A STUDY OF GOLD ASSOCIATIONS IN A REFRACTORY ORE

by

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A Thesis

submitted to the faculty of the

Department of Mining Engineering and Metallurgy

in partial fulfillment of

the requirements for the degree of

Master of Science

in the Graduate College

University of Arizona

1937

Approved: [signature], May 13, 1937

Major Professor Date.

Acknowledgment

The writer wishes to express his thanks and appreciation to Dr. T. G. Chapman under whose supervision this work was done and to Mr. A. J. Thompson for helpful advice and criticism with respect to the experimental work.

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Introduction

Chapter I

During the past two years several investigations have been made by the Staff and Graduate Students of the Department of Mining and Metallurgy with the object of determining the occurrence and association of silver in refractory silver ores, with special reference to concentrator tailing products from the milling of such ores.

In 1928, Chapman[1] definitely established the association of the refractory silver with manganese in the La Colorado tailing dumps resulting from cyanidation operations. Runke[2] in 1935 studied the character of the silver loss in tailing from the flotation treatment of the Pankey Mine ore and established the association of silver in iron-manganese minerals, and his results, therefore, definitely associated refractory silver with iron as well as manganese with respect at least to Pankey Mine ore.

Although considerable work along technical lines has been done at the University of Arizona with respect to

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[1] Chapman, T. G., Professional Report on silver associations in La Colorado cyanide dumps, July 1928.

[2] Runke, Morris, "A Method of Studying Silver Losses in Concentrator Tailings" Thesis, Univ. of Arizona, May 1936.

silver associations in refractory ores, little has been accomplished with respect to the application of scientific methods to the study of refractory associations in gold ores.

Head[3] states that a portion of the free gold loss in flotation can be traced to slime coated and tarnished gold particles. Head also found that surface contamination on gold particles decreased the rate of dissolution of these gold particles in cyanide solution. The tarnish observed on gold particles by Head has been determined by him as oxides of iron with the possibilities of lead, silver, manganese, aluminum, and titanium also being present.

Last year (1936) a deposit of tailing from a former operation in Mexico was brought to the attention of the Department of Mining and Metallurgy. This material resulted from treatment by amalgamation and gravity concentration and averaged approximately 0.31 ounce of gold and 2.48 ounces of silver per ton. Preliminary flotation tests using excessive quantities of reagents indicated that a recovery of approximately 65 to 70 per cent of the gold could be expected from this material. The tailing from the flotation treatment of the material still contained 0.11 ounce of gold and 1.69 ounces of silver per ton, and no suitable economic method of treatment has been found to recover this refractory gold. Although cyanide methods had

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[3] Head, R. E., "Physical Characteristics of Gold Lost in Tailings," A.I.M.E. Technical publication number 674, Feb. 1936, pp. 6 to 9 inclusive.

been considered, such treatment was believed to be not commercially feasible as the presence of cyanicides in the dump material resulted in a high cyanide consumption, namely 25 pounds per ton of material tested. The fact that there is present in this material a large proportion of slime, oxides of iron, and 0.8 per cent of copper in the oxidized form indicated possible contamination and associations of the refractory gold with these substances. Since gold is present in an appreciable amount in this tailing, the material was believed satisfactory for a study of refractory gold.

In attacking the problem of studying the character of the refractory gold in this material, it was decided to make the investigation along lines similar to those used by Chapman and Runke on earlier ones. The objective of this experimental work was not to determine, for commercial reasons, the character of the refractory gold in this particular material but, employing this material, to experiment with certain technical methods for determining the character of the gold in any refractory ore or concentrator tailing.

Experimental Work - Chapter 2

The sample used for the experimental work of this thesis was composited from 34 sacks of material sent to the University. As previously mentioned, it contained 0.83 per cent of copper as malachite, azurite, and chrysocolla; 0.31 ounce of gold and 2.48 ounces of silver per ton. In the former treatment of the ore stamp crushing was used, and therefore the material as received contained much slime.

The assays for silver were recorded for each product made in the tests but were considered only for a check on the accuracy of the analysis.

Test 1. Sizing-assay test

As the material was lumpy due to caking of slime, it was ground before sizing in a ball mill for one minute to disintegrate the lumps of slime. The minus 200-mesh fraction was further graded into sand and slime by washing and decanting. The results of the sizing assay test are given in table 1. A summary of the results of table 1 obtained by grouping all products except sand and slime is given in table 2.

Referring to table 1, the results indicate that 75.5 and 82.3 per cents of the gold and silver respectively were in the minus 200-mesh portion of the material and further grading by washing and decanting indicated that 49.8 and 55.8 per cents

Table 1 - Sizing-assay test of tailing as received.

	Weight, grams	Tons in 100	Assay, ounces per ton		Tons X assay, ounces		Per cent of total	
			Gold	Silver	Gold	Silver	Gold	Silver
Head	1220.0	100.0	0.31	2.48	30.89	247.9	100.0	100.0
+100	263.8	21.6	0.22	2.09	4.75	45.1	15.5	18.2
-100, +150	75.1	6.2	0.22	2.04	1.36	12.6	4.4	5.1
-150, +200	64.7	5.3	0.27	2.06	1.43	10.9	4.6	4.4
-200	816.4	66.8	0.35	2.69	23.35	179.3	75.5	82.3
-200 Sand	223.7	27.3	0.29	1.51	7.95	41.1	25.7	16.5
Slime	592.7	39.5	0.39	3.50	15.40	138.2	49.8	55.8

Table 2 - Summary of table 1 results.

	Weight, grams	Tons in 100	Assay, ounces per ton		Tons X assay, ounces		Per cent of total	
			Gold	Silver	Gold	Silver	Gold	Silver
Head	1220.0	100.0	0.31	2.48	31.00	248.0	100.0	100.0
Total Sand	627.3	60.5	0.25	1.81	15.60	109.8	50.2	44.2
Total Slime	592.7	39.5	0.39	3.50	15.40	138.2	49.8	55.8

of the gold and silver respectively were in the slime portion of the minus 200-mesh product. Furthermore, both gold and silver concentrated in the slime product assaying 0.39 and 3.50 ounces gold and silver respectively per ton whereas the heads assayed 0.31 and 2.48 ounces gold and silver respectively. With respect to the effect of degree of grinding upon concentrations of gold and silver in the sand products, the results indicate the unusual tendency of the gold to concentrate in the fine sand products, whereas no such tendency was indicated for the silver. It should be pointed out, however, that the original treatment of this material was by amalgamation and tables, and as both of these treatments tend to recover coarse gold rather than fine gold, it is quite probable that free gold existed in all sand products.

Test 2. Sizing-assay test of flotation tailing

Since the results of the previous sizing-assay test gave information only with respect to concentrations of gold and silver in the original material, it was decided to concentrate the refractory gold and silver in the tailing of a flotation test.

A sample of 500 grams of the original material was treated in a 500-gram capacity Denver flotation cell with 0.10 pound of amylxanthate, 0.10 pound sodium aerofloat, and 0.08 pound G.N.S. pine oil No. 5 per ton of material treated. The material was conditioned for 8 minutes before floating.

Flotation was continued for 20 minutes. The results of this test are presented in table 3.

Referring to table 3, flotation recovered 43.6 and 16.4 per cents of the gold and silver respectively in a concentrate which assayed 6.07 and 18.2 ounces of gold and silver per ton respectively. The concentration ratio was 100 to 2.24 tons. As the objective of this test was to concentrate the refractory gold and silver with the tailing, it should be noted that the tailing of this flotation test assayed 0.18 and 2.12 ounces gold and silver respectively.

Sizing-assay test of flotation tailing of table 3.

A sizing-assay test of the tailing of the previous flotation test was made and the results are given in table 4, and a summary of table 4 results is presented in table 5.

The indicated recoveries of gold in table 4 tailing for each screen size, based on assays only, are given in table 6.

Table 6 - Indicated recoveries on various sizes by flotation based on assays.

Mesh	Assays, ounces gold per ton: Heads	Tailings	Difference	Per cent recovered based on assays
+100 mesh	0.22	0.155	0.065	29.5
-100 +150	0.22	0.17	0.05	22.8
-150 +200	0.27	0.20	0.07	26.0
-200 Sand	0.29	0.18	0.11	38.0
Slime	0.39	0.20	0.19	48.8
Total Sand	0.25	0.17	0.08	31.0
Total Slime	0.39	0.20	0.19	48.8

Table 3 - Results of bulk flotation test

Mesh	Weight, grams	Tons in 100	Assay, ounces per ton: Gold	Assay, ounces per ton: Silver	Tons X assay, ounces: Gold	Tons X assay, ounces: Silver	Per cent of total: Gold	Per cent of total: Silver
Head	500.0	100.0	0.31	2.48	31.2	248.1	100.0	100.0
Concentrate	11.2	2.24	6.07	18.20	13.6	40.8	43.6	16.4
Tailing	488.8	97.76	0.18	2.12	17.6	207.3	56.4	83.6

Table 4 - Sizing-assay test of flotation tailing of table 3.

Mesh	Weight, grams	Tons in 100	Assay, ounces per ton: Gold	Assay, ounces per ton: Silver	Tons X assay, ounces: Gold	Tons X assay, ounces: Silver	Per cent of total: Gold	Per cent of total: Silver
Head	269.0	100.0	0.180	2.12	18.06	212.8	100.0	100.0
+100	52.6	19.5	0.155	2.00	3.03	39.0	16.8	18.2
-100 +150	52.3	19.4	0.170	1.98	3.31	38.5	18.3	18.0
-150 +200	31.4	11.7	0.200	2.00	2.34	23.3	12.9	10.9
-200	132.6	49.4	0.190	2.29	9.38	113.0	52.0	52.9
-200 Sand	63.0	23.5	0.180	1.65	4.23	38.8	23.4	18.3
Slime	69.6	25.9	0.200	2.86	5.170	74.2	28.6	34.6

Table 5 - Summary of results of table 4

Mesh	Weight, grams	Tons in 100	Assay, ounces per ton: Gold	Assay, ounces per ton: Silver	Tons X assay, ounces: Gold	Tons X assay, ounces: Silver	Per cent of total: Gold	Per cent of total: Silver
Tailing	269.0	100.0	0.18	2.12	18.00	212.0	100.0	100.0
Sand	199.4	74.1	0.17	1.86	12.83	137.8	71.4	65.4
Slime	69.6	25.9	0.20	2.86	5.17	74.2	28.6	34.6

Referring to table 5, the results indicate that 71.4 per cent of the gold in the flotation tailing is contained in the sand and 28.6 per cent in the slime. With respect to concentration of the gold lost in the flotation tailing, the assays of the sand and slime were 0.17 and 0.20 respectively.

Reference to table 6 indicates the recoveries obtained on the various screen sizes based on assays.

Test 3. Effect of sodium sulphide in floating the refractory gold.

Inasmuch as the reagent combination of xanthate, sodium aerofloat, and pine oil is considered standard for the flotation of gold and will give satisfactory results in floating clear gold, the gold remaining in the tailing of test 2 will be considered attached, inclosed, or refractory gold.

The object of this test was to determine if any benefit would result from the use of sodium sulphide as this reagent will at times condition refractory gold not amenable to flotation by ordinary reagents such as xanthate or aerofloat.

A 500-gram sample of the tailing was conditioned for 10 minutes in a bottle which was revolved on a set of rolls with 0.10 pound of amylxanthate, 0.10 pound of sodium aerofloat and 2.0 pounds of sodium sulphide per ton of material treated. The pulp was transferred to the Denver flotation machine and further conditioned one minute with the addition of 0.08 pound of G.N.S. No. 5 pine oil. Flotation for a 20-minute period produced concentrate I. The froth taken off

was darker than the froth of test 2, and became lighter in color towards the end of the flotation period.

The tailing was removed from the machine, thickened, and reconditioned in a bottle, employing the same reagents, and in the same amounts as before. This reconditioned pulp was treated in the Denver flotation machine and floated for 20 minutes to produce concentrate II.

In a similar manner retreatment of the tailing so produced gave concentrate III and a final tailing.

The results of this test are given in table 7.

Table 7 - Effect of sodium sulphide

	Weight, grams	Tons in 100	Assay, oz. gold per ton	Tons X Assay, ounces	Per cent of total
Head	500.0	100.00	0.31	31.26	100.0
Concentrate I	22.4	4.48	3.46	15.50	49.5
Concentrate II	30.5	6.10	0.68	4.15	13.3
Concentrate III	12.9	2.58	0.63	1.62	5.2
Tailing	434.2	86.84	0.115	9.99	32.0

A summary of the results of table 7 obtained by combining the concentrates is shown in table 8.

Table 8 - Summary of table 7 results

	Weight, grams	Tons in 100	Assay, oz. gold per ton	Tons X Assay, ounces	Per cent of total
Head	500.0	100.00	0.31	31.46	100.0
Concentrates	65.8	13.16	1.65	21.27	68.0
Tailing	434.2	86.84	0.115	9.99	32.0

Referring to table 7 the results indicate that 49.5 per

cent of the total gold was obtained in the first concentrate which assayed 3.46 ounces of gold per ton. Additional recoveries of 13.3 per cent and 5.2 per cent were obtained in concentrates II and III which assayed 0.68 and 0.63 ounces of gold per ton respectively. The final tailing contained 0.115 ounce of gold per ton. The concentration ratio was 100 to 13.16. Referring to table 8, the total recovery amounted to 68.0 per cent in a product assaying 1.65 ounces per ton.

In comparing the results of tests 2 and 3 to determine the effect of the sodium sulphide, only concentrate I of test 3 should be considered as the conditions for obtaining the concentrate were the same as those when the concentrate of test 2 was produced, except for the presence of sodium sulphide in test 3. In test 2, 43.6 per cent of the gold was floated in 20 minutes as a concentrate containing 6.07 ounces of gold per ton, whereas in test 3 employing sodium sulphide 49.5 per cent of the gold was floated in 20 minutes as a product assaying 3.46 ounces of gold per ton. Since the grades of these products differ widely, no definite statement can be made regarding the beneficial effect of the sodium sulphide.

However, although the test failed in its objective, additional information was obtained as to the character of the refractory gold. The fact that prolonging the conditioning and flotation time from 20 to 60 minutes produced a recovery

of 68.0 per cent compared to 43.6 per cent for 20 minutes, indicated that the material may be classed as "slow floating."

A separation of the final tailing of test 3 into a sand and slime portion was made and these products assayed. The results are given in table 9.

Table 9 - Distribution of gold in the sand and slimes of test 3 tailing

	Weight, grams	Tons in 100	Assay, oz. gold per ton	Tons X Assay, ounces	Per cent of total
Tailing from test 3	106	100.0	0.115	11.50	100.0
Sand	63	59.5	0.140	8.26	71.9
Slime	43	40.5	0.080	3.24	28.1

Referring to table 9, distribution of the gold loss in sand and slime, by per cent, appeared to be about the same as in the tailing of test 2.

Test 4. Effect of copper sulphate in floating the refractory gold.

As copper sulphate is in some cases an activating agent in the flotation of refractory minerals associated with gold or refractory gold, this test was made to determine its effect in floating the refractory gold in this material.

Test 4 was made similar in all respects to test 3, with the substitution of one pound of copper sulphate per ton of material treated for the sodium sulphide in the three conditioning periods and produced three concentrates and a tailing. The results of this test are shown in table 10. A summary of the results of table 10 obtained by combining the

concentrates is given in table 11.

Table 10 - Effect of copper sulphate

	Weight, grams	Tons in 100	Assay, oz.gold per ton	Tons X Assay, ounces	Per cent of total
Head	500.0	100.0	0.31	31.03	100.0
Concentrate I	26.9	5.4	2.78	14.96	48.2
Concentrate II	21.8	4.4	0.64	2.79	9.0
Concentrate III	10.7	2.1	0.44	0.94	3.0
Tailing	440.6	88.1	0.14	12.34	39.8

Table 11 - Summary of results of table 10

	Weight, grams	Tons in 100	Assay, oz.gold per ton	Tons X Assay, ounces	Per cent of total
Head	500.0	100.0	0.31	31.03	100.0
Concentrates	59.4	11.9	1.57	18.69	60.2
Tailing	440.6	88.1	0.14	12.34	39.8

Referring to table 10 the results indicate that 48.2 per cent of the total gold was obtained in concentrate I which assayed 2.78 ounces of gold per ton. Additional recoveries of 9.0 and 3.0 per cents of the gold were obtained in concentrates II and III which assayed 0.64 and 0.44 ounces of gold per ton respectively. The final tailing assayed 0.14 ounces of gold per ton.

Referring to table 11, the total recovery of gold was 60.2 per cent in a product assaying 1.57 ounces per ton. The concentration ratio was 100 to 11.9.

As in test 3, a comparison of concentrate I of test 4 with the concentrate obtained in test 2 indicated that 43.6 per cent of the gold was obtained in the concentrate of test 2 which assayed 6.07 ounces of gold per ton; and in test 4, 48.2 per cent of the gold was obtained in the first 20-minute period which assayed 2.78 ounces of gold per ton. Again a wide difference was noted in the grade of the concentrates of these two tests; therefore, a definite statement cannot be made regarding any beneficial effect of the copper sulphate in floating the refractory gold of this material.

In the test reconditioning and extension of the flotation period resulted in the recovery of 60.2 per cent of the gold and confirmed the "slow floating" character of the material as noted in test 3.

In comparing the effects of the sodium sulphide and the copper sulphate in floating the refractory gold, reference is made to table 8 which indicates that the use of sodium sulphide resulted in a recovery of 68.0 per cent of the gold; a concentrate assaying 1.65 ounces of gold per ton; and a concentration ratio of 100 to 13.16: whereas the use of copper sulphate as given in table 11 indicated a recovery of 60.2 per cent of the gold; a concentrate assaying 1.57 ounces of gold per ton; and a concentration ratio of 100 to 11.9. This comparison indicated better results with sodium sulphide than copper sulphate with reference to recovery, grade of product, and concentration ratio.

A separation of the final tailing of test 4 into sand and slime portions was made and the products assayed. The results are given in table 12.

Table 12 - Distribution of gold in the sand and slime of test 4 tailing.

	Weight, grams	Tons in 100	Assay, oz. gold per ton	Tons X Assay, ounces	Per cent of total
Tailing	220	100.0	0.140	14.00	100.0
Sand	127	57.7	0.165	9.55	68.3
Slime	93	42.3	0.105	4.45	31.7

Referring to table 12, 68.3 per cent of the gold in test 4 tailing was in the sand portion and 31.7 per cent in the slime portion. This distribution was approximately the same as shown in tables 5 and 9 for the tailings of tests 2 and 3.

Test 5. Experimental work in the segregation of the refractory gold.

Test 1 to 4 inclusive, previously described, have indicated the approximate amount of the refractory gold in this material and furthermore had indicated that extended conditioning time and prolonged flotation periods would recover a substantial part of this refractory gold in the form of a low grade concentrate. The experimental work of these tests had not, however, given any evidence as to the character or associations of this refractory gold.

The object of test 5 was, if possible, to segregate the refractory gold into several fractions by methods which will be described, and to determine the character of the fractions

with respect to gold concentration.

A 500-gram sample was conditioned in the Denver flotation machine for 6 minutes with 0.10 pound of amylxanthate and 0.10 pound of sodium aerofloat per ton of material. G. N.S. No. 5 pine oil was added at the rate of 0.08 pound per ton and the pulp treated by flotation for 20 minutes producing a concentrate and a tailing. This operation was similar to the flotation in test 2, and the gold remaining in the tailing was assumed to be refractory. The xanthate tailing was separated into sand and slime portions by washing and decanting. The sand portion was treated by a Wetherill magnetic separator operated with a magnetic field of high intensity which produced magnetic and non-magnetic products.

The non-magnetic product from the magnetic separator was panned, producing a concentrate and tailing.

The tailing of the panning operation was conditioned in a flotation machine with 6 pounds of sodium sulphide per ton, added intermittently through a 15-minute conditioning period. At the end of the 15-minute period, 0.10 pound of amylxanthate and 0.10 pound of sodium aerofloat per ton of material were added and conditioning continued for one minute when 0.08 pound of G.N.S. No. 5 pine oil was added and the conditioned pulp treated by flotation. The froth was at first thick and light in color, but became thin and darker within 5 minutes. Froth was skimmed for about 20 minutes, at the end of which time the froth showed a distinctly lighter color. The products

of this operation were a sodium sulphide concentrate and a final sand tailing.

The slime portion of the original flotation tailing was thickened to 2 parts water to 1 part solids, and passed over a canvas table which produced a canvas table concentrate and a final slime tailing. The results of test 5 are given in table 13.

Reference to table 13, lines 5 and 6, indicated that 61.0 per cent of the refractory gold was in the sand portion of the xanthate tailing and 39.0 per cent in the slime portion. This distribution of the refractory gold approximately confirmed the distributions obtained in the tailings of tests 2, 3, and 4.

Reference to line 8 of table 13 indicated that the magnetic product assayed 0.795 ounce of gold per ton but amounted to only 0.44 per cent of the original material and contained only 1.9 per cent of the refractory gold.

The results of the panning test given in lines 11 and 12 of table 13, indicated that 9.7 per cent of the refractory gold was obtained in a concentrate assaying 0.37 ounce of gold per ton. This pan concentrate contained considerable hematite and coarse grains of oxidized copper. The pan tailing contained 49.4 per cent of the refractory gold and assayed 0.152 ounce of gold per ton.

The results of the sodium sulphide in floating the gold remaining in the pan tailing are given in lines 14 and 15 of

Table 13 - Experimental work in the segregation of the refractory gold.

	Weight, grams	Tons in 100	Assay, oz. gold per ton	Tons X Assay, ounces	Per cent of total	Per cent recovery as indicated	Per cent of the gold as indicated
1. Head	500.00	100.00	0.310	31.34	100.0		
2. Xanthate concentrate	12.46	2.49	5.160	12.79	41.0		
3. Xanthate tailing	487.54	97.51	0.190	18.55	59.0		100.0
4. Xanthate tailing from 3 to washing:							
5. Sand portion	329.80	65.96	0.170	11.36	34.4		61.0
6. Slime portion	157.74	31.55	0.225	7.19	24.6		39.0
7. Sand (5) to magnetic separator						100.0	
8. Magnetic product	2.20	0.44	0.795	0.35	1.1	3.1	1.9
9. Non-magnetic product	327.60	65.52	0.168	11.01	33.3	96.9	59.1
10. Non-magnetic tailing (9) to gold pan						100.0	
11. Concentrate	24.26	4.85	0.370	1.79	5.7	16.2	9.7
12. Tailing	303.34	60.67	0.152	9.22	27.6	83.8	49.4
13. Tailing (12) to sodium sulphide flotation						100.0	
14. Concentrate	7.32	1.46	0.645	0.94	3.0	10.2	5.0
15. Tailing	296.02	59.21	0.140	8.28	24.6	89.8	44.4
16. Slime (6) to canvas table						100.0	
17. Concentrate	46.40	9.28	0.295	2.74	8.8	38.2	14.7
18. Tailing	111.34	22.27	0.200	4.45	15.8	61.8	24.3

table 13. The concentrate assayed 0.645 ounce of gold per ton and contained 5.0 per cent of the refractory gold; the final sand tailing assayed 0.14 ounce of gold per ton and contained 44.4 per cent of the refractory gold.

The canvas table treatment of the slime portion of the xanthate flotation tailing, as given in lines 17 and 18 of table 13, recovered 14.7 per cent of the refractory gold as a concentrate assaying 0.225 ounce per ton. The final slime tailing assayed 0.20 ounce of gold per ton and contained 24.3 per cent of the refractory gold.

In a subsequent test, slime that was obtained in a similar manner to the slime of test 5 was passed over a new canvas surface at a feed pulp density of 1 to 1. This test produced a tailing which assayed 0.12 ounce of gold per ton, and it was therefore concluded that the pulp of test 5 was too dilute for best results.

The results of test 5 indicated that although some association of the refractory gold has been shown with magnetic minerals, the extent of this association is of minor importance, amounting to only 1.9 per cent of the refractory gold. Indirect evidence given in table 13 indicated that the refractory gold was comparatively free from associations with friable heavy minerals which might be expected to concentrate on the surface of a canvas table.

Test 6. Gold-Copper Association

In this test some experiments were made to obtain data to determine indirectly whether an appreciable association existed between the so-called refractory gold and the copper minerals present in this material. Chapman and Runke, as previously mentioned, had used this method to good advantage in determining manganese-silver associations by segregating manganese-silver fractions by two different methods, for example, magnetic and heavy solution methods, and establishing ratios between the manganese and silver. If the ratios were constant or approximately constant, some evidence was believed to point to an association between the manganese and silver.

In trying to apply this method to the material described in this paper, the writer was unable to produce two fractions by two different methods, as the oxidized copper minerals cannot be segregated as readily as manganese minerals.

The segregation of copper was made by sodium sulphide flotation, and the only evidence the writer can present as to copper-gold associations is the per cents of gold and copper floated in this fraction. The gold floated amounted to 2.70 per cent based on the so-called refractory gold, and the copper floated with the so-called refractory gold amounted to 9.42 per cent of the total copper. The writer believes that this evidence, although not conclusive, indicates no appreciable association between the so-called refractory gold and the copper minerals of this material.

Test 7. Cyanidation

Tests 2, 3, and 4, indicated that the maximum recovery of gold by flotation of this material was 68.0 per cent and that from 60 to 71 per cent of the gold loss was in the sand portion of the flotation tailing. Test 5 results did not indicate any notable associations of the so-called refractory gold with minerals other than gangue. The evidence given in test 6 indicated that the amount of gold that was associated with the copper oxides was small.

Since a study of the gold concentrations obtained in fractions made in tests 5 and 6 did not give any evidence as to the character of the major portion of the refractory gold of this material, it was decided to experiment with cyanide methods in order to determine if the refractory gold was intimately associated with commoner gangue minerals. Cyanide methods are different from flotation or gravity methods in recovering gold of this character, since the latter methods require essentially that the gold be free of common gangue minerals if recovery is to be effected, while cyanide will attack and dissolve any free gold if exposed, although attached to gangue minerals.

In test 7 a 2000-gram sample was treated by flotation as in test 2, in order to obtain a tailing containing the refractory gold. A 100-gram sample of the tailing obtained was used for cyanidation by bottle agitation. The cyanide consumption amounted to 12.4 pounds per ton of material treated.

The gold dissolved amounted to 93.0 per cent of the refractory gold (as defined by the writer) based on solution assay.

Another sample of 500 grams was treated by flotation employing sodium sulphide. A sample of the tailing of the sodium sulphide flotation test was treated by cyanide, which resulted in a consumption of 8.2 pounds of sodium cyanide per ton of material treated. The gold dissolved amounted to 91.8 per cent of the gold present in the test.

The results of these tests indicated that the so-called refractory gold was free gold intimately associated with common gangue minerals in that 93 per cent of the refractory gold was soluble in cyanide solution with the same degree of grinding as was used for previous flotation tests.

Test 8. Fine grinding and flotation

A fine grinding flotation test was made in order to obtain data which would to some extent confirm the results of test 7. A sample of the flotation tailing produced in test 7 was separated into sand and slime by washing and decanting. A sample of 200 grams of the sand portion was ground in a ball mill to 12 per cent plus 325-mesh. The ground material was conditioned in a 500-gram capacity flotation machine for 10 minutes with one pound of copper sulphate per ton of material; amylxanthate was then added at the rate of 0.10 pound per ton of material and the pulp further conditioned for 4 minutes. G.N.S. No. 5 pine oil was then added at the rate of 0.08 pound per ton and the pulp treated by flotation for 10

minutes. Sodium sulphide was then added at the rate of 2 pounds per ton and additional xanthate at the rate of 0.05 pound per ton, and froth removed for 10 minutes. The flotation operation produced a concentrate and a tailing. The results of test 8 are given in table 14.

Table 14 - Fine grinding and flotation.

	Weight, grams	Tons in 100	Assay, oz. gold per ton	Tons X Assay, ounces	Per cent of total
Sand head	200.00	100.00	0.17	17.00	100.0
Concentrate	7.58	3.8	2.95	11.23	66.0
Tailing	192.42	96.2	0.06	5.77	34.0

Reference to table 14 indicated that 66.0 per cent of the refractory gold in the sand was obtained as a concentrate assaying 2.95 ounces of gold per ton, with a concentration ratio of 100 to 3.8. The tailing assayed 0.06 ounce of gold per ton.

These results confirmed in general the statement made in interpreting the results of test 7, namely, that the major portion of the refractory gold is native gold, but intimately associated with gangue minerals.

Conclusion

The data presented in this paper indicate the conclusions which follow:

(1) The methods used by Chapman and Runke for determining the character of silver losses in concentrator products have not been found satisfactory in the study of the refractory gold of the material tested.

(2) With respect to the material tested, no appreciable associations were found between minerals other than gangue minerals with the so-called refractory gold.

(3) The writer believes he has presented fairly convincing data to support the statement to the effect that the so-called refractory gold in this material is native gold intimately associated with gangue minerals.

(4) The writer recommends more experimental work on the slime portion of this material with respect to slime coatings.