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APPLICATION OF GEOTHERMAL ENERGY TO MINERAL PROCESSING: CYANIDE HEAP-LEACHING OF LOW-GRADE GOLD ORE

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ABSTRACT

The advent of cyanide heap-leaching for low-grade gold and silver ores has resulted in an unprecedented increase in the output of mines throughout the world. This simple and economical process entails open-pit mining, milling, and stacking ore, which is then soaked with a dilute solution of sodium cyanide. The cyanide solution dissolves both gold and silver, which is subsequently recovered by additional processing. Many of these mines are located in remote, inaccessible areas and are subject to severe climatic conditions. Some operations are terminated during extreme cold or rainy seasons. As a result of United States Department of Energy sponsored investigations conducted by the Division of Earth Sciences, University of Nevada, Las Vegas, and the Mackay School of Mines, University of Nevada, Reno, some operating mines in Nevada were found to be co-located with geothermal resources suitable for use in cyanide heap-leaching operations. Low-to moderate-temperature geothermal resources may be used to heat the cyanide circuit, providing a low-cost method of maintaining the operation during freezing conditions. This paper describes the results of bench-scale heap-leaching experiments using a simulated geothermal source to increase metal dissolution rate. In addition, examples from two active mines that utilize geothermal energy in commercial-scale operations are included. The implications for co-development of gold and geothermal resources in Central America are discussed.

INTRODUCTION

Mining and mineral processing activities throughout the world are often located in remote, poorly accessible areas. A reliable and affordable energy source is an essential factor in profitable mine management. Geothermal energy resources, which appear at the surface as fumaroles and hot springs, are often co-located with hydrothermal mineral deposits (Trexler, Flynn, and Hendrix, 1987). Recent technological advances permit utilization of moderate temperature resources for process heating and electric power generation. In addition, large-scale gold and silver mines, which exploit low-grade, disseminated ore bodies, may operate in one location for 20 to 30 years. The critical need for low-cost energy and close proximity of geothermal resources combine favorably for the mining and mineral processing industry. This paper describes the results of ongoing investigations on geothermal energy applications in the mining industry. Bench-scale experimental results, examples of present-day use, and suggestions for geothermal energy utilization at selected mine sites are included.

The original purpose of this research was to demonstrate a practical application of geothermal energy for active mines in Nevada that use cyanide heap-leaching to recover gold and silver from low-grade ore. During the course of the investigation, two other applications of geothermal energy to

Table 1. Proximity of Geothermal Resources to Active Mines in Nevada.

Name of Mine	Type of Ore	Geothermal Proximity	Fluid Temperature
Pegasus Gold Corp.	Gold/Silver	On Site	100°C
Round Mountain Gold	Gold/Silver	On Site	86°C
West Northumberland	Gold	13 km	68°C
Jerritt Canyon	Gold/Silver	6 km	90°C
Boot Strap Mine	Gold	On Site	50°C
Rawhide Mine	Gold/Silver	10 km	62°C
16 to 1 Mine	Silver	1 km	48°C
Maggie Creek Mine	Gold	On Site	warm
Gold Quarry Mine	Gold	On Site	warm
Tonopah Divide	Gold/Silver	On Site	warm

the mining industry were identified. One process is an experimental pre-treatment of sulfide-rich gold and silver ores using bacteria. The other process is the use of moderate- to high-temperature geothermal fluids to produce electricity using binary fluid technology. This paper focuses on the application of geothermal energy to cyanide heap-leaching operations. The principal effort was to illustrate the benefits of low-temperature geothermal fluids as an economical alternative to fossil fuels used to maintain temperatures in aqueous cyanide solutions during cold winter months.

CO-LOCATION OF PRECIOUS METAL MINES AND GEOTHERMAL RESOURCES

The benefits of using geothermal fluids are directly related to the proximity of the resource to the mine site. In Nevada, for example, 32 mines that produce gold, silver, or both, were identified, but only ten were found to be closely associated with known geothermal areas (Table 1).

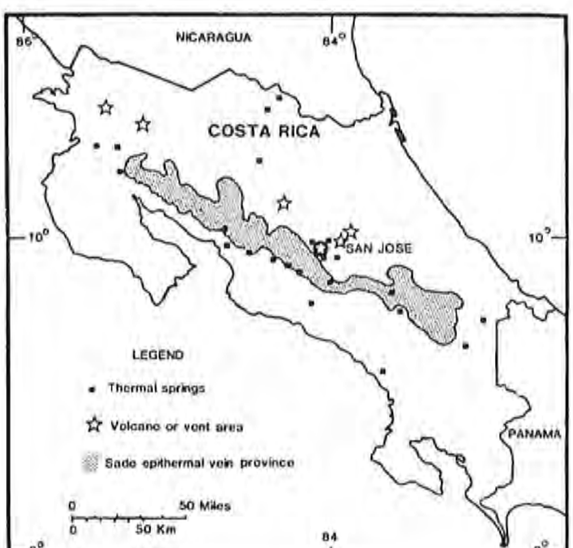

Figure 1. Location of thermal manifestations in relation to the Sado epithermal vein metallogenic province of Costa Rica.

Geothermal springs are widespread throughout Central America and geothermal resource exploration and development are underway from Guatemala to Panama. Gold mining, especially of low-grade ores, has become increasingly more important to the economic development of all of the countries in Central America. Because mineral and geothermal resources are both site-specific activities, a reasonable degree of co-location must be achieved to maximize the potential economic benefits of joint exploitation. Figure 1, for example, shows the location of geothermal activity in relation to the principal metallogenic province in Costa Rica. Potential sites for co-development appear along or close to the Sado epithermal vein province.

The principal benefit of using geothermal energy in cyanide heap-leaching operations is the increase in productivity that results from chemical processing conducted at elevated temperatures. The use of geothermal fluids in cyanide heap-leaching operations should include a careful consideration of the following parameters.

Effects of Temperature

Julian and Smart (1903) were the first to demonstrate the relationship between temperature and rate of dissolution of gold by cyanide solutions and established 85°C as the maximum temperature for cyanide dissolution of gold. Several years later Meyer (1931) determined a maximum dissolution temperature of 80°C.

Solution temperature is critical because it is difficult to control and because external adjustments will alter chemical reaction rates. Temperature is difficult to control because in Nevada, for example, heap-leaching operations are performed outdoors where diurnal temperature variations of 10°C to 21°C are not uncommon. Operational difficulties in freezing temperatures can be reduced or eliminated by increasing the cyanide solution temperature.

Effect of Oxygen

Temperature is not the only factor that controls the rate of dissolution of gold in cyanide solutions. Elsner (1846) first recognized the essential need for atmospheric oxygen in the

Table 2. Ions that affect cyanidation.

Accelerating	Neutral	Retarding
Pb, Hg, Bi, Tl	Na, K, Cl, NO_3, SO_4	Fe, Cu, Zn, Ni, Ca, Ba, C, (Pb), Mn, S_2^-

dissolution of gold in cyanide solutions. Lund (1951) pointed out that in cyanide dissolution experiments with silver, oxygen is continuously consumed during the reaction. Habashi (1967) noted that atmospheric oxygen (20 percent of a volume of air) is the oxidizing agent universally used in cyanide gold mills.

The solubility of oxygen is inversely proportional to the temperature of aqueous solutions. It is essential that dissolved oxygen levels not decline as a result of adding heat to the aqueous solution. Habashi (1967) indicated that the important consideration is not the absolute amount of cyanide ion and oxygen, but the ratio of the molar concentrations. He determined that the maximum dissolution rate occurs when the molar ratio $[CN^-]/[Q]=6$.

Effect of pH

Another critical factor is the pH of the aqueous solution. In near-neutral pH or acidic solutions, the cyanide ion, $[CN^-]$, is subject to hydrolysis by water or decomposition by atmospheric carbon dioxide. In cyanide practice, the pH of mill solutions usually ranges from 11 to 12.

Effect of Foreign Ions

Habashi (1967) summarized the impact of foreign ions on the cyanide dissolution of gold and silver. He found that ions can accelerate, retard, or have no effect on the dissolution rate. Table 2 lists the ions most likely to be encountered in gold ores and their associated effects.

EXPERIMENTAL RESULTS

A series of bench-scale experiments were performed to determine the effects of elevated temperatures on typical Nevada gold and silver ores. All tests were conducted using a flask and shaker bath apparatus. One hundred grams of ore were placed in the 500 ml Erlenmeyer flask and 200 ml of 0.5 g/l NaCN solution with a pH of 10.5 was added to the flask. The flask was then attached to a shaker arm and immersed in a thermostatically controlled temperature bath. The flask was oscillated in the bath for a prescribed period of time at a constant temperature. The independent variable in these experiments was temperature.

The gold ore was obtained from the Freeport Jerritt Canyon mine, in Elko County, Nevada, and contained 0.25 oz/T gold. The silver ore was obtained from the Gooseberry mine in Washoe County, Nevada; it contained 6.30 oz/T. These data, reported as Troy ounces, were obtained by fire assay technique.

Gold Ore Results

Figure 2 shows that the extraction of gold from the Freeport ore is significantly increased at higher temperatures. Extraction is measured as a percentage of the total amount of gold in the ore. Maintaining the cyanide solution at 20°C provides an increase in the extraction rate of eight to twenty percent relative to 5°C. In addition to demonstrating the enhanced extraction rates at higher temperatures, these data show the influence of carbonaceous material in the ore on the pregnant cyanide fluids. In all three cases, but especially at 10°C, the data suggest that gold recovery actually decreases after two hours. This phenomena is caused by allowing pregnant solutions to remain in direct contact with carbonaceous material in the ore. In actual cyanide practice, the pregnant solutions are piped from the ore body to a series of columns that contain carbon. The gold is stripped from solution by the carbon and returns to the heaps depleted of gold. The gold is removed from the carbon columns in another processing step.

Silver Ore Results

The silver ore experiments were nearly identical to the gold ore tests. Results of the silver extraction from the Gooseberry ore for four different temperatures are shown in Figure 3. The effect of increasing temperature on the extraction rate for silver is also evident. In 24 hours, at 35°C, more than 90 percent of the available silver was extracted. At 5°C,

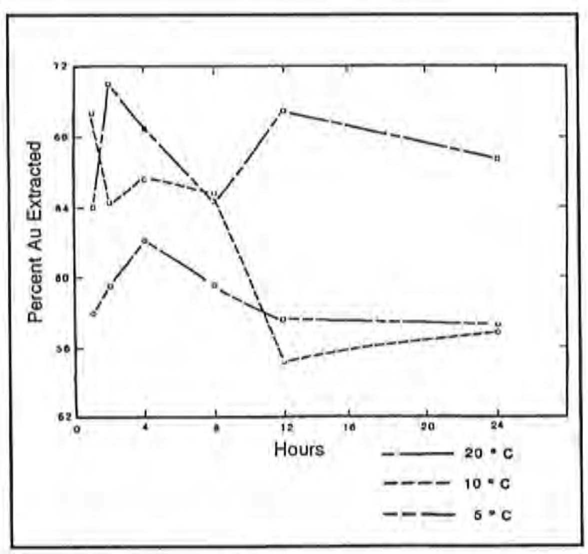

Figure 2. Gold extraction from Freeport ore when leached at various temperatures.

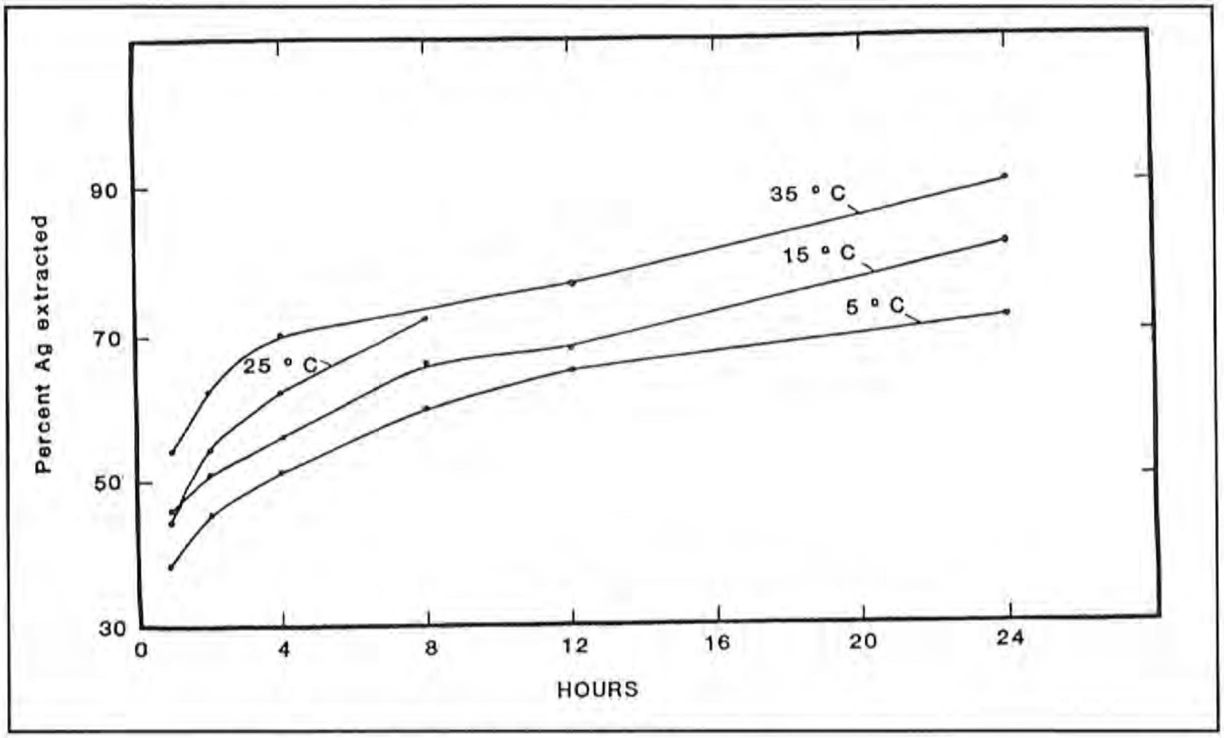

Figure 3. Silver extraction from Gooseberry ore when leached at various temperatures .

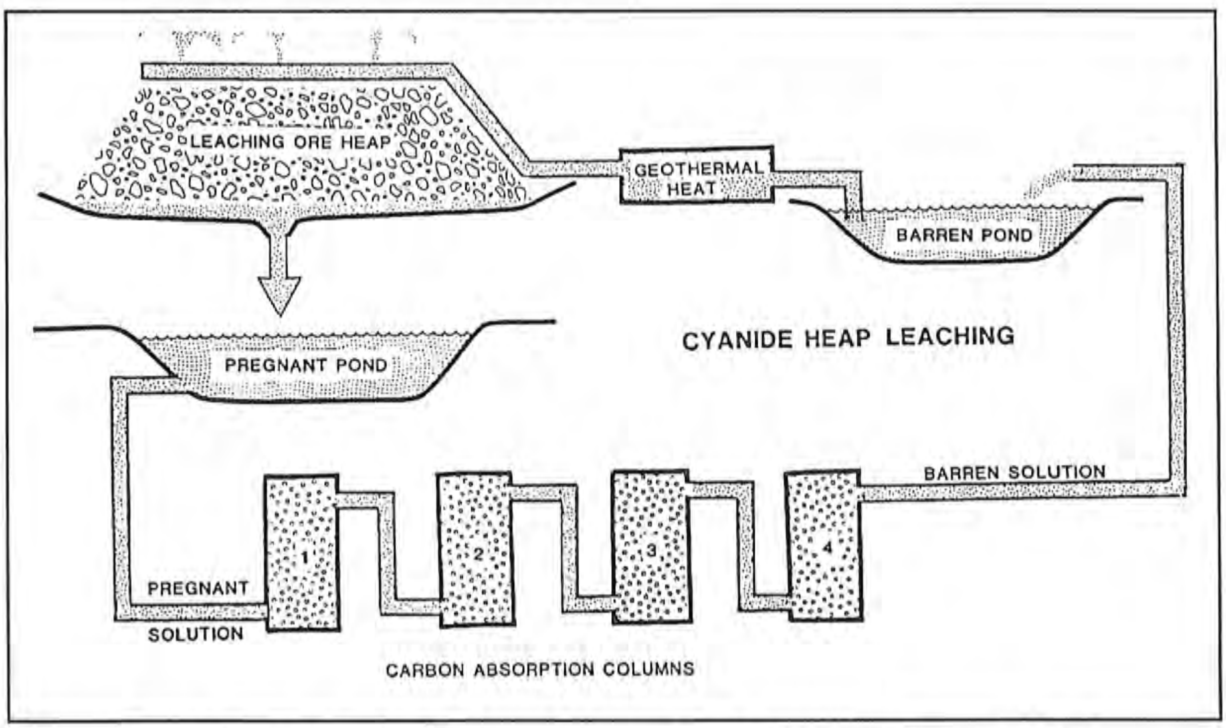

Figure 4. Diagram showing the major components of a cyanide heap-leaching operation using geothermal heat.

only 72 percent was extracted. Increases in recovery of silver with cyanide solutions at 35°C range from 17 to 39 percent for these short duration laboratory tests. These experiments demonstrate that higher temperatures can effectively increase the rate of gold and silver ore extraction from typical Nevada ores.

EXAMPLES OF GEOTHERMAL APPLICATIONS AT TWO NEVADA MINES

Figure 4 shows the configuration of a typical cyanide heap-leaching operation heated by geothermal fluids. The ore heap is soaked with a dilute solution of sodium cyanide, maintained at a pH of 11. Gold-rich solutions are pumped from the pregnant pond to carbon-filled columns that strip the gold and return the solution to a barren pond. From there, the cyanide solution is pumped back to the heap and the process is repeated. Many mines use sprinkler heads because the fluids are aerated in the process. Heating is usually applied to the solution immediately before it is sprayed on the heap. Figure 5 is a flow chart that illustrates the use of thermal fluids as a water resource, and the use of injection wells for geothermal fluid disposal.

Pegasus Gold Corporation - Florida Canyon Mine

The Florida Canyon gold deposit is located on the west flank of the Humboldt Range, within the Imlay mining district of central Nevada. The ore body consists of hydrothermally altered argillaceous sediments of the Late Triassic Grass Valley formation. The age of the hydrothermal alteration is uncertain, but K-Ar data from nearby quartz-adularia assemblages suggest an age of 70 to 75 m.y. (Silberman et al., 1973). The deposit is adjacent to the juncture of northeast-trending lineament and north-south-trending Basin and Range normal faults. The present open-pit minable reserves are 17.8 million t with an average grade of 0.025 oz/t. The waste to ore mass ratio is 1.09:1. The annual production for 1988 was 60,000 oz.

Geothermal fluids are pumped from a well, 180 m deep, which is located on the property. The mine is adjacent to the Rye Patch KGRA (Known Geothermal Resource Area). The maximum temperature in the well is 115°C and fluids are produced at 98°C. Geothermal fluids are high in total dissolved solids (TDS) and are the only source of groundwater at this mine. Pumped geothermal fluids are not immediately used in this operation, but are stored in an open pond where they are allowed to cool and absorb oxygen from the atmosphere (Figure 5). Once cooled, they are chemically treated with lime, sodium cyanide and an anti-scaling compound. The cyanide rich solution is then pumped through a geothermal heat exchanger to the heap. The heat exchanger receives fluids from the geothermal well and those fluids are piped to the cooling pond. The gold-laden pregnant cyanide solution is processed, the gold is removed, and the barren cyanide fluid is returned to the heap. Detailed geothermal fluid flow rates and temperature data are not available, but it has been estimated that the annual energy budget for this system is 40 billion BTU/yr.

Round Mountain Gold Corporation

Round Mountain Gold is currently the world's largest open-pit, heap-leach, gold mine. The mine is located in Big Smoky Valley, in central Nevada, at an elevation of 2 km above sea level. The ore body occurs within hydrothermally altered rhyolitic tuffs and ignimbrites. Gold is disseminated throughout the volcanic rocks and individual particles range in size from 6 mm to 2 microns. Only the smallest gold particles are leached.

In 1988, 234,000 oz of gold were produced. Ore production was recently increased from 18,000 t/d to 40,000 t/d with an anticipated recovery of 320,000 oz of gold in 1989 (production increase of 37 percent).

During the cold winter months, geothermal energy is used to heat the cyanide circuit from a temperature of 5°C to 22°C. This prevents the solution from freezing on the top of the heap, which would effectively terminate the operation. Geothermal fluids at a temperature of 82°C are pumped from three wells, located on the property, at a combined flow of 158 l/s to two flat-plate heat exchangers. The separate cyanide circuit has a flow rate of approximately 632 l/s, and this solution is also recycled (Figure 5).

Make-up water, i.e., water lost to evaporation, is piped from a non-thermal well, located approximately eight miles from the mine. Geothermal fluids, therefore, are not required as a fluid source and are injected back into the thermal aquifer.

Prior to the installation of the geothermal heating system, two oil emersion burners were used to heat the cyanide circuit during the cold winter months at an estimated

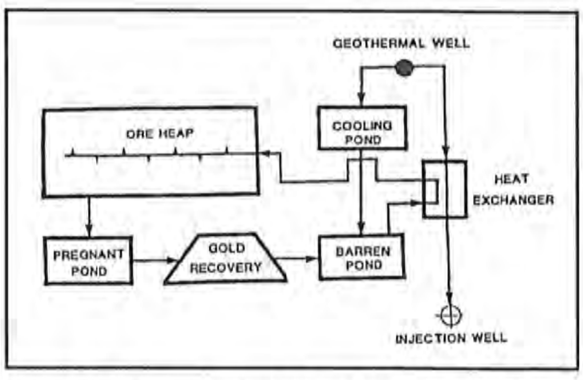

Figure 5. Flow diagram showing the application of geothermal fluids at operating mines in Nevada.

cost of $3,000/d. At current production rates, approximately 58 billion BTU per month are supplied by the geothermal resource to maintain leaching operations during the winter.

IMPLICATIONS FOR CENTRAL AMERICAN GOLD MINING OPERATIONS

Precious metal deposits and geothermal resources have been shown to be co-located in Nevada and Costa Rica. It is likely that this relationship is repeated throughout Central America. Unlike Nevada, however, Central America is not subject to freezing conditions, but climate-related problems may be minimized by using geothermal energy in cyanide heap-leaching operations.

Average daily temperatures, for example, vary with both latitude and elevation. Although nighttime temperatures may approach freezing at some mine sites in Central America, substantial damage to the heap is unlikely. Instead, cyanide dissolution of gold and silver simply slows down, increasing residence time on the heap and decreasing productivity. The application of geothermal heat increases the dissolution rate and can maintain high levels of productivity.

Another climate-related problem, which is characteristic of tropical regions, is a prolonged rainy season. Clay-rich hydrothermally altered volcanic and sedimentary rocks, which are the principal hosts for low-grade disseminated ore, present special logistical problems for heavy equipment operation. The combination of mud and near-constant rainfall disrupts production. Optimum productivity will occur by increasing production rates during the dry season. Using geothermal fluids can significantly increase productivity by reducing the time required for leaching. The end result is a more efficient use of time available.

CONCLUSIONS

The economic recovery of gold from low-grade, disseminated ore bodies can be enhanced by the application of low- to moderate-temperature geothermal fluids in cyanide heap-leaching operations. Large-scale, long-term mining activities should consider geothermal applications to prolong leaching operations in cold climates and to accelerate leaching in tropical climates that may have a rain-shortened mining season. Gold mines co-located with geothermal resources are common throughout the Pacific Basin and co-development of these resources is now practiced in Nevada. The identification of co-located resources may be important for leasing or concessions. In the western United States, for example, mining companies are encouraged to lease both mineral and geothermal rights to capitalize on the low cost energy resource and to eliminate potential conflicts with other organizations. This technology, which has been proven and demonstrated at two mines in Nevada, may find future application to precious metal mining in Central America.

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