

# THE METALLURGICAL DEVELOPMENT OF THE EL BOLEO COPPER-COBALT-ZINC PROJECT

DAVID DREISINGER, WILLIAM MURRAY – BAJA MINING CORP.; KEN BAXTER, MICHAEL HOLMES, HERCULUS JACOBS – BATEMAN ENGINEERING PTY LTD; AND RON MOLNAR – SGS

## INTRODUCTION AND PROJECT HISTORY

The Boleo Copper-Cobalt-Zinc Project of Baja Mining Corp. is situated adjacent to Santa Rosalia on the Baja Peninsula of Mexico (Figure 1). Formal mining of the Boleo Property ("Boleo") was initially undertaken by a French company, the Compagnie du Boleo, (the "Compagnie") in 1865. Working a number of deposits over 11 km the Compagnie extracted copper from sedimentary ore-bodies located near Santa Rosalia a small port about half way down the Baja peninsula on the Sea of Cortez.



Figure 1. Geographical Location of the Boleo Copper-Cobalt-Zinc Project.

Boleo produced approximately 19 million tonnes of copper ore at a grade in excess of 4.3% copper during the period 1868 to 1972. Despite the very high grade, such was the complexity of the ore; the Compagnie was unable to produce a concentrate and used direct smelting to treat the ores. Only ores grading >4.3% copper were smelted in fuel-oil fired reverberatory furnaces that produced a high-grade copper matte. Low grade ores (<4%) that formed the majority of the deposit were simply backfilled into the mined areas and no attempt was made to recover valuable cobalt, zinc and other metals also present.

Operations by the Compagnie continued until 1938 when some 13.6 million tonnes of ore had been mined to release just over 560,000 tonnes of copper. Under Mexican law, the company could not be sold, and it lingered on in one form or another until the 1970's when the picturesque mill and the miniature rail line were shut down. The project was then taken over by the Mexican para-statal mining organization, Fomento Minera, who operated a small leach/precipitate/float (LPF) plant. Operations finally closed in 1985 and the project was placed in the federal strategic land reserve.

In the early 1990's, at a time of high copper prices, the deposits were re-examined by Terratech International Corp., a private company. Terratech then optioned Boleo to International Curator Resources (a Lundin company), through its then subsidiary, Mintec International Corp. International Curator Resources completed an extensive exploration program and commissioned a pre-feasibility study by Fluor Daniel Wright. The study identified 81 Million tonnes of ore grading 1.36% copper, 0.6% zinc and 0.089% cobalt, all from open-pit resources contained within a global resource of 464 million tonnes grading an average of 0.7% copper, 0.7% zinc, and 0.06% cobalt. International Curator were unable to complete a Definitive Feasibility Study on Boleo and therefore, in 2001, the Boleo project reverted to the original owners (Mintec).

Since 1992 approximately US\$25 million has been spent on the Boleo Property to assess reserves and to develop modern techniques for the processing of the ore to extract the contained copper-cobalt-zinc. This body of work was fully reviewed by Bateman Engineering (Australia) in 2002 in the preparation and issuance of a new pre-feasibility study for the project development. The Bateman study focussed on making maximum use of the newer high rate thickening technology to deal with the clayey Boleo ores. The use of thickening and the associated counter-current washing system was expected by Bateman to allow direct recovery of copper, cobalt and zinc products from the leach solution. Direct recovery from solution was expected to be a significant improvement over the approach taken by Fluor Daniel Wright and International Curator. Fluor/Curator had tested an in-pulp re-precipitation of copper-cobalt-zinc sulfides followed by flotation/roasting/re-leaching and refining.

On April 20, 2004, the privately held Boleo project became a publicly trading company. First Goldwater Resources Inc. concluded the reverse takeover of Mintec International Corporation, of Barbados, and consequently its wholly owned Mexican subsidiary Minera Y Metalurgica del Boleo, S.A. de C.V. (MMB). MMB holds a 100% interest in the Boleo Copper-Cobalt-Zinc deposit on the Baja Peninsula, Mexico. Contemporaneous with the RTO, First Goldwater Resources also concluded a \$10 million equity placement. In mid-2004, the name of the company was changed to Baja Mining Corp.

Baja Mining Corp. has now commissioned a Definitive Feasibility Study (DFS) led by Bateman Engineering Pty. Limited (Australia). A major portion of the work under the feasibility study is to define and test the metallurgical process for extraction of copper, cobalt and zinc from Boleo ores. The program has quickly moved to a "proof of concept" continuous pilot plant testing. The following paper reports on metallurgical developments taking place as part of the DFS program.

## MINERALIZATION AND RESOURCES OF BOLEO

The copper-cobalt-zinc mineralization at Boleo occurs within widespread, stratiform clayrich horizons or beds known as "Mantos". At Boleo, up to 7 Mantos have been identified. These occur as relatively flat to generally shallow dipping, stratabound and uniform beds. These include, with increasing depth, Manto 0, 1, 2, 3AA, 3A, 3, 4. Historically, the major producing Manto was number 3.

The Mantos tend to be clay-rich (montorillonite). Underlying lithologies vary from predominantly ortho-conglomerates in the heart of the Boleo basin to coarse sandstones. The contact between the Mantos and the footwall is sharp. Overlying lithologies vary from fine to medium grade sandstones. The contact between them and the clay rich slump breccias can be both sharp and gradational.

The economic metals at Boleo are predominantly copper, cobalt and zinc. A very wide variety of oxide and sulfide minerals have been identified at Boleo. Oxide and oxide/sulfide mixed ores represent about 80% of the orebody with sulfide ores making up the balance. Common copper oxide minerals include chrysocolla, malachite and atacamite. Cobalt oxide minerals include cobaltiferous smithsonite, reminzonite and sphero cobaltite. Zinc occurs as smithsonite and probably some sort of zinc ferrite. Cobalt and zinc are strongly associated with manganese oxides and occur in cryptomelane. Manganese is widespread over the entire area with grades ranging from 3.5% to 5%.

For sulfide ores, the dominant copper mineral is chalcocite. The chalcocite grains are very fine and are dispersed in the clay matrix. Minor chalcopyrite, bornite and covellite are also present. Sulfide minerals of cobalt (also very fine) consist of cupriferous carrollite and cobaltiferous pyrite. Zinc appears as sphalerite in the sulfide ores.

The gangue mineralization of the Boleo ore is the major factor in selection of a metallurgical process for treatment of the ore. The ore is dominated by clay (typically 40- 50% montmorillonite clay). The presence of clay controls the pulp rheology and settling and filtration properties for the ore. There is also some carbonate mineralization in the ore which has a major impact on acid consumption during whole-ore leaching.

Hellman and Schofield have completed a resource estimate for Boleo upon which to base the development of a mine plan and they have also built a 3D block model for the deposit.

The resource estimate has been summarized in Table 1 below using the Copper Equivalent method. The copper equivalent is defined as;

$$\text{Cu equiv} = \text{Cu\%} + \text{Co\%} \times (12/0.95) + \text{Zn\%} \times (0.45/0.95)$$

As is apparent from the formula, a copper price of \$0.95/lb, a cobalt price of \$12/lb and a zinc price of \$0.45/lb have

been used as the basis of the copper equivalent calculation.

The resource models developed by Hellman and Schofield have allowed mine planning to move forward. However, the resource models still include significant contributions from the Inferred Minerals Resource category and the assumptions used in the preliminary mine plan are still awaiting confirmation. An underground mining trial is planned for mid-2005. Australian Mine Design and Development (AMDAD) of Sydney is advancing the preliminary mine plan. The mine plan is focussed predominantly on underground mining with small contributions from open-cut mining of some higher grade, near-surface targets. The mining plan shows 2.6 Mtpa of ore (dry basis) being mined and processed over a 20 year life. Copper production sits at or above 50,000 tpa for the first 4 years of mine life and then drops off as lower grade ores are encountered. Cobalt production varies up to close to 2000 tpa and zinc production peaks over 9,000 tpa (as zinc in a zinc sulfate salt product).

## METALLURGICAL TREATMENT OF BOLEO ORE

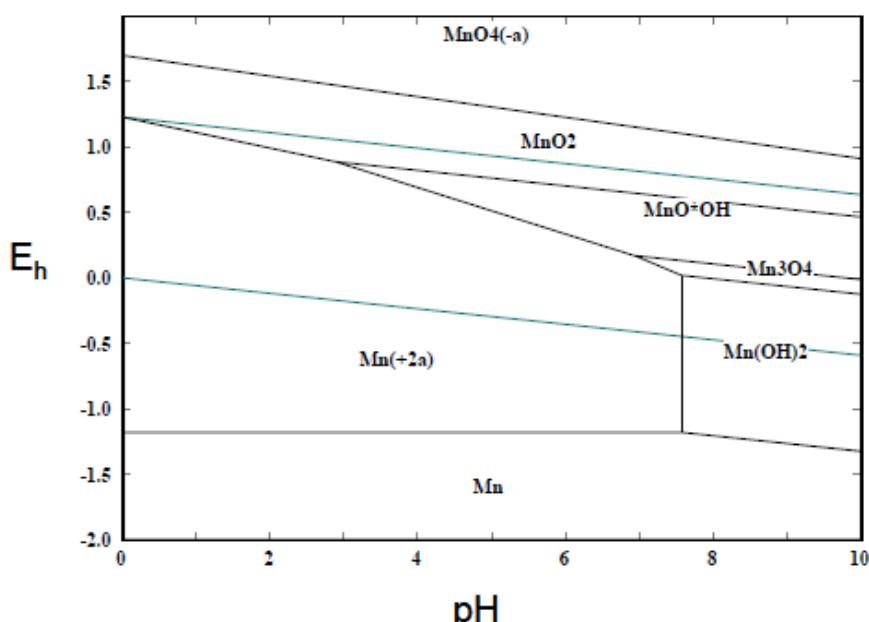
There are a number of key aspects in the metallurgical treatment of Boleo ore. Direct flotation of the ore is not an acceptable option as the metal values are distributed as oxides and sulfides and consequently are very difficult to float. This ore characteristic has driven the need to consider whole of ore leaching. The key aspects to consider in the whole ore process include:

- Leaching of metal sulfides and oxides for maximum metal extraction into solution
- The need to use seawater for leaching as fresh water is not available at site
- Difficult solid/liquid separation and washing due to high clay content of ore
- Recovery of copper from complex solution containing chloride from seawater
- Recovery and separation of cobalt and zinc from a complex solution that has high levels of manganese
- Acid consumption

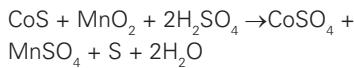
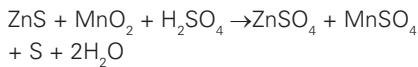
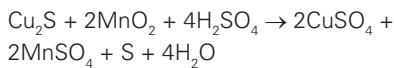
Table 1: Hellman and Schofield Resource Estimate (March 2005)

Cu EQUIV CUT-OFF GRADE	0.50%	1.00%	1.50%	2.00%	
Measured tonnes (10 <sup>6</sup> )	51.7	45.7	35.3	24.7	
	CuEq %	2.09	2.26	2.56	2.91
	Cu %	0.76	0.83	0.99	1.18
	Co %	0.089	0.096	0.107	0.119
	Zn %	0.45	0.46	0.47	0.47
Indicated tonnes (10 <sup>6</sup> )	172.1	114.1	65.4	36.1	
	CuEq %	1.49	1.86	2.33	2.82
	Cu %	0.57	0.78	1.09	1.46
	Co %	0.05	0.061	0.072	0.081
	Zn %	0.58	0.66	0.68	0.68
Total tonnes (10 <sup>6</sup> )	223.8	159.8	100.7	60.8	
	CuEq %	1.63	1.97	2.41	2.86
	Cu %	0.062	0.79	1.06	1.35
	Co %	0.059	0.071	0.084	0.097
	Zn %	0.55	0.6	0.61	0.61
Inferred tonnes (10 <sup>6</sup> )	310.3	188.13	112.34	65.6	
	CuEq %	1.47	1.95	2.43	2.94
	Cu %	0.57	0.83	1.14	1.51
	Co %	0.045	0.057	0.067	0.074
	Zn %	0.69	0.85	0.95	1.03
Grand Total tonnes (10 <sup>6</sup> )	534.1	347.9	213	126.4	
	CuEq %	1.53	1.96	2.42	2.9
	Cu %	0.59	0.81	1.1	1.43
	Co %	0.051	0.063	0.075	0.085
	Zn %	0.63	0.73	0.79	0.82

The leaching of the sulfides and oxides from the Boleo ore requires the use of an oxidation and reduction leaching process in order to achieve maximum extraction. The inherent oxidation power of the manganese in the ore is used to advantage in the initial oxidation stage of the process with the manganese dioxide minerals having the role of effective oxidant. Figure 2 shows the Eh – pH diagram for the manganese – water system. At a pH of about 1.0, the oxidation potential (Eh) exceeds 1.0 V, a very high oxidation potential. At this potential, the fine, reactive sulfides in the Boleo ore would be expected to oxidize quickly.

Figure 2: E<sub>h</sub> – pH Diagram for the Mn-H<sub>2</sub>O System at 25 °C. All Solutes have Unit Activities (drawn with Outokumpu HSC 5.1).

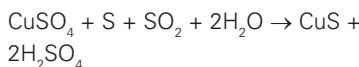
Oxidation leaching (acid leaching with manganese dioxide in the ore)



Reduction leaching (addition of sulfur dioxide to the ore slurry)



The combination of oxidation and reduction leaching with acid, sulfur dioxide has been used in the copper belts of Zambia and DRC. It is very effective at leaching the copper, cobalt and zinc. The reduction process has to be carefully controlled to prevent reprecipitation of copper. If the leach is over-reduced, the result will be re-precipitation of copper on residual elemental sulfur and loss of copper leaching efficiency.



Fluor Daniel Wright used this reaction as a starting point for development of "in-pulp" reprecipitation of copper with addition of finely ground elemental sulphur to collect the copper. This "in-pulp" precipitation of copper sulfides has been abandoned in the current metallurgical development so it is important to not over-reduce the slurry with sulfur dioxide addition.

A further challenge to Boleo metallurgical development is the use of seawater for leaching as fresh water is not available on site. This mostly affects the "materials of construction" area of plant design rather than having a material impact on metallurgical performance. Demineralized water is required for some applications in the process (eg. metal sulfate electrowinning) and will be produced as required for these unit operations.

The clayey ores of the Boleo deposit are well known to be very difficult to settle and wash. The clays are very fine and tend to settle very slowly under conventional thickening conditions. The Fluor-Curator study avoided this problem by moving toward the "in-pulp" treatment of the leach slurry to re-precipitate the metals of value. While this approach was innovative, the economics of leaching and then re-precipitating and floating the fine sulfides produced were very poor and this approach had to be abandoned.

In the current metallurgical program, high rate thickening was investigated and found to be feasible. High rate thickening involves the dilution of the incoming slurry (by recycle of overflow from the same thickener) so as to create a dilute slurry (3-5% solids) for flocculation and settling into the thickener bed. This approach was verified by testing performed by Pocock Industrial and by Outokumpu in lab scale testing at SGS Lakefield.

The recovery of copper from complex chloride containing solutions is feasible using modern selective copper solvent extractants combined with a "wash stage" during SX recovery of copper to prevent transfer of chloride from leaching through to electrowinning. This approach has been widely reported at plants in Chile with saline PLS solutions and has been adopted for Boleo as well.

The recovery of cobalt and zinc from complex solutions containing high levels of manganese poses a significant challenge for processing of Boleo ore. The first solution that was put forward by Bateman in the 2002 pre-feasibility study was to use sulfide precipitation for selective removal of cobalt and zinc away from manganese and iron (ferrous) in solution. While sulfide precipitation is conventional technology and likely to be successful in this application, this route was viewed as challenging due to (1) hazards of working with hydrogen sulfide, (2) possible difficulties in precipitating zinc away from a large background of manganese and (3) the need to re-oxidize (autoclave leach) the resulting sulfide precipitate. It would be a simplification to the flow sheet if a selective method could be developed for recovery of zinc and cobalt from the copper SX raffinate.

CSIRO Division of Minerals in Perth, Australia has been working on "synergistic" mixtures of solvent extraction chemicals that give rise to new possibilities for metal separation and recovery. Figure 3, shows the results for one of these mixtures. In this case (and all cases for Boleo), the mixture is a combination of commercially available solvent extractants (i.e. novel or developmental extractants are not required to make the system work).

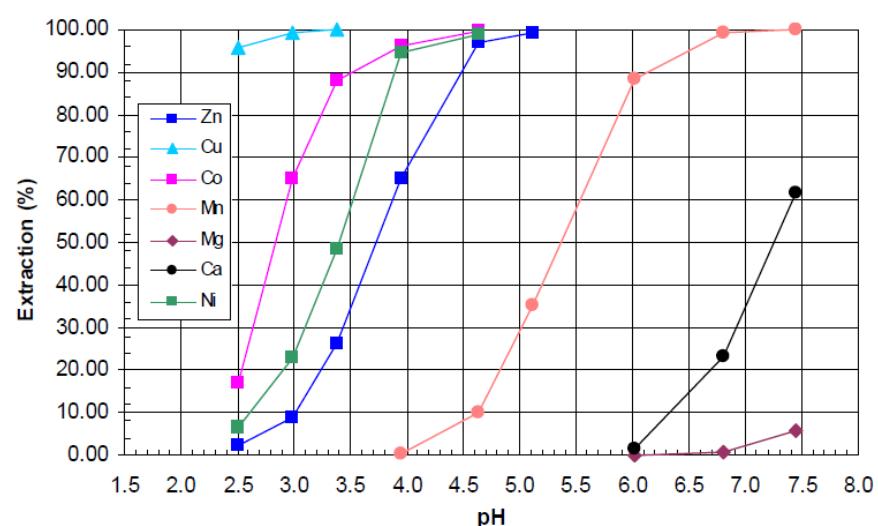


Figure 3: Order of Metal Extraction for CSIRO Synergistic Reagent System Published by Chu Yong Cheng et al, International Laterite Symposium, Charlotte, USA, March 2004.

Inspection of Figure 3 shows that it is possible with this synergistic system to extract cobalt and zinc before manganese. Note that the data presented in Figure 3 are not for the Boleo system as they were published prior to starting the definitive feasibility study on Boleo. Nevertheless, these data are "indicative" of the potential of a synergistic solvent extraction system in being able to open up new windows of possibility for metal separation and recovery.

Acid consumption is a function of mineralogy of the ore. Major acid consuming species include carbonates, oxides and clay minerals. There is no ready solution to acid consumption other than to try to control acid use by minimization of free acid levels in leaching.

## PILOT PLANT TESTING OF THE BOLEO FLOWSHEET

The metallurgical development of Boleo has recently culminated in a pilot plant operation at SGS Lakefield Research Canada in late 2004. The pilot plant treated a bulk sample of Boleo ore grading 1.85% Cu, 0.095 % Co, 0.59% Zn, 4.3% Mn and 7.9% Fe. This ore sample was a composite of 24 individual drill samples extracted from Manto 3 and represented substantially oxide material. The objectives of the pilot plant were as follows:

- Demonstrate Flowsheet Feasibility;
- Demonstrate CCD Settling Behavior of Leach Residue;
- Confirm Suitability of CSIRO Synergistic Solvent Extraction for Zn & Co Recovery;
- Confirm overall Cu, Co, Zn recovery;
- Confirm Cu cathode quality;
- Extract Engineering Design Data;
- Determine Reagent Consumption.

In addition, pilot plant results were used for initial investigation of materials of construction for appropriate use through the plant circuit, organic stability, ore variability, solution balance and control philosophy. Further pilot plant work will be required to cover each of these areas more completely before final feasibility.

The pilot plant was established at a nominal rate of 6 kg of ore (dry basis) per hour treatment rate. The plant operated for a total of 12 days in leaching, 11.5 days in CCD, 9.5 days in copper SX/EW and 9 days in cobalt and zinc SX using the CSIRO direct solvent extraction technology (DSX). Two further pilot programs were performed off-line to complete the recovery of final products. The zinc strip solution from the DSX circuit was treated by evaporative crystallization to recover a zinc sulfate product. The cobalt strip solution from the DSX circuit was subjected to a further test comprising impurity removal (zinc solvent extraction with Cyanex 272), cobalt extraction with Cyanex 272 and finally stripping and electrowinning to make a final cobalt metal product.

The main pilot plant results are reported below.

The feed preparation circuit for the pilot plant involved the following steps:

- Bulk sample was dry screened at 3.36 mm;
- The +3.36 mm size fraction was crushed and reconstituted with the -3.36 mm size fraction;
- The ore was wet screened (in a synthetic brine solution) at 297 µm;

- The +297 µm material was ground in a Denver 16X32 ball mill and reconstituted with the -297 µm size fraction;
- The final combined ore sample was slurred to 22% solids using brine solution.

The size analysis of the homogenized slurry showed a  $P_{80}$  of 79 µm and a  $P_{50}$  of 19 µm. The oxidation and reduction leaching circuit gave excellent recoveries of copper, cobalt and zinc. Copper extraction exceeded 90% during pilot operation while cobalt varied from about 80% to 90%. Zinc extraction was somewhat lower at 70% due to the likely presence of zinc ferrite phases which are "refractory" to zinc extraction. The extraction numbers were consistent with a large body of data generated by the International Curator/Fluor prefeasibility study program (the "front end" leach process is similar for the two process flowsheets). Table 2 shows the average analyses and extractions across the leach circuit for all the major elements.

The CCD circuit worked very well in the pilot plant. The CCD circuit was set up to simulate the use of "high rate" type of thickeners with recirculation of overflow solution to dilute the feed slurry prior to flocculation. This method of settling and washing was based on recommendations from Outokumpu and Pocock Industrial and proved to be highly effective. The leach residue settled quickly, producing clear overflow solutions to advance to copper, cobalt and zinc recovery.

Table 2: Average Assays and Extraction through the Continuous Leach Circuit

ELEMENT	SOLID ANALYSIS (%)			EXTRACTION (%)	
	FEED	OXIDATIVE LEACH	REDUCTION LEACH	OXIDATIVE LEACH	REDUCTION LEACH
Cu	1.85	0.372	0.203	81	92
Co	1.095	0.062	0.018	34	83
Zn	0.59	0.3	0.191	50	70
Fe	8.04	7.21	5.56	7	33
Al	5.74	5	4.66	10	17
Mn	4.44	3.53	0.44	33	96
Mg	2.73	1.57	1.21	49	63

Figure 4 shows the wash efficiency per stage for the 6 stage CCD circuit calculated at steady state for three pilot periods. A wash ratio of 1.6 m<sup>3</sup>/t solids was used throughout the run. The calculated efficiency ranged up to 96% compared with a design value of 97%.

Underflow densities were low throughout the pilot due to the clayey nature of the ore and consequently the leach residue. Typical values ranged from 22-25% solids with CCD overflow suspended solids of 300-500 ppm. Flocculant addition (Hychem 301) was also large at 100-200 g/t. Further work with vendor support is planned to improve underflow densities and reduce flocculant consumption to the maximum extent.

The copper SX/EW circuit worked very well as would be expected. A total of 15.5 kg of copper metal were electrowon during the pilot campaign. The organic solution was 9% LIX 84i in Escaid 110. Two extract, one scrub (wash) and one strip stages were used. The copper cathodes met the LME specifications for all impurities as would be expected from the SX/EW process.

The iron removal circuit was designed to remove iron, aluminum and other impurities from the solution prior to recovery of cobalt and zinc using DSX technology. The first stage of the circuit used oxygen and limestone to oxidize and precipitate iron while the second stage of the circuit used a hydrogen peroxide "polish" to oxidize trace amounts of residual ferrous ion.

Table 3 shows the average assays across the iron removal process. The losses of residual copper and cobalt were negligible. The solid residue settled to 20-25% solids in the iron precipitate thickener. Early in the pilot plant campaign the iron removal solid underflow was recycled back to CCD2. This change had a negative impact on the CCD settling characteristics and so this practice was discontinued. The solids were then diverted to the partial neutralization stage of the flowsheet. This change also had a negative impact on CCD settling so was discontinued.

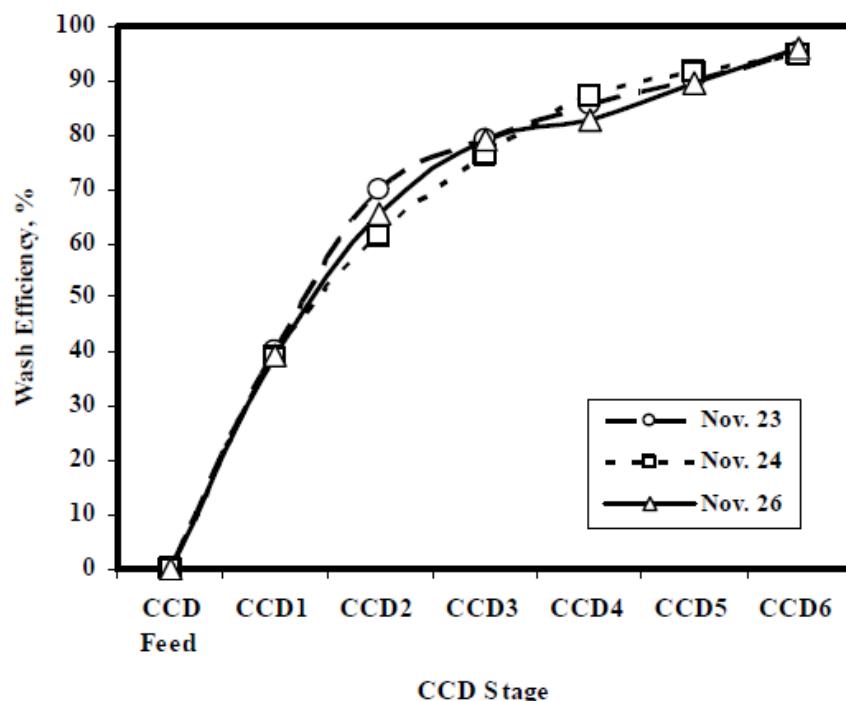


Figure 4: Calculated Wash Efficiency for the CCD Circuit for Three Periods During the Pilot Plant

Table 3: Analyses of Solution Feed and Solid Product from the Iron Removal Process

ELEMENT	SOLUTION ASSAY (mg/L)	SOLID ASSAY (%)	EFFICIENCY/LOSSES (%)
Cu	45	29	0.06
Co	127	122	0.0071
Zn	627	573	0.099
Fe	24,000	23,300	0.84
Al	1898	3.6	4.79
Mn	600	634	19.3
Mg	7300	7000	0.33
Al	1742	84	4.4
Ni	33	33	n.d.
Si	105	24	0.34
			77.1

The "base case" for treatment of this residue was therefore changed to thickening/filtration/washing with the residue disposed with the CCD underflow tailings.

The DSX solvent extraction system treated the iron removal product solution for zinc and cobalt recovery. The DSX organic extractant formulation is not reported here as CSIRO are applying for patents to cover these developments. However, it can be reported that only

commercially available extractants that have a history of application are used in the DSX formulation that was used in the pilot plant study.

The circuit configuration for cobalt and zinc recovery consisted of 3 extraction stages, 2 scrub stages, 2 zinc strip stages and 2 cobalt strip stages. The scrub was used to displace weakly extracted manganese from the loaded organic prior to stripping. The loading of cobalt and zinc was controlled by

maintaining a pH of 4.5 with addition of 25 g/L NaOH. The scrubbing of manganese was accomplished with a small flow of zinc sulfate solution containing minor cobalt. The stripping of zinc was performed at pH = 3.0 using weak sulfuric acid. The subsequent stripping of cobalt was at pH = 1.0, also based on sulfuric acid.

Table 4 summarizes the results achieved in the DSX circuit over the course of the pilot plant run.

The results of testing confirm that cobalt and zinc are effectively recovered from the feed solution with good selectivity over manganese and magnesium. Improved pH control in loading will be used to increase overall extraction of cobalt and zinc for the next pilot plant campaign and for the commercial plant. Some manganese persists into the zinc strip stage (and a small amount into the cobalt strip stage). In the pilot plant, higher levels of zinc in the scrub solution were found to give better scrubbing of manganese. Small amounts of cobalt enter the zinc strip solution. Some of this cobalt would be expected to be returned to the system as a bleed from zinc recovery is used as a scrub solution (and this solution would carry the cobalt). Similarly, some zinc is present in the cobalt strip solution. This zinc is removed in a subsequent "cleanup" SX on the cobalt strip prior to cobalt recovery with Cyanex 272.

After the completion of the continuous pilot plant, zinc sulfate crystals were recovered using evaporative crystallization of the zinc strip liquor. Tests 1 and 2 were performed using a Rotovap system heated to about 100-105 C via an oil bath. Tests 3-5 were performed using an open beaker system of evaporation. The results are shown in Tables 5 and 6.

The zinc sulfate product is intended to be sold into the agricultural and feed markets. The presence of some cobalt and manganese is not an obstacle to sale into this market as these elements are also essential nutrients. The range of tests indicate that cobalt and manganese will crystallize with the zinc sulfate in

Table 4: DSX Circuit Results for Pilot Plant

STREAM	ANALYSIS (Mg/L)						
	Cu	Co	Zn	Mn	Fe	Ca	Mg
PLS	30	128	592	23,100	<3	623	7050
RAFFINATE	<3	15	31	21,800	<1	592	6,660
SCRUB LIQUOR	<2	16	668	9,990	<1	57	505
Zn STRIP LIQUOR	<2	184	12,500	2,050	<1	4	11
Co STRIP LIQUOR	715	2,660	5,600	48	4	2	0
LOADED ORGANIC	152	571	2,380	609	3	<2	<2
SCRUBBED ORGANIC	159	589	2,710	338	3	<2	<2
Zn STRIPPED ORGANIC	148	527	1,170	50	3	<2	<2
Co STRIPPED ORGANIC	64	142	116	2	3	<2	<2

Table 5: Head Assays for Solutions used in Evaporation Testing

TEST	ANALYSIS (Mg/L)										
	Cu	Co	Zn	Mn	Fe	Ca	Mg	Al	Na	Ni	Si
1	0.2	300	13,000	3,200	0.9	1.7	11	14	17	<0.6	<50
2	0.2	118	9,530	4,690	<0.1	3.4	16	13	28	<0.6	<50
3	1.2	220	17,000	1,200	<0.2	2	7.4	12	16	<0.6	<50
4	0.5	158	17,200	77	<0.2	1.4	9.3	5.2	12	<0.6	<50
5	0.6	172	16,800	564	<0.2	1.5	11	5.7	16	<0.6	<50

Table 6: Composition of Zinc Sulfate Crude Crystal Product

TEST	ANALYSIS (g/t)									
	Cu	Co	Zn	Mn	Fe	Ca	Mg	Al	Si	
1	<10	5,080	175,000	26,800	<80	315	202	<100	<70	
2	<10	2,850	174,000	51,000	<80	100	392	<100	<70	
3	<10	2,810	176,000	7,400	<80	352	100	<100	<70	
4	<10	2,430	195,000	705	<80	<45	135	<100	<70	
5	<10	2,690	221,000	5,700	<80	<45	154	<100	<70	

rough proportion to the feed composition of the zinc strip solution. The key to manipulating the final composition of these elements then is to (1) increase manganese scrubbing prior to zinc strip and (2) strip zinc more selectively, leaving cobalt on the organic advancing to the cobalt strip process.

The design of the commercial evaporation at Boleo will be to use solar evaporation ponds to crystallize zinc sulfate from the zinc strip solution. The zinc sulfate crystals will then be harvested from the evaporation ponds on a regular cycle. The Baja Peninsula

of Mexico is renowned for use of solar evaporation for the purpose of salt (NaCl) crystallization from seawater. Recovery of zinc sulfate from the strip solution will naturally follow the same process.

The recovery of cobalt from the cobalt strip solution used a simple setup with the goal of producing a final cobalt metal product. The cobalt strip solution first went through an impurity removal SX circuit consisting of three extraction, one scrub and two strip stages. The extraction pH was controlled at 3.0 using 25 g/L NaOH addition. This circuit was designed to remove residual zinc and

copper. A second circuit was designed to recover the cobalt using 3 E, 1 Sc, 2 S stages and pH of 5 for extraction. The extractant in each case was Cyanex 272. The final cobalt strip solution was electrowon in a diaphragm cell at 65°C using a lead anode and stainless steel cathode. The quality of cobalt was excellent with Ni of 8-79 ppm, 28-115 ppm Pb and < 50 ppm Fe. The lead level would be expected to decrease as the anodes were conditioned over a longer period. The one element that is targeted for improvement was cadmium at 1100 – 3100 ppm in the cathode product. Future pilot runs will have to target removal of cadmium by zinc dust cementation ahead of the DSX circuit and/or ahead of the cobalt metal recovery circuit (Cyanex 272 extraction).

The final raffinate from the DSX circuit will contain a manganese concentration of greater than 20 g/L Mn. On an annual basis, up to 120,000 tpa of Mn will be leached from Boleo ore. Treatment of the DSX raffinate for Mn product recovery is under consideration and there is some indication that up to about 50% of this Mn may be available for recovery. Consideration of a manganese co-product will be part of the final feasibility program.

Figures 5 – 9 were taken during the main pilot plant program. These figures illustrate the major process sections of the overall pilot plant.

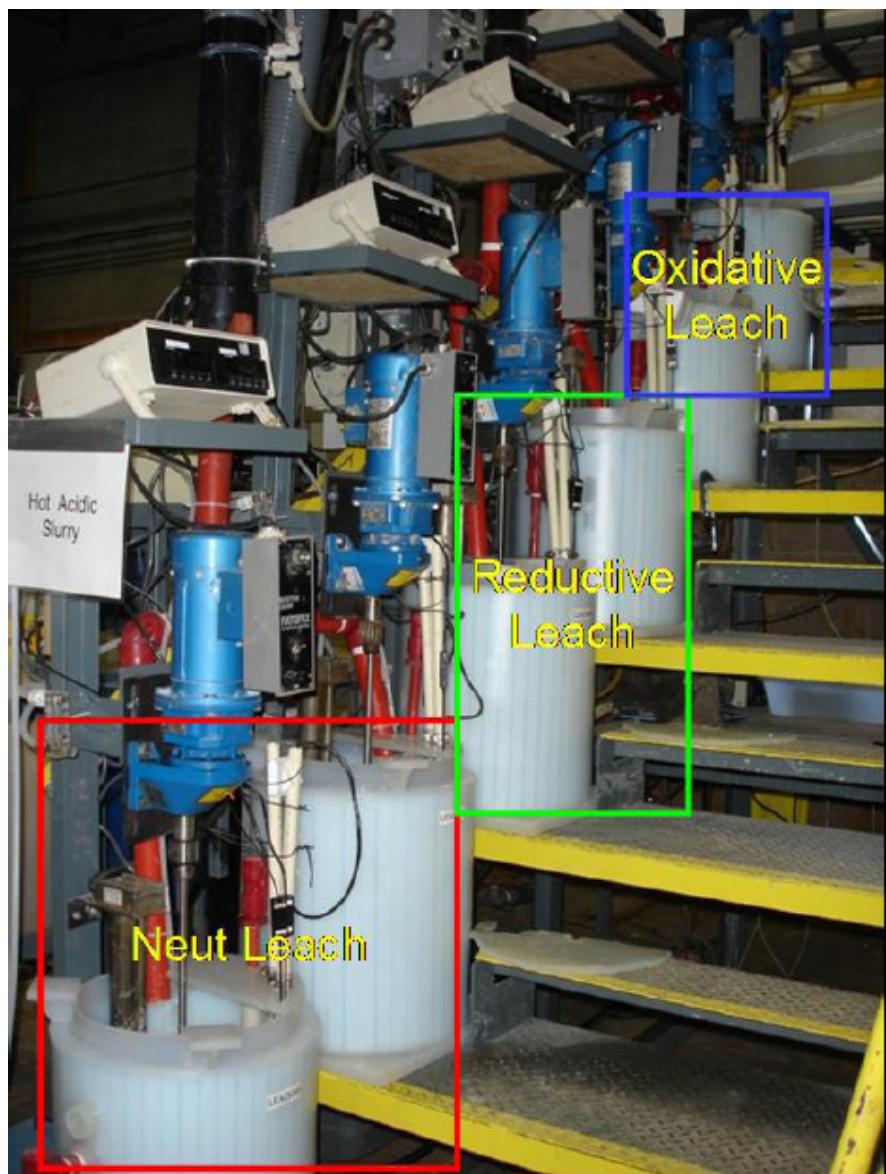


Figure 5: The Oxidative Leach, Reduction Leach and Partial Neutralization Cascade.



Figure 6: The 6 – Stage CCD Circuit Process Section



Figure 7: The Copper Solvent Extraction and Electrowinning Section



Figure 8: The 2 - Stage Iron Removal Circuit with the Iron Residue Thickener in the Background

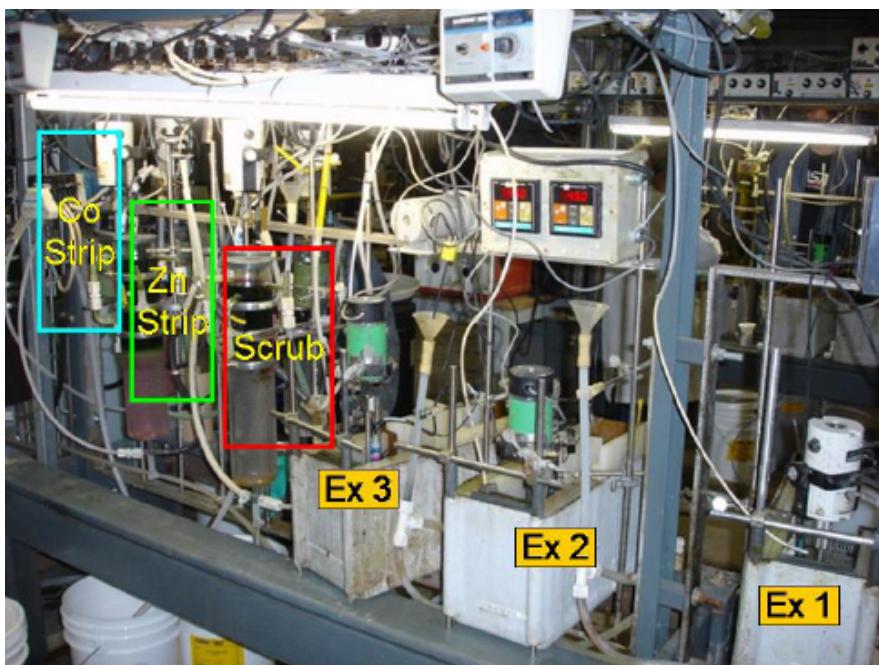


Figure 9: The Zinc and Cobalt Recovery Solvent Extraction Circuit using DSX Technology

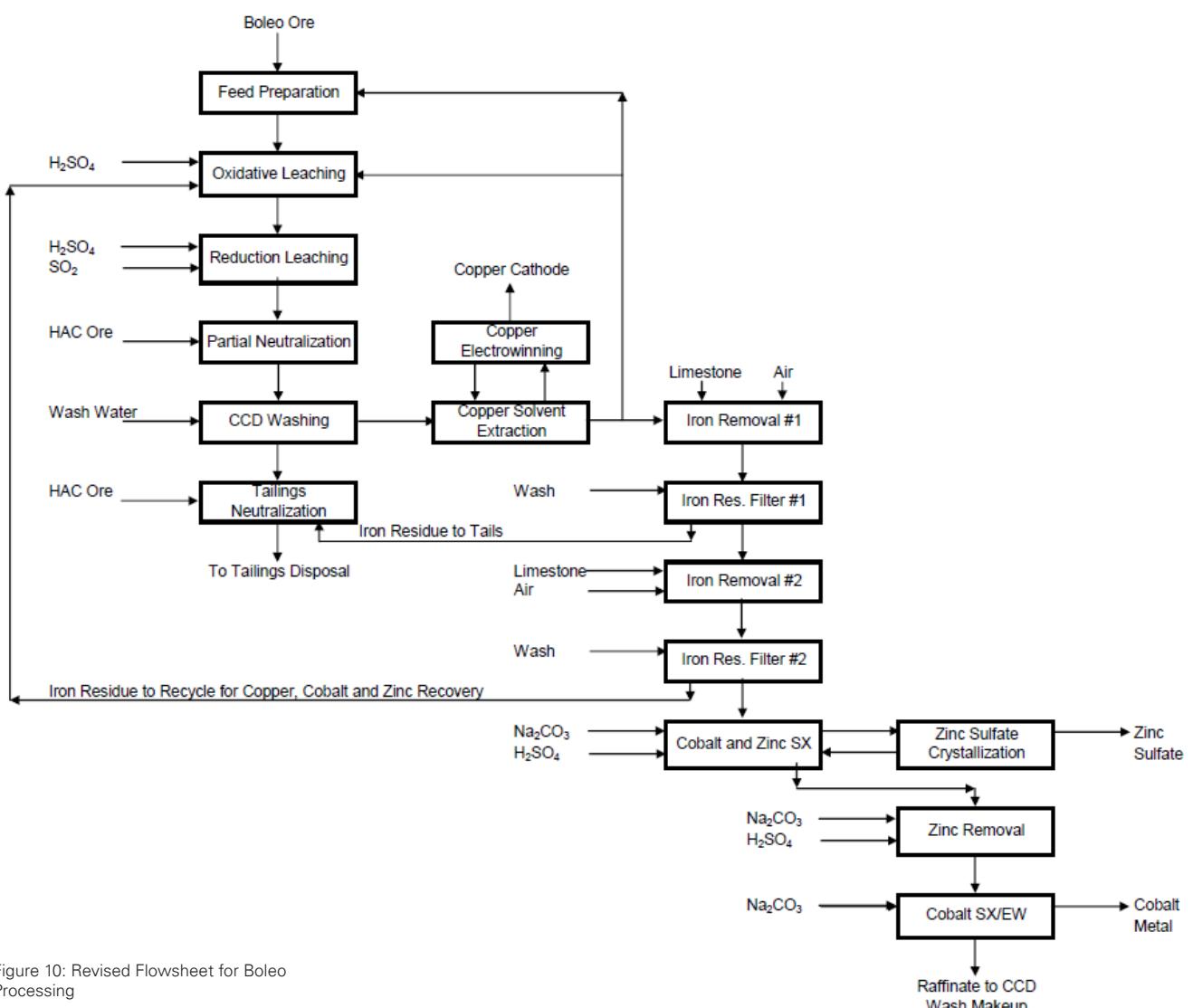


Figure 10: Revised Flowsheet for Boleo Processing

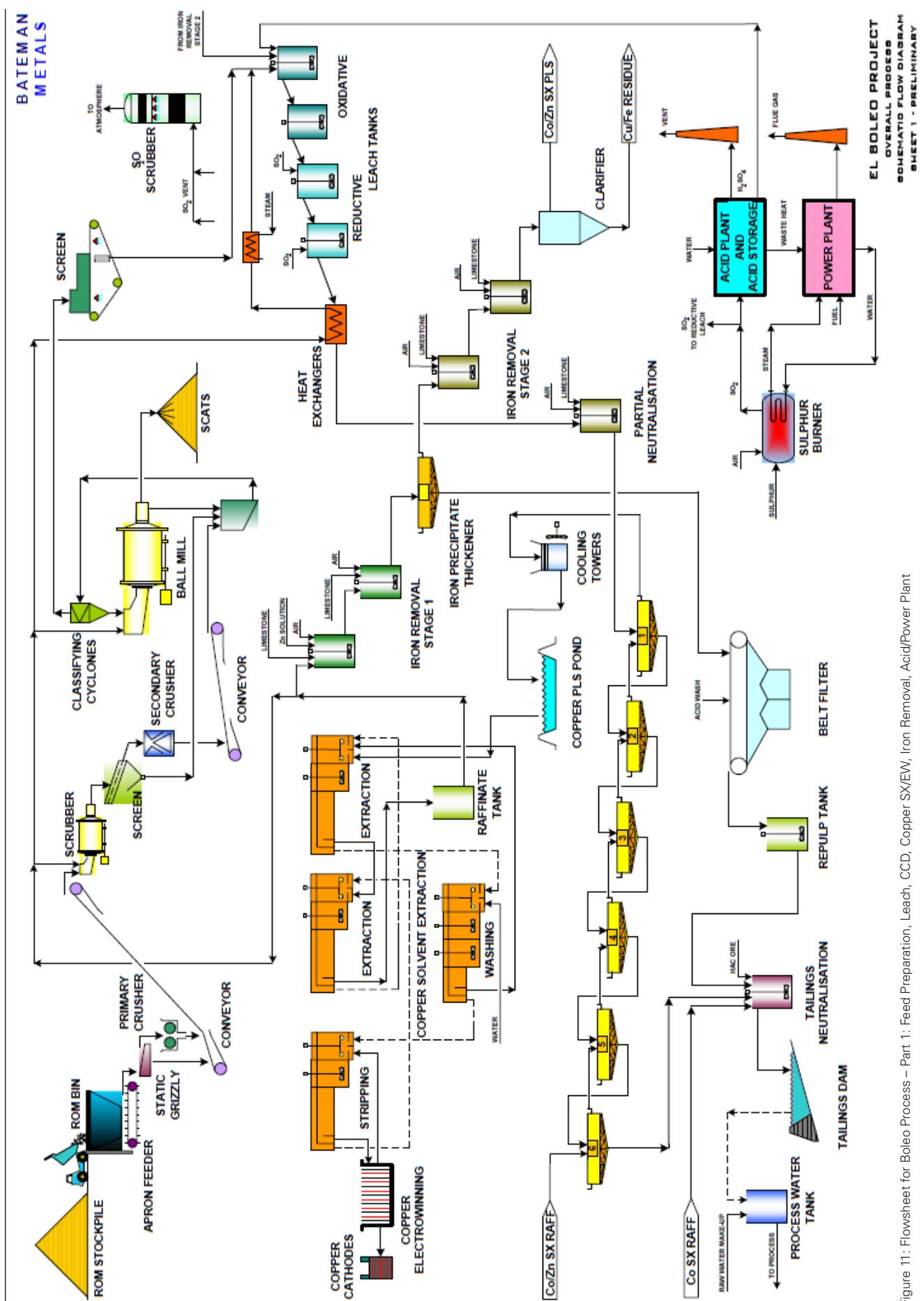


Figure 11: Flowsheet for Boleo Process – Part 1: Feed Preparation, Leach, Copper SX/EW, Iron Removal, Acid/Power Plant

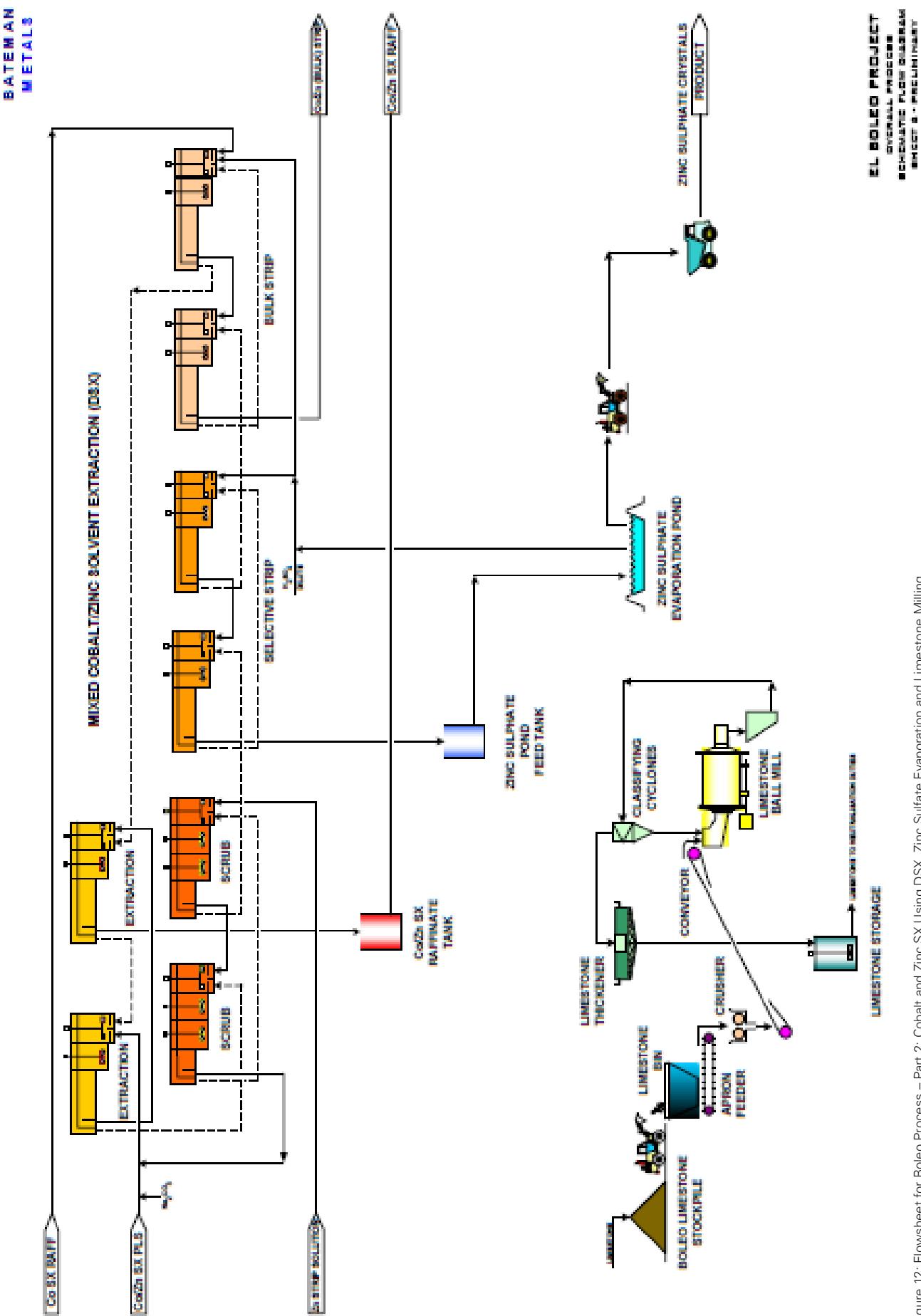


Figure 12: Flowsheet for Boleo Process – Part 2: Cobalt and Zinc SX Using DSX and Limestone Milling

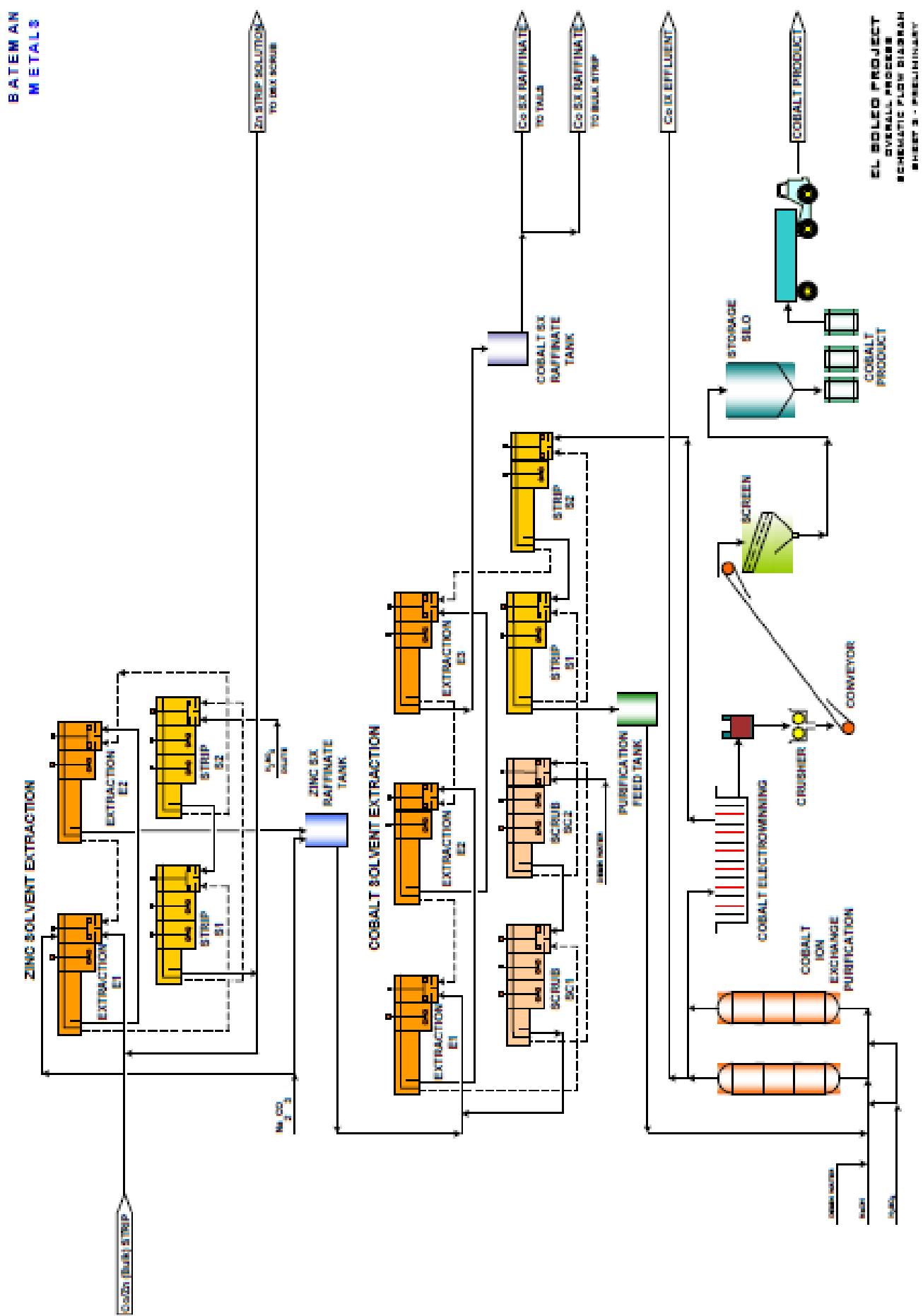


Figure 13: Flowsheet for Boleo Process – Part 3: Zinc and Cobalt Solvent Extraction and Cobalt Electrowinning

## SUMMARY AND CONCLUSIONS

A number of major process breakthroughs have allowed the Boleo project to proceed forward toward completion of a Definitive Feasibility Study. The two major breakthroughs at a pilot plant in 2004 were (1) successful demonstration of the use of high rate thickening for washing the Boleo leach residue and recovering a PLS solution carrying copper, cobalt and zinc values and (2) successful demonstration of the CSIRO DSX solvent extraction technology for recovery of cobalt and zinc in the presence of large background concentrations of manganese and other metals.

The results of the pilot testing have been synthesized into a revised flowsheet for the purpose of advancing the Definitive Feasibility Study program. Figure 10 is a simplified block diagram of the revised flow sheet and Figures 11-13 show the schematic for enhanced definition.

Figure 10 shows two major improvements over the previous pilot plant flowsheet. First, the copper raffinate is to be "split" with a large recycle of raffinate to feed preparation and to the oxidative leach. The advantages of this change are (1) that acid in the raffinate will be recycled back to contact fresh ore, reducing overall

acid consumption, (2) the cobalt and zinc content of the solution advancing to iron removal will be increased (approximately double) and (3) the downstream unit operations of iron removal and DSX solvent extraction will be proportionally smaller in physical size. The second improvement is that the iron removal will be divided into two stages, the first producing a "clean" residue nearly free of Cu, Co, Zn values for disposal with the CCD underflow tails and the second producing a contaminated product that is recycled to oxidation leaching to ensure high overall recovery of the pay metals.

Table 7 summarizes the expected overall recovery of pay metals from the Boleo ore using the process under development (at the current state of piloting and engineering).

The technical development of the Boleo flow-sheet will be the subject of a further definitive, integrated pilot plant at SGS Lakefield in the latter half of 2005 prior to completion of the DFS. The goal will be to test and demonstrate the chemistry and processing of the Boleo ore over an extended period. Further improvement and optimization of CCD performance, iron removal, DSX extraction and selective stripping and impurity management in production of final zinc sulfate and cobalt metal products is expected.

Table 7: Predicted Metallurgical Recoveries for Boleo Process Flowsheet from Pilot Plant and Engineering Studies

	Cu	Co	Zn
<b>LEACH EXTRACTION (%)</b>	92	83	70
<b>PARTIAL NEUTRALIZATION RECOVERY (%)</b>	100	100	100
<b>WASH RECOVERY (%)</b>	97	97	97
<b>SX RECOVERY (%)</b>	99.9	99	99
<b>OVERALL RECOVERY TO PRODUCT (%)</b>	89.2	80.5	67.2

## CONTACT INFORMATION

Email us at [minerals@sgs.com](mailto:minerals@sgs.com)

[WWW.SGS.COM/MINERALS](http://WWW.SGS.COM/MINERALS)

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