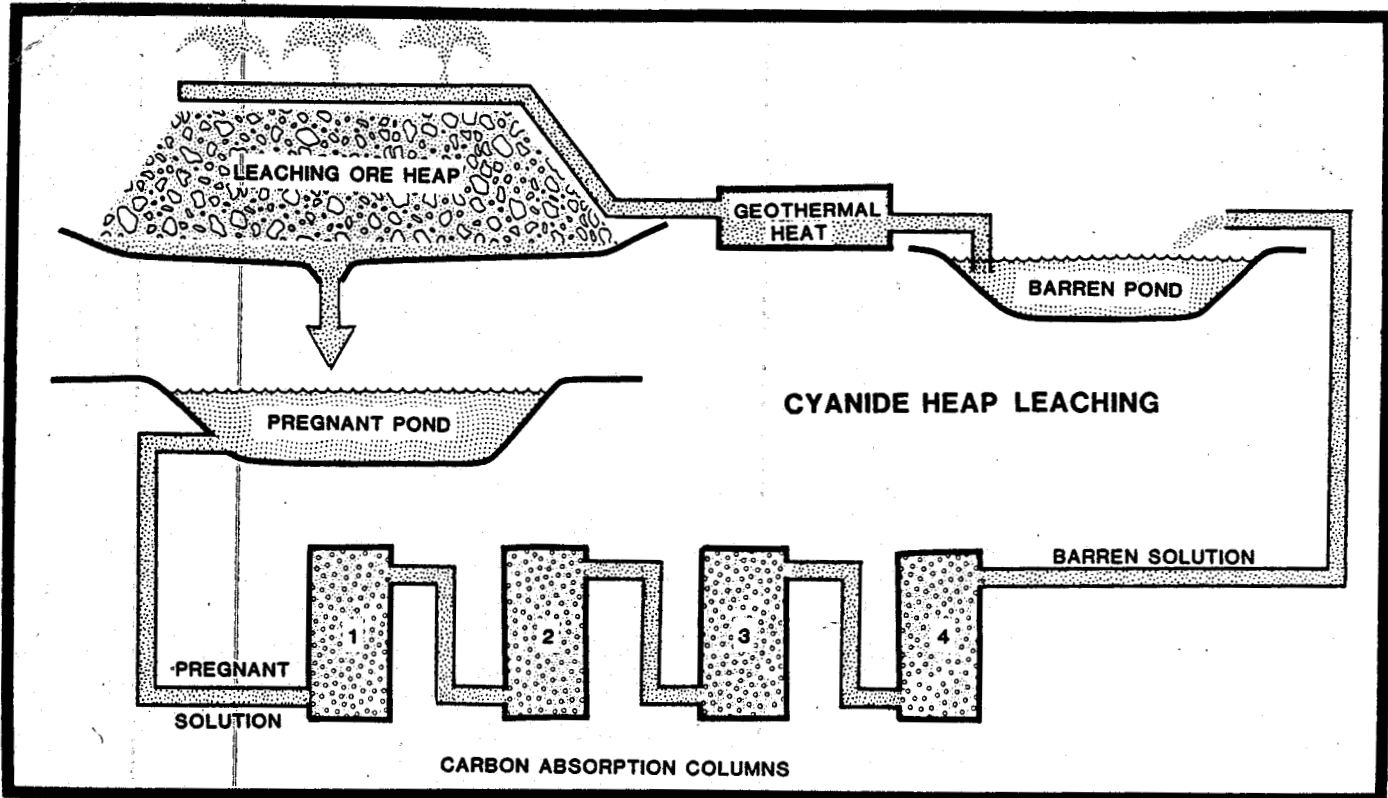


Geothermal Enhancement of Mineral Processing in Nevada

Final Report for the Period April 25, 1985 - June 30, 1986



Work Performed Under Grant No. FG03-85SF15603

By: THOMAS FLYNN, DENNIS T. TREXLER and JAMES L. HENDRIX¹

University of Nevada, Las Vegas

University of Nevada, Reno¹

Reno, Nevada

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

November, 1986

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DOE/SF/15603--1

DE87 003852

DISCLAIMER

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Printed in the United States of America

Available from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes:

Printed copy: A03
Microfiche copy: A01

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

**GEOHERMAL ENHANCEMENT OF
MINERAL PROCESSING IN NEVADA**

Final Report

April 25, 1985 - June 30, 1986

Thomas Flynn, Dennis T. Trexler
and James L. Hendrix

Prepared by:

DIVISION OF EARTH SCIENCES
Environmental Research Center
University of Nevada, Las Vegas
255 Bell St., Suite 200
Reno, Nevada 89503

Prepared for the:

U.S. Department of Energy
Division of Geothermal Energy
Under Grant No. DE-FG03-85SF15603

MASTER

November, 1986

mf
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
ORGANIZATION.	2
FINDINGS.	2
REVIEW OF CURRENT MINERAL RECOVERY TECHNIQUES.	4
CYANIDATION	4
SULFATE LEACHING.	5
CHLORIDE LEACHING	5
BACTERIAL LEACHING.	6
SUMMARY	7
CO-LOCATION OF ACTIVE PRECIOUS METAL MINES & GEOTHERMAL RESOURCES.	8
COLLECTION OF GEOTHERMAL FLUIDS AND ORE SAMPLES FOR LABORATORY TESTS	13
GEOTHERMAL FLUIDS	13
<u>Sample Collection Procedure</u>	13
<u>Darrrough's Hot Springs</u>	13
<u>Gabbs Geothermal Wells</u>	16
ORE SAMPLES	16
LABORATORY TESTS	18
CYANIDE HEAP-LEACHING STUDIES	18
<u>Effect of Temperature</u>	18
<u>Effect of Oxygen</u>	20
<u>Effect of pH</u>	21
<u>Effect of Foreign Ions</u>	21
EXPERIMENTAL.	23
RESULTS	24
<u>Gold Ore</u>	24
<u>Silver Ore</u>	26

(Table of Contents, continued)

	<u>Page</u>
BACTERIAL LEACHING.	28
<u>Metabolism</u>	29
<u>Effect of Temperature.</u>	29
<u>Effect of Oxygen</u>	31
<u>Effect of pH</u>	31
<u>Effect of Foreign Ions</u>	31
<u>Thiobacillus ferrooxidans Cultures</u>	32
<u>Procedure.</u>	32
<u>Ore Sample</u>	33
EXPERIMENTAL.	34
RESULTS AND DISCUSSION.	35
<u>Ten Percent Slurry</u>	35
<u>pH</u>	35
<u>Toxic Metals</u>	39
SUMMARY AND CONCLUSIONS.	40
REFERENCES	45

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Active precious metal mines in Nevada, 1986.	9
2. Chemical Analyses.	15
3. Ions That Affect Cyanidation	21
4. Gold Extraction From Freeport Ore When Leached at Various Temperatures	24
5. Percent Increase in Gold Recovery at 20°C vs. 5°C.	24
6. Silver Extraction From Gooseberry Ore Leached at Various Temperatures	26
7. Percent Increased Recovery of Silver at 35°C vs. 5°C	28
8. Partial Analysis of High-Sulfide Ore Sample.	34
9. Extractions Achieved with <u>T. ferrooxidans</u> with a 10 Percent Slurry	36
10. Extractions Achieved with <u>T. ferrooxidans</u> with a 25 Percent Slurry	36
11. Extractions Achieved with <u>T. ferrooxidans</u> with a 40 Percent Slurry	37

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Distribution of major geothermal fluid types in Nevada	14
2. Effect of temperature on rate of dissolution of gold in 0.25 percent KCN.	19
3. Solubility of O ₂ in pure water in equilibrium with O ₂ only	22
4. Gold extraction from Freeport ore when leached at various temperatures.	25
5. Silver extraction from Gooseberry ore at various temperatures.	27
6. Metabolism of microorganisms as a function of temperature (top) and pH (bottom)	30

(List of Figures, continued)

<u>Figure</u>	<u>Page</u>
7. Extractions achieved with <u>T. ferrooxidans</u> in a 10 percent slurry	38
8. Comparison of temperature and pH requirements for bacterial digestion and cyanide leaching with Nevada's geothermal resources	42
9. Soil temperature at a depth of 10 cm. (4 inches) at Central Nevada Field Laboratory near Austin, elevation 5,950 ft	43

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 from ore/geothermal-fluid/cyanide-solution incompatibility. 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.

FINDINGS

1. Active mines that use cyanide heap-leaching are widespread in Nevada and either shut down during the winter or use expensive oil emersion heaters to prevent freezing in the heap and the pipelines.
2. At least six operating mines are located near or adjacent to known geothermal resources with temperatures that are compatible with the cyanide heap-leaching process. Additional exploration of gold, silver and geothermal resources is continuing and will likely increase the number of co-located mines and geothermal resources.

3. Some gold ores in Nevada contain base metal sulfides that are known to interfere with and retard the cyanide solution process. During the literature review, a process known as bacterial digestion was identified as having potential for enhancement by the application of geothermal energy. The process entails using Thiobacillus sp. to selectively remove arsenic, copper, nickel, and other metals that interfere with the cyanidation process.
4. Nevada's geothermal resources are dilute, maximum total dissolved solids are less than 5000 ppm. No large concentrations of interfering ions were identified.
5. In experiments run at 5°C and 20°C (41° and 68°F), the amount of gold recovered at the 20°C showed a twenty percent increase over the test run at the lower temperature. Silver ore leached at 35° (95°F) registered increased extraction rates of 17% to 40% over ores leached at 5°C (41°F).
6. Successful sulfide leaching experiments using bacteria were limited to only four metals and only at slurry concentrations of 10%. No significant temperature effects were recorded.

REVIEW OF CURRENT MINERAL RECOVERY TECHNIQUES

Elevated temperatures are important in many chemical processes. In the mining industry, hydrometallurgical processes, those involving the extraction of metals using aqueous solutions, are particularly amenable to enhancement by addition of heat energy.

This review concentrates on those hydrometallurgical processes most applicable to enhancement by using geothermal heat. The principal processes include:

1. Cyanidation (precious metal metallurgy)
2. Sulfate leaching
3. Chloride leaching
4. Bacterial leaching

CYANIDATION

Habashi (1967) has shown that the rate of dissolution of gold and silver increases with temperature. Many precious metal operations presently use cyanide heap leaching. In cold winter months, a preheat of the solution is required. At Round Mountain, Nevada, the Smoky Valley Mining Company uses oil emersion heaters to heat the cyanide solutions and prevent freezing of the sprinkler system.

Another potential application of geothermal energy in the precious metals industry is the evaporation of leach liquors to concentrate the metal content. Current practices use carbon columns to recover the soluble metals for concentration. Electrowinning or zinc precipitation is then employed to recover the metal values from the concentrated solutions.

Important factors to be considered are the destination of all the species - primarily gold-cyanide complex and excess cyanide. Gaze (1898) and Raub and Muller (1967), indicate the evaporation of pregnant cyanide solutions should result in a vapor phase consisting of H₂O with little or no cyanide.

Typically, a concentration between 6 and 80 grams per liter of gold is necessary for electrowinning (U.S. Patents 3,104,212; 3,445,352; and 2,884,322). Leach liquors generally assay between 0.1 and 0.5 grams of gold per liter. This would require a volume decrease on the order of 160 times. Geothermal energy could supply a substantial portion of the heat required for concentrations amenable to electrowinning.

SULFATE LEACHING

Sulfate leaching was used primarily in the recovery of copper from oxidized ores. There has been a substantial decline in the number of leaching operations that use the sulfate method. During the 1960's and 1970's, Anaconda Copper Company used a seven-stage sulfuric acid vat-leaching process at their operation at Weed Heights, Nevada. The process was performed at ambient temperature. Heating the sulfuric acid may have increased the kinetics of the leaching process, but the economics were probably unfavorable. The mine is no longer operating.

CHLORIDE LEACHING

Several well known chloride processes use "hot" solutions. For example, the ferric chloride leach process used by Anaconda at the Nevada Moly Operation in south-central Nevada was operated at 90°C (190°F). This process upgraded the mill molybdenite concentrate by removing the unwanted chalcocite, chalcopyrite, and galena. The temperature of the water obtained

from a well on the property was measured at 28°C (82°F). The water was typically used as makeup, wash, and boiler feed water, inadvertently providing the operator with an apparent, but undetermined, savings. The Anaconda process is closely related to the Clear Process of Duvall (U.S. Patent 3,785,944).

Another process, developed by the U.S. Bureau of Mines, involves the recovery of elemental sulfur from chalcopyrite and chalcocite concentrates (Haver and Wong, 1971). This process uses ferric chloride at a temperature of 106°C (223°F).

The Falconbridge Matte Leach Process (Thornhill et al., 1971) is a chloride process that operates at 70°C (158°F), a temperature that can be achieved using geothermal energy. This process selectively leaches nickel from a copper-nickel matte using hydrochloric acid.

Currently, there are no chloride leaching operations at Nevada mines. If the molybdenum market recovers, there may be a need for geothermal energy at the Nevada Moly Operation, in Nye County.

BACTERIAL LEACHING

One species of bacteria, Thiobacillus, has been the focus of several recent studies (Schwartz, 1977; Murr, Torma, and Brierley (eds.), 1978). Thiobacillus has the ability to leach reduced iron and metal sulfides from ores. This bacteria has been tested to determine recovery rates for such metals as copper, iron, antimony, lead, and uranium.

Of particular interest is the thermophilic strain of a thiobacillus-like bacteria discussed by Brierley and LeRoux (1977). While most of the thiobacilli do not typically grow at elevated temperatures, this report

describes thermophilic strains that grow above 50°C (122°F). High-sulfur geothermal waters would be an excellent medium for culturing these microorganisms.

SUMMARY

Based on the review of current mineral recovery techniques, two processes, cyanide heap-leaching and bacterial leaching, have the greatest potential for application of geothermal energy. These two processes were selected for investigation of enhanced mineral recovery by the application of heat in laboratory tests.

CO-LOCATION OF ACTIVE PRECIOUS METAL MINES AND GEOTHERMAL RESOURCES

A listing of active precious metal mines and mills was prepared. Information on the operator, location, commodity, recovery process, and available production is shown in Table 1. There are 32 producing gold, silver or gold/silver mines in operation in Nevada today.

The location of each mine was plotted on the 1:500,000-scale map of the "Geothermal Resources of Nevada," (Trexler and others, 1983). 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) content of 4,500 ppm.
2. Smoky Valley Mining Company, located in the Big Smoky Valley in Nye County, reported warm water in several mineral exploration holes. The mine is located on the east side of the valley, approximately 9 miles from the Darrough's Hot Spring KGRA, which has temperatures of 115°C (240°F).
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,

MINE	LOCATION	COMMODITY	RECOVERY PROCESS	OPERATOR	PRODUCTION
Couer's Rochester	T.29N., R.34E.	Silver	Cyanide Heap Leaching	Couer d'Alene Mining	
Goldfield Tailings Project	Goldfield, T.2S., R.43E.	Gold/Silver	Cyanide Heap Leaching	Black Hawk Mining Placer Management	700 tons/day (ore)
McCoy Mine	So. of Battle Mountain	Gold	Cyanide Heap Leaching	Tenneco	75,000 oz./yr (gold)
Paridise Peak	Gabbs, T.10N., R.37E.	Gold/Silver	Cyanide Heap Leaching	FMC	100,000 oz./yr. (Au) 3,500,000 oz./yr. (Ag)
Rawhide Mine	T.13N., R.32E.	Gold/Silver	Cyanide Heap Leaching	Kiewit Mining & Eng.	5,000 tons/day (ore)
Florida Canyon Project	Humboldt House T.31N., R.33E.	Gold	Cyanide Heap Leaching	Pegasus Gold Corp.	8,000 tons/day (ore)
Tonkin Springs Mine	T.23N., R.49E.	Gold	Cyanide Heap Leaching	Silver State Mining Corp.	30,000 oz./yr. (Au)
Gold Bar Property	T.23N., R.49E.	Gold	Cyanide Heap Leaching	Atlas Corp.	
Hog Ranch Gold Mine	North of Gerlach T.38N., R.23E.	Gold	Cyanide Heap Leaching	Western Goldfield Co.	3,000 tons/day (ore)
Sleeper Mine	North of Winnemucca T.39N., R.36E.	Gold/Silver	Cyanide Heap Leaching	AMAX	55,000 oz./yr. (Au) 60,000 oz./yr. (Ag)
Cooper Canyon	Battle Mountain	Gold	Heap Leach/ Mill	Battle Mountain Gold Corp.	70,000 oz./yr. (Au) 1.2 million oz/yr. (Ag)
Star Pointer	Robinson Mining Dist., Ely	Silver	Cyanide Heap Leaching	Silver King Mines	1,000 tons/day (ore)
Wonder Mine	Wonder District	Gold/Silver	Cyanide Heap Leaching	Belmont Resources	
Jerritt Canyon	45 Miles North of Elko	Gold	Cyanidation	Freeport Gold Co.	2,600 tons/day (ore)
Tonopah Divide	Divide District Near Tonopah	Gold/Silver	Cyanide Heap Leaching	Ebco Enterprises	
Boot Strap	Carlin	Gold	Cyanide Heap Leaching	Carlin Gold Co. (Newmont Corp.)	
Bullion Monarch	Carlin	Gold	Cyanide Heap Leaching	Carlin Gold Co. (Newmont Corp.)	

Table 1. Active precious metal mines in Nevada, 1986.

MINE	LOCATION	COMMODITY	RECOVERY PROCESS	OPERATOR	PRODUCTION
Gold Strike	Carlin	Gold	Cyanide Heap Leaching	Carlin Gold Co. (Newmont Corp.)	9,000 oz./yr. (Au)
Blue Star	Carlin	Gold	Mill	Carlin Gold Co. (Newmont Corp.)	
Maggie Creek	Carlin	Gold	Mill/Heap Leaching	Carlin Gold Co. (Newmont Corp.)	3,500 tons/day (ore)
Gold Quarry	Carlin	Gold	Mill/Heap Leaching	Carlin Gold Co. (Newmont Corp.)	170,000 oz./yr. (Au)
Atlanta	T.7N., R.68E.	Gold/Silver	Cyanidation	Standard Slag Co.	
Candalaria	T.3N., R.35E.	Gold/Silver	Cyanide Heap Leaching	Nerco Metals	9,000 oz./yr. (Au)
West Northumberland	T.13N., R.46E.	Gold/Silver	Cyanide Heap Leaching	Cyprus Mines Corp.	3,000 tons/day (ore)
Round Mountain	T.10N., R.44E.	Gold/Silver	Cyanide Heap Leaching	Smoky Valley Mining Co.	18,000 tons/day (ore)
Alligator Ridge	T.22N., R.57E.	Gold	Cyanide Heap Leaching	Amselco Minerals Inc.	2,200 tons/day (ore)
Bald Mountain Project	T.24N., R.57E.	Gold	Cyanide Heap Leaching	Placer Amex Inc.	3,500 oz./yr. (Au)
Pinson	T.38N., R.42E.	Gold	Cyanidation	Pinson Mining Co.	1,500 tons/day (ore) 56,000 oz./yr. (Au)
Horse Canyon	T.27N., R.48E.	Gold/Silver	Cyanide Heap Leaching	Cortez Gold Mines	40,000 oz./yr. (Au)
Buckhorn	T.27N., R.49E.	Gold/Silver	Cyanide Heap Leaching	Cominco American	270,000 oz./yr. (Ag)
Borealis	T.6N., R.29E.	Gold/Silver	Cyanide Heap Leaching	Tenneco Minerals	42,500 oz./yr. (Au)
16 to 1	T.2S., R.38E.	Gold/Silver	Tank Leach	Sunshine Mining	

(Table 1, continued)

eight miles from the mine. The leaching operation is located north of the Smoky Valley Mining Company (2, above) and lies along the same structural trend where warm water has been reported in shallow mineral exploration wells.

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 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).

Discussions were conducted with Smoky Valley Mining, Carlin Gold Company (Boot Strap, Maggie Creek, and Gold Quarry Mines) and Pegasus Gold Corporation (Florida Canyon Project) regarding a site for a full-scale demonstration of the application of geothermal heat to the enhancement of precious metal recovery. Pegasus Gold Corporation has submitted a letter of interest in cooperating with the Division of Earth Sciences and the Chemical and Metallurgical Department at the Mackay School of Mines in conducting a full-scale test of geothermal heat augmentation of cyanide heap-leaching.

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 to study enhancement of cyanide reaction chemistry by the application of geothermal energy. The geothermal sites selected are Darrrough'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 collected were untreated. Temperature was measured at the time of collection with a Digitec Model digital thermometer.

Darrrough's Hot Springs

Darrrough'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 approximately 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; this well has 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 (fig. 1). A complete chemical analysis is presented in Table 2.

Typically, sodium/calcium-carbonate type geothermal fluids have low to moderate TDS. A unique characteristic of the Darrrough Hot Spring analysis

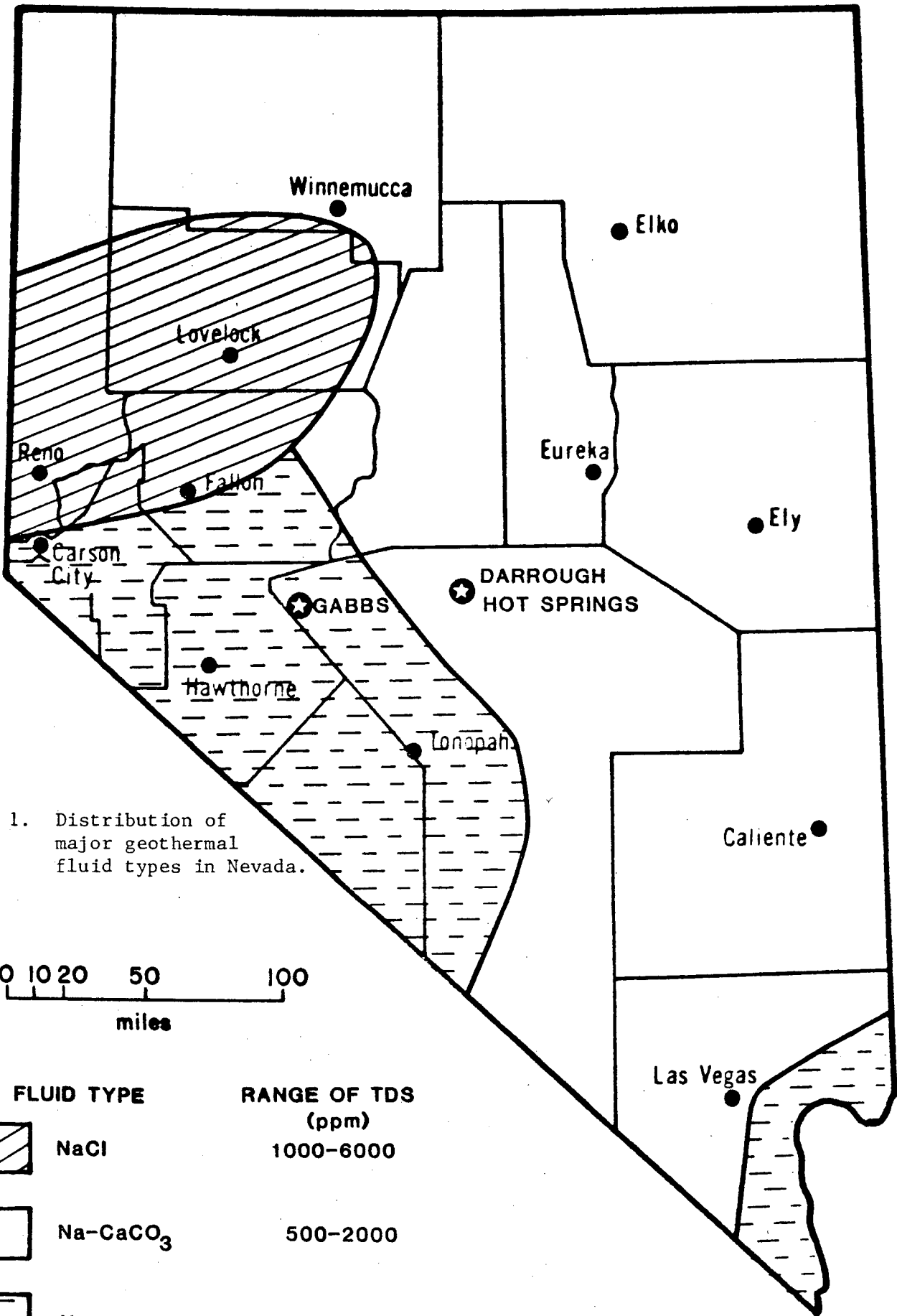
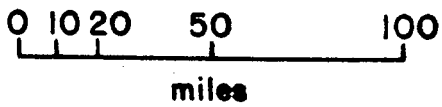


Figure 1. Distribution of major geothermal fluid types in Nevada.






FLUID TYPE	RANGE OF TDS (ppm)
 NaCl	1000-6000
 Na-CaCO ₃	500-2000
 NaSO ₄	1000-2000

TABLE 2
Chemical Analyses

CONSTITUENT	CONCENTRATION IN PPM						
	GABBS, WELLS						DARROUGH'S SPRING
	3	4	5	7	8	10	
TDS	746	702	835	770	-	849	425
Hardness	58	53	70	58	65	80	-
Calcium*	23	21	28	23	19	32	1.24
Magnesium	0	0	0	0	4	0	<0.05
Sodium	212	199	233	213	417	225	98.2
Potassium	6	5	6	6	-	6	3.00
Sulfate	400	375	442	405	382	442	50.7
Chloride	34	29	40	29	27	35	13.5
Nitrate	0.2	0.0	0.7	0.0	0.03	0.0	0.04
Bicarbonate	12	22	17	24	-	27	108
Carbonate	10	10	8	6	-	4	22.3
Fluoride	9.65	9.65	9.25	10.2	7.45	9.45	14.2
Arsenic	0	0	0	0	0	0.005	.059
Iron*	0.05	0.02	0.04	0.04	0.44	0.07	0.05
Manganese*	0.01	0.01	0	0	0.0024	0.01	<0.05
pH, Units	8.43	8.39	8.42	8.42	8.45	8.33	8.85
Temperature °C	48	57	62	60	21	68	96
Well Depth (ft.)	169	341	250	575	285	198	Artesian

*Shown to have retarding characteristics.

is the high concentration of silica, 105 ppm SiO₂, in a fluid that has a TDS of only 425 ppm.

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 (fig. 1).

Temperatures in the Gabbs wells range from 21° to 68°C (70° to 154°F) and 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). Chemical analyses for the Gabbs wells are shown in Table 2. Well 10 has 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 Washoe 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."

A third ore was collected from the Battle Mountain Gold Company mine in Lander County. This is a high-sulfide type ore that had been mined for silver and copper, and is now mined for gold. This ore was used in the bacterial leaching experiment.

LABORATORY TESTS

On the basis of the literature survey, the extent of geothermal fluids, and the nature of the gold mining operations in Nevada, two applications were determined to have potential for enhancement by geothermal heating. The first process described is the cyanide heap-leaching process which is used throughout Nevada to extract gold and silver from oxide-rich ore. The second process is an experimental pre-treatment of sulfide-rich gold and silver ores. In this process, Thiobacillus sp. bacteria are used to remove ions that retard the cyanidation process. Ions of As, Cu, Hg, and Mn are metabolized by these bacteria and the rate of metabolic activity increases with temperature. Once extracted, the interfering ions are removed and the remaining gold and silver oxide ore can be treated with cyanide solutions.

CYANIDE HEAP-LEACHING STUDIES

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. 2) 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).

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

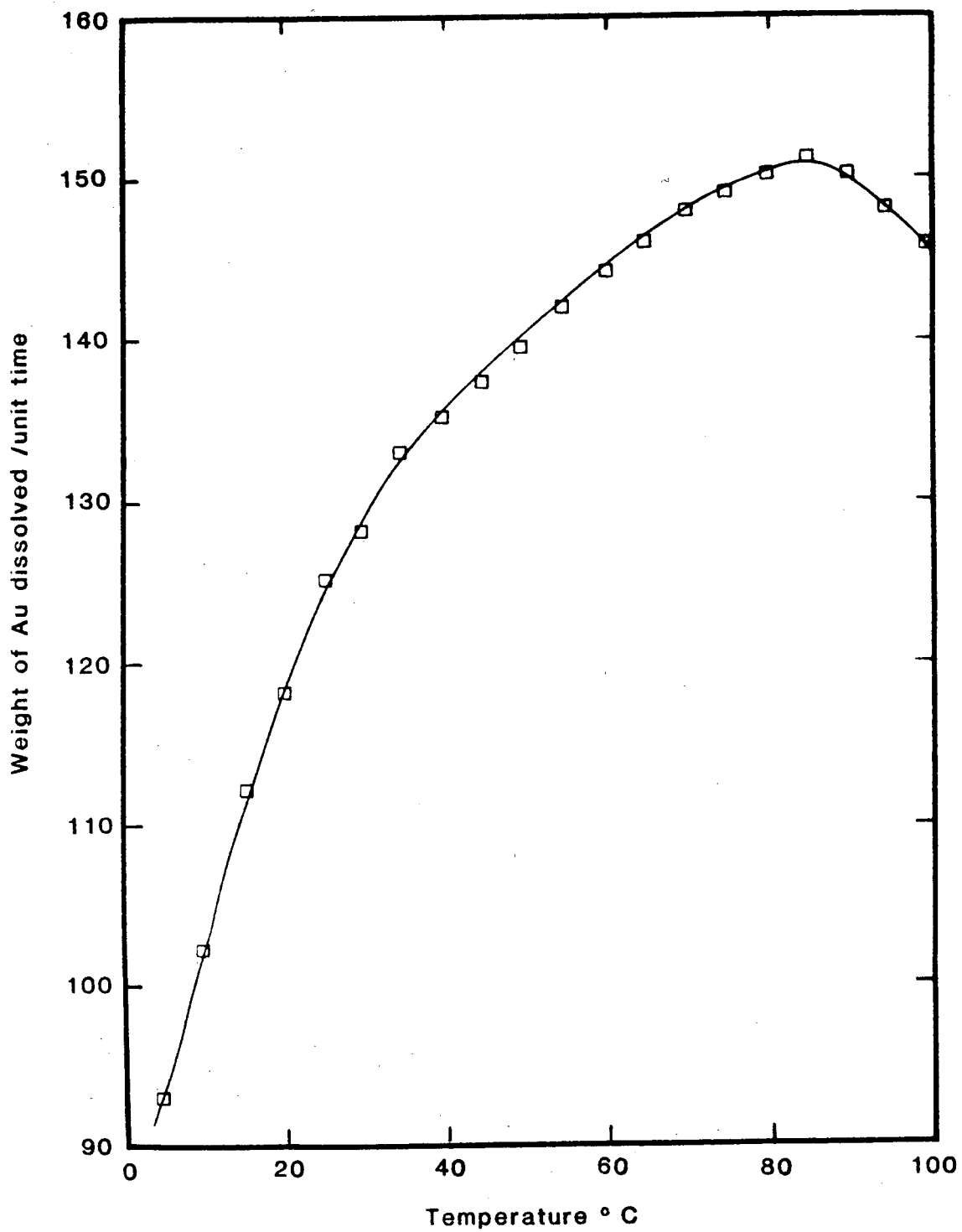


Figure 2. Effect of temperature on rate of dissolution of gold in 0.25 percent KCN (after Julian and Smart, 1921).

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 3 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 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 CO₂. 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 3 lists the ions most likely to be encountered in gold ores and their associated effects.

Table 3

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⁻

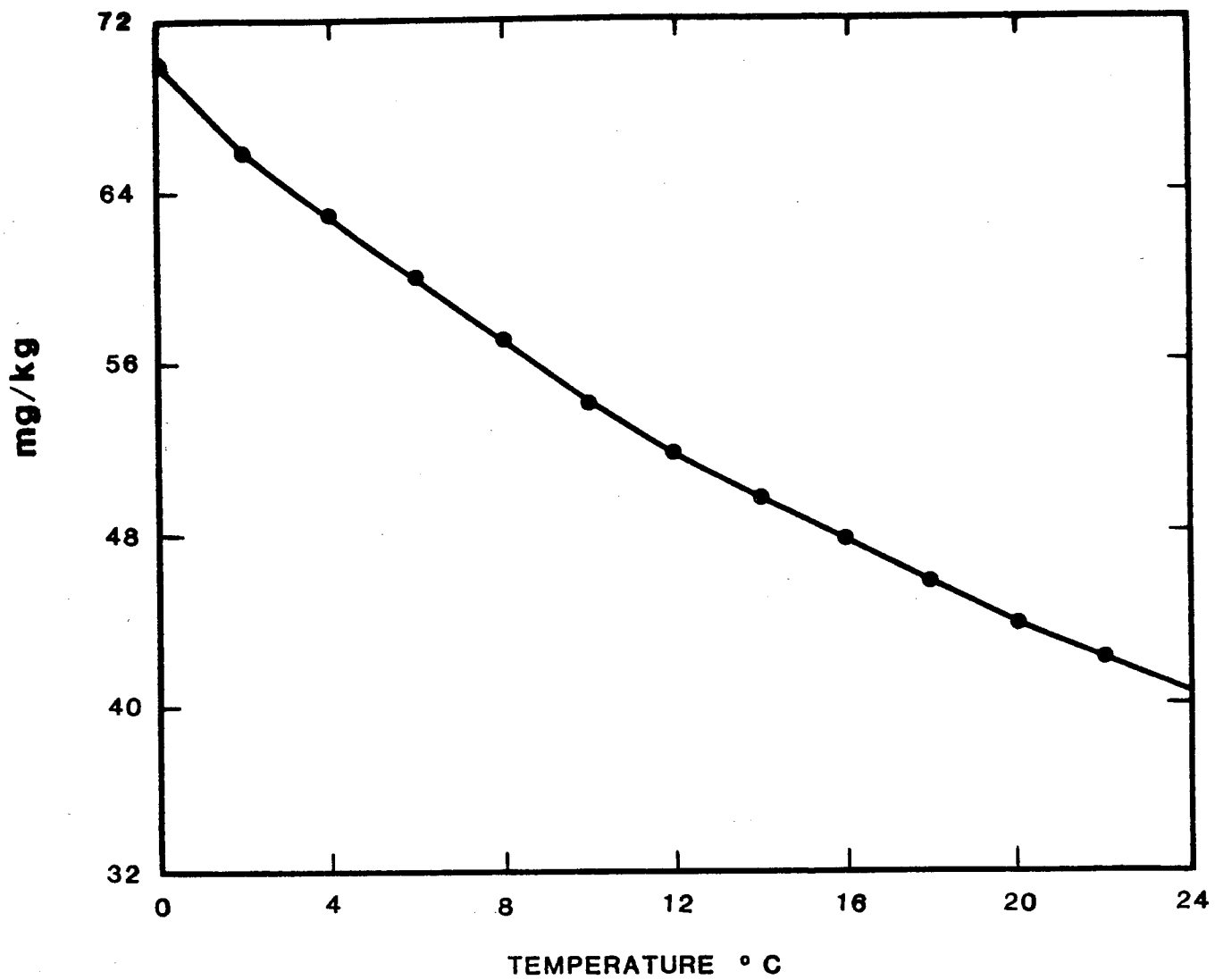


Figure 3. Solubility of O_2 in pure water in equilibrium with O_2 only.

EXPERIMENTAL

All tests reported were conducted using a flask and shaker bath apparatus. The ore was first crushed in a six-inch jaw-crusher and passed through a nested sieve. Weight percents of the crushed ore were recorded as follows: screen size - 100 to 140, 14.3%; 140 to 200, 23.7%; 200 to 325, 4.5%; and less than 325, 57.5%. 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 Washoe 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 4 and Figure 4.

Table 4

Gold Extraction From Freeport Ore When Leached at Various Temperatures

Temperature (°C)	Percent Gold Extracted at Specific Times					
	HOURS					
	1	2	4	8	12	24
20	64.05	71.09	68.51	64.37	69.48	66.77
10	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

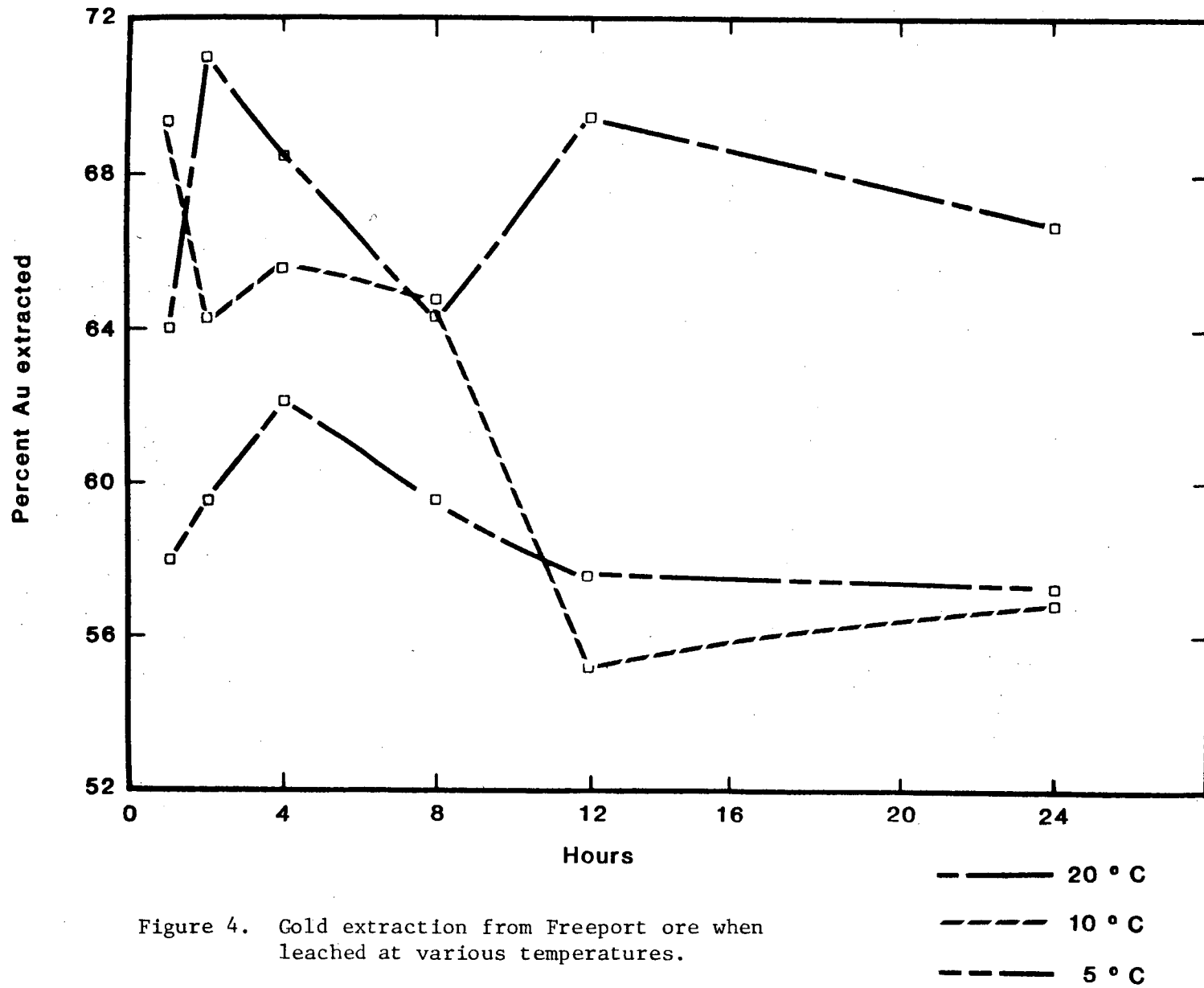
From these data, it is obvious that the extraction of gold from the Freeport ore is significantly increased at higher temperatures. Table 5 shows the percentage increase of gold recovered at 20°C (68°F) as compared to 5°C (41°F).

Table 5

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

Maintaining the cyanide solution at 20°C (68°F) provides an increase in the extraction rate of eight to twenty percent.



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 caused 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 the cyanide solution returns to the heaps. 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 6 and Figure 5.

Table 6

Silver Extraction from Gooseberry Ore Leached at Various Temperatures

Temperature (°C)	Percent Silver Extracted at Specific Times					
	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

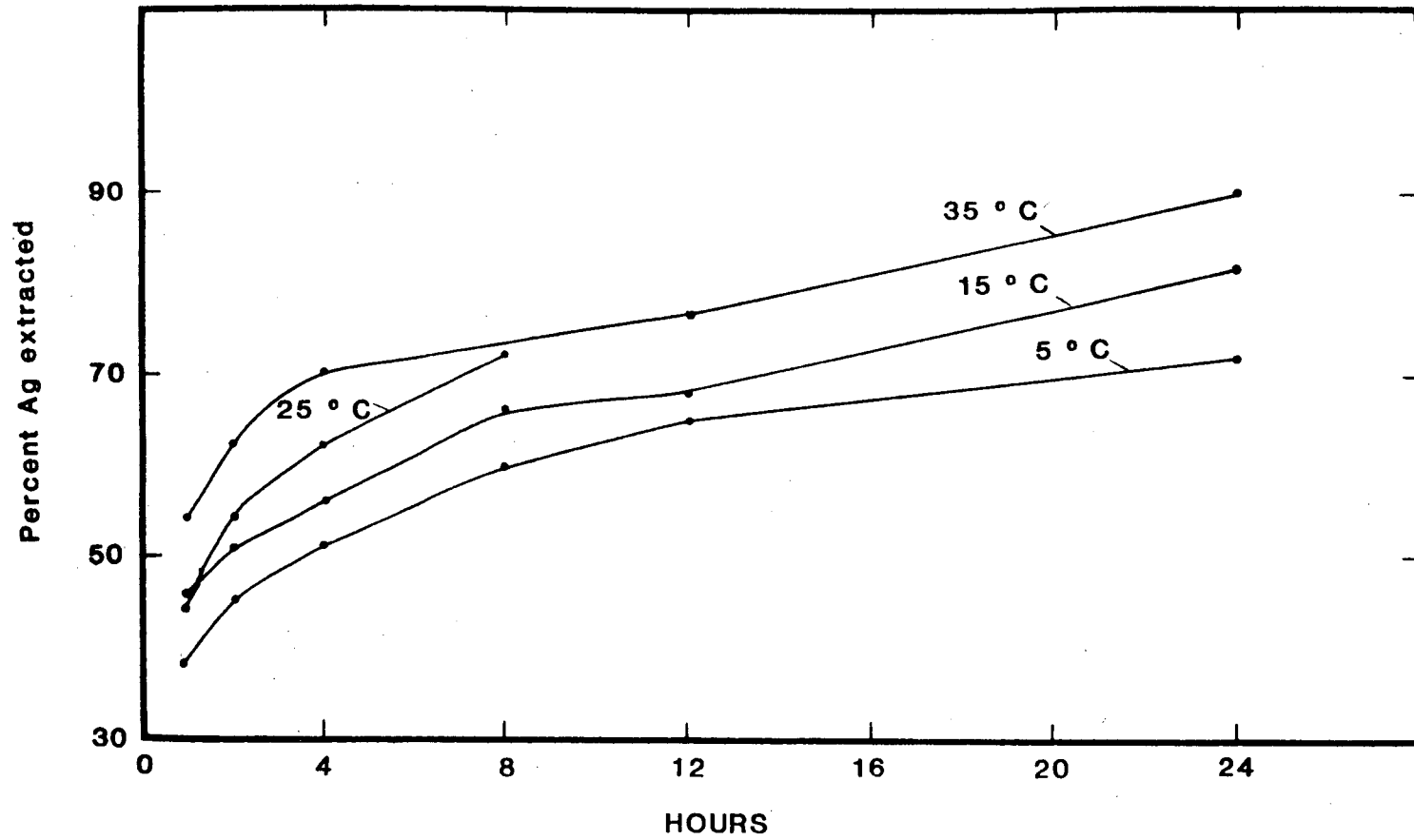


Figure 5. Silver extraction from Gooseberry ore at various temperatures.

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 has been 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 7.

Table 7
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.

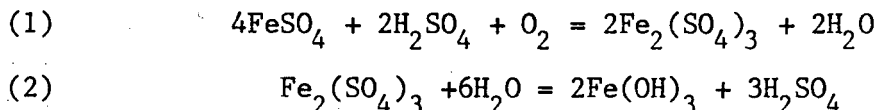
BACTERIAL LEACHING

Recent studies, described in the literature review, have revealed the application of selected bacterial strains on metal recovery processes. The species discussed in this report, Thiobacillus ferrooxidans, is a member of the Family Thiobacteriaceae, a single, independent, gram-negative, cocci, that forms straight or curved rods, or spirals, and measures 0.5 microns by 10 microns. They are strict facultative chemolithotrophs that thrive in

mud, sea water, sewage, coal-mine drainage, and sulfur springs and other environments where sulfur and its reduced compounds occur naturally or as a result of microbial metabolism.

Metabolism

The metabolic activities of T. ferrooxidans result in the formation of ferric iron when the bacterium is grown in a ferrous rich medium. The following reactions summarize the metabolic activity exhibited by these bacterium:



Similar oxidation and hydrolysis reactions involving metal sulfides also produce sulfuric acid (Corrans et al., 1972 Keenan and Wood, 1971).

Effect of Temperature

The optimal and limiting temperature for all living organisms is a function of the optimal and limiting temperature for their enzymes (Frobisher, 1968). Figure 6 shows the relationship between temperature and a hydrolytic enzyme from different species of microorganisms. Thiobacilli are known to exist in a wide variety of environments, and a thermophilic species has already been described. It can be said in general that there is an optimal temperature for growth in all living cells, and this activity decreases sharply both above and below the optimal temperature.

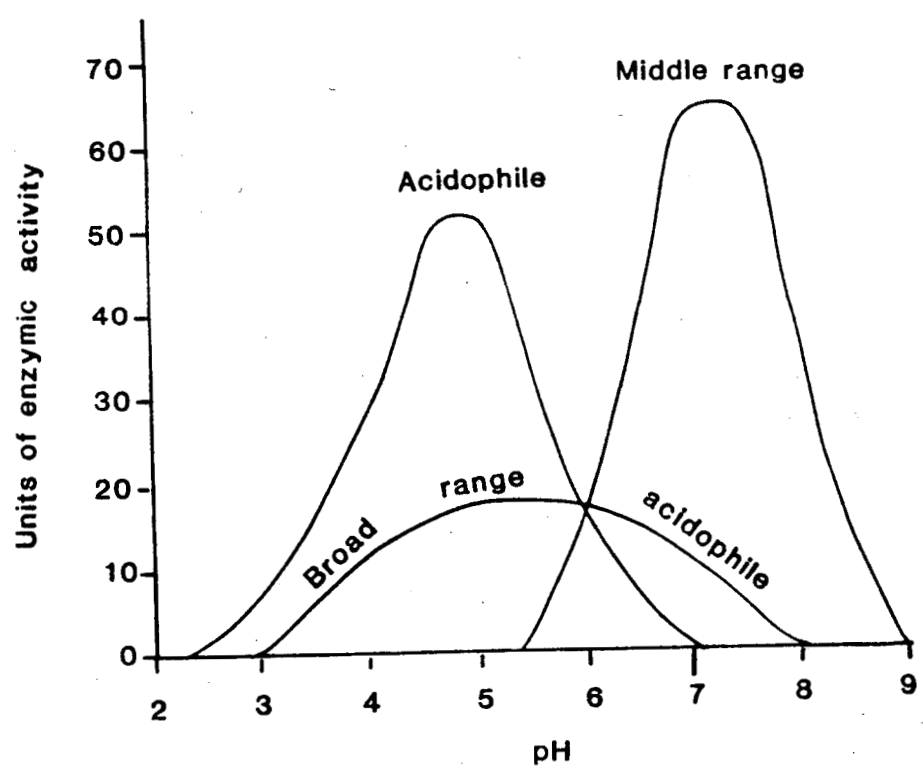
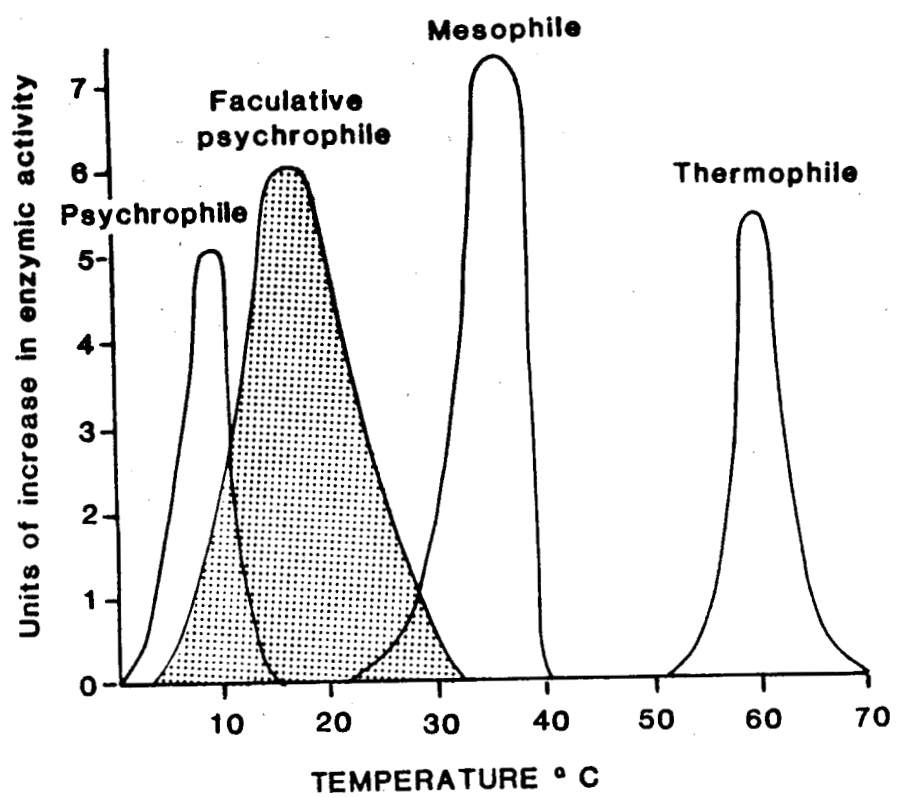


Figure 6. Metabolism of microorganisms as a function of temperature (top) and pH (bottom). (Modified from Frobisher, 1968).

Effect of Oxygen

Thiobacilli have been described as facultative organisms, they have the ability to grow either aerobically or anaerobically (with or without free oxygen). Anaerobic growth may occur in the presence of some other easily reducible substance, like sulfur or carbon, but is generally less energy efficient and may produce an incompletely oxidized substrate.

Effect of pH

According to equation 2 (above), the oxidation of ferrous iron ultimately results in the formation of sulfuric acid. As the bacteria produce more and more acid, the immediate effect is a decrease in the pH of the aqueous solution. This species grows readily at pH 3, is known to grow at pH 1, and can tolerate and produce higher concentrations of acid than any known organism (Frobisher, 1968 after Starkey).

Effect of Foreign Ions

Preliminary data suggest that these bacteria are very sensitive to silver ions, and mildly sensitive to gold and mercury ions. Aqueous solutions that contain the following elements and compounds meet all nutritive requirements of thiobacilli:

<u>Ingredients</u>	<u>Percent</u>
S	1.000
Na ₂ S ₂ O ₃	0.500
(NH ₄) ₂ SO ₄	0.030
KH ₂ PO ₄	0.025
CaCl ₂	0.050
FeSO ₄	0.001
KCl	0.050
MgSO ₄	0.020
Ca(NO ₃) ₂	0.050

Thiobacillus ferrooxidans Cultures

A pure culture of Thiobacillus ferrooxidans was obtained from the American Type Culture Collection (ATCC). The strain was that deposited with the ATCC by the National Collection of Industrial Bacteria in Aberdeen, Scotland, and was derived from a culture isolated by Leathen et al (1954). This material was received as 6 ml of actively growing culture.

Procedure

One ml of the solution containing the bacteria was introduced into each of six test tubes containing six ml of media composed of water and the following salts:

$(\text{NH}_4)_2\text{SO}_4$	0.80 g/l
KH_2PO_4	0.40 g/l
$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	0.16 g/l
$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	10.00 g/l

Enough H_2SO_4 was added to adjust the pH to 2.80 and distilled, deionized water was then added to bring the volume to 10 ml. This is the medium recommended by the ATCC. The test tubes were incubated on a New Brunswick Scientific "AquaTherm" water bath shaker at 35°C (95°F) for five days. This device has variable water levels, a constant-controlled motor for driving the shaker in a 1/2 inch circular orbit, and a heating and cooling coil to maintain a constant temperature. Each 10 ml culture was then placed into 90 ml of culture medium in a 250 ml Erlenmeyer flask and again incubated on the water bath shaker for five days.

Enough culture material for all tests was provided and maintained by weekly inoculations of 90 ml of medium with 10 ml of growing culture. Culture not in use were refrigerated for as long as 25 days.

As a result of the chemical reactions (equations 1 and 2 above), it is possible to monitor the growth of the cultures in the following ways:

1. The ferric ions in solution produce a distinctive reddish-brown color and the ferric hydroxide appears as an easily recognizable orange solid, allowing the culture to be visually monitored.
2. The concentration of ferric ions may be monitored more precisely by chemical methods.
3. The concentration of the metal ions in solution, due to the oxidation of the sulfides, may be measured.
4. The pH of the solution may be monitored. In this experiment, the pH of the medium and the cultures was monitored with a Corning Model 7 pH meter using an Ag/AgCl triple purpose electrode and a fibre-junction calomel reference electrode.

Ore Sample

All tests were conducted using an ore selected on the basis of its high sulfide and gold content. The ore used was from property owned by the Battle Mountain Gold Company in Lander County, Nevada. This area has been a target for mineral production since it was first mined for silver in 1863. Prior to the start-up of the gold mining operation, the property was mined for copper. Stager (1977) notes that although the principal production in the Battle Mountain Mining District has been copper, significant quantities of gold, antimony, lead, silver, and zinc have also been mined. A partial chemical analysis of the ore used in this experiment is given in Table 8.

Table 8

Partial Analysis of High-Sulfide Ore Sample.

Metal	Weight Percent or ppm
As	0.17%
Cu	0.23%
Hg	23 ppm
Mn	0.17%
Ni	56 ppm
Pb	217 ppm
Sb	60 ppm
Zn	483 ppm

EXPERIMENTAL

All tests were carried out in the constant temperature shaker bath, using the previously described crushed and sieved ore, and each test was run in triplicate. Three different slurry densities were used: 10%, 25%, and 40% by weight. The tests were conducted at three different temperatures: 25°C, 35°C, and 45°C (77°F, 95°F and 113°F).

The first procedure in testing consisted of placing the ore and sterile medium into a 250 ml Erlenmeyer flask and adjusting the pH of the aqueous solution to a value between 2.5 and 3.0 using concentrated sulfuric acid (H₂SO₄). Following this, 10 ml of active T. ferrooxidans culture was added to the flasks which were placed in the temperature bath for two weeks. The pH was monitored daily and used as an indication of bacterial growth.

In addition to the inoculated samples, control samples, using only sterile media and sterilized ore samples, were run simultaneously.

After two weeks, the samples were removed from the temperature bath, filtered, dried, and chemically analyzed. All analyses were completed on

an Induction-Coupled Plasma (ICP) instrument by the Reno Metallurgy Research Laboratory of the U.S. Bureau of Mines.

RESULTS AND DISCUSSION

The results of the bacterial leaching tests are shown in Tables 9 through 11. In general, the results are mixed. On one hand, the data show enhanced extraction rates with increased temperature for some metals in the 10% slurry. On the other hand, there was essentially no extraction at slurry concentrations of 25% and 40%.

Ten percent slurry

Figure 7 illustrates the results achieved in the 10% slurry for all temperatures. Copper, manganese, nickel, and zinc were consistently extracted in this experiment. Although the percent extraction of both copper and nickel was low, 15-30%, the data show a positive correlation of enhanced extraction with temperature increase. Manganese was extracted at much higher rates, 40-50%, but appeared to be effected less by the temperature increase. At 35°C (95°F), nearly 70% of the available zinc was removed by the bacteria, but the numbers drop off at both 25°C and 45°C (77°F and 113°F). No extraction was achieved for arsenic, mercury, and lead at any temperature or slurry concentration.

There are several factors that reflect on the results of these experiments including pH, toxic metals, and slurry concentrations.

pH

Thiobacillus ferrooxidans is an acidophilic organism that derives all of its nutritional requirements from the oxidation of inorganic sulfur and

Table 9. Extractions Achieved with T. ferrooxidans with a 10 Percent Slurry.

Metal	Extraction (percent)			
	Control	25°C	35°C	45°C
As	0	0	0	0
Cu	0	13	26	43
Hg	0	0	0	0
Mn	12	42	46	51
Ni	0	13	20	28
Pb	0	0	0	0
Sb	*	*	*	*
Zn	0	46	68	55

*Not detectable

Table 10. Extractions Achieved with T. ferrooxidans with a 25 Percent Slurry.

Metal	Extraction (percent)			
	Control	25°C	35°C	45°C
As	0	0	0	0
Cu	0	0	13	0
Hg	0	0	0	0
Mn	18	0	41	0
Ni	0	0	7	0
Pb	0	0	0	0
Sb	*	*	*	*
Zn	0	0	21	0

*Not detectable

Table 11. Extractions Achieved with T. ferrooxidans with a 40 Percent Slurry.

Metal	Extraction (percent)			
	Control	25°C	35°C	45°C
As	0	0	0	0
Cu	0	0	0	0
Hg	0	0	0	0
Mn	0	0	6	0
Ni	0	0	0	0
Pb	0	0	0	0
Sb	*	*	*	*
Zn	0	0	8	0

*Not detectable

reduced iron compounds. Apel and Dugan (1978) point out there are no protons (H⁺ ions) associated with the energy source and the "obligatory acidophilic nature" of these organisms may be explained by the immediate availability of H⁺ ions in low pH (1 to 3.5) environments. In the absence of H⁺ ions, the metabolic activity of these bacteria is severely curtailed.

During the course of the experiments, it was noted that there was some difficulty in maintaining the pH level at 2.5. It was suggested that the ore itself was contributing to this problem by providing a buffer that maintained the pH at approximately 6, well above the ideal growing range. It appears that a carbonate mineral, calcite, siderite, or malachite, may have been present in sufficient quantities to produce this effect. Bosecker and others (1978) report a nearly identical problem with a carbonate-rich copper shale.

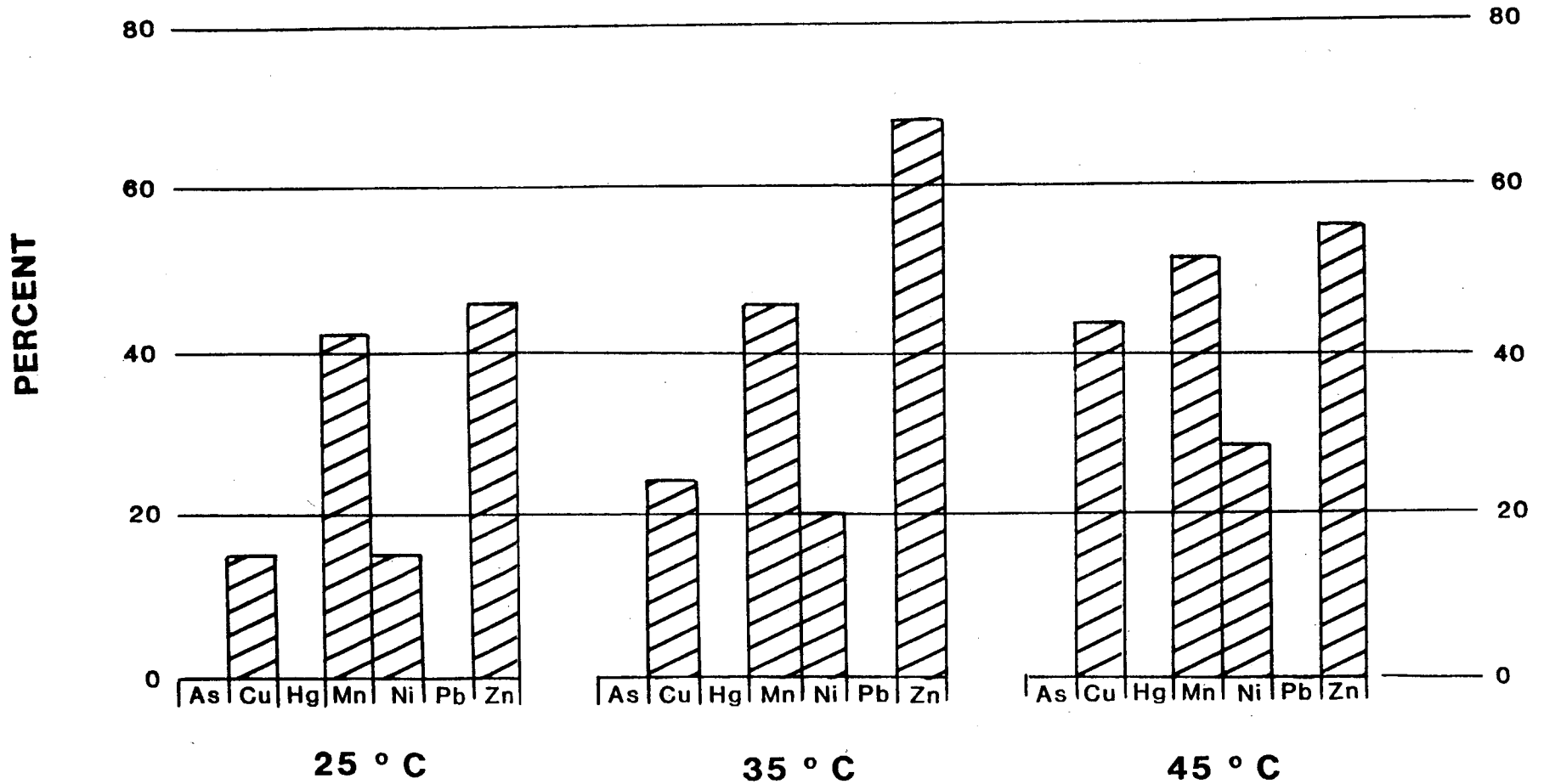


Figure 7. Extractions achieved with T. ferrooxidans in a 10 percent slurry.

Toxic Metals

Norris and Kelly (1978) confirmed the reported high toxicity of silver (Ag⁺) to Thiobacillus ferrooxidans at concentrations from 0.1 ppb to 0.01 ppm in acid solutions. Ag⁺ ions are believed to accumulate in the cells of T. ferrooxidans, possibly competing with H⁺ sites, and disrupting the metabolic activities of the organism. Since this area was first mined for silver, it is likely that the ore contains enough silver to produce toxicity in the aqueous solutions, contributing to the small extraction rates.

Mercury and gold are also believed to be toxic to these organisms and it is noted that Hg was not leached by the bacteria. Data on the action of lead leaching by T. ferrooxidans suggest that lead sulfides are oxidized to lead sulfates, which, unlike other metal sulfates, are insoluble. Hence, the action of the bacteria will not be registered. No corresponding data were found for arsenic.

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, determine if they are compatible 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 two hydrometallurgical processes; cyanide heap-leaching of gold and silver ores and bacterial leaching of sulfide rich gold 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. Nevada's geothermal waters do not contain significant amounts of ions that would interfere with the reactions, but the aqueous solutions will have to be slightly modified to match the high pH required for cyanide heap-leaching (fig. 8). Geothermal fluids typically contain little dissolved oxygen and some aeration would be required.

Perhaps the most important aspect of this research is the fact that geothermally enhanced heap-leaching operations can provide year-round production, independent of the prevailing weather conditions. Figure 9 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

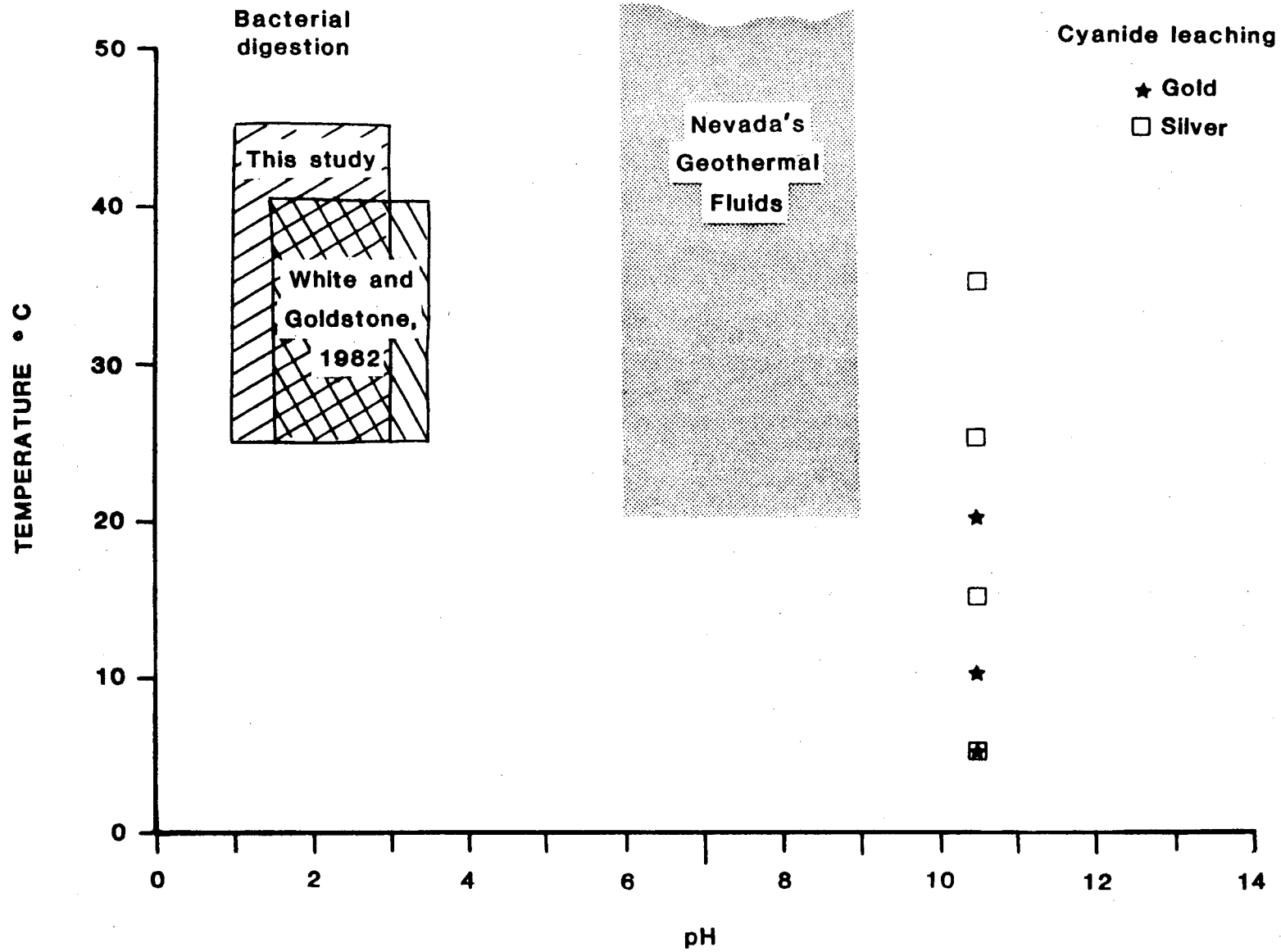


Figure 8. Comparison of temperature and pH requirements for bacterial digestion and cyanide leaching with Nevada's geothermal resources.

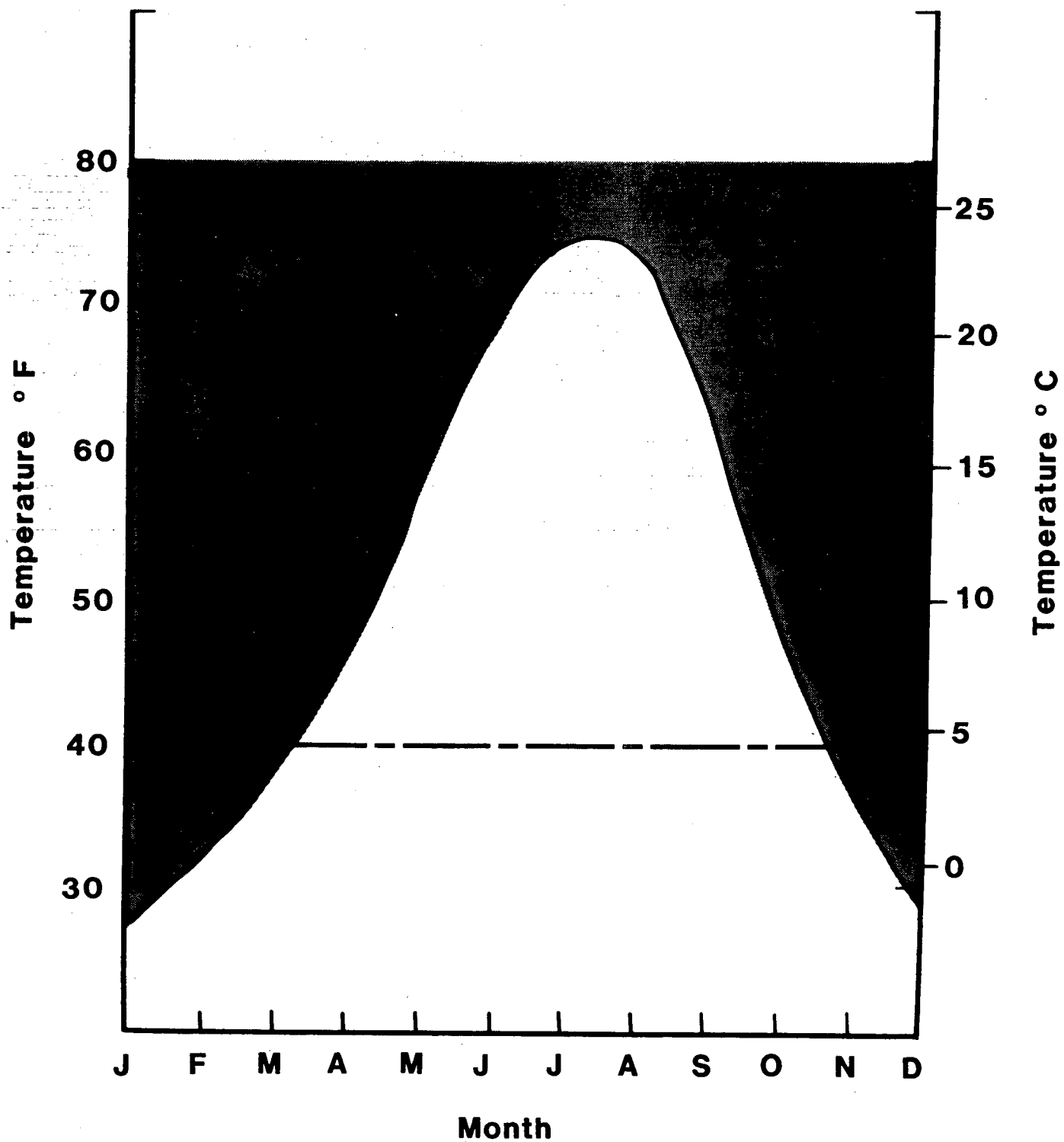


Figure 9. Soil temperature at a depth of 10 cm. (4 inches) at Central Nevada Field Laboratory near Austin, elevation 5,950 ft.

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. 9) 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.

The experimental data obtained in the bacterial studies suggest that enhancement of metal leaching by *Thiobacillus ferrooxidans* using higher than ambient temperature is restricted to selected metal ions at a slurry concentration of 10%. Copper and nickel showed enhanced extraction with increasing temperatures. Zinc extraction was highest at 35°C (95°F), and manganese appeared to be unaffected by temperature. Arsenic, mercury, and lead were not extracted at any temperatures or slurry concentrations. Maintaining the pH at levels compatible with the optimum growth environment was complicated by the apparent self-buffering of the ore itself. This phenomena is attributed to the presence of a carbonate mineral in the ore. In addition, most of Nevada's geothermal fluids have pH values considerably above the 2.5-3.0 range required by the bacterium (fig. 8) and may not be applied directly without substantially impairing the growth and viability of the micro-organisms. These restrictions may limit the application of large-scale bacterial leaching on the high-sulfide gold-bearing ores of Nevada.

REFERENCES

- American Type Culture Collection, 1974, The American type culture collection catalogue of strains; Eleventh Edition, Rockville, Maryland.
- Apel, W.A., and Dugan, P.R., 1978, Hydrogen ion utilization by iron-grown Thiobacillus ferrooxidans; in Murr, L.E., Torma, A.E., and Brierley, J.A., (eds.), 1978, Metallurgical applications of bacterial leaching and related microbiological phenomena: Academic Press, New York.
- Bosecker, K., Neuschutz, D., and Scheffler, U., 1978, Microbiological leaching of carbonate-rich German copper shale; in Murr, L.E., Torma, A.E., and Brierley, J.A., (eds.), 1978, Metallurgical applications of bacterial leaching and related microbiological phenomena: Academic Press, New York.
- Brierley, J.A., and LeRoux, N.W., 1977, in Schwartz, W. (ed.), 1977, Conference on Bacterial Leaching: Verlag Chemie, Weinheim.
- Corrans, I.J., Harris, B., and Ralph, B.J., 1972, Bacterial leaching: an introduction to its application and theory and a study on its mechanism of operation: J. South African Inst. Min. Met., 72(8): 221-223.
- Elsner, L., 1846, Über das Verhalten verschiedener Metalle in einer wässrigen Lösung von Cyankalium: J. Prakt. Chem., v. 37, p. 441-446.
- Frobisher, Martin, 1968, Fundamentals of microbiology: W.B. Saunders Co., Philadelphia.
- Gaze, W.H., 1898, A handbook of practical cyanide operations: George Robertson and Company, Melbourne.
- Habashi, F., 1967, Kinetics and mechanism of gold and silver dissolution in cyanide solutions: State of Montana Bur. of Mines and Geol., Bulletin 59.
- Haver, F.P., and Wong, M.M., 1971, Recovering elemental sulfur from non-ferrous minerals; ferric chloride leaching of chalcopyrite concentrate: U.S. Bur. of Mines, Reports of Investigations 7474.
- Julian, H.F., and Smart, E., 1903, Cyaniding gold and silver ores: Griffen, London (3rd ed., 1922).
- Keenan, C.W., and Wood, J.H., 1971, General college chemistry: Fourth edition, Harper and Row Publishers, New York.
- Leathen, W.W., Kinsel, N.A., and Braley, S.A., 1956, Ferrobacillus ferrooxidans; a chemosynthetic autotrophic bacterium: J. Bact., 72:700-704.
- Lund, V., 1951, The corrosion of silver by potassium cyanide solutions and oxygen: Acta Chim. Scand., v. 5, p. 555-567.
- Meyer, H., 1931, Über die Wirksamkeit der Arbeitslösungen in Cyanidprozess: Metall. U. Erz., v. 28, p. 261-280.

(REFERENCES, continued)

- Murr, L.E., Torma, A.E., and Brierley, J.A. (eds.), 1978, Metallurgical applications of bacterial leaching and related microbiological phenomena: Academic Press, New York.
- Norris, P.R., and Kelly, D.P., 1978, Toxic metals in leaching systems; in Murr, L.E., Torma, A.E., and Brierley, J.A. (eds.), 1978, Metallurgical applications of bacterial leaching and related microbiological phenomena: Academic Press, New York.
- Raub, E., and Muller, K., 1967, Fundamentals of metal deposition: Elsevier Publishing Company, Amsterdam.
- Schwartz, W. (ed.), 1977, Conference on bacterial leaching, 1977: Verlag Chemie, Weinheim, 1977.
- Stager, H.K., 1977, Geology and mineral deposits of Lander County, Nevada: Nevada Bur. of Mines & Geol., Bull. 88, 106 p.
- Thornhill, P.G., et al., 1971, The Falconbridge matte leach process: Journal of Metals, 23, 7, pp. 13-18, July, 1971.
- Trexler, D.T., Flynn, T., Koenig, B.A., and Ghusn, G.E., Jr., 1983, Geothermal Resources of Nevada: National Oceanic and Atmospheric Administration Map Series, 1:500,000 scale; Division of Earth Sciences, University of Nevada, Las Vegas.
- U.S. Patent 2,884,322
- U.S. Patent 3,104,212
- U.S. Patent 3,427,231
- U.S. Patent 3,445,352
- U.S. Patent 3,785,944
- White, D.H., and Goldstone, L.A., 1982, Geothermal energy for copper dump leaching: Final Report, U.S. DOE Contract #DE-FC03-80RA50076, Subcontract 115-80 with Dept. of Chemical Engineering, University of Arizona, 39 p.