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GOLDEN BEAR — PROCESS ALTERNATIVES TESTING AND FLOWSHEET SELECTION FOR A REFRACTORY BRITISH COLUMBIA GOLD ORE

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Presented at the 93rd Annual
Northwest Mining Association Convention
Spokane, Washington

December 3, 1987

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ABSTRACT

The Golden Bear gold property is located northwest of Telegraph Creek in northwestern B.C. Mineralization occurs as disseminations and fracture fillings of extremely fine-grained pyrite predominantly along fault contacts of tuff and strongly silicified and brecciated limestone.

Metallurgical testwork and evaluations since 1982 have determined that dry grinding, whole ore roasting, cyanidation, carbon-in-pulp and conventional gold recovery is the best flowsheet for this refractory ore. This paper will review bench and pilot testing leading to the flowsheet selection.

GOLDEN BEAR — PROCESS ALTERNATIVES

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1.0 PROJECT LOCATION

The Golden Bear project, a joint venture between North American Metals Corporation and Chevron Minerals Ltd., is located at Muddy Lake in northwestern British Columbia, Canada, approximately 80 km northwest of Telegraph Creek and 135 km west of Dease Lake. A location map is shown in Figure 1.

The project site lies on the east side of the Coast Mountains, 70 km east of tidewater. The area is in rugged alpine terrain with elevations ranging from 900 m to 2,000 m above sea level at the mineral claims. A major rock landslide and a number of alpine glaciers are on the project claims. The northeasterly flowing Samotua River basin drains the project area.

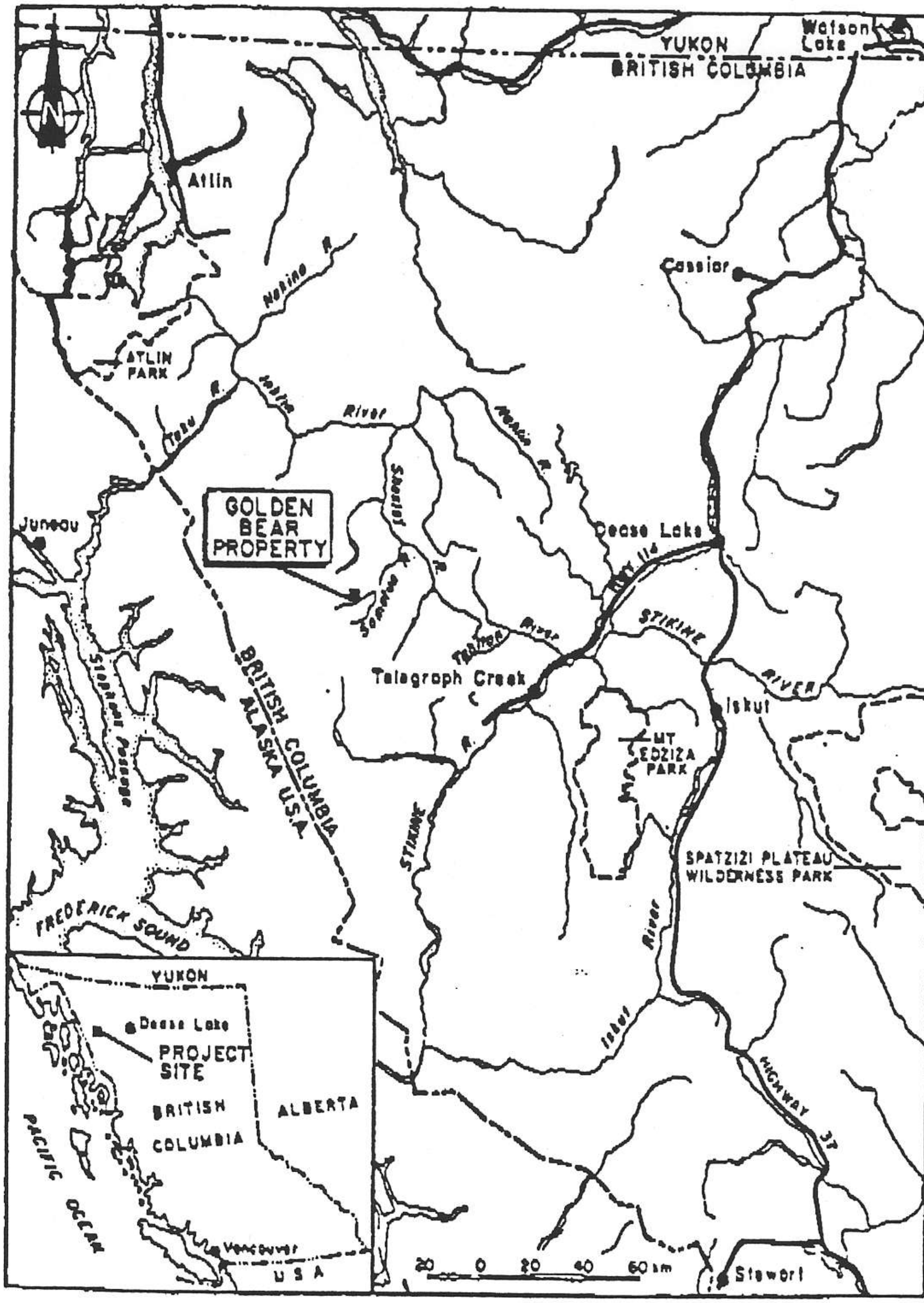
The transition from heavy coastal precipitation to the drier interior plateau takes place in the immediate vicinity of the property. The mean annual temperature over the last 3 years was 0.8°C with a mean daily maximum of 15.4°C in July and a mean daily minimum of -17.4°C in February. Annual total precipitation varied from 581 mm to 680 mm with a mean for the three years of 642 mm.

2.0 BACKGROUND

The first known mineral claim in the project area was staked by an independent prospector in 1956, covering a number of small copper showings near Muddy Lake. Chevron Canada Resources Limited initiated a reconnaissance work program in the area in 1980. Claims were staked in 1981 and 1982. Surface work and detailed drilling over the next three years resulted in the discovery of the Bear and Fleece ore bodies. The property was joint ventured to North American Metals (B.C.) Inc. in 1986. The main objectives were to place the Chevron geological reserves into a proven category and to obtain bulk samples for metallurgical testing.

FIGURE 1

GOLDEN BEAR PROJECT
LOCATION MAP



The mineral resources at Golden Bear total 1,635,000 tonnes grading 10.86 g Au/tonne in all categories, with two zones, the Bear and Fleece, making up the deposit. In the initial years of production a total of over 600,000 tonnes of ore averaging 18 to 19 g Au/tonne will be processed from the Bear zone.

3.0 ORE DESCRIPTION

The Golden Bear ore reserves in the Bear zone are made up of an open pit ore and an underground ore of varying mineralogical characteristics. Based on current ore reserve distributions, the anticipated feed for the Golden Bear mill will be a 50:50 blend of open pit and underground ore.

The open pit ore is made up of four ore types, mostly quartz breccia (55%) and clay gouge (35%), and minor amounts of pyritic tuff and silicified dolomite. The quartz breccia is essentially quartz, dolomite, a trace of muscovite and fine-grain pyrite inclusions in quartz with some alteration to goethite. The clay gouge is made up of quartz, dolomite, muscovite, fine-grain pyrite, goethite, gypsum and illite- or montmorillonite-type clays. The pyritic tuff, a minor component of the open pit ore, is made up of quartz, dolomite, muscovite, feldspar and pyrite/marcasite inclusions in quartz. The silicified dolomite is essentially quartz, dolomite and fine-grain inclusions of pyrite in quartz.

The underground ore is made up of two ore types, 20% quartz breccia and 80% pyritic tuff. The underground quartz breccia is the same as the open pit quartz breccia except half the contained pyrite is liberated and half is present as fine-grain inclusions in quartz. The underground pyritic tuff contains a much higher percentage of sulphides and a much higher marcasite content compared to the open pit pyritic tuff.

An extensive petrographic and mineralogical study of Golden Bear samples, performed by Chevron Research, provided the following additional main conclusions:

- the Golden Bear ore is a sulphide-rich gold ore which has had a complex history involving several episodes of fracturing and alteration

- several forms of gold and silver mineralization have been identified or postulated. The leachable minerals include native gold, which includes some silver, and tetrahedrite, which contains a small percentage of silver. More than half of the gold, and probably also silver, occurs as submicroscopic inclusions in arsenical pyrite, possibly in the form of telluride or arsenide. The submicroscopic gold and silver are unleachable in straight cyanide, hence these values require complete breakdown of the host pyrite. Of this submicroscopic gold and silver, by analogy with the occurrence of arsenic, part occurs concentrated at the edges of early pyrite grains and in pyrite overgrowths, and part occurs disseminated in early pyrite and bravoite

- the concentrated form of submicroscopic gold is in the black matrix of the ore which cements breccia fragments of quartzite and altered greenstone. The black matrix consists of an intimate mixture of finely crushed quartz, illite, and arsenical, and presumably gold- and silver-rich, pyrite. The leachable gold also occurs in this black matrix

- only traces of chalcopyrite were observed, hence cyanicide minerals are not expected to be a problem.

A typical analysis of the Golden Bear ore, based on a 50:50 blend of open pit and underground ore, is presented in Table 1. Although refractory in nature, the ore is a very clean ore with the content of potentially deleterious elements being very low.

TABLE 1

GOLDEN BEAR PROJECT

TYPICAL GOLDEN BEAR ORE ANALYSIS (%)

Analyte	Mill Feed Blend
Au	18.6 g/t
Ag	15 g/t
S	4.5
S^{2-}	3.9
Fe	5.0
As	0.09
Hg	0.00023
Pb	0.002
Sb	<0.005
C(G)	0.09
Cu	0.010
Zn	0.006
Te	0.002
CO_2	5.36
Al_2O_3	6.99
SiO_2	75.0
MgO	2.32
CaO	4.00
Na_2O	0.020
K_2O	2.06
LOI	10.3

4.0 EARLY PROCESS WORK

4.1 Background

The refractory nature of the Golden Bear ore led to numerous metallurgical studies being completed by various groups since 1982. The early work, completed by Chevron Research Co. of Richmond, California, established the basic metallurgical characteristics of the ore and identified the recalcitrant nature of the contained gold. Follow-up testwork was completed by Lakefield Research (Lakefield, Ontario) in 1985 in conjunction with an order of magnitude pre-feasibility evaluation of process alternatives by Kilborn Engineering. This was followed up with additional testwork by Lakefield Research and Coastech Research of North Vancouver, B.C. in 1986 when further process evaluations were carried out. This work was co-ordinated by Wright Engineers Ltd. of Vancouver, B.C. and the test results used in a pre-feasibility assessment of processing options for the ore. This assessment concluded that dry grinding and whole ore roasting was the favoured processing option for the refractory Golden Bear ore. A brief summary of early metallurgical results for various processing options are presented below.

4.2 Metallurgical Results

Early bottle cyanidation tests in 1983 on Golden Bear exploration samples showed gold recoveries of 25% to 98% could be achieved in 2 hours of cyanidation of minus 149 micron (100 mesh) material. Extended leach times of 72 hours, higher concentrations of cyanide, elevated temperatures, and finer grinds did not increase the percentage of gold leached. Samples from the oxidized portion of the orebody gave high gold recoveries, while samples from the sulphide portion gave very low gold and silver recoveries. Roasting the sulphide ore samples in a muffle furnace and then leaching with cyanide increased the percentage of gold leached to 81-84%.

Additional drill core samples were submitted to bench-scale tests in early 1984 and these samples showed similar results. A total of 29 drill core samples were dried, crushed to minus 3.36 mm (6 mesh) and blended to prepare a 64 kg composite sample for testing. Normal cyanidation tests only leached 35-40% of the gold and 25-30% of the silver from the composite sample in 4 hours of leaching; again, extended leach times did not increase the gold extraction. Almost every imaginable pretreatment method for increasing the gold recovery was tested on the composite sample. A few of these pretreatments along with the subsequent percentage of gold extraction by cyanidation were: H_2SO_4 pug leaching (39%), bacterial leaching (44%), pressure cyanidation (40%), ammonium thiosulphate leaching (44%), chlorine leaching (51%), NaCl roasting (73%), and reductive roasting using carbon (75%). Froth flotation was only able to recover about 75% of the gold into a concentrate which was 48% of the feed weight. The Golden Bear ore does not respond well to flotation since the majority of pyrite grains are in the 5 micron size range.

From 86 to 98% of the gold could be leached by cyanidation after oxidation of the ore by roasting or autoclaving. Eleven out of 27 roasting/cyanidation tests leached greater than 85% of the gold from the ore and two tests gave over 90% gold extraction. Best roasting results were obtained when the ore was ground to at least 32% minus 74 micron (200 mesh) followed by roasting in a muffle furnace for 1 to 4 hours at 500°C with air as the oxidizing atmosphere. Roasting at 550-600°C, or with a reducing atmosphere, gave lower gold cyanidation recoveries.

Acid pressure oxidation followed by cyanidation gave gold extractions as high as 96 to 98%. The best autoclave leach conditions were (1) a fine grind of 60 to 96% minus 74 micron, (2) H_2SO_4 addition of 175 to 300 kg/tonne to reach the desired pH of 1.2, (3) an autoclave temperature of 180°C, (4) 4 hours autoclaving time, (5) an oxygen over-pressure of 1725 kPa (250 psig), (6) 5.5 kg ferric sulphate/tonne and an emf of 480 mV as measured versus a oalomel electrode. The major drawback of the autoclaving technique for the Golden Bear ore was the large quantities of H_2SO_4 required to reach the desired autoclaving pH of 1.2 due to the natural dolomite content in the ore. Acid is produced in the autoclave but the net consumption of H_2SO_4 was still in the range of 50-100 kg/tonne. Removal of carbonates by flotation was evaluated but high gold losses to the carbonate flotation concentrate were unacceptable.

Further testwork completed in the course of Wright's pre-feasability evaluation generally confirmed the results of the Chevron testwork.

4.3 Process Comparisons

In Wright's preliminary assessment (April, 1987) the following process options were evaluated in greater detail as potential circuits capable of achieving at least an 85% gold recovery at an economic cost for all ore types:

- wet grinding, neutral pressure oxidation, cyanidation
- wet grinding, roasting, cyanidation
- dry grinding, roasting, cyanidation
- wet grinding, flotation, roasting of concentrate, cyanidation of calcine and flotation tailing.

All other options either failed to achieve reasonable gold recovery or were uneconomic due to high capital and operating costs.

Since the above four circuits were considered to be metallurgically feasible, preliminary capital cost estimates were completed to determine the relative economic viability of each process. The relative capital cost of each option, summarized in Table 2, showed that the dry grind/whole ore roast option was the most economic circuit for the Golden Bear ore.

A two-stage semi-autogenous grinding (SAG) mill, ball mill wet grinding circuit followed by neutral autoclaving of the slurry and subsequent cyanidation could give an estimated 85% gold recovery but the capital costs of an oxygen plant made the capital cost substantially higher.

TABLE 2

GOLDEN BEAR PROJECT

PRELIMINARY COMPARISON OF PROCESS OPTIONS

PROCESS	RELATIVE CAPITAL COST	EXPECTED GOLD RECOVERY (%)
Dry Grinding/Roasting	1.0	90
Wet Grinding/Flotation/Roasting	1.06	85
Wet Grinding/Roasting	1.11	92
Wet Grinding/Neutral Pressure Oxidation	1.24	85

The operating costs were in line with the other options but the gold recovery was lower.

Wet grinding the ore in a SAG mill/ball mill circuit, filtration of the ore, and direct roasting of the wet cake would necessitate a relatively large roaster and additional fuel to accommodate the moisture in the roaster feed. An estimated 92% gold recovery was expected for this circuit but capital and operating costs were high.

The circuit comprising wet grinding, flotation, roasting of the concentrate and cyanidation of roaster calcine and flotation tailings was felt to be a good compromise to reduce fuel requirements in the roaster but a lower estimated gold recovery of 85% would have to be accepted.

The more economically favourable dry grind/fluid-bed roast circuit presented the potential for lower capital and operating costs while maintaining an estimated gold recovery of 90%. The high clay content in the Golden Bear ore was of concern at the time of evaluation hence a conventional crushing plant with an intermediate ore drying stage ahead of a dry grinding wet mill was the selected comminution circuit. The resulting coarser grind of the calcine would result in a slightly lower anticipated gold recovery. A dry SAG mill was not selected at the time due to a concern for mill plugging in light of the high clay, moisture content in the feed.

As a result of this evaluation more detailed metallurgical work was commissioned to evaluate the dry grinding/roasting circuit in more detail, to confirm the anticipated gold recovery for this circuit, and to investigate areas where economic savings could be realized. This led to the bulk sample testwork described below.

5.0 BULK SAMPLE TESTWORK

5.1 Background

A systematic sampling of the open pit orebody and the underground orebody during the 1986-1987 winter program provided a bulk sample of ore for detailed metallurgical evaluation. A total of 50, 200 L drums of ore were blended in ratios representing the ore reserves of the Golden Bear deposit to provide a representative sample of open pit ore, underground ore,end a blended ore representing the anticipated mill feed.

Detailed metallurgical tests were completed at Lakefield Research during May and June 1987 under the supervision and direction of Melis Engineering Ltd. of Saskatoon, Canada. The main purpose of this work was to:

- establish the design criteria for the dry grind/roast processing option
- briefly assess previously considered processing options
- determine waste treatment requirements
- generate environmental data.

Dry grinding tests using a 46 cm (18 inch) Aerofall SAG mill were also completed at this time by Hazen Research of Golden, Colorado. As a result of this work, preliminary process and waste treatment design criteria were established from which capital and operating cost estimates were prepared by Melis Engineering Ltd.

Since a dry grind/roast is not commonplace for gold milling circuits, and additional data were required to substantiate the proposed waste treatment circuit, a pilot test on the remaining bulk sample of ore was completed at Hazen Research in July and early August 1987. The pilot work included the following:

- dry grinding tests in an Aerofall SAG mill
- continuous pilot testing of fluid-bed roasting, cyanidation and carbon-in-pulp (CIP) gold recovery

- pilot testing of roaster off-gas scrubbing
- continuous pilot test of acid pressure oxidation
- generation of environmental data.

In conjunction with the pilot work, roasting tests were completed by Allis Chalmers of Milwaukee, Wisconsin to evaluate the performance of a rotary kiln for roasting the ore. Comparative cyanidation tests were completed by Lakefield Research on fluid-bed calcine from the Hazen pilot plant and on the Allis Chalmers rotary kiln calcine. The loaded carbon collected in the Hazen pilot test was submitted to a continuous pressure stripping/electrowinning test at Saskatchewan Research Council in Saskatoon, Canada under the supervision of Melis Engineering Ltd.

The metallurgical results of the bulk sample studies were reviewed and assimilated during the course of the testwork and a revised process and waste treatment design criteria was submitted by Melis Engineering in October 1987.

This report concluded the metallurgical work for the Golden Bear ore in preparation for the detailed engineering and mill construction phase of the Golden Bear project.

5.2 Metallurgical Results

5.2.1 Lakefield Program

The Lakefield test program in May and June 1987 concentrated on obtaining design criteria for the roasting pre-treatment option. Brief tests were also completed to evaluate the response of the different bulk sample ore types to direct cyanidation, flotation and pressure oxidation.

5.2.1.1 Bulk Sample Characteristics

Blended samples of each of the ore types were analysed for gold, silver and sulphur to characterize the open pit ore and underground ore. These analyses are summarized in Table 3.

5.2.1.2 Direct Cyanidation

Each ore type was submitted to a standard bottle cyanidation test with a fine grind (minus 37 micron (400 mesh)) to determine the ultimate gold recovery possible by direct cyanidation. The results are presented in Table 3. The refractory nature of the ore is evident from these results, especially for the underground pyritic tuff material.

5.2.1.3 Flotation

Flotation tests, under optimum gold flotation conditions, were completed on the bulk sample of ore. These tests confirmed the poor results obtained in the earlier work. The results of these tests are presented in Table 4. The poor gold recovery to a flotation cleaner concentrate, combined with a poor cyanidation efficiency on the flotation tail, makes flotation a non-viable option as a pre-concentration step for both the open pit and underground Golden Bear ore.

5.2.1.4 Pressure Oxidation

Although acid pressure oxidation had been previously discounted as an economically viable process for the Golden Bear ore, a total of 4 batch tests were completed to assess the behaviour of the bulk sample of ore under neutral and acid pressure oxidation conditions. The test conditions were 33% solids pulp density, 205 °C, 862 kPa (125 psi) oxygen over pressure and a 2-hour reaction time. Neutral pressure oxidation was done on the slurry as is and acid pressure oxidation was completed using an acid pre-conditioning step. The oxidized slurry was subsequently cyanided to determine gold extraction efficiencies.

Results are presented in Table 5. Acid pressure oxidation treatment gave high gold recoveries but high acid requirements were observed in the batch tests. As mentioned earlier the high cost of acid, combined

TABLE 3

GOLDEN BEAR PROJECT

TYPICAL ANALYSIS OF BULK SAMPLE ORE TYPES

ORE	ORE TYPE	WEIGHT (%)	Au (g/t)	Ag (g/t)	% S	% GOLD EXTRACTION DIRECT CYANIDATION
Open Pit	Quartz Breccia	53.7	10.6	14.1	0.77	52.1
	Clay Gauge	36.2	41.6	14.9	4.56	58.5
	Silicified Dolomite	8.7	7.8	9.7	0.55	56.5
	Pyritic Tuff	1.4	10.7	9.7	0.42	78.1
Underground	Pyritic Tuff	80	17.6	23.7	7.49	7.4
	Quartz Breccia	20	8.6	10.5	0.98	45.3

TABLE 4

GOLDEN BEAR PROJECT

FLOTATION TEST RESULTS

ITEM	ORE TYPE OPEN PIT	ORE TYPE UNDERGROUND
Flotation – % gold recovery to cleaner con	48	55
– % sulphur recovery to cleaner con	59	71
– weight % to cleaner concentrate	7.5	18
– cleaner concentrate grade:		
– Au g/t	151	61
– % S	26.7	20.5
% gold recovery from cyanidation of flotation tail	38	13.5
Inferred overall % gold recovery (assuming 90% extraction from roasted concentrate)	63	56

TABLE 5

GOLDEN BEAR PROJECT

PRESSURE OXIDATION TEST RESULTS

ITEM	ORE TYPE OPEN PIT	ORE TYPE UNDERGROUND
Neutral Pressure Oxidation		
pH	8.0	0.6
emf (mV)	370	595
free acid (g/L)	0	31.1
cyanide residue grade (Au g/t)	3.4	1.95
% gold extraction	84.3	86.8
Acid Pressure Oxidation		
pH	0.8	0.5
emf (mV)	670	640
free acid (g/L)	23.2	40.1
kg H_2SO_4/t	147.2	82.2
cyanide residue grade (Au g/t)	0.69	0.57
% gold extraction	96.6	95.6

with the requirement for an oxygen plant, made acid pressure oxidation an uneconomic option for Golden Bear ore. However, the high gold recovery obtained in the batch test justified further investigations in a continuous reactor at Hazen Research.

5.2.1.5 Roasting

In light of the poor flotation results, whole ore roasting appeared to be the only possible option for a roast pre-treatment ahead of cyanidation. Earlier work had indicated that roasting would be a viable option for the Golden Bear ore.

Continuous roasting tests were therefore conducted in a 17.8 cm (7 inch) fluosolids roaster at two temperatures using open pit ore, underground ore and a mixture of open pit/underground ore. The calcine products, bed overflow, dust and combined calcine, were submitted to cyanidation tests to identify gold extraction efficiencies. The following variables were evaluated:

- grind of roaster feed
- roast temperature
- hot water wash stage ahead of cyanidation.

The effect of roaster feed grind on gold extractions is summarized in Table 6 for both the open pit and underground ore. The finer grind gave a slightly better gold extraction for the open pit ore and a markedly better extraction for the underground ore. The alternative of roasting a coarse feed (-3.36 mm) and grinding the calcine ahead of cyanidation was also investigated. This approach resulted in poor gold extractions as indicated in Table 6.

The effect of temperature on roasting efficiency is clearly depicted in Table 7. A 525°C roast was significantly better in terms of gold extraction efficiency versus a 675°C roast.

TABLE 6

GOLDEN BEAR PROJECT

ROASTING TEST RESULTS

EFFECT OF GRIND (525 °C ROAST)

ROASTER FEED GRIND (% -74 MICRON)	% GOLD EXTRACTION			
	OPEN PIT		UNDERGROUND	
	BED O/F	DUST	BED O/F	COMBINED
63	92.8	94.2	--	--
39	91.6	95.5	--	--
48	--	--	90.3	90.7
50	--	--	78.0	77.8
- 3.36 mm (6 mesh) followed by grinding of calcine to -74 micron	89.0		79.6	

TABLE 7

GOLDEN BEAR PROJECT

ROASTING TEST RESULTS

EFFECT OF TEMPERATURE

ROAST TEMPERATURE (° C)	% GOLD EXTRACTION			
	OPEN PIT		UNDERGROUND	
	BED O/F	DUST	BED O/F	COMBINED
525	92.8	94.2	90.3	90.7
650 - 675	85.5	89.6	82.8	66.6

The benefit of a calcine wash stage ahead of cyanidation is shown in Table 8. Lower lime consumption and an apparent improvement in gold extraction were evident for the tests with a calcine wash stage ahead of cyanidation.

The results of the above tests were then used in running a continuous roasting test with a 60/40 blend of open pit/underground ore as feed. The calcine bed overflow, the calcine dust and a combined calcine product were then submitted to a hot water wash prior to bottle cyanidation/CIP tests. The results of these tests, summarized in Table 9, provided the process conditions for the Hazen pilot test. The optimum processing conditions determined for the Golden Bear ore from the Lakefield test program were:

grind	-	60% -74 micron
roast temperature	-	525°C
calcine wash	-	yes
cyanidation time	-	8 hours
g/L NaCN	-	1
pH	-	11
NaCN kg/t	-	2.5
CaO kg/t	-	9.0

5.2.1.6 <u>Waste Treatment</u>

With the utilization of roasting as a pre-treatment step prior to cyanidation, waste treatment for the Golden Bear process would need to include roaster off-gas scrubbing. A brief continuous test was performed where roaster off-gas generated from roasting the combined open pit/underground ore was purged into CIP tailings slurry via flotation cells. Scrubbing was very efficient with concentration in the gas being reduced from 10,000 ppm SO_2 to 1-2 ppm SO_2. The results were sufficiently encouraging to warrant further evaluation in the Hazen pilot program.

TABLE 8

GOLDEN BEAR PROJECT

ROASTING TEST RESULTS

EFFECT OF WASH STAGE (OPEN PIT ORE)

CONDITION		NaCN (kg/t)	CaO (kg/t)	% Gold Extraction
525°C				
Bed O/F	- no wash	0.92	9.5	88.9
	- wash	0.72	1.1	92.8
Dust	- no wash	3.04	26.7	94.7
	- wash	1.20	5.8	94.2
675°C				
Bed O/F	- no wash	0.72	5.0	77.6
	- wash	1.21	1.2	85.5
Dust	- no wash	1.22	12.5	89.6
	- wash	0.34	3.8	89.6

TABLE 9

GOLDEN BEAR PROJECT

ROASTING TEST RESULTS

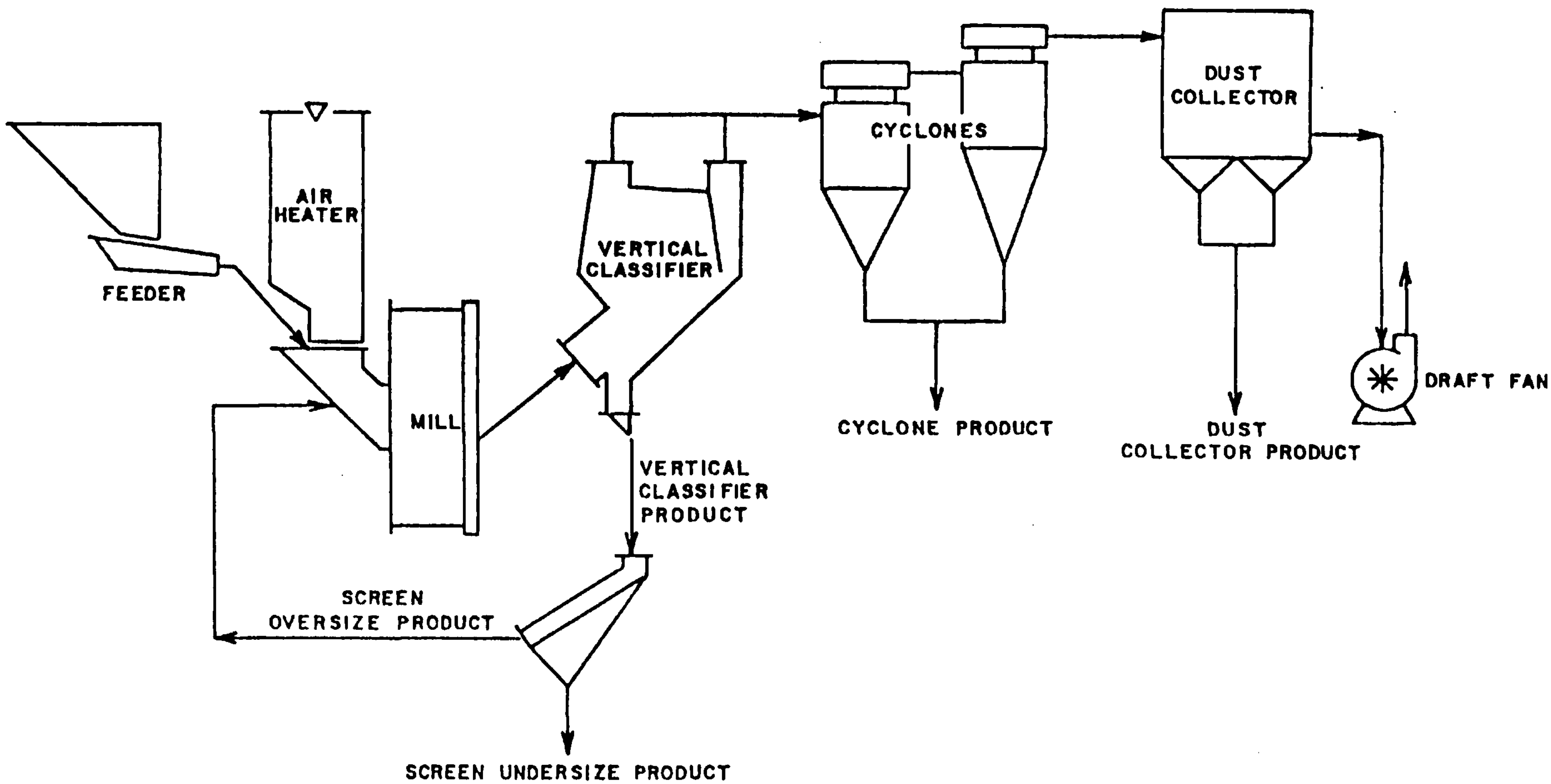
COMBINED OPEN PIT/UNDERGROUND ORE

	BED O/F	DUST	COMBINED
% gold extraction - 24 h leach	93.2	96.4	94.6
- 8 h leach	--	--	94.0
- 6 h leach	--	--	94.6
Residue grade (Au g/t)	1.14	0.89	1.01
NaCN consumption (kg/t)	1.50	1.98	1.40
CaO consumption (kg/t)	3.0	17.5	9.0

FIGURE 2

GOLDEN BEAR PROJECT

PILOT PLANT FLOWSHEET FOR THE GRINDING OF GOLD ORE FOR THE GOLDEN BEAR PROJECT



5.2.2 Hazen Pilot Plant

The Lakefield testwork provided the basic data to establish a preliminary process design for the Golden Bear ore for use in the feasibility study. A pilot test program was commissioned at Hazen Research to confirm the process selection and to provide a detailed engineering basis for the Golden Bear process. The work at Hazen did not focus on recovery but rather on identifying any operating concerns with the circuit under a continuous mode of operation. Hazen Research was chosen for the work since an Aerofall dry SAG mill is installed in their facility and a 0.38 m (15 inch) fluid-bed roaster was available for continuous roasting tests.

The pilot test program included dry SAG milling tests on blended ore samples to determine the work index for the ore and a continuous (48 hour) test of the proposed circuit including roasting, calcine wash, cyanidation, carbon-in-pulp, and scrubbing of roaster off-gas in flotation cells. In addition to the pilot test, confirmatory roasting tests were completed in a 10 cm (4 inch) fluid-bed roaster, a pressure oxidation test was completed in a continuous horizontal autoclave, and miscellaneous tests were completed to generate other design data.

The Aerofall SAG mill circuit used in the pilot grinding of ore is depicted in Figure 2. It consists of a 1.73 m (5 ft. 8 in.) diameter Aerofall mill, a draft fan to supply the air flow for removing ground material from the mill, and a collection system to recover and classify ground products from the air stream.

The flowsheet for the continuous pilot plant is shown in Figure 3. Ground ore from the SAG milling tests was roasted in the 38 cm fluid-bed roaster. The calcine products were combined and blended to serve as feed to the cyanidation/CIP circuit. A portion of the off-gas advanced to a flotation machine scrubber and the balance reported to the roaster's normal venturi scrubber.

The sulphated components in the blended calcines were removed by washing with hot water. The wash circuit operated at 25% solids with one hour retention time and the slurry was thickened to 50% solids for feed to cyanidation. The thickener overflow, containing most of the soluble sulphates, advanced to the tailings treatment system.

Thickened, washed calcine slurry was adjusted to pH 11-12 by the addition of hydrated lime slurry. The alkaline slurry then advanced to a five-stage cyanidation circuit with a total retention time of 8 hours. The cyanide pulp then advanced to five 1-hour stages of CIP to remove the solubilized gold. Loaded carbon was retained for a stripping/electrowinning test.

The tailings slurry from the CIP combined with the wash thickener overflow and advanced to the flotation machine scrubber where it was used to scrub a bleed of the roaster off-gas. The pH of the scrubber slurry was controlled by the addition of hydrated lime slurry.

5.2.2.1 Grinding

A total of four separate runs were completed to identify the work index for the anticipated mill feed blend and to check on the operating characteristics of a dry grinding circuit when feeding a blend of ore with a high clay, high moisture content. The main test results are summarized in Table 10.

The Golden Bear ore was found to be very amenable to dry grinding. The autogenous work index for the anticipated mill feed blend of ore was 19.75 kWh/t. A high clay gouge or high moisture content in the ore did not present any difficulties with material handling or grinding except for some hangup of ore in the feed hopper to the mill at an elevated feed moisture of 13.4%.

The single-stage SAG mill did not provide the required 60% minus 74 micron grind and the 595 micron screen used in the circuit left some

FIGURE 3

GOLDEN BEAR PROJECT

PILOT PLANT FLOWSHEET

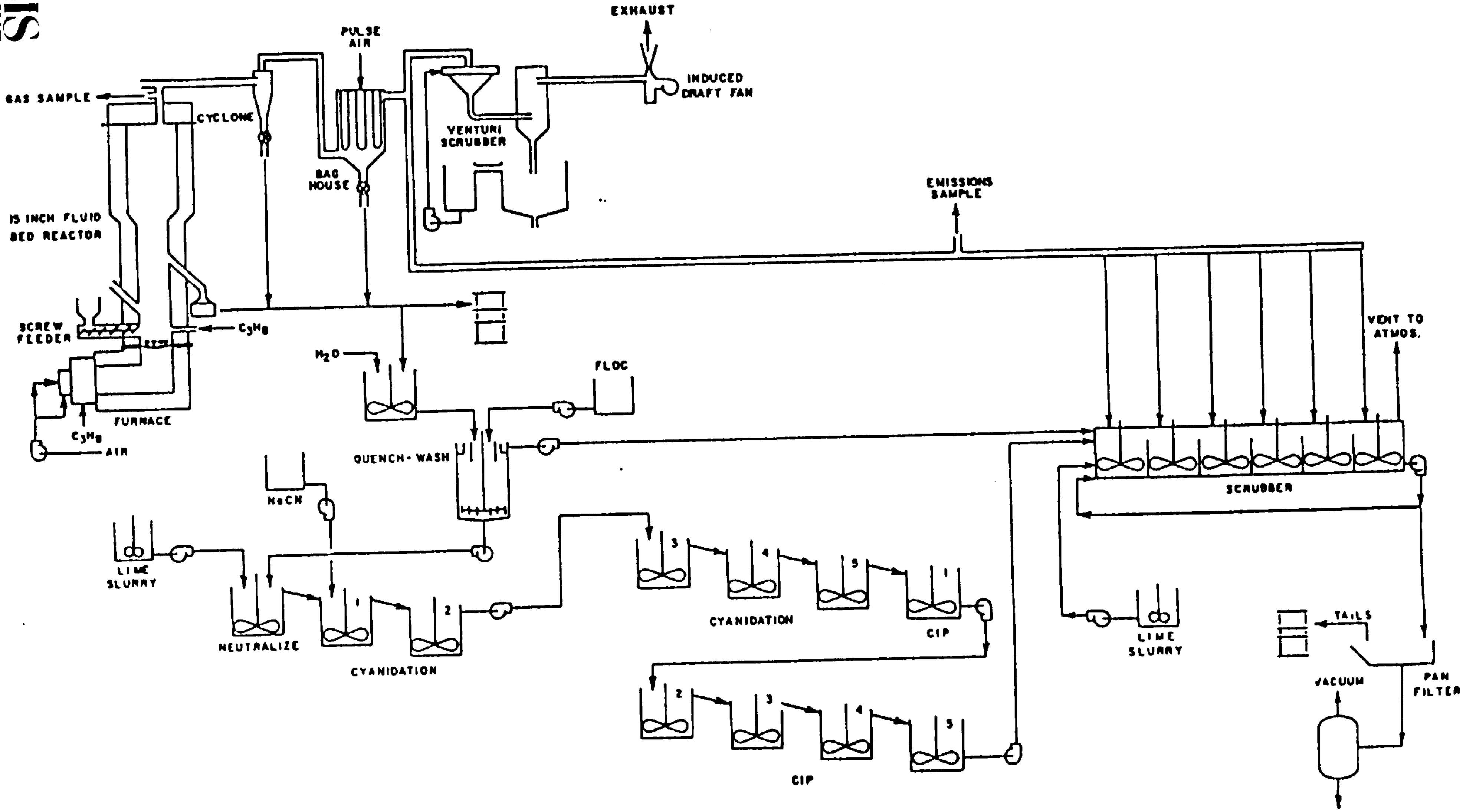


TABLE 10

GOLDEN BEAR PROJECT

DRY GRINDING TEST RESULTS

	ORE BLEND			
ITEM	MILL FEED	MILL FEED	HIGH CLAY	HIGH CLAY
% clay gouge in feed	18	18	65	65
Feed sizing % minus 77.2 mm	81.66	82.81	80.29	--
% moisture in feed	6.8	5.4	9.4	13.4
% ball charge	2.5	2.5	2.5	2.5
Product sizing screen (micron)	841	595	595	595
Ore treated (kg)	1130	4560	1146	924
Net power consumption (kWh/t)	8.88	10.75	8.73	8.21
Calculated work index	17.95	19.73	14.34	--
Product size:				
-- % plus 420 micron	20.0	2.5	2.5	
-- % minus 74 micron	39.0	41.1	43.1	--

plus 420 micron material in the final product. An assessment of the test results concluded that a secondary dry grinding ball mill would be required to achieve the mesh-of-grind for a CIP circuit.

5.2.2.2 <u>Roasting/Cyanidation</u>

The fluid-bed roaster was run at three different temperatures during the course of the pilot plant run. Feed to the roaster consisted of blended dry grinding product from the SAG milling test averaging 39% minus 74 micron. The major roasting results are summarized in Table 11. Subsequent cyanidation tests confirmed that optimum gold extractions would be achieved with a 525°C roasting temperature. The decrease in gold and silver extraction with increasing roasting temperature is depicted in Figure 4.

The pilot circuit, under inconsistent operating conditions, resulted in a gold extraction efficiency of 87.1%. Standard bottle leach tests on the same calcine material indicated a gold extraction of 88.8%. Other leach tests were completed with continuous roasting of coarse and fine ore in a 100 mm (4 inch) diameter fluid-bed roaster followed by bottle cyanidation of the calcine products. The results of these tests are summarized in Table 12. There was a 3% improvement in gold extraction with a 60% minus 74 micron grind versus a 40% minus 74 micron grind.

The open pit and underground blends of ore were submitted to rotary kiln roasting tests to see if there would be any noticeable difference in metallurgy between a rotary kiln and a fluid-bed roaster. The results of these tests are summarized in Table 13. Although acceptable gold extractions were obtained for the open pit ore in the lower temperature tests, the low gold extractions obtained for the higher sulphide underground ore would seem to suggest that a rotary kiln is not suited for roasting the Golden Bear ore.

5.2.2.3 <u>Carbon-in-Pulp</u>

The CIP portion of the circuit operated for approximately 36 hours. Sanding out problems were experienced due to the coarse nature of the

TABLE 11

GOLDEN BEAR PROJECT

380 MM DIAMETER FLUID BED ROASTER TEST RESULTS

ITEM	ROASTING TEMPERATURE (°C) 525	550	600
Calcine distribution - % to Bed O/F	69	65	64
- % to Cyclone	27	31	31
- % to Baghouse	4	4	5
Calcine sulphide analysis (% S^{2-})	0.39	0.20	0.11
Calcine sulphate analysis (% SO_4)	3.53	3.81	3.64
Space Velocity (m/sec)	0.52	0.60	0.58
% gold extraction - pilot circuit	87.1	--	--
- bottle leach tests	88.8	87.5	85.0
% silver extraction	52.6	48.5	39.8

FIGURE 4

GOLDEN BEAR PROJECT

EFFECT OF ROASTING TEMPERATURE ON GOLD & SILVER EXTRACTION

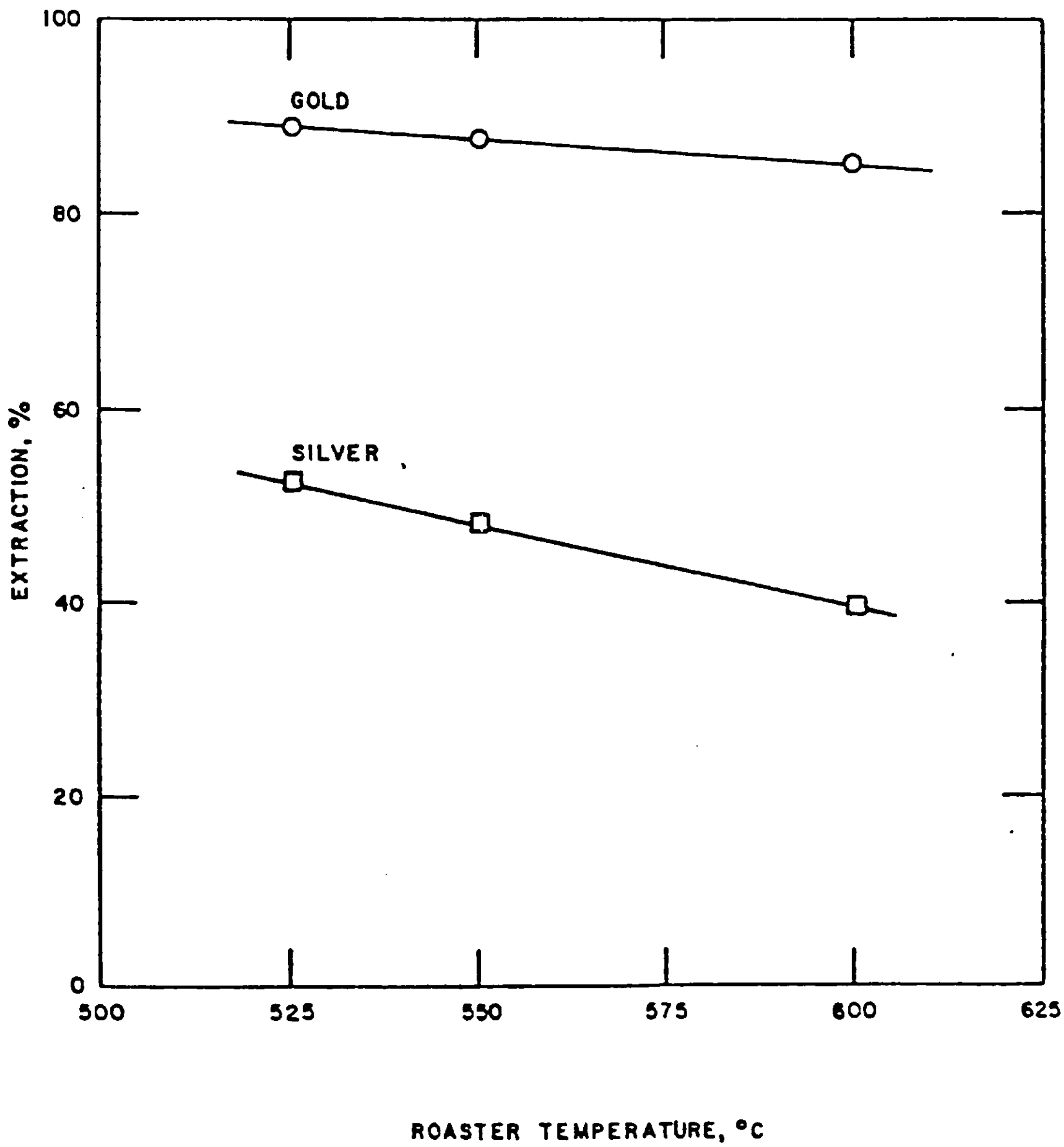


TABLE 12

GOLDEN BEAR PROJECT

100 MM DIAMETER FLUID BED ROASTER TEST RESULTS

ITEM	ROASTER FEED COARSE	ROASTER FEED FINE
Roaster feed size - % +420 micron	3.5	0.2
- % -74 micron	38.8	60.2
Calcine distribution - % to Bed O/F	60	50
- % to Cyclone	36	42
- % to Baghouse	4	8
Calcine sulphide analysis (% S^{2-})	0.66	0.34
Calcine sulphate analysis (% SO_4)	2.49	2.99
Space velocity (m/sec)	0.50	0.30
Roasting temperature (°C)	525	525
% gold extraction	85	88
% silver extraction	50	44

TABLE 13

GOLDEN BEAR PROJECT

ROTARY KILN ROASTING TEST RESULTS

	ROASTING TEMPERATURE (°C)		
	525	600	675
OPEN PIT ORE			
Roast retention time (min)	90	90	60
% total sulphur in calcine	1.07	1.05	1.47
% gold extraction	91.5	91.7	83.9
UNDERGROUND ORE			
Roast retention time (min)	90	90	60
% total sulphur in calcine	0.83	0.79	1.71
% gold extraction	79.4	80.9	80.2

pilot plant feed but nevertheless the carbon adsorption efficiency was 99.5% with barren solutions assaying 0.01 to 0.09 mg Au/L. Due to the short duration of the pilot run, the carbon was not advanced through the CIP circuit. The carbon from each CIP tank was collected at the end of the run. Loaded carbon analyses are presented in Table 14. Very high gold loading was observed on the carbon at the head of the circuit.

5.2.2.4 Carbon Stripping/Electrowinning

A combined loaded carbon sample assaying 3,429 g Au/t and 2,023 g Ag/t was subsequently submitted to a continuous pressure stripping/electrowinning test with re-use of barren electrolyte as strip solution. The loaded carbon assayed 41 ppm As and 9.6 ppm Hg and the stripped carbon assayed 29 ppm As and 6.6 ppm Hg indicating approximately 30% removal of both elements into the pregnant strip solution. After dissolving the loaded steelwool in acid solution the gold sponge assayed only 4.8 ppm As and 0.4 ppm Hg indicating that the majority of these two elements stay with the strip solution during the electrowinning process.

5.2.2.5 Off-Gas Scrubbing

The earlier Lakefield work had shown that scrubbing of the roaster off-gas in the CIP tailings was quite effective with very high SO_2 scrubbing efficiencies being achieved. A scrubbing circuit made up of a 6-compartment Denver "Sub-A" No. 8 flotation cell was an integral part of the continuous pilot plant in order to fully evaluate the waste treatment circuit.

The portion of the roaster off-gas reporting to the scrubbing circuit was manifolded to the air inlet for each compartment. Slurry from the CIP circuit passed through the flotation cell and hydrated lime was used to neutralize the acidity generated by SO_2 scrubbing. The scrubbed gas was then exhausted to atmosphere. Gas analyses are presented in Table 15. Sulphur dioxide scrubbing was essentially complete and 90% of the arsenic and mercury was removed from the gas stream. High

TABLE 14

GOLDEN BEAR PROJECT

LOADED CARBON ANALYSES

CIP STAGE	Au g/t	Ag g/t	Au/Ag Ratio
1	21,051	4,011	5.2
2	15,257	3,737	4.1
3	5,280	2,606	2.0
4	2,119	1,783	1.2
5	854	1,029	0.8

TABLE 15

GOLDEN BEAR PROJECT

GAS ANALYSIS

	OFF-GAS	SCRUBBER GAS
% CO_2	4-5	--
% O_2	10-12.5	--
% SO_2	1.5-2.0	0.0001
ug Hg/m^3	20-30	1-4
ug As/m^3	1,000-2,000	75-150

scrubbing efficiency was consistent throughout the complete pilot plant run with the results confirming the viability of this scrubbing method for the Golden Bear circuit.

5.2.2.6 Pressure Oxidation

In light of the high gold extraction possible with acid pressure oxidation pre-treatment of the ore, a continuous pilot test was run in a 22 L horizontal autoclave. The operating conditions were as follows:

temperature	209°C
pressure	2400 kPa
density	40, 50% solids
retention time	90 minutes
feed rate	0.25 L/min.
H_2SO_4 addition	60, 100, 120 kg/t.

The sulphuric acid was added to the ore slurry and the acidified pulp allowed to mix for 30 minutes prior to feeding to the autoclave.

The test results are summarized in Table 16. From these results it is seen that the carbonate content of the ore is equivalent to an acid consumption of 100 kg/t in the pre-leach step but solution recycle could reduce the net acid consumption to somewhere between 30 and 50 kg/t. A gold extraction of 90% appears possible with acid pressure oxidation. The silver extraction is very low, approximately 10%, due to the formation of non-cyanide leachable argentojarosite. As noted earlier, acid pressure oxidation was not economically justifiable for the Golden Bear ore.

6.0 SELECTED PROCESS

The selected process for the Golden Bear ore consists of dry grinding, roasting, cyanidation and carbon-in-pulp gold recovery.

A blended mill feed will be obtained by reclaiming stockpiled open pit and underground ore in a 50/50 ratio to optimize the sulphur content

TABLE 16

GOLDEN BEAR PROJECT

ACID PRESSURE OXIDATION TEST RESULTS

TEST NO.	% SOLIDS	H_2SO_4 kg/t ADDED	H_2SO_4 kg/t CONSUMED Pre-Leach	H_2SO_4 kg/t CONSUMED Net	MOLE RATIO O_2/S	FREE ACID g/L PRE-LEACH	FREE ACID g/L AUTOCLAVE	RESIDUE ASSAY Au g/t	RESIDUE ASSAY Ag g/t	RESIDUE ASSAY % SO_4	RESIDUE ASSAY % S^{2-}	% EXTRACTION Au	% EXTRACTION Ag
1	40	120	100	43	4.0	13	48	1.2	16.1	10.9	0.02	93.4	11.0
2	40	100	100	26	3.9	1	49	2.3	16.1	10.6	0.12	86.3	8.0
3	50	60	>60	30	2.7	<0.1	29	1.6	15.4	9.3	0.26	90.6	9.8

for roaster operation. The run-of-mine ore will be ground to 60% minus 74 micron in a dry SAG mill/ball mill combination. Ore classification will be accomplished by a vertical classifier and screen. Ground product collection will be done by cyclone collectors and baghouse. A heat exchanger in line with the roaster off-gas will provide the heat for drying the ore in the air-swept mill.

The dry, ground ore will be fed to a fluid-bed roaster operating at 525°C. The bed calcine, cyclone calcine, and baghouse calcine will be collectively quenched at 20 to 25% solids and partially washed in a thickener prior to cyanidation. The pH of the thickened slurry will be adjusted to 11 with lime and the alkaline slurry then leached in four cascading cyanidation tanks with a total retention time of eight hours.

The cyanide slurry will flow by gravity to a five-stage CIP circuit to recover the dissolved gold. Gold-loaded carbon from the CIP circuit will be stripped with a hot caustic/cyanide solution and the gold will be recovered on steelwool in an electrolytic cell. The steelwool will be smelted in a bullion furnace to produce dore bullion.

Roaster off-gas will be scrubbed in a series of srubber flotation cells. Lime slurry will be added to control pH and to neutralize the acidity generated from scrubbing the roaster off-gas. The tailings will be discharged to the tailings containment area after cycloning to produce mine backfill.

7.0 ACKNOWLEDGEMENTS

The authors wish to extend their sincere appreciation to North American Metals Corporation and Chevron Resources Co. for permission to present this paper. Efforts extended by all concerned in the course of the process development work are also appreciated.