and metal dissolution from tailings
- Tailings surface stability including effects of freezing of the entire water cover
- Dam and spillway stability

[1] million Swedish kronor
[2] million US dollars

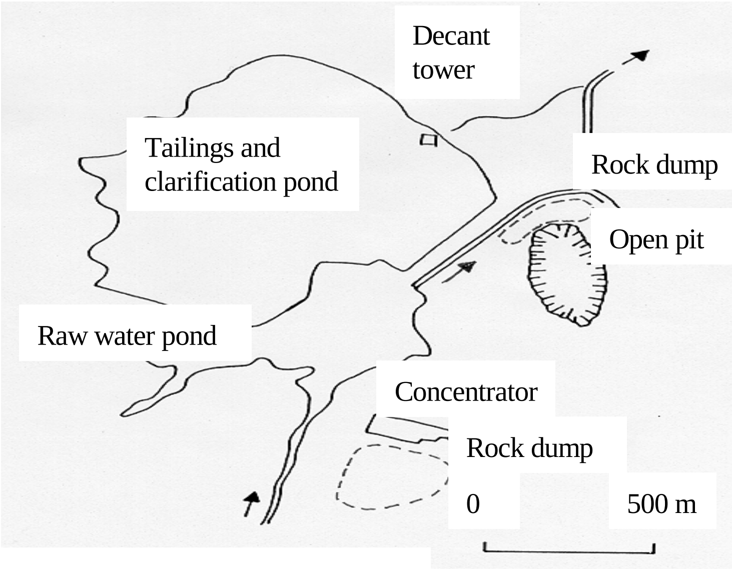

Figure 1.
Conceptual map of the Stekenjokk mine area

The final action plan was completed between summer 1990 and late summer 1991 and comprised the following steps:

1. Lowering of the water level
2. Raising the perimeter dams
3. Lowering the tailings in the upstream part of the area
4. Construction of breakwaters
5. Tailings surface stabilisation
6. Raising of the water level

Minor supplementary measures were later needed due to freezing in the spillway channel and leakage through the downstream dyke. The freezing caused a momentary elevation of the water level inside the tailings pond.

The performance of the water covered tailings area has been examined by sampling the pond water and discharge, and conducting fish studies. The objective was to reach an annual average metal (Cu+Pb+Zn) discharge, mainly zinc, from the tailings pond of about 800 kg. That actual discharge, however, showed a rapid decrease and has for the last five years been at or below 50 kg per year. Repeated fish studies have demonstrated the presence of reproducing arctic char in the tailings pond. Moreover, the metal content in that char was lower than in char captured in the upstream raw water pond used as a reference site.

<u>Saxberget</u>

The Saxberget deposit, which was discovered in 1880, had at the time of closure in 1988, been mined for nearly one hundred years. It was one of the richest ~~ores~~ deposits ever mined in Sweden, with combined zinc and lead grades occasionally reaching 15 %. The ownership and the layout of the operations were subject to changes over the years. The layout of the mining area was established in the beginning of the 1930's. Boliden acquired the mine in 1957, and shortly thereafter a new tailings pond was constructed (Lindvall & al, 1997).

A Steering Committee for the reclamation work was formed, with representatives of Boliden, the EPA, the County administration and the town of Ludvika. It was agreed that the costs up to a certain level should be shared equally between the company and the community. A project budget of 37 MSEK ($ 4.6 M USD), was set up for the reclamation of the tailings ponds.

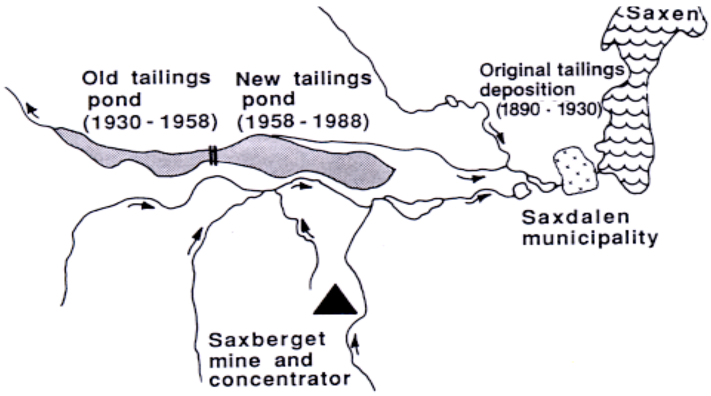

Figure 2. Conceptual map of the Saxberget mine area

The mine adit was located on the Saxberget Mountain. The mill and other facilities were located adjacent to the shaft. Sulphide containing rock had been used for levelling of the ground before erecting the buildings. A 250 m by 100 m subsidence area, partly filled with waste rock, represented the former outcrop of the ore. When remediating the mine area, this cavity was filled with waste rock collected from the cleaning up the industrial area and covered with moraine.

The older waste, deposited in the lower parts of the valley close to Lake Saxen, consisted mainly of mill tailings, slag and roasting residue. These deposits were found to be the source of the majority of the metal transport to the recipient, Lake Saxen, at the time of the mine closure. About 100 000 m^3 of material, with a metal content that exceeded 1% combined of lead and zinc, were removed and deposited in the mill tailings pond. After clean up, the area was covered with fresh soil.

Two separate ponds had been used during different periods: the Western pond during the period 1930 to 1958, and the Eastern pond between 1958 and 1988. The Western pond occupies an area of 18 hectares, while the Eastern pond is twice the size, 35 hectares (Figure 2). In total, the tailings amount to 4 Mt, with a composition of about 2 % S, less than 1 % Zn and 0.5 to 1 % calcite. The mineral composition suggested that the material was potentially ARD generating even though the tailings produced circum-neutral pH drainage. In the year of 1989, the mobilisation of zinc from the ponds was estimated to be 5 tonnes per year and the total load from the historical deposits to Lake Saxen was 25 tonnes per year.

Studies showed that after depletion of readily available buffering minerals, the pollution load would increase considerably if the oxygen supply to the material could not be controlled. As the hydrogeological situation excluded flooding of the ponds, the only realistic option remaining was a dry cover designed to reduce the oxygen transport into the tailings. The cover was designed in accordance with principles defined within the Swedish EPA's investigation programme aiming at long-term, low maintenance remediation solutions for mining waste. This called for a cover with at least two components, a sealing layer with low permeability, and a protective layer on top of the sealing layer. Engineering work started in 1990, and by 1995, the tailings ponds and the historical deposits in the valley had been subject to decommissioning measures.

The follow up monitoring program shows that infiltration has been considerably reduced. Flow measurements have begun, which will provide an estimation of the mass flow of pollutants in the future. The economic follow-up shows that the project met the cost budget. The unit cost for the cover was 70 SEK/m^2 ($ 7.5 USD/m^2). The project was Boliden's first major composite cover construction, generating experience for similar, future projects.

Predictions of future pollution loads in circum-neutral drainage indicate that 500 kg of zinc per year will be mobilized from the tailings ponds over a period of a few thousands of years. A few thousand years is the predicted time required to deplete calcite. When calcite has been depleted, the pollution load is predicted to increase to just below 3000 kg (3 tonnes) per year, limited by the rate of oxygen transport through the cover. If no mitigation action had been taken, the pollution load from the tailings pond after calcite depletion was predicted to increase to 600 tonnes of zinc per year.

The results obtained from the follow-up monitoring program confirm the integrity of the cover layers and so far point towards success. Oxygen measurements under the cover show that oxygen transport into the tailings is almost eliminated by the cover. The goal of reducing the hydraulic conductivity has also been met, resulting in a significant reduction in the infiltration.

As a result of the various mitigation measures taken at Saxberget, mobilisation of zinc to Lake Saxen has decreased from approximately 25 tonnes in 1989 to approximately 7 tonnes in 2003. The difference between the 25 tonnes from the site as a whole in 1989 and the 500 kg predicted from the tailings is explained by residual weathering products being washed out from the system, the majority coming from sources other than the tailings pond. Residual weathering products washed from the tailings pond include old roasting residue in the lower areas that was moved up to the tailings pond and covered (probably a mistake) and weathered tailings that had been exposed to air prior to mitigation.

Kristineberg

The Kristineberg mine and mill in northern Sweden was opened in 1940, during World War II. The mill was closed in 1991, as a consequence of the closing of a number of mines which reduced tonnage to the mill and raised milling costs. Today, the ore is transported to the Boliden concentrator on highway trucks, which are also used to transport backfill tailings back to the mine (Lindvall & al 1999).

The Kristineberg area is subject to a decommissioning plan more complex and extensive than any of the projects undertaken earlier by Boliden. The mining area comprises a large tailings ponds area, five mines, a large central industrial area including an old concentrator and three open pits. The tailings area consists of five separate deposits containing pyrite rich tailings, including old, drained ponds that are strongly weathered, one recently operated pond containing unweathered material, and one pond containing substantial quantities of precipitates from straight lime treatment of acidic mine water. The ponds are located along a valley between two mountain ridges (Figure 3).

The technical solutions selected were individually designed according to the specific conditions at each pond. Both engineered till covers and flooding are used. One innovative method has been successfully applied: groundwater saturation accomplished by surface water control and a simple till cover. The Vormbäcken River, earlier diverted to bypass the ponds, will at the completion of the decommissioning project be redirected into the lower pond, converting it into an artificial lake with a hydrology controlled by the river.

Flooding was chosen as the technical solution for the lower part of tailings pond #2 and for pond #4. Investigations show that, for the given properties of the sediments and under the hydraulic, hydrological and meteorological conditions, a 1.5 m water cover will prevent any re-suspension of sludge and tailings. In tailings pond 4, the dyke will be raised to create a water cover with a minimum depth of 1.4 m. Shallow areas along the shoreline will be covered with waste rock to prevent mobilisation of the sediments.

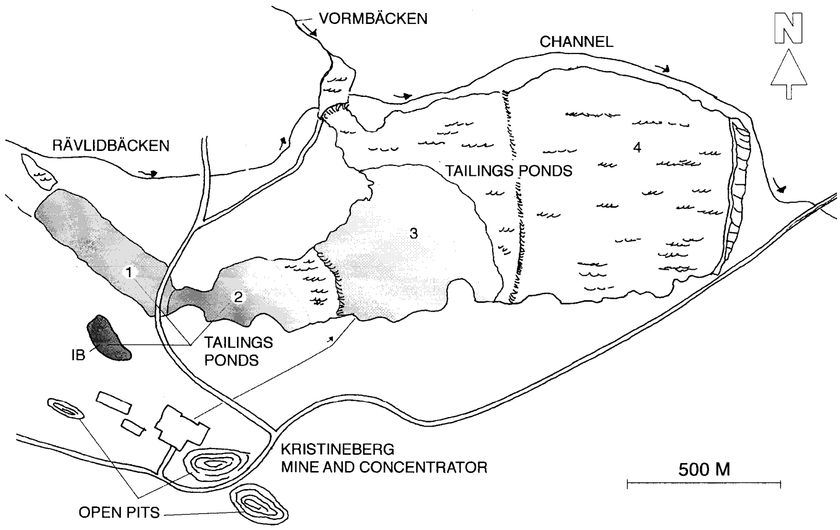

Figure 3. Conceptual map of the Kristineberg mine area

In the upper part of tailings pond #4, the tailings are partly covered by hydroxide sludge produced from mine water treatment with lime. This sludge is more sensitive to erosion than tailings. Physical stabilisation of the sludge will be accomplished by a waste rock covering and construction of breakwaters. The sludge has undergone leach tests to determine the chemical stability. The results show that no significant mobilisation will occur at a pH above 5, a level that will easily be exceeded due to the natural alkalinity of the Vormbäcken River water.

The tailings ponds area has a wide range of hydrogeological conditions, from completely drained deposits to permanent underwater deposits. In between these extremes are extensive areas with a shallow groundwater table, only a fraction of a metre under the tailings surface. Field sampling indicates that the material below the groundwater table is permanently protected from oxidation. and it would likely be unnecessary to apply a cover several times more extensive than the unsaturated zone it was intended to protect.

Result from leaching tests showed that the accumulated concentration of soluble metals in the thin layer above the water table was limited, corresponding to one year of weathering. The limited accumulation of soluble metals meant that, Boliden could develop a new, cost-effective remediation method: groundwater saturation of the tailings. This method is as simple as it is efficient. When a till cover is applied on a tailings deposit and the hydraulic properties of the till and tailings are similar, the groundwater will rise due to the capillary force into the till cover. If the thickness of the cover exceeds the thickness of the unsaturated zone, all tailings will become permanently water saturated.

Apart from reducing the volume of cover material required, advantages of the ‘groundwater saturation’ method are the simplified procedure for cover placement - no compaction is required - and the drastically reduced quality requirements for the cover material. The limited accumulated soluble metals load predicted in the unsaturated zone has so far been confirmed, as no pulse of metals has been measured after application of the cover and saturation of the tailings.

In some areas, the hydraulic situation was such that neither groundwater saturation nor flooding was applicable. In these areas, a composite cover of 0.3 m compacted clayey till (10^{-9} m/s hydraulic conductivity) and 1,2 m protective till cover was applied. The location of these areas was determined using groundwater modelling. Field monitoring of the covered areas after covering showed that the modelling prediction had been very conservative, with groundwater saturation in large areas where composite cover has been placed.

For many years, acid drainage from the downstream dyke of pond #4 has been a matter of concern. Several investigations have addressed the problem of the dyke´s content of pyrite, which is generating acid rock drainage. To manage the problem prior to decommissioning, the water has been collected, and returned to the tailings ponds using a collection ditch and a pumping station. The long term solution in the decommissioning plan includes reducing the slope and covering the dyke which buries the ditch at the toe of the dyke. A solution was designed, in which the collection ditch was filled with coarse waste rock, creating a hydraulic conductor underneath the expanded toe of the dyke. The drainage is collected in a well constructed through the cover, equipped with submersible, acid-proof pumps. When the drainage water is considered acceptable, the pumps will be removed and the well filled with till. Sampling results in the well show encouraging improvements in the water quality, just as predicted.

The surface of many of the areas intended to be covered by the capillary single layer cover were already saturated, and covered with a layer of slimes and hydroxides. As the physical stability of these areas was poor, the application of the cover was not a trivial operation. Boliden solved the problem by using the cool temperatures in the winter frost as a tool. By compacting the snow layer using snowmobiles and snow tractors, freezing of the surface layer occurred in a controlled manner. When the thickness of the frozen tailings was sufficient, access to the area was possible for the heavy equipment. By such means, large areas were till covered during the winter, at a cost well below the budget.

The Kristineberg area has been subject to detailed studies by the MiMi research programme between 1997 and 2003. Extensive studies have been conducted, verifying the success of the methods chosen. In particular, MiMi’s conclusion was that water saturation is an efficient method with rapid improvements in groundwater quality. Also, the systems approach using a flooded pond downstream as a sink for pollutants mobilised upstream was considered ideal. Remaining work includes the section of pond #3 that remains to be covered. The final restructuring of the river will be the last step of the project.

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