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APPROXIMATE QUANTITATIVE MICROSCOPY OF PULVERIZED ORES

INCLUDING THE USE OF THE CAMERA LUCIDA

BY

WILL H. COGHILL and J. P. BONARDI

This report is the result of work done under cooperative agreements with the College of Mines, University of Washington, and the Colorado School of Mines

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APPOROXIMATE QUANTITATIVE MICROSCOPY OF PULVERIZED ORES, INCLUDING THE USE OF THE CAMERA LUCIDA.

By Will H. Coghill and J. P. Bonardi.

INTRODUCTION.

In its investigations of ore dressing the Bureau of Mines has given attention to the use of the microscope in the study of ores as an aid in determining their physical nature and their amenability to the methods of concentration. This paper, which deals with the study of pulverized ores and the use of the camera lucida in such work, discusses an investigation undertaken at the Seattle and the Golden mining experiment stations of the Bureau of Mines.

Devices for the concentrating of ores are now so well developed and the methods of use are so generally known that even the novice may expect fair results when he undertakes ore testing. If the ore is amenable to gravity concentration the novice can crush and classify it and pass it over jigs and tables with the assurance of fair recoveries. If the ore is amenable to flotation he can probably "dope" the charge with an oil that will produce a good mineral-bearing froth; but if good manipulation falls a little short of the mark in recovery or grade of product, the novice will not be able to make the requisite diagnosis for obtaining better results. At this point the work of the metallurgist begins. Consequently the metallurgist must be a diagnostician.

In one instance an unknown physical property may interfere, and in another an unknown chemical property; each property may have its complexes. Hence a large number of methods for gathering information is necessary in order to find one method that will serve as a basis for the solution of the problem. This paper discusses a microscopic method; it is limited in its application to those ores in which the unpolished mineral grains may be identified at sight.

ACKNOWLEDGMENTS.

The writers deeply appreciate the cooperation of the College of Mines, University of Washington; the assistance of R. B. Moore and S. C. Lind of the Golden mining experiment station; and particularly
the helpful advice of F. K. Ovitz of the Seattle mining experiment station of the Bureau of Mines. An acknowledgment of indebtedness is due also to Charles A. Chase, manager, of the Liberty Bell Gold Mining Co.

**REVIEW OF LITERATURE.**

Microscopes are common in metallurgical laboratories where they are used for a hurried examination of pulverized ores, but the benefit of their application to quantitative work has not been fully emphasized in the technical literature of this country.

Thomas and Apgar\(^a\) have used the microscope for quantitative work on minerals. They called attention to the importance of the subject by saying—

A simple and rapid method for obtaining an approximately accurate quantitative mineral analysis of a concentrate by means of the microscope gives immediate results when they are most wanted, whereas a complete chemical analysis, with the calculation involved for recasting in terms of minerals, requires considerable time and expense and the results are often delayed until after the immediate necessity for them is past.

They might well have added that often it is impossible for the chemist to "recast in terms of minerals" and that his dissolving process defeats the purpose of his work as regards that phase of metallurgy which primarily concerns physical properties.

In the method advocated by Thomas and Apgar\(^b\) the sample is spread on a glass slide, and the number of grains of the respective minerals is counted to obtain a percentage "volume" analysis. They say:

The relative volume so obtained multiplied by specific gravity and again reduced to parts per hundred will give the desired weight percentage of the different minerals and will be found sufficiently accurate for most practical purposes. The method will take considerably less time than would be required for chemical analysis recast in terms of mineral percentages.

Recognizing that the minerals may not be entirely unlocked by the grinding process, Thomas and Apgar say further:

If a large proportion of the grains are complex in character, minerals included in gangue, the approximation will be less accurate, but at the same time, perhaps, this very fact is of utmost importance as suggesting the desirability of fine grinding.

Examination of their work shows, however, that Thomas and Apgar did not place enough emphasis on screen sizing and the arranging of the glass slide so that it could be rapidly and accurately oriented.

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\(^b\) Thomas, Kirby, and Apgar, F. W., work cited.
Clayton\(^a\) in a more recent article points out that the microscope can be used for at least four purposes in ore dressing as follows:

1. The determination of the mineral constituency of an ore that has been crushed.
2. In conjunction with a set of standard sieves for the determination of the critical diameter of an ore (the diameter of grain that shows all free mineral, no middling).
3. In obtaining an approximate analysis of the products of various concentrating machines.

Hynes,\(^b\) while working with one of the writers, several years ago, developed a system of sorting under a reading-glass and applied it to sized grains down to 28 mesh. He describes his method as follows:

For sorting, the apparatus required is a square of plate glass six or eight inches on a side and a reading-glass mounted on a ring stand or other support. The method of procedure is as follows: Weighed samples are taken, decreasing the weights of the samples as the size becomes smaller. A sample is placed a little at a time on a glass plate and sorted into the several desired classes, which are accumulated in piles on separate pieces of paper or in receptacles distributed around the edges of the plate. From a small pile on one corner of the plate a number of grains are moved under the magnifying glass and examined rapidly. As the grains are determined, they are slid by the finger into the proper piles. When all the sample has been sorted, the classes are weighed. By this method, the waste obtained is clean waste, the concentrate is clean, and the middling consists only of included or mixed grains. By separating carefully a pile of each important mineral, and making a specific-gravity determination of each, useful information may be obtained.

When samples of all the sizes it is thought necessary to investigate have been sorted, the percentage of included grain material should be calculated for each size, and the results plotted to make a curve.

Sorting in this manner can be done on sizes down to 0.589 mm. or 28 mesh.

Hynes went further and used the counting process for microscopic analysis of sized products down to 200 mesh, but his equipment was inferior. He made the common mistake of using the mechanical stage, and while turning the thumb-screws counted the grains that “touched the cross-hair” of the microscope. Naturally he came to the conclusion that, “the work is trying, and the observer will have to rest at intervals.”

**PURPOSE OF THIS PAPER.**

This paper shows how to improve upon Hynes’s methods by using an offset device which makes the counting of grains smaller than 28

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mesh less irksome. But the prime purpose of this paper is to show how the results of microscopic analysis may be used to diagnose difficulties in ore treatment.

Approximate accuracy, with as much speed as possible is the requisite in any method of quantitative microscopy. As this quantitative microscopy is an art, it can not be described minutely. By actual manipulation, the reader will have to compare this method with others in order to appreciate the advantages of the improvement.

DESCRIPTION OF MICROSCOPE.

The set-up for counting and classifying powdered mineral grains, as shown in Plate I, consists of a binocular microscope with a stage adapted to convenient orientation.

The binocular is preferable to the monocular instrument. By means of the double optical system—two eyepieces and two objectives—the object is seen with both eyes so that it appears in relief as when viewed with the unaided vision, a stereoscopic effect being obtained. Moreover, the image is shown in true form, and not transposed or inverted as when viewed with the regular microscope. The magnification of the standard instrument is 10 to 75 diameters, a range adequate for studying grains finer than 28 mesh. For illumination in this range good daylight is excellent.

Plate I shows how the glass slide carrying the pulverized ore may be oriented for each reading by adjusting it along a ruled offset, each square of which has a distinguishing letter or numerical marking.

The squares constituting this offset should be of such dimensions that consecutive readings will not contain overlapping fields. Obviously only a part of the grains sprinkled upon the slide are counted, but groups of these grains are taken systematically after the manner of ordinary sampling. The illumination is probably best when a dark green paper is placed as a background under the glass slide.

PROCEDURE IN EXAMINATION.

Close and thorough screen sizing is essential. The separate products should be washed and dried so as to present clean and clear-cut mineral surfaces. The coarser products may be sprinkled on from a spatula, and the readings are most satisfactory when each field contains about a dozen grains. Then, with the 25 settings indicated by the offset in Plate I, 300 grains will be included.

The preparation of the samples is not difficult but the method of procedure is important. It is best to begin with wet screening on the finest sieve. To use pure water, as in the ordinary method of wet screening, is unsatisfactory. It is best to use a wetting solution
BINOCULAR MICROSCOPE AND SET-UP FOR COUNTING GRAINS OF POWDERED ORES.
CAMERA LUCIDA ATTACHMENT TO MICROSCOPE, AND
SET-UP FOR SKETCHING.
containing saponin or soap, thus breaking up the flocks that are likely to form in, and float on, pure water. An additional advantage is that the wetting solution lubricates the meshes and the mineral grains, thus facilitating the sizing that is sought. Material finer than 300-mesh may be dried and screened in the dry state.

The wetting solution offers another advantage. By its use flotation concentrates have been handled that were so gummed with oil that they could not be screened while dry, and in water formed flocules that were too large to pass the meshes.

Furthermore, long standing of the sized products tends to facilitate cohesion and adhesion effects which are decidedly strong in the smaller sizes. Grains in this condition appear under the microscope like metallics influenced by a magnet. When this effect is pronounced it can be readily detected, but when only moderate it is likely to deceive by giving the appearance of natural locking. The possibility of such effects must be borne in mind and if there is danger of deception, the sample should be screened again to separate the particles. When this effect is as marked as it was in the 300-mesh material, it is probably much like the adhesion of dust to a mirror. As time progresses, the grains become more persistently locked, like the dust on a new automobile after long standing.

To load the slide from the point of a spatula when the grains are larger than 150 mesh is simple, but smaller grains require a delicate procedure. A sample of such sizes should be placed on a fine sieve and the grains spread over the plate by gently tapping the sieve. If preliminary examination shows a satisfactory loading the count may proceed.

A typical record sheet for assembling results is shown in Table 1. Four products are recorded, namely, siliceous gangue, pyrite, siliceous gangue locked with molybdenite including estimated “volume per cent” MoS₂, and MoS₂ flakes. The word “locked” is limited in this paper to grains which, without being made into polished sections, reveal at least two mineral constituents.

The footing of “siliceous grains locked with MoS₂” shows that 77 were counted, approximately eight of which by volume were calculated as equivalent MoS₂, so that the remainder represents 69 siliceous gangue matter. This proportion must be considered in determining “weight” per cent results from the “volume” per cent results.

The fields are recorded in alphabetical order, thus facilitating a quick comparison of any two fields by a quick hand-adjustment of the plate rather than by the tedious manipulation of thumb screws as with the mechanical stage of petrographic microscopes.
Table 1.—Record sheet for counting and classifying powdered ores. Material, minus 60, plus 80 mesh.

<table>
<thead>
<tr>
<th>Field</th>
<th>Siliceous gangue</th>
<th>Pyrite</th>
<th>Siliceous grains locked with MoS₂ and estimated &quot;volume&quot; per cent MoS₂</th>
<th>Calculated equivalent as MoS₂</th>
<th>Molybdenite flakes, MoS₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Number, &quot;Vol.&quot; p.c.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>1</td>
<td>1 10</td>
<td>0.10</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>10</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>15</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>15</td>
<td>0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>10</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>2</td>
<td>15</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>6</td>
<td>10</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>2</td>
<td>10</td>
<td>0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>2</td>
<td>2</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>3</td>
<td>10</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>4</td>
<td>5</td>
<td>0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>4</td>
<td>10</td>
<td>0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>3</td>
<td>10</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>2</td>
<td>10</td>
<td>0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>4</td>
<td>10</td>
<td>0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>2</td>
<td>10</td>
<td>0.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>6</td>
<td>10</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>4</td>
<td>15</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>3</td>
<td>10</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>U</td>
<td>3</td>
<td>15</td>
<td>0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>4</td>
<td>15</td>
<td>0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>4</td>
<td>10</td>
<td>0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>1</td>
<td>10</td>
<td>0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>4</td>
<td>10</td>
<td>0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Footing</td>
<td>8</td>
<td>3</td>
<td>77 11</td>
<td>8.54</td>
<td>12</td>
</tr>
</tbody>
</table>

Microscopic diagnosis of a molybdenite concentrate.

THE PROBLEM.

As already stated, the chief purpose of this paper is to show how a diagnosis may be made with the aid of a microscope. The particular problem considered here—and it is intended to be symbolic—concerns a molybdenite concentrate from a flotation mill. The operator desired to grade up the concentrate and sent the writers a sample for treatment in experimental machines. A preliminary test showed that the sample had altered while in transit and had become difficult to treat. The sample looked as though gummed by the oil, and frothed so freely that a satisfactory separation could not be made by the ordinary methods of flotation. As an aid in ascertaining the trouble, products of the screen analysis of the mill concentrate were obtained for microscopic analysis.

ANALYSES.

Table 2 shows the screen, the chemical, and the microscopic analysis. Columns J, K, L, and M are made up from record sheet footings like those previously mentioned in Table 1. Perhaps the reader on looking at the footing of column I and seeing that 2,546 grains were counted may think this method of analysis
extremely tedious. Actually, a slide of 300 grains may be counted and the four products classified in 20 minutes. Less than three hours was required for the actual microscopic work, by which result 24 products were determined (one every 10 minutes) with approximate accuracy.

Table 2.—Screen, chemical, and microscopic analyses of a molybdenite concentrate.

<table>
<thead>
<tr>
<th>Mesh</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>analysis</td>
<td>Weight, per cent</td>
<td>Assay, per cent</td>
<td>Content, assay × weight</td>
<td>Per cent total MoS₂</td>
<td>Per cent FeS₂</td>
<td>Per cent insoluble</td>
<td>Total per cent MoS₂, FeS₂, and insoluble.</td>
</tr>
<tr>
<td>1. Minus 40, plus 60</td>
<td>5</td>
<td>19.9</td>
<td>1.00</td>
<td>2.4</td>
<td>3.9</td>
<td>73</td>
<td>95.8</td>
<td></td>
</tr>
<tr>
<td>2. Minus 60, plus 80</td>
<td>8</td>
<td>24.4</td>
<td>1.95</td>
<td>4.7</td>
<td>7.7</td>
<td>65</td>
<td>98.1</td>
<td></td>
</tr>
<tr>
<td>3. Minus 80, plus 120</td>
<td>14</td>
<td>27.6</td>
<td>3.86</td>
<td>9.3</td>
<td>9.1</td>
<td>62</td>
<td>98.7</td>
<td></td>
</tr>
<tr>
<td>4. Minus 120, plus 200</td>
<td>15</td>
<td>28.1</td>
<td>4.21</td>
<td>10.1</td>
<td>11.8</td>
<td>56</td>
<td>98.9</td>
<td></td>
</tr>
<tr>
<td>5. Minus 200, plus 300</td>
<td>13</td>
<td>42.3</td>
<td>5.50</td>
<td>13.3</td>
<td>12.3</td>
<td>40</td>
<td>94.6</td>
<td></td>
</tr>
<tr>
<td>6. Minus 300, residue</td>
<td>33</td>
<td>61.5</td>
<td>20.30</td>
<td>49.0</td>
<td>9.0</td>
<td>22</td>
<td>92.5</td>
<td></td>
</tr>
<tr>
<td>7. Minus 300, suspension</td>
<td>12</td>
<td>38.5</td>
<td>4.62</td>
<td>11.2</td>
<td>3.6</td>
<td>38</td>
<td>80.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Footing</td>
</tr>
</tbody>
</table>

Microscopic analysis; grains, per cent.

<table>
<thead>
<tr>
<th>Mesh</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of grains counted</td>
<td>Grains, per cent silicious free gangue</td>
<td>Grains, per cent pyrite</td>
<td>Grains, per cent silicious grains locked with MoS₂ and estimated volume per cent MoS₂</td>
<td>Grains, per cent MoS₂ flakes</td>
</tr>
<tr>
<td>1. Minus 40, plus 60</td>
<td>331</td>
<td>12</td>
<td></td>
<td>82—8 per cent (75+7)</td>
<td>6</td>
</tr>
<tr>
<td>2. Minus 60, plus 80</td>
<td>405</td>
<td>11</td>
<td>1</td>
<td>82—10 per cent (74+8)</td>
<td>6</td>
</tr>
<tr>
<td>3. Minus 80, plus 120</td>
<td>503</td>
<td>15</td>
<td>4</td>
<td>71—14 per cent (61+10)</td>
<td>10</td>
</tr>
<tr>
<td>4. Minus 120, plus 200</td>
<td>525</td>
<td>14</td>
<td>6</td>
<td>50—6 per cent (53+3)</td>
<td>24</td>
</tr>
<tr>
<td>5. Minus 200, plus 300</td>
<td>572</td>
<td>29</td>
<td>6</td>
<td>33—16 per cent (23+5)</td>
<td>32</td>
</tr>
<tr>
<td>6. Minus 300, residue</td>
<td>522</td>
<td>19</td>
<td>10</td>
<td>6—7 per cent (6+)</td>
<td>65</td>
</tr>
<tr>
<td>7. Minus 300, suspension</td>
<td></td>
<td>a 56</td>
<td>a 4</td>
<td>a 48</td>
<td>a 40</td>
</tr>
</tbody>
</table>

* Approximation guided by chemical analysis.

The chemical assay of the composite sample (38.2 per cent MoS₂) does not agree well with the chemical assay calculated from the screen products (41.44 per cent MoS₂, column D, footing), but the latter checks the microscopic analysis closely, as shown in footings of Table 3.

Column C, Table 2, shows how the grade of the product increases uniformly in the smaller meshes down to the minus 300-mesh residue (line 6), which assays 61.5 per cent MoS₂. This rich material
is contained in 33 per cent (column B, line 6) of the composite sample and represents 49 per cent (column E, line 6) of all the MoS$_2$.

DISCREPANCY.

The recasted determinations on the concentrate (column H) do not total 100 per cent, and the discrepancy increases for the finer material. Two facts may account for this accumulative variation. First, soluble base-metal silicates that have not been determined are present and the solubility of the finer material is naturally greater because of the larger total area of surface exposed to the dissolving agent.\textsuperscript{a} Second, it is possible that the concentrate contains a brittle, soluble mineral other than silicates, such as calcite, which is concentrated in the fines. In fact, calcite has been identified but it is classed with the siliceous gangue in the microscopic analysis. The solubility of the siliceous gangue must be considered in comparing the microscopic and chemical analysis.

INTERPRETATION OF RESULTS.

A detailed microscopic examination such as this shows how a hurried examination of an unsized sample may give wrong impressions.

For example, columns L and M (line 1), indicate that about six parts by volume of the MoS$_2$ in the siliceous locked grains (82×8 per cent) are locked, and that six parts are free; that is, 50 per cent is locked. But the same columns in lines five and six show that a very small percentage is locked. Therefore, conclusions must not be formed until a more nearly correct idea of the nature of the composite sample is had. Further information is presented in Table 3, which shows the weighted microscopic analyses and the deductions made from them.

The weighting is subject entirely to one's judgment and familiarity with the ore; the chemical analysis serves as a guide.

The siliceous gangue is weighted as one. The pyrite and the estimated equivalent molybdenite in the locked grains are weighted as two. The free molybdenite flakes are weighted as one because, although they have a relative specific gravity of about two as compared with the siliceous gangue, they break into thin flakes about one-half as thick as the other grains, this fact being determined by calibrating with a microscope the thickness of a number of grains.

\textsuperscript{a} Each sample was analyzed without regrinding.
### Table 3.—Weighted microscopic analyses and deductions.

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Screen analysis</th>
<th>Per cent number of grains from Table 2 reduced to weight per cent.</th>
<th>Per cent MoS₂ flakes.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight per cent.</td>
<td>Per cent siliceous free gangue.</td>
<td>Per cent pyrite.</td>
</tr>
<tr>
<td>1. Minus 40, plus 60</td>
<td>5</td>
<td>11</td>
<td>. . . . . .</td>
</tr>
<tr>
<td>2. Minus 50, plus 80</td>
<td>8</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>3. Minus 80, plus 120</td>
<td>14</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>4. Minus 120, plus 200</td>
<td>15</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>5. Minus 200, plus 300</td>
<td>12</td>
<td>26</td>
<td>11</td>
</tr>
<tr>
<td>6. Minus 300, residue</td>
<td>33</td>
<td>19</td>
<td>10</td>
</tr>
<tr>
<td>7. Minus 300, suspension</td>
<td>12</td>
<td>58</td>
<td>4</td>
</tr>
<tr>
<td>Footing</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Content in grams.</th>
<th>Total.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>J₁×B.</td>
<td>K₁×B.</td>
</tr>
<tr>
<td>1. Minus 40, plus 60</td>
<td>0.5</td>
<td>3.5-6.6</td>
</tr>
<tr>
<td>2. Minus 50, plus 80</td>
<td>8</td>
<td>6.4-3.8</td>
</tr>
<tr>
<td>3. Minus 80, plus 120</td>
<td>1.8</td>
<td>7.3-2.5</td>
</tr>
<tr>
<td>4. Minus 120, plus 200</td>
<td>1.8</td>
<td>7.3-2.6</td>
</tr>
<tr>
<td>5. Minus 200, plus 300</td>
<td>3.2</td>
<td>3.2-1.2</td>
</tr>
<tr>
<td>6. Minus 300, residue</td>
<td>3.3</td>
<td>3.3-1.3</td>
</tr>
<tr>
<td>7. Minus 300, suspension</td>
<td>7.0</td>
<td>3.9-1.5</td>
</tr>
<tr>
<td>Footing</td>
<td>21.6</td>
<td>8.0</td>
</tr>
<tr>
<td>Total</td>
<td>50.4</td>
<td>8.0</td>
</tr>
</tbody>
</table>

* Total siliceous (21.6+28.8).  
* Total pyrite.  
* Total MoS₂ (8.4+35.5).

The following calculations indicate readily how the figures in, say, line 2 of the columns J₁, K₁, L₁, and M₁ were obtained. By referring to line 2 under the corresponding columns in Table 2, one sees that, on a 100-grain basis, 11 were free siliceous gangue, 1 pyrite, 82 locked (74 of which are estimated as siliceous, and 8 as MoS₂) and 6 free MoS₂ flakes.

Then,

\[
\begin{align*}
11 \text{ free siliceous} & \times \text{ weight factor 1} = 11 \\
1 \text{ pyrite} & \times \text{ weight factor 2} = 2 \\
74 \text{ locked siliceous} & \times \text{ weight factor 1} = 74 \\
6 \text{ locked MoS₂} & \times \text{ weight factor 2} = 12 \\
6 \text{ free MoS₂} & \times \text{ weight factor 1} = 6 \\
\text{Total} & = 105
\end{align*}
\]

and,

\[
\frac{11}{105} = 10 \text{ per cent siliceous free gangue (column J₁, line 2)}.  \\
\frac{2}{105} = 2 \text{ per cent pyrite (column K₁, line 2)}.  
\]

The other percentages are obtained in the same manner.
There is one deviation from this system of weighting, in Table 2, column K, line 6. There the pyrite grains amount to 10 in 100, too high a proportion to agree with the chemical analysis. But as the material has been hydraulically classified and contains, as the microscope reveals, fine grains of pyrite with coarse grains of sand, it ought to require a weighting different from the others which are screen sized. Hence the factor here is one.

**APPLICATION OF RESULTS TO "GRADING UP."**

The sum of the footing of columns $J^1 \times B$ and $K^1 \times B$ (line 8, Table 3), shows that 29.6 per cent (21.6+8.0) of the material is ready for discard without loss. If this were discarded the concentrate would be "graded up" from 41.9 per cent $\text{MoS}_2$ to 59.5 per cent $\text{MoS}_2$ (41.9 parts in 70.4).

Again, columns $L^1 \times B$ and $M^1 \times B$ (line 8) show that 35.5 parts of the $\text{MoS}_2$ are free and 6.4 parts are locked, making a total of 41.9 parts. An ideal concentrate containing 100 per cent $\text{MoS}_2$ could be made by sacrificing 15 per cent of the values that are now recovered.

Assuming a ratio of mill concentration of 75 to 1, one finds that if this locked material were all diverted to the tailing in order to make a 100 per cent shipping product, it would add 0.08 parts (6.4 parts in 7,500) to the tailing; that is, the grade of the tailing would be increased 0.08 per cent $\text{MoS}_2$ or 0.05 per cent Mo.

This, of course, would not be undertaken because, first, the loss would not be allowable, and, second, commercial operations would not divide the products as indicated.

In further reference to "grading up," let it be assumed that a small cleaner is added to the equipment, that as much as possible of the free molybdenite is removed, that the tailing from the cleaner is ground to pass 120 mesh and that by this grinding the molybdenite in the grains coarser than 120 mesh is entirely liberated. Assuming an ideal separation one finds that only 12.5 parts (7.3+3.2+2.0, column $L^1 \times B$, lines 4, 5, and 6) of gangue would remain with the original 41.9 parts of $\text{MoS}_2$. To convert this, one deals with 54.5 parts (12.5+41.9) of which 41.9 parts are $\text{MoS}_2$, or a concentrate carrying 76.8 per cent $\text{MoS}_2$.

Actually regrinding the siliceous material coarser than 120 mesh in the present concentrate would add to the percentage of locked grains in the product finer than 120-mesh. But it is believed that this would be balanced by a loss of similar material so that a company would be justified in attempting to make a shipping product of the aforesaid grade of 76.8 per cent. Good commercial work should give a 75 per cent product. Of course, some loss of molybdenite will take place.
Turning now from the consideration of an ideal process to commercial operation, one can determine in terms of tailing loss the probable cost of "grading up" the concentrate after regrinding the locked grains coarser than 120 mesh.

In columns $J^1 \times B$, $K^1 \times B$, and $L^1 \times B$ (line 8), there are 64.8 parts ($21.6 + 8.0 + 6.4$) of which 6.4 parts are MoS$_2$. This mixture, on the assumption that all the free flakes of MoS$_2$ are recovered otherwise, assays 10.0 per cent MoS$_2$ ($6.4 - 64.8$). An assumed loss of 20 per cent of the molybdenite of this nature and grade after grinding and re-flotation seems reasonable. There would then be a loss of 1.3 parts ($6.4 \times 20$ per cent), or a loss of 3.1 per cent ($1.3 \div 41.9$) of the molybdenum which is now recovered. Assuming again a ratio of concentration of 75 to 1, one sees that this would add 0.02 per cent MoS$_2$, (1.3 parts in 7,500) to the grade of the tailing.

The grade of the concentrate that would result by this procedure is determined as follows:

By the above assumption 1.3 parts of the MoS$_2$ would be lost. Then there would remain 40.6 parts of MoS$_2$ and 12.5 parts ($7.3 + 3.2 + 2.0$) of siliceous material in the form of locked grains. Hence, a mixture of 40.6 parts MoS$_2$ with 12.5 parts insoluble matter would amount to 53.1 parts, of which 74.6 per cent would be MoS$_2$.

Other deductions may be made, but those given will suffice to indicate the scope of this part of the work.

USE OF THE CAMERA LUCIDA.

PURPOSE.

The camera lucida is a common accessory of the microscope in biologic and petrographic work. Plate II (p. 7) shows it attached to a common biologic microscope. The instrument is employed to facilitate the sketching of objects as seen under the microscope. With it the observer sees the reflected image projected on a background consisting of a sheet of paper mounted on a drawing board. Thus the observer can pass a pencil over the outlines of the image—pencil, image and paper being simultaneously visible. Johannsen, who refers to the use of the camera lucida in petrographic work, says:

The drawing paper and the image seen through the microscope appear to lie superimposed in the same plane, due to reflection through a prism, consequently it is an easy matter to make a drawing of a rock section by tracing the outlines.

SET-UP OF INSTRUMENT.

The drawing board should be mounted as shown in Plate II, so that the image will be in the plane of the paper. Then the pencil

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point and the image will be seen with the same focusing of the eye, and parallax is obviated. When the observer shifts his gaze the pencil point is not displaced on the image.

The mirror of the camera lucida is set at the 45° stop, so that the image on the paper will not appear distorted when the microscope is in an upright position. In case the inclination of the mirror has to be changed to take in a special part of the field the drawing board must be tilted to keep it at an angle of 45° to the mirror and thus avoid distortion. Raising or lowering the drawing board changes the size of the image.

Johannsen, a in describing the set-up of the camera lucida, says:

When the drawing board lies at a distance of 250 mm. from the exit pupil of the microscope, the distance being measured through all the changes of the path of the ray in passing through the drawing apparatus, the image will be drawn with the so-called magnification of the microscope. To test the accuracy of the setting of a camera lucida, use may be made of test objects, such as circles, squares, or parallel lines drawn on a glass slip. The drawings made from such objects may be measured; a compass set in the center of the circle should exactly follow the lines drawn, the square should have equal sides, and the parallel lines be truly parallel.

As the study of powdered mineral grains under the microscope is essentially a study with reflected light and not with transmitted light, as used by petrographers and biologists, some difficulty was encountered at first in making the set-up for reflected light. This difficulty was overcome by placing black paper under the stage and using black paper on the drawing board. Outlines penciled on the black paper are simultaneously transferred to white paper by means of an inserted carbon sheet. In some types of instruments the light from the paper can be moderated by one or more tinted glasses, which permit the image to be seen clearly.

APPLICATION.

With the camera lucida accurate and magnified reproductions of an unlimited number of mineral grains can be made. Probably photographic reproduction showing an equal amount of detail would not be possible. Success in photographing petrographic slides is assured by the transmitted light, but because of the intense illumination surrounding them these mineral grains are practically opaque. Besides, sketching is desirable because of its being such a rapid procedure.

METHOD OF SKETCHING.

The camera lucida reproduction of the slide from which the typical record sheet (Table 1) was made is shown in Plate III. As

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a Johannsen, Albert, work cited.
Plate III is developed with the monocular microscope, the image is transposed or inverted, so that A appears in the upper left-hand corner of the offset in Plate II, but is reproduced at the lower right-hand corner of Plate III. Twenty-five settings were required conforming to the squares on the drawing. The nature of the material is thus portrayed so that anyone may see it as it was seen through the microscope by the successive setting. The reader will note how a camera lucida sketch would enable an engineer to depict the nature of an ore as he would wish to present it to a court, for example. The record of an accurate sample of a certain product from an entire vein would thus be made legible, whereas a petrographic slide shows only one small fragment.

Plate III calls attention to some possible theories of flotation. Locked grains carrying molybdenite at their surface are markedly floatable. An examination of the tailing shows that scarcely a locked grain remains whereas free siliceous grains abound.

It is difficult to use the orthodox explanation and picture the bubbles as picking up these locked grains individually and separately; for about 80 per cent of the surface of the molybdenite is armored not with oil but with siliceous gangue—a material that is supposed to be so thoroughly wetted that it could not ride at the surface of a bubble.

The writers are inclined to wonder whether locked grains are not more abundant in flotation concentrates than was formerly supposed. A complete explanation of flotation must include the conditions of each and every example, including this one.

SUMMARY.

1. In an improved method of quantitative microscopic analysis for powdered ores a binocular instrument takes the place of the monocular instrument used in the older methods.

2. Various details of the method have received particular attention.

(a) Close and thorough screen sizing is essential.

(b) The separate screen products must be washed and dried so as to present clean and bright mineral surfaces. A wetting solution that contains saponin or soap is best for wet screening of the finer sizes. Rescreening is often necessary to separate particles grouped by cohesion and adhesion.

(c) The finer products should be spread over the microscope plate by use of a fine sieve.

(d) Orientation for each reading is made by adjusting the glass slide along a ruled offset.
3. The advantages claimed for the method are as follows:
   (a) Low cost.
   (b) Rapidity.
   (c) Gives closer approximation to chemical analysis than is obtainable by the older methods.
   (d) Serves as a guide to the metallurgist in mill operations.
4. A typical record sheet has been developed.
5. The results of microscopic analysis are interpreted and applied to a metallurgical problem, the “grading up” of a molybdenite concentrate.
6. By using a camera lucida the outlines of the powdered mineral grains, as seen through a monocular microscope, can be sketched. Such a sketch, being as representative as a composite sample, may be used by the engineer as a true index of an ore.

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