5 The GeoBiotics GEOCOAT® Technology – Progress and Challenges

TODD J. HARVEY, MURRAY BATH

5.1 Introduction

Minerals biooxidation is now accepted as a viable technology for the pretreatment of refractory sulfidic gold ores and concentrates, and for the leaching of base metals from their ores and concentrates. Tank bioleaching or biooxidation is successful in achieving high metal recoveries, but both capital and operating costs are relatively high. Heap biooxidation has lower costs, but to date has suffered from low metal extraction rates and low ultimate metal recoveries. These disadvantages may outweigh the lower capital and operating costs of heap processes. GeoBiotics has developed and patented the GEOCOAT® biooxidation and bioleaching technology, which combines the high recoveries of tank processes with the low costs of heap-based processes. The process has been commercialized for the pretreatment of a refractory sulfidic gold concentrate. GeoBiotics is also developing the GEOLEACH™ technology for bioleaching and biooxidation of gold and base metal ores in heaps (Fig. 5.1).

5.2 The GEOCOAT® and GEOLEACH™ Technologies

The GEOCOAT® technology offers a unique approach to the application of bacterial minerals processing, combining the low capital and operating costs of heap leaching with the high recoveries obtained in agitated tank bioreactors (Harvey et al. 1998). Both of these technologies are well accepted in the minerals industry and both are in commercial operation worldwide (Brierley 1999). In the GEOCOAT® process, sulfide flotation or gravity concentrate is coated as a thickened slurry onto crushed and size-sorted support rock which may be barren or which also may contain sulfide or oxide mineral values. The coated material is stacked on a lined pad for biooxidation. The process is applicable to the biooxidation of refractory sulfide gold concentrates and to the bioleaching of copper, nickel, cobalt, zinc, and polymetallic base metal concentrates. Mesophilic or thermophilic microorganisms catalyze the sulfide oxidation reactions. In the processing of chalcopyrite concentrates, the higher temperatures associated with the use of thermophilic microorganisms

Biomining
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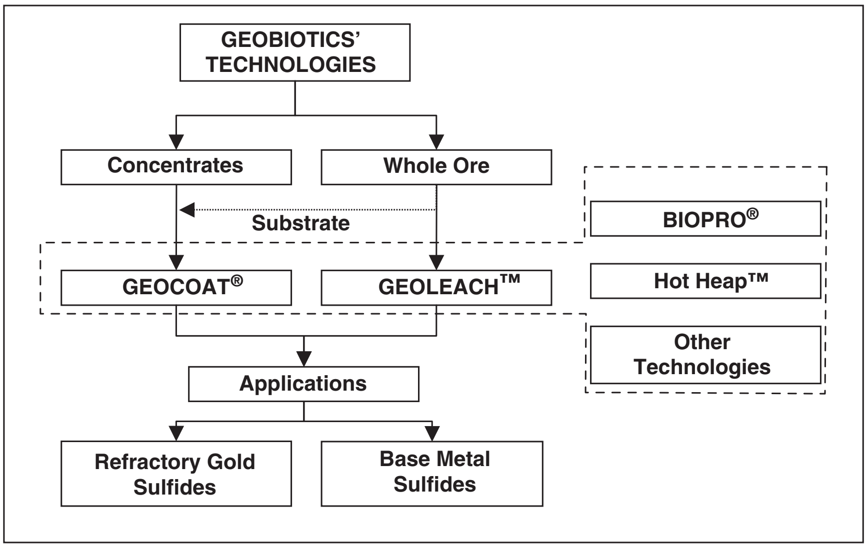

Fig. 5.1. GeoBiotics technology portfolio

have proven highly beneficial in increasing the rate and extent of copper leaching.

In the processing of refractory gold sulfide concentrates, the GEOCOAT® process offers significant cost advantages over established processes (roasting, pressure oxidation, and agitated tank biooxidation). In base metals operations, the process is particularly suited to the treatment of "dirty" concentrates, reduces transportation costs by allowing the on-site production of metal at remote operations, and can take advantage of the depletion of oxide reserves through the utilization of existing solvent extraction/electrowinning equipment. The process is simple, robust, and ideally suited to operation in remote locations.

The GEOLEACH™ technology is applicable to whole-ore systems where the metals occur as sulfides, or are occluded within sulfides, as with refractory gold. The incentive for the development of the process is the recognition that oxidation of the sulfides in most whole-ore leaching systems potentially can release enough energy to raise the heap temperature to very high levels; however, in practice, poor, or lack of any, heat management prevents a significant temperature rise. Unless heap temperatures can be raised above ambient, sulfide leaching kinetics is extremely slow; higher temperatures (above 70°C) appear to be particularly important for the successful bioleaching of chalcopyrite (Stott et al. 2000). The GEOLEACH™ technology is designed to maximize heat conservation through careful control of aeration and irrigation rates. GEOLEACH™ has built upon the best industry knowledge of bioleaching operations. The technology is very similar to that of conventional whole-ore acid heap leaching systems, but with the addition of an operational strategy to maximize heat conservation, raise temperature, and maintain bacterial activity.

5.2.1 Complementary GeoBiotics Technologies

The GEOCOAT® and GEOLEACH™ technologies, together with a wide variety of additional expertise and patents, constitutes the GeoBiotics technology suite, including high-temperature bioleaching, toxins removal, HotHeap™, BIOPRO™, and other complementary processes focused around pretreatment, aeration, stacking, and instrumentation. HotHeap™ is a bacterial heap leaching operating strategy coupled with an instrumentation and control system, that maximizes heat conservation, thereby enhancing bioleaching kinetics, while BIOPRO™ is an inoculation method for bacterial heap leaching systems licensed from Newmont Gold Company.

GeoBiotics has successfully commercialized the GEOCOAT® process for the treatment of refractory gold concentrates at African Pioneer Mining's (APM's) Agnes Mine near Barberton, Mpumalanga, South Africa. The plant was commissioned in June of 2003 to treat 12,000 t of concentrate per year, yielding approximately 25,000 oz of gold (Harvey and Bath 2003).

As with any new process, the development and implementation of the GEOCOAT® technology has taken considerable effort and time. This chapter provides an outline of the technology, its applications and advantages, a description of the Agnes GEOCOAT® plant, and a discussion of the challenges faced in the implementation of the new technology. It includes a brief description of GeoBiotics's plans for expansion into new biohydrometallurgical applications, particularly whole-ore chalcopyrite leaching.

5.2.2 The GEOCOAT® Process

The GEOCOAT® process uses iron- and sulfur-oxidizing microorganisms to facilitate the oxidation and leaching of sulfide minerals in an engineered heap environment. These microorganisms include the mesophilic (moderate-temperature) bacteria *Acidithiobacillus ferrooxidans*, *Acidithiobacillus thiooxidans*, and *Leptospirillum ferrooxidans*, and thermophilic (high-temperature) microorganisms such as the archaea *Sulfolobus* and *Acidianus*.

After concentration by conventional processes, typically flotation or gravity concentration, the sulfide minerals are coated as a thickened slurry onto a support rock, which may be barren (waste) rock or a low-grade sulfide or oxide material. The size of the support material is typically 6–25-mm diameter, allowing the concentrate to form a coating less than a 0.5-mm thick on the rock surfaces. The mass ratio of concentrate to support rock is typically in the range 1:7–1:10. The coating is applied by contacting the thickened concentrate slurry with the support as it discharges from the stacking conveyor onto the heap. This results in the formation of a thin, relatively uniform coating on the support rock surfaces. The adherent coating is not washed out of the heap by solution application or by heavy rain. The relatively uniform size of the support rock particles results in large interstitial spaces within the heap, offering very low resistance to air and solution flows. Low-pressure fans supply air through an engineered system of perforated pipes placed under the heap. The air-flow rate is varied to maximize bacterial activity and provide evaporative heat control.

The large interstitial spaces, combined with the thin concentrate layer, create ideal conditions for biooxidation. The sulfide mineral grains and the attached bacteria are constantly exposed to the downward-flowing solution and the countercurrent flow of air. The result is the efficient transfer of oxygen and thus rapid oxidation rates. Typically, oxidation is complete within 60–120 days, whereas in whole-ore heap biooxidation, oxidation may not be complete even after several hundred days. The larger void spaces and rigid support provided by the sized support rock particles in the GEOCOAT® heap prevent the compaction typical of whole-ore heaps and ensure uniform distribution of air and solution to all parts of the heap.

In the basic GEOCOAT® process for refractory gold concentrates, the concentrate is coated onto a barren, essentially inert, support rock. After biooxidation, the heap is reclaimed and the oxidized concentrate is separated from the support rock by wet screening. The washed support rock is recycled for recoating with fresh concentrate. A potentially attractive option is to coat the sulfide concentrate onto low-grade sulfide material which would otherwise be stockpiled or discarded as waste. The bacterial action in the concentrate coating is also effective in oxidizing the sulfide minerals in the support rock, making additional metal values available for recovery. This may allow subcutoff-grade material to be brought into the economic reserve. An alternative is to use a screened and sized portion of the ore as a support medium. The rest of the ore is ground and floated, producing the concentrate that is coated onto the support rock fraction for biooxidation.

Downstream processing operations depend on the purpose of the biooxidation or bioleaching process. In the treatment of refractory gold ores, the gold remains in the oxidized solid residue, which is removed from the pad for additional treatment, typically cyanidation. In the processing of copper and other base metal sulfides, the valuable metal is solubilized and is recovered from the leach solution, while the residue remains on the pad. An "on–off"-type pad is used for refractory gold ores, with the oxidized material being offloaded for further processing, and the pad reused. However, for copper and other base metal ores, a permanent pad may be used, with the pad area being expanded as required. Alternatively, additional lifts of coated support rock may be stacked on top of the first. Figure 5.2 is a schematic representation of an "on–off" pad.

The GEOCOAT® process is also applicable to the treatment of concentrates containing both gold and copper values. The heap is bioleached to pro-

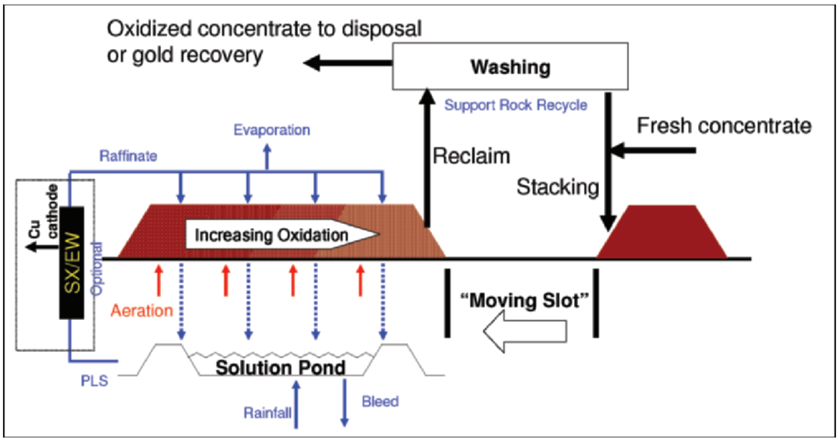

Fig. 5.2. Reusable pad configuration. *SX* solvent extraction, *EW* electrowinning, *PLS* pregnant liquor solution

duce a pregnant solution from which copper is recovered by solvent extraction and electrowinning. The residual copper-depleted material is unloaded from the pad and screened to remove the oxidized concentrate containing the gold values. The gold is typically recovered from the oxidized concentrate by cyanidation.

Figure 5.3 shows the flowsheet options for the application of the GEOCOAT® process for the treatment of refractory gold ores. Figure 5.4 is a schematic flowsheet for the processing of a base metal concentrate, in this case copper.

5.2.3 Advantages of the GEOCOAT® Process

The GEOCOAT® process has advantages over other refractory gold pretreatment options such as roasting, pressure oxidation, and stirred-tank biooxidation. Primary advantages are lower capital and operating costs, stemming from the simplicity of the process, the use of low-cost materials of construction, particularly plastics, the use of low-pressure air as the primary oxidant, and the relative ease with which most sulfides are biooxidized.

A recent independent assessment for GeoBiotics of the GEOCOAT® technology included an evaluation of the treatment options for refractory gold sulfides, showing the cost advantages of GEOCOAT®. Table 5.1 is an excerpt from the report showing selected capital and operating cost estimates for refractory gold GEOCOAT® plants.

As shown, the operating cost of the GEOCOAT® plant can vary substantially. The main reason for this, besides effects of scale, is the widely ranging cost of effluent neutralization. For the first project listed in Table 5.1, lime, at

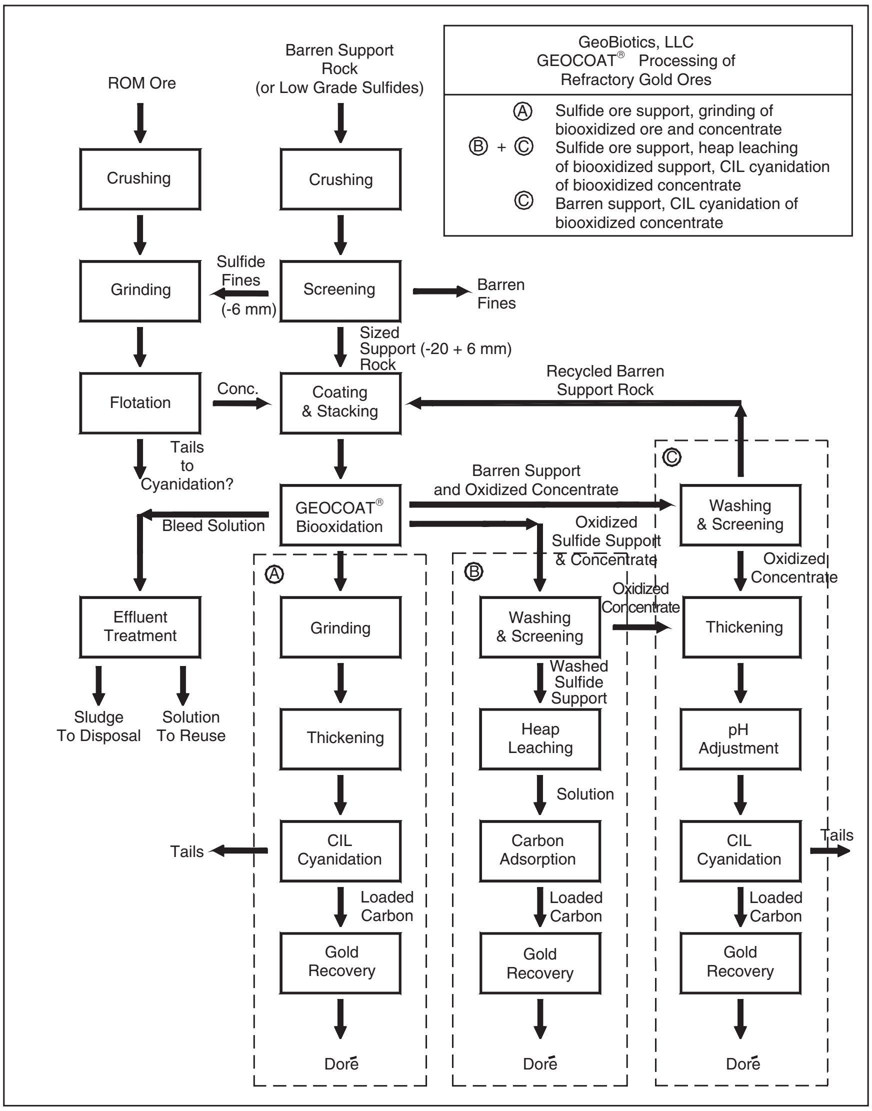

Fig. 5.3. GEOCOAT® flowsheet – refractory gold. *CIL* carbon in leach

a cost of US $120 per tonne, was employed for neutralization, whereas the other estimates were based on the use of much cheaper locally available limestone. It should be noted that the cost of neutralization is common to all sulfide oxidation processes. Unlike pressure oxidation and stirred-tank biooxidation, power costs for GEOCOAT® are extremely low, with consumption generally in the range 60–80 kWh t^{-1} of concentrate treated. Table 5.2 compares capital and operating costs of sulfide oxidation processes.

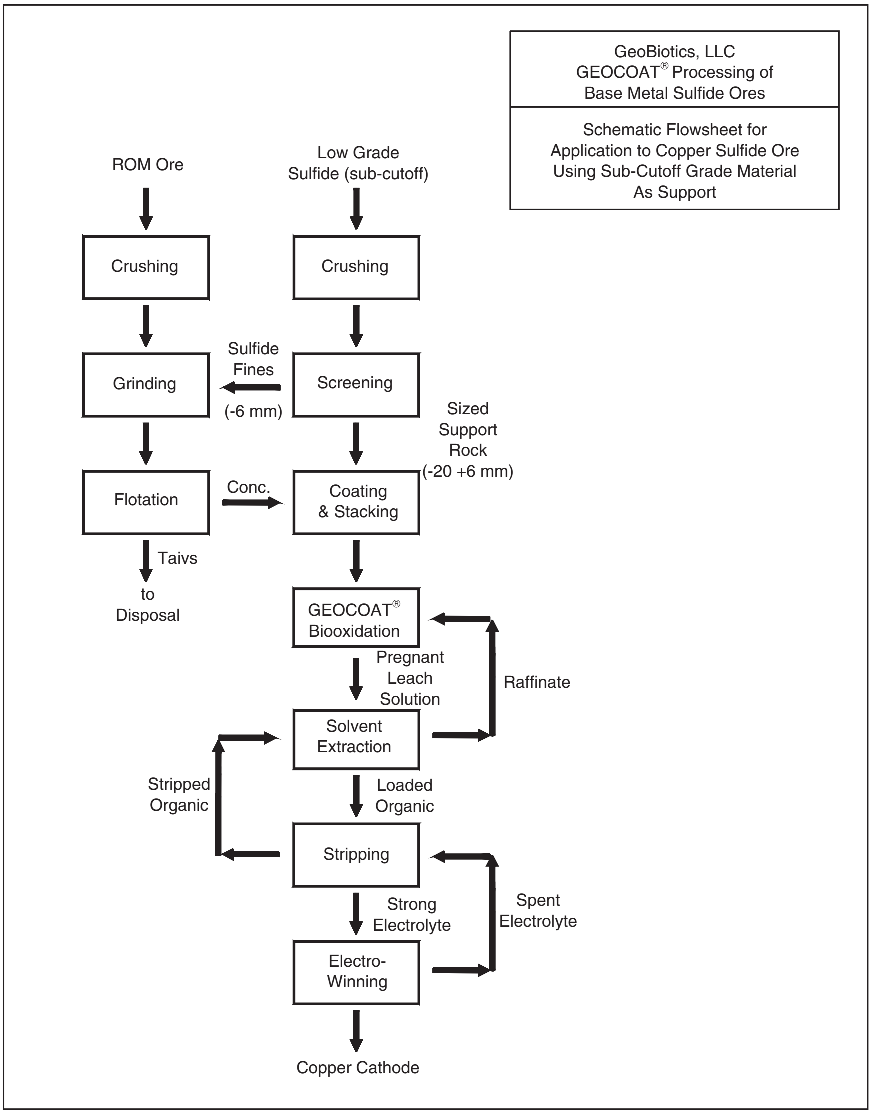

Fig. 5.4. GEOCOAT® flowsheet – base metals

5.3 The Agnes Mine GEOCOAT® Project

The Agnes orebodies, near Barberton in Mpumalanga Province, South Africa, were first exploited in 1893. The present owners and operators, APM, a subsidiary of Metallon Resources, acquired the property in 2002 from Cluff Mining. The refractory sulfide ore is mined by underground methods and a

Table 5.1. Selected GEOCOAT® capital and operating cost estimates

GEOCOAT® plant capacity (t day^{-1})	Capital cost ratio (US $)	Operating cost ratio ($ US t^{-1} concentrate)	Notes
80	1.00	1.00	Includes cost of neutralization, power $0.022 kWh^{-1}
1,000	2.62	0.12	Includes cost of neutralization, power $0.08 kWh^{-1}
4,400	9.32	0.07	Includes cost of neutralization, power $0.025 kWh^{-1}

Table 5.2. Relative costs of sulfide oxidation processes (tonnes per day)

Process	100 t day^{-1} concentrate feed		1,000 t day^{-1} concentrate feed	
	Capital cost ratio	Operating cost ratio	Capital cost ratio	Operating cost ratio
Roasting	1.67	1.63	2.14	5.56
Pressure oxidation	2.50	2.50	3.21	8.33
Agitated-tank biooxidation	1.33	1.63	2.86	6.11
GEOCOAT®	1.00	1.00	1.00	1.00

conventional milling and flotation plant produces a gold-bearing sulfide concentrate. In 2000, Cluff Mining signed a license agreement with GeoBiotics for the use of the GEOCOAT® heap biooxidation process for pretreatment of the concentrate. Column biooxidation testwork at SGS Lakefield confirmed the amenability of the concentrate to biooxidation, and APM prepared a feasibility study based on the use of the GEOCOAT® process. Design and construction followed, with commissioning starting in the first quarter of 2003. Table 5.3 lists the general design criteria for the GEOCOAT® facility at the Agnes Mine.

A double pad liner system of synthetic geomembranes ensures that the process solution is fully contained. A leak detection system is installed between the liners to give an early indication of potential solution loss and allow remedial action before any discharge to the environment occurs.

Three low-pressure fans installed along the edge of the heap provide process air via a system of high-density polyethylene headers, subheaders, and perforated stringers. The stringers are buried in a 1-m-deep layer of crushed rock to assist in the uniform distribution of the air. One of the fans and the air distribution headers and piping are shown in Fig. 5.5. The rock layer also provides a path for the leach solution draining from the heap to reach the pad liner and the solution collection trench.

Table 5.3. Key design criteria of the Agnes Mine GEOCOAT® process

	As-built design specifications
Stacking rate	34.5 t h^{-1}
Concentrate rate	4.6 t h^{-1}
Biooxidation time	60 days
Irrigation rate	10–30 L m^{-2} h^{-1} (80 m3 h^{-1})
Solution application	Wobbler sprinklers
Aeration equipment	Centrifugal fan 3×360 m^3 min^{-1} at 2.5 kPa
Air distribution	Perforated pipes in drain rock base
Pad dimensions	50 m×120 m
Heap dimensions	6 m×45 m×60 m
Solution pond capacity	7,000 m^3
Stacking method	Slewing radial stacker with automated materials handling
Concentrate recovery	Front-end loader, trommel, thickener
Gold recovery	Carbon in leach 6×20-m^3 tanks
Effluent disposal	Heap bleed solution is neutralized by mixing with carbonate flotation tails. Cyanide in carbon-in-leach residue is destroyed using excess acid bleed
Performance monitoring	Solution analysis, solids sampling, and temperature monitoring

Fig. 5.5. Air supply fan and distribution system. Note the pad liner

Support rock was initially prepared by crushing and screening waste rock from an old dump. Recycled support rock is fed to a horizontal conveyor which runs alongside the heap. This conveyor transfers the support via a tripper to a "grasshopper" conveyor, which in turn feeds the heap-stacking conveyor. The grasshopper and stacker operate on the surface of the drain rock layer and the heap is stacked to a height of 6 m above this surface. The "moving slot" method is used to stack and reclaim the heap in an "on–off" configuration. Freshly coated rock is stacked at the advancing face of the slot and oxidized material is reclaimed from the opposite, retreating face. Once sufficient new heap area has been stacked, solution distribution piping is installed and irrigation is started. Solution is applied via sprinklers at a rate of 10–30 L $m^{-2}\ h^{-1}$. Figure 5.6 is a general view of the Agnes GEOCOAT® heap and materials handling system. Figure 5.7 shows the surface of the heap with solution application in progress; note the stream leaving the heap.

Solution is recirculated to the heap via a lined pond. A stainless steel pump delivers solution from the pond to sprinklers on the heap. A portion of the circulating solution is bled off to maintain the iron concentration within design limits. The bleed stream is pumped to the neutralization circuit, a series of agitated tanks, where flotation tailings are added to neutralize acid and precipitate iron. Flotation tailings at the Agnes operation contain carbonate minerals and provide an inexpensive and convenient source of neutralizing agent. The neutralized solution, containing the precipitated iron,

Fig. 5.6. General view of the Agnes GEOCOAT® plant

Fig. 5.7. Irrigation of the heap surface

is pumped to a tailings impoundment. A separate impoundment is provided for the cyanide residue to ensure that no cyanide is returned to the GEOCOAT® circuit in recycled process water. Cyanide and its decomposition products are highly toxic to bioleaching microorganisms.

Support rock, with its oxidized concentrate coating, is reclaimed from the heap by a front-end loader and conveyed to a trommel screen where the concentrate is separated (Fig. 5.8). The concentrate slurry underflow from the trommel screen is pumped to a stainless steel high-rate thickener. Thickener underflow is transferred to the pH-adjustment tank, after secondary screening for rock chip removal, and lime is added to raise the pH in preparation for cyanidation. The concentrate slurry is then pumped to the carbon-in-leach (CIL) plant located adjacent to the GEOCOAT® heap. The washed support rock is returned to the stacker for recoating with fresh concentrate. Support losses are made up by the addition of fresh rock.

The original as-built GEOCOAT® flowsheet for the Agnes operation is shown in Fig. 5.9. This reflects a conventional approach to refractory gold pretreatment, in that the concentrate is oxidized before cyanidation. The flotation concentrate is coated onto the support rock and stacked on the GEOCOAT® heap. After biooxidation for 60–75 days, the coated rock is reclaimed from the heap and the concentrate separated by screening. The pH of the oxidized concentrate slurry is adjusted with lime, and the slurry is subjected to CIL for gold recovery. However, various circumstances have resulted in the

Fig. 5.8. Trommel for concentrate separation

evolution of the flowsheet to that shown in Fig. 5.10. This flowsheet is non-conventional in that the flotation concentrate is biooxidized only after initial cyanide leaching. Since the baseline cyanide gold recovery is relatively high at 60–70%, economic benefits were seen in removing the cyanide-leachable gold before biooxidation.

Although the original Agnes flowsheet was operated successfully, it was modified as a result of difficulties in development of the underground mine, leading to cash-flow shortfalls. Additionally, teething problems associated with the GEOCOAT® plant exacerbated the cash-flow situation.

The reason for the decision to change the flowsheet was APM's failure to ramp up mine production to the design level in the expected timeframe. The resulting lack of ore led to the decision by the owner to reclaim the GEOCOAT® heap prematurely, "robbing" the inventory to maintain cash flow. It was always expected that the heap inventory would quickly be replenished but the underground production ramp-up took much longer than expected. Furthermore, APM started cyanidation of the unoxidized concentrate, producing enough cash flow to cover costs. The tailings from cyanidation of the flotation concentrate, containing 15–25 g gold/t^{-1}, was discarded. The intermittent supply of concentrate to the GEOCOAT® plant created commissioning difficulties and complicated the identification and resolution of commissioning issues.

When, after a period of several months, it became evident that a return to the original flowsheet was unlikely, GeoBiotics and APM embarked on a

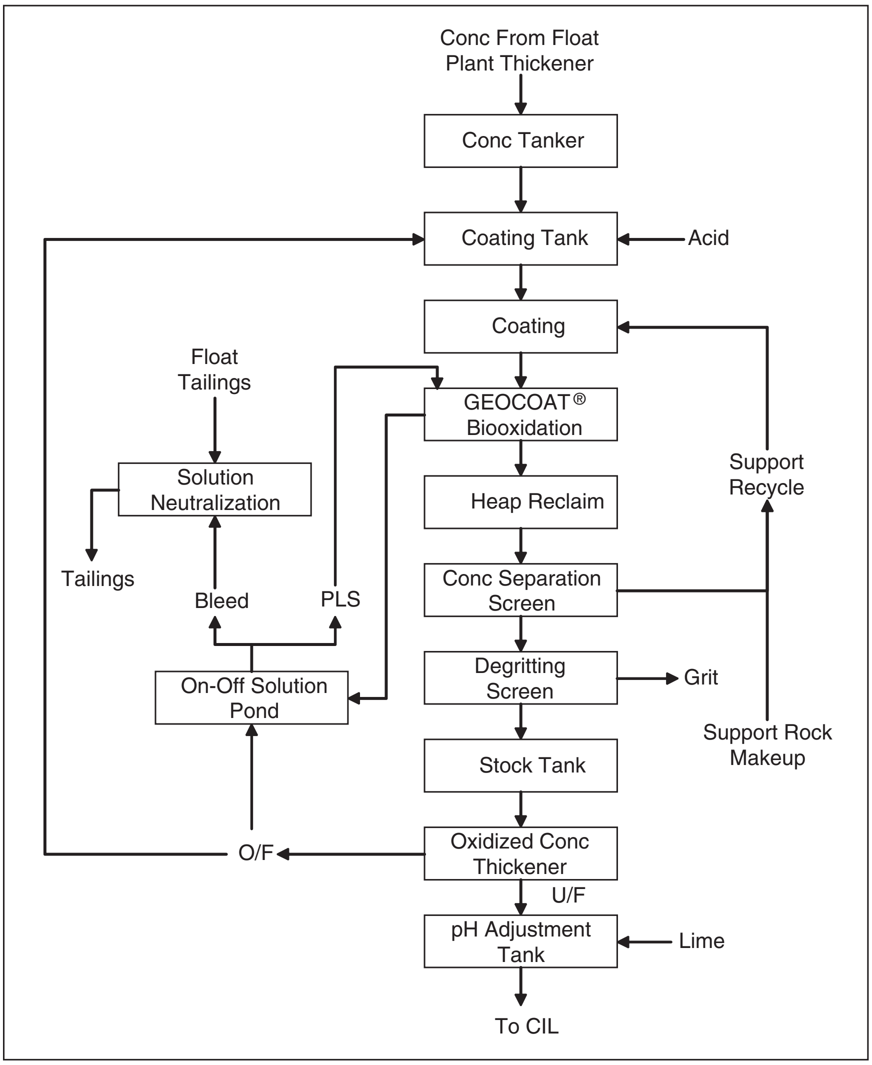

Fig. 5.9. Original Agnes GEOCOAT® flowsheet

program to recover the residual gold in the CIL tailings by treatment in the GEOCOAT® plant. A comprehensive test program demonstrated that the CIL tailings would require thorough washing and acid pretreatment to remove cyanide and reduce toxicity to the bacteria sufficiently to allow biooxidation.

Several issues associated with the operation of the GEOCOAT® plant revealed during commissioning required attention to optimize biooxidation. The main problems were the unexpectedly high level of carbonates in the concentrate and support rock, and control of the coating system. The high

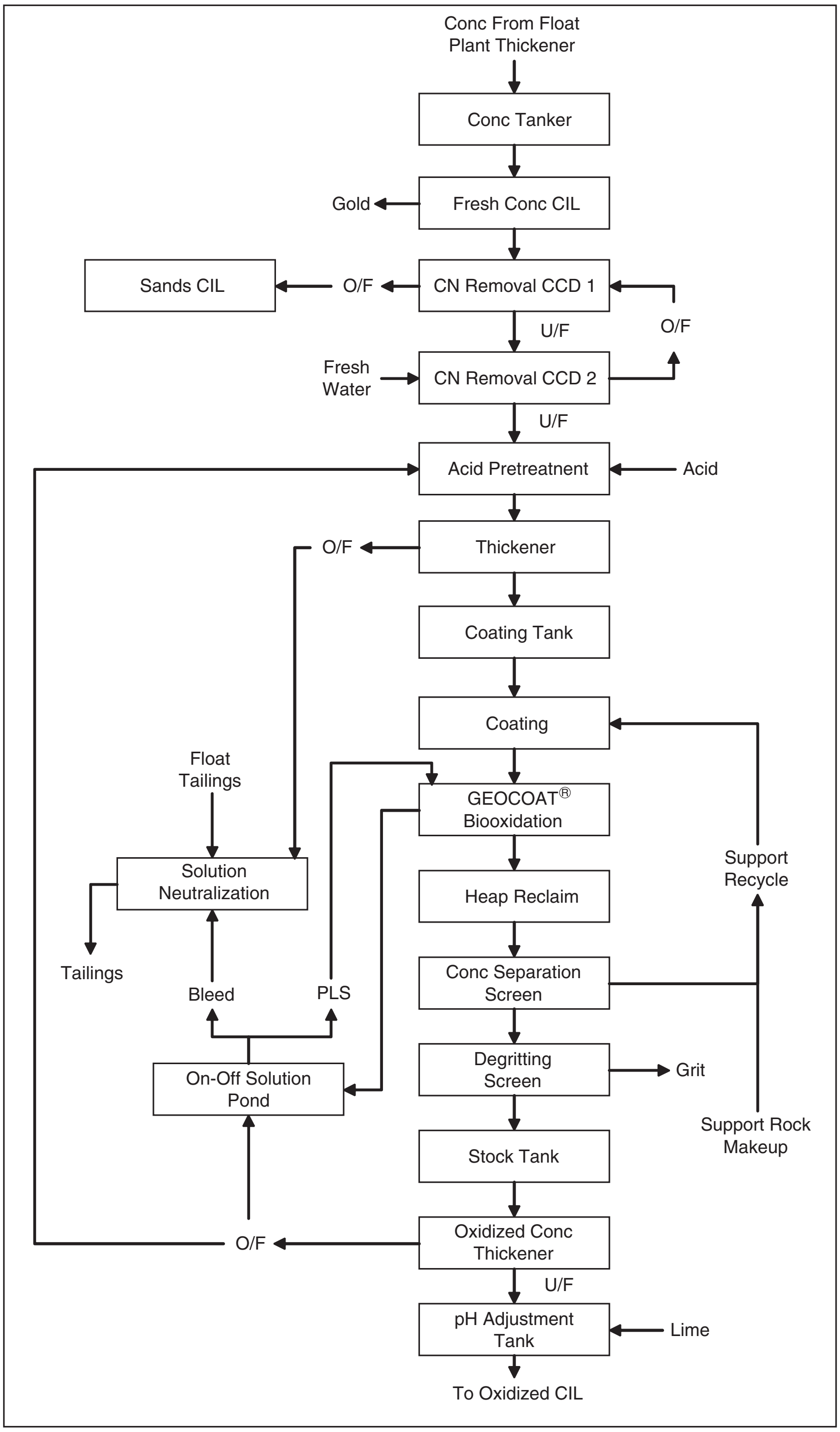

Fig. 5.10. Modified Agnes GEOCOAT® flowsheet

carbonate content of the support rock resulted from the decision to use a different rock from that tested in the initial design work. Carbonate levels in the concentrate were high because the flotation circuit was operated with a high concentrate mass yield in an attempt to maximize gold recovery; much of the additional concentrate mass was made up of carbonate gangue minerals.

The high carbonate content of the concentrate was addressed by the installation of an acid pretreatment stage, but the support rock issue was more difficult to rectify. Wholesale replacement of the support rock was not feasible, so operational controls were developed to minimize the impact of its carbonate content. It was necessary to maintain the irrigation solution pH sufficiently low to allow for acid consumption by the support rock. A bulk-acid storage tank was installed to facilitate control of the pH in the solution pond and to allow the use of lower-cost bulk acid. Poor control of the concentrate slurry coating density and uneven concentrate distribution resulted in the migration of some of the concentrate from the support rock into the drainage layer beneath the heap. The coating system was modified through the addition of a "coating contactor" to intimately mix the concentrate and support, ensuring a more uniform distribution of concentrate on the support rock surfaces. Additionally, a new high-density concentrate thickener was installed as part of the acid pretreatment circuit, replacing the existing undersized flotation concentrate thickener. Subsequent testwork has demonstrated that the use of finer support rock is highly beneficial in preventing migration of the concentrate. This change is expected to be implemented in the future.

GeoBiotics continues to have a significant presence at the Agnes plant, working closely with APM to further development of the GEOCOAT® process. A planned expansion of the Agnes Mine is under way to bring a second orebody on-stream and to treat the highly refractory concentrate by GEOCOAT®.

5.4 Developing Technologies

GeoBiotics is continuing to develop novel biotechnologies for the minerals industry. The GEOLEACH™ technology is expected to revolutionize the copper industry by allowing whole-ore chalcopyrite heap leaching to yield what is predicted to be unprecedented copper extractions in relatively short leach cycles. Traditionally, whole-ore heap leaching of primary copper sulfides has been plagued by low copper extractions and very long leach times. The ability to leach chalcopyrite ore in a heap promises to change the way in which these ores are processed. Additionally, GeoBiotics continues to work on refractory gold, with promising results coming from research on double refractory gold ores such as those commonly found in the Carlin Trend in Nevada, and the Ashanti Trend in Ghana. GeoBiotics expects to test the GEOLEACH™ technology at scale at a copper mine in Chile in late 2006.

References

Brierley CL (1999) Commercial concentrate and ore biooxidation plants. In: Randol copper hydrometallurgy roundtable, pp 55–58

Harvey TJ, Adutwum KO, Potter GM (1998) Heap biooxidation for the treatment of low grade refractory ores at Ashanti Goldfields' Obuasi operations. In: Randol gold and silver forum, Denver, pp 267–274

Harvey TJ, Bath MD (2003) Development of the first commercial GEOCOAT® heap leach for refractory gold at the Agnes Mine, Barberton South Africa. In: Tsezos M, Hatzikioseyian A, Remoundaki E (eds) Biohydrometallurgy: a sustainable technology in evolution (part I). National Technical University of Athens, pp 387–398

Stott MB, Wattling HR, Franzmann PD, Sutton D (2000) Role of iron-hydroxy precipitates in the passivation of chalcopyrite during bioleaching. Miner Eng 13:1117–1127