Proceedings of the International Conference "Protection and Restoration of the Environment VI" Skiathos, July 1-5, 2002, pages 43 – 48. (Editors: A.G. Kungolos, A.B. Liakopoulos, G.P. Korfiatis, A.D. Koutsospyros, K.L. Katsifarakis, A.C. Demetracopoulos)

ENVIRONMENTALLY FRIENDLY METHODS FOR GOLD RECOVERY

E. Th. Stamboliadis, 0.I. Pantelaki and E.K. Manutsoglu
Department of Mineral Resources Engineering
Technical University of Crete
73100 Chania, Greece
E-mail: elistach@mred.tuc.gr, olgapan@mred.tuc.gr, emanout@mred.tuc.gr

ABSTRACT

Combined geological and metallurgical research work has indicated the existence of appreciable concentrations of placer gold in the sediments of the flysch of the Ionian Zone in Western Greece as well as the possibility to recover it by an environmentally acceptable method. In these sediments gold exists as free metal in the form of flakes and nuggets in sizes of the range 5-1000 μm. Laboratory test work has proved that the recovery of gold by modern gravitational methods, which are environmentally friendly, is satisfactory and comparable with the recovery obtained by the method of cyanidation.

ΑΝΑΚΤΗΣΗ ΧΡΥΣΟΥ ΜΕ ΠΕΡΙΒΑΛΛΟΝΤΙΚΑ ΦΙΛΙΚΕΣ ΜΕΘΟΔΟΥΣ

Η. Θ. Σταμπολιάδης, Ο.Ι. Παντελάκη και Ε.Κ. Μανούτσογλου
Τμήμα Μηχανικών Ορυκτών Πόρων,
Πολυτεχνείο Κρήτης
73100 Χανιά.

ΠΕΡΙΛΗΨΗ

Συνδυασμένες γεωλογικές και μεταλλουργικές έρευνες απέδειξαν την ύπαρξη ικανοποιητικών συγκεντρώσεων προσχωματικού χρυσού και την δυνατότητα ανάκτησης του από τα ιζήματα του φλύσχη της Ιονίου Ζώνης, στη Δυτική Ελλάδα. Στα ιζήματα αυτά ο χρυσός βρίσκεται ελεύθερος με μορφή φυλλαρίων και μικροσυσσωμάτων, σε μεγέθη που ποικίλουν μεταξύ 5-1000 μm. Εργαστηριακές δοκιμές έδειξαν ότι με την χρήση φιλικών προς το περιβάλλον σύγχρονων βαρυτομετρικών μεθόδων, τα ποσοστά ανάκτησης του χρυσού είναι ικανοποιητικά και συγκρίσιμα με αυτά που προκύπτουν από την χρήση μεθόδων κυάνωσης.

Proceedings of the International Conference "Protection and Restoration of the Environment VI" Skiathos, July 1-5, 2002, pages 43 – 48. (Editors: A.G. Kungolos, A.B. Liakopoulos, G.P. Korfiatis, A.D. Koutsospyros, K.L. Katsifarakis, A.C. Demetracopoulos)

INTRODUCTION

Gold is a precious metal and has contributed to the artistic, cultural and economic development of mankind. It was probably the first metal used by humans because of its occurrence as a free metal in placer deposits, enabling its recovery without the requirement of complex separation techniques. The form in which gold exists in ore deposits implies the techniques to be used for its recovery.

Gravity separation techniques were used in the beginning to extract native metal nuggets and flakes. This was relatively easy for visible metal grains. As the size of the grain becomes smaller traditional gravity separation techniques become inadequate to recover native gold. Cyanidation was invented as a solution to the problem. According to it, gold and other precious metals are dissolved in water by sodium cyanide, separated from the remaining solids and recovered from the water solution in a concentrated form. Gold also occurs associated with other minerals, mainly as an inclusion. The recovery of gold from these minerals can be achieved only after its liberation by distraction of the corresponding mineral lattice. In practice this is achieved by pyro- and hydro-metallurgical processes and the so liberated gold is consequently recovered by cyanidation. The above mentioned metallurgical techniques require close control in order to avoid environmental disturbance.

In our days there is a strong opposition from different social groups against the application of these techniques for gold recovery. New developments in gravity separation technology can allow the recovery of very fine free gold particles in sizes that were not possible by traditional machines. This is due to the creation of a fluidized bed under strong gravity field of the order of 200 G (gravity) caused by centrifugal forces. Fine gold can now be recovered from placer deposits.

There are indications for the existence of free fine gold in Western Greece. The aim of this study is to examine the possibility to recover gold from samples of this area by the use of gravity separation machines, which use centrifugal forces. The results show that this environmentally friently technique can compete with cyanidation and give acceptable gold recovery.

2. GEOLOGY

The primary gold bearing lode ores are of magmatic origin and depending on the stage of their formation are distinguished into:
• Magmatic (Intrusion related breccia-hosted, Skarn). Usually they are of low gold content.
• Hydrothermal. Most of these lode ores are quartz veins deposited from hydrothermal fluids in fault zones at medium (mesothermal) or shallow (epithermal) depths in the crust [1]. However due to geological and climatic phenomena the gold bearing magmatic and/or hydrothermal rocks are eroded and the weathering products are transported by rivers. Due to its high density (19,3 gr/cm^3) gold is mechanically concentrated in river and beach environments and forms placer deposits, which account for more than two-thirds of the total world gold supply. In these deposits gold occurs as native metal, usually associated with varying amounts of silver as alloys such as electrum. It also occurs in chemical combination with tellurium and mercury. In the hydrothermal rock formations gold is finely disseminated into the lattice of pyrite, arsenopyrite, galena and many other sulfide minerals. This type of gold is called refractory gold and can be liberated only after the distraction of the sulfide mineral lattice. In metallurgy this can be achieved by oxidation of the sulfide mineral. In nature oxidation can occur when the ore body is exposed to the atmospheric conditions and gold is liberated in the so oxidized ore body. Acid liquid drainage during oxidation creates a lot of environment concern about sulfide ore deposits. This is the case of the ore deposits

Proceedings of the International Conference "Protection and Restoration of the Environment VI" Skiathos, July 1-5, 2002, pages 43 – 48. (Editors: A.G. Kungolos, A.B. Liakopoulos, G.P. Korfiatis, A.D. Koutsospyros, K.L. Katsifarakis, A.C. Demetracopoulos)

in Chalkidiki and Thrace [2].

From the environmental point of view the easier to handle are the placer formations, which exist in Western Greece. The Western mainland of Greece is situated in the External Hellenides. Geologically this area includes the Ionian Zone, which on its stratigraphic top has a thick exposed sedimentary sequence, mainly composed of monotonous clays, marls, sandy marls and conglomerates, called West Hellenic flysch [3]. The flysch sediments are the products of the uplift and subsequent erosion of the cordillera situated to the east of the Ionian Zone. Within these sedimentary host rocks disseminated fine gold is concentrated together with other heavy minerals into placers. The main gold minerals are native gold and electrum.

3. ORE PROCESSING

Different methods are used for native and refractory gold. For native gold gravity concentration is used to preconcentrate the ore followed by cyanidation. For very fine gold, which cannot be recovered by gravity concentration, cyanidation is the only method used. The traditional gravity equipment used to recover relatively coarse gold are jigs, cones, spiral classifiers, shaking tables and shutes [4].

Run of mine ore is wet ground for better gold liberation. The coarse fraction is usually treated by gravity concentration to recover any liberated gold while the fine fraction is pumped to cyanidaton. Sodium cyanide is added to the pulp at a concentration about 400-ppm and pH 10.5-11.0, adjusted by calcium hydroxide. The pulp is agitated for at least 24h in the presence of active carbon. Cyanide dissolves gold and forms soluble complexes, which are adsorbed by the active carbon. The loaded carbon is screened from the finely ground ore and is processed to recover gold. The barren pulp is treated to destroy the remaining cyanide and then is rejected into the tailings pond where the solids settle and the water is recycled into the process. The main processes used to destroy cyanide are the alkaline chlorination, oxidation by sulfur dioxide, (INCO process), oxidation by hydrogen peroxide (DEGUSSA process) and biological degradation. Regardless of the cyanide destruction there is a strong opposition by certain social groups for the use of cyanidation.

For refractory gold it is necessary to oxidize the gold bearing sulfide mineral in order to liberate gold. For obvious reasons the sulfide mineral is usually concentrated by flotation. The methods used to oxidize the sulfide concentrate are:

- Calcination at elevated temperature (roasting). This creates a lot of environmental problems due to the evolution of sulfur and arsenic oxides and tends to the abandoned.
- Chemical oxidation in autoclaves, using oxygen gas at high pressure and elevated temperature.
- Biological oxidation using bacteria, mainly *Thiobacillus ferrooxidants* and *Spirilium* [5].

The last two techniques produce sulfuric acid and use limestone for its neutralization. The oxidation residue from all the above methods is treated by cyanidation to recover gold. The rejection of the neutralization products and the cyanidation tailings arise a lot of protest and gold processing is under severe environmental terms, which increase the cost of production.

4. NEW DEVELOPMENTS IN GOLD RECOVERY EQUIPMENT

For native gold deposits gravity concentration by traditional techniques is restricted to sizes above

Proceedings of the International Conference "Protection and Restoration of the Environment VI" Skiathos, July 1-5, 2002, pages 43 – 48. (Editors: A.G. Kungolos, A.B. Liakopoulos, G.P. Korfiatis, A.D. Koutsospyros, K.L. Katsifarakis, A.C. Demetracopoulos)

50 μm. At smaller sizes the drug force by water overcomes the difference in specific gravity between gold and the gangue minerals and separation is not effective. In the last years a new type of gravity equipment have been produced which create a gravitational field up to 200 G and can separate gold from gangue minerals at sizes below 50 μm. The strong gravitational field is created by centrifugal forces and the separation occurs is a fluidized bed formed by water flow. The specific equipment can handle large throughputs of ore because the quantity of the heavy fraction produced is very small in volume compared to the volume of light gangue mineral fraction. Experimental results of samples from the West Greece flysch treated by such equipment are presented bellow.

5. TEST WORK

5.1 Sample preparation

Two combined different samples, A and B, were collected from the flysch sediments of the Ionian Zone in Western Greece. Each sample was broken to –4 mm using a laboratory jaw crusher. The –4 mm product was further ground to –1mm using a rotating disk mill. At this size the liberation of gold is expected to be satisfactory. The ground product was divided in two fractions by screening at 0.250 mm. The fine –0.250 mm fraction was washed with water and classified at 10 μm by the use of a hydrocyclone.

5.2 Gravity separation

The equipment used for gravity separation tests was a centrifugal Falcon concentrator model SB40 [6]. The objective of these tests was to concentrate the gold that was contained in the samples. Three tests were made with the following samples:

- Test 1: Sample A fraction 10-250 μm.
- Test 2: Sample B fraction 250-1000 μm.
- Test 3: Sample B fraction 10-250 μm.

The operating conditions of gravity separation [7] on each of the three tests, as well as the recovery of weight for the corresponding separations appear in Table 1.

Table 1: Separation conditions

	Test 1 Sample A 10-250 μm	Test 2 Sample B 250-1000 μm	Test 3 Sample B 10-250 μm
Rotation frequency	35 Hz	30 Hz	35 Hz
Water pressure	6 psi	8 psi	6 psi
Feeding rate	6.33 Kg/h	11.04 Kg/h	7.50 Kg/h
Water flow	2.0 l/min	1.8 l/min	2.0 l/min
Pulp density	5.0 %	9.3 %	5.9 %
Weight recovery	1.52 %	1.99 %	0.51 %

The separation products, heavy concentrate and light gangue, were weighted and assayed for gold. The heavy fraction was also examined by optical microscopy in order to determine the free gold.

5.3 Cyanidation

For comparison purposes cyanidation tests were also performed using the two size fractions of sample B. The operating conditions were the same for both cyanidation tests and the technique was the one of rolling bottle. The pulp contained 1 Kg of sample, 3 lt of water and the following reagents were added:

- 7,5 gr $Ca(OH)_2$ for the adjustment of pH in the desirable level, (pH 11),
- 4,5 gr NaCN, that corresponds to concentration 1500 ppm NaCN in the leaching solution or 4,5 Kg NaCN per ton of ore.
- 50 gr active carbon (+ 1.7 mm), for the adsorption of the dissolved gold.

The pulp was placed in a cylindrical bottle and was rolled for 48 hours. At the end of the reaction period the pulp was screened at 1.00 mm, to remove the active carbon that was assayed for gold and the remaining pulp was sampled and rejected.

5.4 Fire assay

The products from gravity separation and cyanidation were assayed using the fire assay technique. According to this method a certain quantity of the sample to be assayed, 30g from mineral samples and 1g from active carbon samples, were mixed with the appropriate quantities of Na_2CO_3, PbO, $CaCO_3$, SiO_2, $Na_2O.2B_2O_3.10H_2O$ etc. and fired at about 950 ^oC to obtain the gold nugget. This nugget was consequently dissolved in aqua regia and assayed for gold by atomic absorption spectrometry.

5.5 Results

Using the assays of the products and the weights from the separation tests one can calculate the recoveries (distribution of gold) and the mass balance of each test, which is presented in Table 2. The degree of concentration for gravity concentration is calculated as the ratio of the gold assay in the concentrate to the assay in the feed. No cyanidation test was made for the sample A, 10-250 μm. The comparison of gold recovery obtained by the two methods is made between the distribution of gold in the concentrate of the gravity separation and the active carbon of the cyanidation. From the results obtained by gravity concentration and the optical microscopy observations it is obvious that better results can be obtained by finer grinding. However optimization of the process is beyond the scope of the present work

6. CONCLUSIONS

Based on the above test work the following conclusions can be made:

- The gold present in the flysch of West Greece is in the form of native metal and can be recovered by high gravity equipment.
- The degree of concentration obtained by gravity separation is very high.
- The results of table 2 suggest that although concentration of gold can be obtained at relatively large sizes (0.25-1.00 mm) the recovery is better at lower sizes. The optimum size of grinding must be determined by further research work. Optical microscopy has shown that gold nuggets are smaller in size than the associated gangue minerals.
- The recovery of gold obtained by gravity separation is comparable with the one obtained by cyanidation. This means that gravity separation can replace cyanidation without an appreciable metal loss.
- The concentrate grade obtained by gravity separation can be possibly increased after regrinding and second pass.
- Pilot plan size test work is required to optimize the process and evaluate the results.
- Although cyanidation gives relatively better metallurgical recoveries the advantage of the gravity separation is surpassing because it eliminates environmental concerns.

Proceedings of the International Conference "Protection and Restoration of the Environment VI" Skiathos, July 1-5, 2002, pages 43 – 48. (Editors: A.G. Kungolos, A.B. Liakopoulos, G.P. Korfiatis, A.D. Koutsospyros, K.L. Katsifarakis, A.C. Demetracopoulos)

Table 2: Test Work Results

Sample	GRAVITY SEPARATION					CYANIDATION	
	Product	Weight %	Gold Assay g/ton	Gold Distri-bution %	Degree of concen-tration	Product	Gold Distri-bution %
Sample A 10-250 μm	Concen-trate	1.52	6.43	70.71	45.9	Active carbon	-
	Tailings	98.48	0.04	29.29		Tailings	-
	Total	100.00	0.14	100.00		Total	-
Sample B 250-1000 μm	Concen-trate	1.99	906.90	71.75	36.1	Active carbon	91.2
	Tailings	98.01	7.25	28.25		Tailings	8.8
	Total	100.00	25.15	100.00		Total	100.00
Sample B 10-250 μm	Concen-trate	0.51	7,847.3	82.76	162.3	Active carbon	99.74
	Tailings	99.49	8.38	17.24		Tailings	0.26
	Total	100.00	48.36	100.00		Total	100.00

REFERENCES

1. Bierlein F.P. and Maher S., “Orogenic disseminated gold in phanerozoic fold belts – examples from Victoria, Australia and elsewhere”, **Ore Geology Reviews**, Vol. 18, pp.113-148, (2001)

2. Shawh A.J. And Constantinides D.C., “The Sappes gold project”, **Bulletin of the geological Society of Greece**, Vol. XXXIV/3, pp. 1073-1080, (2001)

3. I.F.P./I.G.S.R., “Etude géologique de l’Epire (Grèce nord-occidentale)”, Paris, (1966)

4. Wills B. A., “**Mineral Processing Technology**”, 4th edition, Pergamon Press, (1988)

5. Yannopoulos J. C., "**The Extractive Metallurgy of Gold**", Van Nostrand Reinhold, New York, (1990)

6. Falcon Concentrators ltd: Selecting Batch-Type, Fluidized Bed Enhanced Gravity Concentrating Equipment, Longley, British Columbia, Canada, (2001)

7. Pantelaki O. I., "Gold Recovery from Flysch Sediments of Ionian Zone with Environmentally Friendly Gravity Separation Methods", **Post graduate thesis, Technical University of Crete**, Chania, Greece, (2001)