RED MOUNTAIN MINES – 5 YEARS OF CLOSURE WORK

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ABSTRACT

This paper reviews the closure activities undertaken at, and reclamation standards applied to, the tailings facilities of the abandoned Red Mountain molybdenum mine. The selection of the appropriate criteria was based on an assessment of the consequence of failure. Design and construction work included water diversion channels, spillways, and a toe berm.

The paper summarizes the results from the geochemical and aquatic monitoring programs for the past 6 years. Predictions regarding the potential effects of closure activities on water levels and seepage rates from the tailings facilities indicate that water levels within the tailings would drop and seepage rates would be reduced. Mass loading of molybdenum, copper and other trace elements are presented and the implications for downstream water users are discussed. Despite elevated molybdenum in the tailings solids and the mobility of molybdenum at neutral pH, downstream water quality has not been adversely affected.

INTRODUCTION

This paper describes the work undertaken to enable the surrender of the mine permit for the two tailings deposits at the abandoned Red Mountain Mine site located approximately 4 km northwest of Rossland in the West Kootenay region of south-central British Columbia. The two tailings facilities are referred to as Good Friday, which is a side valley impoundment, and Jumbo, which is a cross-valley impoundment. Both are located in the headwaters of the Little Sheep Creek drainage, 11 km upstream from the US border. See Figure 1.

Historical Background

Mining by both underground and open pit methods had been conducted for many years in the general area. Gold mining was prevalent in the early part of the century. In 1964 a number of claims were staked and a molybdenum deposit was outlined. The mine operated from 1966-1972, producing 6 million pounds of molybdenum sulphide concentrate from 1,040,00 tons of ore mined from a series of 9 open pits on the west slope of Red Mountain. Minor exploration work was conducted during the 1970s but no further work has been done on the property since 1979.

Attention was focused on the site in 1997 when the Mines Branch of the BC Ministry of Energy and Mines (MEM) became aware of a prior, uncontrolled release of pond water over the Good Friday dam. In 1998, under the authority of the Mines Branch and acting as an agent for the Mines Branch, Inco, with technical assistance from Klohn Crippen, made some temporary repairs to the Good Friday dam. Both tailings
Impoundments were inspected daily during the 1999 and 2000 freshet. Problems developed suddenly on June 4/5, 1999, when the old creek diversion culvert beneath the Jumbo dam failed. This resulted in a series of emergency repairs being undertaken. The repairs were completed on June 29, 1999 with a successful diversion of the creek around the tailings facility and grouting of the culvert. Further physical stabilization works have been carried out annually since then.

**Site Conditions**

At Red Mountain, folded Carboniferous and Jurassic sedimentary and volcanic rocks are intruded by a variety of younger, igneous rocks; molybdenum, gold-silver-copper, and other mineralization is apparently centred on the mountain and related to local facies of the Eocene Trail granodiorite batholith. The molybenite orebodies are in brecciated Mount Roberts hornfels.

The average annual total precipitation, as rainfall equivalent, at the nearby Rossland Maclean station, which is at an elevation of 1085 m, is 908 mm (based on data from late 1963 to early 1990). Precipitation values used in the Klohn Crippen design were adjusted for elevation, since the tailings facilities are located at an elevation of about 1300 m. The adjusted annual precipitation is 985 mm. Approximately half of this falls as snow.

The area experiences warm summers with daytime highs averaging over 23°C in July and August, occasionally reaching 35°C. Winters are moderately cool, with daily minimum temperatures averaging -8°C in December and January. The mean annual temperature is 5.5°C. Annual lake evaporation as determined from the Castlegar BCHPA Dam, less than 30 km to the north, is 732 mm, distributed over the months of April to October.

**Good Friday Impoundment**

The Good Friday impoundment covers an area of about 6 ha. The slope of Red Mountain ski hill bounds the impoundment to the east and north while an earthfill dam, comprised of two limbs, bounds the impoundment to the south and west. Tailings from the processing facility have formed a beach that slopes from north to south into a pond located against the southern arm of the perimeter dyke.

The only design or “as-built” drawings available are photocopies of B-size hand drawings from 1965. The design drawings indicated the south limb to be a downstream constructed till-core dam with an ultimate crest elevation of 1283 m, well below the current crest elevation of 1286 m, with an original ground elevation of 1268 m for a maximum dam height of about 18 m. It appears that the south limb of the dam was raised upstream, or at least the crest was widened to about 15 m, using rockfill dressed with road base material. Tailings sand (likely hydraulically separated) was placed upstream of the centreline of the crest. This south limb is generally in good condition.

The characteristics of the dam appear to change where the main dam (or south limb) joins the west limb. Observations suggest that this west limb is likely an upstream raised dam, as there is insufficient space to have
constructed a downstream dam without impacting the main mine access road below. The west limb is characterized by a significant amount of tailings sand with a downstream rockfill face, presumably for erosion protection. The northern half of the west limb is primarily a sand (tailings) dyke. The 1997 overtopping incident, at the south end of the west limb, has significantly altered the dam profile and may even have washed away most of the till starter dam in that area.

The design drawings also identify the presence of decant towers and associated structures in the southeastern portion of the impoundment. The two wooden decant towers visible above the tailings surface were grouted and backfilled as part of Klohn Crippen’s closure works.

**Jumbo Impoundment**

The Jumbo dam is a valley fill dam about 28 m high with a crest elevation of 1296 m. It appears that the dam was built essentially to full height with rockfill, with upstream coarse and fine filter zones and a foundation blanket drain. The main structure appears stable. The dam impounds a 340 m long by 120 m wide tailings beach, which was normally (most of each year) dry, except during the freshet. The beach is at about 1295 m elevation and the Little Sheep Creek valley at the dam toe is at about elevation 1268 m. Until 1999, Little Sheep Creek was intercepted upstream of the tailings beach and directed into a 600 mm diameter, asphalt coated, corrugated metal (CMP) diversion culvert. The culvert ran beneath the impoundment and discharged in mid-valley, into the water reclaim pond (now the stilling basin). By the time the culvert failed in 1999, the intake was about half filled with alluvial gravel and was surrounded by heavy second growth. The failure of this culvert caused the development of large sinkholes and release of tailings from the impoundment during early June, 1999.

The main operating decant for the impoundment was located at the south end of the impoundment. The decant was a wood structure and it has now been grouted and backfilled.

**DESIGN CRITERIA AND PHYSICAL STABILIZATION**

The assessment of the consequence of failure of the two dams was based on the current downstream uses, primarily irrigation, but also bull trout habitat further downstream, and observed impacts from the 1999 release of approximately 3000 tonnes of tailings. Using the rating system presented in the Canadian Dam Safety Guidelines (CDA, 1999) the dams were deemed to be low consequence structures since there was very little likelihood of any human fatalities resulting from a catastrophic failure of the dam. Nevertheless, given the proximity to the United States, it was decided to select closure design criteria at the upper end of the low consequence classification.

Given the properties of the materials used in the dams and the foundation conditions determined through geotechnical drilling, it was decided to set the seismic design criteria equivalent to the Maximum Credible Earthquake for the area (Peak Ground Acceleration of 0.1 g for a Magnitude 7 SBC (NBCC 2001)), as only
portions of the West Limb of the Good Friday dam did not already meet this criteria. For hydrologic design purposes, the 1 in 1000 year return period flood event was selected. For Jumbo, this was determined to be a flow of 29 m$^3$/s for a 5 minute peak duration from the 1.85 km$^2$ drainage basin area based on a 2-hour duration rainstorm with a total rainfall of 38 mm and an associated snow melt of 19 mm. For Good Friday, the peak flow was found to be 5 m$^3$/s for this 0.2 km$^2$ drainage basin for the same event, following the methodology described by Obedkoff (MELP, 1989).

Between 1999 and 2003, the following construction activities were undertaken to ensure the facilities can withstand events up to and including the design criteria. The following briefly summarizes the major work components:

**Jumbo**

- Grout all pipes through dam including main 600 mm CMP creek diversion, decant pipe, decant vent pipe and 200 mm side creek diversion pipe;
- Install diversion channel for Little Sheep Creek across surface of tailings to right (west) abutment of dam, channel is sized such that large floods may exit the channel briefly but that a 1.7 m freeboard, relative to the dam crest is maintained;
- Cut spillway into bedrock at abutment; spillway chute downstream of dam is steeply sloped over a combination of large riprap and bedrock. Large floods may cause some loss of riprap in this area but this is not expected to affect dam stability and can be subsequently repaired as required;
- Create a stilling basin for energy dissipation at the bottom of the spillway chute below the toe of the dam;

**Good Friday**

- Grout all pipes through dam including the two decant lines;
- Install a drainage channel along the left (east) side of the impoundment to divert water from up slope and to drain the tailings surface to the left abutment. A minimum freeboard of 1.6 m relative to the dam crest is maintained during the peak of the design flood event;
- Install a rip rap lined spillway in till through the main dam at the east abutment, with a training berm to ensure flood flows are directed away from the downstream toe of the dam;
- Construct a “toe berm” at the south end of the west limb to stabilize the dam where it previously had overtopped; and
- Construct an extension of the west limb to tie into native ground at the north end of the impoundment to prevent tailings washing out and to reduce accessibility to the surface of the tailings.

Concurrent with the physical stabilization work, an extensive program of recontouring, till placement and revegetation was undertaken. A seed mix was either tilled or hydrosededed on all suitable surfaces. An application of fertilizer was added following seeding. Willows were hand planted on either side of the channel upstream from the Jumbo tailings, where the inlet to the diversion culvert had been. By the summer of 2003, a healthy growth was occurring on more than three-quarters of the tailings areas. A second application of fertilizer was applied in 2003.
MONITORING

Environmental monitoring has been underway at Red Mountain since 1998. Monthly monitoring of piezometric levels and surface water quality will continue until October 2004, at which time monitoring frequency will be reduced to two or three occasions per year.

Geochemistry

Tailings samples were collected on seven occasions, either by testpitting or drilling. Both unoxidized (grey) and oxidizing (orangey) materials were sampled. All samples were submitted for Acid Base Accounting and ICP metals analyses. There was no demonstrable change in tailings characteristics over the period from June 1998 to October 2002, in that the surface materials did not appear to be noticeably more oxidized later on, nor did the depth of the interface between consistently orange and consistently grey material appear to be significantly deeper.

Figure 2 presents the key ABA results of sulphide content vs. NP:AP ratio. All of the samples with elevated sulphide and an NP:AP ratio less than 1 came from material deeper in the Jumbo impoundment which would not have had a chance to oxidize in the time since mine closure. Figure 3 presents sulphide content vs. paste pH, and confirms that the high sulphur samples had not oxidized sufficiently to become acidic. It is worth noting that none of the samples collected had a paste pH less than pH 4. It appears that the sulphide may oxidize without causing a significant depression in paste pH. The lack of samples with intermediate sulphide content may be a sampling artefact in that samples were visually classified and selected in the field based on whether they were unoxidized (completely grey) or actively oxidizing (completely orange). Striated samples containing both grey and orange tailings were generally avoided, as they did not clearly fit either classification.

Solid phase metals testing was used to establish which elements were enriched in the tailings. An aqua regia digest was used with a standard ICP scan. Molybdenum was found to be highly enriched, exceeding 100 times normal crustal abundance in almost all samples. Copper was also generally found to be enriched, exceeding 5 times crustal abundance in most samples.

Solubility testing using the modified Leachate Extraction Procedure (using distilled water as a leachant at a 20:1 liquid to solid ratio) was performed. Oxidizing samples (with depressed paste pH) were found to have enhanced mobility of aluminium, copper and some zinc. Unoxidized samples (i.e., with neutral (>pH 6.3) paste pH) were found to have a lesser degree of mobility, while the oxidized samples exhibited no detectable release of molybdenum.

Groundwater

Monitoring of the water levels in the tailings has been underway since mid-1999. The constructed water diversion works and improved vegetation growth on the surface of the tailings were expected to lower the water table in Good Friday by about 1.5 m. The water table at Jumbo was expected to be unaffected (since the
creek passes along the surface of the tailings). Figure 4 illustrates the seasonal variability of the water inputs and the correlated piezometer readings at Good Friday. There is little evidence of a sustained drop in water levels within the Good Friday tailings as was predicted by the modelling. This is not entirely surprising since the model did not consider the degree of cementation in the oxidizing tailings. Cementation of the tailings reduces near-surface permeability to a level below that which was predicted in the pre-construction model, thus making it the limiting component in infiltration rates. Nevertheless, infiltration and subsequent seepage are predicted to vary as a function of annual precipitation. Seepage rates were estimated based on SEEP/W models; 1 L/s for Jumbo and 0.6 L/s for Good Friday. However, in June 2003, measured seepage from the west limb at Good Friday was 0.2 L/s, with some additional unquantified, minor seepage from the south limb at less than 0.1 L/s.

Groundwater monitoring at the site has established that the groundwater is near neutral pH at all sample locations, ranging from pH 6.7 to pH 8.1. The neutral pH has prevented significant quantities of copper and other heavy metals from going into solution. The maximum observed copper concentration in a sample was 0.175 mg/L but the median value from over 30 samples is just 0.008 mg/L. Molybdenum, on the other hand, is quite mobile at these neutral pH values, as was suggested by the LEP tests, with samples ranging up to nearly 5 mg/L, although most samples were less than 2 mg/L. Figure 5 illustrates the correlation between pH and Mo concentration amongst the samples collected.

Seeps

The seeps at Good Friday and Jumbo are quite different in character. The Jumbo seep samples have all been neutral and are all collected from within a few metres of each other at the toe of the dam. The Good Friday seep samples have been collected at a variety of sites along the west limb and below the south limb. As of late 2002, the seepage from the west limb is now collected into 3 monitoring points, which simplifies the sampling and flow gauging. One extremely low pH sample was collected from a seep on the west limb in June 1998, in an area now covered by the toe berm and which now drains to the Lower Weir monitoring station. This result has never been duplicated and is unlikely to be representative of a significant portion of the Good Friday seepage. Generally the Good Friday seep samples have exhibited a pH >5, with the lowest pH seepage water coming from the north end of the impoundment, below the mill site. This is possibly the area with the coarsest tailings, and which contains the tailings that have been deposited for the longest period of time. Figure 6 shows the correlation between molybdenum concentration vs. pH or selected seeps, while Figure 7 shows the correlation between copper concentration vs. pH for the same seeps. Generally, the molybdenum concentration in the seeps is significantly lower than in the groundwater wells, while the copper concentration, particularly in the seep at the north end of Good Friday, has ranged up to 2.5 mg/L.

Most of the seepage from along the toe of Good Friday reports to one of two weirs located along the mine access road. During those times of the year with no snowmelt and with little rainfall, these weirs typically
indicate only a minimal aggregate seepage baseflow (less than 0.1 L/s). In the spring of 2003 it became possible to monitor the flow at the north end of the west limb of Good Friday. Flows there have dropped from a peak of 20 L/min (0.3 L/s) (during freshet) to less than 0.1 L/s in July.

The seepage flows from Jumbo all report to the spillway stilling basin through the rockfill at the dam toe and cannot be accurately quantified. The majority of the seepage appears to report from the underdrain system. The underdrain is likely hydraulically connected to the filter layer that the design drawings show passing under the dam and that was intercepted by Well J-01-05 in June 2001. Both the well and underdrain were sampled in June 2001 and the samples had molybdenum concentrations of 0.440 mg/L and 0.177 mg/L, respectively.

**Surface Water**

Water samples taken in Little Sheep Creek indicate that the creek water quality seems to be relatively good despite the historic mining activity. Water quality is strongly influenced by dilution along the length of the creek. At the US border, the total molybdenum concentration in Little Sheep Creek has consistently met the BC guideline for livestock watering since the in-stream work at Jumbo was completed in 1999. Similarly, the total copper concentration has consistently met the aquatic life guideline. These are the most restrictive limits, respectively, for these parameters. Molybdenum concentrations now vary within a tight range between 4 and 10 µg/L at the Boundary Dairy site (at the US border). Copper has maintained a similarly tight range of between 0.5 µg/L (detection limit) and 2 µg/L at Boundary Dairy. Even within the mine site area, the molybdenum concentration in Little Sheep Creek has not exceeded the 50 µg/L limit since the majority of the water management works were completed in 2000. Figure 8 and Figure 9 illustrate the annual trend of water quality in Little Sheep Creek. The annual excursion in copper is only partly related to the dispersion of fine sediment during freshet, and will need continued monitoring.

**Mass Loading**

Mass loading calculations have been made based on seep and stream samples collected at various times, and using monthly average flow rates recorded at a gauge on nearby Big Sheep Creek. These show that the minesite drainage basin, including the tailings areas, only contributes 12% to 35% of the molybdenum mass load (from less than 5% of the total Little Sheep Creek drainage basin), while the open pit and waste dumps contribute 25% to 50% of the total from an additional 2% of the drainage basin area (i.e., 10 to 20 times more than would be expected on a pro-rated drainage basin area basis). Below the mine gate there is a further 20% to 60% increase in mass loading from areas unrelated to the mine site. The total molybdenum mass load has averaged about 0.5 kg/d over the past 5 years, with up to 2.5 kg/d during the May freshet period. Although the highest molybdenum concentrations in the LEP tests were found to be lower than the highest copper concentrations, the relative abundance of unoxidized (pH neutral) tailings to oxidizing (acidic) tailings results in a higher mass loading of molybdenum than copper to Little Sheep Creek. The minesite appears to
contribute only 10% to 15% of the copper mass load at Boundary Dairy, which is only 2 to 3 times higher than the proportion expected based on drainage basin area.

CONCLUSIONS

The Red Mountain tailings are not presently causing any significant deterioration to water quality in Little Sheep Creek. Based on the seepage modelling, there is not expected to be any significant change in tailings oxidation and subsequently metal leaching rates. Therefore, the mass loading rates are not expected to increase in the foreseeable future. Eventually the tailings will “burn out” and the mobile molybdenum and copper will have flushed from the system. Mass loadings to the environment will ultimately decrease to background levels.

Figure 1 – Site Location and Water Quality Station Location Plan
Figure 2 – Sulphide vs. NP:AP

Figure 3 – Sulphide vs. Paste pH
Figure 4 – Good Friday Water Level

Figure 5 – pH vs. Molybdenum in wells
Figure 6 – pH vs. Molybdenum in seeps

Figure 7 – pH vs. Copper in seeps
Figure 8 – Total Molybdenum in Little Sheep Creek

Figure 9 – Total Copper in Little Sheep Creek