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ENHANCEMENT OF PRECIOUS METAL RECOVERY BY GEOTHERMAL HEAT

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ABSTRACT

Nevada is the leading producer of gold in the United States. Processing large volumes of low-grade ore is accomplished by cyanide heap-leaching. The process entails mining, crushing, grading and stacking the ore which is then soaked with a dilute solution of sodium cyanide. The cyanide dissolves both gold and silver, which is eventually recovered by additional processing. Heap-leaching takes many months to complete, and the operation depends heavily on the weather. Active mines that use cyanide heap-leaching either shut down during the winter, or use expensive oil emersion heaters to prevent freezing in the heap and pipelines. The rate at which cyanide can dissolve gold and silver increases, like most chemical reactions, with the application of heat. Laboratory experiments indicate that the recovery of precious metals was 17 to 40 percent greater when "geothermal" heat was applied to the cyanide leaching process. Increasing cyanide solution reaction rates decreases the time required for batch-heap leaching and increases productivity.

INTRODUCTION

Mining is the second largest industry in Nevada. The Silver State is the largest producer of gold and the third largest producer of silver in the United States. The major operations are open pit mines that use a process known as heap-leaching to extract gold and silver from low-grade ore. The process entails mining, crushing, grading, and stacking the ore, which is then soaked with a dilute solution of sodium cyanide. The cyanide dissolves both gold and silver, which is eventually recovered from solution by additional processing. Heap-leaching takes many months to complete, but the operation depends heavily on the weather.

Like most chemical reactions, the reaction rate is increased by the addition of heat. Since the invention of the commercial process in 1887, many authors have demonstrated that the judicious application of heat to cyanide solutions will accelerate the reaction kinetics in proportion to the quantity of heat applied. This immediately suggests two important benefits to the mining industry in general and to Nevada gold mines in particular:

1. Increasing cyanide solution reaction rates decreases the time required for batch heap-leaching and increases productivity.

2. Maintaining a constant temperature in the piles by heating the cyanide solution will permit the operation to continue at a profitable level on a year-round basis, even through the cold winter months.

In addition to its gold and silver reserves, Nevada has an abundance of geothermal energy resources. Trexler and others (1983) identified more than 900 hot springs and wells throughout Nevada, more than any other state. Applications include production of electric power, industrial process heating, space heating, and aquaculture. One application that has not been attempted is the use of geothermal energy in the mining industry. This project was designed to investigate the feasibility of using geothermal heat energy to enhance gold and silver heap-leaching operations in Nevada.

ORGANIZATION

The program was divided into two phases. Activities in the first phase included a review of existing literature, a survey of active mines and nearby geothermal resources that could be utilized in a heap-leaching operation, and an appraisal of the effects of ion interference associated with incompatibility in the silver and gold ore, geothermal-fluids and cyanide-solution. The second phase consisted of collecting representative ores and geothermal fluids, fabricating the test facilities, performing the laboratory tests, obtaining the analytical results, and assessing the potential for large-scale application.

CO-LOCATION OF ACTIVE PRECIOUS METAL MINES AND GEOTHERMAL RESOURCES

There are 32 producing gold, silver or gold/silver mines in operation in Nevada today. Of the 32 operating mines, 10 have geothermal resources on the mine property or in close proximity to the leaching operation. A brief description of the geothermal resources and locations for the 10 mines is presented below:

1. Pegasus Gold Corporation drilled a 500 foot well for mine construction and process water at their new mine in Pershing County, 35 miles north of Lovelock. The well has a maximum temperature of 114°C (238°F) and can produce 200 gpm at a temperature of 100°C (212°F). The chemical composition is reported as sodium-chloride type fluid, typical for that area, with a total dissolved solid (TDS) of 4,500 ppm.

2. Smoky Valley Mining Company, located in the Big Smoky Valley in Nye County, drilled a geothermal well that produces 600 gpm of 86°C (186° F) water. The fluids have a total dissolved solids (TDS) content of 340 ppm.

3. West Northumberland Mine is located near the crest of the Toquima Range on the east side of the Big Smoky Valley in Nye County. Ore is hauled daily to leach pads located in the Big Smoky Valley, eight miles from the mine. Geothermal fluids were encountered in a recently completed well near the leach pad. The estimated fluid temperature is 68° C (180° F) (Steven Kleeberger, personal communication, 1987).

4. Jerritt Canyon Mine, located on the east side of Independence Valley in northern Elko County, is less than four miles from a warm spring.

5. Boot Strap Mine, located in the northern part of the Carlin Gold Company mining area, has water with temperatures in excess of 50°C (122°F) in water supply wells.

6. Maggie Creek Mine is located in the central part of the Carlin Mining District and has warm water in an industrial process supply well.

7. Gold Quarry Mine is located in the southern part of the Carlin Mining District and also has warm water supply wells.

8. Tonopah Divide Mine, located between Tonopah and Goldfield in Esmeralda County, has reported hot water in underground workings at a depth of 1,000 feet.

9. Rawhide Mine located west of Gabbs in Mineral County, is located within six miles of a warm spring.

10. 16 to 1 Mine located west of Silverpeak, in Esmeralda County, is near hot wells to the north and a warm spring at Silverpeak with a temperature of 48°C (118°F).

COLLECTION OF GEOTHERMAL FLUIDS AND ORE SAMPLES FOR LABORATORY TESTS

GEOTHERMAL FLUIDS

Based on detailed investigations of geothermal resources and active mines, or mines under construction, two areas were selected for study of reaction chemistry in relation to mineral enhancement. The geothermal sites selected are Darrough's Hot Springs in Big Smoky Valley and the geothermal water wells in the City of Gabbs.

Sample Collection Procedure

Approximately 28 liters of geothermal fluid were collected at each site. A 9-liter sample was acidified with 1.5 liters of concentrated HNO_3. The remaining 19 liters were collected untreated. Temperature was measured at the time of collection with a Digitec Model digital thermometer.

Darrough's Hot Springs

Darrough's Hot Springs is located in northern Nye County, approximately 9 miles west of the Smoky Valley Mine at Round Mountain, Nevada. The springs discharge 200 gpm of 96°C (205°F) water into a concrete-lined pool through a four-inch diameter pipe. In 1962, Magma Power Company drilled a well on the property to a depth of 830 feet with a reported temperature of 114°C (238°F) at 750 feet.

The chemical composition of the water from these springs is typical of the sodium-bicarbonate type that is found throughout central and eastern Nevada.

Gabbs Geothermal Wells

The City of Gabbs is located in northwestern Nye County. Six geothermal wells supply water to the city. The water is pumped to cooling towers prior to use. Fluids from this site represent the sodium-sulfate variety, which is the dominant type of geothermal water in the west-central and extreme southern portion of Nevada. Temperatures in the Gabbs wells range from 21° to 68°C (70° to 154°F); depths range from 169 to 575 feet. Geothermal fluids were collected from well no. 10, which is completed to a depth of 198 feet. The water temperature at the time of collection was 60°C (140°F). The sample had a TDS of 849 ppm.

ORE SAMPLES

Ores representing some of the mineralogies of Nevada's precious metal mines were selected to determine the feasibility of using geothermal heat to enhance the hydrometallurgical practices associated with the mining operations. Gold ore from the Freeport Jerritt Canyon Mine in northern Elko County and silver ore from the Gooseberry Mine in Lyon County were used in the thermally-enhanced cyanide heap-leaching operation. The gold ore represents the Carlin-type disseminated gold deposit that is found in carbonaceous rocks in the northeastern part of the state. The silver ore is a vein-type deposit which is common throughout the entire state and is largely responsible for the nickname "Silver State."

CYANIDE HEAP-LEACHING LABORATORY TESTS

Several factors affect the process of cyanidation of precious metal ores. Significant effects are caused by temperature, dissolved oxygen, pH, and the presence of "foreign" ions. Each of these parameters is discussed below.

Effect of Temperature

Julian and Smart (1921) were the first to demonstrate the relationship between temperature and rate of dissolution of gold by cyanide solutions (fig. 1) and established a temperature of 85°C (185°F) as the maximum for cyanide dissolution of gold. Several years later Meyer (1931) determined a maximum temperature of 80°C (176°F).

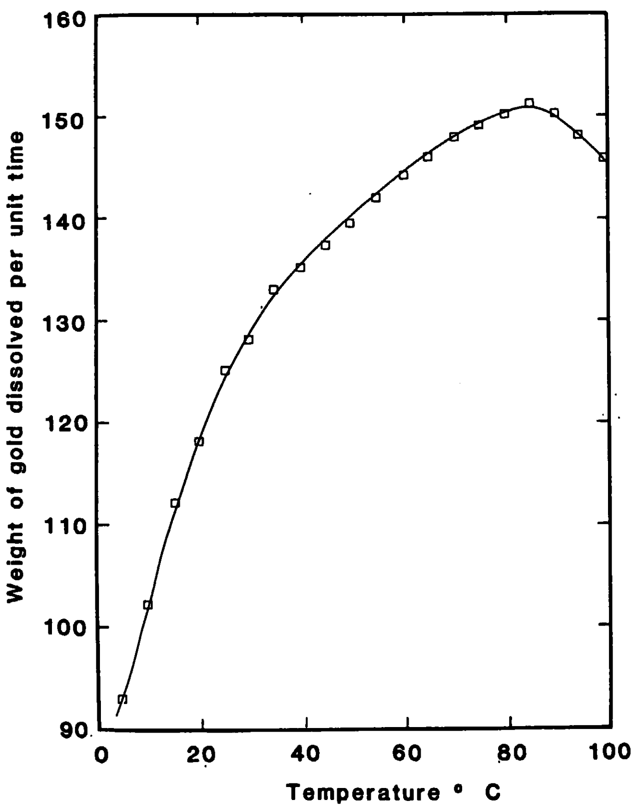

Figure 1. Effect of temperature on rate of dissolution of gold in 0.25 percent KCN (after Julian and Smart, 1921).

One of the most critical aspects of commercial-scale cyanide heap-leaching is the temperature of the leaching solutions. It is critical not only because it is difficult to control, but any external adjustments can immediately result in drastic changes in the chemistry of the cyanide solutions. 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 (50°F to 70°F) are not uncommon. Winter temperatures may fall well below freezing for weeks. This will not only slow or stop the reaction kinetics of dissolution, but will likely freeze the pipes, pumps, and sprinkler-heads.

One way to deal with this problem is to abandon heap-leaching in late fall and start-up operations in early spring. This solution has the advantage of maintaining the equipment, but poses the problem of seasonal unemployment in rural Nevada. Another solution is to use oil emersion heaters to maintain the temperature in the cyanide solution. Although this system has been used in some mines, it is an expensive investment. Historically in Nevada, most mines close down during the winter.

Effect of Oxygen

Although temperature is an important element in the chemical reaction, it is not the only factor that controls the rate of dissolution of gold in cyanide solutions. Elsner (1846) is credited as the first to recognize the essential need for atmospheric oxygen in the 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) notes that atmospheric oxygen (20% of a volume of air) is the oxidizing agent universally used in cyanide gold mills and that the maximum dissolution rate occurs when the molar ratio

$$[CN^-]/[O_2] = 6.$$

Concentrations resulting from equilibrium with the atmosphere alone account for approximately 8.2 mg/liter oxygen in dilute cyanide solutions. This value is applicable only for ideal conditions of aeration and agitation, assuming none of the gangue minerals consume oxygen.

The solubility of oxygen, like most gases, is also a function of temperature. Unlike solids, however, the solubility of oxygen in aqueous solutions is inversely proportional to temperature. Figure 2 illustrates this relationship. It is essential that dissolved oxygen levels not decline as a result of adding heat to the aqueous solution. Habashi (1967) argues that the important consideration is not the absolute amount of cyanide ion and oxygen, but the ratio of the molar concentrations.

Effect of pH

Another critical factor is the pH of the aqueous solution. Most operations maintain pH between 10

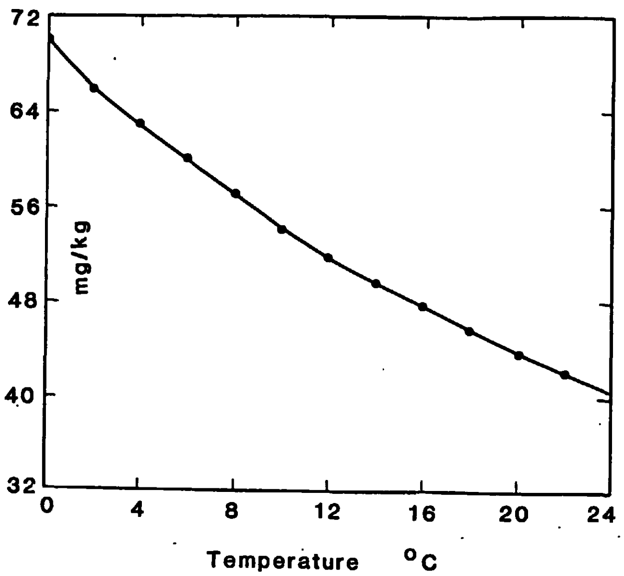

Figure 2. Solubility of oxygen in pure water in equilibrium with oxygen only.

and 13. The cyanide ion [CN-] acts in concert with oxygen to dissolve gold. In near-neutral pH or acidic solutions, the [CN-] ion is subject to hydrolysis by water or decomposition by atmospheric CO_2. 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 1 lists the ions most likely to be encountered in gold ores and their associated effects.

TABLE 1

Ions That Affect Cyanidation

Accelerating	Neutral	Retarding
Pb, Hg, Bi, Tl	Na, K, Cl, NO3, SO4	Fe, Cu, Zn, Ni Mn, Ca, Ba, C (Pb), S2-

EXPERIMENTAL

All tests reported 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 0.5g/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 Lyon County, Nevada; it contained 6.30 oz/T. These data, reported as Troy ounces, were obtained by fire assay technique.

RESULTS

Gold Ore

The results of the experiment on the extraction of gold from the Freeport ore are shown in Table 2 and Figure 3.

TABLE 2

Gold Extraction From Freeport Ore When Leached at Various Temperatures

Percent Gold Extracted at Specific Times

Temp. °C	HOURS 1	2	4	8	12	24
20	64.05	71.09	68.51	64.37	69.48	66.77
15	69.31	64.19	65.63	64.82	55.26	56.85
5	56.98	59.52	62.28	59.62	57.58	57.16

From these data, it is obvious that the extraction of gold from the Freeport ore is significantly increased at higher temperatures. Table 3 shows the percentage increase of gold recovered at 20°C (68°F) as compared to 5°C (41°F).

TABLE 3

Percent Increase in Gold Recovery at 20°C vs. 5°C

	HOURS 1	2	4	8	12	24
Percent Increase	12.41	19.44	10.00	7.97	20.67	16.81

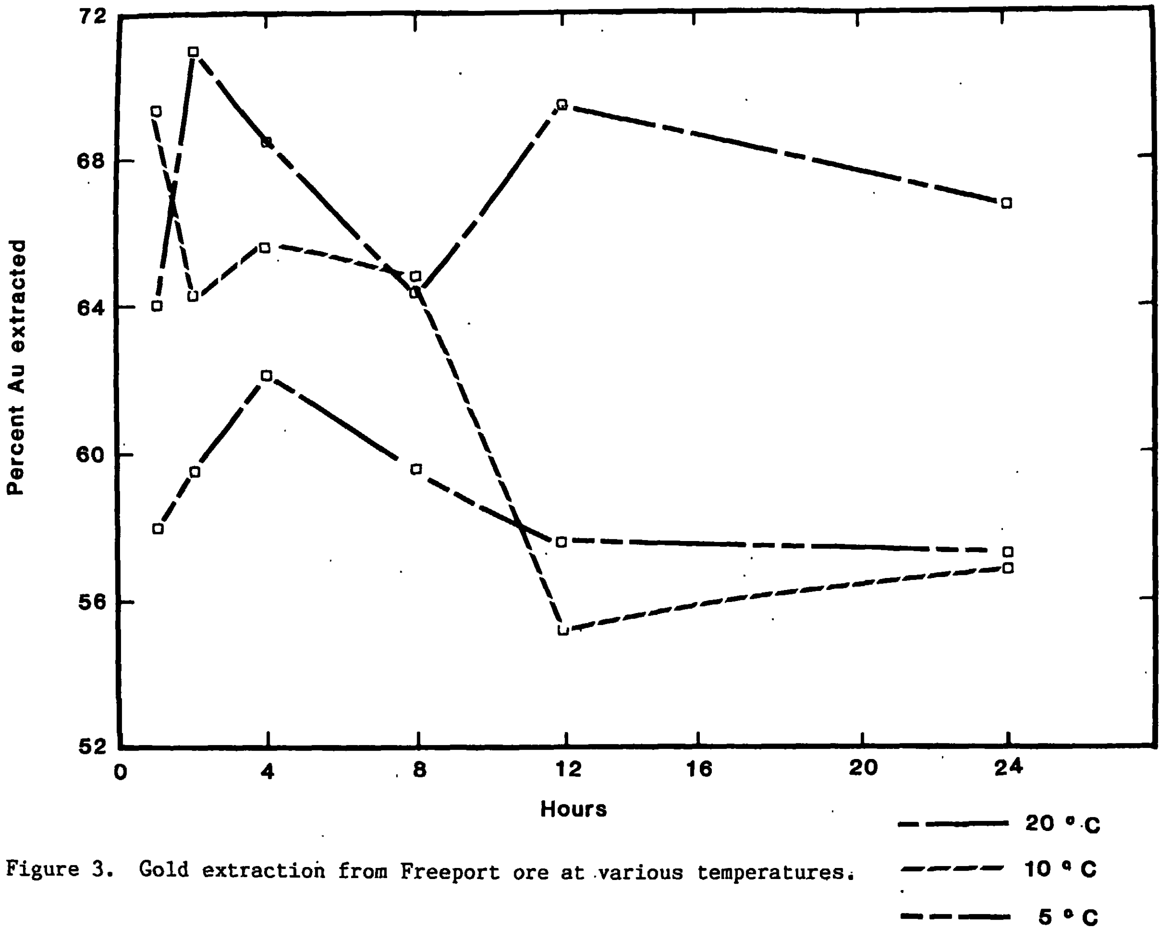

Figure 3. Gold extraction from Freeport ore at various temperatures.

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 (50°F), the data suggest that gold recovery actually decreases after two hours. This phenomena is cause by pregnant solutions in direct contact with the ore, which contains carbonaceous material. 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

The silver ore experiments were essentially identical to the gold ore tests. The results of the silver extraction from the Gooseberry ore for four different temperatures are shown in Table 4 and Figure 4.

TABLE 4

Silver Extraction from Gooseberry Ore Leached at Various Temperatures

Precent Silver Extracted at Specific Times

Temp. °C	HOURS 1	2	4	8	12	24
35	53.78	62.23	70.64	nd	75.99	90.51
25	44.63	55.15	62.66	72.89	nd	nd
15	45.93	51.09	56.24	66.34	68.05	82.13
5	38.66	45.10	50.98	60.23	64.72	71.18

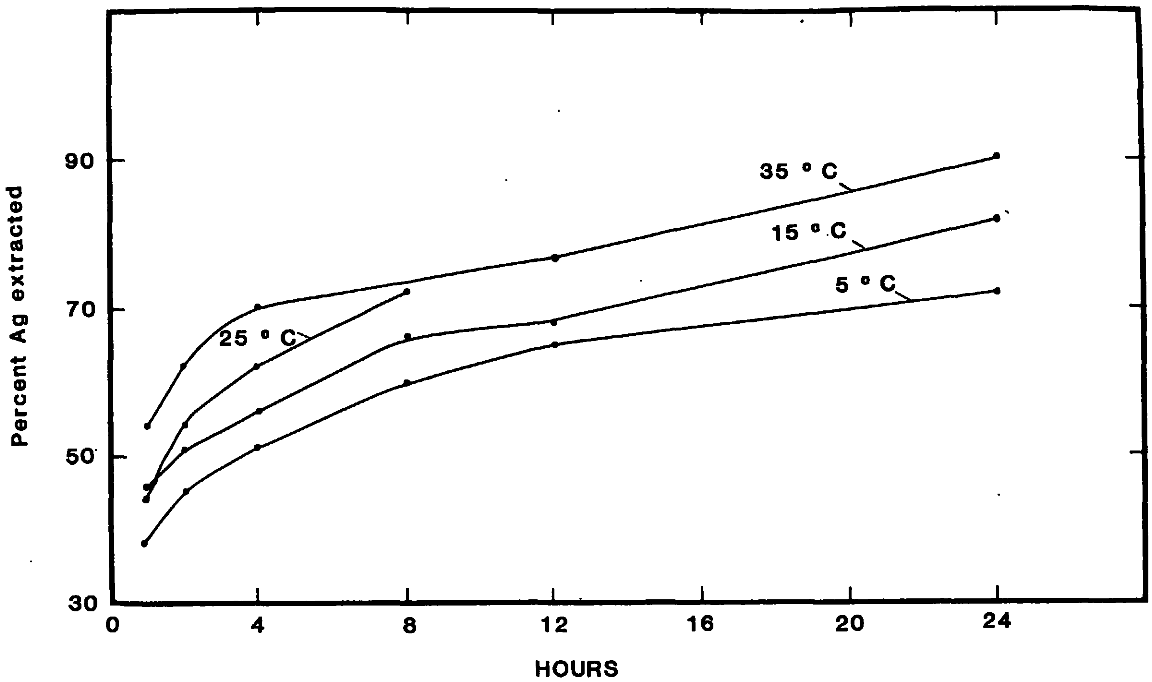

Figure 4. Silver extraction from Gooseberry ore at various temperatures.

The effect of increasing temperature on the extraction rate for silver is also evident. In 24 hours, at 35°C (95°F), more than 90% of the available silver was extracted. At 5°C (41°F), only 72% has been extracted. The percentage increase in silver recovery at 35°C (95°F) compared with 5°C (41°F) is shown in Table 5.

Table 5

Percent increased recovery of silver at 35°C vs. 5°C

	HOURS 1	2	4	8	12	24
Percent Increase	39.11	37.98	38.56	nd	17.41	20.25

Increases in recovery of silver with cyanide solutions at 35°C (95°F) 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. Significant percentage increases are seen at 35°C (95°F), which is well within the range of most of the geothermal resources in Nevada.

SUMMARY AND CONCLUSIONS

Mining is the second largest industry in Nevada. Gold mining, in particular, has increased substantially in the last five years making Nevada the leading producer of gold in the United States. Most of this increase in gold production can be attributed to the widespread use of the cyanide-heap leaching process. This has been shown to be a cost-effective way to process many low-grade ores throughout Nevada.

Because this is a hydrometallurgical technique that is practiced outdoors on a large scale, the process is subject to "modification" by the weather. Specifically, when winter temperatures produce freezing conditions, many of the mines shut down until early spring. Some mines employ oil-fired water heaters to maintain working temperatures in the leach-solutions and allow production to continue throughout the winter.

These mining operations are widespread in Nevada. More widespread are the 900 hot springs and wells that constitute Nevada's greatest natural energy resource - geothermal energy. It seems logical that the combination of a readily available, low-cost source of renewable energy and cyanide heap-leaching would produce a multitude of benefits: it would increase gold production; it would maintain a year-round labor force and stabilize rural working conditions; it would conserve fuel oil; and, properly monitored, it would provide long term data on the geothermal reservoir and on the engineering feasibility of another direct heat application.

This report was prepared to review mineral recovery techniques practiced at active mines throughout Nevada and to determine those that may be enhanced by the application of geothermal heat energy from a nearby resource. Of the thirty-two active precious metal mines identified, ten have hot water on or near the property and could potentially benefit.

A second purpose was to collect ore samples and geothermal fluids, establish their compatibility in the hydrometallurgical process, and carry out laboratory tests to determine the effects of heating on recovery rates. In addition, interfering or counterproductive factors were also to be identified. The laboratory work consisted of measuring the effects of thermally enhancing cyanide heap-leaching on gold and silver ores.

Thermally enhanced cyanide heap-leaching of gold and silver ores produced increases in extraction ranging from 8 to 20% for gold and 17 to 40% for silver. The temperature required for these increases is 35°C to 40°C (95°F to 104°F), well within the range of available geothermal resources. The fluid chemistry of the geothermal waters will not interfere with the reactions, but the aqueous solutions will have to be slightly modified to match the high pH required for cyanide heap-leaching. Geothermal fluids typically contain little dissolved oxygen and some aeration would be required.

Perhaps the most important aspect of this research is fact that geothermally enhanced heap-leaching operations can provide year-round production, independent of the prevailing weather conditions. Figure 5 illustrates a cyanide heap-leach "production window" that may be expected in central Nevada. This curve is provided for illustration purposes only and has not been substantiated by actual production data. If the production window opens at a minimum temperature of 4°C (40°F), then leaching operations may be expected to begin in mid-March and continue through late October. This has been the historical practice at Nevada mines. Since enhanced recovery of gold from heated cyanide solutions has already been established, maximum production would be restricted to June, July, and August. Using geothermal fluids would substantially increase the size of the production window (shaded area, fig. 5) and would allow super-maximum extraction rates on a year-round basis. The benefits include increased revenue to the mine operator, year-round employment for the labor force, increased royalty payments for mineral leases to both the federal and state governments, and increased information on the geothermal resources and their applications.

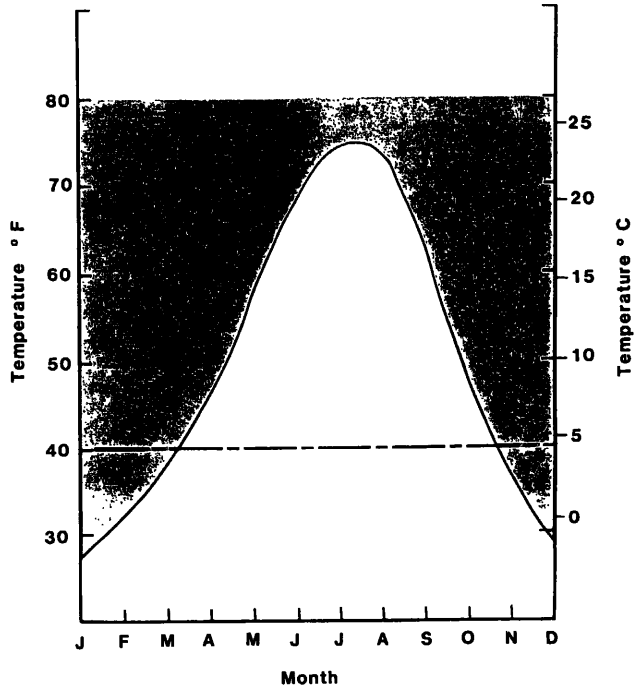

Figure 5. Soil temperature at a depth of 10 cm (4 inches) at Central Nevada Field Laboratory near Austin, NV (elevation 5,950 ft. (modified after Houghton et al., 1975)

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