

HYDRO-JEX[®] OPERATIONS AT ANGLOGOLD ASHANTI'S CRIPPLE CREEK & VICTOR GOLD MINE

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Abstract

Hydro-Jex[®] re-leaching was undertaken during the summer of 2010 at the Valley Leach Facility (VLF) at AngloGold Ashanti's Cripple Creek & Victor Gold Mine. Several advancements to the technique were made in response to the technical design and operational challenges posed by the unique site conditions. New geophysical resistivity monitoring techniques were developed to monitor solution migration during the injections. These developments are presented along with discussion of gold production resulting from the project.

Introduction

Heap leaching operations at the Valley Leach Facility (VLF) at AngloGold Ashanti's Cripple Creek & Victor (CC&V) Gold Mine began in 1994. The VLF was originally designed with 7.5M ft² (0.7 M m²) of lined area and one internal pregnant solution storage area. A two-stage open-circuit crushing operation was used to process approximately 27,000 tons (24,500 mt) of ore per day to a nominal P80 of 1.5 in (38 mm). The ore was stacked on the heap in 50-foot (15 m) lifts under an ultimate height restriction of 300 ft (91 m). Several expansion projects and permit amendments have since increased the scope of operations at CC&V, ultimately increasing the lined area to over 16 M ft² (66.5 M m²). Additional pregnant solution storage areas were added in 1996 and 2003 and the crushing circuit was upgraded in 2002 to process 72,000 tons (65,300 mt) per day to a P80 of ¾ in (19 mm). At the deepest point the VLF is currently over 600 ft (183 m) deep.

The growth of the VLF to over 220M tons (200M mt) of placed ore is a testament to the historic productivity of the operation, but the extreme depths of the heap also create operational challenges that impact gold production from the

heap. In any large heap, compaction, variations in ore type and grade, as well as variations in leaching efficiency and protective alkalinity in placed ore can lead to incomplete extraction of gold from localized areas within the heap. Minimizing the number and extent of these areas is of prime importance, as the contained metal is essentially passive inventory. However, once the material is placed on the heap, the flow of leaching solutions can only be partially controlled by management from the surface and transport of lixiviants to the affected areas becomes increasingly difficult as the height of the heap increases.

Starting in 1996, Thom Seal began developing a method of injecting leach solutions directly into specific areas while overseeing Newmont's Nevada heap leach operations. [1,2] The method, trademarked Hydro-Jex[®], uses techniques similar to those developed for the oil and gas industry. **Figure 1** shows a conceptualized illustration of the Hydro-Jex[®] process depicting newly-created flow channels radiating laterally from four injection zones along a central well, with the top zone undergoing pumping. The flow of solution during injection is initially limited by the porosity of the heap, but as the pressure is increased above the overburden pressure in the targeted zone, breakdown occurs and solution is pushed laterally into the heap upwards of one hundred feet. Any combination of reagents can be added to the solution pumped down the well to accelerate gold dissolution or remediate any adverse chemical conditions. Additional recovery and chemical changes are realized by periodically irrigated the well with leaching solution after the initial injection to introduce fresh reagents and rinse dissolved gold from the affected areas.

Hydro-Jex[®] operations at Newmont Mining Corp. in Nevada have since expanded to over one hundred wells and the technology has recently been exclusively licensed to Metal Recovery Solutions (MRS) Inc. for commercial

application. CC&V contracted with MRS to treat a series of Hydro-Jex[®] wells on the VLF as part of ongoing efforts to continuously increase gold production. The ability to target specific areas and transport lixivants directly to under-leached areas made the process attractive because of the large volume of ore currently beneath side slope areas and the difficulty in leaching the areas via surface-based solution application.

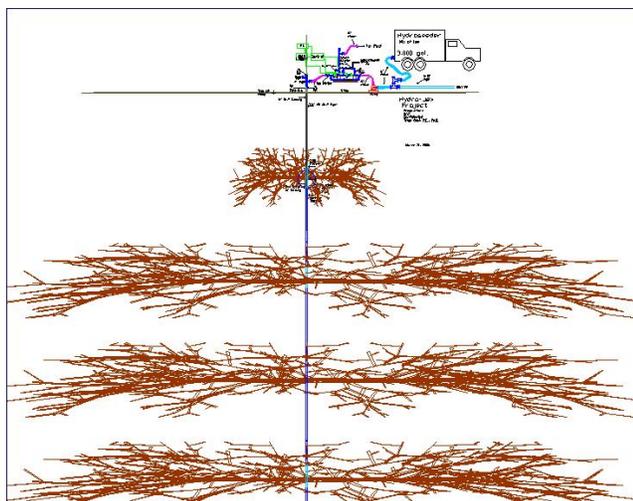


Figure 1. Illustration of the Hydro-Jex[®] method showing four discrete injection zones.

This installation at CC&V was the first application of the Hydro-Jex[®] technology outside of Newmont Mining Corp., where the process has been heretofore limited to depths of 250 ft (76 m) on conventional heaps. Significant modifications to the technology had to be made to apply it to a valley-fill-type heap and to account for the extreme depths of the VLF.

The modifications to the Hydro-Jex[®] technology for use at CC&V and the project's results are summarized below along with a discussion of the impact on gold production. Also included, is a presentation of the advancements made in the ability to monitor the injections *in situ* and in real time.

Planning and Design

Several times during the last decade, CC&V has undertaken extensive pad-wide drilling campaigns. Samples are obtained over the breadth and depth of the VLF using sonic drill rigs and are then analyzed to assess reagent consumption and residual gold department. The pad drill program was conceived as a method to directly inspect leaching conditions within the heap and to assess the sagacity of inventory estimates for the VLF. This program

has been instrumental in guiding VLF operation, but has also generated a comprehensive dataset perfectly suited to identifying areas that would benefit from target treatment via Hydro-Jex[®].

Data from the 2008 and 2009 drilling programs identified an area on the west side of the VLF that had abnormally high residual grade at depth. Leachable grades in excess of 0.017 troy ounces gold per ton (0.583 g/mt) were common; based on ore placed at similar times elsewhere, the expected grade, should have been 0.0005 opt (0.017 g/mt) or less. The results also showed that samples from the area consumed relatively high amounts of lime during bottle roll tests. Comparison of these results to ore stacking records indicates that the target area corresponds to approximately 1.65 M tons (1.5 M mt) of ore obtained from a historic dump placed in 2001. The ore was essentially waste from a historic mine with grades high enough to justify placing it on the leach pad, but it also contained a significant quantity of active sulfides that had been oxidizing for several decades. Very little lime was added to this ore when it was placed and it was hypothesized that a lack of protective alkalinity was severely limiting the efficacy of leaching reagents in the area. However, because the area was approximately 350 ft (107 m) below the current surface of the VLF, transporting additional alkalinity, and the necessary reagents, to the under-leached ore could not easily be accomplished via traditional approaches and the target area was selected for the first test of the Hydro-Jex[®] method at CC&V.

Fortuitously, the target area was beneath a side slope bench that provided a great many logistical benefits on the surface. Access to the bench was at the confluence of major haul roads providing easy access for material delivery, drilling equipment, and installation of the plumbing necessary to provide solution during the injection. Additionally, relatively little new ore was scheduled to be added to the heap during the project that would report to the drainage pond below the target area, allowing the impact of the project to be gauged from changes in pregnant solution grade with minimal interference from freshly-stacked material.

Assuming that the radius-of-impact would be similar to previous Hydro-Jex[®] operations, sites for nine injection wells were selected across the bench above the target zone spaced 160 ft (50 m) apart. The depth to liner below the wells varied from 480 (146 m) to 580 ft (177 m) as the bench was oriented orthogonal to the contours of the underlying valley. Each of the nine wells was designed to terminate 100 ft (30.5 m) above liner to ensure that the integrity of the liner would not be compromised. The overall design called for 4,000 ft (1,219 m) of installed

casing and contained 191 injection zones. Estimates on the potential impact to production suggested that upwards of 10,000 troy ounces of gold could ultimately be recovered if observed grades were consistent through the entire area influenced by the injections. **Figure 2** shows the layout of the nine wells in relation to the May 2010 topography of the heap along with the well depths.

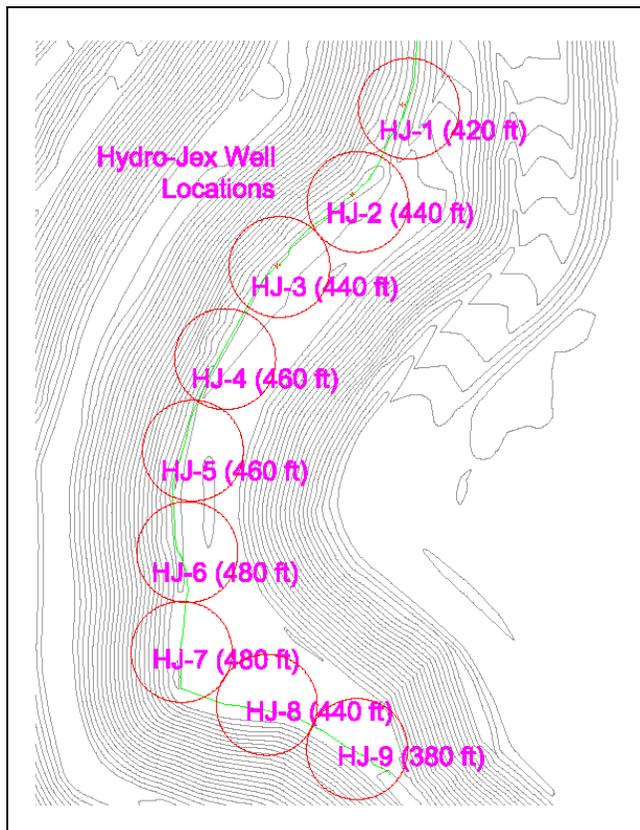


Figure 2. Layout of the 9 Hydro-Jex[®] wells along the 9925 ft elevation. Circles represent 80 ft radii-of-impact assumed in the design.

As shown in **Figure 2**, the target area for the injection is on a side slope. The width of the bench is considerably larger than typical benches, but stacking plans for the VLF called for the bench to be dumped in to maintain a setback of 1.6:1; the ultimate width of the bench would be considerably narrower. Hence, in order to maintain access to the injection wells they had to be located close to the crest of the bench - within 20 ft (6 m). The margin between the injection well and the crest of the lift has never been less than 50 ft (15 m) in previous Hydro-Jex[®] applications [1-3].

Preliminary engineering work indicated the risk of the injections causing a slope failure, particularly at deeper injection zones was minimal, provided that appropriate measures were taken. The uppermost injection zones above

90 ft (27 m) were strictly limited to fluid pressures equal to one half of the overburden pressure. This provision alone would have been suitable to eliminate the risk of a side slope failure, but as an additional level of safety, CC&V contracted with hydroGEOPHYSICS Inc. (HGI) to install an array of monitoring electrodes around each of the first three holes planned for injection. The arrays featured a string of electrodes down the side slopes normal to the injection well designed to give real time feedback allowing operations to be immediately shut down if wetting fronts advanced to near to the side slopes.

System Design and Fabrication

Use of the Hydro-Jex[®] method on Newmont's Nevada heap leach operations has been limited to depths of 200-250 ft (61 to 76 m). Because the pressure required to overcome the overburden pressure from the ore above injection scales with the depth of the injection, the Hydro-Jex[®] equipment had to be significantly redesigned to accommodate the target depths on the VLF in approaching 500 ft (152 m).

Water balance considerations limited the supply of solution devoted to the injection to approximately 1,500 gallons (5.67 m³) per minute. Detailed pressure-drop calculations showed that it would not be possible to fully utilize the available flow with the HQ (3.5 inch or 8.9 cm OD) pipe that had been used on previous Hydro-Jex[®] applications. Increasing the pipe diameter to 4.5 inch (11.4 cm) OD by selecting HWT pipe to carry the injection fluid would allow the flow to be fully utilized, but the increased mass required a change in the down-hole collar support, lifting, and depth-isolation mechanism. Ultimately, a flatbed boom truck was selected to accomplish the lifting of the injection pipe with a more robust collar support and depth isolation mechanism. A diesel-powered centrifugal pump was selected to provide the necessary energy to drive the flows during the injections once the system requirements had been fully engineered. Pioneer Pump, Inc. of Canby, OR provided the pump. DEA of Elko, NV mounted the pump and auxiliary equipment on a flatbed trailer, fabricated all the necessary piping, and assembled the unit. Their tools and expertise in welding, fabrication, electrical, data monitoring and painting delivered a first rate unit for the operation. **Figure 3** shows a photograph of the completed injection system.

Field Operation

Injection operations on the VLF began in late April 2010. While the project was regularly challenged with snow, hail, lightning, and high winds there were relatively few engineering-related issues that held up progress. The high elevation of the project caused underperformance of

the diesel and gasoline engines, which typically ran rich (due to 30% less oxygen at 3025m), exhausting black smoke, fouling plugs and exhaust port screens, which proved to be the most significant operational difficulty. While the diesel pump engine provided adequate pressures – it was designed with a safety factor of 25% for the operation – it ran uneven and very hot causing reductions in the pumping rate. Possible modifications to the engines air-fuel mixture and cooling management systems are currently being researched and designed.



Figure 3: Hydro-Jex[®] unit deployed at CC&V

One of the primary operational goals of the project was to add as much additional alkalinity during the injections as possible to satisfy the deficiency indicated by the test samples. CC&V owns and operates a lime slaker capable of slaking 50 tons (45 mt) of CaO per day. The lime slurry could be easily transported to the project site in a 4,000 gallon (15 m³) tanker truck, but offloading the lime to feed the injection pumps proved to be a challenge.

The lime slurry arrived to the project with approximately 30% solids. However, a significant fraction of the overall solids consisted of insoluble grit from impurities in the lime. A 0.375 inch (9.5 mm) filter upstream from the main injection pump removed any material that could not be flushed through the system during the injection. The filter occasionally clogged and choked off the flow of lime, but it was not the primary impediment of the offloading process. Initially, the primary bottleneck in the offloading process was the three-inch discharge valve on the slurry transport truck. Upwards of 40 minutes was required to completely off load the lime. The truck was subsequently outfitted with a six-inch discharge valve, significantly improving the offload rate, but the temperature of the slurry then became the limiting factor. To prevent damage to the down-hole depth isolation mechanism the hot

slurry had to be mixed with barren solution to decrease the temperature. Ultimately, the average offload time was decreased to 22 minutes and it was possible to offload two transport trucks into each injection zone. The total quantity of lime injected during the project exceeded 1,100 tons (998 mt) as CaO. **Figure 4** shows a photo of the slurry transport truck offloading directly to the injection system.



Figure 4: Slurry transport truck offloading slaked lime during down-hole injection stage.

Beyond the small difficulties stemming from site conditions and limitations during the lime slurry injection, field operations during the project were exceedingly smooth and every operational target was either met or exceeded.

During a typical day, three different injection zones were treated over a twelve-hour shift. At each zone, the down-hole isolation mechanism was positioned at the target zone. Solution was allowed to flow down the well under line pressure with no pumping to measure and fill the void space. Initial flows were typically on the order of 100 gpm (0.38 m³/min) but there were a few particularly tight zones where the flow was under 60 gpm (0.22 m³/min).

After the void space in the ore near the injection site had been filled the pump was started and the speed was progressively increased to achieve maximum down-hole flow rates of nearly 1,400 gallons per minute (5.3 m³/min). At the end of the injection cycle the pump speed was ramped down and switched off. **Figure 5** shows the volumetric flow rate and pressure to the well over time for a typical injection. As solution continued to flow down the hole under line pressure the post-treatment flow rates and pressures were recorded. In every case the pressure was reduced and flow rate was increased - upwards of 20 times in some cases - than the initial measurements.

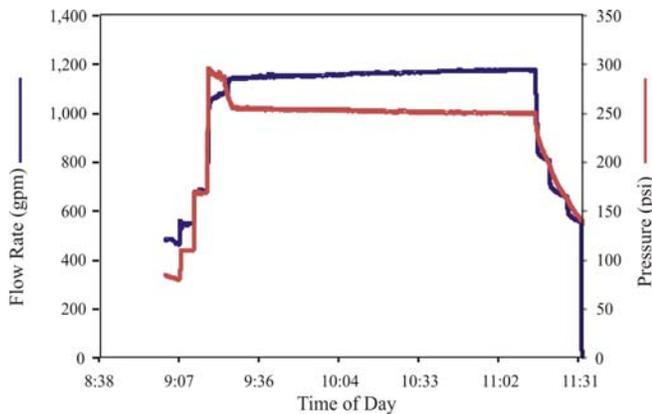


Figure 5: Pump injection volume & pressure v. time

Over 31.5 million gal (119,350 m³) were injected over 191 zones with an average 164,000 gallons (621 m³) at each zone. However, the flow rate in the three uppermost injection zones in each well was limited because of restrictions on the injection pressure. The average flow to zones without permit restrictions was 178,000 gallons (673 m³).

Geophysical Monitoring

Monitoring the movement of solution and defining flow characteristics during the injections was one of the primary goals for the project at CC&V. Arrays of surface and subsurface electrodes designed to be capable of capturing the three-dimensional propagation of the injected plumes through time were installed by HGI around three of the injection wells. **Figure 6** shows a typical layout of the electrodes around an injection well, with three boreholes of 14 electrodes each completed to depth of 430 ft (131 m), and 45 electrodes on the surface spreading radially out from the well. The borehole electrodes were arranged so that one set was 80 ft (24 m) south of the injection well, one at 80 ft (24 m) north, and one at 60 ft (18 m) east.

Given the nature of the project and the real-time data presentation to assure slope stability, the usual geophysical processing and modeling methodology of inversion was dispensed with. Inversion modeling is a time-intensive process that aims to reconstruct the spatial distribution of the property electrical resistivity from all of the voltage measurement combinations. Instead, the electrical current output from the borehole electrodes were monitored for changes, which could be acquired without further processing. It was expected that an increase in saturation would reduce the contact resistance between the electrode and heap. The electrical current output on an electrode would then increase according to Ohm's Law; as shown in **Figure 7**.

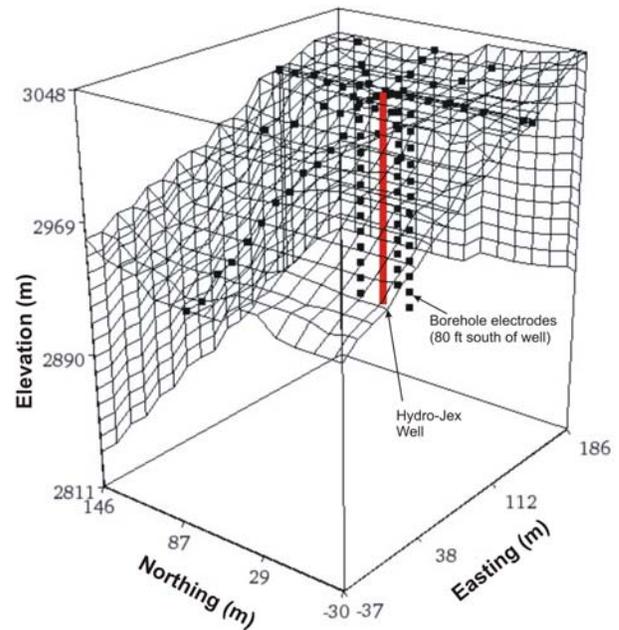


Figure 6: Electrode layout around a Hydro-Jex[®] well, including surface and borehole electrodes.

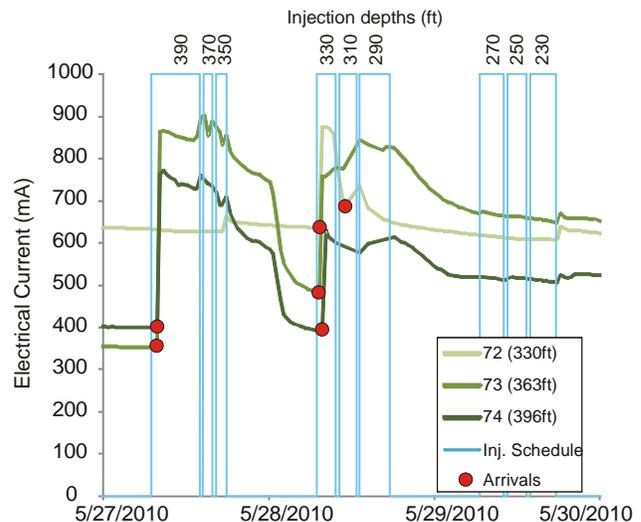


Figure 7. Electrical current output from borehole electrodes during injection on HJ-4. Lixiviant arrivals to the boreholes are shown as red dots.

Figure 7 shows an example of the electrical current output from electrodes in the eastern borehole during injection on well HJ-4. Three electrodes are shown, corresponding to depths of 330, 363, and 396 ft (101, 111, and 121 m) below the surface of the heap. The injection schedule is also overlain on the time series of electrical current to show the timing of lixiviant arrivals at the electrodes. For example, during injection at the 390 ft (119 m) depth, the electrodes at 396 and 363 ft (121 and 111 m) registered an arrival (red dot) within 45 min, during which

time the current output almost doubled. Throughout the remaining injections, the electrical current remained high suggesting a continued source of solution to the borehole. After cessation of injections for the day, electrical current drops precipitously, as vertical drainage becomes the primary mode of solution movement. The following day, the Hydro-Jex[®] injection at 330 ft (101 m) registers an arrival at the 330 ft (101 m) electrode in about 18 min. These arrival times were then used to assess coverage and impact to the heap.

While the time series of electrical currents provided a temporal assessment of lixiviant arrivals, assessing the spatial distribution of the arrivals was accomplished by evaluating the voltage potential measured on the surface electrodes during current transmission on the centralized Hydro-Jex[®] well. The voltages were linearly transformed to apparent resistivity, compared to a background measurement just before injection began (as percent difference), and plotted as spatially-continuous contours. To pick which contour represents the wetting front, we plotted contours at the time of first arrival indicated by the electrical current increase from the nearby borehole electrodes. **Figure 8** shows an example; where at 7:55am the lixiviant had arrived at the eastern borehole during injection on the 390 ft (119 m) zone. We then tracked this same contour to understand the area of impact by the injection. Specific to the 390 ft (119 m) injection zone, the wetting front appears to move southward in excess of 100 feet (30 m). The large lateral spread of the injected lixiviant was a maximum, with most injections propagating 60-80 ft radially from the well as demonstrated in other projects [4-6].

Gold Production

The VLF features three discrete pregnant solution storage areas (PSSAs). Each PSSA is supplied by a different region of the heap and pregnant solution from each can be sampled, but the grade represents the average grade of all solutions reporting over the millions of square ft of lined area within the drainage. It is not possible to directly sample solutions from any subsection of the drainage, therefore an indirect method was used to calculate the quantity of gold produced as a result of the Hydro-Jex[®] project. The impact to production was estimated by comparing trends in the pregnant solution grade against those expected from stacking and leaching histories.

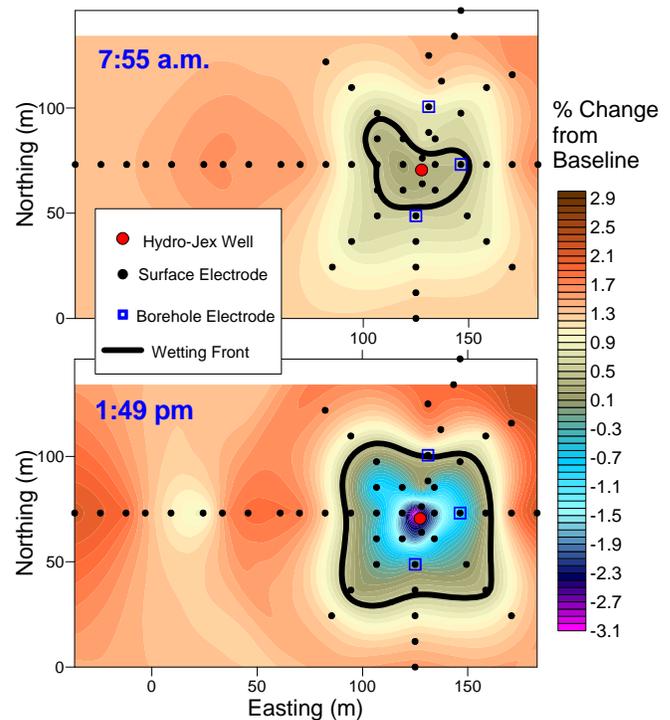


Figure 8. Apparent resistivity contours presented as percent difference from pre-injection measurements for the injection on the 390 ft (119 m) zone in HJ-4. Position of the lixiviant wetting front was interpreted from arrivals (7:55 a.m.) recorded during electrical current transmission.

As mentioned previously, one of the primary advantages of the project site was that relatively little fresh ore was scheduled to be stacked within the drainage ahead of and during the injection period. This would allow the overall pregnant solution grade to fall to 0.005 opt (0.171 ppm Au), since no solution from fresh-stacked material would be reporting to the PSSA. This base solution gold grade would permit the ounces produced during the injection to be determined from any upswings in grade. Unfortunately, because extra ore was added within the drainage area during the spring of 2010, the expected breakthrough time coincided with the injection project. Approximately 420,000 tons (381,000 mt) of ore with an average gold grade of 0.008 troy ounces per ton (0.274 g/mt) were stacked. Because the ore had a relatively low head grade and was placed in an area with a depth over 400 ft (122 m), it was not expected to produce any significant change in the overall pregnant solution grade. This further complicated the task of estimating the impact of the injections on gold production. However, there is more than enough evidence to show that the impact from the injections was very positive.

Figure 9 shows a plot of the pregnant solution grade from the Phase 2 drainage over a period spanning the

injection phase of the project. The shaded areas indicate days that injections occurred. From the graph it is clear that the solution grade was approaching 0.005 opt (0.171 ppm Au) ahead of the startup of the project as predicted and that there were several sharp grade increases coincident with the injections. Variations in liner elevations beneath the injection wells and local conditions within the VLF precluded any definitive correlations to the changes in grade; but the trends and magnitudes of the observed changes are consistent with data from drill samples – injections in areas with high residual grades were accompanied by upswings in solution grade soon after. This trend is particularly clear in the last three wells. In each case there was a solution grade increase approximately three to five days after injections on each well for the injection period. The lag time corresponds to the time that the injections reached the 290 to 350 foot (88 to 107 m) zones, the region known to exhibit higher residual grades.

Making the conservative assumption that the pregnant solution grade would have remained at approximately 0.005 opt (0.171 ppm Au); an estimated 2,700 troy ounces of gold were recovered during the injection phase of the project. However, it is likely that over 4,300 gold ounces have been recovered from the areas surrounding the injection wells. Each of the Hydro-Jex[®] wells has been subjected to

additional rinsing in the months after the injection. By fitting the wellheads with a standard flanged tee and movable depth isolation mechanism down each well, the injection zones have been rinsed further to drive out gold dissolved following the injection phase. Typically, each zone is rinsed for three to four days with a targeted flow rate of 200 gallons per minute (0.76 m³/min), with two to four wells in rinse mode at the same time. The protracted upswings in solution grade after completion of the injection phase correspond to rinsing wells HJ-4, HJ-7, and HJ-8. In each case the post-injection production likely exceeded 700 troy ounces of gold.

Rinsing of the Hydro-Jex[®] wells is planned to continue for upwards of two years. Each successive cycle introduces fresh reagents into the VLF and should continue to rinse gold from the pad that was dissolved during the previous stage. However, the number of ounces produced during each rinse should decrease and continued stacking on the VLF is likely to completely mask any impacts. It is unlikely that the ultimate impact to production will ever be able to be determined from solution analysis alone.

Directly assaying material within the areas affected by the injections will provide the most definitive indication of the overall impact of the project. As part of the overall

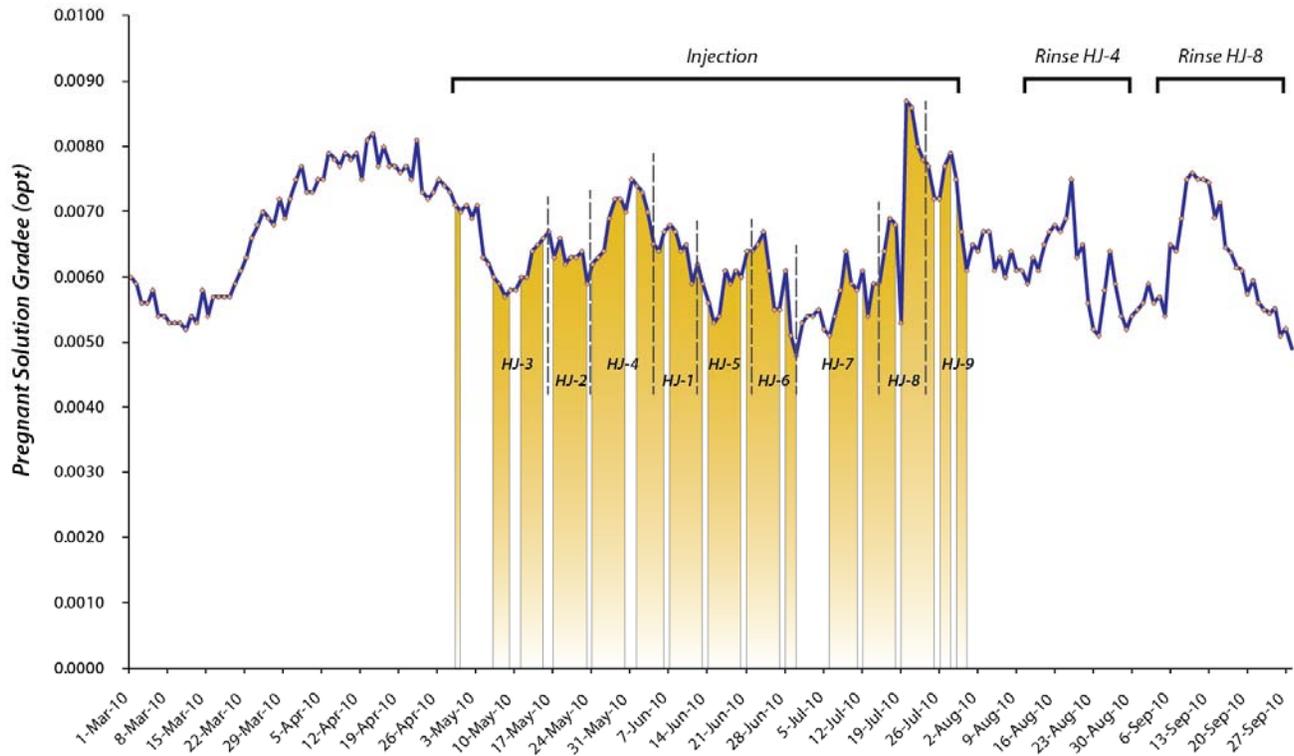


Figure 9. Pregnant solution grade vs. time. Shaded areas denote days with active injections. Time periods for rinsing HJ-4 and HJ-8 are also indicated.

project design the holes used to install the down-hole electrodes for the resistivity monitoring were incorporated into the 2010 VLF pad drill campaign. The holes were drilled with sonic drill rigs and sampled every ten ft (3 m) over the entire depth. Grade profiles from the holes agree very well with those obtained in the same area during previous pad drill campaigns. They show an area with residual recoverable grades upwards of 0.015 troy ounces per ton (0.51 g/mt) approximately 300 ft (91 m) below surface and an overall indicated inventory of approximately 10,000 troy ounces. This area will be drilled again in May 2011. Each of the nine Hydro-Jex[®] wells will have been rinsed at least twice by this time. Given the trends in the pregnant solution grade, the results should be very exciting.

Conclusion

Hydro-Jex[®] re-leaching was undertaken at the Valley Leach Facility at AngloGold Ashanti's Cripple Creek & Victor Gold Mine during the summer of 2010. The project was the first application of the Hydro-Jex[®] process outside of Newmont's Nevada heap leach operations and was the first application on a valley-fill-type heap.

The unique site conditions and extreme depths of the VLF required reengineering and upsizing of the injection system. However, Hydro-Jex[®] operations at CC&V were extremely successful. Every operational objective for the project was either met or exceeded and geophysical monitoring confirmed leaching solution was pushed well over sixty ft laterally into the heap during the injections.

Inability to directly sample solution draining from the injections forestalls direct calculation of the impact of Hydro-Jex[®] to the overall production from the VLF. However, trends in the pregnant solution grade over the course of the project, as well as the ensuing rinsing, suggest

that upwards of 4,500 troy ounces have been recovered as a direct result of the injections.

Acknowledgements

Many people provided input into the development of this technology and the project at the Cripple Creek and Victor mine and heap leach. Special thanks must be given to CC&V, DEA, the primary fabrication contractor of Elko, NV, Newmont Mining Corporation, University of Nevada, Reno, and Art Soukup, plus the Hydro-Jex[®] crews and suppliers.

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