Dr R W Dawes

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OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 73-50

PROCESS DEVELOPMENT FOR THE CONCENTRATION OF COPPER, GOLD, SILVER, AND TUNGSTEN MINERALS FROM ORES OF ROBERT MINES LIMITED, NELSON, B.C.

D. RAICEVIC AND R.W. BRUCE

MINERAL PROCESSING DIVISION

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PROCESS DEVELOPMENT FOR THE CONCENTRATION OF COPPER, GOLD, SILVER, AND TUNGSTEN MINERALS FROM ORES OF ROBERT MINES LIMITED, NELSON, B.C.

by

D. Raicevic* and R.W. Bruce**

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SUMMARY OF RESULTS

Two ore samples received for this investigation assayed:

	Oz/ton		%	%	%	%
	Au	Ag	Cu	WO_3	PPb	Zn
Copper Ore :	0.44	1.90	1.0	-	0.02	0.06
Copper-Tungsten:	0.19	0.83	0.24	0.3	0.02	0.03

Chalcopyrite was the main copper mineral in both samples.

Scheelite was the only tungsten mineral in the low-grade copper-tungsten ore. Gold and silver were present in both samples as inclusions in chalcopyrite, pyrite, and gangue minerals. As a result, these ores required fine grinding to liberate the values.

Flotation of copper ore produced a marketable copper-gold-silver concentrate with 85% copper, 66% gold, and about 62% silver recoveries.

Flotation of the copper-tungsten ore produced a marketable copper-gold-silver concentrate with 70% copper, 34.5% gold, and 50% silver recoveries.

A marketable tungsten concentrate with about 42% tungsten recovery was produced by table concentration from the copper-tungsten ore sample.

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INTRODUCTION

Property

The property from which the samples were obtained is about 9 miles south of Nelson, British Columbia, close to the Salmo River. The property is owned by Robert Mines Limited (NPL); the head office of the company is at 1075 W Georgia Street, Vancouver, B.C.

Ore Shipment

Two ore samples, weighing about 300 lb each, consisting of crushed rock fragments, were received on March 21, 1973. The first sample (Barrel No. 1), designated as "Copper Ore", was taken "from the area of an old slope, 900 ft from the portal".

The second ore sample (Barrel No. 2), designated as "Copper-Tungsten Ore", was taken from the face, 1400 ft from the portal.

Chemical Analysis

The samples as received were crushed to approximately 10 mesh, and head samples were riffled out by conventional methods and sent to the Analytical Chemistry Subdivision, Mineral Science Division, for analysis. The rejects from sampling were set aside to be used for the investigation testwork.

TABLE 1

Chemical Analysis of Ore Samples

Ore	Assay					
	Oz/ton		% Cu	% Pb	% Zn	% WO_3
	Au	Ag				
Copper Ore	0.44	1.90	1.0	0.02	0.06	-
Copper-Tungsten Ore	0.19	0.83	0.24	0.02	0.03	0.3

Nature of Investigation Requested

The Company is planning on erecting a concentrator near Salmo River, and requested the Mines Branch to recommend a flowsheet for concentrating these ores.

In his letter of January 21, 1972, Mr. Karl Schindler, President of Robert Mines Ltd. said that "the mill will be close to the Salmo River so, to avoid pollution, it is practically mandatory that we use gravity separation rather than flotation or cyanidation".

When gravity concentration failed to recover the gold, silver, and copper minerals satisfactorily, flotation concentration was investigated to recovery these minerals followed by table concentration to recover the tungsten.

It should be noted that flotation is not a pollution generating process, if effluents are recirculated and if tailings are properly impounded.

MINERALOGICAL EXAMINATION

A detailed mineralogical examination of these ore samples is reported in the Mines Branch Investigation Report IR 72-34 by Dr. W. Petruk, Research

Scientist, Mineral Sciences Division, Mines Branch, Department of Energy, Mines and Resources.

Only the pertinent mineralogical results obtained from this report, with particular emphasis on how the mineralogy relates to the concentration objectives, will be recorded here. The approximate mineralogical composition of these two ore samples is given in Table 2.

TABLE 2

Approximate Mineralogical Composition of Head Samples

Mineral	Copper Ore % Weight	Copper-Tungsten Ore % Weight*
Quartz	50	The amounts of pyrite and chalcopyrite were about one third of those in copper ore.
Mica	17	
Calcite	5	
Kaolinized feldspar	4	
Dolomite	1	The amount of scheelite present in this ore was about about 0.3% by weight.
Pyrite	20	
Chalcopyrite	2.5	
Sphalerite	0.3	The amounts of other minerals were similar to those of copper ore.
Tetrahedrite	0.1	
Galena, gold, aikinite, silver	0.1	
Total	100.0	

*Estimated

The mineralogical association of the main metallic minerals with each other and the gangue material will be described separately and, in the most characteristic cases, shown on photomicrographs.

Pyrite, FeS_2

Pyrite is the main metallic mineral in the sample. It is present as euhedral disseminated grains in the schistose rock and vein quartz and as rounded grains in chalcopyrite (Figure 1). The grains are between 20 and 1,000 microns in diameter but most are about 300 microns. Those associated with chalcopyrite are fractured and contain chalcopyrite, sphalerite, and tetrahedrite veinlets, and rounded inclusions of chalcopyrite, galena, tetrahedrite, gold, alkinite, and silver.

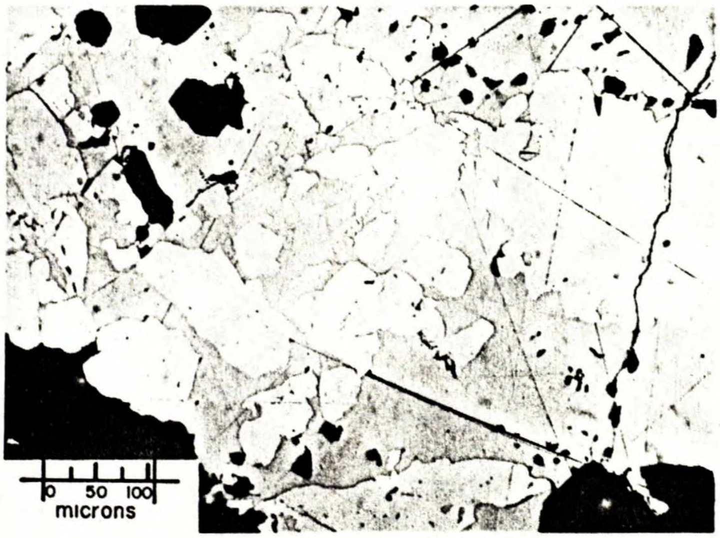

Figure 1. Pyrite (light grey) inclusions in chalcopyrite (grey).

Chalcopyrite, $CuFeS_2$

Chalcopyrite is a major ore mineral in the sample. It occurs as small masses in quartz, as veinlets and minute rounded inclusions in pyrite, and as intergrowths with sphalerite. Some chalcopyrite is free of impurities but most contains rounded pyrite inclusions and some contains tetrahedrite, sphalerite, gold, galena, alkinite, and silver inclusions,and veinlets. Much of the chalcopyrite in the 65 to 100-mesh fraction is locked in pyrite grains (Figure 2).

Figure 2. 65 to 100-mesh, 3.70-gravity sink fraction showing pyrite (light grey) and chalcopyrite (grey) grains. Some of the chalcopyrite is locked in pyrite.

Tetrahedrite, $(Cu,Ag)_{10}(Fe,Zn)_2(Sb,As)_4S_{13}$

Tetrahedrite occurs as irregular grains, up to 50 microns in size, in chalcopyrite and as veinlets in chalcopyrite and pyrite.

Gold, Au

Gold was found in all specimens containing chalcopyrite and pyrite. Most of the gold is present as rounded inclusions, 1 to 75 microns in diameter, in chalcopyrite but some occurs as rounded inclusions in pyrite, gangue, and sphalerite (Figure 3). Many of the inclusions in chalcopyrite occur as veinlets in pyrite (Figure 4).

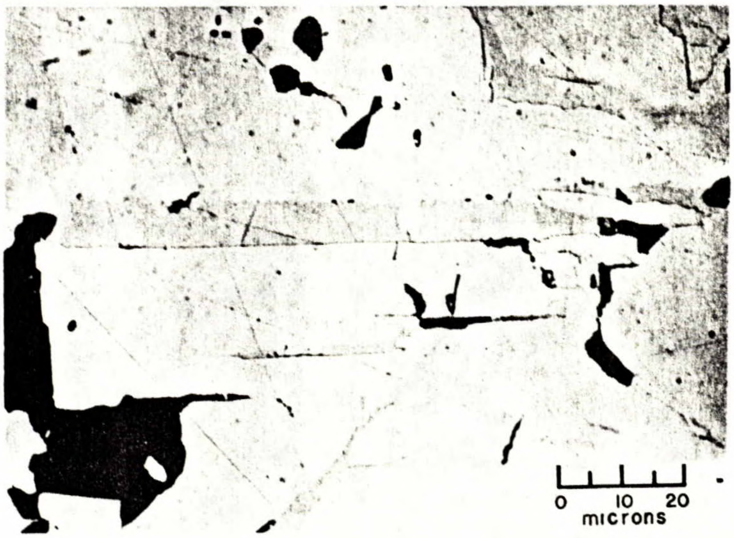

Figure 3. Gold (white) in chalcopyrite veinlets (grey) in pyrite (light grey).

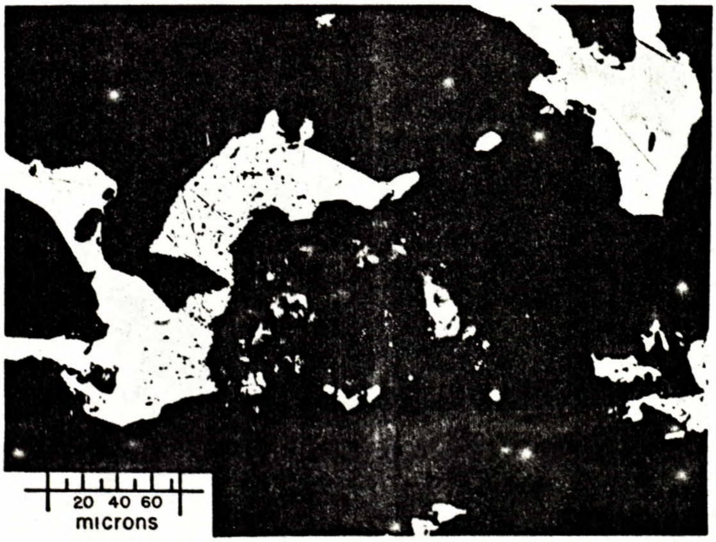

Figure 4. Gold (white) in gangue (black) and chalcopyrite (grey).

Silver Ag

A small amount of silver was found as rounded inclusions in pyrite and chalcopyrite and as veinlets in pyrite.

Small amounts of aikinite ($CuPbBiS_3$), sphalerite (ZnS) and galena (PbS) are also present as inclusions in chalcopyrite and pyrite and some also is intergrown with the latter two minerals.

Scheelite ($CaWO_4$)

Some scheelite was found in mineralized quartz-calcite specimens in and adjacent to incipient mineralized fractures. The mineral occurs as separate euhedral and irregular grains, up to 500 microns in size, in the parts of fractures enriched by gangue minerals but is absent from pyrite veinlets.

The conclusions of the mineralogical examination are recorded in the following paragraph.

> "It is estimated that the chalcopyrite would be liberated at a moderate grind (200 mesh). On the other hand, a copper concentrate obtained from this ore may contain some impurities because the chalcopyrite contains numerous small inclusions of pyrite, sphalerite, tetrahedrite, aikinite, gold, and silver. The gold is medium- to fine-grained and thus some gold would be liberated at a moderate grind (200 mesh). Fine grinding (325 mesh) would be required to liberate the remainder which is present as minute inclusions in chalcopyrite and pyrite. The silver minerals are argentian tetrahedrite and silver. Both are associated with chalcopyrite and are fine-grained. It is expected that very fine grinding (400 mesh) would be required to liberate them and that any locked silver minerals would show up in a copper concentrate".

OUTLINE OF INVESTIGATION

The results of the chemical analyses of two ore samples, Table 1, showed that the amount of lead and zinc was too low for economic recovery.

At the Company's request the first part of the investigation (Part I) was carried out by applying:

> gravity concentration of the ore using jigging and tabling for pre-concentration and tabling of the re-ground and sized pre-concentrates for upgrading.

The gravity concentration failed to produce satisfactory results, so the second part of the investigation (Part II) was done by applying:

(i) tabling as a pre-concentration method and flotation as a method for upgrading the pre-concentrates;

(ii) straight flotation for concentration of gold, silver and copper minerals from both ores and tabling as a method for concentrating tungsten (scheelite) from the copper-tungsten ore.

Part I: Gravity Concentration

A general approach to applying this method consisted of pre-concentrating the ores by rejecting maximum amounts of the waste material with minimum losses of the valuables. A 1M Denver laboratory jig and a Deister sand deck table were used for the pre-concentration treatment. The upgrading of the pre-concentrates was done on a Deister sand- and slime-deck table.

The results of the two preliminary tests are recorded in Table 3. In these tests samples of the copper ore were ground to minus 35 mesh and minus 48 mesh. In each test, the jig and the tabling tailing were separated on a 200-mesh screen. The minus 200-mesh fraction which contained most of the values lost during the gravity separation was assayed separately.

TABLE 3

Pre-Concentration Results from Preliminary Jigging and Tabling Tests on Copper Ore

Grind, Mesh	Product	% Weight	Assays			Distribution		
			Oz/ton		%	%		
			Au	Ag	Cu	Au	Ag	Cu
-35	Jig Test, R-5							
	Jig conc	36.4	0.81	3.26	1.40	66.1	63.3	55.4
	Jig tail, -200 mesh	17.1	0.51	2.59	1.55	19.5	23.6	28.8
	Jig pre-conc (calcd)	53.5	0.714	3.05	1.45	85.6	86.9	84.2
	Jig tail, +200 mesh	46.5	0.14	0.55	0.31	14.4	13.1	15.8
	Feed (calcd)	100.0	0.45	1.87	0.92	100.0	100.0	100.0
-48	Table Test, R-8							
	Table conc	17.5	1.84	7.43	2.87	72.5	59.7	58.0
	Table tail, -200 mesh	30.5	0.25	1.99	0.92	17.0	28.3	32.2
	Table pre-conc (calcd)	48.0	0.826	3.98	1.64	89.5	89.0	90.2
	Table tail, +200 mesh	52.0	0.09	0.44	0.16	10.5	11.0	9.8
	Feed (calcd)	100.0	0.44	2.11	0.86	100.0	100.0	100.0

The results from Table 3 showed that, for a pre-concentration method, the recoveries of the valuables in the pre-concentrates were low from 35- and 48-mesh grinds.

To determine how fine this ore must be ground to improve the recoveries in the pre-concentrates, one series of jigging tests and one series of the tabling tests were done at various fineness of grind, applying the same separation procedure as mentioned earlier. In tabling tests done on grinds from minus 48-mesh and minus 65-mesh, the ground ore was separated into plus and minus 325-mesh fractions and each fraction was tabled separately on sand- and slime-deck tables respectively.

All jig and table tailings were separated into fine and coarse fractions, depending on the fineness of the original grind, the fine fractions were added to the related concentrates to form the pre-concentrates, and the coarse fractions of the tailings were rejected.

The results of these two series of tests are summarized in Table 4.

The results from Table 4 showed the ore was not amenable to pre-concentration by jigging and to obtain a reasonable recovery in tabling, the ore had to be ground to minus 100 mesh, separated into two size fraction, and each fraction tabled separately. This procedure produced 94.4, 94.2, and 96.3% recoveries of gold, silver, and copper respectively; however, only 38% of the ore by weight was rejected.

TABLE 4

Summary of Pre-concentration Results from Jigging and Tabling at Various Fineness of Grinds

Methods Applied	Grind Mesh	Test No	Pre-concentrate								Tailing					
			% Weight	Assay			Dist'n			% Weight	Assay			Dist'n		
				Oz/ton		%	%	%	%		Oz/ton		%	%	%	%
				Au	Ag	Cu	Au	Ag	Cu		Au	Ag	Cu	Au	Ag	Cu
Jigging	-10	R-4A	38.6	0.87	3.83	1.59	77.0	75.0	75.0	61.4	0.17	0.79	0.33	23.0	25.0	25.0
Jigging	-20	R-5	53.5	0.71	3.05	1.45	85.6	86.9	84.2	46.5	0.14	0.52	0.31	14.4	13.1	15.8
Jigging	-35	R-6	58.2	0.64	2.79	1.21	85.6	84.5	82.8	41.8	0.15	0.71	0.35	14.4	15.5	17.2
Tabling*	-20	R-1	43.3	0.86	3.96	1.72	83.8	82.7	84.3	56.7	0.13	0.63	0.24	16.2	17.3	15.7
Tabling*	-48	R-2	47.5	0.83	3.98	1.64	89.5	89.0	90.2	51.5	0.090	0.44	0.16	10.5	11.0	9.8
Tabling**	-48	R-8	38.7	0.93	4.10	2.11	88.7	83.0	88.5	61.3	0.075	0.56	0.17	11.3	17.0	11.5
Tabling**	-65	R-7	48.5	0.75	3.55	1.65	88.3	89.6	93.0	51.5	0.093	0.39	0.14	11.7	10.4	7.0
Tabling	-100	R-14	62.0	0.68	3.04	1.39	94.4	94.2	96.3	38.0	0.068	0.30	0.09	5.6	5.8	3.7

* Whole ground ore.

** Two size-fractions of the ground ore.

To determine whether gravity concentration (tabling) could be utilized to produce a marketable grade of copper concentrate, a final tabling test was made on a sample of the copper ore which had been ground to minus 100 mesh, separated into three fractions by screening on 200- and 325-mesh screens; each fraction was tabled separately. The rougher concentrates produced were then retabled to produce final cleaned concentrates. The detailed results are shown in Table 5 and summarized in Table 6.

TABLE 5

Detailed Results from Rougher and Cleaner Tabling of Copper Ore

Products	% Weight	Assays			Distribution		
		oz/ton		% Cu	% Au	% Ag	% Cu
		Au	Ag				
Test R-11							
Table cl conc 1, +200 mesh	0.52	4.91	12.79	0.32	6.1	3.3	0.2
" " " 1, -200 mesh	0.38	11.83	15.47	0.27	10.7	3.0	0.1
Comb cl conc 1 (calcd)	0.90	7.83	13.50	0.30	16.8	6.3	0.3
Table cl conc 2, +200 mesh	4.78	1.79	7.91	2.00	20.6	19.1	10.7
" " " 2, -200 mesh	2.07	2.71	11.01	1.65	13.5	11.4	3.9
Comb cl conc 2 (calcd)	6.85	2.07	8.90	1.89	34.1	30.5	14.6
Table cl conc 3, +200 mesh	1.67	1.80	8.52	7.90	7.2	7.1	14.9
" " " 3, -200 mesh	2.61	1.42	8.74	6.70	8.9	11.3	19.8
Comb cl conc 3 (calcd)	4.28	1.56	8.62	7.17	16.1	18.4	34.7
Slime Deck ro conc, -325 mesh*	2.83	0.52	2.97	1.76	3.5	4.2	5.6
Table cl tail, + 200 mesh	2.17	0.29	1.41	0.80	1.6	1.6	2.0
" " " , - 200 mesh	5.57	0.37	2.03	1.77	4.9	5.6	11.2
Comb cl tails (calcd)	7.74	0.35	1.85	1.50	6.5	7.2	13.2
Table ro tail, +200 mesh	37.15	0.09	0.43	0.15	8.0	8.0	6.3
" " " , +325 mesh	11.90	0.05	0.28	0.09	1.4	1.7	1.2
Sl. Deck " , -325 mesh	28.35	0.20	1.66	0.75	13.6	23.7	24.1
Comb ro tails	77.40	0.12	0.86	0.36	23.0	33.4	31.6
Feed (calcd)	100.00	0.42	2.00	0.885	100.0	100.0	100.0

*Cleaning not carried out.

TABLE 6

Summary of Results from Rougher and Cleaner Tabling of Copper Ore

Product	% Weight	Assays			Distribution		
		oz/ton		%	%	%	%
		Au	Ag	Cu	Au	Ag	Cu
Test R-11							
Comb table cl conc 1	0.90	7.83	13.50	0.30	16.8	6.3	0.3
" " " " 2	6.85	2.07	8.90	1.89	34.1	30.5	14.6
" " " " 3	4.28	1.56	8.62	7.17	16.1	18.4	34.7
Slime deck ro conc*	2.83	0.52	2.97	1.76	3.5	4.2	5.6
Comb table cl tails	7.74	0.35	1.85	1.50	6.5	7.2	13.2
Comb. table ro tails	77.40	0.12	0.86	0.36	23.0	33.4	31.6
Feed (calcd)	100.00	0.42	2.00	0.89	100.0	100.0	100.0

*cleaning not carried out.

The results from Table 5 and Table 6 showed that:

- cleaner tabling could not produce copper concentrates of marketable copper grade,
- high amounts of valuables were lost to the slime-deck rougher tailing,
- the over-all recovery of the valuables was lost.

It was therefore concluded that treatment of the ore by gravity concentration alone was impractical,

Part II: Gravity Concentration and Flotation

When the gravity concentration alone did not give satisfactory results, a combination of flotation and gravity concentration was investigated with particular emphasis on a flowsheet in which the possibility of pollution would be eliminated. Each procedure applied will be described separately.

(i) Pre-Concentration and Flotation of Both Ores

It was observed from the results shown in Table 4 that, after the copper ore was ground to minus 100 mesh, sized and each size fraction pre-concentrated separately by tabling, the combined table pre-concentrate comprized 62.0% of the ore by weight and had high gold, silver, and copper recoveries (94.4%, 94.2%, and 96.3% respectively). A similar pre-concentration tabling test was done on the copper-tungsten ore. The pre-concentrate from this test comprized 54.5% of the ore by weight with gold, silver, and copper recoveries of 87.0%, 89.3%, and 87.6% respectively.

These pre-concentrates represented reasonable recoveries of the valuables, so it was decided to try to upgrade them by conventional modifier-collector-frother flotation, using lime as an alkalinity regulator, potassium amyl xanthate as a collector, and pine oil as frother.

After optimum flotation conditions were established the pre-concentration and flotation procedure of this part of the investigation consisted of the following major steps:

(i) grinding the ore to minus 100 mesh and separating it into plus and minus 200-mesh fractions;

(ii) tabling each fraction separately on sand decks, obtaining two rougher concentrates and discarding tailing from the plus 200-mesh;fraction;

(iii) separating the rougher tailing from the minus 200-mesh fraction into plus and minus 325-mesh fractions, and discarding the plus 325-mesh fractions;

(iv) combining the minus 325-mesh fraction from (iii) with two table rougher concentrates from (ii) to form a table pre-concentrate;

(v) upgrading the pre-concentrates by flotation.

The flowsheet of this procedure is given in Figure 5 and results in Table 7.

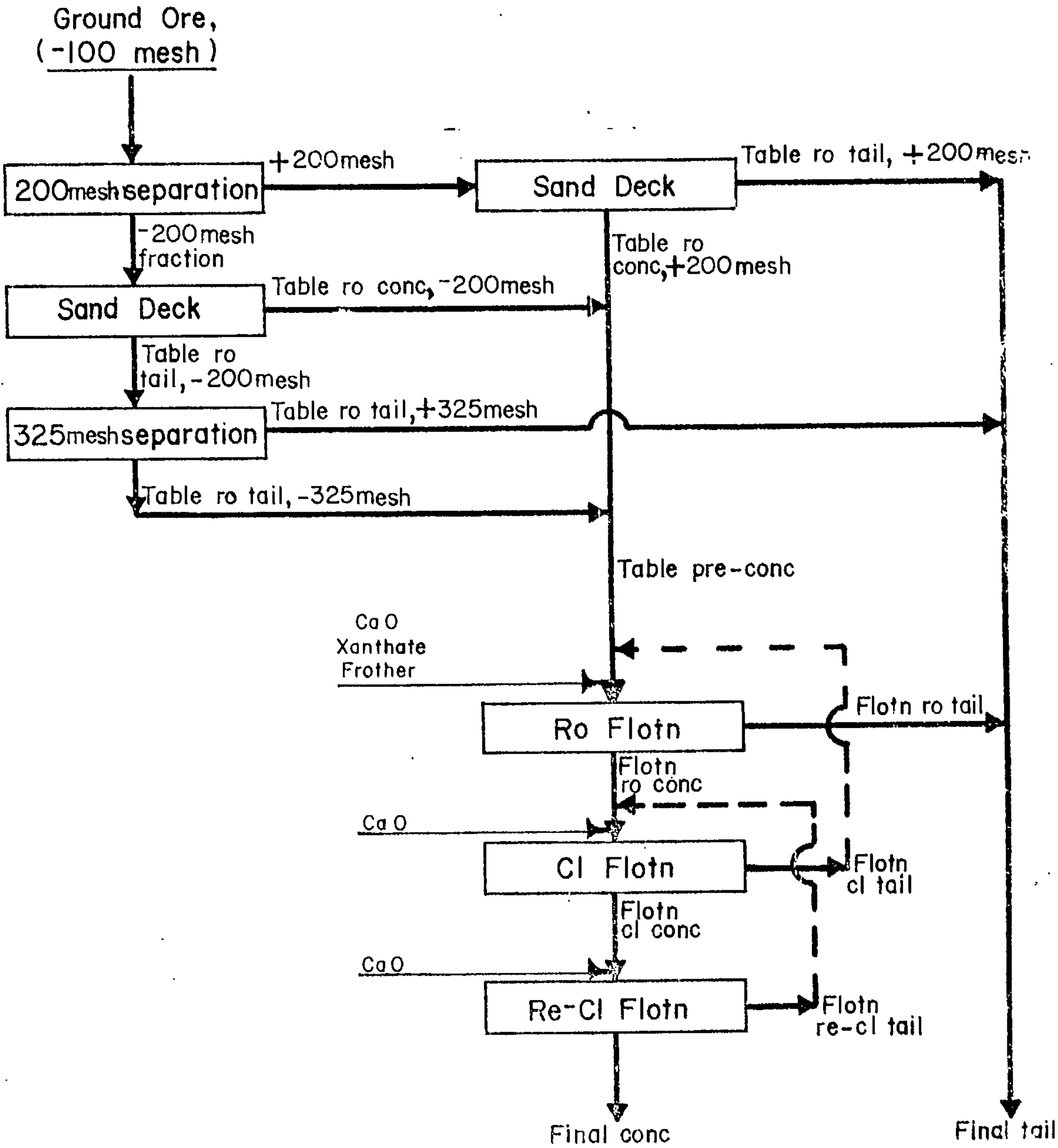

Figure 5 PRE-CONCENTRATION AND FLOTATION OF BOTH ORES SEPARATELY

TABLE 7

Results from Pre-Concentration and Flotation

Ore and grind	Test No. and products	% Weight	ASSAYS				DISTRIBUTION			
			oz/ton Au	oz/ton Ag	% Cu	% WO3	% Au	% Ag	% Cu	% WO3
Copper Ore	**Test R-14**									
	Flot. cleaner conc	1.5	7.36	31.60	25.20	-	24.7	24.2	42.9	-
	Flot. cleaner tail	4.4	3.86	16.08	8.15	-	37.8	35.2	39.6	-
	Flot. rougher conc (calcd)	5.9	4.73	20.08	12.53		62.5	59.4	82.5	-
	Flot. rougher tail	56.1	0.25	1.23	0.22	-	31.9	34.8	13.8	-
	Table pre-conc (calcd)	62.0	0.68	3.04	1.39	-	94.4	94.2	96.3	-
	Table ro tail, +200 mesh	27.1	0.07	0.31	0.09	-	4.3	4.2	2.7	-
	Table ro tail, +325 mesh	10.9	0.06	0.29	0.08	-	1.3	1.6	1.0	-
	Table ro tail comb. (calcd)	38.0	0.068	0.30	0.087	-	5.6	5.8	3.7	-
-100 m	Feed (calcd)	100.0	0.445	1.99	0.89	-	100.0	100.0	100.0	
Copper-Tungsten Ore	**Test R-22**									
	Flot. re-cleaner conc	0.6	8.96	80.80	19.30	0.12	30.3	47.3	42.3	0.2
	Flot. re-cleaner tail	0.2	3.40	16.17	5.00	0.30	4.9	4.3	4.4	0.2
	Flot. cleaner conc (calcd)	0.8	7.31	61.60	15.02	0.18	35.2	51.6	46.7	0.4
	Flot. cleaner tail	3.7	1.72	6.84	2.22	0.13	39.5	26.9	32.9	1.4
	Flot. rougher tail	50.0	0.04	0.19	0.04	0.54	12.3	10.8	8.0	80.4
	Table pre-conc (calcd)	54.5	0.26	1.52	0.40	0.51	87.0	89.3	87.6	82.2
	Table ro tail, +200 mesh	29.3	0.05	0.29	0.06	0.20	9.3	8.6	7.2	17.4
	Table ro tail, +325 mesh	16.2	0.04	0.15	0.08	0.09	3.7	2.1	5.2	0.4
	Table ro tails comb. (calcd)	45.5	0.046	0.22	0.066	0.13	13.0	10.7	12.4	17.8
-100 m	Feed (calcd)	100.0	0.162	0.93	0.25	0.337	100.0	100.0	100.4	100.0

Results in Table 7 showed that, although marketable grades of copper concentrate can be produced by this flowsheet, the overall recovery of the metals was low. Tabling as a pre-concentration method was discarded in favour of straight flotation to recover the copper, gold, and silver values.

(ii) Flotation Followed by Tabling

(a) Copper Ore

Mineralogical examination of the ore indicated that a fine grind would be necessary to liberate the valuable minerals and make them amenable to flotation.

A preliminary flotation test was done in which the ore was ground to minus 100 mesh and floated with the reagents described earlier. The results of this test are recorded in Table 8.

TABLE 8

Straight Flotation Results on Copper Ore

Grind	Test No. and Products	% Weight	Assays			Distribution		
			oz/ton		%	%		
			Au	Ag	Cu	Au	Ag	Cu
	Test R-13							
	Flot. cl conc	1.64	5.68	30.28	20.00	21.2	26.8	38.7
	Flot. cl tail	12.22	2.27	9.37	3.76	63.1	61.9	54.2
	Flot. ro conc	13.86	2.67	11.83	5.68	84.3	88.7	92.9
	Flot. ro tail	86.14	0.08	0.24	0.07	15.7	11.3	7.1
-100 m	Feed (calcd)	100.00	0.44	1.85	0.85	100.0	100.0	100.0

Table 8 showed that a commercial grade of copper concentrate could be produced, but the gold, silver, and copper recoveries were low. It is significant that most of the values were left in the cleaner tailing, indicating that regrinding of the cleaner tailing may be necessary to recovery.

Another factor that is sometimes responsible for low gold and silver recoveries is the use of lime as the alkalinity regulation because lime depresses pyrite. This is particularly true if the gold, silver, and copper are still locked in the pyrite particles.

A second straight flotation test was done applying a two-stage grinding circuit. The procedure is illustrated in Figure 6. The flowsheet shows how pollution can be reduced by the recirculation of the mill effluents.

The amount and point of addition of the flotation reagents are shown in Table 9 and the results of the test in Table 10.

TABLE 9

Amount and Point of Addition of Flotation Reagents

Point of Addition	Lb per Ton of Ore		
	Soda Ash	Pot. Amyl Xanthate	Pine Oil
Ro conditioner (C-1)	0.0030	0.0030	0.0002
Cl conditioner (C-3)	0.0010	0.0002	-
Re-Cl conditioner	0.0005	-	-
Scav conditioner (C-2)	-	0.0120	0.0002
Total	0.0045	0.0152	0.0004

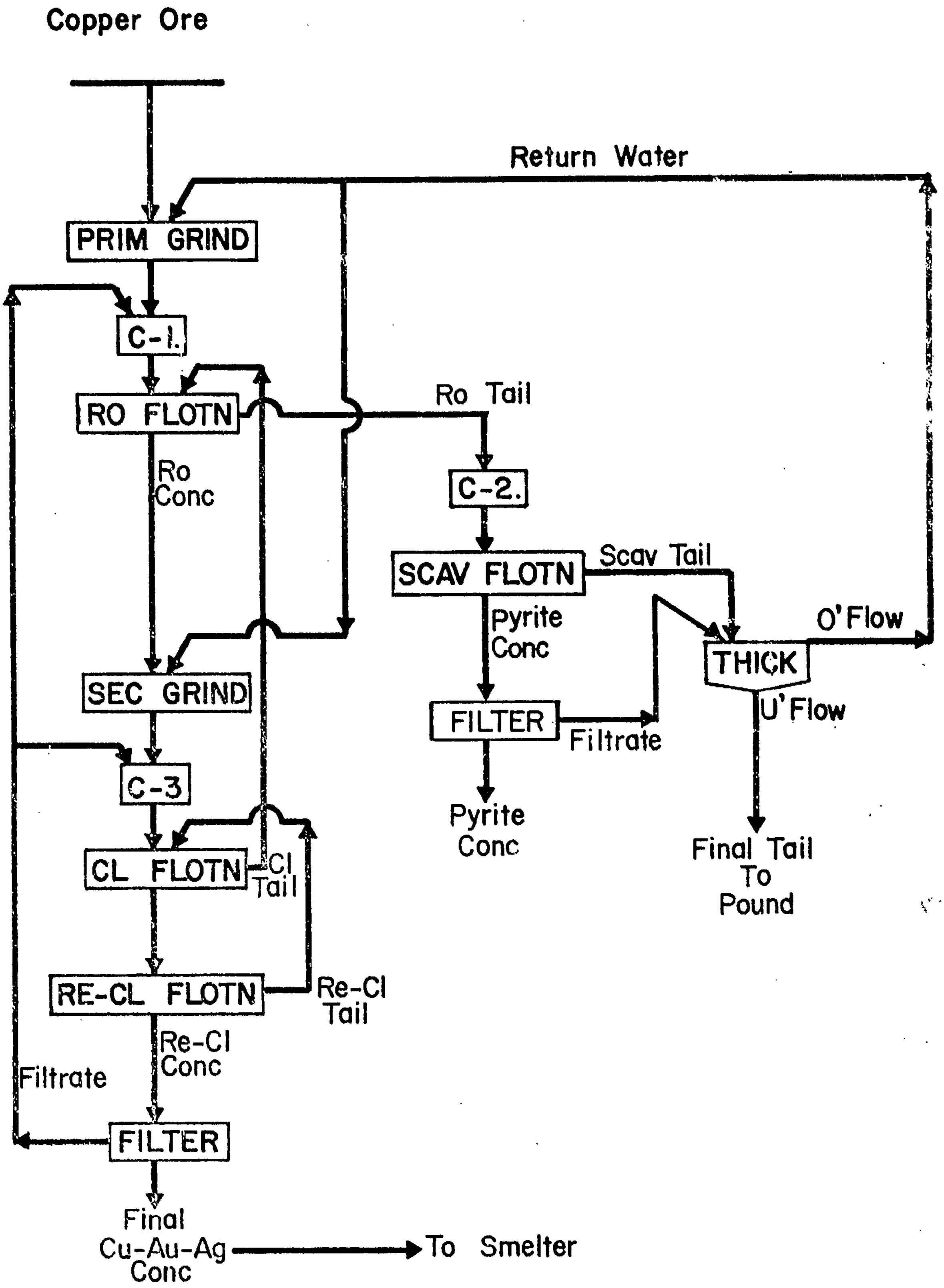

Figure 6 FLOTATION OF COPPER ORE

TABLE 10

Flotation Results on Copper Ore

Grind, Mesh		Product	% Weight	Assay			Distribution		
				Oz/ton		%	%		
Prim	Sec			Au	Ag	Cu	Au	Ag	Cu
		Test, R-16							
	200	Re-cl conc	2.9	7.63	25.40	21.90	50.3	43.8	76.7
	200	Re-cl tail	1.0	3.39	9.06	4.94	8.9	4.6	5.9
	200	Cl conc (calcd)	3.9	6.66	24.58	17.50	59.2	48.4	82.6
	200	Cl tail	5.6	1.40	7.26	0.62	14.1	20.6	4.2
100		Ro conc (calcd)	9.5	3.40	14.38	7.58	73.3	69.0	86.8
100		Py ro conc	5.5	1.37	7.34	1.36	17.1	20.3	9.1
100		Scavenger tail	85.0	0.05	0.25	0.04	9.6	10.7	4.1
100		Feed (calcd)	100.0	0.44	1.98	0.83	100.0	100.0	100.0

In plant operation, where the cleaner tailing is recycled to the rougher feed (see flowsheet), about half of the values from this tailing is usually recovered in the copper concentrate. It can be expected, therefore, that this procedure would recover about 66% of the gold, 60% of the silver, and about 85% of the copper from this ore in a 17.5% copper concentrate. The exact amounts of the gold, silver, and copper recoverable from the cleaner tailing by recycling can be determined only by a pilot plant investigation.

It should be noted from Table 9 that the amount of collector required to float pyrite from this ore was about four times higher than that used for the the flotation of gold, silver, and copper.

(b) Flotation and Tabling of Copper-Tungsten Ore

The mineralogical examination of the ore sample showed that it contained a small amount of tungsten as scheelite besides small amounts of gold, silver, and copper.

An effective method for recovering scheelite (specific gravity 5.9 to 6.1) is table concentration. The sulphides are normally floated from the ore before tabling.

To avoid overgrinding scheelite the primary grind was to minus 65 mesh. The gold, silver, chalcopyrite, and pyrite were floated in the same manner as from the Copper Ore.

The details of the procedure used in this test is illustrated by the flowsheet presented in Figure 7. The amounts and points of addition of the flotation reagents are shown in Table 11 and the results in Table 12.

TABLE 11

The Amounts and Points of Addition of Flotation Reagents

Point of Addition	Lb per Ton of Ore		
	CaO	Pot. Amyl Xanthate	Pine Oil
Ro conditioner (C-1)	0.2	0.0020	0.0002
Cl conditioner (C-3)	0.2	0.0001	-
Re-Cl conditioner	0.3	-	-
Scav. conditioner	-	0.0080	0.0001
Total	0.7	0.0101	0.0003

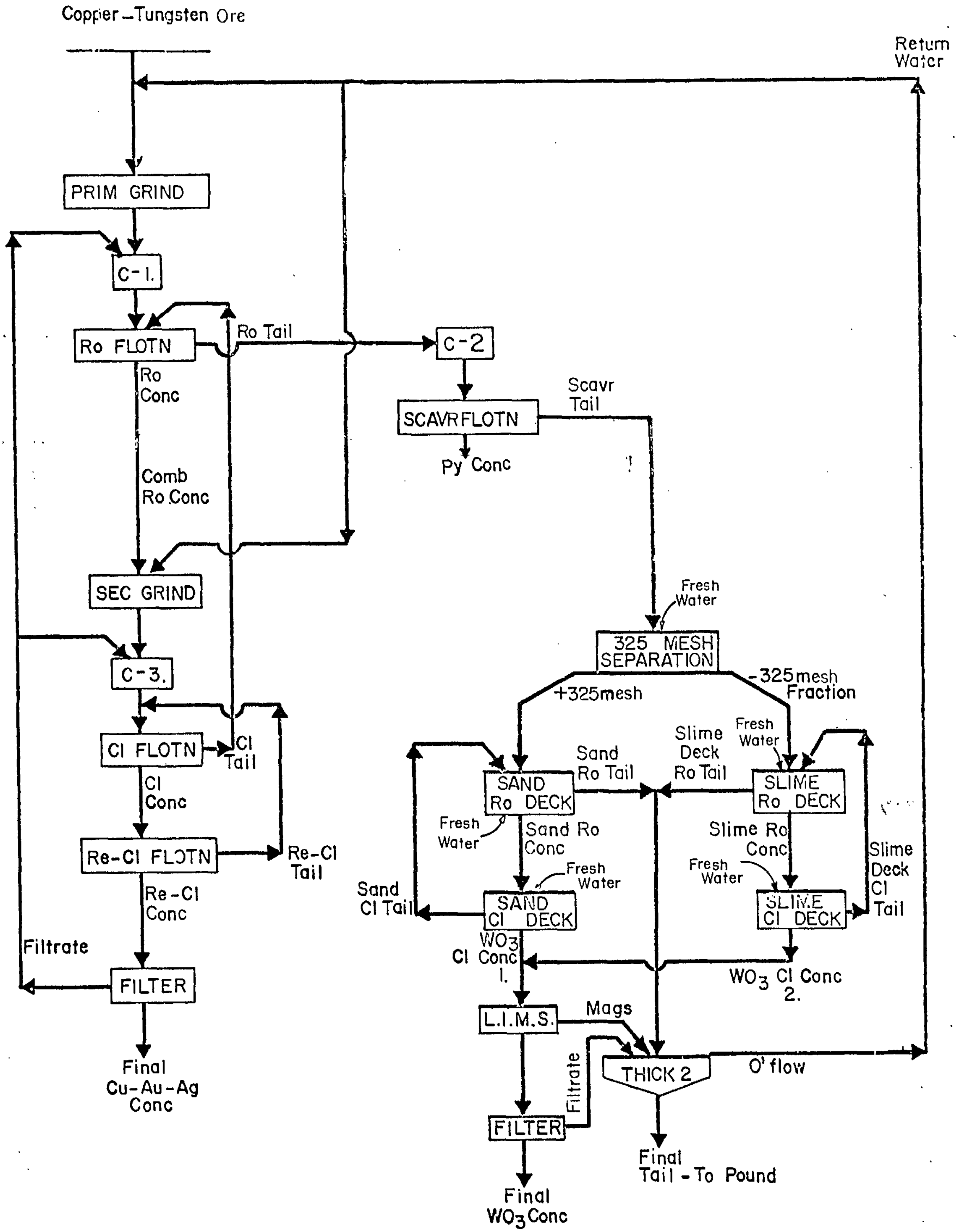

Figure 7 FLOWSHEET FOR TREATING COPPER-TUNGSTEN ORE

TABLE 12

Flotation Results on Copper-Tungsten Ore

Grind, Mesh	Product	% Weight	Assay				Distribution			
			oz/ton		%		%			
			Au	Ag	Cu	WO_3	Au	Ag	Cu	WO_3
	Test, R-24									
-100	Cu re-cl conc	0.7	6.80	48.64	18.83		29.3	44.5	65.4	
-100	Cu re-cl tail	0.4	4.54	18.79	4.52		10.2	9.0	8.2	
-100	Cu cl conc (calcd)	1.1	5.10	38.4	13.90		29.5	53.5	73.6	
-100	Cu cl tail	2.2	2.41	7.89	1.69		31.8	22.0	17.3	
-65	Cu ro conc (calcd)	3.3	3.29	21.00	6.02	0.72	71.3	75.5	90.9	12.5
-65	Py ro conc	4.4	0.53	2.52	0.03	0.14	15.0	14.0	0.5	2.5
-65	Scav. tailing	92.3	0.025	0.09	0.02	0.23	13.7	10.5	8.6	85.0
65	Feed (calcd)	100.00	0.17	0.89	0.21	0.26	100.0	100.0	100.0	100.0

The results of tungsten concentration from two-stage rougher and two-stage cleaner tabling of the flotation scavenger tailing are recorded in Table 13.

TABLE 13

Results of Tungsten Concentration

Product	% Weight	% WO_3	
		Assays	Distribution
Sulphide conc (Cu and Pyrite)	7.70	0.49	15.0
WO_3 conc, +325 mesh	0.09	55.0	18.5
WO_3 conc, -325 mesh	0.04	69.0	11.0
Comb. WO_3 conc	0.13	60.0	29.5
Table cl tail, +325 mesh	2.06	2.72	22.1
Table cl tail, -325	0.50	1.96	3.9
Table ro tail, +325 mesh	55.50	0.03	6.7
Table ro tail, -325 mesh	34.11	0.17	22.8
Scavenger flot tail (calcd)	92.30	0.13	85.0
Feed (Ore Sample No. 2)	100.00	0.25	100.0

In plant operation, the table cleaner tailings would be recycled to the the rougher tables and about half of the tungsten contained in these tailings should be recovered in the final concentrates. The over-all tungsten recovery from this ore, therefore, would be between 40 and 42 per cent. The final tungsten concentrate would contain between 60 and 65% WO_3. Based on the 0.25% WO_3 in the ore, this represents a production of about 2 pounds of the marketable tungsten concentrate per ton of ore milled. Although this by-product was produced by a relatively simple and inexpensive procedure, the economics of the tungsten recovery should be investigated.

As in the flotation of the copper ore, the amount of the collector used for pyrite flotation was about four times higher than that used for the flotation of gold, silver, and copper values. The rejection of pyrite from this was necessary to prevent its concentration with scheelite during tabling.

(c) Integrated Treatment of Copper Ore and Copper-Tungsten Ore

The two ores would be treated in the same mill, so the flowsheet, illustrated in Figure 8, was developed.

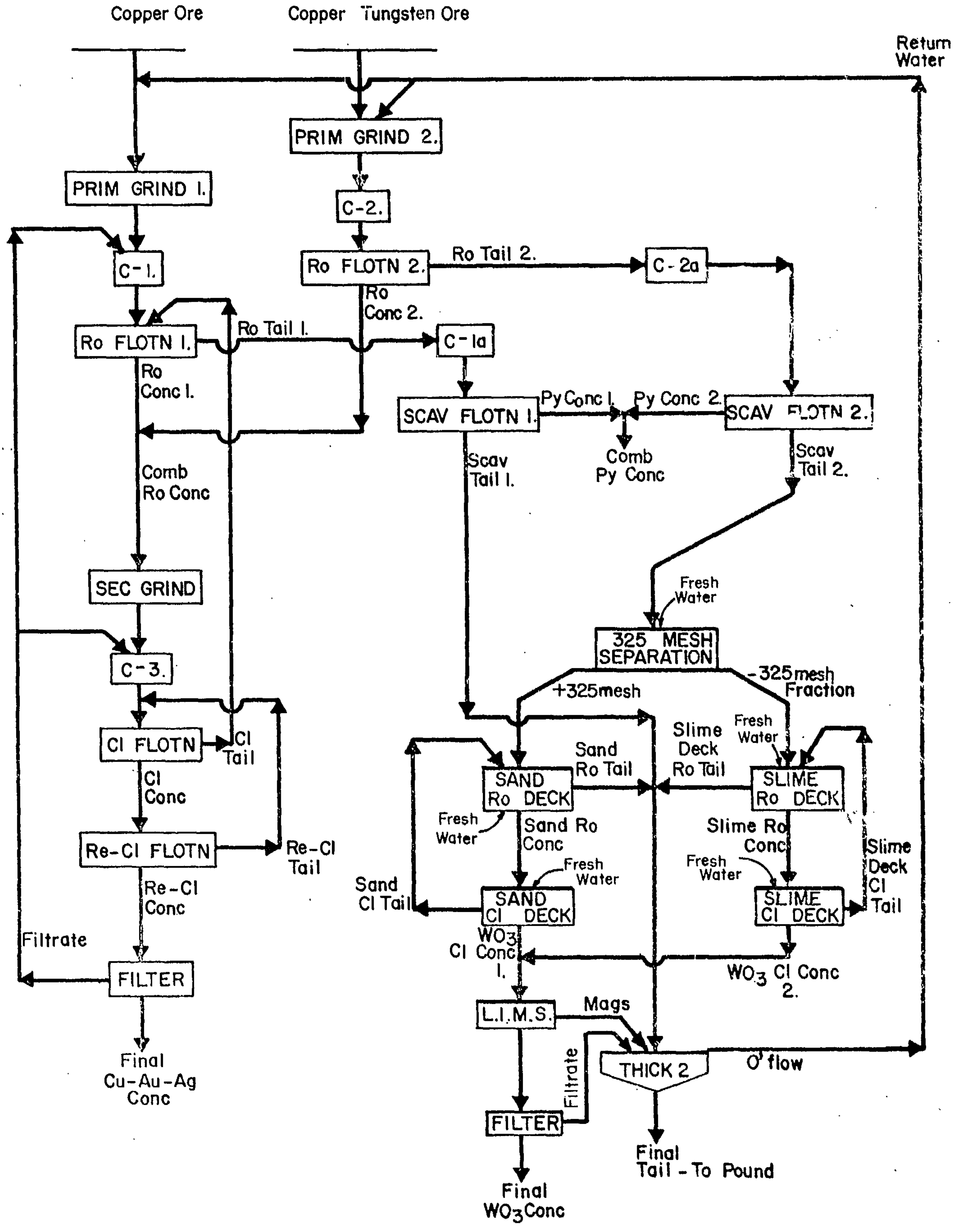

Figure 8.

INTEGRATED FLOWSHEET FOR TREATING COPPER ORE AND COPPER-TUNGSTEN ORE

A description of the major steps of this procedure follows.

(i) Each ore was ground separately and copper-gold-silver rougher concentrates floated from each, followed by flotation of separate pyrite rougher concentrates using either lime or soda ash as the alkalinity regulators, potassium amyl xanthate as collector, and pine oil as a frother.

(ii) The two copper-gold-silver rougher concentrates produced were combined, reground and then cleaned twice to obtain a final copper-gold-silver concentrate which was filtered and analyzed.

(iii) The scavenger flotation tailing from the copper-tungsten ore was sized into two fractions and each fraction treated by two-stage tabling to obtain a tungsten concentrate. In the plant operation the final copper-gold-silver concentrate and the combined pyrite concentrate would be filtered and the filtrates would be returned to the corresponding circuits to reduce the reagent costs and, at the same time, to minimize pollution.

The final tailings from both the flotation and gravity circuits would be combined, thickened, and the thickener overflow returned to the grinding circuits (return water) to minimize pollution and the consumption of fresh water.

After a few preliminary tests, three tests were run, using soda ash and lime as the alkalinity regulators and varying the primary grind of the copper ore from minus 65 to minus 100 mesh. The fineness of the primary grind of the copper-tungsten ore was kept at minus 65 mesh to prevent overgrinding the scheelite. The secondary grind of the combined copper rougher concentrate was kept at minus 200 mesh. The objective of these tests was to compare the effects of soda ash and lime as pH regulators and, at the same time, to compare the effect of coarser and finer grinds on the gold, silver, and copper recoveries.

The flotation results of this series of tests with the flotation conditions are given in Table 14. No attempt was made to recover the tungsten in these tests.

TABLE 14

COMPARISON OF FLOTATION RESULTS FROM TEST RC-1, RC-2 AND RC-3

FLOTATION FEED: COPPER ORE AND COPPER-TUNGSTEN ORE COMBINED AT 1 : 1 RATIO

PRODUCT	% WEIGHT			ASSAY									DISTRIBUTION								
				Au - oz/ton			Ag - oz/ton			Cu - %			Au - %			Ag - %			Cu - %		
	RC - 1	RC - 2	RC - 3	RC - 1	RC - 2	RC - 3	RC - 1	RC - 2	RC - 3	RC - 1	RC - 2	RC - 3	RC - 1	RC - 2	RC - 3	RC - 1	RC - 2	RC - 3	RC - 1	RC - 2	RC - 3
Cu re - cl conc	1.6	2.1	1.8	7.71	6.94	7.53	33.15	28.11	32.43	24.55	19.45	20.70	41.7	51.0	46.4	42.1	49.2	43.9	71.7	78.8	71.6
Cu re - cl tail	0.7	0.6	0.4	4.18	2.46	2.88	20.74	13.35	16.73	6.43	2.46	2.60	9.3	5.0	3.8	10.6	6.4	4.7	7.5	2.7	1.9
Cu cl conc (calcd)	2.3	2.7	2.2	6.68	5.96	6.73	29.60	24.92	29.63	19.30	15.74	17.60	51.0	56.0	50.2	52.7	55.6	48.6	79.2	81.5	73.5
Cu cl tail	4.8	5.3	3.4	1.46	1.035	0.90	6.22	4.61	4.60	0.61	0.49	0.39	23.1	19.4	10.4	23.1	20.3	11.9	5.2	5.0	2.5
Cu ro conc (calcd)	7.1	8.0	5.6	3.16	2.69	3.17	13.79	11.43	14.33	6.66	5.75	7.04	74.1	75.4	60.6	75.8	75.9	60.5	84.4	86.5	76.0
Py ro conc 1	4.6	4.6	7.5	0.68	0.83	1.05	3.22	3.66	4.47	0.50	0.76	1.25	10.3	12.0	27.0	11.5	12.5	25.4	4.1	5.0	18.1
Py ro conc 2	2.8	1.6	2.9	0.61	0.41	0.455	1.85	1.26	1.47	0.47	0.33	0.20	5.6	2.5	3.1	4.0	1.7	2.2	2.3	1.0	1.0
Py ro conc comb.	7.4	6.2	10.4	0.65	0.726	0.926	2.70	2.99	3.80	0.49	0.64	1.04	15.9	14.5	30.1	15.5	14.2	27.6	6.4	7.0	19.1
Scav. tail 1	40.2	40.3	39.0	0.04	0.045	0.04	0.20	0.20	0.29	0.04	0.06	0.04	5.3	6.2	5.5	6.2	6.9	8.8	2.8	4.8	3.1
Scav tail 2	45.3	45.5	45.0	0.03	0.025	0.025	0.07	0.08	0.09	0.08	0.02	0.01	4.7	3.9	3.8	2.5	3.0	3.1	6.4	1.7	1.8
Feed (calcd)	100.0	100.0	100.0	0.30	0.284	0.289	1.29	1.20	1.31	0.58	0.53	0.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

CONDITIONS:	TEST NO:	RC - 1	RC - 2	RC - 3
	Prim grind:			
	Ore 1:	- 100 mesh	- 65 mesh	- 65 mesh
	Ore 2:	- 65 mesh	- 65 mesh	- 65 mesh
	Sec grind:	- 325 mesh	- 200 mesh	- 200 mesh
	Alkali:	Soda ash	Soda ash	Lime
	Collector:	Pot. amyl xanthate	Pot. amyl xanthate	Pot. amyl xanthate
	Frother:	Pine oil	Pine oil	Pine oil

The effect of finer grinding can be seen in Table 14 by comparing the results of Tests RC-1 and RC-2. This shows that finer grinding results in a significant increase in both the grade and the recovery of the copper, gold, and silver.

The effect of lime can be seen by comparing the results of Tests RC-2 and RC-3. As might be expected, lime has a stronger depressing effect than soda ash on pyrite during copper flotation resulting in a higher grade of concentrate but accompanied by a lower metal recovery due to the metal values locked in the depressed pyrite. These values lost during copper flotation are then concentrated in subsequent pyrite flotation. It is suggested that both lime and soda ash be tested in the milling of this ore for a proper evaluation and to arrive at a balance been grade and recovery.

DISCUSSION

The "copper ore", containing slightly less than one per cent copper, but a fair amount gold and silver, is considered economically feasible to treat. The "copper-tungsten ore", containing about one third or less of the values in the copper ore, and a small amount of tungsten (about 0.3% WO_3), is considered a marginal ore.

Appreciable amounts of precious metals are finely disseminated in the pyrite and gangue minerals, therefore a high recovery of the precious metals in a copper concentrate alone can not be realized. If a pyrite concentrate were produced, it would contain locked-in particles of precious metals and the overall gold and silver recoveries could be increased providing that a market for the pyrite concentrate exists.

Treating the copper ore alone by straight flotation, as shown by Figure 6, recovered about 66% of the gold, 60% of the silver and about 85% of the copper in a marketable copper concentrate in which primary and secondary grinds were kept at minus 100 mesh and minus 200 mesh respectively (see Table 10). With a secondary grind of minus 325 mesh, these recoveries might be slightly improved as was indicated by the results in Table 14.

Treatment of the copper-tungsten ore alone by flotation and tabling as shown by Figure 7,the gold, silver, copper and tungsten recoveries from this low grade ore were 34.5%, 53%, 70% and about 42% respectively assuming that about one half of the values from the cleaner tailings are recoverable in the final copper and tungsten concentrates.

The economic feasibility of treating both ores together according to the flowsheet, shown in Figure 8, looks possible. From the results of Table 14, Test RC-1, and with the assumption that about one half of the values from the cleaner tailing is recoverable by recycling of these tailings in a plant operation, the gold, silver and copper recoveries would be 62.5%, 64%, and 82% respectively from the combined ores assaying 0.30 oz Au/ton, 1.29 oz Ag/ton of ore and 0.56% copper.

CONCLUSIONS

(a) Treatment of these ores by gravity concentration alone did not produce satisfactory results.

(b) Flotation of gold, silver and copper values from both ores followed by tabling of the copper-tungsten ore for scheelite recovery will give satisfactory recoveries.

The relatively low gold and silver recoveries from these ores were caused by the fine dissemination of these precious metals in pyrite and gangue minerals.

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