Exploration and Optimized Extraction of Retained Gold Inventory in Heap Leach Stacks Prior to Closure

J. B. Fink, Ph.D., P.E., and R. S. Bell, hydroGEOPHYSICS, Inc.
Thom Seal, P.E., Ph.D., Newmont Mining Corp., Inc.

Abstract

High Resolution Resistivity (HRR™) is used to explore for retained gold inventory within a heap leach stack prior to closure. The gold is orphaned within the heap because of incomplete wetting of the leaching solution. Injection wells are then drilled and set within the mineralized zones. Newmont’s innovative Hydro-Jex 3-D leaching process is applied to stimulate the heap and directly apply a lixiviant.

HRR™ is used to monitor in real-time the Hydro-Jex stimulation to achieve maximum metal recovery with minimum application of lixiviant solution. Such optimization leads to a significant reduction in the time required to recover the retained Au inventory and accomplish full heap closure.

Introduction

Resource recovery from heap leach-able ore piles assumes a consistent flow of lixiviant through a highly permeable volume of rock. Fluid flow depends on directional hydraulic conductivity, which is a function of the particle size and heap construction. In some cases, the leaching solution will not adequately wet portions of the heap because of low permeability confining layers formed as a result of the agglomeration of fine grained material or chemical precipitation. Thus, inadequately leached ore zones from within the shadow of the confining layers. The net result is orphaned yet recoverable gold inventory such as illustrated by Figure 1.

Electrical resistivity of earth materials is largely a function of the degree of fluid saturation within the pore space. Because shadowed zones are dry, they resist the flow of electrical current. Therefore, electrical resistivity is the obvious geophysical method for exploiting these phenomena in the exploration for this style of deposit. However, once discovered, the extraction of the resource requires a new approach since the very existence of the shadowed zones is often due to the construction of the heap or the conventional mode of extraction.

Newmont Mining developed the Hydro-Jex method (Seal, 2007) for stimulating a heap and delivering the lixiviant, often in high concentration, directly to the pay zones identified through the use of the resistivity method to characterize of the heap. Through real-time observation of the spatial changes electrical properties of the heap during a Hydro-Jex fluid injection, the hydrodynamic behavior of the heap is monitored and the effectiveness of the process can be assessed.

![Figure 1: Retained Metal Inventory.](image-url)
**HRR™ Characterization of Heap Leach Piles**

hydroGEOPHYSICS, Inc. (HGI) developed the HRR™ method to take advantage of the superior signal-to-noise and depth of investigation characteristics of the pole-pole array (Fink, 1995). Fortuitously, the advent of multi-channel, taskable, digital recording data acquisition systems makes the acquisition of high spatial density resistivity data affordable. The data are processed using a proprietary algorithm designed to integrate the terrain into a geometrically corrected 2D resistivity versus depth image section, which in many cases will closely resemble the true lateral and vertical resistivity distribution. Moreover, the high spatial density of the data is highly amenable to 3D inversion resulting in a volumetric rendering of distribution of resistivity variations within the heap. In the most simplistic case, the exploration targets become the zones of higher resistivity.

Figure 2 shows is illustration of the HRR™ lines that were acquired on a heap at Gold Quarry mine operated by Newmont Mining near Carlin, NV. The majority of the HRR™ lines were primarily oriented east-west to characterize the area of interest centered about well NP-26 prior to stimulation of the heap with the Hydro-Jex process. The rectangle outlines the volume of resistivity data that was used for the detailed 3D inversion.

Figure 3 is an example HRR™ resistivity versus depth image section acquired on the heap. The red hues are more resistive while the blue hues are less resistive.

The HRR™ data were processed using the Advanced Geosciences Inc. (AGI) EarthImager™ 3D resistivity inversion software. Figure 4 is a volumetric rendering of the 3D inversion results highlighting the anomalously resistive zones (red), as well as the anomalously conductive zones (blue). Figure 5 shows the resistive and conductive zones in plan view as well as a volumetric rendering.
Figure 4: Volumetric Rendering of 3D Inversion Results.

Figure 5: Resistive and Conductive Zones from 3D Inversion.
Hydro-Jex Stimulation of Heap Leach

The Hydro-Jex process stimulates the heap by opening up plugged pathways and creating new flow paths while simultaneously delivering a customized lixiviant to the pay zones. Resistivity is used to characterize the heap, identify potential pay zones, and influence drilling locations for the injection well field. A specialized drill rig is employed to collect samples from the heap while setting the steel casing. The samples are analyzed to obtain an inventory versus depth profile, which is then used determine the optimum formulation of the chemistry for injected solution as well as the depth for each Hydro-Jex injection. Figure 6 is an example of a Hydro-Jex assay profile. Figure 7 illustrates the fluid injection and heap stimulation process.

Electrical Monitoring of Hydro-Jex Process

The increase in the level of water saturation in geologic materials improves the ability of the formation to conduct electrical current. This suggests that it is possible to map the apparent zone of influence of each Hydro-Jex fluid injection by measuring the variation in the transfer resistance. Since the casings are points of electrical contact with the formation, they can be used in conjunction with discrete electrodes on the surface as sensors for measuring the variations in transfer resistance with time. Figure 8 is an illustration of the configuration deployment of a monitoring system using steel casings as long electrodes.
A network of electrodes composed of the steel well casings used of the Hydro-Jex injections and surface electrodes were wired into a trailer mounted 30-channel resistivity data acquisition system. Transfer resistance measurements were made at discrete, closely spaced time intervals to obtain an electrical time series representing the hydrodynamic behavior of the heap before, during, and after each injection. Figure 9 shows a plot with a set of four (4) receiver well casings. A common current transmitter was used to acquire each waveform.

The time period of each Hydro-Jex injection is highlighted by the gray vertical band. The transfer resistance ramps up during the injection to a peak value then ramps down during the recovery period after the active stimulation is complete. The time constant derived for each part of the time series is function of the effective hydraulic conductivity of the formation, \( k_e \).

Figure 10 is a composite of some polar plots. It shows the spatial variation of the effective hydraulic conductivity, \( k_e \), calculated for the rise (i.e., during the injection) and the recovery (i.e., the period after the injection) at depths of 30 ft. and 170 ft. At the 30 foot level, the hydraulic conductivity derived from the electrical data for the injection is approximately 8 times the value derived for the electrical data acquired during the recovery period. In contrast, the effective conductivities for the 170 ft level for the injection and recovery periods are more similar.
Conclusions

HRR™ characterization of the heap identified zones of higher resistivity that are likely the result of inadequate wetting. These dry zones have a high probability for containing gold. The zones of lower resistivity imply an increase in moisture content indicating the possible development of preferential fluid flow paths within the heap volume.

The asymmetry of the effective hydraulic conductivity calculated from the changes transfer resistance resulting from the Hydro-Jex stimulation suggests a more consistent application of lixiviant occurs at depth than closer to the surface. The quantitative assessment of the hydrodynamic response of the heap obtained through electrical monitoring of the injections offers the promise of optimizing the extraction process, both with respect to reducing the amount of time and the amount of lixiviant required. Once the remaining metal inventory has been successfully removed, closure and reclamation procedures can commence.
References

*Update on the Hydro-Jex Technology – Enhanced Gold Extraction from Heap Leach Pads* by Thom Seal, P.E., Ph.D., presented at the Northwest Mining Association Conference, December 2006.