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Reclamation and mine closure plan at Pogo Mine, Alaska

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Abstract

The Pogo gold mine is located in an undisturbed and pristine natural setting in central Alaska. The reclamation and mine closure plan needs to ensure that water quality is not unduly influenced after mining operations cease. The key components of the plan are underground mine closure and the reclamation of drystack tailings facility. The drainage from the underground should be prevented by sealing the portals properly. The seepage/runoff from drystack tailings facility will be collected at the recycle tailings pond and treated until the water quality meets the standards. The water quality of surface water and groundwater will be monitored for 40 years after mine operations cease.

1 Introduction

The Pogo gold mine is located approximately 140 km east of Fairbanks in central Alaska (Figure 1). The mine produces gold bearing ore from the underground mine at a rate of about 2,250 tonnes per day. Flotation and cyanide leach-CIP process is applied to produce gold bullion at the on-site mill plant. The mine commenced operation in 2006, and is expected to have a production life of about 11 years or more. Since the mine is located in an undisturbed and pristine natural setting, the reclamation and mine closure plan needs to ensure that water quality is not unduly influenced after mining operations cease. The key components of the plan include underground mine closure and reclamation of Drystack Tailings Facility (DSTF).

Figure 1 Location map

2 Project descriptions

2.1 Historical background

The Pogo deposit was discovered in 1994 by the exploration carried out by WGM and financed by Sumitomo Metal Mining Co., Ltd. (SMM) and other companies that later withdrew. Teck Corporation (now known as Teck Resources Ltd.) acquired a 40% interest in the Pogo Claims from SMM in 1997, and assumed operatorship. The permit application was filed in early 2002 following the completion of environmental baseline studies, and the construction began in 2004, with the first gold poured in February 2006. Teck sold its 40% interest to SMM and Sumitomo Corporation (SC) in July 2009, and SMM became the operator of Pogo Mine. Currently, SMM owns 85% interest, and SC owns 15%.

2.2 Site infrastructure

A 77 km long all-season road was constructed from the Richardson Highway to the Pogo Mine. Power is supplied via a 79 km long, 13.8 kilo volt, three phase transmission line constructed along the access road.

Figure 2 shows the overall site plan. Major facilities were constructed at the Liese Creek Valley area, which includes mill plant, administration offices, main camp, and maintenance workshop. Two portals were also excavated at this area. The DSTF and recycle tailings pond (RTP) were constructed upstream of Liese Creek valley. The total disturbance of the mine site is about 133 ha, of which 31% of the area met the regulatory definition of a wetland.

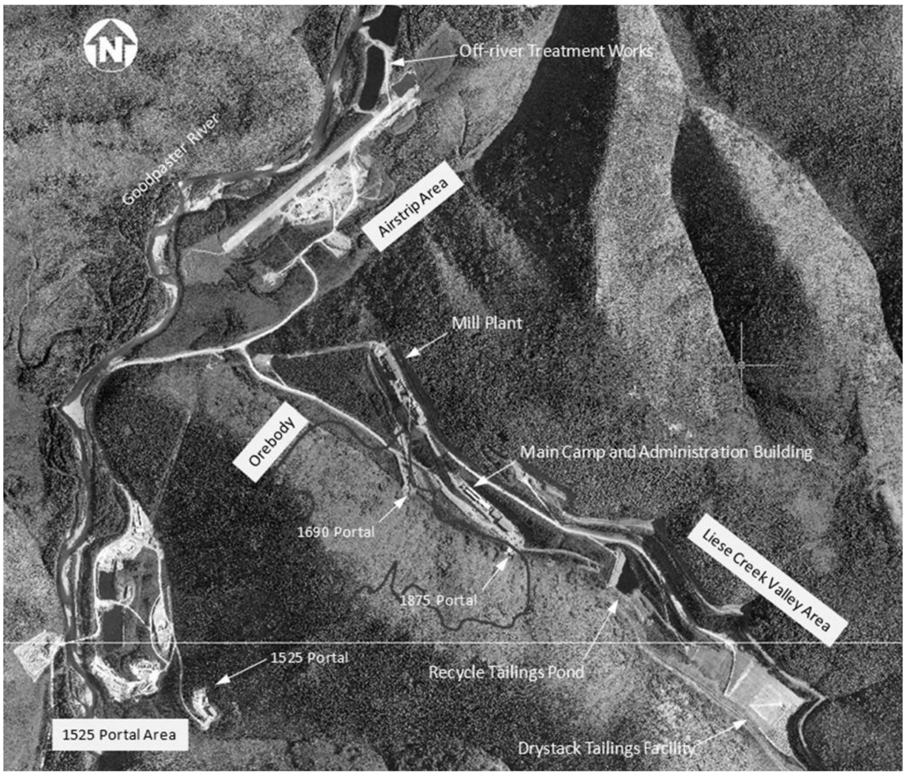

Figure 2 Overall site plan

2.3 Geology and ore resources

The gold resource within the Pogo Upland Mining Lease includes sub-parallel quartz veins (Liese veins) hosted in a sequence of amphibolite-grade, paragneiss and orthogneiss of probable Proterozoic to mid-Paleozoic age. Mid-Cretaceous, granitic, plutons and dikes intrude the gneisses, which in turn are generally cut by the veins. A post-vein, diorite pluton has been age dated at 94 Ma age, constraining the minimum age of the deposit.

The Liese veins are shallow dipping quartz veins which have an average thickness of 4 m and dips at approximately 30 degree. As of year-end 2010, proven and probable reserves stood at 5.1 million tonnes (Mt) of 14.1 grams per tonne (g/t). The geologic resource, outside the reserve, stood at 5.0 Mt of 9.9 g/t.

2.4 Ecological settings

The Pogo Mine is located near the Goodpaster River in the Tanana Uplands, an area of rolling hills and mountains on the north side of the Alaska Range in Interior Alaska. The Goodpaster River is a major north side tributary to the Tanana River in the Yukon drainage basin. Elevations range from approximately 400 m above mean sea level (amsl) along the alluvial floodplain to over 1,200 m amsl along the ridge tops.

The climate in the Pogo project area is similar to other areas of interior Alaska. Winter temperatures range from -40°C to 0°C. Summer temperatures range from 5°C to 30°C. The predicted mean annual precipitation ranges from 300 mm to 480 mm with approximately 38% occurring as snowfall.

The Goodpaster River supports anadramous salmon as well as resident Arctic grayling, round whitefish, northern pike and burbot and is listed in the "Catalog of Waters Important for Spawning, Rearing or Migration of Anadromous Fishes" issued by Alaska Department of Fish and Game in 1998.

2.5 Mining

Figure 3 shows the 3-D view of Liese veins with underground structure. Three portals are used to access to the "Liese" veins which are located 150 to 300 m below the surface. The 1875 portal and the 1525 portal are used for the access for workers, supplies, equipment and provide intake ventilation. The 1690 portal is used primarily for conveyor access and for exhaust ventilation.

Underground development consists primarily of lateral and ramp development. The orebodies are accessed via a series of ramps and stope access drifts. The ramps driven at a 15% grade are located a minimum of 15 m from the footwall of the orebody. Stope access drifts are developed from the ramps at vertical intervals of 15 m and driven perpendicular to both the ramp and the strike of the stope.

Cut-and-fill is the primary mining method used at Pogo. This method is selective and yields a high overall ore recovery at a low dilution factor, as mining conforms to the shape of the deposit. After the stopes are mined, cemented paste backfill is used to fill all mining voids.

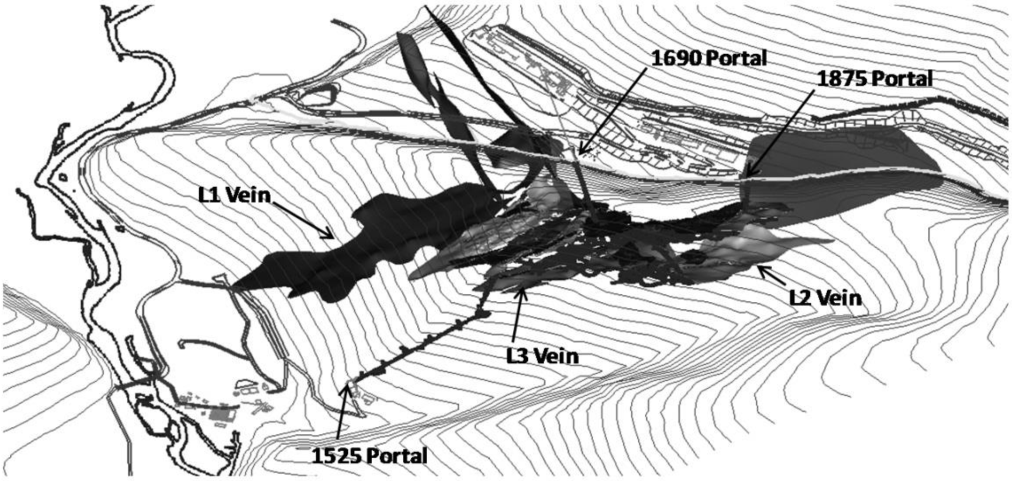

Figure 3 Liese veins with underground structures

2.6 Processing

Figure 4 provides the process flow sheet for Pogo. Gold is recovered from the mined ore using a milling method consisting of:

1. Grinding the ore to a fine particle size to liberate the gold contained in the ore.
2. Recovering a portion of the gold using gravity methods.
3. Floating the remaining gold and sulphide minerals using froth flotation.
4. Recovering the gold from the flotation concentrate using cyanide leach.

The use of gravity recovery and flotation allows for the downsizing of cyanide leach, cyanide detoxification, and carbon recovery. Reducing the size of the cyanide leach circuit in turn reduces the amount of cyanide required for ore processing. The gravity process recovers less than 1% by weight of the mill feed with up to 40% of the recovered gold.

The flotation process recovers the gold not collected in the gravity circuit and generates a sulphide rich concentrate representing about 10% by weight of the mill feed. The flotation concentrate is leached in a conventional cyanide leach circuit where the remaining gold is extracted. All aspects of the cyanide leach circuits are designed to prevent contact between slurry and the external environment. Following leaching, the cyanide slurry is detoxified and placed underground as paste backfill. Weak Acid Dissociable (WAD) cyanide residue in the detoxified cyanide leach tailings is controlled not to exceed 1 mg/kg.

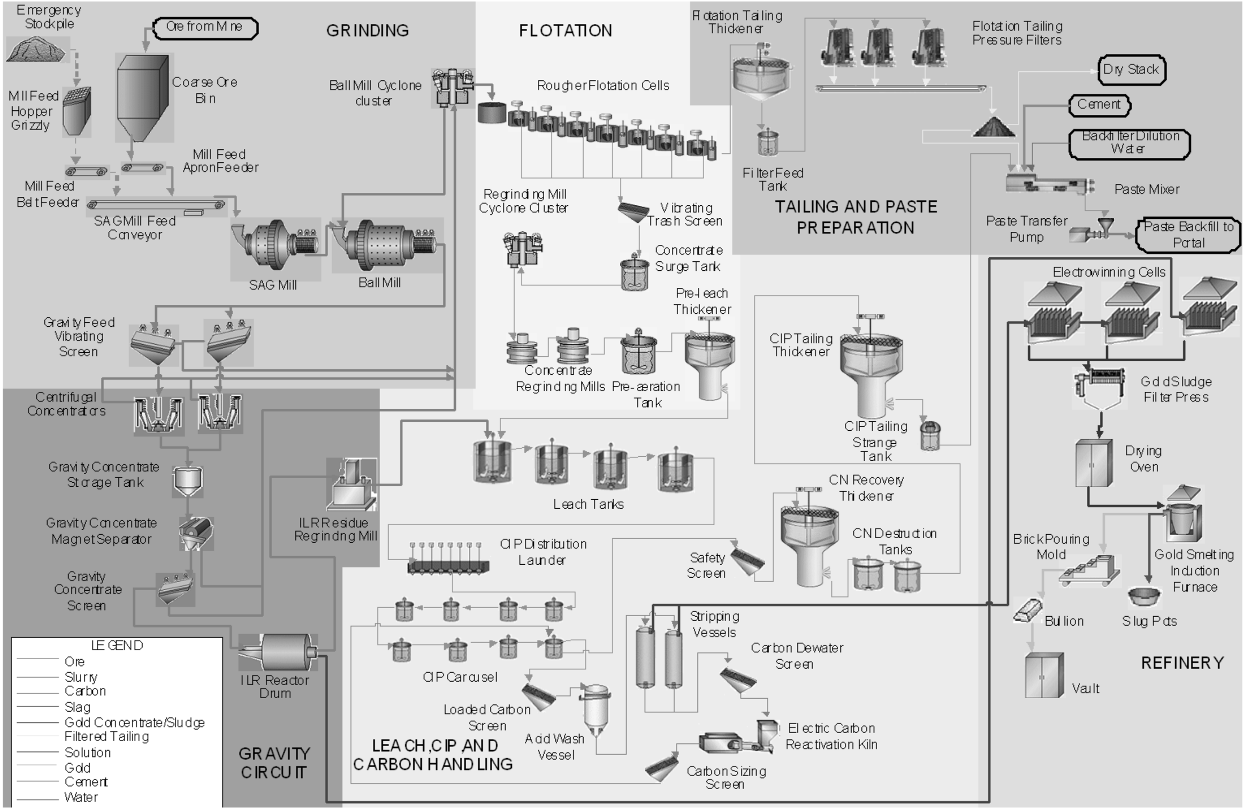

Figure 4 Process flow

2.7 Tailings and waste rock management

The Pogo mill produces two types of tailings: 1) Tailings from the flotation circuit; and 2) Tailings from the cyanide leach circuit. Flotation tailings comprise approximately 90% of the total tailings mass. Flotation tailings are dewatered by pressure filtration and about 67% of them are placed in the DSTF. The remaining flotation tailings are mixed with the detoxified tailings from cyanide leach circuit and cement producing “cemented paste backfill” and placed in the mined-out stope for ground support.

Dewatered flotation tailings (called “drystack”) and mine waste rocks are placed in the DSTF (Figure 5). The drystack are compacted to achieve 90% of Standard Proctor maximum dry density. Mine waste rock is segregated by individual blasted rounds based on the assay of grab samples. If the material is above either 0.5% sulphur or 600 mg/kg arsenic, the blasted waste rock is classified as “mineralised”, which accounts for about 30% of waste rock. Mineralised rock is encapsulated in the drystack to prevent the generation of acid rock drainage. The capacity of current DSTF is about 6.8 Mt, and will be expanded to 18 Mt.

A flow-through drain was constructed in the existing stream valleys to augment the existing drainage course and allow runoff to flow under the stack. The RTP collects seepage/runoff from the DSTF so that it can be treated before discharge. The RTP has a maximum storage capacity of 165,000 m^3.

2.8 Water management

The mine drainage and the RTP water are treated and recycled at the mill or treated and discharged to the Goodpaster River via the Off-River Treatment Works (ORTW) which mixes treated water with river water before discharging to the river in order to balance parameters like temperature and pH. To minimise the discharge of mine drainage, a filtering station was constructed adjacent to the main underground sump. The sump water is filtered and recycled for drilling water as needed.

There are two water treatment plants on site. Their primary purpose is to treat naturally occurring arsenic in the groundwater. One of the plants is used to treat the underground drainage which contains low level WAD cyanide attributed to the paste backfill, and the treated water is recycled at the mill plant.

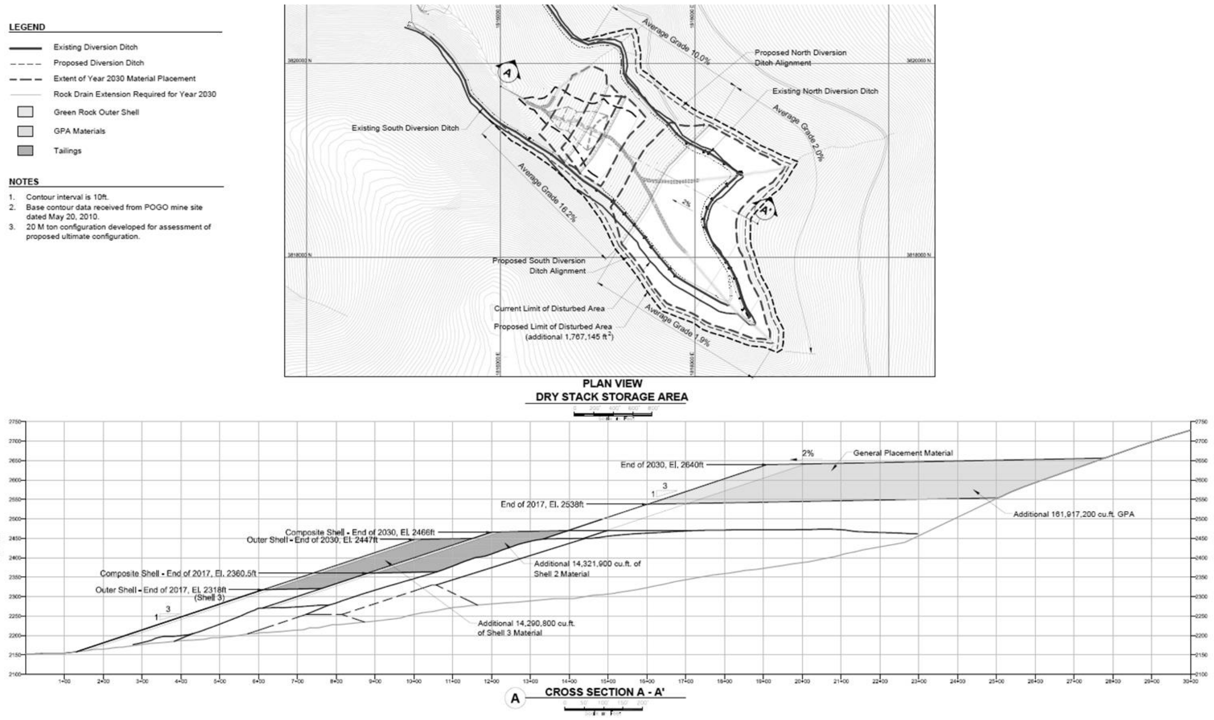

Figure 5 18 Mt Drystack tailings facility

3 Reclamation and mine closure plan

3.1 Reclamations and mine closure prescriptions

The reclamation plan is divided into five phases (Phase I–V) based on the design, construction, operation, and closure activities of the mine. Figure 6 summarises the reclamation schedule.

3.1.1 Phase I Reclamation of construction disturbance

Reclamation of the temporary facilities used for exploration and construction. So far, the temporary airstrip and exploration camp have been demolished or reclaimed.

3.1.2 Phase II Reclamation with concurrent mining

During construction, the growth media, which consists of a combination of organic material, topsoil, and overburden, was stripped and stockpiled. Approximately 190,000 m^3 of growth media was salvaged and stored. It is enough to reclaim the overall disturbance assuming a 15 cm lift of growth media is applied to enhance revegetation efforts.

Vegetation test trials and assessments of reclamation technique such as engineered soil cover and hydraulic plugs will be conducted during this phase.

3.1.3 Phase III Final reclamation of mine site

Phase III will consist of the major closure activities required to decommission the mine, removal of all facilities and structures not needed to support Phase IV activities from the property, and placing the site in a stable condition. The facilities removed include mill facilities, main camp, office, and shop. The disturbed area will be re-contoured and covered with growth media, and seeded as necessary. The alluvial gravel material sites located in the Goodpaster River flood plain will be reclaimed to establish wetland habitat with suitable features for waterfowls and shorebirds. The mined-out stopes in underground will be paste filled and concrete plugs installed in all mine portals. An engineered soil cover will be installed on the surface of drystack tailings facilities.

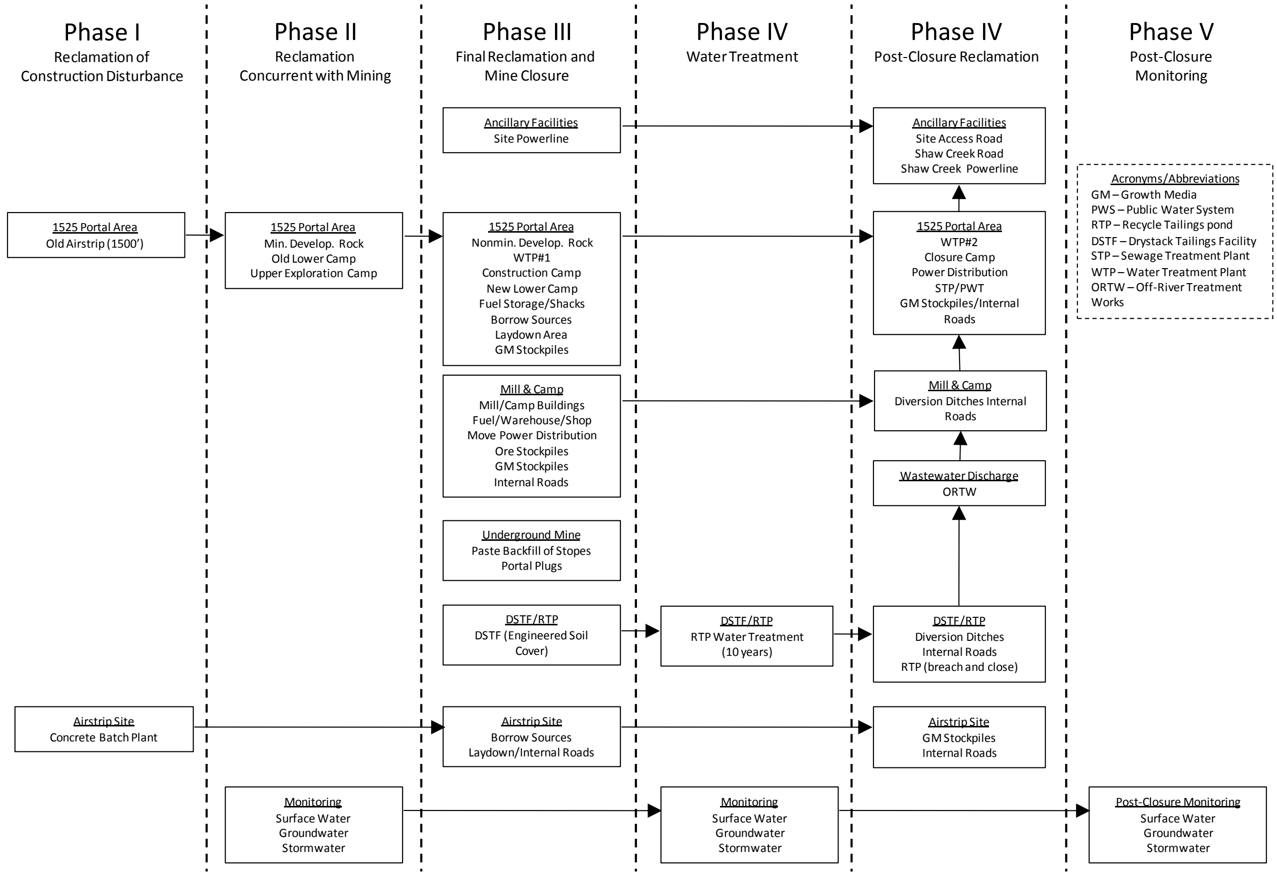

Figure 6 Pogo mine reclamation schedule

3.1.4 *Phase IV Water treatment and post-closure reclamation*

After completion of Phase III activities, the RTP water will be treated and discharged until it meets the water quality standards. It is anticipated that the Phase IV water treatment will last 10 years. When appropriate, the RTP dam will be breached. Then the remaining facilities such as water treatment plant and 700 m airstrip can be demolished and all remaining disturbed area reclaimed. The ORTW will be reclaimed into a wetland. The private portion of Pogo access road (41 km) and the entire portion of transmission line will also be reclaimed.

3.1.5 *Phase V Post-closure monitoring*

The water quality of surface water and groundwater will be monitored at the designated locations in 1, 2, 5, 10, 15, 20, and 30 years after the completion of Phase IV post-closure reclamation.

3.2 Underground mine closure plan

In general, the closure plan for the underground mine involves removing salvageable equipment, backfilling of open stopes and some access drifts, installing cement plugs in all mine openings, and re-flooding.

3.2.1 Hydrogeology of mining area

The groundwater table in the project area is a subdued replica of the topography with the water table at a higher elevation beneath the ridge than beneath the valley. Recharge of the groundwater system occurs predominantly in the upland areas. Regional discharge is to the Goodpaster River valley. The pre-mining water table beneath the ridge is deep and up to approximately 150 m below the ground surface.

The orebodies are underlain by low permeable bedrock consisting predominantly of igneous and metamorphosed sedimentary rocks. The major northwest striking faults such as Liese Creek and Graphite faults act as conduits for groundwater. The quartz veins have significantly higher permeability than the host rocks and act as a collector for water and deliver water to the open stopes. The seepage rate into the underground mining area is currently about 1 m^3/min, and is expected to increase to 2 m^3/min with the advance of underground mine development.

3.2.2 Underground mine closure

All mined-out stopes will be backfilled completely with cemented paste backfill before mine closure. The relatively impervious nature of the paste backfill will seal mineralised areas of the wall rock and prevent oxidation and subsequent leaching. Select areas of the connecting access declines and ramps will also be backfilled to compartmentalise the hydrogeology and to reduce the potential for water flow through the mine.

3.2.3 Portal plugs

All portals will be sealed using hydraulic concrete plugs (Figure 7) to prevent mine drainage from being released from the openings and to re-establish groundwater conditions similar to the pre-mining conditions. The plugs will be located in competent ground to resist the pressure head developed between natural groundwater and the plug elevation. Type II Portland cement mixed with type F fly ash will be used for the plugs to ensure low shrinkage and good sulphate resistance. A grout curtain will minimise seepage across the plugs. Preliminary design of the plugs was carried out according to Lang's “Permanent Sealing of Tunnels to Retain Tailings or Acid Rock Drainage” (1999). The plug design will consider static and dynamic failure mode, seepage rates for each plug, and the feasibility of long-term monitoring. The water head on the plugs is estimated to be up to 145 m based on the both piezometer data and by modelling the pre-development heads.

After the 1525 and 1690 portals are sealed, the mine workings will be flooded through the 1875 portal to accelerate groundwater level recovery towards pre-operational levels. The 1875 portal will then be sealed and the remainder of the mine flooded through a surface borehole. The purpose of re-flooding is to confirm if there is any seepage from the portals, however, further study is necessary to determine details and methodology.

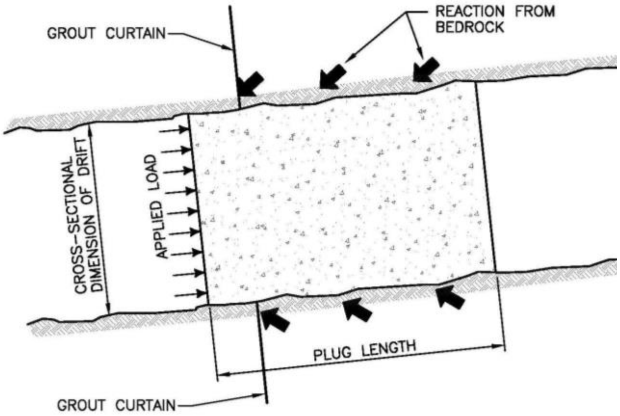

Figure 7 Conceptual design of portal concrete plug

3.2.4 Groundwater monitoring

After mine closure, the groundwater will flow through the backfill materials and ultimately emerge in the alluvium of the Goodpaster River. The concentrations of dissolved species may temporarily increase in bedrock groundwater down gradient of the mine. Post-closure groundwater chemistry was quantified by modelled integration of groundwater hydrology information and the chemical characteristics of the orebody, host rock and backfill. The model predicted a slight increase in concentrations of major ion species and metals in the alluvium and surface water of the Goodpaster River.

To monitor potential effects of groundwater into Goodpaster River, the groundwater monitoring wells installed down gradient from the underground workings will be sampled throughout Phases II, III, and IV. So far, no adverse effect has been observed at these monitoring wells.

3.3 Reclamation of drystack tailings facility and recycle tailings pond

The long-term reclamation goal for the DSTF is to establish an alpine grass meadow. The closure concept includes creating a final configuration that limits erosion potential; diverts runoff water from upstream in the watershed around the drystack in permanent ditches; and provides an engineered cover that includes erosion resistant armour over the entire drystack with growth media to enhance revegetation.

3.3.1 Structural stability of the drystack tailings facility

The structural stability of the DSTF was analysed using the limit equilibrium program SLOPE/W under the static and pseudo-static conditions. This analysis considered four failure modes and three phreatic surfaces in the ultimate design of DSTF shown in Figure 5. The peak ground acceleration (PGA) of 0.2 g, which would have a return period of 2,475 years at the mine site based on the seismic hazard mapping completed by the USGS, was selected as the Maximum Design Earthquake (MDE), and the reduced PGA by 50% was applied for pseudo-static analysis.

The physical and strength properties of the materials were reviewed carefully based on the in situ measurements and laboratory test results. Sensitivity analysis using reduced strength parameters by 20% was also conducted.

The allowable minimum factor of safety (FoS) was set at 1.5 and 1.1 under the static and pseudo-static conditions, respectively. For all cases analysed, the calculated FoS exceeded the minimum FoS specified as design criteria, but it also suggested that the phreatic surface developed in the DSTF would reduce the FoS.

3.3.2 Engineered soil cover

The engineered soil cover will consist of 30 cm of non-mineralised development rock applied over the surface of the crowned drystack facility, followed by a 15 cm sand and gravel layer to provide support for an additional 15 cm of growth media (Figure 8). A soil cover is proposed due to the relatively modest annual rainfall at the site, the low hydraulic conductivity of the compacted drystack tailings (about 1.0×10^{-7} m/s), and the lack of acid generating potential because of the encapsulation of the mineralised rock in the drystack tailings.

During mine operations, a field trial programme will be undertaken to evaluate the optimum cover depths. Performance will be evaluated over a three-year period. Variables to be assessed during the field tests include various depths of engineered soil cover material, topsoil, vegetation type, soil amendments.

3.3.3 Runoff control

Runoff control for the general placement area surface of the drystack facility will include crowning with a two percent slope to the closure perimeter ditches. The surface of the slope of DSTF will be constructed with non-mineralised rock to prevent the erosion of drystack tailings. The closure perimeter ditches will be constructed as wide ditches with flat side slopes. This configuration has a significantly higher flow capacity than the maximum probable precipitation catchment potential. This design will allow for significant ice development and still maintain requisite freshet capacity. Riprap protection will be provided to prevent erosion on both sides of the ditch adjacent to the slope.

3.3.4 Recycle tailings pond dam

When appropriate, the RTP dam will be breached. Slopes will be trimmed to a maximum of 2:1 side slopes on the dam, and a 15 m wide floodplain will be re-established. Disturbed areas will be re-contoured for drainage and the channel re-establishment for Liese Creek. Foot slopes and the former impoundment area will be covered with growth media and seeded and fertilised as necessary. Micro-wetlands sites will be established where possible. Steeper side slopes will be armoured as necessary and shaped to blend with the natural talus slopes of the Liese Creek valley.

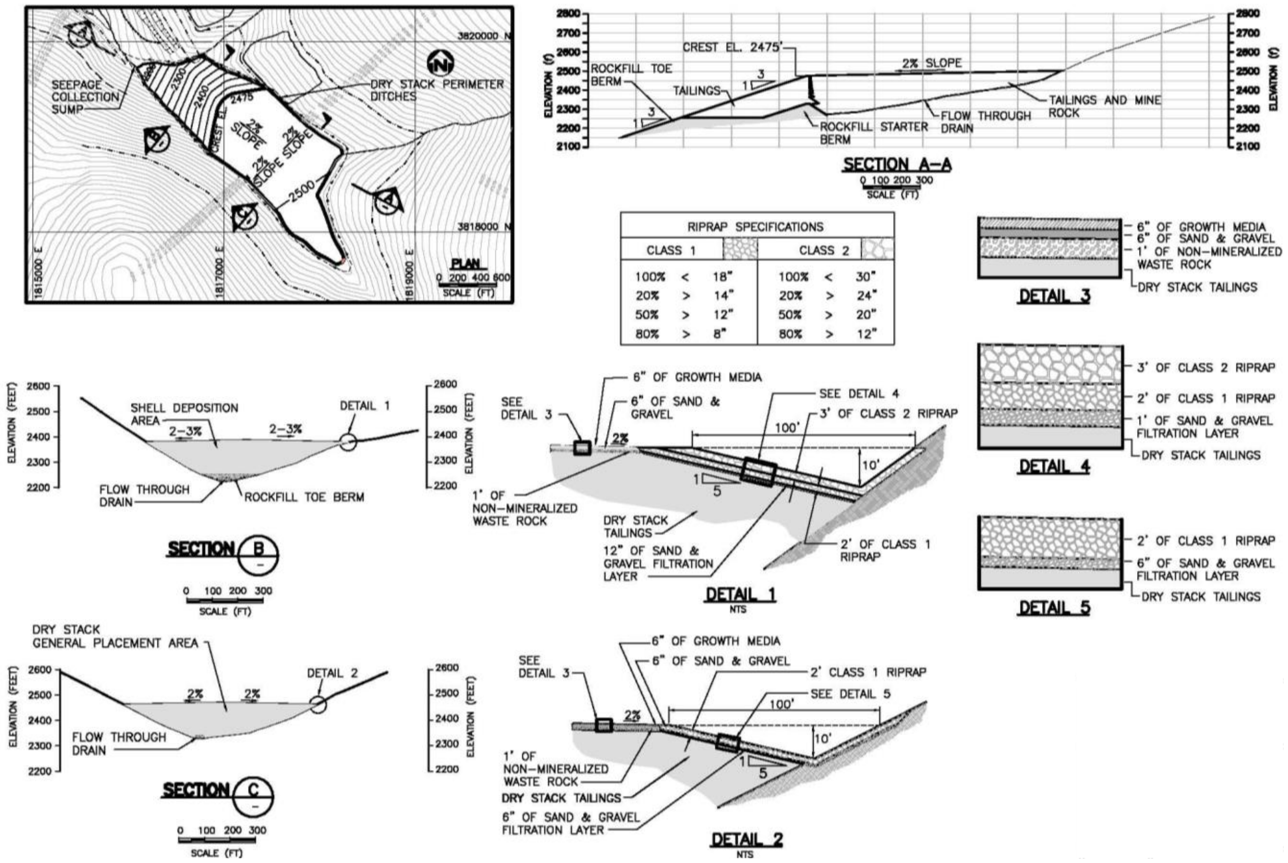

Figure 8 Conceptual design of reclamation at drystack tailings facility

3.3.5 Closure water management

The water quality of seepage/runoff water from the DSTF was predicted based on the information obtained from the humidity cell and column test works. Since the mineralised rock is encapsulated in the drystack tailings, the water quality model input was selected such that the mineralised rock would not be considered a source of degraded water quality. The anticipated seepage flow from drystack tailings is expected to be very low because of their low moisture content (approximately 15% after filtration), and it would diminish as the DSTF is capped and reclaimed. The load released by drystack tailings in contact with runoff was estimated by assuming that annual release from a reactive skin (set at 1 cm) is contained in the total runoff including snowmelt in spring.

Samples of runoff water from the DSTF are taken periodically at the end point of flow-through drain. The water quality data show some degradation; however, the concentration is much lower than predicted, and fall below the water quality standard except for arsenic. Table 1 compares the predicted water quality with measured in 2010. To enhance the monitoring of seepage/runoff from the DSTF, two monitoring wells will be installed at the downstream of DSTF to monitor the water quality of groundwater near surface.

One of the potential closure water management issues at the DSTF is if the flow-through drain plugs. This would potentially cause the rise of phreatic surface in the DSTF and could lead to further discharge of materials from the drystack tailings. To further assess DSTF closure issues, additional hydrological and geochemical studies are planned, which will include installation of piezometers with thermisters and/or geophysical survey at the DSTF, and kinetic tests using waste rocks and flotation tailings.

Table 1 Predicted and measured water quality of runoff water from drystack tailings facility

Parameter	Unit	Predicted Worst Case	Measured in 2010
TDS	mg/L	523	200–400
Cl	mg/L	164	1–4
SO_4	mg/L	302	50–90
TKN	mg/L	0.5	0.2–0.7
As	µg/L	400	13–22
Cd	µg/L	0.4	<0.1
Cr	µg/L	1.1	0.33–0.55
Cu	µg/L	3	0.8–2.1
Fe	µg/L	0.3	<10
Pb	µg/L	0.4	<0.1
Hg	µg/L	0.2	n/a
Mn	µg/L	380	10–40
Ni	µg/L	20	2–4
Se	µg/L	6	0.4–1
Ag	µg/L	0.2	<0.1
Zn	µg/L	60	0.3–1.6

Note: Concentrations are dissolved metal.

4 Conclusions

It is necessary to establish reliable reclamation and closure schemes for the underground mine and DSTF at Pogo. The current plan is conceptual. Detailed engineering studies with long-term field trials should be promoted systematically during the mine operation.

Another key issue on the mine closure is the prediction of water quality of the seepage/runoff from the DSTF and underground mine. Hydrological/geochemical studies and modelling studies will be conducted in the future using the water quality data collected during operation.

It is also important to have an environmental specialist on staff at the mine, who is responsible for keeping up on state-of-art technologies on the reclamation and managing the test plots.

Acknowledgements

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