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Chief Inspector and Executive Director, Health & Safety

British Columbia Ministry of Energy and Mines
Health and Safety and Permitting Branch
PO Box 9320 Stn Prov Govt
Victoria, BC
V8W 9N3

Re: Understanding of foundation conditions, water balance adequacy and filter adequacy at the closed Snip tailings impoundment in northwest BC

Dear Mr. Hoffman:

In response to the instructions of your memorandum dated 03 February 2015 to our Mr. Robbin Harmati, BC Properties Closure Manager for Barrick Gold Corporation (Barrick), I have reviewed the available information regarding the foundation conditions, the water balance and the filter adequacy (specifically, the internal zoning) of the constructed earthfill embankment of the tailings impoundment at the closed Snip mine site. This letter has been prepared and submitted to the BC Ministry of Energy and Mines (MEM) to summarize the results of my review findings, following the item numbering system provided in your memorandum of 03 February.

Snip Mine and Tailings Impoundment Background

The closed Snip mine site is located in the Iskut River basin of the North Coast Mountains of BC, some 320 km northwest of Smithers and about 80 km northeast of Wrangell, Alaska. Gold-bearing ore from underground mining operations at Snip was milled at just over 500 tonnes per day from January 1991 until June 1999, when site closure operations commenced; active closure work concluded in October 1999. Cominco Ltd. operated the mine from startup until mid-1996 when Homestake Canada Inc. (Homestake) took over. Homestake shareholders voted in December 2001 to merge with Barrick, and in 2003, the merged company adopted the Barrick name. The Snip Mine was a fly-in, fly-out operation that utilized the nearby Bronson Creek airstrip; equipment, materials and concentrate to and from site was transported by air and, during the initial years of the mine's operating life, via hovercraft on the Iskut River. In its current closure condition, the only access to the Snip site is by helicopter. Mine closure personnel at Barrick's nearby (30 minute helicopter trip) Eskay Creek site conduct inspections of the Snip site, including the closed tailings storage facility (TSF) at least quarterly and typically about every two months.

During operation, tailings from the mining and milling process were discharged to the Snip TSF which was developed in a narrow, steep-sided mountain valley at the drainage divide between Upper Monsoon Creek to the northeast and Sky Creek to the southwest. Upper Monsoon Creek drains into Monsoon Lake, which feeds Lower Monsoon Creek which in turn discharges into the Iskut River; Sky Creek drains into the Craig River, which then joins the Iskut River further downstream. Figure 1, attached to this letter, shows the location of the Snip site and the general layout of the closed TSF.

The tailings impoundment was formed by development of Dyke 1 to the southwest and Dyke 3 to the northeast. An intermediary Dyke 2 was constructed during initial stages of the operation to assist tailings deposition and water management in the TSF, but was abandoned in later operation of the facility. Construction of the starter embankments and other ancillary structures was completed from June to September 1990. An overflow spillway for the tailings impoundment was initially developed in the right (east) abutment of Dyke 3; towards the end of operation and for closure, an overflow spillway for the TSF was cut into the right (west) bedrock abutment of Dyke 1. Toe berms were constructed downstream of Dyke 1 and Dyke 3. During the eight and a half year operating life of the Snip TSF, the Dyke 1 crest was raised five times, from its initial elevation of 140.0 masl to its final elevation of 145.0 masl, initially by upstream and then centreline construction methodology. In its final (closed) configuration, Dyke 1 has a crest length of about 175 m and a maximum height of around 10 m. Dyke 3 was raised four times, first via upstream construction and thereafter using centerline and finally downstream construction techniques, from its initial crest elevation of 140.0 masl to a final elevation of 145.0 masl. Dyke 3 has a crest length of about 155 m and maximum section height of around 20 m.

As documented in the design and as-built construction reports prepared by Klohn Leonoff Consulting Engineers, foundation conditions for Dyke 1 and Dyke 3 were similar and comprised up to approximately 40 m of valley-bottom sediments, specifically alluvial and floodplain deposits overlying coarser glacial outwash materials and till, underlain by feldspathic wacke bedrock (Klohn Leonoff, 1988; 1989; 1990). Abutment conditions comprised as much as 10 m of colluvial deposits, generally silt-sand with gravel, overlying bedrock. The geotechnical site investigation to support the Snip TSF design and starter facility construction included 28 test pits, 8 boreholes with standard penetration test (SPT) work and in situ permeability tests, 19 dynamic cone penetration test (DCPT) soundings, 6 seismic refraction survey lines, 4 electrical soundings, 29 piezometer installations (standpipe and pneumatic tips) and 2 inclinometer installations. Laboratory work included index property, consolidation, permeability, and static and dynamic direct shear tests.

Table 1 summarizes the inferred valley-bottom foundation conditions in more detail.

Table 1. Snip TSF Dyke 1 and Dyke 3 Foundation Conditions (from Klohn Leonoff, 1988)

Depth (m)	Unit	Description	Inferred Geologic Process
0 – 15	Silt, Sand and Gravel	Highly variable, interlayered sequences of silts, sands and fine gravels; generally finer with depth although granular layers occur throughout; loose to medium dense	Alluvial and floodplain environments, possibly more dynamic than in past
15 – 28	Silt	Fine sandy silt grading to low plasticity clayey silt with some fine sand layers; soft to firm	Post-glacial alluvial to backwater floodplain environment, potentially caused by periodic damming of the valley by colluvial slide debris
28 – 40	Sand-Gravel and Till	Fine sand grading to sand and gravel generally overlying very dense silt-sand-gravel till with some clay; till contains gravelly zones	Glacial deposit (till) followed by some glacial outwash (sand-gravel)
> 40	Bedrock	Very competent feldspathic wacke	Early Jurassic sedimentary and volcanoclastic sedimentary

The Dyke 1 embankment design comprised an upstream, wide low-permeability core of processed sand and silt soil keyed into the foundation soils and supported by a downstream sand and gravel fill. Phreatic surface control in the downstream shell was provided by construction of a mine waste rock blanket drain with internal finger drains built using oversize material from concrete aggregate production at site. Mine waste rock was also used as foundation support on the tailings for the upstream and centerline crest raises. Upstream and downstream slopes for the embankment (not including the closure buttress) were completed to 1.5H:1V (horizontal:vertical) and 3H:1V, respectively. The Dyke 3 embankment design was similar to that of Dyke 1, but with its thinner low-permeability core inclined on a greater width of downstream sand and gravel. A mine waste rock blanket drain with internal, oversize material finger drains was also provided in the Dyke 3 downstream shell, and a buttress built for closure.

Foundation preparation for Dyke 1 and Dyke 3 included dynamic compaction over the design final footprint area (excluding the closure buttresses). The work, completed during July and August 1990, was carried out with a 10-ton mass dropped 20 m from a 50-ton crane. Mine waste rock was used to build the dynamic compaction pads, and the dynamic compaction work was carried out on three (Dyke 1 footprint) and two (Dyke 3 footprint) phases of offset, 6 m grids of 8 to 17 drops per point. Results were monitored using pneumatic piezometers and pre and post-compaction SPT and DCPT soundings. Details of the construction activities, including the results of the dynamic compaction work for the Dyke 1 and Dyke 3 starter embankment footprints, are provided in the as-built report (Klohn Leonoff, 1990). The supporting studies for development of the Snip TSF are described in the original design report (Klohn Leonoff, 1988) and a design addendum (Klohn Leonoff, 1989).

The report references cited above include detailed descriptions of the foundation conditions, embankment fills and tailings materials as encountered in the site investigation work and characterized by laboratory testing. Paper copies of these documents as well as the annual operating review reports and the post-closure dam safety inspection and dam safety review reports are kept in Barrick's off-site archive in Salt Lake City, and can be made available at your request.

Geotechnical monitoring of the Snip TSF during its operating life included the regular collection of piezometer, inclinometer and survey hub data. According to the annual operating review reports, the foundation pneumatic piezometer readings generally indicated a slight upward gradient at Dyke 1 and downward gradient conditions at Dyke 3. The embankment pneumatic and standpipe piezometer data indicated that the downstream drainage elements functioned as intended. Minor lateral deformations were inferred from the inclinometer data, while those instruments remained in service (they were eventually destroyed during crest raise construction campaigns). A transverse crack reported in Dyke 1 during its early stages of operation was repaired and additional monitoring in the area was established. In June 1997, visible seepage and a soft, saturated zone were reported over a localized area of the downstream face of Dyke 1. The remediation work included installation of geotextile filter cloth over the entire downstream face followed by placement of a 3.5 m wide layer of silty sand and gravel. Over the facility's eight year operating period, survey hub readings indicated a greater amount of surface settlement at Dyke 1 than at Dyke 3; however, the total amount and rates of deformation for both structures were reported to be acceptable.

Closure Design, Conditions and Monitoring

Geotechnical considerations for the closure design of the Snip TSF were discussed by Klohn-Crippen Consultants Ltd. (Klohn-Crippen, 1999), with particular attention to tailings cover design, spillway design and embankment stability. Both wet (water pond) and dry (soil cover) closure cover options were considered, and the potential liquefaction under earthquake loading of the loose silt, sand and gravel and weak silt foundation materials was recognized as the controlling factor for closure design geotechnical stability. The design seismic loading for closure as recommended to Snip by the BC MEM in a letter dated 23 April 1999 was the M 7.0 earthquake having 0.12g peak horizontal ground acceleration on firm ground, associated with the 1:1,000 year event. Associated, potential modifications to Dykes 1 and 3 included flattening the downstream slopes and building toe berms (buttresses); the latter option was selected and buttresses constructed using nearby borrow soil were completed as part of the Snip TSF closure work. The closure cover placed on most of the tailings surface between June and October 1999 comprised about 0.6 m of borrow soil. The only portion of the impoundment not capped was the remnant decant pond located in the southwest corner of the TSF.

As indicated above, Eskay Creek Mine closure personnel inspect the Snip TSF and perform routine maintenance, including brush removal and spillway clearing. The field personnel also collect data and water samples from the TSF closure spillway and underground mine portal weirs, as required to fulfill BC Ministry of Environment (MoE) Effluent Permit PE-9079. As well, Barrick continues to receive data and summary reports from long-term humidity cell testing of samples of the Snip tailings; the cells, which are maintained at the Vizon Scitech laboratory in Burnaby, BC, have been in operation since 1998. Knight Piésold Consulting Ltd. (Knight

Piésold) has conducted and reported on its dam safety inspections for the Snip TSF in 2001, 2002 and 2014, as well as its dam safety reviews for the facility in 2003, 2010 and 2013. I have visited the Snip TSF site twice, in August 2011 and October 2014.

In late 2014, Barrick submitted to the BC MEM the most recent dam safety inspection report (Knight Piésold, 2014) and an independent review of the dam safety inspection report by Golder Associates Ltd. (Golder, 2014) for the Snip TSF, in fulfillment of your Order of 18 August 2014. A Dam Classification of Significant was assigned to the Snip TSF, following the scheme summarized in Table 2-1 of the 2013 Dam Safety Guidelines of the Canadian Dam Association (CDA, 2013).

<u>Understanding of TSF Dam Risk Items in 03 February 2015 Memorandum</u>

1. Undrained shear failure of silt and clay foundations

   According to the Independent Expert Engineering Investigation and Review Panel, failure of the Mount Polley TSF was attributed to the failure to identify a continuous glaciolacustrine silt layer underlying the Perimeter Embankment and recognize that the material was susceptible to undrained failure in a normally consolidated state under the loading associated with the increasing height of the TSF (Province of British Columbia, 2015). A review of the geotechnical reports pertaining to the Snip TSF resulted in the following conclusions:

   a. Strata of loose silt, sand and gravel and underlying weak, lacustrine silt were identified within the foundations of the Dyke 1 and Dyke 3 tailings dams at Snip during pre-development site investigations. Within the dam footprints, the upper silt, sand and gravel materials were densified by dynamic compaction to a depth of about 7 m. Below the effective depths for ground treatment, strength parameters estimated using the results of in situ testing were used for geotechnical design.

   b. Sufficient site investigations have been completed to have confidence in this assessment.

   c. The embankments' designs accounted appropriately for their respective, inferred foundation conditions. In situ testing was conducted before and after the ground treatment (dynamic compaction) work to develop corresponding strength parameters for geotechnical stability analyses, including estimates of post-liquefaction (residual) strength for the foundation materials identified as being susceptible to liquefaction.

   d. No new subsurface investigation work is currently planned to further assess embankment foundation conditions.

   Final earthworks at the Snip TSF, including downstream buttress construction and tailings closure cover placement, was completed in October 1999 and there has been no new loading imposed on the embankments or foundation materials for over fifteen years. Periodic visits to review site conditions, including for dam safety inspections, have not reported indications of slope instabilities or other embankment deformations. Although no new in situ testing of the foundation soils has been conducted since that done in 1990 to verify the ground improvement program, ongoing consolidation associated with loads imposed by the tailings impoundment, embankments and closure buttresses would continue to improve soil strengths.

2. Water balance adequacy

   Under current conditions, water is impounded in the south and central portions of the Snip TSF (i.e. against Dyke 1), to within about 200 m of the Dyke 3 crest. This water is understood to be predominantly the result of runoff and direct precipitation reporting to the TSF, with a minor contribution (discussed below) from the former underground mine works. The water impounded in the Snip TSF is released year-round via the overflow spillway in the right bedrock abutment of Dyke 1. No detailed water balance model has been developed or maintained for the TSF closure condition.

   a. Currently, a roughly-estimated 90,000 m^3 of water is stored in the remnant pond on the Snip TSF (450 m x 200 m x 1 m depth).

   b. Currently, water released from the concrete P-trap installed within the 300 Portal of the underground mine workings reports to the Snip TSF impoundment, as required by BC MoE Effluent Permit PE-9079. Seepage flow from the concrete plug in the 180 Portal also reports to the Snip TSF impoundment, though this flow has historically been too small to measure reliably. The concrete plugs and P-traps were designed and constructed to flood the underground mine workings to the 300 Level, with the intent of reducing acid rock drainage and metals leaching (ARD/ML) processes. Although no formal study has been done of relative contributions to the Snip TSF impoundment from mine drainage and meteorological processes, estimated flow rates from the existing measurement weirs suggest that the 180 Portal and 300 Portal combined discharge contributes around 10% or less of the estimated surface water release from the TSF, with the primary water input to the impoundment being from direct precipitation, snowmelt and runoff.

   c. Barrick currently releases water directly from the Snip TSF impoundment to the environment, in compliance with Effluent Permit PE-9079. The conditions of this release include quarterly water quality sampling, testing and annual reporting to the BC MoE.

   d. Under the current wet (pond) closure cover condition, there is no tailings beach above water at Dyke 1. At Dyke 3, the beach width is typically around 200 m, with seasonal variation.

   e. The ability for the Dyke 1 and Dyke 3 embankment to undergo deformation without the release of water was discussed in the closure design report (Klohn-Crippen, 1999). Estimates of seismically-induced displacements and post-earthquake deformations associated with the 1:1,000-year design event indicated that post-earthquake lateral deformations associated with shear strain in the liquefied foundation soils could result in loss of containment under the wet closure cover scenario. Under the dry cover option, estimated post-earthquake lateral deformations were not considered to result in loss of containment. Stability analyses for the Dyke 1 and Dyke 3 embankments were re-evaluated as part of a later dam safety review (Knight Piésold, 2004). Similar to the Klohn-Crippen (1999) work, foundation soils inferred to liquefy were assigned estimated residual strength values. In contrast, all non-liquefied soils were assigned undrained strengths and static porewater pressure conditions, rather than being further subdivided into strain-softened soils (with modified pore pressure ratios) and drained (effective strength) soils. Knight Piésold (2004) also assigned moderately greater strengths to the near-surface foundation soils, on the basis of progressive consolidation and strength gain under loading by the embankments. Results of these post-earthquake stability analyses yielded factors of safety greater than unity, indicating that significant deformations would not be expected.

f. The right abutment spillway at Dyke 1 was designed to pass the inflow from the 24-hour probable maximum precipitation (PMP) over its undiverted catchment area, i.e. the 24-hour probable maximum flood (PMF) while maintaining a 0.5 m freeboard at the Dyke 1 crest (Knight Piésold, 2014).

g. Barrick is currently reviewing its water quantity and quality monitoring, testing and reporting obligations under BC MoE Effluent Permit PE-9079. As well, Barrick has requested a meeting with BC MEM representatives to discuss vegetation control on Dyke 1 and Dyke 3.

3. Filter adequacy
   a. As previously described, Dyke 1 and Dyke 3 were provided with internal blanket and finger drains to help maintain a low phreatic surface within the downstream portion of the embankments. No internal filter or transition material zones were included in the embankment sections. Treatment of the localized seepage observed during mine operations at Dyke 1 in June 1997 (also described previously) appeared to have been successful, and the area was further protected by construction of the downstream closure buttress. No post-closure seepage at Dyke 1 has been reported, and the 1.0 L/s to 1.5 L/s post-closure seepage at the downstream toe of Dyke 3 has been reported as consistent and free of solids (Knight Piésold, 2014).

   b. No filter zones were included in the Dyke 1 and Dyke 3 embankment designs. The impounded tailings; the low-permeability, sand and silt core; the supporting sand and gravel fill; and the waste rock and the select cobble drainage materials were determined in the original design to be respectively filter-compatible, and were reportedly constructed in accordance with design.

   c. No new work is currently planned to further characterize material gradation and piping potential.

Letter Closure

I trust that the information contained in this letter is sufficient for your present needs. Please contact me should you have any questions or concerns.

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27 June 2015

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Reference Reports – Snip Tailings Impoundment

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Knight-Piésold Ltd., 2014. Barrick Gold Inc. Snip Tailings Storage Facility, 2014 Dam Safety Inspection, File No. VA101-2/17-1, Rev. 0, 28 November 2014.

Province of British Columbia, 2015. Report on Mount Polley Tailings Storage Facility Breach, Independent Expert Engineering Investigation and Review Panel, 30 January 2015.

Figure 1 – Snip Mine Site Location and General Layout of Closed Tailings Impoundment