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The Benefication of a Low-Grade, Montana Scheelite Ore

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THE BENEFICIATION OF A LOW-GRADE,
MONTANA SCHEELITE ORE

by

Walter G. Parker

A Thesis

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

MONTANA SCHOOL OF MINES
BUTTE, MONTANA
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INTRODUCTION

The increasing importance of tungsten as an industrial metal and the recent discoveries of extensive deposits of low-grade tungsten ores in Montana led to the investigation which is reported in this paper. The purpose of this investigation was to determine if a saleable concentrate could be obtained from one of these low-grade, Montana scheelite ores.

History. Tungsten is a relatively new industrial metal. It was isolated and identified by the d'Elhuyar brothers, Don Fausto and Don Juan Jose, in 1783, but remained in the class of laboratory curiosities until early in the twentieth century when it found its first important use in tool steels and in sintered tungsten carbides.(2) From the turn of the century to date, the importance of tungsten has grown rapidly. The development of rockets and jet-propelled aircraft in the last decade has produced a great demand for the heat resistant alloys of tungsten.

The growth of the prospecting, mining, beneficiation, and chemical processing of tungsten ores has been marked by the same series of developments as noted in the history of other industrial metals.(2) That is, the initial demands were met by the exploitation of the easily found, high-grade deposits. These high-grade ores were beneficiated by gravity concentration methods which were typified by high-grade concentrates and low recoveries. The depletion of the high-grade deposits was followed by the utilization of medium-grade ores and by the refinement of the beneficiation methods to include the application of flotation to the relatively high-grade tailings produced by gravity concentration methods. At the

present time, the tungsten industry is turning to the task of utilizing its low-grade ores.

Until recently, no attempt had been made to exploit these low-grade ores, because of the great price fluctuations to which tungsten has been subjected for the past fifty years. However, shortly after the last war, the price of tungsten fell to \$20.00 per unit, and much of the domestic tungsten mining industry was forced to shut down. By 1951, the government became aware that 80 percent of the world's supply of tungsten had passed into the control of Russian-dominated countries. Faced with a potential shortage of this strategic metal, the government established a base price of \$63.00 per unit for tungsten concentrates of suitable grade. With the price stabilized at this level many old producers have gone back into production, and many new deposits are being exploited.

Occurrence. The common ore minerals of tungsten are scheelite, CaWO_4 ; hubnerite, MnWO_4 ; wolframite, $(\text{FeMn})\text{WO}_4$; and ferberite, FeWO_4 . These last three, hubnerite, wolframite, and ferberite, have very similar physical properties and are members of an isomorphous family of minerals whose composition varies from FeWO_3 to MnWO_3 . If the mineral is less than 20 percent FeWO_4 it is called hubnerite, and if it is less 20 percent MnWO_4 it is called ferberite. These limits are purely arbitrary, and any member of this family can be called wolframite.

Table I shows some of the important properties of these minerals.

(16)

Table I

<u>Composition</u>	<u>Weight Percent WO₃</u>	<u>Color</u>	<u>Specific Gravity</u>	<u>Hardness</u>
CaWO ₄	80.6	White-Yellow	6.0	4.5-5.0
FeWO ₄	76.4	Black	6.9	5.0-5.5
(FeMn)WO ₄	76.5	Black-Brown	7.2	5.0-5.5
MnWO ₄	76.6	Brown	7.3	5.0-5.5

Tungsten minerals are commonly found in place in contact-metamorphic deposits pegmatites, disseminated grains in igneous masses, and veins. (8) They are most often found as veins or as fine grains disseminated throughout the ore body. They often occur as accessory minerals in gold ores and in deposits of sulfides of heavy metals such as copper, silver, lead, zinc, and molybdenum. The most important gangue minerals are quartz, calcite, apatite, fluorite, garnet, and other complex silicates.

In addition to the occurrence of tungsten minerals in place, they have also been found in placer deposits, for, although they are friable, they are heavy and are resistant to chemical weathering. Another very minor occurrence is in the form of hot-spring deposits. (8)

Marketing requirements. Tungsten concentrates are marketed on the basis of tungstic oxide (WO₃) content. The specifications that a tungsten concentrate has to meet vary according to the intended use. A typical set of specifications is shown in Table II. (10) In many cases, when the market is heavy, industry will accept only carload lots (35 tons).

The government base price of \$63.00 per unit applies only to high

Table II

WO ₃	60-70%
Mo (max)	0.10%
Sn (max)	Trace
As (max)	0.035%
Sb (max)	0.035%
Bi (max)	0.035%
Cu (max)	0.05%
S (max)	0.75%
P (max)	0.05%

grade concentrates such as that shown in Table II. The industry will accept lower grade concentrates down to 10 percent WO₃, but these are heavily penalized.

SURVEY OF FLOTATION METHODS

In flotation technology minerals are divided into two general classes, metallic and non-metallic. Native metals and most metal sulfides are members of the metallic group and respond to a particular type of flotation. Siliceous minerals, halides, carbonates, phosphates, most metal oxides, etc. are members of the non-metallic class and respond to another type of flotation. (14)

In non-metallic flotation the collectors used usually show a very low degree of selectivity. Because of this, the success of a non-metallic flotation often depends upon the addition of and the careful regulation of modifying agents. These modifying agents are used to depress the gangue minerals and to activate the ore minerals. The collectors commonly used in tungsten flotation are the fatty acids and soaps of fatty acids. Some of the most common are oleic acid, Elastoil (fish oils), Aliphat (cottonseed oil foots and oleic acid), sodium oleate, sodium stearate, Orso (sulfonated fatty acids), etc. Some of the most common modifying agents are sodium silicate, tannic acid, quebracho, Emulsol X-1, Aerosol 18, Aerosol OT, sodium carbonate, and sodium hydroxide. (14) The sodium silicate, tannic acid, and quebracho are used for depressing the gangue; the Emulsol X-1, Aerosol 18, and Aerosol OT are used for aiding the selectivity and the frothing characteristics; the sodium carbonate and sodium hydroxide are used for pH regulation. Pine oil and cresylic acids are the common frothing agents used.

One of the most common troubles encountered in soap flotation is the formation of insoluble earth-metal soaps, and because of this, the

water used must be soft.(3,4,14) The greatest offenders in this respect are the calcium ions and the magnesium ions which commonly occur in hard waters. The addition of excess carbonate ion, usually added as sodium carbonate, is often sufficient to satisfactorily precipitate out these earth-metal ions.

Because of the friability of most tungsten ores, there is always a high loss of tungsten in the slimes when gravity concentration methods are used. The first application of flotation to tungsten ores was made in an attempt to recover these slime losses. Now that low-grade ores are being utilized, in most cases the tungsten mineral particle-size is so small that gravity concentration methods cannot be used, and flotation is being applied as the primary concentration method.

In general, a tungsten flotation results in a recovery between 70 and 90 percent, but the concentrate produced ranges from 2 to 75 percent WO_3 , depending upon the grade of the feed. The low-grade concentrates are sometimes up-graded on a slime table to a WO_3 content of from 50 to 65 percent.(9) This results in a saleable product, but the recovery from the tabling circuit is only from 50 to 80 percent. Another type of up-grading often resorted to is a mild hydrochloric acid leach. This process will remove lime and phosphate which often are the principal contaminants in a flotation concentrate.(10) However, some tungsten is invariably lost in this process regardless of how closely it is controlled.

If it is possible for the tungsten miner to build a processing plant at or near the mine and mill, the low grade flotation concentrate

need not be up-graded, because the most modern and efficient method of tungsten processing, the pressure reactor process, works most efficiently on a 10 percent WO_3 concentrate.(2) The small producer, however, is often forced to up-grade the flotation concentrate and to suffer a loss in over-all recovery in order to keep freight rates at a minimum and to meet the market requirements.

PROCEDURE AND DATA

The ore tested was a low-grade scheelite ore from Marysville, Montana. The sample was submitted by Messrs. W. R. Wade and H. G. Obendorf, both of Marysville.

Sample preparation. The ore, as received, weighed about 800 pounds and consisted of large pieces, free of fines, averaging four inches in diameter. The presence of lichens on many of the pieces indicated that the majority of the sample was taken from the surface of the outcrop. It may be that a fresher, less weathered sample would give different flotation results than the sample tested.

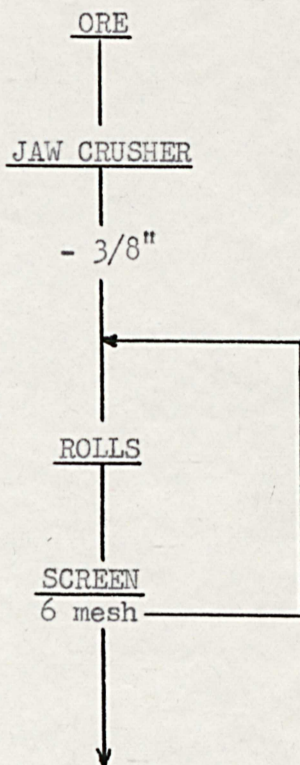
Several representative pieces were selected at random to furnish material for briquetting and thin section preparation. The remainder of the ore was crushed in the laboratory jaw crusher to all minus 0.371 inches and then crushed to all minus six mesh in the laboratory rolls. The ore is extremely hard and extremely tough. In the finer sizes the particles tend to be flat, plate-like shapes which pass through the rolls without being crushed. Figure I shows the crushing circuit.

Sampling and chemical analyses. After comminution to minus six mesh the whole ore sample was dumped on the laboratory floor, thoroughly mixed, and coned and quartered. The sample was further reduced in size through the Jones riffle until a twenty-pound sample was obtained. This twenty-pound sample was reduced to all minus two-hundred mesh in Braun pulverizer, thoroughly mixed, and divided into four five-pound samples.

Since the beneficiation of this ore was one of the projects of the

Figure I

CRUSHING CIRCUIT -- FLOW SHEET



Montana Bureau of Mines and Geology, practically all of the chemical analyses were run by the Bureau's analyst.* The procedure used was one of the standard methods using cinchonine as a specific organic precipitant on a sample of five grams. Although this method is recommended by many chemists, it was soon found to be insufficiently sensitive for low grade ores. For example, this ore had previously been assayed by a commercial analyst who reported a WO_3 content of 0.30 percent. The owners of the claim stated that this analyst used a method which handled a two-hundred-gram sample. The sample which was prepared from the ore received here showed an assay of 0.015 percent WO_3 . The owners of the claim were informed of this low assay. Further verbal correspondence with them revealed that they had had the ore assayed by several commercial analysts using the standard procedure and the results from these assays showed the ore to have a WO_3 content of 0.01 to 0.05 percent WO_3 .

Further verification of the inaccuracy of the standard method of tungsten analysis was obtained in a conference with Mr. R. B. Shaw of the Minerals Engineering Company. He pointed out that his company had found that reliable tungsten assays on low-grade ores could only be obtained by using at least two-hundred grams of sample. He also said that their laboratory customarily used a small pressure-reactor which handled a 200 gram sample and that this system gave results that correlated very closely with the recoveries actually obtained in their refining plant.

Therefore, in spite of the low WO_3 content reported by the

* Mr. Clem J. Bartzen, Analyst

analyst, several flotation and jig tests were run, and the products were sent for analysis. The composite head assays computed from these analyses showed a wide variation from 0.059 to 0.237 percent WO_3 , and all of the tailing assays were reported as 0.01 percent WO_3 , regardless of the success of the particular concentration step. However, the more successful the operation was, the closer the composite assay was to 0.300 percent.

The above facts led to the conclusion that only the concentrates and middlings from any tests would be sent to the analyst, and that the tailings would be assumed to have a WO_3 content of 0.01 percent. Any critical tests would be run by the author using the laboratory digester bomb and, if possible, a 200 gram sample. Wherever a tailing assay shown in the appendices was assumed to be 0.01 percent WO_3 it is underlined in red.

Mineralogical examinations. The various size fractions of the screen analysis of the crushing circuit product were examined with the binocular microscope. Garnet, scheelite, limestone, and quartz were the only minerals which could be identified as being present in any quantity. However, very minor amounts of sulfides were also observed.

The average specific gravity of the ore was determined with the Jolly balance and was recorded as 3.14. A sample of the limestone waste which occurs with the ore was tested on the same apparatus and was recorded as 2.88. These figures are the averages of approximately twenty measurements on each material.

Liberation studies. The large pieces of ore as received were given a visual examination with the aid of a pocket rule and a fluorescent lamp. This method was highly unsatisfactory because the grain sizes were so small---less than one millimeter.

The products of the screen analysis of the crushing circuit product were examined with the aid of the binocular microscope and the fluorescent lamp. This examination showed that liberation started at about 35 mesh and was satisfactorily complete between 150 and 200 mesh.

No particle count was attempted, because the difficulty in identifying scheelite particles without using the fluorescent lamp would have made this method unnecessarily tedious.

Ten samples of the minus six mesh material were run through the laboratory rod mills at various pulp dilutions, time periods, and weights of pulp. Screen analyses were made of these products, and the results are recorded in Appendix I together with rod mill size, load, and speed. Examination of the screen analyses products under the binocular microscope verified the previous liberation studies.

The liberation and mineralogical studies indicated that flotation would probably be the primary concentration method and that a 600 gram sample ground at 50 percent solids for 15 to 20 minutes should be ideal for flotation purposes.

Gravity concentration. Although the liberation studies indicated that gravity concentration methods could not be successfully applied to this ore, several jig and table tests were run. The results of these

tests, shown in Appendix II, were as low as they were expected to be.

A series of five jig tests were run in which the feed size was varied. Table III shows the results of these runs. The composite assays for these tests ranged from 0.239 to 0.333 percent WO_3 . This table shows

Table III

<u>Mesh Size of Feed</u>	<u>% Recovery</u>	<u>Grade (% WO_3)</u>
-14	10.74	1.40
-20	19.28	2.55
-28	24.74	2.15
-35	17.23	3.40
-48	11.66	1.10

that the optimum size for jigging is about 28 mesh. The grades of the concentrates shown in this table are much too low, of course, for a commercial application, but further experimentation showed that these concentrates could be cleaned with jig or table to about 60 percent WO_3 with a slight drop in recovery.

Another test was run in which the jig tailings were retreated on a table. The results of this test are shown in Table IV. This test

Table IV

	<u>% Recovery</u>	<u>Grade (% WO_3)</u>
Jig concentrate	7.11	60.4
Table concentrate	9.28	38.7
Tailings	83.61	0.251
Composites	100.00	0.300

indicated that tabling alone might effect an equally good separation.

Table V shows the results of such a table test. The feed for this test

Table V

	<u>% Recovery</u>	<u>Grade (% WO₃)</u>
Table concentrate	22.90	37.4
Table tailings	77.10	0.260
Composite	100.00	0.298

was all minus 48 mesh, and it is probable that better results could be obtained if the feed was even finer. The concentrate from the tables can be up-graded to about 60 percent WO₃, but the recovery is cut in half by doing so.

The overall results of the gravity concentration testing shows that only 10 to 15 percent of the total tungstic oxide content can be recovered in the form of a premium concentrate, i.e. 60 percent WO₃ or better. The optimum size of feed for jigging is about 28 mesh and optimum size of feed for tabling is between 48 and 65 mesh.

Flotation testing. Since no previous testing had been done on this ore, a number of spot tests were run to determine if the scheelite could be concentrated by any of the standard reagent combinations. Over a hundred individual flotation tests were run, about fifteen of which are tabulated in Appendix III as being significant. All of these tests were run on the 600 gram laboratory Fagergren Flotation Cell, and all of the

grinding was done in the laboratory rod mill. Practically all of these tests were run at night so visual examination of the concentrates could be made with the fluorescent lamp.

The inadequacy of the standard assaying procedures led to some difficulties in the evaluation of the flotation tests. Although the percent distribution and recovery are recorded in the appendices, the figure which was used in the evaluation of the tests was the composite assay. The reason for this is that the assays on the concentrates, which ranged from 0.9 to 5.0 percent WO_3 , seemed to be accurate while the assays on the tailings and some of the low-grade middlings were inaccurate. Therefore, as was pointed out in the section on sampling and assaying, any deviation of the composite head assay from 0.300 percent tungstic oxide can be assumed to be due to the inaccuracy of the assay on the low-grade tailings. The recoveries shown were computed from the composite head assay reported for the particular test. So, the recoveries, as shown, are not valid unless the composite head assay for the test in question is comparatively close to 0.300 percent.

A study was made of the reaction of the ore to pH regulation. These tests showed the ore to have a natural buffering action which prevented the pH from going below 8.40 unless an exorbitant amount of acid was added. The pH of the crushing circuit product, diluted to 50 percent solids with both distilled and tap water, was recorded at ten minutes and two hours. The pH with distilled water was 9.10 and with the tap water was 9.72, with no variation with time. The tap water used in this test had a pH of 8.49. The pH of the grinding tests varied from 8.40 to 8.92

with the average at 8.78. The tap water during the grinding tests showed a pH of 8.10.

The first reagent combination tried was that using oleic acid, sodium silicate, sodium carbonate, tannic acid or quebracho, and pine oil or cresylic acid. Aerosol OT and Aerosol 18 were also tried as secondary promoters in several tests. Only three of these tests were recorded as being typical. Although a sufficiently high grade of concentrate could be produced for further concentration on a slime table, the best results running 1.50 to 5.00 percent WO_3 , the recoveries were so low that this reagent combination was discarded.

However, the testing did indicate that recirculation of the middlings in order to up-grade the feed to the rougher flotation cell would result in much higher grades as well as recoveries. The tests further indicated that tannic acid was a useful depressing agent, especially for the limestone, but that it would be extremely difficult to handle in a plant scale operation. Quebracho apparently did as good a depressing job as the tannic acid, and was much easier to handle. Aerosol OT helped to produce the "lacey" type of froth desired, but, outside of that, it seemed to have little effect. The Aerosol 18 also promoted the formation of a desirable froth and also seemed to have some mild collecting properties with respect to scheelite. Other Aerosols were tried, but none were as effective as the Aerosol 18. Among the frothing agents tried, pine oil seemed to be the best, although the cresylic acid was satisfactory.

A number of tests were run grinding with distilled water in a pebble mill, to determine if the water was not being softened sufficient-

ly by the sodium carbonate or if the iron contamination from the rod mill was activating the gangue. These tests showed no noticeable improvement over the standard procedure.

Another group of tests were tried using sodium oleate and mixtures of sodium oleate and oleic acid. These tests showed little improvement over the tests with oleic acid alone and all of them were discarded.

The next collector tried was Elastoil LL, a mixture of refined fish oils, using the same modifying agents as were used with the oleic acid. These tests showed a little improvement over those in which oleic acid was used. Near the end of this series several tests were completed using saponified Elastoil. This reagent gave much better results than the straight Elastoil.

The next reagent combination tested was a mixture obtained from the Anaconda Copper Mining Company. This mixture contained cottonseed oil foots, American Cyanamid Reagents S-470, and sodium hydroxide in aqueous solution. The same modifying reagents were used as in the other tests. This series of flotations was much more successful than the previous ones had been.

During these tests it was noted that the wetting agent Aerosol 18 was doing some collecting on its own. A number of tests were run to determine if this reagent could be used as a collector. Reference to Appendix III shows that these tests were outstanding as compared to the previous flotation runs with other reagents.

Aerosol 18 is said by the American Cyanamid Company to be N-octadecyl disodium sulfo-succinimate. When used alone it seems to have

an affinity for the siliceous gangue; no scheelite at all is floated. However, very small amounts of sodium silicate cause the froth to drop the siliceous gangue and to float the scheelite. Apparently the collecting power of this reagent is rather weak, because the larger particles of scheelite remain in the sink. It was found that, although a 15 to 20 minute grind was satisfactory for the more commonly used collectors, the Aerosol 18 required a grind of from 25 to 30 minutes for satisfactory collection.

The principal objection to the use of Aerosol as a collecting agent is that the froth produced is much too stiff to be handled in a conventional type of flotation machine. Many of the common frothing agents were tried in conjunction with this reagent and, although the character of the froth became satisfactory, all of these frothing agents adversely effected the collection of the scheelite. Unless some satisfactory frothing agent is found, a flotation machine using this reagent combination must be equipped with a positive mechanical method of froth removal. However, it is felt that this reagent and other sulfonated hydrocarbons may be worthy of further research with respect to their selectivity for scheelite in flotation.

Reference to Table VI, which shows the best tests with the different types of collectors tried, indicates that either cottonseed oil foots or the saponified Elastoil can be used satisfactorily with this ore. The results achieved should at least equal those currently being attained by other scheelite flotation plants using different reagents.

Table VI

<u>Test</u>	<u>Collector</u>	<u>Composite (% WO₃)</u>	<u>Grade (% WO₃)</u>	<u>Recovery %</u>
FH-51	Oleic Acid	0.177	1.65	95.0
FH-12	Elastoil	0.177	0.99	95.4
FH-87	Saponified Elastoil	0.208	2.01	94.0
FH-56	Cottonseed Oil Foots	0.235	2.05	96.4
FH-70	Aerosol 18	0.280	2.75	96.7

CONCLUSIONS

The ore tested was a low-grade scheelite ore averaging about 0.300 percent WO_3 . The principal gangue constituents were garnet, quartz, and limestone. The fine size of the scheelite grains disseminated throughout the ore coupled with the friability of the scheelite as compared to the relative toughness of the garnet and quartz renders the ore unsuitable for gravity concentration methods. The one possible exception to this would be that the pre-existing mill facilities at Marysville might have tables or jigs already set up for operation.

The primary method of concentration must necessarily be flotation. This ore is amenable to the standard methods of flotation as practiced at present. This means that about 80 to 90 percent of the scheelite will be recoverable as a concentrate of about 10 to 12 percent WO_3 , or that about 50 percent of the scheelite will be recoverable as a concentrate of about 60 percent WO_3 .

Therefore, there are four possible concentration schemes to consider. These are outlined in Table VII. The choice of flowsheet depends,

Table VII

<u>Method</u>	<u>Expectable Recovery (% Total WO_3)</u>	<u>Expectable Grade (% WO_3)</u>
1. Flotation	80 - 90	10 - 15
2. Flotation Followed by Slime Table	40 - 50	60 - 65
3. Jigging or Tabling	10 - 12	60 - 65
Flotation	70 - 80	10 - 15
4. Jigging or Tabling	10 - 12	60 - 65
Flotation Followed by Slime Table	35 - 40	60 - 65

naturally, on which method will show the most profit. The lowest grade of concentrate which will be accepted by the refineries at present is 10 percent. This concentrate is worth about \$38.00 per unit or \$380.00 per ton F.O.B. refinery. A concentrate of over 65 percent WO_3 is worth about \$65.00 per unit or \$4225.00 per ton F.O.B. refinery. The price per unit of contained WO_3 varies between these two limits. As far as this particular ore is concerned, there might be a penalty because of its molybdenum content. A concentrate from this ore with a WO_3 content of 60.4 percent has a molybdenum content of 0.68 percent. The other impurities in this concentrate are either harmless or well below the stated maximum content. Using the minimum expectable recoveries and grades as shown in Table VII, the value of the ore in place can be computed. These values are shown in Table VIII. However, these values do not take into

Table VIII

<u>Method</u>	<u>Value</u>
1.	\$9.12 per ton
2.	\$7.68 per ton
3.	\$10.80 per ton
4.	\$8.64 per ton

consideration the differences in the costs of treatment for the different methods nor do they take into account the differences in the costs of shipping the concentrates to the refinery. This table is merely presented to point out that the differences between the various methods of concentration result in only minor differences in the recoverable dollar value of the ore.

It is evident that the exploitation of this ore will be, at best, a marginal operation even with the present, high, government-subsidized price of tungsten concentrate. There are, however, two other factors which might, in the future, effect the marginal character of this ore body. The first is that a refinery could be built in a more accessible location as far as this deposit is concerned. The second is that some method of up-grading may be devised to re-treat low-grade flotation concentrates without the extreme drop in recovery suffered when using a slime table.

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APPENDIX I

Crushing Circuit Screen Analysis

Rod Mill Specifications

Grinding Tests - Screen Analyses

SCREEN ANALYSIS

Crushing Circuit Product

<u>Mesh</u>	<u>Grams</u>	<u>% Held</u>	<u>% Cum.</u>
8	6.4	1.1	
10	94.8	16.4	17.5
14	126.4	21.9	39.4
20	98.2	17.0	56.4
28	67.7	11.7	68.1
35	43.2	7.5	75.6
48	30.7	5.3	80.9
65	21.2	3.7	84.6
100	18.7	3.2	87.8
150	12.9	2.2	90.0
200	10.7	1.8	91.8
-200	46.2	8.0	99.8
	<hr/>	<hr/>	
	577.1	99.8	

ROD MILL LOAD

<u>Diameter</u>	<u>Number</u>
1 1/2 inches	1
1 1/8 inches	1
5/8 inches	12
3/8 inches	10
1/4 inches	2

Weight of Rods = 12.23 kilograms

ROD MILL SPECIFICATIONS

Speed 48 rpm
Inside diameter 8 1/8 in.
Inside length 10 in.

SCREEN ANALYSIS

Rod Mill

Time: 5 minutes
% Solids: 50%
Wt. of Sample: 600 grams

<u>Mesh</u>	<u>Grams</u>	<u>% Held</u>	<u>% Cum.</u>
14	5.9	1.0	
20	24.0	4.1	5.1
28	74.6	12.7	17.8
35	97.0	16.5	34.3
48	77.0	13.1	47.4
65	59.1	10.0	57.4
100	48.0	8.2	65.6
150	33.2	5.6	71.2
200	26.4	4.5	75.7
-200	<u>142.4</u>	<u>24.2</u>	99.9
	587.6	99.9	

SCREEN ANALYSIS

Rod Mill

Time: 10 minutes
% Solids: 50%
Wt. of Sample: 600 grams

<u>Mesh</u>	<u>Grams</u>	<u>% Held</u>	<u>% Cum.</u>
35	1.2	0.2	
48	9.6	1.9	2.1
65	94.6	18.5	20.6
100	102.0	19.9	40.5
150	67.5	13.2	53.7
200	39.6	7.7	61.4
-200	<u>197.9</u>	<u>38.6</u>	100.0
	512.4	100.0	

SCREEN ANALYSIS

Rod Mill

Time: 15 minutes

% Solids: 50%

Wt. of Sample: 600 grams

<u>Mesh</u>	<u>Grams</u>	<u>% Held</u>	<u>% Cum.</u>
35	1.2	0.2	
48	1.9	0.3	0.5
65	20.0	3.4	3.9
100	99.3	17.1	21.0
150	92.8	16.0	37.0
200	69.5	12.0	49.0
-200	<u>295.6</u>	<u>50.9</u>	99.9
	580.3	99.9	

SCREEN ANALYSIS

Rod Mill

Time: 20 minutes

% Solids: 50%

Wt. of Sample: 600 grams

<u>Mesh</u>	<u>Grams</u>	<u>% Held</u>	<u>% Cum.</u>
35	0.6	0.1	
48	0.8	0.1	0.2
65	2.5	0.4	0.6
100	19.6	3.2	3.8
150	79.0	12.7	16.5
200	87.2	14.0	30.5
-200	<u>430.7</u>	<u>69.4</u>	99.9
	620.4	99.9	

SCREEN ANALYSIS

Rod Mill

Time: 10 minutes

% Solids: 60%

Wt. of Sample: 720 grams

<u>Mesh</u>	<u>Grams</u>	<u>% Held</u>	<u>% Cum.</u>
28	1.1	0.2	0.6
35	3.1	0.4	6.5
48	41.6	5.9	24.9
65	130.8	18.4	39.9
100	106.4	15.0	49.4
150	67.2	9.5	55.9
200	46.3	6.5	100.0
-200	<u>313.3</u>	<u>44.1</u>	
	709.8	100.0	

SCREEN ANALYSIS

Rod Mill

Time: 10 minutes

% Solids: 70%

Wt. of Sample: 840 grams

<u>Mesh</u>	<u>Grams</u>	<u>% Held</u>	<u>% Cum.</u>
20	4.0	0.5	4.2
28	30.6	3.7	17.3
35	109.4	13.1	33.6
48	135.6	16.3	45.4
65	98.6	11.8	54.1
100	72.2	8.7	60.1
150	50.4	6.0	64.8
200	39.0	4.7	100.0
-200	<u>292.8</u>	<u>35.2</u>	
	832.6	100.0	

SCREEN ANALYSIS

Rod Mill

Time: 10 minutes
% Solids: 50%
Wt. of Sample: 1000 grams

<u>Mesh</u>	<u>Grams</u>	<u>% Held</u>	<u>% Cum.</u>
20	2.6	0.3	
28	26.7	2.7	3.0
35	124.2	12.5	15.5
48	158.9	16.0	31.5
65	136.9	13.8	45.3
100	105.6	10.6	55.9
150	73.7	7.4	63.3
200	59.0	5.9	69.2
-200	<u>307.0</u>	<u>30.9</u>	100.1
	994.6	100.1	

SCREEN ANALYSIS

Rod Mill

Time: 10 minutes
% solids: 60%
Wt. of samples: 1200 grams

<u>Mesh</u>	<u>Grams</u>	<u>% Held</u>	<u>% Cum.</u>
14	6.5	0.5	
20	42.8	3.6	4.1
28	155.5	13.1	17.2
35	199.5	16.8	34.0
48	136.0	11.5	45.5
65	115.2	9.7	55.2
100	98.5	8.3	63.5
150	75.9	6.4	69.9
200	54.2	4.6	74.5
-200	<u>302.3</u>	<u>25.5</u>	100.0
	1186.4	100.0	

APPENDIX II

Gravity Concentration Data

Typical Jig Setting

Feed 50% solids
Bedding Size -6 -14 mesh
Bedding Depth 3/4 inch
Stroke Length 3/8 inch
Water Valve Setting 3/8
Water Supply Low
Weight of Balls 170.5 grams

Jig Test Results

JH-1 Feed Size -14 mesh

<u>Products</u>	<u>Wt. in Grams</u>	<u>% WO₃</u>	<u>% Distribution</u>
Concentrate	120.5	1.40	10.74
Tailing	<u>5851.0</u>	<u>0.24</u>	<u>89.25</u>
Composite	5971.5	0.263	99.99

JH-2 Feed Size -20 mesh

<u>Products</u>	<u>Wt. in Grams</u>	<u>% WO₃</u>	<u>% Distribution</u>
Concentrate	134.5	2.55	19.28
Tailing	<u>5742.5</u>	<u>0.250</u>	<u>80.72</u>
Composite	5877.0	0.303	100.00

JH-3 Feed Size -28 mesh

<u>Products</u>	<u>Wt. in Grams</u>	<u>% WO₃</u>	<u>% Distribution</u>
Concentrate	133.0	2.15	24.74
Tailing	<u>4703.6</u>	<u>0.185</u>	<u>75.26</u>
Composite	4836.0	0.239	100.00

JH-4 Feed Size -35 mesh

<u>Products</u>	<u>Wt. in Grams</u>	<u>% WO₃</u>	<u>% Distribution</u>
Concentrate	102.6	3.40	17.23
Tailing	<u>5985.0</u>	<u>0.280</u>	<u>82.77</u>
Composite	6087.6	0.333	100.00

JH-5 Feed Size -48 mesh

<u>Products</u>	<u>Wt. in Grams</u>	<u>% WO₃</u>	<u>% Distribution</u>
Concentrate	164.5	1.10	11.66
Tailing	<u>5713.0</u>	<u>0.240</u>	<u>88.34</u>
Composite	5877.5	0.264	100.00

Jig - Table Test

<u>Products</u>	<u>Wt. in Grams</u>	<u>% WO₃</u>	<u>% Distribution</u>
Jig Concentrate	1.88	60.4	7.11
Jig Tailing	5328.32	0.279	92.87
Table Concentrate	3.82	38.70	9.28
Table Tailings	5324.50	0.251	83.61

Table Test

<u>Products</u>	<u>Wt. in Grams</u>	<u>% WO₃</u>	<u>% Distribution</u>
Concentrate	10.86	37.40	22.90
Tailings	5910.0	0.300	77.10

APPENDIX III

Flotation Data

SCHEELITE FLOTATION TEST NO. FH-5

Grind:

Primary: -6 mesh
 Final: Rod mill, 10 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	14.8	2.4	3.00	57.1
Middling No. 1	32.1	5.3	0.63	26.0
Middling No. 2	10.0	1.6	0.76	10.4
Tailings	547.9	90.6	0.01	6.5
<hr/>				
Composite	604.8	99.9	0.127	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Sodium Silicate	1.5				
Quebracho	0.1				
Oleic Acid		0.25	0.50		
Cresylic Acid		0.1	0.1	0.1	0.1
Aerosol 18	0.3				
Sodium Carbonate	2.0				

Remarks: Three stage flotation.

SCHEELITE FLOTATION TEST NO. FH-6

Grind:

Primary: -6 mesh
 Final: Rod mill, 15 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	24.7	4.0	1.75	84.3
Middling	29.7	4.8	0.07	3.9
Tailings	557.0	91.1	0.01	1.8
<hr/>				
Composite	611.4	99.9	0.083	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Sodium Silicate	1.5				
Quebracho	0.1				
Oleic Acid		0.25			
Cresylic Acid		0.20	0.05		
Aerosol OT			0.6		
Sodium Carbonate		3.0			

Remarks: Four stage flotation.

SCHEELITE FLOTATION TEST NO. FH-51

Grind:

Primary: -6 mesh
 Final: Rod mill, 15 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	68.9	10.2	1.65	95.0
Tailings	609.8	89.8	<u>0.01</u>	5.0

Composite	678.7	100.0	0.177	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Oleic Acid			1.80		
Sodium Carbonate	10.0				
Sodium Silicate	2.0				
Pine Oil			0.6		
Tannic Acid			0.06		

Remarks: Four stage flotation.

SCHEELITE FLOTATION TEST NO. FH-16

Grind:

Primary: -6 mesh
 Final: Rod mill, 12 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	24.2	1.3	7.00	64.8
Middling No. 1	105.4	5.8	0.28	11.5
Middling No. 2	43.4	2.4	1.07	17.6
Tailings	1627.0	90.4	<u>0.01</u>	6.1
<hr/>				
Composite	1800.0	99.9	0.145	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Quebracho	1.0				
Aerosol 18	1.8	1.8			
Elastoil LL			2.05		
Sodium Carbonate	2				

Remarks: Three stage flotation, three 600 gram samples, each concentrate cleaned once, middlings recirculated to next sample, all concentrate combined and recleaned.

SCHEELITE FLOTATION TEST NO. FH-11

Grind:

Primary: -6 mesh
 Final: Rod mill, 8 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	8.2	1.4	2.25	20.4
Middling	51.7	8.6	1.25	73.9
Tailings	543.8	90.1	0.01	5.7
<hr/>				
Composite	603.7	100.1	0.146	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Sodium Silicate	3.0				
Aerosol OT	0.3				
Elastoil LL			0.65		
Sodium Carbonate	2.0				

Remarks: Four stage flotation.

SCHEELITE FLOTATION TEST NO. FH-12

Grind:

Primary: -6 mesh
 Final: Rod mill, 10 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	13.6	2.2	1.40	17.6
Middling	90.0	14.8	0.93	77.8
Tailings	506.0	83.0	0.01	4.6

Composite	609.6	100.0	0.177	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Sodium Silicate	1.5				
Quebracho	0.10				
Sodium Carbonate		2.1			
Aerosol OT		0.18			
Elastoil LL			0.24		

Remarks: Three stage flotation.

SCHEELITE FLOTATION TEST NO. FH-18

Grind:

Primary: -6 mesh
 Final: Rod mill, 12 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	20.8	3.3	3.25	84.0
Middling	35.4	5.7	0.19	8.6
Tailings	566.4	91.0	0.01	7.4

Composite	622.6	100.0	0.130	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Tannic Acid		0.5			
Aerosol 18		0.6			
Elastoil LL			1.06		
Sodium Carbonate	2				

Remarks: Three stage flotation.

SCHEELITE FLOTATION TEST NO. FH-59

Grind:

Primary: -6 mesh
 Final: Rod mill, 15 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	88.6	10.0	1.41	96.1
Tailings	534.4	90.0	<u>0.01</u>	3.9

Composite	623.0	100.0	0.208	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Sodium Silicate	1.0				
Aerosol 18	0.6				
Sodium Carbonate	2.0				
Saponified Elastoil		1.0			
Pine Oil			0.3		

SCHEELITE FLOTATION TEST NO. FH-66

Grind:

Primary: -6 mesh
 Final: Rod mill, 25 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	121.6	20.3	0.98	96.0
Tailings	478.4	79.7	<u>0.01</u>	4.0
<hr/>				
Composite	600.0	100.0	0.207	99.9

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Sodium Silicate	3.0				
Calgon	0.5				
Aerosol AY			0.6		
Cottonseed Foots			16.0		

Remarks: Three stage flotation. Froth much too stiff.

SCHEELITE FLOTATION TEST NO. FH-64

Grind:

Primary: -6 mesh
 Final: Rod mill, 25 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	47.5	7.9	1.65	92.8
Tailings	552.5	92.1	<u>0.01</u>	7.2
<hr/>				
Composite	600.0	100.0	0.140	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Calgon	2.0				
Sodium Silicate	3.0				
Aerosol 18		0.6			
Cottonseed Foots		6.4	22.4		
Pine Oil			0.95		

Remarks: Three stage flotation.

SCHEELITE FLOTATION TEST NO. FH-24

Grind:

Primary: -6 mesh
 Final: Rod mill, 11 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	24.6	3.8	3.25	84.2
Middling	45.2	7.0	0.19	9.5
Tailings	573.7	89.2	<u>0.01</u>	6.3

Composite	643.5	100.0	0.148	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Tannic Acid	0.09				
Sodium Silicate	1.8				
Sodium Phosphate	0.5				
Cottonseed Oil					
Foots		4.8			
Aerosol 18		0.90			

Remarks: Two stage flotation.

SCHEELITE FLOTATION TEST NO. FH-56

Grind:

Primary: -6 mesh
 Final: Rod mill, 15 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	66.5	11.1	2.05	96.4
Tailings	533.5	88.9	<u>0.01</u>	3.6

Composite	600.0	100.0	0.235	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Sodium Silicate	0.30		1.5		
Aerosol 18		1.20			
Tannic Acid			0.06		
Cottonseed Oil					
Foots			3.2		

Remarks: pH = 8.3, temperature at flotation was 40°.

SCHEELITE FLOTATION TEST NO. FH-26

Grind:

Primary: -6 mesh
 Final: Rod mill, 11.5 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	47.8	3.6	1.75	40.4
Middling	114.2	8.7	0.98	53.8
Tailings	1155.0	87.7	<u>0.01</u>	5.7

Composite	1317.0	100.0	0.158	99.9

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Cottonseed Oil			16.0		
Foots					
Tannic Acid	0.18	0.18			
Sodium Silicate	3.6	3.60		2.4	
Aerosol 18					

Remarks: Two 600 gram samples rougher concentrates combined and cleaned.

SCHEELITE FLOTATION TEST NO. FH-70

Grind:

Primary: -6 mesh
 Final: Rod mill, 25 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	118.2	9.8	2.75	96.7
Tailings	1083.9	90.2	<u>0.01</u>	3.3

Composite	1202.1	100.0	0.280	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Sodium Silicate	1.8				
Aerosol 18	1.80		0.60		

Remarks: Two stage flotation. Two 600 gram sample, concentrates combined, tried to reclean, but there was too much froth.

SCHEELITE FLOTATION TEST NO. FH-53

Grind:

Primary: -6 mesh
 Final: Rod mill, 15 min., 50%

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	47.2	7.8	3.30	96.3
Tailings	558.0	92.2	<u>0.01</u>	3.7

Composite	605.2	100.0	0.268	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Sodium Silicate	2.0				
Aerosol 18	0.67		0.96		

Remarks: Three stage flotation.

SCHEELITE FLOTATION TEST NO. FH-69

Grind:

Primary: -6 mesh
 Final: Rod mill, 25 min., 50% solids

Water:

Grind: Tap water
 Flotation: Tap water

Pulp dilution: 3 to 1

Percent solids: 25%

Cell used: Fagergren laboratory cell

<u>Product</u>	<u>Wt. in Grams</u>	<u>Wt. %</u>	<u>Assay (% WO₃)</u>	<u>Recovery (%)</u>
Concentrate	56.5	9.4	2.85	97.0
Tailings	543.5	90.6	<u>0.01</u>	3.0

Composite	600.0	100.0	0.277	100.0

<u>Reagents</u>	<u>Mill</u>	<u>Conditioner</u>	<u>Rougher</u>	<u>Cleaner No. 1</u>	<u>Cleaner No. 2</u>
Sodium Silicate	1.8				
Calgon	0.10				
Aerosol 18	0.90		0.60		

Remarks: Two stage flotation.