DECOMMISSIONING OF TAILINGS AND WASTE ROCK AREAS AT STEKENJOKK, SWEDEN [1]

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Abstract: The zinc-/copper deposits at Stekenjokk were discovered in 1918. Operations started in 1976 and continued until October 1988. The operation left a 110 ha tailings and clarification pond, a minor open pit, waste rock dumps and surface installations mainly comprising a head frame with ore bins and a combined concentrator, workshop and office building.

The tailings pond contained some 4,4 Mtons of tailings, grading approximately 20 % sulphur, making the material a potential AMD source.

A conceptual decommissioning plan for the area was approved in 1983. The detailed planning commenced in 1986 and took almost three years to complete. The solution selected was based on a flooding concept. The decommissioning was largely completed in 1991 with minor completion works in the two following years.

The paper describes the development of and the practical completion of the plan. It describes the reasons behind the selection of the method and reports practical experiences from the decommissioning work as well as the monitoring results so far.

Additional Key Words: acid mine drainage, tailings pond reclamation

Introduction

Stekenjokk is located in Sweden's southern Lapland Mountains (see figure 1). Copper and zinc mineralizations were localized in this area about 80 years ago.

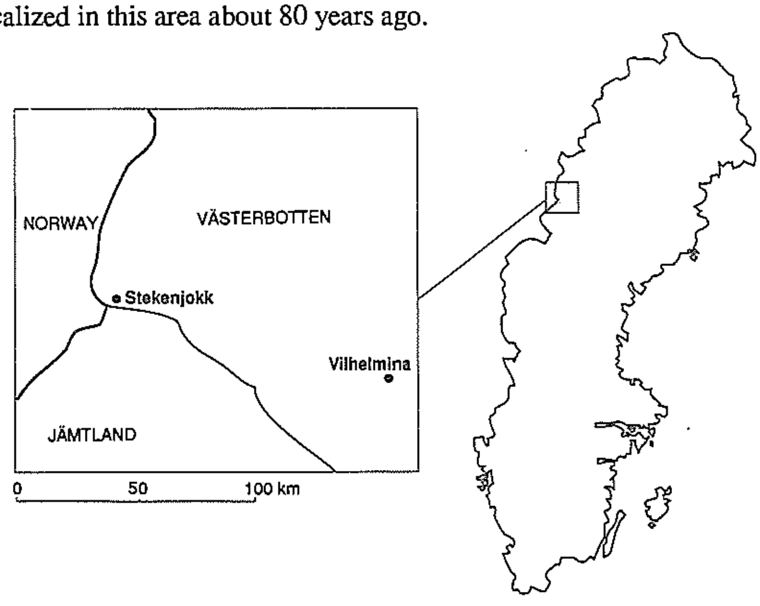

Figure 1. Localization map.

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From 1976 to 1988, Boliden Mineral AB mined and concentrated a total of approximately 8 million tons of ore in this area, of which the value components were copper, zinc and silver (see table 1).

Table 1. Tonnage and ore contents.

Tonnage	8 Mton
Copper content	1.5 %
Zinc content	3.5 %
Silver content	40 g/ton

The mining facilities were situated at approximately 800 meters above sea level in naturally beautiful but barren surroundings. The buildings were specially designed with climate and environment in mind. Practically all mining occured underground by means of cut-and-fill operations. A small amount of ore was mined in an open pit. Following autogenous grinding, the ore was subjected to flotation to produce separate copper and zinc concentrates. A substantial part of the tailings´ coarse fraction was used as backfill, with the slimes fraction deposited in a tailings and clarification pond immediately downstream from the concentrator. At its peak, 630,000 tons of ore were mined annually.

During the period of operation, a range of protective measures were adopted, including water recycling and strict control of pH values of the water in the tailings pond. Accordingly, this limited the environmental impact, enabling the ecological balance of the sensitive surroundings to be maintained.

Remaining in Stekenjokk after operations ceased were a small open pit, a 110-hectare tailings and clarification pond, a dike enclosing Stekenjokk´s raw water pond, rock dumps formed from ramp drifting and overburden stripping, and various, aboveground facilities (see figure 2).

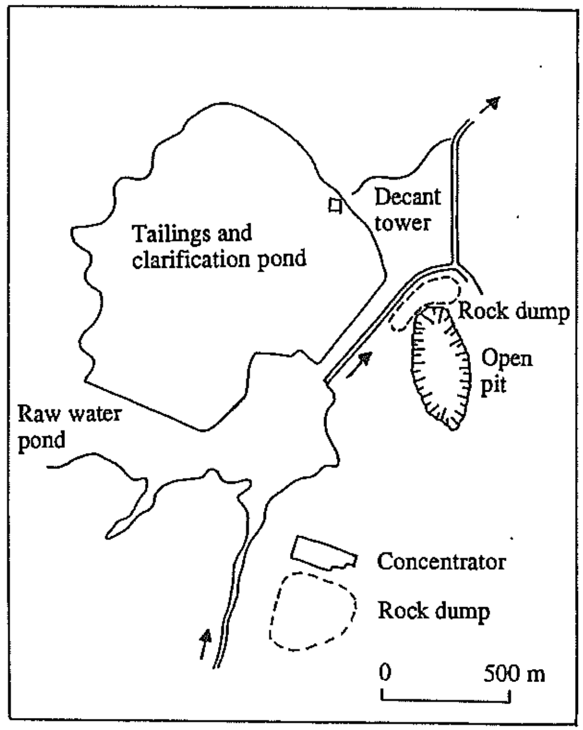

Figure 2. Mining facilities at Stekenjokk.

Decommissioning: General Prerequisites and Objectives

The decisive prerequisites of the decommissioning were that the tailings pond and segments of the rock dump contained significant amounts of sulfur-rich material. For example, the content of the sulfur in the tailings was about 20 %, and the content of the buffering minerals only about 1 % (see table 2). Accordingly, the residue products were potentially strong acid mine drainage (AMD) sources.

Another important consideration was that 2 years of operations remained at the time that detailed planning of the decommissioning started. Other important factors were the localization in a climatically harsh environment and the limited access to covering material, e.g., moraine.

The objectives of the decommissioning were largely the following:

- Preventing the area from becoming a major source of migrating metals and acidic components.
- Removal of facilities that could be hazardous to humans.
- Adapting the area to its natural state.

Table 2. Tailings pond features.

Area	110 hectares
Volume dumped	4.4 Mton
Sulfur content	20.0 %
Copper content	0.19 %
Zinc content	0.64 %
Buffering minerals	1 %

Decommissioning of the Tailings Pond: Studies of Alternatives

The basic phenomenon that the decommissioning must address is the oxygen-induced weathering of sulfides. There are two principal methods of overcoming weathering. One approach is to eliminate access to oxygen, thereby inhibiting the reaction. The other is to manipulate the composition so that weathering can occur without consequences to the surroundings. The detailed decommissioning plan began with a study of both these alternatives.

There is no better method of eliminating access to oxygen than using water as a barrier. The material can be either permanently immersed in water or sealed by a film of water. Such a water film can be attained in connection with a fine-particle cover layer as shown in figure 3. The capillary forces in the cover layer prevent it from being drained of water as well as reduce evaporation.

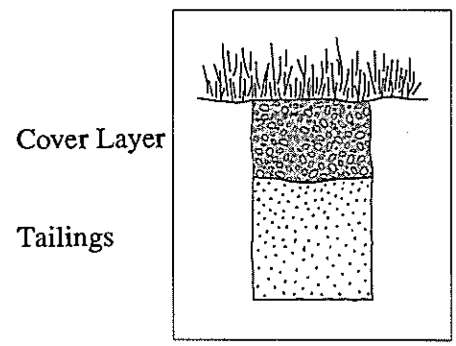

Figure 3. Cover layer.

Manipulating the composition to form a buffering mineral system, as shown in figure 4, can be accomplished either through pyrite removal or mixing in a suitable quantity of buffering material. Both variations were evaluated.

The technical measures representing the different principles can be summarized as follows:

Flooding
Dry moraine covering
Depyritization
Buffering

As the term implies, flooding involves damming the water so that it covers the entire tailings area. The flooding must be permanent. Accordingly, the water level is not allowed to fall and thereby drain parts of the tailings pond, nor can any physical forces be permitted to resuspend the fine tailings particles in the water cover.

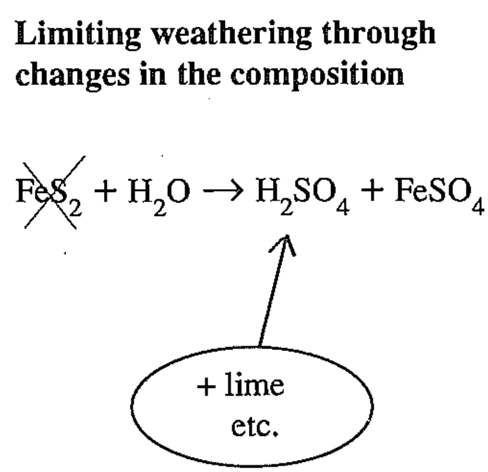

Figure 4. Possibilities for limiting the effects of weathering.

Dry covering involves covering the entire tailings area with moraine of appropriate thickness and quality. Stekenjokk is remote from suitable moraine deposits. In the comparative study, it was supposed that moraine of dike-construction quality would be applied to a thickness of 0.5 m.

Depyritization, or the removal and separate disposal of pyrite, involves an extra step in the ore treatment process in the form of pyrite flotation. The open-pit mine would be a suitable site for dumping of the pyrite.

Finally, buffering involves opening an olivine quarry and adding coarse olivine to the concentrator's autogenous system in quantities corresponding to 15 % of the ore volume.

In comparing the four options, we attempted to take all conceivable and relevant parameters into consideration. A central parameter was, of course, the environmental protection effect. Other important parameters were:

- the requirement for methods development and other studies;
- the requirement that final dumping sites be determined;
- the time required for implementation;
- the necessity for supplementary protective measures;
- the consequences for other landscape preservation measures;
- the uncertainties and limitations of the various methods; and
- the most critical parameter cost.

A comparison of the different options, illustrated in table 3, yielded results that were very easily interpreted. Neither manipulation alternative was feasible due simply to the fact that the remaining time of operation was too short. It is essential that enough time be available to form a sufficiently thick layer of buffering tailings and thereby provide an adequate protection.

Ultimately, the choice was between the flooding and moraine-cover alternatives. In practically all respects, the evaluation favored the flooding method. Simply stated, flooding was judged to be safer and more effective, above all, eight times more cost-effective. The two manipulation options, which were eliminated, were judged to be two to three times more expensive than flooding.

Table 3. Comparison of the decommissioning options examined.

Parameter	Flooding	Dry moraine covering	Depyritization	Buffering
Environmental protection	+	-		
Methods development	+	-		
Other studies	+	-		
Requirements of the deposition		-		
Implementation time			Prohibitive circumstances	
Supplementary protection	+	-		
Other landscape preservation measures				
Uncertainty, limitations	+	-		
Approximate cost (MSEK, 1989 cost level)	15	120	45	30

Decommissioning of the Tailings Pond: Detailed Planning Phase

The decision was reached, in consultation with the appropriate government agencies, that the ongoing work should focus on the detailed planning of the flooding option. A number of consultants were hired for this work.

Flooding rests on two fundamental conditions. First, the flooding must be permanent. Accordingly, any droughts of the area must be prevented. Second, the water-immersed tailings not be subjected to movement. Any disturbance causing resuspension will break the thin film of oxidized material at the tailings surface and the shielding of other tailings particles.

Permanent flooding is, of course, a matter of water balance and is determined largely by precipitation and evaporation effects on the water surface, the runoff of surface water from adjoining land, inflow and outflow of ground water, and seepage through the dikes. A hydrogeological study indicated an assured water availability and, in the event of extreme drought occurring once every 1,000 years, that the water level would fall a maximum of 20 centimeters.

The question of the stability of the tailings surface is somewhat more complicated. This is almost exclusively a matter of the shear force exerted, i.e., the wave-induced lateral forces that affect the tailings layer. The shear force diminishes if the water cover thickness is raised, i.e., the water depth is increased, or if the wave fetch is decreased. The resistance to shear force increases if the tailings surface is stabilized by superimposing a layer of coarse material.

The solution that eventually was formulated required that all stabilizing possibilities be used. As figure 5 demonstrates, this comprehensive action plan includes a large number of interim steps. First, the water level was lowered, and the dykes were raised three meters, the extent permitted by the availability of construction material, mainly moraine. Attaining the required water depth required more than raising the height of the dikes, it also proved necessary to lower the surface of the upstream part of the tailings area. To obtain a decrease in wave force, it was required that a breakwater system be constructed. It was also deemed necessary to superimpose coarse material in the shallow parts for added resistance to shear forces. Other important features of the plan included the design and construction of erosion-stable dikes having a long-term safety factor and able to withstand an earthquake with an intensity of 6 on the Richter Scale, with an epicenter directly under the dikes. Of equal importance was the design of erosion-stable spillway arrangements. Prior to plan approval, we were also required to demonstrate the effect of the lake´s water freezing into a complete ice cover.

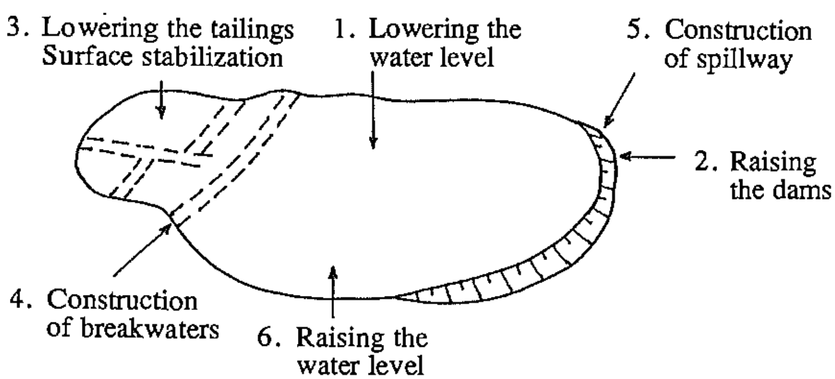

Figure 5. The working out of the flooding solution in detail.

After 3 years of studies (see reference list at end) and consultations with representatives of the National Environment Protection Board, Västerbotten´s County Council, Vilhelmina Municipality and the southern Lapp village of Vilhelmina (a total of nine consultations), the County Council approved the plan in 1990.

Deommissioning of the Tailings Pond and Waste Rock Areas: Implementation

The work was initiated in the summer of 1990 and was completed by late summer 1991. The work on the dikes, mainly the nearly 2-km-long downstream dike, provided an excellent opportunity for eliminating the existing sulfide bearing waste rock dumps (see figure 6). Large amounts of sulfide free waste rock were required to raise the dike and reduce its slope to a 1:3 proportion. An erosion-inhibiting, breakwater shelf was set in place on the dike´s inner side. Here, large amounts of sulfide-bearing waste rock were deposited to ensure safe underwater disposal during a long period. The breakwaters were constructed using similar type waste rock and, preferably, such material that required underwater deposition for safe, long-term disposal. The breakwaters were constructed somewhat in a checked pattern, which covered the shallow part of the future lake (see figure 7). The tailings were excavated and removed using the breakwaters as working and transport surfaces for excavators and hauling vehicles. The tailings´ ground water level proved to be higher than originally calculated, resulting in water saturation of the tailings surface occuring prior to the final depth being reached. Driving vehicles over such material was impossible. In this instance, the area´s plentiful supply of crushed waste rock turned a drawback into an advantage. By using waste rock, the surface could actually be made sufficiently stable for trafficability. Approximately 100 hectares, or one-tenth of the surface, were thus covered with waste rock. About 90,000 m^3 of tailings were excavated from other locations, hauled to the lower-lying areas, and deposited.

An erosion-stable spillway was built in the land area adjoining the dike.

Figure 8 shows the area when completed.

Figure 6. The completed downstream dike.

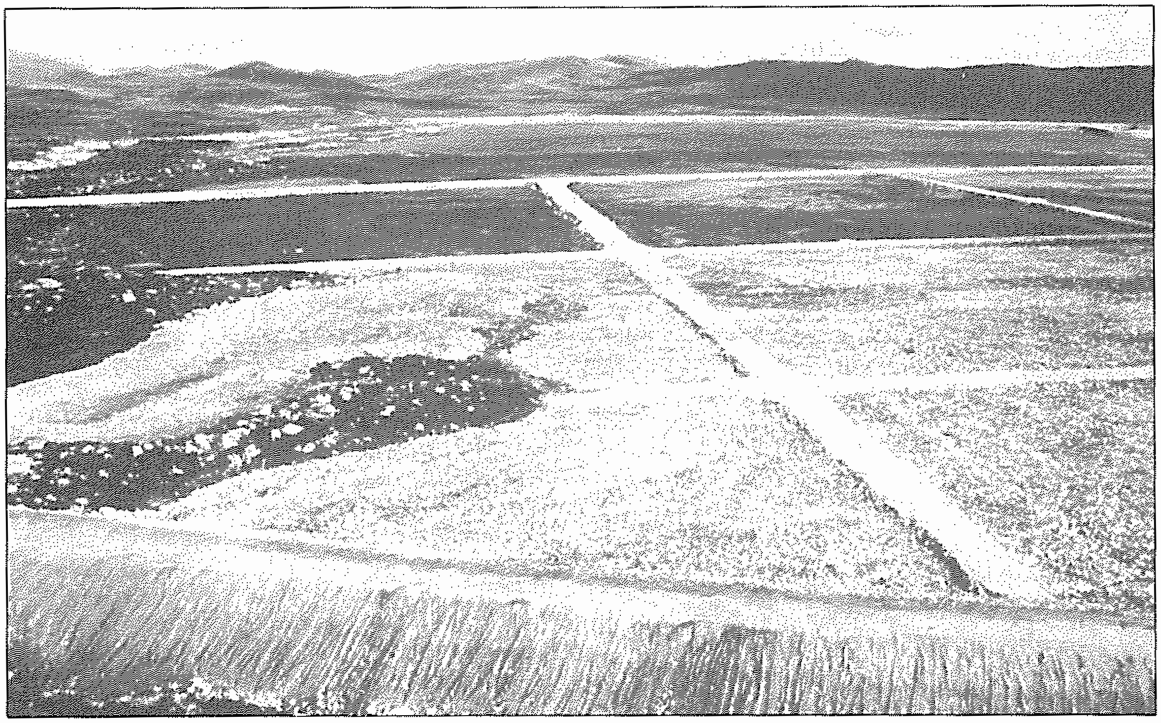

Figure 7. Breakwaters in the shallow part of the lake.

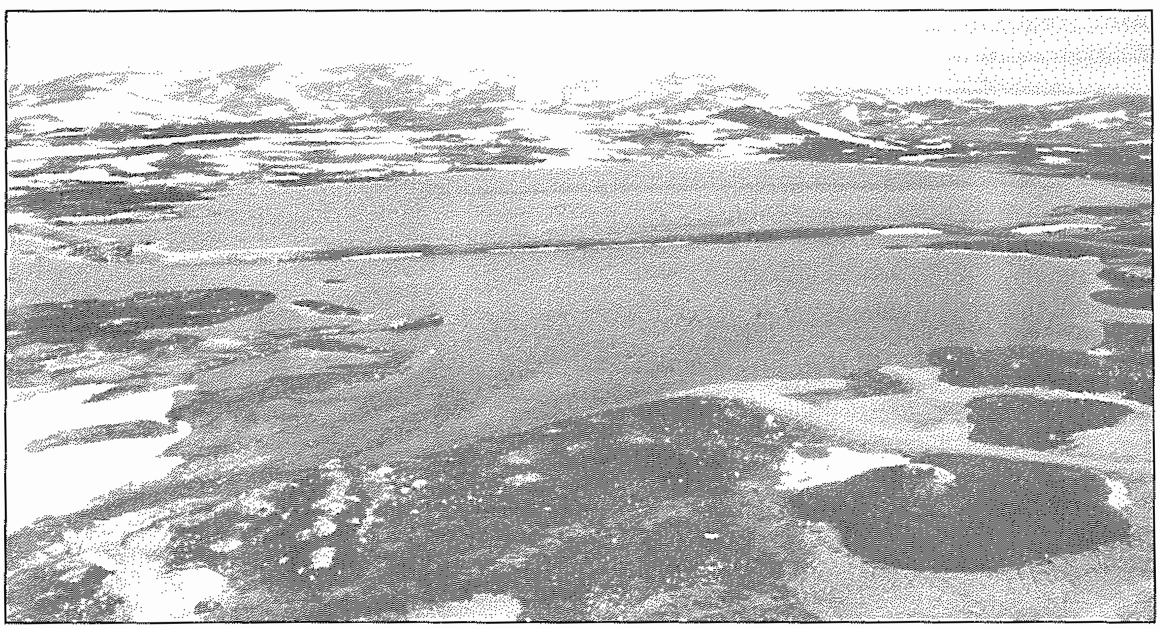

Figure 8. The tailings pond following flooding (the photo´s middle and background). Shown in the foreground is the raw water pond.

The water has risen to a level covering the adjoining land area on the lake´s western shore. The surface of the water remains undisturbed, except when strong winds blow, wherein the waves are broken along the breakwaters. In the event of a 1,000-year drought, the breakwaters would be visible, even during a calm. To the casual onlooker, this lake is indistinguishable from any other in the area. Eventually, normal biological life should develop in the lake.

Anticipated Results and Those to Date

The simulations of the lake´s water quality development are shown in figure 9. In the figure, the anticipated development of the zinc content, under two assumptions, is shown. The simulations assume that a maximum zinc load of about 800 kg will be transported by overflow from the lake annually. This is the same level as when operations were underway. Ultimately, this transport will decline to very low levels.

The effect of the decommissioning will be followed by means of a monitoring program which primarily is focused on a 5-year period. Results to date have been positive. The zinc contents from samples taken from spillway water are also illustrated in figure 9 and are well within the anticipated range.

The monitoring has demonstrated that a certain level of metal migration occurs at some areas of the dike base. A review of the causes of this diffuse metal transport is presently underway. To date, two explanations have been formulated: (1) the transport originates from the "flushing" of the partially weathered rock that has been deposited on the inside of the dike; (2) the transport results from acid-generating rock fractions in the dike´s outer support filling. The survey now in progress shall determine the extent to which actions are necessary, as well as those which are feasible and suitable.

Costs

The decommissioning at Stekenjokk has taken place largely according to plan. The overall cost has amounted to 25 million Swedish crowns in 1991, of which the tailings pond accounts for 15 million Swedish crowns. Table 4 summarizes the major cost items.

Table 4. Major cost items for decommissioning the tailings pond (1991 cost level).

Tailings dams	9 MSEK
Spillway arrangement	1 MSEK
Excavation of tailings	2 MSEK
Construction of breakwaters	2 MSEK
Others	1 MSEK

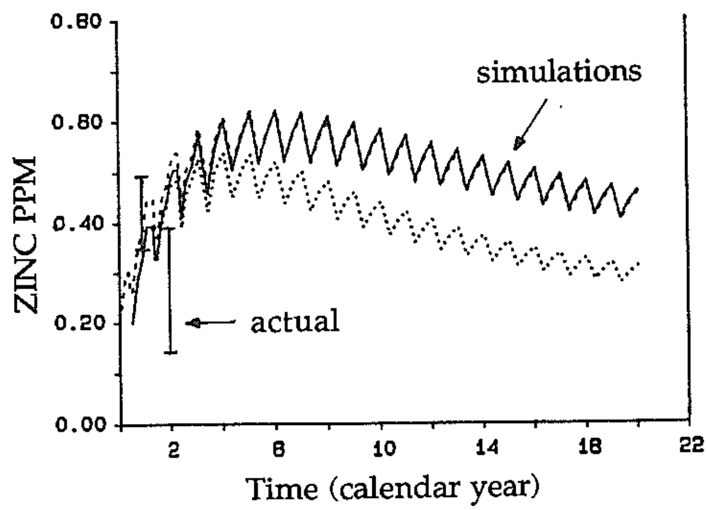

Figure 9. Simulated zinc concentration as a function of time and zinc concentration levels for 1992 (year 1) and 1993 (year 2).

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