Integrated Mine Waste Storage Concept, Krumovgrad Gold Project, Bulgaria

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Abstract

This paper presents a case history of the development of an integrated mine waste management concept for the Krumovgrad Gold Project, Bulgaria. The project description in 2005 included extraction of gold and silver in a carbon-in-leach process with conventional disposal of thickened tailings behind a lined valley fill dam. To address community and environmental concerns, flotation was investigated as the primary recovery process, thereby eliminating the use of cyanide. This then allowed major changes to the tailings management strategy. A concept was developed for an integrated mine waste facility where tailings are dewatered to a paste consistency and then deposited into cells constructed within the mine waste rock facility. The mine rock promotes drainage and consolidation of the tailings. The resulting deposit uses the waste rock for stability and is fully drained, thereby allowing progressive reclamation during operations. The strategy eliminates the tailings dam and stores both tailings and waste rock within an area previously designated for mine waste rock. The project footprint is significantly reduced and the liabilities associated with management of cyanide tailings and a water retaining tailings dam are eliminated.

Introduction

This paper presents the evolution of mine waste management strategies for the Krumovgrad Gold Project. The Project is located approximately 3 km south of the town of Krumovgrad in the southernmost part of Bulgaria, near the Greek border. A Thracian aged gold mine has been identified on the property; but there has been no modern mining activity in the immediate vicinity of the project. Gold soil geochemical anomalies were identified in the 1990’s and the property has been explored since that time. A gold-silver ore body of approximately 7.2 Mt has been defined and is being prepared for development as an open-pit truck and shovel mining operation.

The Krumovgrad Gold Project has been through two major phases of design studies that have produced different mine waste disposal strategies. The first phase was finished in 2005. The result of this study was a mine development plan that included the open-pit, a mine waste rock facility, a carbon-in-leach process plant to recovery gold-silver dore, a cyanide destruction circuit, a tailings management facility comprising a fully geosynthetic lined impoundment behind a cross valley dam, water supply reservoirs and the associated roads between the various mine facilities. This layout is shown in Figure 1 and the area for the mine rock storage is shown in the photograph in Figure 2.
Following completion of the 2005 designs, Dundee carried out a detailed review of the project to ensure that the development would address community concerns related to development of the project, and to ensure that the development would comply with Natura 2000 and other European Union requirements that would apply to Bulgaria when it entered the European Union in 2007. Issues that could require changes to the development plan included identification of sensitive environmental habitats in the area proposed for the tailings management facility, small land holdings with absentee land-owners and no defined method of contacting these owners, community and regional land use regulations, downstream community water supplies and the potential European ban on the use of cyanide in mining.

Revision of the development plan was started in 2009 focussing on the tailings management plan and the gold recovery process. This revision was an iterative process carried out by a team comprised of
process engineers, geotechnical engineers, mining engineers, biologists, geochemists, hydrologists, environmental scientists and permitting specialists. Potential tailings management concepts considered were low density slurry deposition, thickened non-segregating tailings and paste-consistency tailings contained behind some form of embankment, filtered tailings placed in a dry-stack to fully mixed co-disposal of the tailings and mine rock. Potential areas for the various types of tailings management were identified and conceptual plans were developed and then screened against environmental, community and land-use criteria. Figure 3 shows one of the land-ownership, land-use and environmental screening maps that was used to identify constraints for the tailings management facility. Varying degrees of complexity of obtaining the rights to use a particular area are represented by the different colours, with green being the areas with the fewest constraints.
Other potential mine waste disposal strategies were examined for the area upstream of the originally proposed tailings management facility. These sites had insufficient capacity to store slurry tailings in a conventional dam and pond arrangement, so the concept of dewatering the tailings was investigated. Tailings dewatered to a paste required large embankment containment structures to contain even a small tonnage due to the steep, narrow valley. Large embankment construction would require either development of a borrow source near the facility, or a haul road to transport mine rock from the open pit around or across sensitive habitats. After some effort, it was concluded that the numerous small
landholdings in the area could not be purchased in a reasonable time frame because the owners had moved and could not be traced. Next, dry stack of filtered tailings was examined for a number of sites, but costs for filtering one of the clay-rich ore types was found to be prohibitive. Finally, tailings disposal strategies focussed on sites adjacent to the open pit. At the same time, the gold recovery process was changed to one using an ultra-fine grind of the ore and flotation without the use of cyanide. This allowed consideration of disposal methods with minimum seepage control measures, and eliminated the need for a completely lined facility.

Two sites were identified for a facility to contain both the mine waste rock and the tailings, located in forested areas to the north and south of the open pit. Preliminary capacity assessment, as well as optimisation of the mine, haul road and process plant layout, resulted in selection of the south site, called the Ada Tepe South site. The area is defined by two small valley catchments that drain to the Krumovitsa River. The valleys have steep sides and bottoms and relatively shallow overburden. The Ade Tepe South site was previously identified for mine rock storage in the 2005 design, marked as the Waste Dump area in Figure 1.

The 2010 design includes storage of both the tailings and the mine waste rock generated from the Ada Tepe Pit in a single facility named the Integrated Mine Waste Facility (IMWF), shown in Figure 4. The IMWF falls within the same footprint as the 2005 waste dump shown in Figure 1. The combination of tailings and mine rock storage areas allowed re-design of the mine infrastructure into a single area that includes the open pit, process plant, process water reservoir, and a single area for tailings and mine rock storage. A near 50% reduction in the total mine footprint is largely due to elimination of the tailings area shown in Figure 1. The development and details of the integrated mine waste concept are described below.

![Figure 4: 2010 Proposed Integrated Mine Waste Facility](image-url)
Integrated Mine Waste Facility

The concept for the IMWF is that tailings dewatered to paste consistency are placed within cells constructed from mine rock. The outer face of the facility will have a continuous face of mine rock. Mine rock not needed for construction of the outer face will be placed as internal berms to allow mine equipment access. The facility will be developed in two valleys which will enhance stability, starting near the river and building up-hill. The lowest areas of the facility will be stripped of all soils and soft materials to provide a high quality foundation. An underdrain system will be installed along the base of the ravines and natural drainage channels. The drainage system will collect and convey both rainfall that infiltrates into the facility and also water expelled from the tailings during consolidation to a sump at the toe of the facility. This water will then be pumped to a water pond for use in process.

To prevent tailings being carried through the outer mine rock berm, a two zone filter system will be placed. This will consist of a heavy, non-woven geotextile directly against the mine rock and covered by a layer of sand. The sand will contain the tailings and the geotextile will prevent movement of the sand into the mine rock. A schematic of the conceptual layout and development of the IMWF is presented in Figure 5. The external faces of the completed portions of the IMWF can be covered with topsoil and vegetated. This means that the IMWF can be almost completely covered and reclaimed prior to the end of the mining operations.
**Design Challenges**

Key issues identified during design of the IMWF included operational sequencing with concurrent deposition of both tailings and mine waste, variations in the mine waste properties and proportions, stability during construction over soft fills (paste tailings), control of water and costs.

The IMWF facility is built beginning at the bottom of two ravines. Platforms for tailings and mine rock placement are constructed over the underdrain system from excess material from site development excavations and mine pre-stripping. During earlier years of the mine life, the area on the working platform available for cells for tailings placement is limited by topography. The initial
platform area for start-up was calculated to allow time for the tailings to drain and consolidate before additional materials were placed over the tailings. As the IMWF gains elevation, the working area increases and the rate of rise decreases. The final configuration includes outer slopes constructed with horizontal benches at 10 m vertical intervals with the intervening slope constructed at 2.5 horizontal to 1 vertical. The design allows control of water and progressive closure during operations. This slope also matches the natural slopes in the area and will allow the IMWF to blend into the terrain once vegetation is established.

Construction of an integrated facility ties the mining operation directly to the tailings disposal because of the need for mine rock to construct cells for the tailings and the need for the mine haul trucks to be travelling through and dumping in the tailings area. Impacts to mining can therefore impact processing by affecting tailings disposal, and vice versa. Management is required to carefully sequence ongoing waste rock and tailings deposition, tailings pipeline moves, berm and filter construction and drainage layer placement.

The layout of cells constructed of mine rock to contain tailings is based on the mine design and the ratio of waste rock to tailings production. Surplus waste rock can be placed to build additional cells. Surplus tailings, equivalent to lack of tailings storage capacity, could potentially limit production. Contingency storage for tailings was therefore incorporated into the design. During the early years of mine life two additional storage areas are built in the upper part of the catchment. During later years of mine life, the contingency storage areas are buried, and excess storage capacity is carried as extra cells on the larger working platforms.

Thickener design studies have indicated that a range of initial solids contents are possible for deposited tailings, and will depend on ore type and operation of the thickeners. Upset at the thickener typically results in temporary production of tailings that are wetter than design. The change in properties is accommodated by carrying a contingency for additional tailings storage, described above.

Variation in material properties of the mine wastes can impact operations. Mine rock was defined as non-potentially acid generating (NPAG) and will be managed using truck, shovel and dozer operation. Tailings are also defined as NPAG, but require dewatering and then consolidation and volume change following deposition to gain shear strength. The use of an ultra fine grind to promote gravity separation and flotation produces fine tailings. Tailings examined in the study had a grain size shown in Figure 6, had non-plastic behaviour with a Shrinkage Limit of 25%, specific gravity of 2.74, a slump of 24 cm at 64% solids content (Figure 7), air entry value of greater than 100 kPa, peak and residual friction angles near 30 degrees, and peak and residual cohesion values of near 25 kPa and 14 kPa, respectively.
Figure 6: Tailings Grain Size
Tailings are transported by pipeline and placed hydraulically to form soft layers that must consolidate to gain shear strength, undergoing large changes in volume. Fine grained tailings can require longer times to consolidate and have the potential to cause instability if rate of rise is too fast. Tailings were therefore characterized for void ratio versus hydraulic conductivity and void ratio versus effective stress relations and the progress of consolidation was predicted using CONDES0 (Yao and Znidarcic 1997). Tailings production rate and lift thickness were then used to define the minimum required footprint areas for working platforms in the IMWF.

Intuitively, waste rock in the IMWF will have a higher frictional strength than the tailings. Tailings will have little strength at deposition and will only gain strength with consolidation. Limit equilibrium analyses of the stability of the IMWF were conducted using criteria from guidelines for waste rock dumps (BC MWRPRC 2001) and dams (CDA 2007). A tailings friction angle of approximately 20 degrees is required to achieve the design criteria of a Factor of Safety of 1.3 for static loading conditions. Strength testing indicates that drained tailings have a friction angle of 30 degrees, so the facility will have stability exceeding the design criteria over the long term under consolidated, drained conditions. A sample stability analysis result is shown in Figure 8.
Figure 8: IMWF Cross Section and Stability Analysis

The mine rock cells will provide containment to freshly placed tailings but the overall stability of the IMWF requires consolidation and gain in shear strength of tailings in the lower layers. Sensitivity analyses conducted to examine the effect of tailings strength on overall stability indicated that the outer rockfill berms should not be constructed over more than 20 meters of undrained tailings. Stability is achieved by consolidation of the tailings and dissipation of excess pore water pressures. In operation, the progress of consolidation can be monitored using vibrating wire piezometers buried in each lift of tailings. Operation in multiple cells will allow flexibility to switch deposition between working areas to allow time for consolidation.

Water produced by consolidation of tailings and also from precipitation falling on the IMWF must be controlled, primarily to limit erosion and sediment release. The IMWF includes internal filters that will retain tailings and also fines from the waste rock. Water will drain into ribs of mine rock that act as internal drains, then through the underdrain system to collection sumps located at the toes of the ravines. Limited storage volume is available in the ravines and water is pumped to a water pond for use in process or treatment, if required, prior to release to the environment.

The IMWF does not include an integral water pond, but an additional pond is required for mill water supply. Dewatering of tailings at the mill reduces the volume requirement for water supply storage. The water pond and dam are used during operations and then drained and decommissioned for closure. It is noted that the 2005 design included water dams in addition to the tailings pond and water reclaim system.

Thickening tailings and integrated disposal will increase operating costs for mine waste disposal. Additional costs for the IMWF include dewatering of tailings, cell construction including waste rock handling, and also filters and drainage layers. The increase in cost is incremental and results in a better environmental solution due to reduced area requiring closure with fewer monitoring points.

Discussion

The main issues for mine waste disposal for the Krumovgrad Project design in 2005 included:
use of large areas for waste disposal with environmentally sensitive habitats;
proximity to stakeholders and associated concerns;
requirement for lined systems for tailings storage;
liabilities associated with storage of cyanide tailings and water retaining dams over the long term.

Elimination of the use of cyanide and dewatering of tailings allowed development of an integrated concept where tailings are disposed in the same area as the mine waste rock. The integrated facility provides several advantages during the closure period, and a comparison of closure conditions for the 2005 and 2010 designs is presented in Table 1.

### Table 1. Comparison of Mine Waste Designs for Closure

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<tr>
<td>Perpetual management of tailings dam</td>
<td>No tailings dam</td>
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<tr>
<td>Post closure management of soft unconsolidated tailings deposit, plus closure of separate waste rock facility in separate catchment area</td>
<td>Progressive reclamation and closure of consolidated, drained tailings and waste rock during operations</td>
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<td>Cyanide residual in tailings area</td>
<td>No cyanide</td>
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<td>Area of Mine Waste Storage = 96 hectares</td>
<td>Area of Mine Waste Storage = 41 hectares</td>
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### Summary and Conclusions

The evolution of mine waste management strategies is described for the Krumovgrad Gold Project. Designs initially included a conventional waste rock dump and thickened tailings discharge into a lined impoundment with cross valley dam and water reclaim. Changes to process allowed elimination of cyanide and the development of an integrated concept for mine waste disposal which significantly reduces the mine footprint, facilitates mine closure, and eliminates the long term liability associated with water retaining dams and cyanide tailings.

### References