INTEGRATING HYDRO-FRACTURING TECHNOLOGY AND GEOPHYSICS INTO 3D MAPPING AND EXTRACTION OF METALS IN HEAP LEACHING; HYDRO-JEX AND HIGH RESOLUTION RESISTIVITY ™.

Authors:

Thom Seal, Ph.D., P.E. Manager of Metallurgical Technology – Nevada for Newmont Mining Corp., Inc. P.O. Box 6415, Elko NV 89802, Thom.Seal@Newmont.com

James B. Fink, Ph.D., P.E. President of hydroGEOPHYSICS, Inc. 2302 N. Forbes Blvd. Tucson, AZ 85745, jfink@hgiworld.com

Paper prepared for presentation at the Society of Mining, Metallurgy and Exploration Inc. Annual Meeting & Exhibit, 2008 SME in Salt Lake City, UT, Feb 24-27, 2008. Mineral & Metallurgical Processing – Leveraging New Process Technology: From Other Industries – Cross Pollination, Session Chair: Patrick R. Taylor

ABSTRACT

Large heap leach operations around the world contain significant under-leached metal values that present recovery challenges to operators. The first challenge is to find the location of the highest inventory. High resolution resistivity ™ has proven sensitive enough to detect such zones in the interior of heap leach pads to target treatment or re-leaching. Newmont Mining Corp. has adapted the high pressure fracturing technology, used in oil wells to stimulate select zones in heap leach pads to add reagents in 3-D for re-leaching, changing zonal chemistry for improved recovery and heap closure. High Resolution Resistivity ™ is able to subsequently monitor injected solution flow and determine directional permeability during Hydro-Jex stimulation. The combination of these technologies has shown strong economic success, for selecting targets in the heaps and monitoring solution application. These technologies are now available to the mining industry for adoption.

INTRODUCTION

Large heap leach operations cover many hectares of containment and contain millions of metric tons of low-grade ore. The methods of ore placement and leaching on the pad can lead to compaction, channeling and dry zones within the heap with a resultant build up of potential recoverable metal values or inventory. Currently, after the ore material is placed, ripped and piped, the only operational technique to improve recovery evolves around solution and reagent management. The key to reducing metal values in the heap leach inventory is to promote the contact of the leaching lixiviant to the valuable mineral and rinsing the dissolved metal from the ore material to a recovery system. This is normally accomplished by added solution to the surface of the leach pads in a two dimensions (2-D) fashion via emitters and sprays. Hydro-Jex was invented to take heap leaching into three dimensional (3-D), which is new to the mineral extractive industry. hydroGEOPHYSICS has developed technology to produce 2D cross sections and 3-D volumetric image maps of the dry zones in the heap leach pad to optimally target the Hydro-Jex drilling and 3-D leaching. In addition, hydroGEOPHYSICS also is able to monitor leaching solution flows optimizing the Hydro-Jex process to 4-D (includes time). .

INVENTORY

The inventory of recoverable metal values in a heap leach operation is often tracked by accounting for the recoverable values placed minus the metal values recovered and sold.

As the life cycle of the ore placement culminates in a mature heap of ultimate height, the leach cycles are extended to re-leach and rinse out the residual inventory values and to adjust the chemistry and solution volume to facilitate closure. At this point the capital invested in the heap leach pad construction and the mining plus placing the ore costs are realized. Recoverable inventory metal values in the heap are “booked” reserves and are either produced or written off. Additional recovery of metal values often reflects production free of construction and mining costs.

The inventory of un-recovered metal values found in un-leached or under-leached zones in the heap’s interior are mostly unavailable to standard surface solution management leaching and rinsing techniques.

Additional data on inventory in the heap can be determined by assays sampled during drilling. Data from a set of 20 drill holes on one rinsed, mature heap sampled every 5 feet in the 200 ft depth show a moisture variance of 0.25 % to 25% and cyanide soluble gold contained (AuCN) values from 0 to 1.5 grams/metric ton (g/t), with an average of 0.17 g/t. At current gold prices of approximately $750 per troy ounce of gold, the AuCN inventory is over $ 4 per metric ton. Drilling of other regional heaps also show inventory values in the range of $ 2 – $ 5 per metric ton. Modeling the drill data does show regions of higher gold inventory correlating with lower moistures, (**Fig 1).** Drilling is expensive**.** hydroGEOPHYSICS Inc. provided resistivity surveys to map the dry zones in the heap, allowing potential Hydro-Jex drill targets to be identified and drilled, (**Fig 2).**

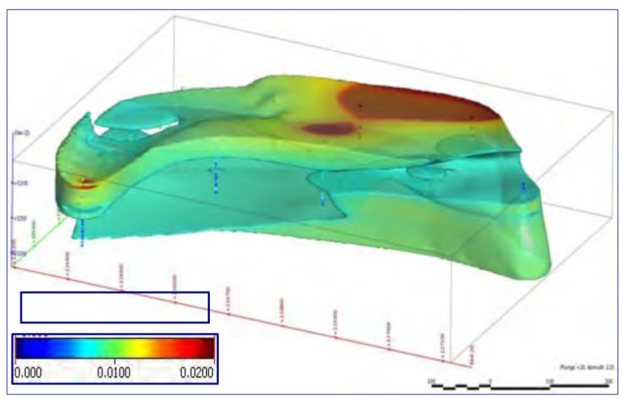

FIGURE 1: Gold Inventory Locations in a Heap

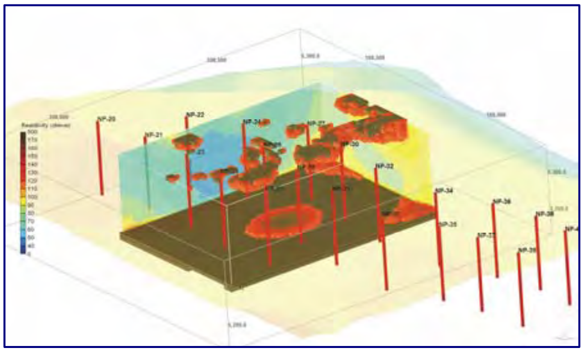

FIGURE 2: Location of Dry Zones by Resistivity

These resistive, dry zones are normally the result of compaction, heap settlement, migration of fines, clay zones, inadequate ripping of lifts after ore placement, and chemical precipitation. Assay data from the top of the drill hole NP-22 in (**Fig 2)** shows a 10 meter dry anomaly near the top of the hole with average 3% moisture and an AuCN grade of greater than 0.2 g/t gold.

The chemistry of the rocks in the heap and the resultant solution flowing to recovery is often not of the quality required for closure. Operators normally rinse a mature heap for years to recover as much of the reserve metal value inventory and attempt to change the chemistry of solution from the heap. It is estimated that rinsing Newmont's Property Pad will take over 20 years with pumping and operational costs of $ 5 million dollars/year. Operators can also drill the heap and assay the sections to evaluate the inventory and pad chemistry, (**Fig 3).** If an operator is planning to drill a mature heap, why not use Hydro-Jex?

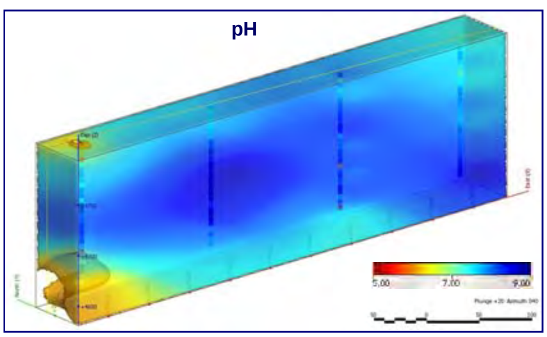

FIGURE 3: pH Mapped in 3-D from Drill Assays.

HYDRO-JEX

In an effort to meet the challenge of introducing all the lixiviants to the dissolution sites and then rinsing the dissolved metal values, a new technology was developed and a provisional US patent on the technology has been filed. The technology is called Hydro-Jex for water chemistry (**<u>Hydro</u>**)-lixiviant solution in**<u>j</u>**ection and metal **<u>ex</u>**traction.[1] This new technology is compatible with heap leach chemistry and recovery systems. The technology has been designed into four stages:

1) Site Design Drawings of the mature pad and construction information are analyzed for slope stability and integrated with data from geophysical resistivity surveys resulting in the drill hole design for implementation in an approved modification of the state solution management permit.

2) Drilling The heap leach pads are drilled and sampled to quantify the inventory and chemistry using mine software kriging.

3) Stimulation High pressure pumping of solution to facilitate reagent addition to targeted zones of un-leached or under-leached ore material in 4-D.

4) Re-Leaching Extractive solution with reagents are added periodically into the stimulated zones to re-leach and rinse the dissolved metal values for recovery and to further enhance chemical changes.

Enhancing the heap re-leaching and rinsing process into 3-D via Hydro-Jex could reduce pumping, closure time and operational costs compared to conventional operational techniques. Thus with the Hydro-Jex technology a heap leach operator can add a gamut of reagent formulations and concentrations to a pre-selected zone or depth to facilitate leaching, change the chemistry or pH, re-channel solution migration paths, and then periodically rinse the dissolved metal values from the zone. This process is currently being used at four of Newmont's heap leach pads in Nevada and is approximated in (**Fig 4)**.

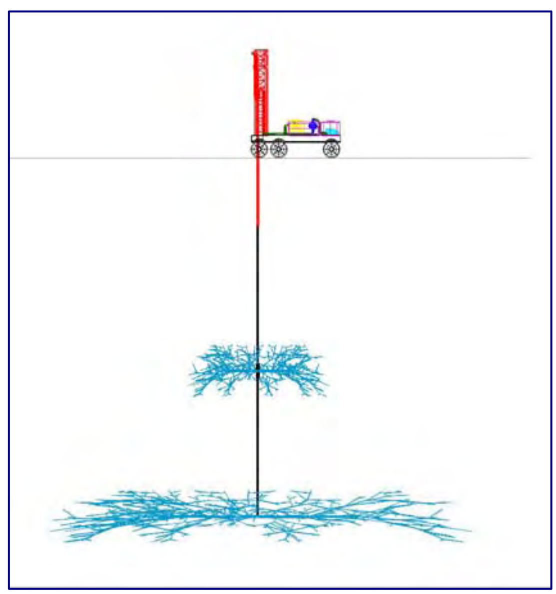

FIGURE 4: Hydro-Jex Illustration.

HYDRO-JEX OPERATIONS

Site Design: Currently, the state of Nevada is requiring an Engineering Design Change (EDC) to the process solution management plan permit. This EDC includes engineering construction site review and slope stability analysis. The evaluation of slope stability consists of defining a likely failure surface, then calculating the factor of safety along that failure surface. The major items affecting stability analyses are a) the geometry of the section of material analyzed, b) the shear strengths and/or frictional resistances of the materials, and c) the pore water pressure conditions in the heap and subsoils.[2] A slope stability analysis for a Hydro-Jex saturated zone during the re-leach/rinse cycle near a heap crest is presented in (**Fig 5)**, with a safety factor of 1.6 (S.F.).[3]

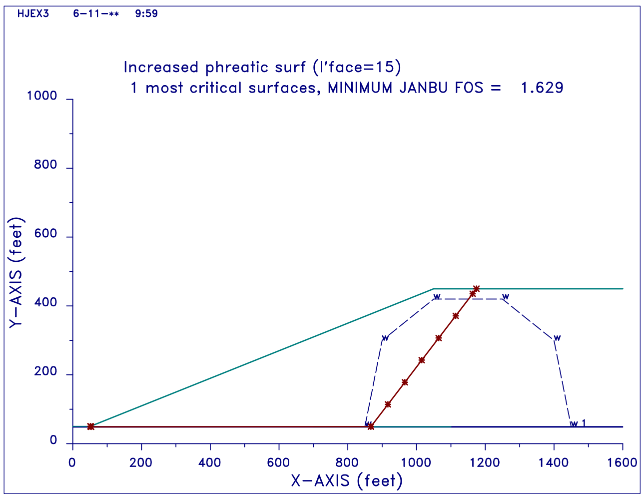

FIGURE 5: Engineering Slope Analysis, S.F. = 1.6.

Drilling: A typical Hydro-Jex field has drill holes surveyed to be 50 to 60 meters apart (160 to 200 ft) with depths 15 meters (50 ft) above the collection liner as a safety factor. The drill holes are also designed to be 15 meters (50 ft) from the heap leach sloped edge, (**Fig 6)**.

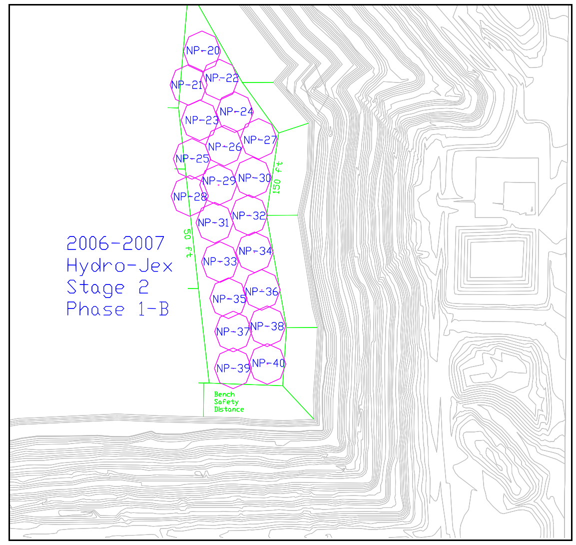

FIGURE 6: A Hydro-Jex Field

The field is then drilled using a dual rotary drill or Barber drill with samples every 1.5 meters (5 ft) that are assayed and krigged, (**Fig 7).**

FIGURE 7: Dual Rotary Drill

A drill casing is inserted while drilling and the casing perforated at specific depths to target compact or dry zones. The Barber drill can drill, sample and perforate a 60 meter (200 ft) hole in a twelve hour shift at a cost of about $120 per meter ($40/ft) including mobilization, casing and operational costs.

Stimulation: The Hydro-Jex control trailer linked with a high-pressure pump is positioned near the drill hole and downhole packers are inflated below and above each perforated zone, (**Fig 8)**. This system monitors fluid pressure and volume in time, (**Fig 9-10)**.

FIGURE 8: Hydro-Jex Stimulation System.

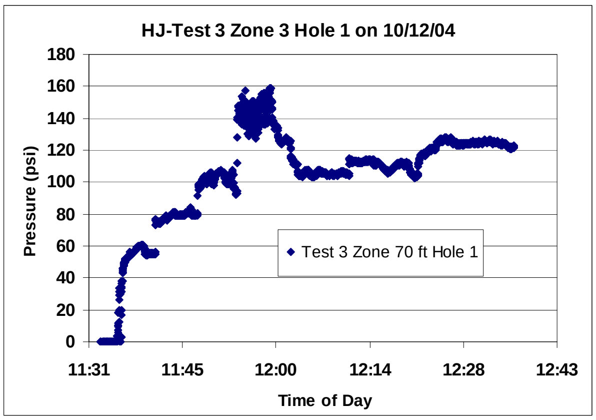

FIGURE 9: Pump Pressure (psi).

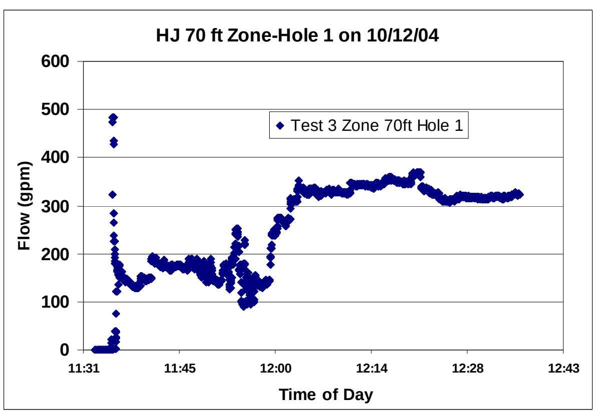

FIGURE 10: Pump Volume (gpm).

Initially, the zone's permeability is measured as a function of flow and barren line pressure. The pump is then started and pressure builds as the pump rpm is increased stepwise. When the pump's pressure exceeds the rock pressure found in the zone, breakdown occurs and the pressure decreases and the solution flow increases. Typical solution pumping time is 1.5 to 2 hours per zone. Geophysical resistivity of the heap shows solution flows, hydraulic conductivity and recovery or solution drain down after pumping. (**Fig 11-12).** Vertical staging from zone to zone takes about 0.5 hours. Trailer and pump movement from hole to hole takes 0.5 days.

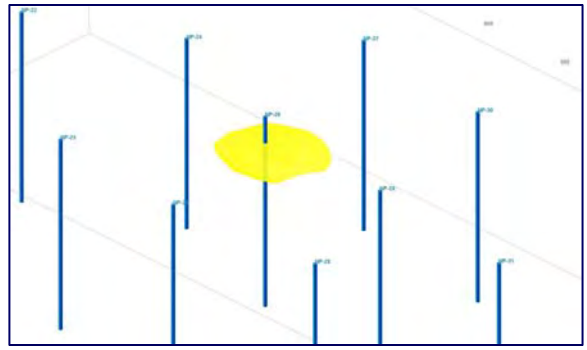

FIGURE 11: Geophysical Resistivity after Hydro-Jex Stimulation at 1.5 hours (meters).

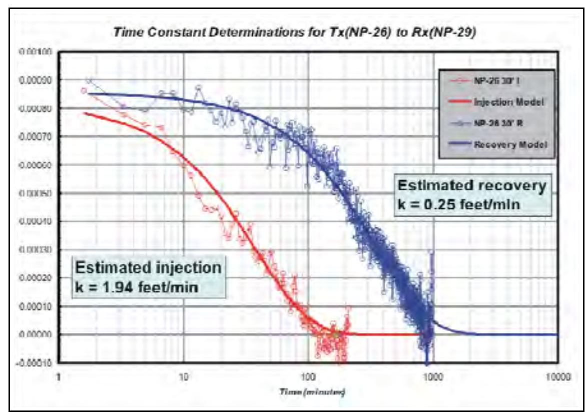

FIGURE 12: Hydraulic Conductivity (k) from Injection and Recovery by Geophysical Resistivity.

A variety of reagents are added to facilitate pumping pressures, leaching, pH enhancement, and chemical changes in the heap. Typical costs for the stimulation are about $120 per meter ($40/ft) at remote sites, which include supplies, mobilization, operational and travel expenses.

Re-Leaching/Rinsing: A time period between stimulation is needed for the reagents to dissolve the metal inventory, followed by re-leaching/rinsing cycles, (**Fig 13**). A vacuum at the wellhead is found to facilitate reagent addition as rinse flow is monitored. (**Fig 14-15).**

FIGURE 13: Re-Leaching/Rinsing in 3-D.

FIGURE 14: NaCN Solution, Air and Scale Inhibitor added to Heap via Vacuum at Wellhead.

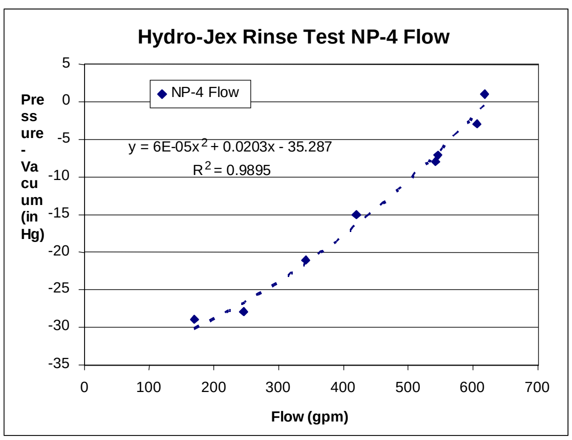

FIGURE 15: Wellhead vacuum (In Hg) v. Flow (gpm).

HYDRO-JEX METAL PRODUCTION

The heap liner design and collection system used on many heap leach pads allows collection and assaying of the pregnant solution (solution flowing from the heap with dissolved metal values)[4] so the effects of the Hydro-Jex technology can be evaluated on a mature heap, (**Fig 16)**. The gold production averaged 27 troy gold ounces/day for over a year. The average gold solution measured so far has been 13.7 troy gold ounces/meter drilled (4.2 troy gold ounces/ft drilled).

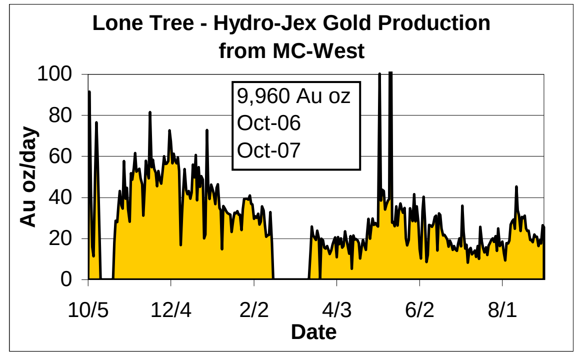

FIGURE 16: Gold production for a Hydro-Jex Field.

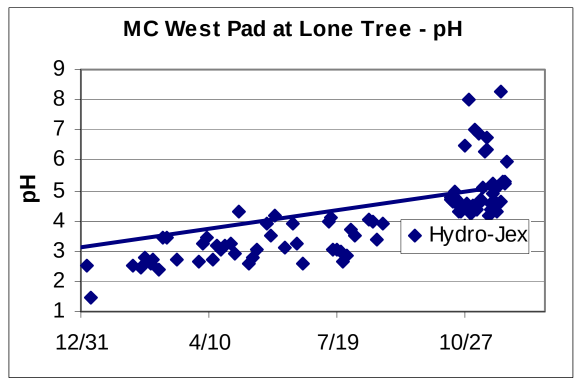

FIGURE 17: pH changes from Hydro-Jex.

Four Hydro-Jex holes were drilled and the effects of adding high pH solution down the Hydro-Jex holes during the re-leach/rinse phase was measured, (**Fig 13 & 17)**.

CONCLUSIONS

Large mature heap leach pads can contain significant metal values found as inventory which represent an economic resource with an operation challenge to recover. Extensive capital expenditures have been spent to place this ore on the heap, such as containment construction, mining, hauling, and reagent addition. Operational expenses, including pumping costs, can be budgeted for years to attempt to rinse as much of the inventory from the heap prior to closure. In an effort to maximize the return from these expenditures, heap leach operators need to optimize the leaching process by introducing the dissolving lixiviant reagents to the 3-D location of the metal values and then rinse the dissolved metals to recovery. Identifying the location of the inventory and chemistry characterization, with use of resistivity surveys and drilling can accelerate closure. 4-D leaching via Hydro-Jex is faster, cheaper and an effective process to augment normal surface 2-D leaching and long term rinsing. The Hydro-Jex technology is an important tool for heap leach operations that will improve metal recovery, change solution chemistry and reduce rinsing time and closure expense.

ACKNOWLEDGEMENTS

Many people provided input into the development of this technology. Special thanks must be given to Newmont Mining Corporation's: process, maintenance and instrumentation departments, Reg Montgomery, Wayne Trudel, Hydro-Jex Tech's, plus Eklund Drilling Co., and hydroGEOPHYSICS. Newmont Mining Corporation, Inc provided funding for this study.

REFERENCES

[1] Seal, T., Enhanced Gold Extraction in Cyanide Heap Leaching Using Hydro-Jex Technology, Ph.D. Dissertation, U of Idaho, May 2004, pp 90-99.

[2] Van Zyl, D.J.A., Hutchison, I.P.G. and Kiel, J.E., 1988, Introduction to Evaluation, Design and Operation of Precious Metal Heap Leaching Projects, Society of Mining Engineers, page 168.

[3] Bryan Ulrich, P.E. (Civil), Pr. Eng. (Mining) B.S. (Mining Engineering), B.S., (Geological Engineering), MEng (Geotechnical Engineering) presentation to the State of NV, June 2007.

[4] Bartlett, R.W., Solution Mining, Gordon and Breach Publishers, 1995, page 25.