Proceedings of Heap Leach Solutions, 2014
November 10–13, 2014, Lima, Peru
Published by InfoMine, © 2014 InfoMine, ISBN: 978-0-9917905-6-2

Characterization of gold inventory and impediments to recovery at an active heap leach facility

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Abstract

A focused data collection and analysis program was conducted to quantify and determine the location of gold inventory at a commercial gold heap leach pad and to identify potential causes of limited gold recovery from the facility. Thirty-two exploratory sonic coreholes were drilled into the leach pad to collect intact leach ore samples. Core samples were logged to describe the rock type, texture, color, mass, and volume. Subsamples were collected for metallurgical and physical property testing. Physical property testing consisted of particle size distribution, particle density, and solution content. Metallurgical testing consisted of fire, cyanide shake, and caustic rinse gold recoveries. Field and laboratory results were interpolated across twelve subzones and averaged over each 20-ft lift. Data revealed an interval of ore containing higher fines fraction. Solution content generally increased and dry bulk density decreased over the same interval. An increase in cyanide-shake and fire assay gold values was also observed at and below this interval, while a decrease in recoverable gold in solution was observed over the same interval. The metallurgical and physical property results indicate that the fine-textured interval of ore is limiting solution movement into the underlying ore and controlling long-term gold recovery within the leach pad. Using additional hydraulic property data from ore samples, the mean saturated hydraulic conductivity was estimated from the <#200 mesh size fraction and the estimated dry bulk density. Ore lifts within each subzone were then classified into different hydrologic types based on estimated saturated hydraulic conductivity. The hydrologic classification provides a large-scale relative assessment of heap permeability that can be used to develop a hydrology-based model to evaluate alternative leaching strategies.

Introduction

Barrick Gold Corporation's Bald Mountain Mine lies within the southern Ruby Mountains of northeastern Nevada, USA. Bald Mountain Mine is an open-pit, run-of-mine, heap leach gold mine with three active leach pads: Bald Mountain, Mooney North, and Mooney South. The ore deposits mined are Carlin-type hydrothermal ore deposits that have primarily undergone silicic, phyllic, or argillic alteration.

Leaching at the Mooney North pad began in 2006. Since 2006 over 34 million tonnes of ore at an average gold grade of 0.6 g/tonne have been stacked on Mooney North and leached. The Mooney North leach pad has significant gold inventories that should have been recovered based on the existing metallurgical model. Ore material from the Saga and Bida Pits constitute the majority of ore material from which gold recovery has been delayed. Top Pit ore material may also contain a significant portion of the gold inventory. The Saga and Bida ores were believed to contain smectite (swelling) type clays that would contribute to low permeability conditions. Additionally, the Saga and Top Pit ores also contain fine-grained/non-competent rock types that may become lower permeability ores under consolidation.

In 2011 a data collection and analysis program was conducted at Mooney North to quantify and determine the location of gold inventory within the active heap leach pad and to identify potential causes of limited gold recovery from the facility. The program was designed to investigate relationships between hydrologic and metallurgic properties using sonic core samples collected from Mooney North. Results from the study will be discussed.

Methodology

Field investigation methods

In July and August 2011, 32 exploratory coreholes were drilled into Mooney North heap leach facility with a sonic drill rig using a 15-cm diameter core barrel. Corehole locations are shown in Figure 1. Drill cuttings were collected in approximately 0.75 m lengths and placed in plastic sleeves. The sonic drill rig was advanced to within approximately 12 to 15 m above the leach pad liner. Drill depths ranged between 36 and 58 m, and totaled 1,490 m.

The length and weight of each 0.75 m core section was recorded. The core sample bags were opened, photographed, logged, and sampled. Geologic logging was conducted on each 0.75 m core run to estimate major particle size fractions, plasticity, and color.

Composited sub-samples (1 to 2 kg) were collected at 1.5 m intervals and placed in a sealed and labeled one-gallon freezer bag for metallurgical and solution content testing. Dry bulk density calculations were derived by converting sample wet masses to dry masses using the measured solution content and core sample volumes.

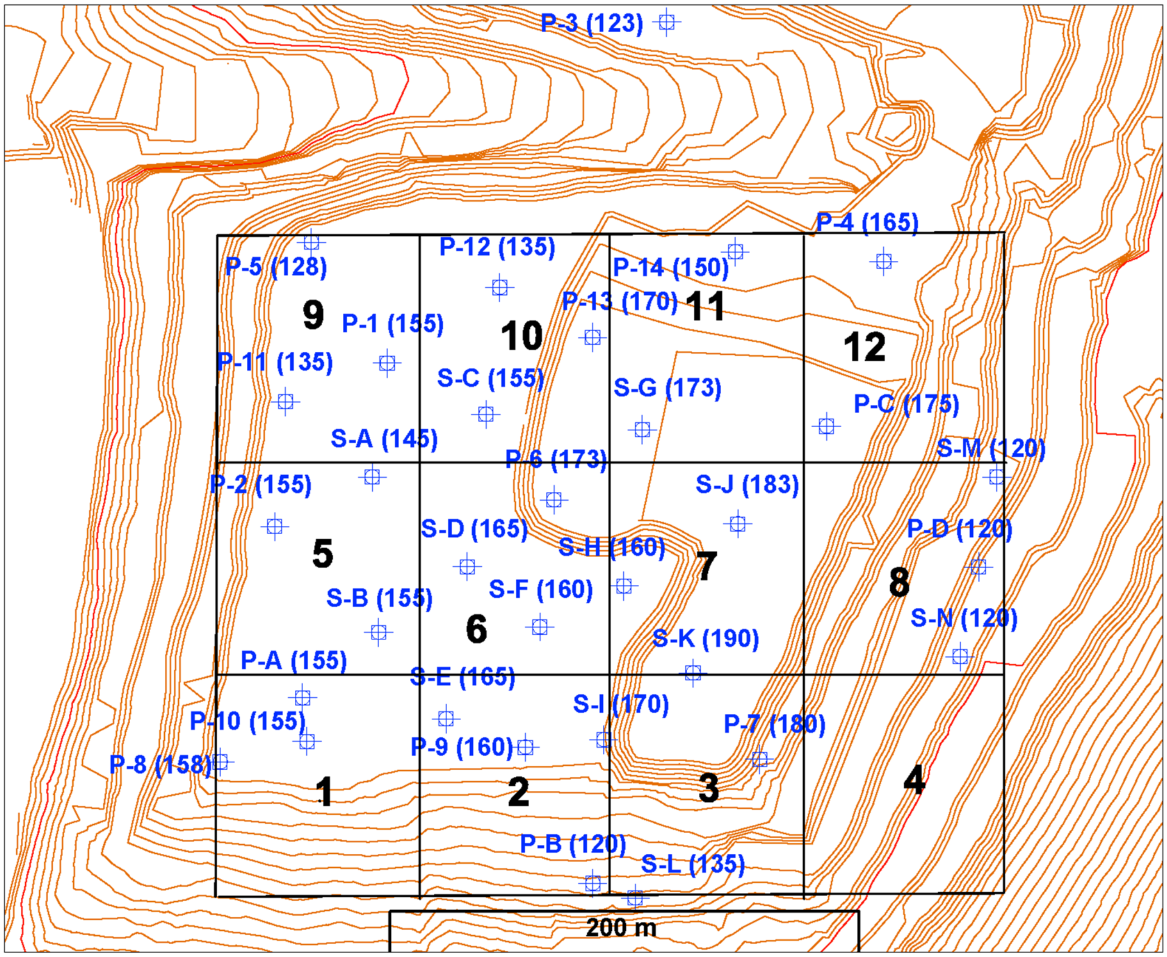

Figure 1: Mooney North corehole locations

Laboratory test methods

Measurements on each subsample from the 1.5 m composited intervals included wet and dry weights, cyanide (CN) shake (gold assay), fire assay, and caustic rinse.

Prior to CN shake and fire assay analysis, samples were dried, crushed to less than 2 mm (#10 mesh), then split and pulverized to less than 0.075 mm (#200 mesh). CN shake and fire assay samples were not rinsed prior to analysis. Caustic rinse samples were not dried, crushed, or pulverized prior to analysis.

Fire assay testing measured gold in solution, CN soluble gold, and refractory gold. CN shake testing measured gold in solution and CN soluble gold and demonstrated recoverable gold. Caustic rinse testing measured gold in solution.

Samples were selected for wet sieve and hydrometer particle size distribution (ASTM C 117, 2004; ASTM C 136, 2006) testing based on field textural descriptions and assay results. Because fines (silt and clay) are typically a good indicator of the relative permeability of a material, samples were selected to represent the distribution of fines content observed in geologic log data and to represent samples with elevated cyanide shake gold content relative to the corehole average.

Wet-sieved material was reconstituted into particle size groups <#100 mesh, >#100 to <#4 mesh, >#4 to <19 mm, >19 mm to <51 mm, and >51 mm for CN shake testing on each particle size group.

Subzone analysis

The Mooney North study area was divided into twelve equally sized subzones for use in describing field and laboratory results. Each subzone was projected vertically into the Mooney North pad and delineated vertically into 6 m sections to approximate the original ore lifts at Mooney North.

Kriging and inverse distance algorithms of Tecplot Focus® (2012, TecPlot, Inc., Bellevue, WA) were applied to the field and laboratory measurements to estimate properties at locations in each subzone. Results were averaged for each 6 m lift of each subzone for most physical properties, and were summed over each 6 m lift for recoverable gold.

Results

Fines content, solution content, and bulk density

Figure 2 presents the mean interpolated percent fines (minus #200 mesh), gravimetric content, and dry bulk density across all subzones. Each point in Figure 2 represents the lift mid-point. Mean fines fractions ranged from 21 to 30 percent and on a subzone basis ranged from 12 to 36 percent (data not shown). Mean percent fines generally increased with depth to 2,172 m above mean sea level (amsl) and remained above 28 percent to a depth of 2,160 m amsl. Mean percent fines steadily decreased below 2,160 m amsl. Mean solution content generally increased with depth to 2,172 m amsl and decreased with depth below 2,166 m amsl. Solution content trends corresponded to the fines trends due to increased water holding capacity (reducing drainage). Mean dry bulk density generally decreased with depth to 2,160 m amsl, possibly due to increasing fines over this interval. Values generally increased below 2,160 m amsl, possibly due to decreasing fines and to ore consolidation from overburden pressure.

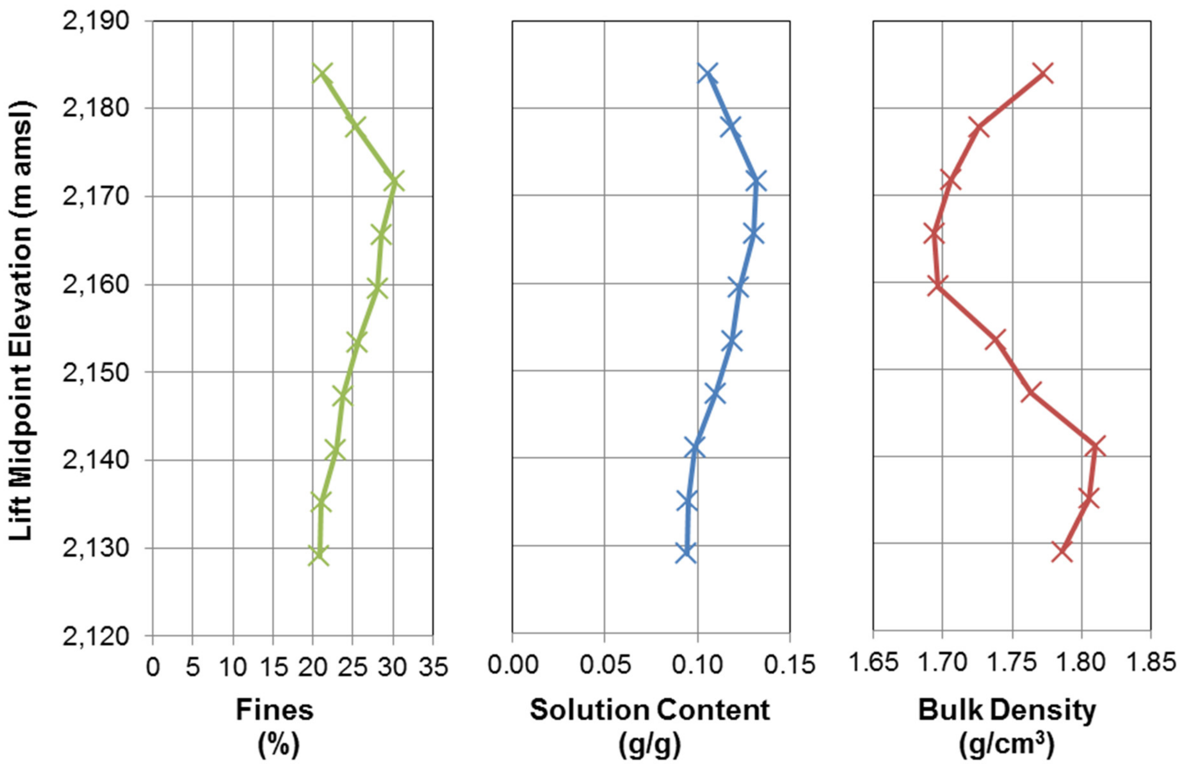

Figure 2: Average interpolated percent fines, solution content, and bulk density

Cyanide shake, fire assay, and caustic rinse gold

Figure 3 presents mean interpolated average gold contents from CN shake and fire assay tests. An increase in mean CN shake gold was observed between 2,172 m and 2,153 m amsl, at and below the layer of elevated fines. Similar to CN shake gold, peaks in mean fire assay gold were apparent between 2,172 m and 2,153 m amsl. Interpolated mean percent CN-soluble gold in solution, calculated as caustic rinse gold divided by CN shake gold, ranged from 29 to 41 percent (Figure 3) and on a subzone basis ranged 10 to 61 percent (data not shown). A sharp decrease in mean CN-soluble gold in solution was observed between 2,166 and 2,160 m amsl, coinciding with observed increases in CN shake gold and decreases in caustic rinse gold.

The increase in CN shake and fire assay gold at and below the layer of elevated fines, coinciding with a decrease in CN-soluble gold in solution over the same interval, indicates that the finer-textured ore layer is controlling gold recovery from Mooney North by limiting leach solution movement into underlying ore. That is, more gold is present in the solid fraction below the layer of elevated fines and less gold is present in solution because of uneven solution flow in this layer.

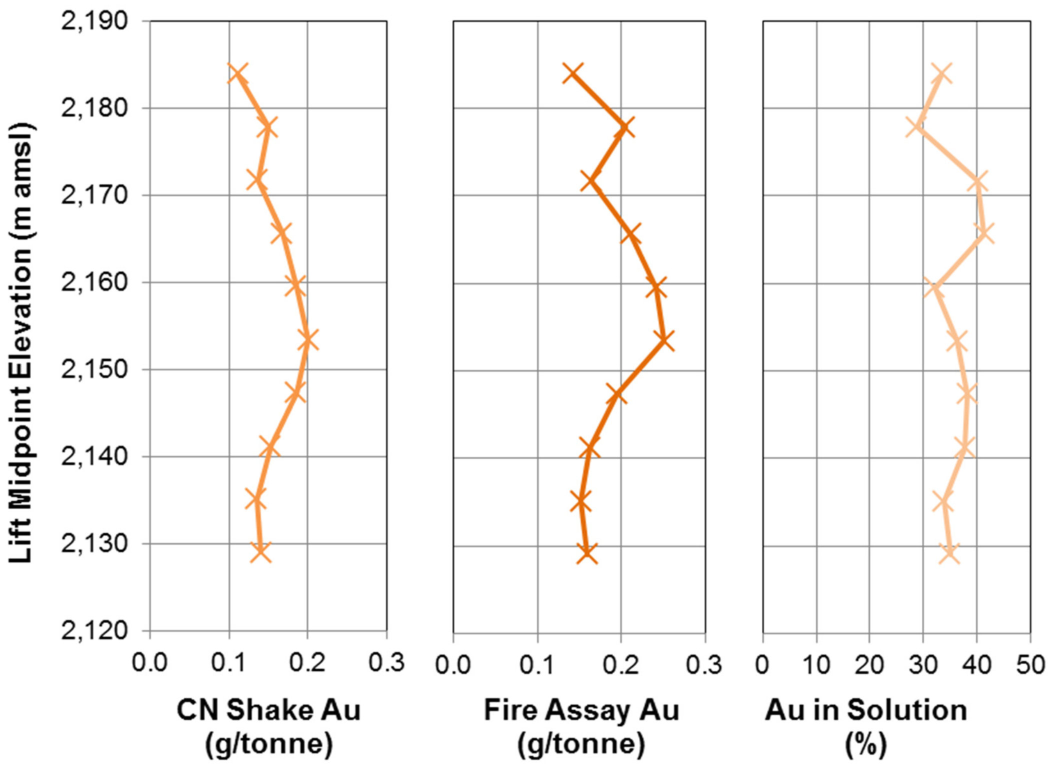

Figure 3: Average interpolated CN shake, fire assay, and gold in solution

Total recoverable gold

Total recoverable gold was calculated as the interpolated CN shake gold concentration (g/tonne) multiplied by the tonnes of ore in each subzone lift. Actual CN shake gold concentrations from non-pulverized ore material are likely less than the pulverized CN shake gold concentrations reported herein; however, the relation between pulverized sample versus non-pulverized sample CN shake gold is not known for the Mooney North ores. To address this uncertainty, total recoverable gold was estimated assuming non-pulverized CN shake gold concentrations range from 70 to 100 percent of pulverized CN shake gold concentrations.

The total recoverable gold profiles for non-pulverized to pulverized ore CN shake gold ratios of 1.0, 0.9, 0.8, and 0.7 are provided in Figure 4. Most of the recoverable gold lies between 2,166 and 2,141 m amsl, at or just below the layer of elevated fines (Figure 2). Total recoverable gold below the layer of high fines (below 2,166 m amsl) ranges from 38,000 oz to 26,600 oz for non-pulverized to pulverized ore CN shake gold ratios of 1.0 to 0.7 and represents gold that may be recovered from further leaching strategies. Total estimated recoverable gold is estimated to range from approximately 47,100 oz, assuming recovery of 100 percent of CN shake gold, to 33,000 oz, assuming 70 percent recovery of CN shake gold.

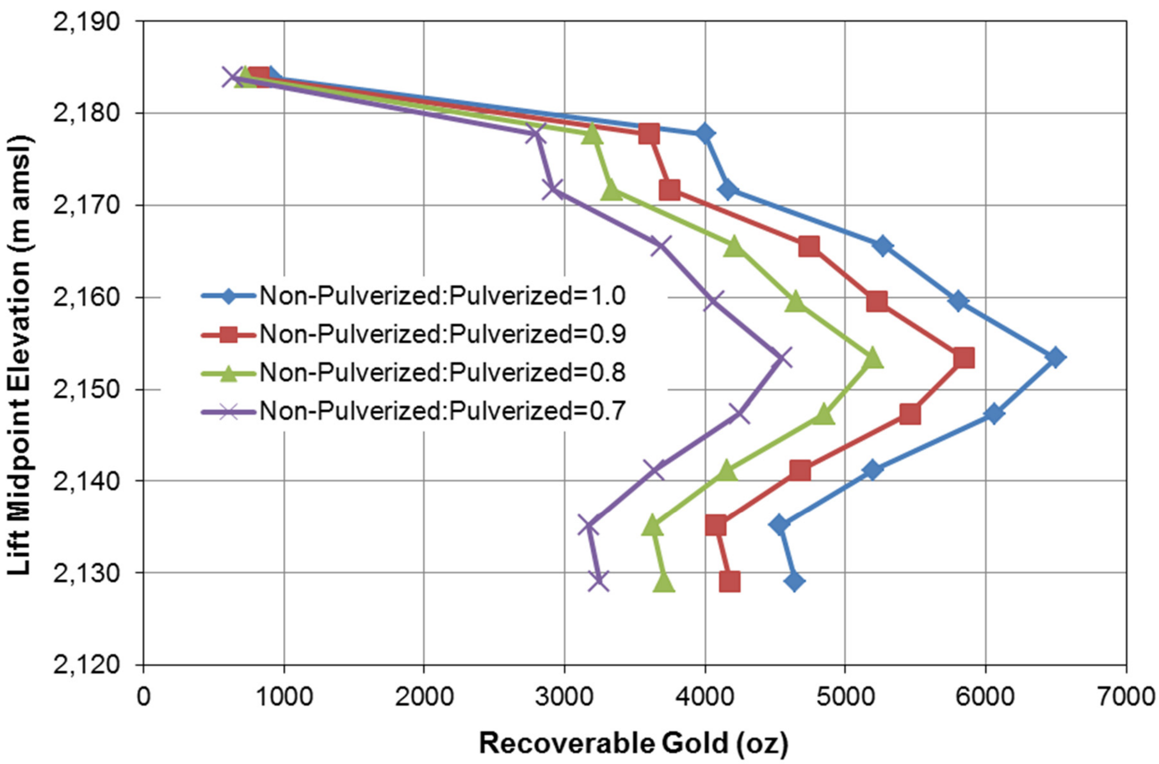

Figure 4: Total estimated recoverable gold profile for non-pulverized to pulverized ore CN shake gold ratios of 1.0, 0.9, 0.8, and 0.7

Leach residue gold values

Figure 5 presents the average cumulative distribution of residual CN shake gold as a function of particle size and the average particle size distribution. Fifty-three percent of total residual CN shake gold is associated with the >#4 mesh size fraction, whereas this size fraction makes up 42 percent of the total particles on a mass basis. Thirty-three percent of total residual CN shake gold is associated with the <#100 mesh size fraction that makes up 29 percent of the total particles. Fourteen percent of the residual CN shake gold is associated with the #100 to #4 mesh size fraction that makes up 29 percent of the total particle mass. The particle size distribution-head grade relationship for the Mooney ores is unknown; however, assuming gold is evenly distributed throughout the ore the results indicate that gold is not leached uniformly from all particle sizes with residual gold skewed towards the >#4 size fraction and to a lesser extent, the <#100 mesh size fraction.

The leach residue gold analysis results may indicate two separate rate limited diffusion processes contributing to reduced gold recovery in the >#4 and <#100 size fraction:

- For the >#4 mesh size fraction, larger diffusion distances from the particle surface to the inner regions of the particle limit gold dissolution; and

- For the <#100 mesh size fraction, limited flow and reduced solution contact within the small pores in that area associated with the fine fraction reduce the transport of dissolved gold from these regions.

As a result, leach solution contact in both regions appear to be primarily limited to the diffusion of leach solution.

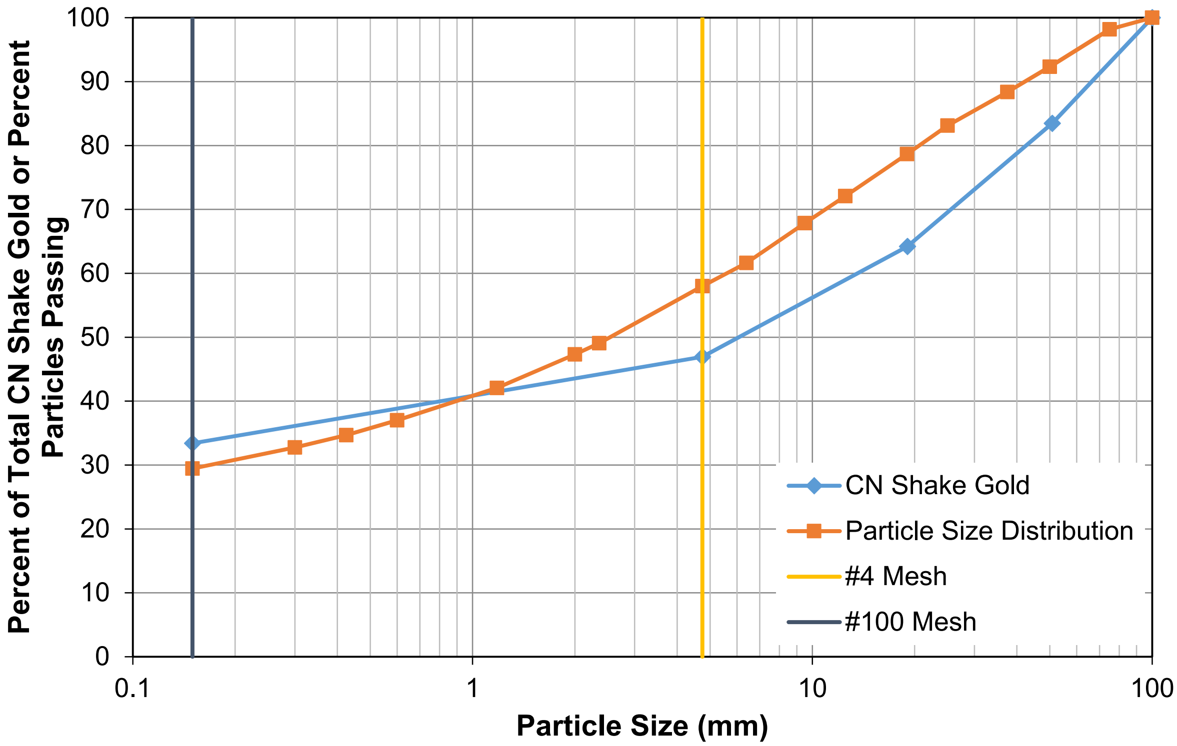

Figure 5: Average cumulative distribution of CN shake leach pad residue by particle size fraction and average particle size distribution

Hydrologic ore types

Hydrologic ore types were assigned to all of the core samples based on laboratory derived saturated hydraulic conductivity (Ksat) values and observed fines and dry bulk density values. A function relating Ksat to fines content and bulk density was developed from consolidation permeability measurements on Saga ore material (data not shown). Figure 6 presents measured consolidation permeability data for the Saga ores versus the percent fines multiplied by dry bulk density, and the function fitted to the data. The resulting Ksat estimation equation (R^2=0.90) is:

$$Ksat = 5 \times 10^7 \times (percent\ fines\ \times dry\ bulk\ density)^{-6.315} \tag{1}$$

Based on the average percent fines and dry bulk density values, the Ksat was estimated from Equation 1 for each subzone and lift (Figure 7). Estimated Ksat generally decreased with depth to 2,172 m amsl and increased with depth from 2,160 m to 2,141 m amsl. Below 2,141 m amsl Ksat trends generally decrease or stay relatively constant. Assuming a Mooney North maximum irrigation rate of 3.7 L/m^2/hr (1×10^{-4} cm/s) and a 10 times (10×) safety factor applied to the irrigation rate to account for variability in the ore and irrigation rate, the predicted Ksat is less than the 10× safety factor (36.7 L/m^2/hr, 1×10^{-3} cm/s) for one or more lifts in all subzones but Subzone 11 and therefore indicates areas where ore permeability may be controlling gold recovery. The estimated Ksat less than the 10× safety factor is found to occur predominately between 2,172 and 2,160 m amsl and coincides with the interval of increased fines (Figure 2). Perched solution was also observed within this interval in 17 of the 32 coreholes. This is indicative of saturation within the finer-textured layer and solution being forced into preferential flow paths with subsequent bypass of much of the underlying ore.

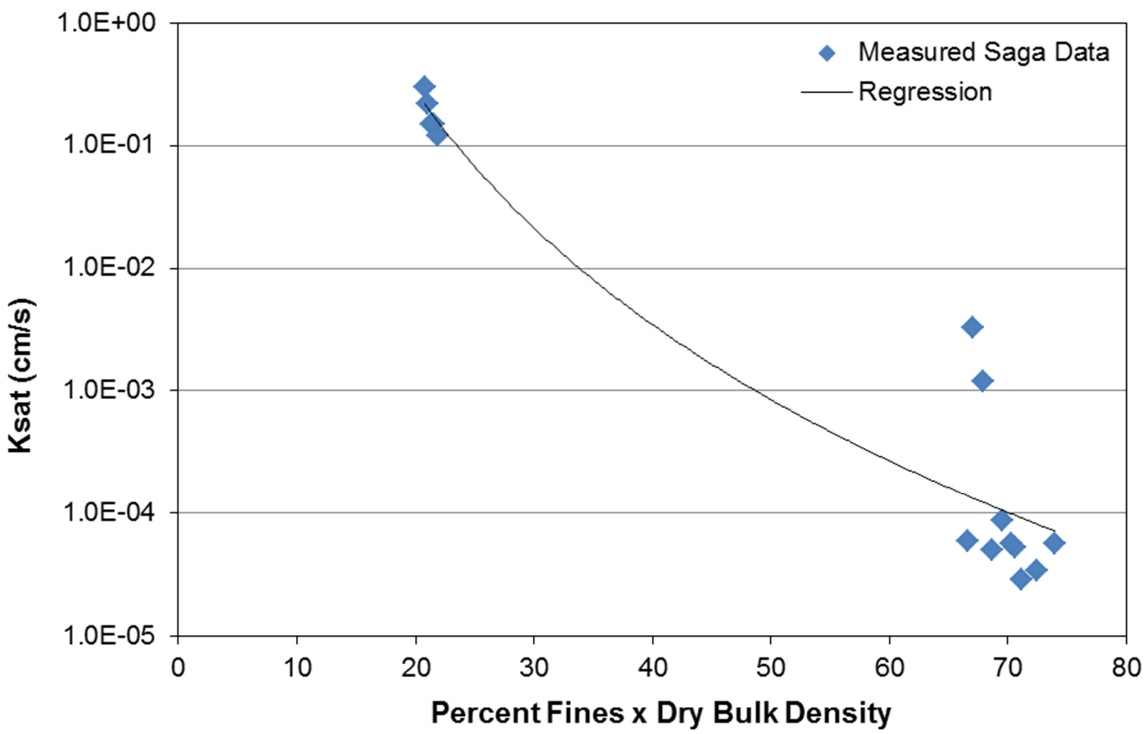

Figure 6: Measured and fitted consolidation permeability for Saga ores as a function of percent fines multiplied by dry bulk density

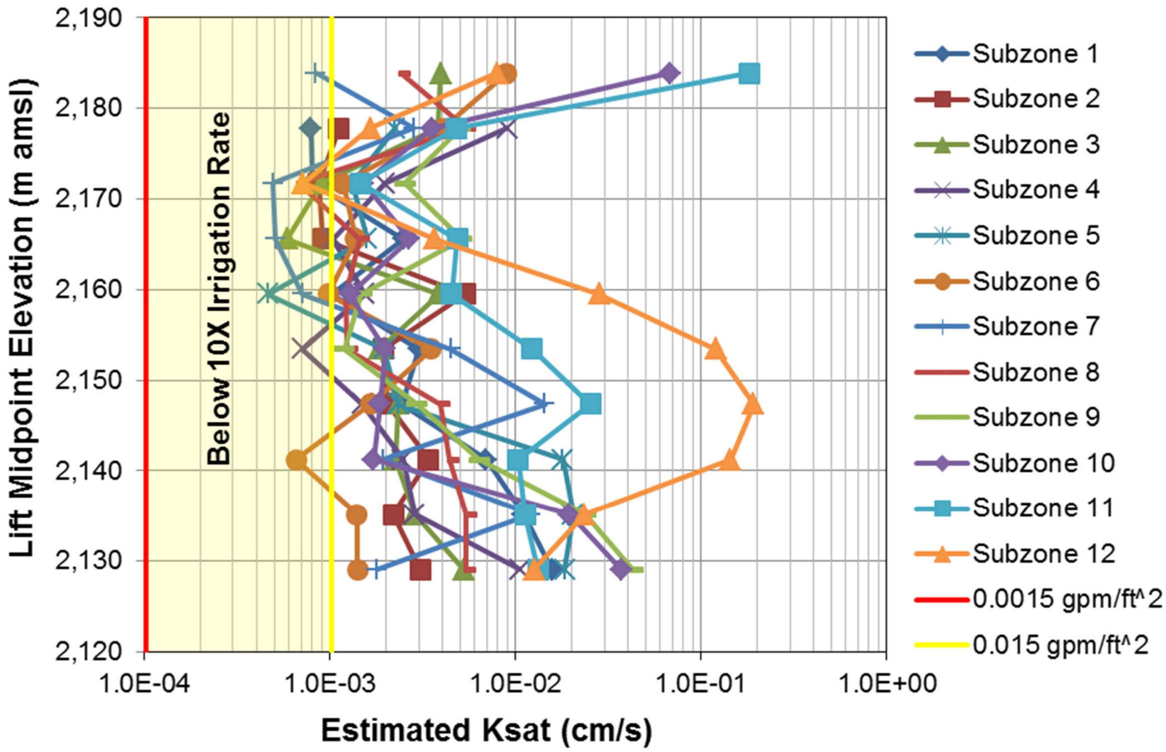

Figure 7: Estimated Ksat

Based on the estimated Ksat values assigned to each corehole depth, ore lifts within each subzone were classified into different hydrologic types in order of optimum hydrologic characteristics for leaching:

- Unit 1 – High Ksat (Ksat > 1×10^{-2} cm/s)
- Unit 2 – Intermediate Ksat (1×10^{-3} cm/s < Ksat < 1×10^{-2} cm/s)
- Unit 3 – Low Ksat (Ksat < 1×10^{-3} cm/s)

Unit 1 ore is expected to have good permeability with effective gold recovery; Unit 2 may be sufficiently leached with adequate leaching periods whereas Unit 3 ore may be considered "bad" ore requiring modifications to leaching practices (i.e., pulsed leaching, agglomeration).

The distribution of lift hydrologic units within each subzone is presented in Figure 8. Unit 2 was the predominant hydrologic unit observed. Unit 3 ores were present in all but Subzone 11 and predominately in lifts above 2,153 m amsl. In addition, the lift-averaged Ksat may not capture the influence of thinner, less permeable layers within the lift which may control percolation behavior. The hydrologic classification provides a large-scale assessment of relative heap permeability that can be used to develop a hydrology-based model to evaluate alternative leaching strategies.

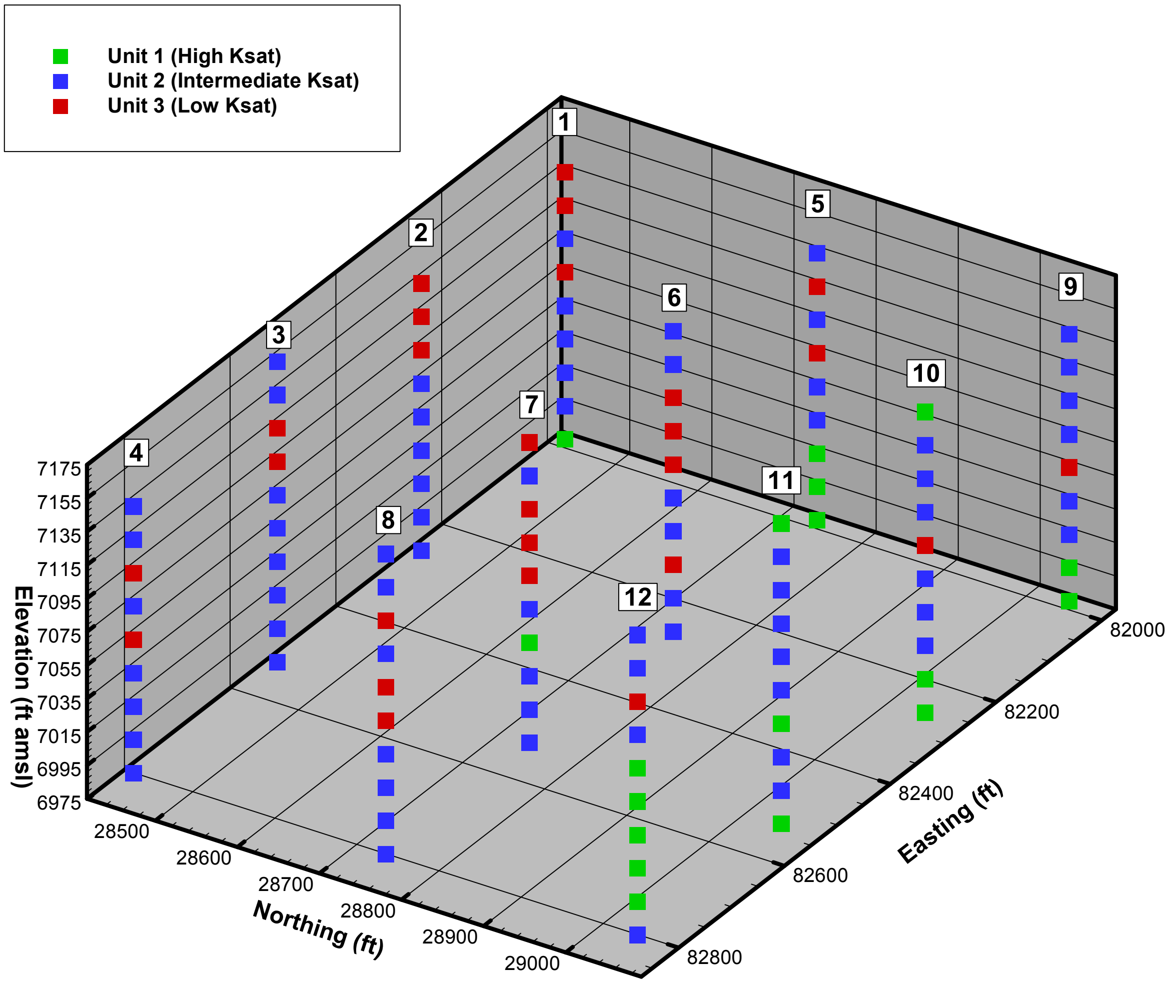

Figure 8: Hydrologic unit distribution for each subzone

Conclusions

Data collected from this study identified a finer-textured layer of ore between 2,172 m and 2,160 m amsl. The existence of finer-textured ore layer is supported by hand texture analysis, solution content, and dry bulk density trends with depth. Specifically, percent fines fraction increased with depth to 2,172 m and gradually decreased with depth below 2,160 m amsl, whereas solution content generally increased and bulk density decreased over the same interval.

An increase in CN shake and fire assay gold was observed at 2,172 m amsl and below, coinciding with a decrease in CN-soluble gold in solution over the same interval. This indicates that the finer-textured ore layer is controlling solution percolation and gold recovery within Mooney North by limiting solution movement into the underlying ore. The lower permeability of the finer-textured layer most likely causes solution movement into preferential flow paths, bypassing the bulk of the ore.

Estimated interpolated recoverable gold for the study area ranged from 47,100 oz, assuming 100 percent of CN shake gold is recoverable, to 33,000 oz, assuming 70 percent of CN shake gold is recoverable.

Leach residue gold analysis indicated that gold is not leached uniformly from all particle sizes with residual gold skewed towards the >#4 size fraction and to a lesser extent the <#100 mesh size fraction. These results indicate diffusion constraints due to large diffusion distances associated with the >#4 mesh size fraction and limited flow and reduced solution contact and gold recovery in the small pores associated with the fine fraction.

Based on laboratory derived Ksat values correlated to percent fine and bulk density values, corehole samples were classified into hydrologic units. Predicted average Ksat values of the ores decreased from the pad surface to approximately 2,160 m amsl; predicted Ksat values increased at depths below the fine-grained leach ore layer. Ksat values less than 10× safety factor irrigation rate of 36.7 $L/m^2/hr$ (1×10^{-3} cm/s) may indicate areas where ore permeability is limiting solution percolation. Predicted Ksat values less than the 10× safety factor were predominantly found to occur between 2,172 and 2,160 m amsl, coinciding with the layer of increased fines.

Based on the hydrologic unit analysis, ore lifts within each subzone were classified in order of optimum hydrologic characteristics for leaching. The hydrologic classification provides a large-scale relative assessment of heap permeability that can be used to develop a hydrology-based model to evaluate alternative leaching strategies.

References

ASTM C117 – 04. 2004. Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing. ASTM International, West Conshohocken, PA, www.astm.org.

ASTM C136 – 06. 2006. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. ASTM International, West Conshohocken, PA, www.astm.org.