THE EXTRACTIVE METALLURGY OF PUEBLO VIEJO

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INTRODUCTION

Centrally located in the Dominican Republic, the Pueblo Viejo gold mine has been in production since 1975 and operated since 1979 by the state owned mining company, Rosario Dominicana S. A. (Rosario). Gold and silver were recovered from several oxide deposits mainly from the Monte Negro and Moore orebodies producing more than five million ounces of gold until 1991. A transition C.I.L. plant was built and commissioned in 1992 to enable Rosario to process a blend of oxide and sulfide ores up to 1997; since then, it has been processing sulfide ore exclusively until 1999 when operations were shut down due to high processing costs, environmental issues, low gold and silver prices and lack of an appropriate technology to process the sulfide ore.

GEOLOGY AND ORE RESERVES

The Pueblo Viejo precious metal deposit occurs in the upper part Los Ranchos Formation (Lower Cretaceous), a unit composed of volcanic and volcaniclastic rocks. The youngest exposed member of the Los Ranchos Formation, the Pueblo Viejo member, is a sedimentary sequence that was deposited in a small basin on the flanks of a volcanic pile. Starting at the bottom, the basinal lithologies include volcanic conglomerates and agglomerates, which grade upwards into sandstones and fine-grained, thin-bedded carbonaceous mudstones. The carbonaceous sediments are at least 120 m thick and host most of the precious metal mineralization. On the east and north sides of the mineralized zone, the sediments grade laterally into coarse conglomerates which were deposited along the shore of the sedimentary basin.

The Pueblo Viejo orebodies contain two adjoining major deposits called Monte Negro and Moore and three smaller satellite deposits. The larger deposit, Moore, is separated from Monte Negro by about 500 meters of barren carbonaceous mudstones.

Pyrite and sphalerite are the main sulfide minerals at Pueblo Viejo. On the average pyrite makes up 10 to 20 percent by weight of the mineralized rocks, reaching as high as 70 percent locally. Sphalerite assays range from trace up to 3 percent by weight. Pyrite is present both in veins and in the wall rocks, and sphalerite is largely restricted to veins. Intergrowths of pyrite and sphalerite are not common in the veins. Early pyrite, which lines the vein walls, is generally coarsely crystalline while later pyrite is finer grained and exhibits well-defined growth zones, which tend to host precious metal inclusions. Sphalerite in the veins is largely in botryoidal aggregates. At the vein centers, galena and minerals of the enargite and boulangerite groups are present in small amounts. The term "enargite group" includes minerals such us antimony-poor enargite ($Cu_3(Sb,As)S_4$); an unnamed phase ($Cu_{12} + X(Sb,As)_4 + YS_3$); lautite ($Cu(As,Sb)S$); and chalcostibite ($Cu(As,Sb)S_2$). The term "boulangerite group" minerals refers to lead-antimony-silver sulfides with composition falling between brongniardite ($Ag_2,PbSb_2S_5$), fuloppite ($Pb_3Sb_8S_{15}$) and boulangerite ($Pb_5Sb_4S_{11}$).

Gold occurs as electrum and gold-bearing tellurides, with the latter approximately twice as abundant as the electrum. Most of the gold-bearing minerals form small (0.1 to 5 microns) inclusions in sulfide minerals. Electrum has been seen only in pyrite whereas 70 percent of the gold-bearing tellurides have been seen in pyrite and the remainder in enargite-group minerals. Most of the tellurides are essentially silver-free, having the approximate composition of calaverite ($AuTe_2$).

Several major international mining companies have completed reserve estimates of the Pueblo Viejo sulfide gold deposit. Gold, silver and zinc reserve estimates for Monte Negro and Moore deposits are summarized in table #1:

METALLURGY

Of this vast geological resource, gold, silver and zinc are the most important from an economical point of view. Metallurgical testwork aimed at developing a process for the extraction of gold, silver and zinc from the Pueblo Viejo sulfide ore was started in 1953. Since then, numerous investigations and studies have been conducted by Rosario and by independent consultants, laboratories and engineering companies, retained by Rosario. Most of this work has been done during the past fifteen years. As result of this, we have a very good understanding of the metallurgical behavior of sulfide deposits.

Gold and Silver Distribution

The ore is considered moderately hard with a work index of 20 kwhr/ton. Several studies indicate the following results:

Gold in Current Ores

- 30% is cyanide leachable (C.I.L.)
- 50% is in the sulfide minerals
- 10% is contained in carbonaceous matter
- 10% is locked in silica

Gold Dissemination

The results shown in table #2 provide an indication of the gold and silver fineness dissemination after a series of fine grinding tests and cyanidation. The tests show that both gold and silver extraction increases as the particle sizes decrease.

Flotation

Different bench scale and pilot plant flotation schemes were tested during the years to establish a flowsheet prior to any oxidation process. The most successful test shows that it is possible to obtain separate zinc and pyrite concentrates as well as a bulk concentrate. The results are shown in table #3.

Bulk Flotation

A flowsheet was successfully demonstrated in a pilot plant program for a bulk sulfide concentrate containing gold and silver values. The projected recoveries are about 85 to 90 percent for gold and 96% for sulfides. The rougher flotation utilizes a grind of 60 cumulative weight percent passing 400 mesh and standard flotation reagents. See table #4.

Roasting

Different samples of whole ore and concentrates were studied at bench scale and continuous pilot plant; the tests have been performed on one and two stages of roasting. For the two stages roasting, temperatures between 600 and 750 degrees C in the first stage and between 650 and 800 degrees C in the second stage were performed with moderate excess and slight deficiency of air.

The contents of sulfur and carbon in the calcine from most of the tests were below 0.50% and 0.1% respectively. The removal of arsenic by roasting was insignificant.

The extraction of gold varied between 77 and 84%, while dissolution of silver was at most 26%.

The roasting has been performed with a capacity of about 70 metric tons per m^2 grid area per day in reactor 1 and about 50 tons in reactor 2.

Single stage recirculating bed reactor gave gold extraction between 85 and 88% at a temperature between 675 to 700 degrees C.

Biological Oxidation

The laboratory bench scale study was performed to evaluate the potential of using bioxidation as a pretreatment for sulfide ore to improve gold recovery. A continuous bioxidation test of one ore type demonstrated the feasibility of the bioxidation process. High gold recoveries were obtained following oxidation of less than 50% of sulfur due to selective oxidation of the gold-bearing sulfides. See table #5.

Pressure Oxidation

Studies of pressure oxidation on sulfide whole ore indicate that gold and silver recoveries are achievable with pressure leach. More than 95% of the gold could be extracted at the condition of 220 degrees C, 100 psi oxygen overpressure and two hours retention time.

More than 95% of the zinc contained in the ore was in solution after the pressure oxidation test. Results are shown in table #6.

Emergent Technologies

In the recent years, technologies that combine ultra fine grinding with a mild ambient or pressure oxidation (Albion or activox) have demonstrated through pilot plant studies that the Pueblo Viejo sulfide minerals have an excellent response to this metallurgical process to recover base and precious metals. Extractions of more than 80% gold, 60% silver and more than 90% of the zinc have been obtained in different pilot plant campaigns.

ECONOMIC EVALUATION

The metallurgical response of an ore to a proposed treatment scheme directly determines the economics of the process or a combination of processes used. The different schemes applied to the whole ore and concentrates of the Pueblo Viejo sulfide deposit indicate that there are several ways to treat this orebody and obtain reasonable recoveries of the precious and base metals contained in the ore.

During the past fifteen years Rosario Dominicana has contracted the services of well-known companies to complete different feasibility studies.

Table #7 shows the economics of the processes being studied.

CONCLUSION

Considered as a low-grade precious metal and high sulfur content ore, the Pueblo Viejo deposit has an excellent metallurgical behavior for the recovery of precious and base metals. All the alternatives that have been studied show a project technically viable at different ranges of scales and throughputs. These studies indicate that the most feasible schemes from the economical and environmental point of view are those that include the ultra fine grinding, low temperature, low pressure leaching sulfide and SX/EW processing of the leach liquor for production of Zn cathode, taking advantage thus of all the economic elements of the ore body.

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Table #1 - Pueblo Viejo - Summary Of Resources

Resources (Mineral Inventory)

MOORE

Cutoff	K tons	Au (g/t)	Ag (g/t)	S (%)	Zn (%)	Au Oz
1.00	305,970	2.05	12.68	6.96	0.54	20,168,441
1.50	192,207	2.53	15.44	7.33	0.63	15,636,132
2.00	118,980	3.04	18.56	7.83	0.72	11,630,199
3.00	45,071	4.04	25.93	8.41	1.06	2,718,240
4.00	16,479	5.13	35.99	9.09	1.06	2,718,240
5.00	6,727	6.18	45.14	9.59	1.2	1,336,748

MONTENEGRO

Cutoff	K tons	Au (g/t)	Ag (g/t)	S (%)	Zn (%)	Au Oz
1.00	236,387	1.89	10.57	6.94	0.54	14,487,184
1.50	129,209	2.46	13.02	7.09	0.63	10,220,390
2.00	69,964	3.09	16.06	7.26	0.72	6,951,407
3.00	24,742	4.42	23.67	8.12	1.06	3,516,387
4.00	11,823	5.51	31.18	8.19	1.06	2,094,686
5.00	6,258	6.44	38.50	8.29	1.20	1,295,869

TOTAL

CUTOFF	K tons	Au (g/t)	Ag g/t)	S (%)	Zn (%)	K Au Oz.
1.0	**544,357**	**1.98**	**11.76**	**6.95**	**0.56**	**34,656**

Table #2 - Percent passing five microns

% minus 5 microns	Gold Extraction	Silver Extraction
50%	75%	50%
80%	77%	62%
95%	90%	75%

Table #3 - Selective Flotation Tests on Low Grade Moore Ore

Product	Weight %	Assays, %, g/t					% Distribution				
		Zn	Fe	S	Au	Ag	Zn	Fe	S	Au	Ag
Zinc cleaner concentrate	1.18	51.3	3.62	33.9	21.54	357	61.7	0.6	5.5	11	30.4
Pyrite Cl. Concentrate	17.58	1.05	32.9	35.2	8.81	40.2	19	87.9	85.1	67.3	51.2
Pyrite Ro. Concentrate	58	0.54	10.7	11.1	3.14	15	32.1	94.1	89	79.3	63.1
Pyrite Flot. Tail	40.76	0.15	0.86	0.98	0.55	2.2	6.2	5.3	5.5	9.7	6.5
Head Calculated	100	0.98	6.59	7.27	2.30	13.8	100.0	100.0	100.0	100.0	100.0

Table #4 - Bulk Rougher Concentrate Moore Samples

Flotation Concentrate	Wt. %	Au G/t	Ag G/t	S %	FeS_2 %	Fe %	Zn %	Pb %	Cu %
Assays	-	11.99	168.4	39.2	67.3	32.6	3.63	0.21	0.50
Distribution	53.1	91.4	93.7	98.0	98.0	96.4	99.0	78.8	97.3

Table #5 - Batch Bioxidation Moore & Montenegro Composites

Product	Sulfur Oxidation %	Au Extraction %	Silver Extraction %
Head	0	27.8	17.9
Bioxidation Res. 1	23.2	63.8	31.0
Bioxidation Res. 2	46.1	77.8	53.8
Bioxidation Res. 3	90.1	90.4	64.7

Product	Sulfur Oxidation %	Au Extraction %	Silver Extraction %
145 hours	76.6	86.0	72.0
145 hours	56.1	79.0	63.0
100 hours	49.9	75.0	55.0
74 hours	19.0	68.0	46.0

Table #6 - Pressure Leach Conditions and Results Montenegro Samples

Temperature Degrees C	Retention Time Hours	Percent Sulfur Oxidation	Percent Gold Extraction	Percent Silver Extraction
220	2	94	95	32
220	1	63	75	22
150	2	35	80	51
150	1	22	66	43
185	3	73	86	33
185	1	35	69	36

Table #7 - Summary Of Economic Evaluation

Options	Roasting + Sulf. Acid	Roasting + Gypsum	Fine Grinding + Zn Conc.	Fine Grinding + Zn Conc.	Fine Grinding + Zn Cathode	Fine Grinding + Zn Cathode	Fine Grinding + Zn Cathode
Capacity tpd	9,000	15,000	10,000	15,000	15,000	15,000	40,000
Gold Recovery %	83	83	64	64	81	81	85
Silver Recovery %	35	35	50	68	60	60	60
Capital Costs M US$	347.5	395	125	130	261	261	750
Operating Costs US$/ton	22	20.3	27.3	29.4	25	25	19
IRR %	18.7*	17.35*	14.5*	22.5*	15**	31**	32-**
Cost per Oz. Au US$ ***	212	182	N/a	N/a	144	148	155
Gold PriceUS$	340	350	340	340	260	340	325

*** Before tax. **After 25% taxes.**

***** after zinc and silver credits**