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The Concentration of Scheelite from the Gold Concentrates of the Jardine Mining Company

John H. Huxley

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THE CONCENTRATION OF SCHELITE FROM THE GOLD CONCENTRATES OF THE JARDINE MINING COMPANY

By

John H. Huxley

Submitted to the Department of Mineral Dressing in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science in Metallurgical Engineering

Montana School of Mines
Butte, Montana
May, 1941

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THE CONCENTRATION OF SCHEELITE FROM THE
GOLD CONCENTRATES OF THE JARDINE MINING COMPANY

The purpose of this thesis was to investigate the possibility of concentrating scheelite from Wilfley table gold concentrates from the mill of the Jardine Mining Company; and to determine whether such concentration is economically feasible and the product of sufficiently high grade to meet commercial specifications for such a product.

Since obtaining the samples on which this work is based, the flow sheet of the mill has been changed to such an extent that there is no longer a table product nor a similar product, hence the actual concentration herein developed may be of no practicable consequence.

An average of the assay values of the table product taken over a period of several months preceding the time of taking the sample reveals an average value of 0.546 per cent CaWO₄, while the general heads of the mill over a similar period of time averaged 0.057 per cent CaWO₄. These data bear considerable weight in the economic consideration of the problem.
TESTING PROCEDURE

Methods of testing were followed as outlined by the Bureau of Mines\(^1\), but since the material used was a table concentrate, several tests were automatically eliminated.

Tests were performed as follows:

1. SCREEN ANALYSIS

From the flow sheet of the mill the concentrate was known to be ground to -20 mesh and from the following screen analysis such tests as float and sink and size of liberation were eliminated. The screen analysis is presented in Table I.

Table I

<table>
<thead>
<tr>
<th>Size</th>
<th>Weight</th>
<th>Weight %</th>
<th>Cum. Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>All passed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-20-28</td>
<td>5.0</td>
<td>0.56</td>
<td>0.56</td>
</tr>
<tr>
<td>-28-35</td>
<td>31.5</td>
<td>3.54</td>
<td>4.10</td>
</tr>
<tr>
<td>-35-48</td>
<td>40.0</td>
<td>4.50</td>
<td>8.60</td>
</tr>
<tr>
<td>-48-65</td>
<td>51.0</td>
<td>5.73</td>
<td>14.33</td>
</tr>
<tr>
<td>-65-100</td>
<td>99.0</td>
<td>11.10</td>
<td>52.43</td>
</tr>
<tr>
<td>-100-150</td>
<td>114.0</td>
<td>12.82</td>
<td>38.25</td>
</tr>
<tr>
<td>-150-200</td>
<td>149.5</td>
<td>16.75</td>
<td>55.00</td>
</tr>
<tr>
<td>-200</td>
<td>400.0</td>
<td>45.00</td>
<td>100.00</td>
</tr>
<tr>
<td>890.0</td>
<td>100.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The weight of the original sample, 903.0 grams, was cut from the concentrates by using a Jones Splitter, and the screen analysis was conducted on a Ro-Tap machine for a period of 45 minutes. No assays were run on the above screen sizes, but an assay of a cut sample of the concentrates gave the following results.

Table II
Assay of Head Sample
Gold---------1.10 oz/ton
Scheelite----0.4059 %

2. MICROSCOPIC STUDY OF SCREEN ANALYSIS FRACTIONS

Preparation of Briquettes
Cut samples of all screen sizes, with the exception of the -200 mesh fraction, were mounted in briquettes of lucite, and the -200 fraction was mounted in bakelite. The plunger of the briquetting press was wetted with mineral oil and then a thin layer of lucite was placed over the oil film on the end of the plunger. The cut sample was then spread in a continuous layer over the lucite coating. The plunger was placed in position in the machine, approximately 13 grams of lucite added to the mold, and the mold heated to 85 degrees, at which time a pressure of 10,000 pounds per square inch was applied. The mold was allowed to cool to 40 degrees Centigrade before
removing the briquette. The briquette was then trimmed on an emery wheel and ground on a glass plate with 600 carborundum until the grain surfaces were well exposed. The specimens were further ground and polished by hand on lap wheels, the first polish with 600 carborundum and the final polish with stannic oxide. This treatment produced a reasonably well polished surface with some relief, but sufficiently good for the identification of minerals present and for grain counts.

The -200 mesh fraction required slightly different treatment. The cut sample of this fraction was mixed with an equal amount of -400 mesh bakelite to insure a matrix for this fine size. This sample was placed in the briquetting press with 13 grams of bakelite and heated to 55 degrees centigrade, pressure applied at 14,000 pounds per square inch, allowed to cool slightly before removing and then treated in the same manner as the lucite briquette.

Identification of Minerals

Examination under the microscope positively identified the following minerals: Arsenopyrite, Pyrite, and Quartz. Scheelite was found to be present in a small amount by making a slide of one of the fine screen sizes and examining it under the petrographic microscope, but none was positively identified under the metallographic microscope.
The association and proportions of the minerals present is given in the following grain count.

Table III
Grain Count

<table>
<thead>
<tr>
<th>Size</th>
<th>% of Total</th>
<th>Arsenopyrite</th>
<th>Pyrite</th>
<th>Quartz</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20+28</td>
<td>0.56</td>
<td>20</td>
<td>25</td>
<td>13</td>
</tr>
<tr>
<td>-28+35</td>
<td>3.54</td>
<td>25</td>
<td>33</td>
<td>15</td>
</tr>
<tr>
<td>-35+48</td>
<td>4.50</td>
<td>24</td>
<td>31</td>
<td>16</td>
</tr>
<tr>
<td>-48+65</td>
<td>5.73</td>
<td>57</td>
<td>35</td>
<td>16</td>
</tr>
<tr>
<td>-65+100</td>
<td>11.10</td>
<td>116</td>
<td>134</td>
<td>217</td>
</tr>
<tr>
<td>-100+150</td>
<td>12.82</td>
<td>110</td>
<td>134</td>
<td>227</td>
</tr>
<tr>
<td>-150+200</td>
<td>16.75</td>
<td>87</td>
<td>95</td>
<td>104</td>
</tr>
<tr>
<td>-200</td>
<td>45.00</td>
<td>Grain count not possible</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Binary Grains

<table>
<thead>
<tr>
<th>Size</th>
<th>No. of Grains</th>
<th>Quartz-Arseno</th>
<th>No. of Grains</th>
<th>Quartz-Pyrite</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20+28</td>
<td>2</td>
<td>50 - 50</td>
<td>16</td>
<td>45 - 55</td>
</tr>
<tr>
<td>-28+35</td>
<td>2</td>
<td>12.5 - 87.5</td>
<td>23</td>
<td>31 - 69</td>
</tr>
<tr>
<td>-35+48</td>
<td>None</td>
<td>-</td>
<td>12</td>
<td>45 - 55</td>
</tr>
<tr>
<td>-48+65</td>
<td>1</td>
<td>25 - 75</td>
<td>7</td>
<td>36 - 44</td>
</tr>
<tr>
<td>-65+100</td>
<td>3</td>
<td>27 - 73</td>
<td>11</td>
<td>35 - 65</td>
</tr>
<tr>
<td>-100+150</td>
<td>None</td>
<td>-</td>
<td>12</td>
<td>39 - 61</td>
</tr>
<tr>
<td>-150+200</td>
<td>None</td>
<td>-</td>
<td>3</td>
<td>33 - 67</td>
</tr>
</tbody>
</table>

In addition, gold was identified in 4 fields but found associated with only the pyrite or quartz-pyrite.
grains. No other binary or ternary grains were observed in the grain count.

It should be noted that the proportion of pyrite to arsenopyrite is very nearly 1 to 1, but this is not necessarily true of the ore, since the mill heads consists of two distinct types of ore, mainly a heavy arsenopyrite ore and a quartz-pyrite ore. Hence this proportion is variable, depending upon which section of the mine was supplying the larger amount of ore at any one time.

Other minerals known to be present but no in sufficient quantity to enter into the grain count as conducted are: calcite, galena, pyrrhotite, native copper, and garnet.

Veins are usually quartz or arsenopyrite, or a combination of these two minerals in varying proportions, and may contain one or both of the ore minerals, gold and scheelite. Other minerals which can be identified microscopically are pyrite, calcite, mica, galena, pyrrhotite, and native copper, as well as the oxidation products of the sulphides.1

The grain count was conducted by taking a series of fields along two or more diameters of each briquette and recording the number of each mineral grains appearing in each field.

1 Gilbert, Ray; Jardine Mine Geology, Mining World, January, 1941, p. 33.
The following illustrations show the association of the three minerals composing the major portion of the concentrates.

No. I

-20 - 23 mesh

Magnification - 30 diameters
1 - quartz with small amount of pyrite
2 - pyrite-quartz grain
3 - arsenopyrite grain
4 - pyrite grain
The matrix is Lucite.
No. II
-23 - 35 mesh

Magnification - 30 diameters
1 - arsenopyrite grain
2 - quartz grain
3 - pyrite grain

No. III
-48 - 65 mesh

Magnification - 30 diameters
1 - arsenopyrite
2 - quartz
3 - pyrite and quartz
3. FLOTATION TESTS

In order to obtain a pulp containing the major proportion of the scheelite with only a limited amount of sulphides present, it was decided to float the sulphides and thus obtain a tailings product containing the scheelite and gangue material which are naturally present in a table concentrate. Another major consideration is to recover a high percentage of the gold values in this same sulphide concentrate. The resulting tails product should then be treated with proper reagents for the recovery of the scheelite.

Grinding

From the screen analysis it may be seen that more than one-half of the material is -150 mesh, so each sample was wet screened through 150-mesh to prevent over-grinding. The remaining over-size was ground in an Abbe' pebble mill in 15 minute stages until it all passed 150 mesh. Since the exact sulphide content of the concentrate was not known at first, four 600 gram samples were ground in this manner, and then when the proportion of sulphide to gangue material was determined, a larger sample of material (2250 grams) was taken and treated in a similar manner. Tap water was used in the grind, in as limited an amount as possible, to avoid an excess of water when the material was transferred to the flotation cell. In general, the grind water was used in the flotation test,
although occasionally more tap water had to be added to the flotation cell.

The pebble load in the mill was approximately 35% of the mill volume and water was added to about one inch below the level of the pebbles in the mill, as this pulp dilution seemed to give the best results when grinding.

Reagents

For the flotation of the sulphides the following reagents were suggested and proved entirely satisfactory, so were used on all the sulphide separations.

Table IV

<table>
<thead>
<tr>
<th>Reagent</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amyl Xanthate</td>
<td>1.0 lb/ton</td>
</tr>
<tr>
<td>Reagent 208</td>
<td>0.5 lb/ton</td>
</tr>
<tr>
<td>Pine Oil</td>
<td>1 drop</td>
</tr>
</tbody>
</table>

The amyl xanthate and Reagent 208 were added to the pulp and allowed to condition for a period of 5 minutes before the addition of the pine oil. After a short conditioning period with the pine oil, the air was turned on and the concentrate gathered for a period of approximately 10 minutes to effect as complete a recovery of sulphide concentrate as possible. Flotation of the sulphides on the 2250 gram charge was conducted in a 2000 gram Denver Cell in order to have sufficient tail product to conduct the Scheelite flotation in the 600 gram Pajergren Cell.
For the scheelite flotation, determination of the proper reagents and concentrations was not so simple. Table V gives a list of the suggested reagents and their respective concentrations.¹

Table V
Scheelite Flotation Reagents

(a)

<table>
<thead>
<tr>
<th>Cleaner</th>
<th>Rougher</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oleic Acid</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>Sodium Oleate</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Sodium Silicate</td>
<td>0.30</td>
<td>0.15</td>
</tr>
<tr>
<td>Tannic Acid</td>
<td></td>
<td>0.40</td>
</tr>
</tbody>
</table>

(b)

<table>
<thead>
<tr>
<th>Cleaner</th>
<th>Rougher</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oleic Acid</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Sodium Oleate</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Pine Oil</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Sodium Carbonate</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Sodium Silicate</td>
<td></td>
<td>0.40</td>
</tr>
</tbody>
</table>

(All are expressed in pounds per ton of dry ore.)

Scheelite Flotation Tests Nos. 1, 2, and 3

Three preliminary tests were run without any regard as to pH control in order to determine the effect of a change in reagents and their concentrations. Assays were run on the heads, concentrates, and tails to determine the grade and recovery of each run. Tables VI, VII, and VIII present all the information about these tests. No cleaner operations were run on the preliminary tests.
Table VI
Scheelite Flotation Test No. 1

Grind:
Primary: -20 mesh
Final: -150 mesh, Abbe’ mill, 15 minute stages.

Water:
Grind: tap water
Flotation: tap water
Pulp dilution: 3 to 1
Per cent solids: 26%
Cell used: Fagergren laboratory cell

<table>
<thead>
<tr>
<th>Product</th>
<th>Wt. in grams</th>
<th>Wt. %</th>
<th>Assay (%WO₃)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W Conc.</td>
<td>43.8</td>
<td>7.92</td>
<td>3.104</td>
<td>18.3</td>
</tr>
<tr>
<td>Tails</td>
<td>510.0</td>
<td>92.08</td>
<td>1.190</td>
<td>81.7</td>
</tr>
<tr>
<td>Composite</td>
<td>553.8</td>
<td>100.00</td>
<td>1.302</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Reagents:
Sodium Oleate 0.1 lb per ton
Oleic Acid 0.32 lb per ton
Sodium Silicate 0.30 lb per ton
Table VII
Scheelite Flotation Test No. 2

Grind:

- Primary: -20 mesh
- Final: -150 mesh, Abbe' mill, 15 minute stages.

Water:

- Grind: tap water
- Flotation: tap water

Pulp dilution: 3 to 1

Per cent solids: 26%

Cell used: Fagergren laboratory cell

<table>
<thead>
<tr>
<th>Product</th>
<th>Wt. in grams</th>
<th>Wt. %</th>
<th>Assay (WO₃%)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W Conc.</td>
<td>123</td>
<td>22.9</td>
<td>4.23</td>
<td>70</td>
</tr>
<tr>
<td>Tails</td>
<td>415</td>
<td>77.1</td>
<td>0.434</td>
<td>30</td>
</tr>
<tr>
<td>Composite</td>
<td>538</td>
<td>100.0</td>
<td>1.29</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Reagents:

- Oleic Acid 0.30 lb per ton
- Sodium Oleate 0.20 lb per ton
- Pine Oil 1 drop
Table VIII

Scheelite Flotation Test No. 3

Grind:

Primary: -20 mesh
Final: -150 mesh, Abbe' mill, 15 minute stages.

Water:

Grind: tap water
Flotation: tap water

Pulp dilution: 3 to 1
Per cent solids: 26%

Cell used: Fagergren laboratory cell

<table>
<thead>
<tr>
<th>Product</th>
<th>Wt. in grams</th>
<th>Wt. %</th>
<th>Assay (%WO₃)</th>
<th>Recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W Conc.</td>
<td>68</td>
<td>12.3</td>
<td>1.813</td>
<td>17</td>
</tr>
<tr>
<td>Tails</td>
<td>483</td>
<td>87.7</td>
<td>1.250</td>
<td>83</td>
</tr>
<tr>
<td>Composite</td>
<td>551</td>
<td>100.0</td>
<td>1.28</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Reagents:

Oleic Acid 0.30 lb per ton
Reagent X - I 0.25 lb per ton
Discussion of Tests and Results Obtained

In all the runs the collecting agents were added to the pulp as the pulp dilution indicated and conditioned for 5 minutes before adding the frother. A few minutes were allowed for conditioning following the addition of the frother and then the concentrate was gathered until no further material was present in the froth.

All three tests proved to be rather unsuccessful since the grade of concentrate as well as the actual recovery were very poor. Assays checked by metallurgical balance, so that there was no possible error from this source. From these results it was determined that pH control in flotation was evidently necessary. Hence a series of tests were run, in which the pH was varied to study the results.

Scheelite Flotation Tests Nos. 4, 5, and 6

Since the assaying of tungsten is rather lengthy, it was decided to run these tests as slop tests, and then to repeat any test which seemed to look favorable, assaying the products. The pH control was regulated with the addition of sulphuric acid, since the pulp prior to flotation had a pH of 9.8 to 10.0. Tables IX, X, and XI give the essential information about each test.
Table IX
Scheelite Flotation Test No. 4

Grind:
Primary: -20 mesh
Final: -150 mesh, Abbe' mill, 15 minute stages.

Water:
Grind: tap water
Flotation: tap water
Pulp dilution: 3 to 1
Per cent solids: 26%
Cell used: Fagergren laboratory cell

Reagents:
- Oleic Acid 0.30 lb per ton
- Sodium Oleate 0.20 lb per ton
- Pine Oil 1 drop
- H₂SO₄ 4 drops

The pH of the pulp prior to flotation was 9.8. By the addition of H₂SO₄, the pH was regulated at 6.4 which was maintained throughout the remainder of the test.

In this case, all of the scheelite remained in the tail product of the flotation test, thus indicating that scheelite does not float readily in an acid pulp.
Table X

Scheelite Flotation Test No. 5

Grind:
Primary: -20 mesh
Final: -150 mesh, Abbe’ mill, 15 minute stages.
Water:
Grind: tap water
Flotation: tap water
Pulp dilution: 3 to 1
Per cent solids: 26%
Cell used: Fagergren laboratory cell

Reagents:
Oleic Acid 0.30 lb per ton
Sodium Oleate 0.20 lb per ton
Fine Oil 1 drop

The pH of the pulp prior to flotation was found to be 10.0, and was left at this figure throughout the test.

In this case a small amount of scheelite was floated but the major portion remained in the tail product. This test corresponds to the results obtained in tests 1 and 3. This would seem to indicate that scheelite will float in an alkaline pulp, but that further pH control is necessary.
Table XI
Scheelite Flotation Test No. 6

Grind:
Primary: -20 mesh
Final: -150 mesh, Abbe' mill, 15 minute stages.

Water:
Grind: tap water
Flotation: tap water
Pulp dilution: 3 to 1
Per cent solids: 26%
Cell used: Fagergren laboratory cell

Reagents:
- Oleic Acid: 0.30 lb per ton
- Sodium Oleate: 0.20 lb per ton
- Pine Oil: 1 drop
- $H_2SO_4$: 2 drops
- Sodium Silicate: 0.30 lb per ton

The pH was regulated at 8.0 prior to flotation by the addition of $H_2SO_4$. The pH of the tail solution was 7.8 to 8.0.

In this case, the major proportion of the scheelite appeared in the concentrate product, with only a small amount remaining in the tail product. This would seem to indicate that with proper pH control, a reasonably good recovery of scheelite could be effected.
Discussion of Tests and Results Obtained

In order to test the products for the presence of scheelite, the slime deck on a Wilfley table was employed. Since the products were all minus 150 mesh and a good part minus 200 mesh, the slope of the table was adjusted at a minimum and only a small amount of water was used. Actual percentages of scheelite present were impossible to estimate, but the tabling showed very definitely where the major proportion of this mineral was concentrated.

In test No. 4, the pulp was at a pH of 6.4, and no scheelite was observed in the concentrate product of the flotation test, while a very definite amount was tabbed from the tail product. This seemed to be sufficient evidence that scheelite would not float in an acid pulp.

In test No. 5, with a pH of 10.0 only a small amount of scheelite was observed in the concentrate product of flotation, and the major proportion was observed on tabling of the tails product. This would seem to substantiate tests 1, 2, and 3 in which no pH control was practised, but for which the pH was 9.6 to 10.0.

In test No. 6, the pH was regulated at 8.0 prior to the addition of the reagents. In this case, when the concentrate product was tabbed, a large amount of scheelite was observed, whereas the tail product showed comparatively little to be present. This indicates that
with the proper regulation of the pH, some where near 8.0,
a reasonably good recovery of this mineral should be made.

Garnet seemed to follow the scheelite very closely in all of these three tests, and is very probably one of the
main reasons for the low grade products obtained in tests 1, 2, and 3. However, with proper reagents, this mineral
could be depressed.

The test run for sulphide flotation to determine the
reagents and concentrations which would give a high recovery of the gold values gave the following results.

Table XII
Sulphide Flotation

<table>
<thead>
<tr>
<th>Product</th>
<th>Wt. in grams</th>
<th>Wt. %</th>
<th>Assay (oz/ton)</th>
<th>Recovery(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conc.</td>
<td>552</td>
<td>79</td>
<td>1.36</td>
<td>98.0</td>
</tr>
<tr>
<td>Tails</td>
<td>148</td>
<td>21</td>
<td>0.05</td>
<td>2.0</td>
</tr>
<tr>
<td>Composite</td>
<td>700</td>
<td>100.0</td>
<td>1.10</td>
<td>100.0</td>
</tr>
</tbody>
</table>

This recovery proved successful so that the same
reagents were used in all of the following sulphide flotation tests to prepare a tailings product for scheelite flotation. Only a negligible amount of scheelite was floated with the sulphide concentrates, thus making these reagents more satisfactory.
CONCLUSIONS

In the main, the tests so far completed proved unsatisfactory in actual results, but indicate that a recovery of the scheelite from such a low grade material may be possible. As suggestions for further study, the writer offers the following:

1) Tests in which the pH control is closely regulated until a good recovery is obtained.

2) Variation of the reagents and their respective concentrations.

3) Investigation of the possibility of tabling the sulphide flotation tails in preference to the scheelite flotation.

4) Table tests of low grade tungsten concentrates to raise the grade to commercial standards.

The gold concentrates used in this thesis work are no longer a product of the Jardine mill, but this investigation should prove of some value in the treatment of higher grade tungsten ores. Tungsten concentration is now being practiced at Jardine, and due to the market price of this mineral, further investigation into its recovery should be most pertinent.

Of the above suggested tests, 4) seems to have considerable possibilities. In making the last three slop
tests, the products were tested for tungsten content by tabling, and it was very apparent that an improved grade of concentrate could be obtained by such an operation.

Due to limited time, this investigation is not complete, and hence this problem is worthy of considerable further study.
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