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CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 73-14

*Mines Branch Program
on Environmental Improvement*

**AN EXPERIMENTAL STUDY OF THE
WEATHERING OF MILL TAILINGS IN
CONNECTION WITH WATER POLLUTION
PART 3:
MINERALOGICAL ANALYSES OF TAILINGS
SAMPLES FROM VARIOUS MINING
COMPANIES IN CANADA**

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MINERAL SCIENCES DIVISION

COPY NO. 3

MAY 4, 1973

Mines Branch Investigation Report IR 73-14

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by

A. Jongejan*

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SUMMARY

The mineralogical compositions of samples of fresh tailings from sixteen companies mining sulphide ores in Canada are compared with each other for the ultimate purpose of possibly correlating the mineralogical composition of a tailings and its effect on the composition of water percolating through it.

In order to compare mineralogical compositions, different minerals that can be expected to have similar weathering properties were grouped together.

Because the methods used for the identification of the minerals were not quantitative, the results of the chemical analyses of the tailings samples were used to proportion the mineralogical information.

Although several tailings samples contained similar mineral assemblages, the ratios between the mineral species in the tailings varied widely. The sulphide contents cover the range from 0.5% to 75%, and the highest carbonate content was 30%.

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1. INTRODUCTION

The study of weathering processes occurring in tailings ponds is aimed at providing information on the effect of the major variables that are involved in this problem.

It is well known that acid drainage from tailings ponds and the production of toxic trace-metals in this drainage originate in the sulphides present in the tailings. However, not much information is available quantitatively how the chemical equilibria in the weathering processes are affected by specific mineral compositions of different tailings. Even less is known as to what extent grain-size distribution and the grain-surface area exposed to water, in particular, affect these processes and, therefore, the composition of water percolating through the tailings.

In order to contribute information on these problems, various aspects of the weathering process are being studied, as has been described elsewhere⁽¹⁻⁴⁾. These aspects are based on the concept that water pollution from tailings ponds originates in the minerals of which the tailings are composed. Consequently, the mineral composition and the physical properties of tailings as mineral aggregates are the factors inherent in tailings themselves that are involved in the process of dissolution.

The "external" factors, such as climate and local topography, that contribute to the dissolution process, are not studied in the present phase of the project because they can be studied more economically after ideas about the magnitude of different variables have been developed from the results of controlled laboratory experiments.

Although the microbial population of a tailings pond can also be considered to be an "external" factor, it participates so much in the chemical processes that it will be included in the last stages of the study of the chemical aspects. Therefore, it is presently being studied separately.

The mineralogical analysis of tailings samples is aimed at providing information on the differences and similarities in the mineral compositions that form the source of possible water pollution from tailings ponds.

Tailings samples were supplied by sixteen companies mining sulphide ore bodies in Canada. The companies were selected by the Waste Water and Tailings Disposal Committee of the Mines Branch on the basis of differences in the metals produced, as well as according to differences in the geological locations of their mines. The selection was aimed at obtaining tailings that would differ as widely as possible in mineralogical composition. The results of the study on the mineralogical composition of these tailings samples would provide the basic information for the preparation of mixtures of pure natural minerals to be used in controlled percolator experiments and also for comparative purposes. The nature of these experiments has been described elsewhere (1,2,3).

Further, the results of the analyses would be used by the Non-Metallic and Waste Minerals Section of the Mineral Processing Division which is interested in converting waste minerals into useful products.

The selection of the methods to be used in the mineralogical analysis was guided by two requirements :

(a) The time required for each analysis should not be out of proportion with the purpose for which its results would be used. Any need for an analysis of tailings samples, collected in the field or of a particular fraction of a tailings, such as could be expected to arise out of the requirements for the percolator experiments, should be fulfilled in a reasonable amount of time.

An accurate mineralogical analysis of the fine-grained tailings might be feasible by applying quantitative microscopy determinations of the minerals constituting the coarse tailings fractions, and by applying quantitative X-ray analysis of minerals constituting the fine fractions, both types of fractions being further divided by specific gravity separations and analysed by physical and chemical methods.

However, the long time required for such an analysis would not only make it impractical for the progress of the project, but it would also not be in economic proportion with the use of the information as explained under "b". The time required for the chemical analysis should be in accordance with that of the mineralogical analysis.

(b) The purpose of the analysis was to compare the compositions of various tailings. Because of the differences between the ore and/or gangue minerals of these tailings, only mineral types common to the samples could strictly be compared, while others that the tailings did not have in common, would not be comparable.

In order to overcome this problem, minerals had to be divided into groups that could be expected to have similar action in the dissolution processes. The mill process is aimed at recovering the valuable sulphides and discarding iron sulphides, iron oxides and hydroxides, while only small quantities of different types of sulphides containing other metals would be left. The differences between the gangue minerals would be far less eliminated than those between the ore minerals. The greatest part of the gangue or bedrock minerals, however, could be expected to be composed of silica and silicates, which would be less soluble than carbonates and sulphides*. The only difference among the silicates that would be worthwhile distinguishing at this stage of the project was possibly that between the solubility of acid and basic silicates, of which the latter weather more rapidly.

*NOTE: Although most minerals dissolve or alter in time in the weathering process - the most resistant being such minerals as zircon, rutile, quartz, etc. - the various rates of solution of different minerals seemed primarily important in the tailings problem. Silicates undoubtedly will alter in time to form clay minerals, chlorites, serpentines, talc, etc. Sulphides and carbonates, however, can be expected to react faster than silicates; the problems in the present study concern reactions that take place during the weathering and during the (geochemical) migration of elements within and from a tailings pond.

Consequently, the minerals in the tailings have been allocated, in this study, in one of the following groups:

1. sulphides, arsenides, arseno-sulphides, etc.;
2. iron oxides and hydroxides;
3. carbonates;
4. basic silicates;
5. acid silicates;
6. free quartz; and
7. *sulphates, phosphates, and other minerals not belonging to one of the other groups.

2. EXPERIMENTAL METHODS

2.1. The Determination of the Mineral Compositions

The requirements for the mineralogical analysis, as explained in the Introduction, and the general major difficulty in mineralogical analyses dealing with any very-fine-grained material led to considering the mineralogical analysis to be derived from the chemical analysis. In the same way as an elemental composition, reported by a chemical analysis, can be converted to an oxide composition where this is more suitable, so could the results of the chemical analysis be combined further into mineral complexes and groups which would approximately represent the actual minerals in the tailings.

*NOTE: This group contains information only if a significant amount of the relevant minerals is present, or if interest had been expressed as to their content. Although small amounts of these types of minerals were present in each tailings sample and were usually referred to as "accessory minerals" (apatite, zircon, rutile, etc.), they have been ignored in the analyses.

Because most of the tailings contained more than 50% minus 325-mesh grains and because the different minerals were not distributed equally over the various grain sizes, due to differences in grindability, the procedure consisted of determining the major mineral species by microscopy and X-ray diffraction techniques. When possible, this examination included a semi-quantitative estimate of the minerals. The results of the chemical analyses were then used, in conjunction with the data obtained by other methods, to arrive at the most probable proportionation between the mineral groups. It will be evident that no exact rules can be given for the application of this procedure because much depends on the results of the microscopy examinations.

In order to facilitate the identification of the minerals, each tailings sample was wet-screened into plus-100, 100 to 200, 200 to 270, 270 to 325, and minus 325-mesh fractions, thereby possibly concentrating specific minerals into one or more fractions. The minus-325-mesh fractions were further divided by a treatment in the Sharples super-centrifuge*.

All wet-screened fractions were examined with the petrographic microscope for the determination and estimation of the various mineral components. Further, a polished section was made of the sample "as received" in order to check the proportionation between the sulphides, iron oxides, and the gangue minerals. A polished and a thin section were prepared of either the 100- to 200-mesh or the 200- to 270-mesh fraction, depending on the amount available for microscopy identification of the minerals*.

The major minerals were also identified by X-ray diffraction analysis* of either the 100- to 200-mesh or the 200- to 270-mesh fractions in some cases, as well as the four fractions

*NOTE: The screen fractions for the microscopy examinations and the super-centrifuge fractions for the X-ray diffraction analysis were prepared by A.L. Wilkins. The polished and thin sections were prepared by P. O'Donovan; the X-ray diffraction analyses were done by E.J. Murray. All are members of the Mineral Sciences Division.

produced by the treatment of the minus-325-mesh fraction in the super-centrifuge. These samples were obtained from the deposit on the liner at, respectively, the entrance and at 2, 4, and 6 inches above the entrance in the super-centrifuge.

In order to aid in the chemical determination of sulphur and carbon dioxide, which could be subject to errors, a thermogravimetric analysis (T.G.A.) was done on the samples, dried at 120°C overnight. A differential thermal analysis (D.T.A.) was done on the samples to cover the possibility that well-defined peaks might aid in the identification of carbonates or hydrated silicates*. No valuable information, however, was obtained from the D.T.A. runs, while the results of the T.G.A. runs could be interpreted only partly satisfactorily. All these runs were done in an argon atmosphere.

In the tables listing the mineral compositions, the left-hand column under "Mineral Groups" is the result of estimations based primarily on the information from the chemical analyses. The final estimates in the right-hand column used those indicated in the left-hand column as much as possible. In several cases, however, values have been changed to bring them more into line with the results of the microscopy examinations.

The chemical analyses were done by the Analytical Chemistry Section of the Extraction Metallurgy Division. The measurements of the particle-size distributions and of the specific gravities of the samples were done by the Non-Metallic and Waste Minerals Section of the Mineral Processing Division. Some of these measurements were also done by A.L. Wilkins of the Mineral Sciences Division in connection with his determinations of the mineral surface-areas exposed to water and the preparation of the fractions used for microscopy.

*The D.T.A. and T.G.A. runs were done by R.H. Lake, Mineral Sciences Division.

In the tables listing the final estimates of the mineral composition of each tailings and in that used for comparing the mineral compositions of all tailings samples, the particle-size distribution was reduced to three fractions viz., plus-100-mesh (coarse), 100- to 325-mesh (medium), and minus-325-mesh (fine). The percentages constituting these fractions were then reduced to fractions of 10. They are listed consecutively, e.g., the code 2.1.5. stands for "20% coarse, 10% medium, and 50% fine". The division into the respective fractions was based on the shape of the particle-size distribution curves which showed often minima between 100- to 150-mesh and between 270- to 325-mesh. This selection, however, is done more for practical purposes than on the basis that the exact statistical evidence showed that the selected limits are meaningful.

2.2. The Determination of the Surface Areas Exposed to Water

The determination of the grain-surface area exposed to water would obviously provide more important information for the percolator experiments than the more valid surface area, determined by either the gas-adsorption or the gas-flow techniques.

Very-fine-grained tailings might be so closely packed that percolating water does not come into contact with all the grain surfaces. It may act, therefore, as if it were composed partly of impervious aggregates. If the surface area exposed to water of such a tailings is compared with that of a coarser-grained tailings, the latter may appear to have a greater surface area exposed to water, because the coarse tailings may be less densely packed than the fine-grained tailings, notwithstanding its true surface area may be less. Generally, the surface area exposed to water is much smaller than the actual surface area.

The grain-size distribution and consequent grain-surface area exposed to water are factors to be considered in the rate of weathering of a tailings pond. The weathering of tailings can,

to a large extent, be compared with the weathering of a fine-grained porous rockmass. The porosity depends on the density of packing of the mineral grains. Weathering takes place, generally, from the surface of a rock inwards. The rate of weathering depends on the flowrate properties of the tailings, not taking shear planes, local conditions in the area, and other structural factors (sedimentation segregation) of a tailings pond into account. Many factors can be determined only in the field and are specific for each tailings pond. However, information about grain-size distribution, grain-surface area, water flow rates, etc., could assist in estimating the rate of weathering when other factors in the field are being considered

The measurement of the "exposed" mineral surface area is associated with the experiments that cover the physical aspects of the weathering study^(3,4).

Although special apparatus has been constructed for measuring water flow through granular material, as has been described in the voluminous literature on that subject, this study used the same simple apparatus as that which was constructed for the measurement of flow rates.

The method described by Dodd et al⁽⁵⁾ has been used for the measurement of the exposed mineral surface area. Refinements of this method, involving tortuosity and shape factors have not been applied in order to keep the method simple and because the results would be used for comparative purposes only.

The surface area was measured for two, and sometimes three, different lengths of tailings column and the reported values are the averages of at least two measurements. The accuracy of the determinations was sufficient for comparative purposes.

For some tailings, however, the values obtained for various column lengths differed substantially. The reason for the variability in the water flow might be due to a particular sensitivity of the tailings to packing.

Chemical reactions started in water flowing through tailings that had a high sulphide content. Iron hydroxides precipitated, or small gas bubbles developed, thereby making volumetric measurements subject to significant variations. The values of the surface areas exposed to water, that are marked with an asterisk in this report, refer to tailings subject to those variations. The values have been expressed in cm^2/cm^3 . The volume of the solid particles is hereby considered rather than the bulk volume which includes the pore volume. The preference for using a volumetric rather than a gravimetric designation originates in associating this factor with the water flow in the field - a water flow through a certain volume of tailings.

3. EXPERIMENTAL RESULTS

3.1. Analysis of a Tailings Sample Supplied by Mining Company No. 1*

The results of the chemical analysis of a tailings sample from Mining Company No. 1 are listed in Table 1.

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 0.8% from room temperature to 460°C ; 1.3% from 460°C to 625°C ; 3.5% from 625°C to 790°C ; and 0.2% from 790°C to 1000°C , totalling 5.8% up to 1000°C .

*It is emphasized that statements in this report concerning a possible acid reaction of a mineral composition in water, or about a mineral composition having a pollutant potential, do not necessarily imply that they will be valid in field conditions. The experiments on tailings samples are aimed at providing information solely about the effects of variables in the weathering processes. Whether or not, or in which way, this information can be applied technically to the abatement of acid drainage is beyond the scope of this study. In order to avoid invalid interpretations of the information supplied by this study, names of mining companies involved have been withheld.

TABLE 1

Chemical Analysis of a Tailings Sample from Mining Company
No. 1*

| Composition in Wt % | | | |
|--------------------------------|-------|-------|--------|
| Na ₂ O | 1.97 | S | 0.20 |
| K ₂ O | 1.81 | As | 0.24 |
| CaO | 7.46 | Cu | 0.090 |
| MgO | 3.90 | Zn | 0.005 |
| Al ₂ O ₃ | 11.51 | Pb | 0.006 |
| SiO ₂ | 51.58 | Ni | 0.007 |
| P ₂ O ₅ | | Co | 0.006 |
| CO ₂ | 3.38 | Mn | 0.054 |
| Fe | 18.1 | Cd | <0.001 |
| | | Total | 100.3 |

Exchange Cap.
2.48 m.equiv./100 g

These losses are probably due to the decomposition of the carbonates and of some of the iron hydroxides.

*The chemical analyses of the tailings samples have been done by the Analytical Section of the Extraction Metallurgy Division, except where indicated. The top seven results in the left-hand column of the tables listing the results were reported as elements. They have been converted to oxides in order to arrive at the total. The comparatively small fractions of Fe that occur as oxides, as hydroxides, or in carbonates and silicates, have been taken into account to arrive at the final results of the mineralogical analysis when they were expected to be significant.

The reported results of the screen analysis of the sample* are listed in Table 2.

TABLE 2
Particle-Size Distribution in a Tailings Sample
from Mining Company No. 1

| Mesh Size | Wt % | |
|-----------|------|----------------------|
| +100 | 31.4 | |
| -100 +150 | 8.4 | Particle-Size Code** |
| -150 +200 | 8.7 | 3.3.4. |
| -200 +270 | 4.5 | |
| -270 +325 | 6.3 | |
| -325 | 40.7 | |

The microscopy examination of the screen fractions indicated the presence of a major amount of altered feldspar and opaque material. Quartz was present in a moderate amount, sometimes occurring as an intergrowth with feldspar. The amount of opaque minerals increased in the fine fractions and appeared to consist mainly of iron oxides and hydroxides. Fair amounts of epidote and amphibole, partly altered to chlorite, and some pyroxene were present. The amount of sericite increased in the fine fractions. The other feldspar alteration products consisted mostly of fine-grained minerals and amorphous material belonging

*The screen analyses were done by the Non-Metallic and Waste Minerals Section of the Mineral Processing Division⁽⁶⁾. The results of the plus-100-mesh fractions have been totalled into the +100 mesh fraction, while the -200 +325 mesh fraction has been divided into -200 +270 mesh and -270 +325 mesh fractions according to the results obtained by A.L. Wilkins, Physical Chemistry Group. The size fractions in the table were selected on the basis of future use in percolation experiments that will be described elsewhere.

**The particle size code used in this table and all the following listing particle size or mineral composition has been explained on Page 7.

to the clay mineral group. A little fresh orthoclase, plagioclase, and only a few grains of carbonates could be observed.

The opaque minerals were principally the iron oxides, hematite and magnetite. Only a very small amount of sulphides could be observed in the polished section.

The X-ray diffraction analysis indicated the presence of chlorite, calcite, quartz, amphibole, feldspar, magnetite, clay minerals, and amorphous material. The amorphous material was concentrated in the fraction of the super-centrifuge close to the entrance and probably contains much iron hydroxides.

The specific gravity was reported to be 3.07 and the grain surface area exposed to water was $68 \text{ cm}^2/\text{cm}^3$.

The foregoing information was combined and the estimated mineral composition of this tailings sample is listed in Table 3.

It will be evident that the amount of iron oxides and hydroxides indicated by the results of the chemical analysis has been decreased in the estimation of the mineralogical composition.

TABLE 3

Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 1

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|------|-----------------------------|------|
| Pyrite, etc. | 0.2 | | |
| Pyrrhotite | | | |
| Chalcopyrite | 0.3 | | |
| Sphalerite | 0.01 | | |
| Galena | 0.01 | | |
| | | Total Sulphides | 0.5 |
| Iron Oxides | 15 | Total Iron (Hydr) Oxides | 15 |
| Iron Hydroxides | 3 | | |
| Calcite, Dolomite Ankerite, Siderite | 7.7 | Total Carbonates | 8 |
| Chlorites, Amphiboles, and other Basic Silicates | 15.5 | | |
| Orthoclase, Sericite, etc. | 12.6 | | |
| Plagioclase, Zoisite, etc. | 28.5 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 41.1 | Total Silicates | 56.5 |
| Quartz | 17.3 | | 15 |
| Sulphates, Phosphates, etc. | | | |
| | | Total | 95 |

Specific
Gravity
3.07
Particle
Size 3.3.4
Surface
Area 68

3.2. Analysis of a Tailings Sample Supplied by Mining Company No. 2

The results of the chemical analysis of a tailings sample from Mining Company No. 2 are listed in Table 4.

TABLE 4
Chemical Analysis of a Tailings Sample from Mining Company No. 2

| Composition in Wt % | | | |
|--------------------------------|-------|-------|-------|
| Na ₂ O | 2.79 | S | 0.10 |
| K ₂ O | 3.22 | As | 0.22 |
| CaO | 2.93 | Cu | 0.067 |
| MgO | 2.07 | Zn | 0.012 |
| Al ₂ O ₃ | 14.00 | Pb | 0.007 |
| SiO ₂ | 66.57 | Ni | 0.005 |
| P ₂ O ₅ | | Co | |
| CO ₂ | 1.35 | Mn | 0.070 |
| Fe | 3.83 | Cd | 0.001 |
| Total | | 97.24 | |

Exchange Cap.
3.9 m.equiv./100 g

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 0.5% from room temperature to 460°C; 1.0% from 460°C to 620°C; 1.3% from 620°C to 750°C; and 0.2% from 750°C to 1000°C, totalling 3.0% in the temperature range up to 1000°C.

These losses are probably due to the decomposition of carbonates, hydrated iron oxides, and amorphous alteration-products of feldspar - all present in small amounts.

The reported results of the screen analyses of the sample are listed in Table 5.

TABLE 5

Particle-Size Distribution in a Tailings Sample
from Mining Company No. 2

| Mesh Size | Wt % | |
|-----------|------|------------------------------|
| +100 | 24.7 | |
| -100 +150 | 11.8 | |
| -150 +200 | 9.7 | Particle-Size Code 2.3.5. |
| -200 +270 | 3.5 | |
| -270 +325 | 5.2 | |
| -325 | 45.1 | |

The microscopy of the screen fractions indicated feldspar and quartz to be the major components. Only a few grains of chlorite and a green-brown mica were observed in the coarse fractions. The feldspar consisted mostly of polysynthetically-twinned plagioclase, altered for the greater part to very fine-grained material that was amorphous or possibly belonged to the clay-mineral group. Some epidote was present as medium-sized grains and as finer-grained aggregates. The amount of brownish-green amphibole increased in the fine fractions. A few grains of pyroxene, inclusions of apatite, some sericite, and a very small amount of carbonate could be observed. The content of opaque minerals was very low, as was confirmed by the examination of the polished sections. Magnetite appeared to be present in a fair amount, while only a few grains of pyrite and chalcopyrite could be detected. Another opaque mineral was present in an amount and with a grain-size too small for identification.

The X-ray diffraction analysis indicated the presence of quartz, chlorite, clay minerals, feldspar, and amorphous material. The major amount of amorphous material was concentrated in the fraction of the super-centrifuge farthest away from the entrance and probably belongs to the clay-mineral group.

The specific gravity was reported to be 2.73 and the grain-surface area exposed to water was $99 \text{ cm}^2/\text{cm}^3$.

The foregoing information was combined and the estimated mineral composition of this tailings is listed in Table 6.

TABLE 6

Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 2

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|------|-----------------------------|------|
| Pyrite, etc. | 0.35 | Total Sulphides | 1 |
| Pyrrhotite | | | |
| Chalcopyrite | 0.2 | | |
| Sphalerite | 0.02 | | |
| Galena | | | |
| Iron Oxides | 2.5 | Total Iron (Hydr) Oxides | 3 |
| Iron Hydroxides | 0.5 | | |
| Calcite, Dolomite | 3.1 | Total Carbonates | 3 |
| Ankerite, Siderite | | | |
| Chlorites, Amphiboles, and other Basic S Silicates | 11.8 | Total Silicates | 58 |
| Orthoclase, Sericite, etc. | 22.5 | | |
| Plagioclase, Zoisite, etc. | 23.6 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 46.1 | | |
| Quartz | 30.6 | | 31 |
| Sulphates, Phosphates, etc. | | | |
| | | Total | 96 |

Specific
Gravity
2.73
Particle
Size
2.3.5.
Surface
Area 99

3.3. Analysis of a Tailings Sample Supplied by Mining Company No. 3

The results of the chemical analysis of the tailings sample supplied by Mining Company No. 3 are listed in Table 7.

TABLE 7
Chemical Analysis of a Tailings Sample from Mining Company No. 3

| Composition in Wt % | | | |
|--------------------------------|-------|----|--------|
| Na ₂ O | 5.50 | S | 0.07 |
| K ₂ O | 0.59 | As | 0.43 |
| CaO | 2.08 | Cu | 0.011 |
| MgO | 3.55 | Zn | 0.014 |
| Al ₂ O ₃ | 13.08 | Pb | 0.018 |
| SiO ₂ | 69.13 | Ni | |
| P ₂ O ₅ | | | |
| CO ₂ | 1.38 | Mn | 0.057 |
| Fe | 3.88 | Cd | <0.001 |
| Total | | | 99.79 |

The thermogravimetric analysis of the sample indicated that weight losses occurred in the following temperature ranges: 0.2% from room temperature to 480°C; 1.53% from 480°C to 640°C; 1.53% from 640°C to 1050°C, totalling 3.26% in the temperature range up to 1050°C.

These losses are due principally to the decomposition of hydrated iron oxides and other amorphous material that appeared to be present.

The reported results of the screen analysis of the sample are listed in Table 8.

TABLE 8

Particle-Size Distribution in a Tailings Sample
from Mining Company No. 3

| Mesh Size | Wt % | |
|-----------|------|--------------------|
| +100 | 23.3 | |
| -100 +150 | 11.0 | |
| -150 +200 | 10.6 | Particle-Size Code |
| -200 +270 | 4.9 | 2.3.5. |
| -270 +325 | 6.3 | |
| -325 | 43.9 | |

The microscopy examination of the screen fractions indicated the presence of quartz and feldspar as the major components. Only a few grains of polysynthetically-twinned plagioclase were present. Most of the feldspar was altered to clay minerals and sericite. Some quartz-feldspar grains may be of sedimentary origin, because they possibly consisted of fine-grained conglomerates. A few grains of carbonate, chlorite, and altered amphibole were also observed. The amount of quartz seemed to increase slightly in the finer fractions. Generally, the amount of opaque minerals in the fractions was very low, as was confirmed by the microscopy examination of the polished sections. The principal opaque minerals were arsenopyrite, cobaltite, safflorite, and possibly a few other arsenides, occurring in trace amounts. A few specks of native silver, some sphalerite, and possibly chalcopyrite could also be observed. The arsenides or arseno-sulphides were altering on the surface to iron hydroxides.

The thin section indicated, in addition to the results of the examination of the screen fractions, the presence of possibly more than one type of amphibole. Also, a colourless mineral, having a high refractive index, a high birefringence, and straight extinction that could not be identified readily, was present as fine-grained masses.

The X-ray diffraction analysis indicated the presence of quartz, anorthite, chlorite, and a large amount of amorphous material.

The specific gravity was reported to be 2.72 and the surface area exposed to water was 135 cm²/cm³.

The foregoing information was combined, and produced the estimate of the mineral composition listed in Table 9.

TABLE 9
Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 3

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|--------|--------------------------|------|
| Pyrite, etc. | 0.7 | | |
| Pyrrhotite | | | |
| Chalcopyrite | 0.04 | | |
| Sphalerite | 0.02 | | |
| Galena | 0.02 | | |
| | | Total Sulphides | 1 |
| Iron Oxides | } 7.2 | | |
| Iron Hydroxides | | | |
| | | Total Iron (Hydr) Oxides | 4 |
| Calcite, Dolomite | 3.1 | | |
| Ankerite, Siderite | | | |
| | | Total Carbonates | 3 |
| Chlorites, Amphiboles, and other Basic Silicates | 12.2 | | |
| Orthoclase, Sericite, etc. | 4.2 | | |
| Plagioclase, Zoisite, etc. | } 46.6 | | |
| Clay, Additional Alteration | | | |
| Total Acid Silicates | 50.8 | Total Silicates | 60 |
| Quartz | 29.2 | | 29 |
| Sulphates, Phosphates, etc. | | | |
| | | Total | 97 |

Specific Gravity 2.72
 Particle Size 2.3.5.
 Surface Area 135

3.4. Analysis of a Tailings Sample Supplied by Mining Company No. 4

The results of the chemical analysis of a tailings sample from Mining Company No. 4 are listed in Table 10.

TABLE 10
Chemical Analysis of a Tailings Sample from Mining Company No. 4

| Composition in Wt % | | | |
|--------------------------------|-------|-------|-------|
| Na ₂ O | 1.13 | S | 0.94 |
| K ₂ O | 2.11 | As | 0.05 |
| CaO | 1.44 | Cu | 0.03 |
| MgO | 17.41 | Zn | 0.01 |
| Al ₂ O ₃ | 9.32 | Pb | 0.005 |
| SiO ₂ | 52.87 | Ni | 0.23 |
| P ₂ O ₅ | 0.03 | Co | |
| CO ₂ | 1.19 | Mn | 0.07 |
| Fe | 7.34 | Cd | 0.003 |
| | | Total | 94.21 |

Exchange Cap.
1.33 m. equiv./100 g

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 0.8% from room temperature to 350°C; 6.6% from 350°C to 855°C; and 0.6% from 855°C to 1050°C, totalling 8.0% in the range up to 1050°C. These losses can probably be attributed to the decomposition of iron hydroxides and hydrated silicates.

The reported results of the screen analysis of the sample are listed in Table 11.

TABLE 11

Particle-Size Distribution in a Tailings Sample
from Mining Company No. 4

| Mesh Size | Wt % | |
|-----------|------|------------------------------|
| +100 | 2.0 | |
| -100 +150 | 3.3 | Particle-Size Code 0.3.7. |
| -150 +200 | 7.4 | |
| -200 +270 | 12.6 | |
| -270 +325 | 1.1 | |
| -325 | 73.6 | |

The microscopy examination of the screen fractions indicated the presence of a major amount of biotite and amphibole in the coarse fractions. This amount decreased radically in fine fractions, whereas the minerals present in minor quantities in the coarse fractions, viz., quartz, chlorite, sericite and feldspar, increased. A few grains of colourless pyroxene and polysynthetically-twinned plagioclase were observed.

The very small amount of sulphides observed in the polished sections confirmed the results of the chemical analysis. The sulphides consisted mostly of pyrrhotite. Some iron oxides could also be observed. The principal amount of iron compounds, however, was assumed to occur in the fine fractions.

The X-ray diffraction analysis of the fractions, obtained in the super-centrifuge, indicated the presence of quartz, amorphous material, serpentine, feldspar, and pyrrhotite. The serpentine was not observed by microscope and is apparently concentrated in the finest fractions. It is possible, however that a fibrous brown amphibole transformed to the serpentine structure, which has been grouped together with biotite. The occurrence of serpentine in the coarse fractions, however, was not obvious.

The specific gravity was reported to be 2.83 and the grain surface area exposed to water was $327 \text{ cm}^2/\text{cm}^3$.*

*Variability in determinations is explained on page 9.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 12.

TABLE 12

Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 4

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|------|-----------------------------|------|
| Pyrite, etc. | | | |
| Pyrrhotite | 2.5 | | |
| Chalcopyrite | 0.1 | | |
| Sphalerite | 0.02 | | |
| Galena | tr | | |
| | | Total Sulphides | 3 |
| Iron Oxides | 5 | | |
| Iron Hydroxides | 3.2 | | |
| | | Total Iron (Hydr) Oxides | 6 |
| Calcite, Dolomite | 3.7 | | |
| Ankerite, Siderite | | | |
| | | Total Carbonates | 4 |
| Chlorites, Amphiboles, and other Basic Silicates | 38.2 | | |
| Orthoclase, Sericite, etc. | 14.8 | | |
| Plagioclase, Zoisite, etc. | 9.5 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 24.3 | | |
| | | Total Silicates | 63 |
| Quartz | 20.4 | | 20 |
| Sulphates, Phosphates, etc. | | | |
| | | Total | 96 |

Surface
Gravity
2.83
Particle
Size 0.3.7.
Surface
Area
327*

*The use of the asterisk following the value of the surface area in this table and all the following tables listing mineral compositions indicates variability in the determinations as explained on page 9.

3.5. Analysis of a Tailings Sample Supplied by Mining Company No. 5

The results of the chemical analysis of a tailings sample from Mining Company No. 5 are listed in Table 13.

TABLE 13
Chemical Analysis of a Tailings Sample from Mining Company No. 5

| Composition in Wt % | | | |
|--------------------------------|-------|----|-------|
| Na ₂ O | 3.96 | S | 1.71 |
| K ₂ O | 1.33 | As | 0.22 |
| CaO | 6.48 | Cu | 0.12 |
| MgO | 4.01 | Zn | 0.020 |
| Al ₂ O ₃ | 11.41 | Pb | 0.005 |
| SiO ₂ | 52.44 | Ni | 0.010 |
| P ₂ O ₅ | | Co | |
| CO ₂ | 2.15 | Mn | 0.10 |
| Fe | 11.7 | Cd | 0.001 |
| Total | | | 95.67 |

Exchange Cap.
5.2 m. equiv./100 g

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 0.4% from room temperature to 425°C; 1.6% from 425°C to 630°C; 2.0% from 630°C to 780°C; 0.2% from 780°C to 910°C; and 0.8% from 910°C to 1050°C, totalling 5.0% in the range up to 1050°C.

These losses can probably be attributed to the decomposition of carbonates and iron hydroxides.

The reported results of the screen analysis of the sample are listed in Table 14.

TABLE 14

Particle-Size Distribution in a Tailings Sample
from Mining Company No. 5

| Mesh Size | Wt % | |
|-----------|------|------------------------------|
| +100 | 28.4 | |
| -100 +150 | 11.7 | Particle-Size Code 3.3.4. |
| -150 +200 | 8.4 | |
| -200 +270 | 5.0 | |
| -270 +325 | 6.1 | |
| -325 | 40.4 | |

The microscopy examination of the screen fractions indicated the presence of quartz, opaque minerals, altered feldspar, and a fair amount of amphibole in the coarse fractions. The amount of amphibole and chlorite increased in finer fractions, in which the amount of sericite had also increased. A few grains of pyroxene were observed, whereas more calcite appeared to be present than was indicated by the chemical analysis. It may, therefore, be concentrated into the coarse fractions.

Only a few grains of polysynthetically-twinned plagioclase were observed, but quartz-feldspar intergrowths were present in a fair amount.

Green, as well as brown, amphiboles were present and a moderate amount of iron hydroxides. The opaque minerals appeared to consist principally of iron oxides and pyrite. Only a small amount of pyrrhotite, chalcopyrite, and sphalerite could be observed.

The X-ray diffraction analysis indicated the presence of clay minerals, chlorite, amphibole, feldspar, calcite, and amorphous material. The amorphous material was concentrated in the heaviest fraction of the super-centrifuge, possibly indicating the presence of iron hydroxides.

The specific gravity was reported to be 2.95 and the grain-surface area exposed to water $102 \text{ cm}^2/\text{cm}^3$.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 15.

TABLE 15
Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 5

| Mineral Groups | Wt % | Final Estimate | Wt % |
|---|------|-----------------------------|------|
| Pyrite, etc. | 2.3 | | |
| Pyrrhotite | 1 | | |
| Chalcopyrite | 0.3 | | |
| Sphalerite | 0.02 | | |
| Galena | | Total Sulphides | 4 |
| Iron Oxides | 10.4 | | |
| Iron Hydroxides | 3 | Total Iron (Hydr) Oxides | 10 |
| Calcite, Dolomite | 4.9 | | |
| Ankerite, Siderite | | Total Carbonates | 5 |
| Chlorites, Amphiboles and other Basic Silicates | 19.7 | | |
| Orthoclase, Sericite, etc. | 9.3 | | |
| Plagioclase, Zoisite, etc. | 33.5 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 42.8 | Total Silicates | 63 |
| Quartz | 14.3 | | 14 |
| Sulphates, Phosphates, etc. | | | |
| | | Total | 98 |

Specific Gravity
2.95
Particle Size 3.3.4.
Surface Area 102

3.6 Analysis of a Tailings Sample Supplied by Mining Company No.6

The results of the chemical analysis of a tailings sample from Mining Company No. 6 are listed in Table 16.

TABLE 16
Chemical Analysis of a Tailings Sample from Mining Company No. 6

| Composition in Wt % | | | |
|--------------------------------|-------|-------|-------|
| Na ₂ O | 3.85 | S | 2.13 |
| K ₂ O | 0.69 | As | 0.04 |
| CaO | 8.60 | Cu | 0.02 |
| MgO | 6.27 | Zn | 0.03 |
| Al ₂ O ₃ | 10.22 | Pb | 0.001 |
| SiO ₂ | 38.76 | Ni | 0.03 |
| P ₂ O ₅ | 0.09 | Co | |
| CO ₂ | 13.40 | Mn | 0.02 |
| Fe | 7.75 | Cd | 0.003 |
| | | Total | 92.08 |

Exchange Cap.
0.90 m.equiv./100 g

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 0.4% from room temperature to 160°C; 0.2% from 160°C to 465°C; 17.0% from 465°C to 890°C; 1.2% from 890°C to 1040°C; and 0.7% from 1040°C to 1100°C, totalling 19.5% in the range up to 1100°C.

These weight losses can be partly attributed to the decomposition of carbonate and pyrite. The rest has been attributed to the decomposition of iron hydroxides. The amount of iron hydroxides, reported in the mineral composition, may, however, be too high because a certain amount of wood fibres was observed in the tailings and these could not be separated. Wood in the sample would make all analyses low and cause the T.G.A. weight-losses to be high.

The reported results of the screen analysis of the sample are listed in Table 17.

TABLE 17

Particle-Size Distribution in a Tailings Sample
from Mining Company No. 6

| Mesh Size | Wt % | |
|-----------|------|---------------|
| +100 | 0.2 | |
| -100 +150 | 0.3 | |
| -150 +200 | 0.5 | Particle-Size |
| -200 +270 | 1.5 | Code 0.0.10. |
| -270 +325 | 0.8 | |
| -325 | 96.7 | |

The microscopy examination of the screen fractions indicated the presence of a major amount of carbonate and quartz in the coarse fractions, whereas chlorite, partly altered orthoclase, and plagioclase were present in smaller amounts. The chlorites were alteration products of basic silicates and consisted of fine-grained masses that included opaque minerals, possibly predominantly limonite.

The X-ray diffraction analysis of the fractions obtained in the super-centrifuge indicated the presence of pyrite, quartz, chlorite, and dolomite in the coarse fractions, whereas dolomite and feldspar were apparently concentrated into the fine fractions.

The specific gravity of the tailings was reported to be 2.88 and the grain-surface area exposed to water was $114 \text{ cm}^2/\text{cm}^3$.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 18.

TABLE 18

Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 6

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|-------|-----------------------------|------|
| Pyrite, etc. | 4.5 | Total Sulphides | 5 |
| Pyrrhotite | | | |
| Chalcopyrite | 0.06 | | |
| Sphalerite | 0.1 | | |
| Galena | | | |
| Iron Oxides | } 8.7 | Total Iron (Hydr) Oxides | 5 |
| Iron Hydroxides | | | |
| Calcite, Dolomite | 26.8 | Total Carbonates | 30 |
| Ankerite, Siderite | 1.6 | | |
| Chlorites, Amphiboles, and other Basic Silicates | 3.0 | Total Silicates | 43 |
| Orthoclase, Sericite, etc. | 4.8 | | |
| Plagioclase, Zoisite, etc. | 34.9 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 39.7 | | |
| Quartz | 12.2 | | 12 |
| Sulphates, Phosphates, etc. | | | |
| | | Total | 95 |

Specific
Gravity
2.88
Particle
Size
0.0.10.
Surface
Area 114

3.7 Analysis of a Tailings Sample Supplied by Mining Company No. 7

The results of the chemical analysis of a tailings sample from Mining Company No. 7 are listed in Table 19.

TABLE 19

Chemical Analysis of a Tailings Sample from Mining Company No. 7

| Composition in Wt % | | | |
|--------------------------------|-------|-----|-------|
| Na ₂ O | 1.24 | S | 7.50 |
| K ₂ O | 1.47 | As | 0.04 |
| CaO | 1.85 | Cu | 0.13 |
| MgO | 1.89 | Zn | 1.21 |
| Al ₂ O ₃ | 8.07 | Pb | 0.24 |
| SiO ₂ | 39.17 | Ni | 0.004 |
| P ₂ O ₅ | 0.06 | Cd | 0.004 |
| CO ₂ | 1.16 | Mn | 0.05 |
| Fe | 4.26 | BaO | 23.36 |
| Total | | | 91.69 |

Exchange Cap.
1.73 m.equiv./100 g

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 0.4% from room temperature to 388°C; 2.1% from 388°C to 605°C; 1.8% from 605°C to 780°C; and 11.1% from 780°C to 1150°C. The last reaction was apparently not finished at 1150°C.

The weight losses in the range up to 780°C were accompanied by the formation of noticeable sulphur dioxide; this would be produced by the decomposition of pyrite. The total weight loss of 15.4%, however, could not be explained.

The results of the screen analysis of the sample are listed in Table 20.

TABLE 20

Particle-Size Distribution in a Tailings Sample
from Mining Company No. 7

| Mesh Size | Wt % | |
|-----------|------|------------------------------|
| +100 | 6.2 | |
| -100 +150 | 7.3 | |
| -150 +200 | 12.6 | Particle-Size Code 1.3.6. |
| -200 +270 | 7.4 | |
| -270 +325 | 5.3 | |
| -325 | 61.2 | |

The microscopy examination of the screen fractions indicated the presence of fine-grained masses of altered minerals, consisting only in part of sericite and chlorite as major constituents of the coarse fractions. Barite was present in small amounts as were quartz, chlorite, polysynthetically-twinned and altered basic plagioclases. The amount of quartz and sulphides increased in the fine fractions.

Only a few grains of biotite, titanite, and rutile were observed. The sulphides appeared to consist of pyrite, chalcopyrite, and sphalerite.

The results of the X-ray diffraction analysis of the fractions obtained in the super-centrifuge indicated the presence of quartz, chlorite, and bornite. The presence of bornite could not be confirmed microscopically in the polished section of the 200- to 270-mesh fraction.

The specific gravity was reported to be 3.30 and the grain-surface area exposed to water was $180 \text{ cm}^2/\text{cm}^3$.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 21.

TABLE 21
Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 7

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|------|-----------------------------|------|
| Pyrite, etc. | 3.6 | Total Sulphides | 6 |
| Pyrrhotite | | | |
| Chalcopyrite | 0.4 | | |
| Sphalerite | 1.8 | | |
| Galena | 0.2 | | |
| Iron Oxides | }4.7 | Total Iron (Hydr) Oxides | 2 |
| Iron Hydroxides | | | |
| Calcite, Dolomite | 2.6 | Total Carbonates | 2.5 |
| Ankerite, Siderite | | | |
| Chlorites, Amphiboles, and other Basic Silicates | 4.7 | Total Silicates | 29 |
| Orthoclase, Sericite, etc. | 12.9 | | |
| Plagioclase, Zoisite, etc. | 11.3 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 24.2 | | |
| Quartz | 23.6 | | 23.5 |
| Sulphates, Phosphates, etc. | 34.5 | | 34.5 |
| | | Total | 97.5 |

Specific Gravity
3.30
Particle Size
1.3.6.
Surface Area
180

3.8.1. Analysis of a Tailings Sample Supplied by Mining Company No. 8

The results of the chemical analysis of the fine-grained tailings sample from Mining Company No. 8 are listed in Table 22.

TABLE 22
Chemical Analysis of a Tailings Sample from Mining Company No. 8

| Composition in Wt % | | | |
|--------------------------------|------|----|-------|
| Na ₂ O | 0.13 | S | 2.99 |
| K ₂ O | 2.74 | As | 0.04 |
| CaO | 1.27 | Cu | 0.01 |
| MgO | 0.15 | Zn | 0.002 |
| Al ₂ O ₃ | 8.2 | Pb | 0.09 |
| SiO ₂ | 76.5 | Ni | 0.004 |
| P ₂ O ₅ | 0.06 | Co | |
| CO ₂ | 0.18 | Mn | 0.002 |
| Fe | 2.37 | Cd | 0.004 |
| Total | | | 94.74 |

Exchange Cap.
0.96 m.equiv./100 g

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 0.7% from room temperature to 250°C; 1.5% from 250°C to 600°C; and 2.9% from 600°C to 1050°C, totalling 5.1% in the range up to 1050°C.

The weight loss could be produced by the decomposition of pyrite, carbonates and, possibly, a small amount of gypsum.

The reported results of the screen analysis of the sample are listed in Table 23.

TABLE 23
Particle-Size Distribution in a Tailings Sample
from Mining Company No. 8

| Mesh Size | Wt % | |
|-----------|------|------------------------------|
| +100 | 7.2 | |
| -100 +150 | 5.3 | Particle-Size Code 1.3.6. |
| -150 +200 | 13.0 | |
| -200 +270 | 6.7 | |
| -270 +325 | 4.4 | |
| -325 | 63.4 | |

The microscopy examination of the screen fractions indicated the presence of a large amount of quartz and opaque minerals in the coarse fractions. Smaller amounts of muscovite, orthoclase, and sericite were observed, whereas plagioclase was present only in a small amount. Hardly any chlorite or any other basic silicates could be observed.

The amount of feldspar increased in the fine fractions.

The results of the X-ray diffraction analysis of the fractions obtained in the super-centrifuge indicated the presence of quartz, mica, and pyrite only.

The specific gravity was reported to be 2.81 and the grain-surface area exposed to water was $149 \text{ cm}^2/\text{cm}^3$.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 24.

TABLE 24

Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 8

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|------|--------------------------|------|
| Pyrite, etc | 4.9 | | |
| Pyrrhotite | | | |
| Chalcopyrite | 0.07 | | |
| Sphalerite | 0.03 | | |
| Galena | 0.1 | | |
| | | Total Sulphides | 5 |
| Iron Oxides | | | |
| Iron Hydroxides | | | |
| | | Total Iron (Hydr) Oxides | |
| Calcite, Dolomite | 0.4 | | |
| Ankerite, Siderite | | | |
| | | Total Carbonates | 0.5 |
| Chlorites, Amphiboles, and other Basic Silicates | 0.8 | | |
| Orthoclase, Sericite, etc. | 19.2 | | |
| Plagioclase, Zoisite etc. | 4.7 | | |
| Clay, Additional alteration | 3.6 | | |
| Total Acid Silicates | 27.5 | | |
| | | Total Silicates | 28 |
| Quartz | 60.6 | | 60.5 |
| Sulphates, Phosphates, etc. | 2 | | 2 |
| | | Total | 96 |

Specific Gravity 2.81
Particle Size 1.3.6.
Surface Area 149

3.8.2. Analysis of a Coarse-Grained Tailings Sample
Supplied by Mining Company No. 8

The coarse-grained tailings sample supplied by Mining Company No. 8 has not been analysed to the same extent as the other samples. It was not comparable in grain size to any of the tailings supplied by the other companies.

The results of the chemical analysis of this sample are listed in Table 25.

TABLE 25
Chemical Analysis of a Tailings Sample
from Mining Company No. 8

| Composition in Wt % | | | |
|--------------------------------|-------|----|--------|
| Na ₂ O | 0.039 | S | 4.10 |
| K ₂ O | 0.98 | As | 0.15 |
| CaO | 0.027 | Cu | 0.017 |
| MgO | 0.054 | Zn | 0.003 |
| Al ₂ O ₃ | 3.12 | Pb | 0.031 |
| SiO ₂ | 87.3 | Ni | 0.094 |
| P ₂ O ₅ | | Co | |
| CO ₂ | 0.03 | Mn | 0.007 |
| Fe | 4.88 | Cd | <0.001 |
| Total | | | 100.83 |

Exchange Cap.
1.35 m.equiv./100 g

The reported results of the screen analysis of the sample are listed in Table 26.

The microscopy of the screen fractions indicated the presence of essentially the same minerals as those observed in the fine-grained sample. The amount of quartz had probably increased, whereas that of sericite and feldspar had decreased. Sections were not examined because of the mineralogical similarity of the samples, nor was any X-ray diffraction analysis done.

TABLE 26
Particle-Size Distribution in a Coarse-Grained
Tailings Sample from Mining Company No. 8

| Mesh Size | Wt % | |
|-----------|------|------------------------------|
| +100 | 70.9 | |
| -100 +150 | 12.8 | Particle-Size Code 7.3.0. |
| -150 +200 | 8.6 | |
| -200 +270 | 5.9 | |
| -270 +325 | 1.8 | |
| -325 | | |

The specific gravity was reported to be 2.52; the grain-surface area exposed to water was not measured.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 27.

Although the results indicate that some segregation had taken place in that the amount of quartz had increased while the feldspar content had decreased, the mineral composition of the coarse-grained sample was not significantly different from that of the fine-grained sample.

TABLE 27

Estimated Mineral Composition of a Coarse-Grained
Tailings Sample from Mining Company No. 8

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|-------|-----------------------------|------|
| Pyrite, etc. | 7 | | |
| Pyrrhotite | | | |
| Chalcopyrite | 0.05 | | |
| Sphalerite | 0.005 | | |
| Galena | 0.02 | | |
| | | Total Sulphides | 7 |
| Iron Oxides | | | |
| Iron Hydroxides | | Total Iron (Hydr) Oxides | |
| Calcite, Dolomite | 1.6 | | |
| Ankerite, Siderite | | | |
| | | Total Carbonates | 1.5 |
| Chlorites, Amphiboles, and other Basic Silicates | <1 | | |
| Orthoclase, Sericite, etc. | 6.8 | | |
| Plagioclase, Zoisite, etc. | } 0.3 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 7.1 | | |
| | | Total Silicates | 7 |
| Quartz | 83.4 | | 83 |
| Sulphates, Phosphates, etc. | | | |
| | | Total | 98.5 |

Specific Gravity
2.52
Particle Size 7.3.0.

3.9. Analysis of a Tailings Sample Supplied by Mining Company No. 9

The results of the chemical analysis of a tailings sample from Mining Company No. 9 are listed in Table 28.

TABLE 28

Chemical Analysis of a Tailings Sample from Mining Company No. 9

| Composition in Wt % | | | |
|--------------------------------|-------|-------|--------|
| Na ₂ O | 1.40 | S | 3.05 |
| K ₂ O | 1.16 | As | 0.34 |
| CaO | 6.34 | Cu | 0.10 |
| MgO | 2.69 | Zn | 0.020 |
| Al ₂ O ₃ | 11.09 | Pb | 0.006 |
| SiO ₂ | 43.88 | Ni | 0.035 |
| P ₂ O ₅ | | Co | 0.030 |
| CO ₂ | 4.68 | Mn | 0.13 |
| Fe | 13.3 | Cd | <0.001 |
| | | Total | 88.25 |

Exchange Cap.
0.28 m.equiv./100 g

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 0.3% from room temperature to 450°C; 3.8% from 450°C to 610°C; 5.1% from 610°C to 805°C; 4% from 805°C to 905°C; and 0.6% from 905°C to 1000°C, totalling 10.2% in the range up to 1000°C.

These weight losses could be produced only partly by the decomposition of carbonates and pyrite. The rest was assumed to originate principally in the decomposition of iron hydroxides and that of the alteration products from the feldspars.

The reported results of the screen analysis of the sample are listed in Table 29.

TABLE 29
Particle-Size Distribution in a Tailings Sample
from Mining Company No. 9

| Mesh Size | Wt % | |
|-----------|------|------------------------------|
| +100 | 30.4 | |
| -100 +150 | 13.0 | |
| -150 +200 | 10.1 | Particle-Size Code 3.3.4. |
| -200 +270 | 3.9 | |
| -270 +325 | 4.8 | |
| -325 | 37.8 | |

The microscopy examination of the screen fractions revealed the presence of a large amount of altered feldspar and a medium amount of quartz and opaque minerals. Only a few grains of polysynthetically-twinned plagioclase could be observed and some calcite. Amphibole, partly altered to chlorite, was present in moderate amounts and also some iron hydroxides. A few grains of zoisite and pyroxene were also observed in the thin section.

The opaque minerals appeared to consist principally of pyrrhotite, with a moderate amount of iron oxides. Only small amounts of pyrite and chalcopyrite were present. The amount of iron oxides observed in the polished section of the 200- to 270-mesh fraction was definitely not as high as that listed in the final results. A certain amount may be concentrated into the fine fractions, and Fe, occurring to a large extent as an oxide may be the reason for the low total of the chemical analysis, where it is listed as the element. The total amount of iron oxides remains questionable however.

The X-ray diffraction analysis indicated the presence of chlorite, quartz, feldspar, calcite, clay minerals, amphibole, pyrite, and amorphous material.

The specific gravity was reported to be 3.02; the grain-surface area exposed to water was $133 \text{ cm}^2/\text{cm}^3$.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 30.

TABLE 30

Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 9

| Mineral Groups | Wt % | Final Estimate | Wt % |
|---|------|-----------------------------|------|
| Pyrite, etc. | 0.5 | | |
| Pyrrhotite | 7.3 | | |
| Chalcopyrite | 0.3 | | |
| Sphalerite | 0.03 | | |
| Galena | | | |
| | | Total Sulphides | 8 |
| Iron Oxides | } 15 | Total Iron (Hydr) Oxides | 10 |
| Iron Hydroxides | | | |
| Calcite, Dolomite Ankerite, Siderite | 10.6 | Total Carbonates | 11 |
| Chlorites, Amphiboles, and other Basic Silicates | 14.5 | | |
| Orthoclase Sericitic, etc. | 8.1 | | |
| Plagioclase, Zoisite, etc. | 11.9 | | |
| Clay, Additional alteration | 5.0 | | |
| Total Acid Silicates | 25.0 | | |
| Quartz | 26.2 | | 26 |
| Sulphates, Phosphates, etc | | | |
| | | Total | 95 |

Specific Gravity 3.02
Particle Size 3.3.4.
Surface Area 133

3.10. Analysis of a Tailings Sample Supplied by Mining Company No. 10

The results of the chemical analysis of a tailings sample from Mining Company No. 10 are listed in Table 31.

TABLE 31

Chemical Analysis of a Tailings Sample from Mining Company No. 10

| Composition in Wt % | | | |
|--------------------------------|-------|----|--------|
| Na ₂ O | 0.97 | S | 5.21 |
| K ₂ O | 0.34 | As | 0.32 |
| CaO | 8.48 | Cu | 0.034 |
| MgO | 10.63 | Zn | 0.008 |
| Al ₂ O ₃ | 5.24 | Pb | 0.006 |
| SiO ₂ | 45.38 | Ni | 0.24 |
| P ₂ O ₅ | | Co | 0.013 |
| CO ₂ | 1.12 | Mn | 0.092 |
| Fe | 15.6 | Cd | <0.001 |
| Total | | | 93.68 |

Exchange Cap.
0.72 m.equiv./100 g

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 0.3% from room temperature to 415°C; 0.4% from 415°C to 515°C; 0.4% from 515°C to 650°C; 1.5% from 650°C to 785°C; 0.3% from 785°C to 905°C; and 0.9% from 905°C to 1051°C, totalling 3.8% in the range up to 1050°C. These weight losses are probably produced by the decomposition of carbonate and minor amounts of sulphides.

The reported results of the screen analysis of the sample are listed in Table 32.

TABLE 32

Particle-Size Distribution in a Tailings Sample
from Mining Company No. 10

| Mesh Size | Wt % | |
|-----------|------|------------------------------|
| +100 | 14.3 | Particle-Size Code 1.4.5. |
| -100 +150 | 12.2 | |
| -150 +200 | 13.0 | |
| -200 +270 | 6.7 | |
| -270 +325 | 7.7 | |
| -325 | 46.1 | |

The microscopy examination of the screen fractions indicated the presence of a major amount of basic silicates. A nearly colourless amphibole, possibly belonging to the actinolite-tremolite group, a brownish-green and, probably, another green amphibole and some pyroxene were observed. Opaque minerals were present in moderate amount, with some quartz and feldspar. The amount of quartz and opaque minerals increased in the fine fractions, where grains of chlorite and biotite were also observed. Only a few grains of polysynthetically-twinned plagioclase and a minor amount of epidote-zoisite, often occurring in fine-grained aggregates, could be detected.

The opaque minerals consisted principally of pyrrhotite and some iron oxides. The pyrrhotite sometimes contained small inclusions of pentlandite. Chalcopyrite could be observed in only a few grains.

The X-ray diffraction analysis indicated the presence of amphiboles, magnetite, feldspar, chlorite, calcite, clay minerals, quartz, and amorphous material. Two types of amphiboles could be distinguished. One appeared to be tremolite; the other might be riebeckite.

The specific gravity was reported to be 3.21 and the grain-surface area exposed to water was $85 \text{ cm}^2/\text{cm}^3$.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 33.

TABLE 33
Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 10

| Mineral Groups | Wt % | Final Estimate | WT % |
|--|------|-----------------------------|------|
| Pyrite, etc. | | | |
| Pyrrhotite | 14.2 | | |
| Chalcopyrite | 0.1 | | |
| Sphalerite | 0.01 | | |
| | | Total Sulphides | 15 |
| Iron Oxides | 3.1 | | |
| Iron Hydroxides | | | |
| | | Total Iron (Hydr) Oxides | 5 |
| Calcite, Dolomite | 2.6 | | |
| Ankerite, Siderite | | | |
| | | Total Carbonate | 2.5 |
| Chlorites, Amphiboles, and other Basic Silicates | 48.5 | | |
| Orthoclase, Sericite, etc | 2.4 | | |
| Plagioclase, Zoisite, etc. | 8.2 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 10.6 | | |
| | | Total Silicates | 60 |
| Quartz | 10.3 | | 12 |
| Sulphides, Phosphates, etc | | | |
| | | Total | 94.5 |

Specific Gravity 3.21
 Particle Size 1.4.5.
 Surface Area 85

3.11. Analysis of a Tailings Sample Supplied by Mining Company No. 11

The results of the chemical analysis of a tailings sample from Mining Company No. 11 are listed in Table 34.

TABLE 34
Chemical Analysis of a Tailings Sample from Mining Company No. 11

| Composition in Wt % | | | |
|--------------------------------|-------|----|-------|
| Na ₂ O | 0.66 | S | 13.1 |
| K ₂ O | 1.00 | As | 0.05 |
| CaO | 0.87 | Cu | 0.13 |
| MgO | 1.16 | Zn | 0.46 |
| Al ₂ O ₃ | 6.43 | Pb | 0.03 |
| SiO ₂ | 33.39 | Ni | 0.007 |
| P ₂ O ₅ | 0.01 | Co | |
| CO ₂ | 0.81 | Mn | 0.06 |
| Fe | 31.3 | Cd | 0.003 |
| Total | | | 89.47 |

Exchange Cap.
130 m.equiv./100 g

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 0.7% from room temperature to 220°C; 1.1% from 220°C to 310°C; 0.3% from 310°C to 375°C; 4.8% from 375°C to 630°C; 1.7% from 630°C to 970°C; and 2.1% from 970°C to 1150°C.

The weight losses were attributed partly to the decomposition of iron hydroxides, the presence of which could be observed by microscope. The total weight loss, however, could not be explained. Pyrrhotite loses only about 3.5% of its weight in the temperature range up to 1100°C.

The reported results of the screen analysis of the sample are listed in Table 35.

TABLE 35
Particle-Size Distribution in a Tailings Sample
from Mining Company No. 11

| Mesh Size | Wt % | |
|-----------|------|------------------------------|
| +100 | 7.5 | |
| -100 +150 | 8.1 | Particle-Size Code 1.4.5. |
| -150 +200 | 18.9 | |
| -200 +270 | 7.8 | |
| -270 +325 | 10.0 | |
| -325 | 47.7 | |

The microscopy examination of the screen fractions indicated the presence of a major amount of opaque material in the coarse fractions, in addition to minor amounts of chlorite, sericite, quartz, urallite, and a fibrous type of amphibole. The occurrence of polysynthetically-twinned plagioclase, sometimes replaced by muscovite and orthoclase, that often occurred as an intergrowth with quartz, appeared to increase in the fine fractions. A few grains, possibly of hypersthene and tourmaline, were observed.

The polished section showed the major sulphide to be pyrrhotite, whereas only a little pyrite and even less chalcopyrite and sphalerite could be observed. A few grains contained native gold.

The X-ray diffraction analysis indicated the presence of quartz, pyrrhotite, feldspar, chlorite, and amorphous material, which was assumed to be an alteration product of iron oxides. Many of the large, dark-brown to opaque grains appeared, on closer study, to be quartz containing very small specks of an iron oxide, possibly hematite, altered to a certain extent to iron hydroxides. They could be observed only microscopically using a 2000X magnification. An X-ray diffraction pattern of these grains indicated the presence of only quartz and amorphous material. The low chemical analysis might thus be partly due to Fe being present as iron hydroxides.

The specific gravity was reported to be 3.39 and the grain-surface area exposed to water was 105 cm²/cm³.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 36.

TABLE 36
Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 11

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|------|--------------------------|------|
| Pyrite, etc. | 1 | Total Sulphides | 36 |
| Pyrrhotite | 34.2 | | |
| Chalcopyrite | 0.4 | | |
| Sphalerite | 0.7 | | |
| Galena | 0.02 | | |
| Iron Oxides | 2.8 | Total Iron (Hydr) Oxides | 15 |
| Iron Hydroxides | 17.1 | | |
| Calcite, Dolomite Ankerite, Siderite | 1.8 | Total Carbonates | 2 |
| Chlorites, Amphiboles, and other Basic Silicates | 5.2 | Total Silicates | 18 |
| Orthoclase, Sericite, etc. | 7.0 | | |
| Plagioclase, Zoisite, etc. | 5.6 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 12.6 | | |
| Quartz | 23.8 | | 24 |
| Sulphates, Phosphates, etc. | | | |
| | | Total | 95 |

Specific Gravity 3.39
 Particle Size 1.4.5.
 Surface Area 105

3.12.1. Analysis of a Sulphide-Rich Tailings Sample Supplied by Mining Company No. 12

The results of the chemical analysis of a sulphide-rich tailings sample from Mining Company No. 12 are listed in Table 37.

TABLE 37
Chemical Analysis of a Sulphide-Rich Tailings Sample from Mining Company No. 12

| Composition in Wt % | | | |
|--------------------------------|-------|----|--------|
| Na ₂ O | 0.53 | S | 17.4 |
| K ₂ O | 0.70 | As | 0.61 |
| CaO | 8.16 | Cu | 0.16 |
| MgO | 5.72 | Zn | 0.11 |
| Al ₂ O ₃ | 5.12 | Pb | 0.02 |
| SiO ₂ | 25.68 | Ni | 0.17 |
| P ₂ O ₅ | | Co | 0.056 |
| CO ₂ | 4.46 | Mn | 0.055 |
| Fe | 23.2 | Cd | <0.001 |
| Total | | | 92.14 |

Exchange Cap.
2.12 m.equiv./100 g

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 1.9% from room temperature to 420°C; 4.7% from 420°C to 620°C; 5.2% from 620°C to 800°C; and 7.7% from 800°C to 1100°C, totalling 19.5% in the range up to 1100°C.

The greatest part of these weight losses is due to the decomposition of carbonate and pyrite. However, waterlogged wood fibres were also observed, and contributed to the weight losses. The weight loss of approximately 6%, however, cannot be explained.

The reported results of the screen analysis of the sample are listed in Table 38. A screen analysis, that could be coded 0.1.9, was obtained from another part of this sample.

TABLE 38

Particle-Size Distribution in a Tailings Sample
from Mining Company No. 12

| Mesh Size | Wt % | |
|-----------|------|------------------------------|
| +100 | 12.6 | |
| -100 +150 | 7.4 | Particle-Size Code 1.2.7. |
| -150 +200 | 6.6 | |
| -200 +270 | 2.8 | |
| -270 +325 | 1.6 | |
| -325 | 69.0 | |

The microscopy examination of the screen fractions indicated the presence of a major amount of opaque minerals in the coarse fractions, together with some quartz, carbonate, chlorite, sericite, and a partly altered amphibole. A few grains of titanite and rutile could be observed. The amount of opaque minerals decreased, whereas quartz and sericite (sometimes muscovite) increased in the fine fractions. Plagioclase was mostly altered. Only a few grains of fresh polysynthetically-twinned plagioclase could be observed and also, possibly, tridymite.

The opaque minerals in the fine fractions were partly altered to a yellowish-brown material which was assumed to be limonite.

The results of the X-ray diffraction analysis indicated the presence of pyrite, quartz, pyrrhotite, chlorite, mica, feldspar, and amorphous material. The pyrite appeared under the microscope to be slightly whiter than usual; this may indicate a small arsenic content. The presence of pyrrhotite, chalcopyrite, and sphalerite could be observed in the polished sections.

The specific gravity was reported to be 3.45 and the grain-surface area exposed to water was $216 \text{ cm}^2/\text{cm}^3$.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 39.

TABLE 39

Estimated Mineral Composition of a Sulphide-Rich Tailings
Sample from Mining Company No. 12

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|------|--------------------------|------|
| Pyrite, etc. | 24 | | |
| Pyrrhotite | 12 | | |
| Chalcopyrite | 0.5 | | |
| Sphalerite | 0.2 | | |
| Galena | 0.02 | | |
| | | Total Sulphides | 36 |
| Iron Oxides | } 8 | | |
| Iron Hydroxides | | | |
| | | Total Iron (Hydr) Oxides | 6 |
| Calcite, Dolomite | 10.1 | | |
| Ankerite, Siderite | | | |
| | | Total Carbonates | 10 |
| Chlorites, Amphiboles, and other Basic Silicates | 22 | | |
| Orthoclase, Sericite, etc. | 4.9 | | |
| Plagioclase, Zoisite, etc. | 4.5 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 9.4 | | |
| | | Total Silicates | 33 |
| Quartz | 8.7 | | 9 |
| Sulphates, Phosphates, etc. | | | |
| | | Total | 94 |

Specific Gravity
3.45

Particle Size 1.2.7.

Surface Area 216*

3.12.2. Analysis of a Silica-Rich Tailings Sample
Supplied by Mining Company No. 12

The results of the chemical analysis of a silica-rich tailings sample from Mining Company No. 12 are listed in Table 40.

TABLE 40
Chemical Analysis of a Silica-Rich Tailings Sample
from Mining Company No. 12

| Composition in Wt % | | | |
|--------------------------------|-------|-------|--------|
| Na ₂ O | 2.44 | S | 0.48 |
| K ₂ O | 1.80 | As | 0.36 |
| CaO | 5.30 | Cu | 0.011 |
| MgO | 4.57 | Zn | 0.010 |
| Al ₂ O ₃ | 13.53 | Pb | 0.004 |
| SiO ₂ | 57.58 | Ni | 0.015 |
| P ₂ O ₅ | 0.07 | Co | 0.006 |
| CO ₂ | 7.22 | Mn | 0.092 |
| Fe | 5.69 | Cd | <0.001 |
| Total | | 99.18 | |

Exchange Cap.
0.85 m.equiv. /
100 g

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 0.3% from room temperature to 475°C; 1.9% from 475°C to 630°C; 6.8% from 630°C to 800°C; and 0.5% from 800°C to 1000°C, totalling 9.5% in the temperature range up to 1000°C. The weight losses are principally due to the decomposition of carbonates.

The results of the screen analysis of the sample are listed in Table 41.

TABLE 41

Particle-Size Distribution in a Silica-Rich
Tailings Sample from Mining Company No. 12

| Mesh Size | Wt % | Particle-Size Code 2.3.5. |
|-----------|------|------------------------------|
| +100 | 18.1 | |
| -100 +150 | 8.5 | |
| -150 +200 | 9.5 | |
| -200 +270 | 4.9 | |
| -270 +325 | 6.3 | |
| -325 | 52.7 | |

The microscopy examination of the screen fractions indicated the presence of a major amount of altered feldspar and quartz. A few grains of calcite, amphibole, and orthopyroxene could be observed. The amount of quartz increased considerably in the fine fractions, in which small amounts of iron hydroxides could also be observed.

The same sulphides were present as were observed in the sulphide-rich tailings sample (see page 48).

The X-ray diffraction analysis indicated the presence of quartz, chlorite, feldspar, clay minerals, dolomite, sphalerite, and amorphous material.

The specific gravity was reported to be 2.85 and the grain-surface area exposed to water was $128 \text{ cm}^2/\text{cm}^3$.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 42.

TABLE 42

Estimated Mineral Composition of a Silica-Rich Tailings
Sample from Mining Company No. 12

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|------|--------------------------|------|
| Pyrite, etc. | 0.9 | | |
| Pyrrhotite | | | |
| Chalcopyrite | 0.04 | | |
| Sphalerite | 0.01 | | |
| Galena | tr | | |
| | | Total Sulphides | 1 |
| Iron Oxides | }4 | | |
| Iron Hydroxides | | | |
| | | Total Iron (Hydr) Oxides | 2 |
| Calcite, Dolomite | 15.3 | | |
| Ankerite, Siderite | | | |
| | | Total Carbonates | 15 |
| Chlorites, Amphiboles, and other Basic Silicates | 16 | | |
| Orthoclase, Sericite, etc. | 12.6 | | |
| Plagioclase, Zoisite, etc. | 20.7 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 33.3 | | |
| | | Total Silicates | 49 |
| Quartz | 30.8 | | 31 |
| Sulphates, Phosphates, etc | | | |
| | | Total | 98 |

Specific Gravity 2.85
 Particle Size 2.3.5.
 Surface Area 128

3.13.1. Analysis of a Tailings Sample Supplied by Mining Company No. 13

The results of the chemical analysis of a tailings sample from Mining Company No. 13, supplied for the present study on tailings, are listed in Table 43.

TABLE 43
Chemical Analysis of a Tailings Sample from Mining Company No. 13

| Composition in Wt % | | | |
|--------------------------------|-------|----|-------|
| Na ₂ O | 0.73 | S | 16.7 |
| K ₂ O | 0.87 | As | 0.11 |
| CaO | 2.99 | Cu | 0.13 |
| MgO | 3.08 | Zn | 0.59 |
| Al ₂ O ₃ | 6.75 | Pb | 0.05 |
| SiO ₂ | 38.53 | Ni | 0.006 |
| P ₂ O ₅ | 0.06 | Co | |
| CO ₂ | 1.76 | Mn | 0.10 |
| Fe | 24.2 | Cd | 0.004 |
| Total | | | 96.66 |

Exchange Cap.
0.96 m.equiv./100 g

The thermogravimetric analysis of the tailings sample indicated that a weight loss of 10% occurred in the temperature range from 400°C to 990°C. This weight loss was not finished at 990°C and is assumed to originate primarily in the decomposition of pyrite.

The reported results of the screen analysis are listed in Table 44. It was also possible to obtain a particle-size distribution, Code 1.5.4., from another sample.

The microscopy examination of the screen fractions indicated that a major amount of opaque minerals was present, together with quartz, biotite, pyroxene, and possibly some brown amphibole in minor amounts. Feldspar, altered to clay minerals, was present in a moderate amount, whereas only a few grains of polysynthetically-twinned feldspar could be observed. The amount

of carbonate was low in all fractions. There was almost no biotite in the fine fractions, in which the amount of opaque minerals had increased significantly.

TABLE 44
Particle-Size Distribution in a Tailings Sample
from Mining Company No. 13

| Mesh Size | Wt % | |
|-----------|------|------------------------------|
| +100 | 20.9 | |
| -100 +150 | 10.7 | Particle-Size Code 2.5.3. |
| -150 +200 | 14.8 | |
| -200 +270 | 8.2 | |
| -270 +325 | 10.6 | |
| -325 | 34.8 | |

The opaque minerals consisted primarily of pyrite and a small amount of iron oxides. Only traces of chalcopyrite and sphalerite could be observed.

The results of the X-ray diffraction analysis indicated the presence of a large amount of clay minerals and amorphous material, and more calcite than magnetite. The presence of quartz, chlorite, pyrite, feldspar, and sphalerite was also indicated.

The principal difficulty in the analysis of the tailings of this company was that, though the quantity of carbonate, as indicated by the CO₂ content chemically determined, appeared to be supported by the microscopy examination, the weight losses indicated by the T.G.A. suggested that the CO₂ content might be higher. A higher carbonate content was supported by the results of the X-ray diffraction analysis. The solution might lie in the presence of amorphous material having a high content of iron.

The specific gravity was reported to be 3.27 and the grain-surface area exposed to water was 78* cm²/cm³.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 45.

TABLE 45
Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 13

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|------|-----------------------------|------|
| Pyrite, etc. | 27 | | |
| Pyrrhotite | 5 | | |
| Chalcopyrite | 0.4 | | |
| Sphalerite | 0.9 | | |
| Galena | 0.05 | | |
| | | Total Sulphides | 34 |
| Iron Oxides | 4 | | |
| Iron Hydroxides | 6.5 | | |
| | | Total Iron (Hydr) Oxides | 5 |
| Calcite, Dolomite | 4 | | |
| Ankerite, Siderite | 1 | | |
| | | Total Carbonates | 5 |
| Chlorites, Amphiboles, and other Basic Silicates | 12.8 | | |
| Orthoclase, Sericite, etc. | 6.0 | | |
| Plagioclase, Zoisite, etc. | 6.2 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 12.2 | | |
| | | Total Silicates | 25 |
| Quartz | 25.6 | | 26 |
| Sulphates, Phosphates, etc. | | | |
| | | Total | 95 |

Specific Gravity 3.27
 Particle Size 1.5.4.
 Surface Area 78*

3.13.2. Analysis of a Tailings Sample Supplied by Mining Company No. 13

The mineralogical analysis of a tailings sample supplied in 1970 by Mining Company No. 13 for other purposes is included in this report for completeness. The mineralogical investigation of this sample, reported by Pinard⁽⁷⁾, was extended and the results were made comparable with those of the other samples.

The results of the chemical analysis of this sample are listed in Table 46.

TABLE 46
Chemical Analysis of a Tailings Sample
from Mining Company No. 13*

| Composition in Wt % | | | |
|--------------------------------|-------|----|-------|
| Na ₂ O | 0.39 | S | 24.10 |
| K ₂ O | 0.47 | As | |
| CaO | 2.60 | Cu | 0.18 |
| MgO | 2.87 | Zn | 0.60 |
| Al ₂ O ₃ | 8.22 | Pb | 0.18 |
| SiO ₂ | 28.87 | Ni | |
| P ₂ O ₅ | | Co | |
| CO ₂ | 2.38 | Mn | |
| Fe | 26.88 | Cd | |
| Total | | | 97.74 |

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 1.0% from room temperature to 440°C; 11.9% from 440°C to 725°C; 1.7% from 725°C to 895°C; and 0.6% from 895°C to 1050°C, totalling 15.2% in the range up to 1050°C. These weight losses were attributed to the decomposition of pyrite and carbonates.

*Chemical analyses by R.R. Craig, Chemist, Analytical Chemistry Section, Mineral Sciences Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa.

The results of the screen analysis of the sample are listed in Table 47.

TABLE 47
Particle-Size Distribution in a Tailings Sample
from Mining Company No. 13

| Mesh Size | Wt % | |
|----------------------------|------|------------------------------|
| +100 | 6.0 | |
| -100 +150 } -150 +200 } | 11.4 | Particle-Size Code 1.3.6. |
| -200 +270 } -270 +325 } | 20.2 | |
| -325 +400 | 57.3 | |
| -400 | 5.1 | |

The microscopy examination of thin sections of fractions, S.G. <2.96 and 2.96<S.G.<3.3, indicated the presence of a considerable amount of feldspar, altered to sericite and clay minerals. Calcite, fine-grained masses containing opaque minerals, some grains of amphibole and chlorite, and quartz, sometimes intergrown with the feldspar, could also be observed. Only a few grains of fresh polysynthetically-twinned plagioclase and some epidote were present. The amount of carbonate present in the S.G. = 2.96 + 3.3 fraction might indicate more Fe-containing carbonate than is indicated in the final results.

The X-ray diffraction analysis of the sample indicated that it consisted primarily of pyrite and quartz, but that pyrrhotite and possibly enstatite might be minor constituents.

The specific gravity was determined to be 3.57 and the surface-area exposed to water was 91* cm²/cm³.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 48.

TABLE 48

Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 13

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|------|--------------------------|------|
| Pyrite, etc. | 40.7 | | |
| Pyrrhotite | 5 | | |
| Chalcopyrite | 0.6 | | |
| Sphalerite | 0.9 | | |
| Galena | 0.2 | | |
| | | Total Sulphides | 47 |
| Iron Oxides | 6.6 | | |
| Iron Hydroxides | | | |
| | | Total Iron (Hydr) Oxides | 6 |
| Calcite, Dolomite | 4.6 | | |
| Ankerite, Siderite | 0.7 | | |
| | | Total Carbonates | 5.5 |
| Chlorites, Amphiboles, and other Basic Silicates | 13 | | |
| Orthoclase, Sericite, etc. | 3.3 | | |
| Plagioclase, Zoisite etc. | 3.3 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 6.6 | Total Silicates | 20 |
| Quartz | 20.5 | | 20 |
| Sulphates, Phosphates, etc | | | |
| | | Total | 98.5 |

Specific Gravity 3.57
Particle Size 1.3.6.
Surface Area 91*

3.14. Analysis of a Tailings Sample Supplied by Mining Company No. 14

The results of the chemical analysis of a tailings sample from Mining Company No. 14 are listed in Table 49.

TABLE 49
Chemical Analysis of a Tailings Sample from Mining Company No. 14

| Composition in Wt % | | | |
|--------------------------------|-------|----|-------|
| Na ₂ O | 1.47 | S | 20.4 |
| K ₂ O | 1.07 | As | 0.13 |
| CaO | 1.04 | Cu | 0.03 |
| MgO | 2.16 | Zn | 0.40 |
| Al ₂ O ₃ | 5.76 | Pb | 0.49 |
| SiO ₂ | 25.47 | Ni | 0.007 |
| P ₂ O ₅ | 0.04 | Co | |
| CO ₂ | 1.11 | Nb | 0.51 |
| Fe | 34.5 | Cd | |
| Total | | | 94.59 |

Exchange Cap.
0.98 m.equiv./100 g

The thermogravimetric analysis of the tailings sample indicated that weight losses occurred in the following temperature ranges: 1.6% from room temperature to 375°C; 6.6% from 375°C to 890°C; and 2.60% from 890°C to 1000°C, totalling 10.8% in the range up to 1000°C.

These weight losses were due in part to the decomposition of carbonates. The major portion of the weight losses, however, could not be readily explained as the loss due to the decomposition of pyrrhotite would amount only to approximately 2% at the maximum.

The results of the screen analysis of this sample are listed in Table 50.

TABLE 50

Particle-Size Distribution in a Tailings Sample
from Mining Company No. 14

| Mesh Size | Wt % | Particle-Size Code 1.3.6. |
|-----------|------|------------------------------|
| +100 | 5.9 | |
| -100 +150 | 5.0 | |
| -150 +200 | 12.1 | |
| -200 +270 | 16.4 | |
| -270 +325 | 0.7 | |
| -325 | 59.9 | |

The microscopy examination of the screen fractions indicated the presence of a large amount of brownish near-opaque grains in the coarse fractions, together with minor amounts of quartz, chlorite, and carbonate. Plagioclase, amphibole, sericite, and pyroxene were apparently concentrated into the fine fractions. A few grains, possibly of zircon, were noted. The brownish near-opaque material consisted of very fine-grained, possibly secondary, minerals. They probably belonged to the clay mineral group and might have caused the weight losses experienced in the T.G.A.

The microscopy examination of polished sections showed the presence of pyrrhotite as the principal iron sulphide; pyrite and sphalerite were present in small amounts only. The amount of iron oxide that could be observed was low.

The X-ray diffraction analysis of the fractions obtained in the super-centrifuge indicated the presence of pyrrhotite, quartz, amorphous material, pyrite, feldspar, and chlorite. A few weak lines possibly belonged to disthene.

The specific gravity of the sample was reported to be 3.70 and the grain-surface area exposed to water $106 \text{ cm}^2/\text{cm}^3$.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 51.

TABLE 51

Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 14

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|--------|-----------------------------|------|
| Pyrite, etc. | 1 | | |
| Pyrrhotite | 53.6 | | |
| Chalcopyrite | 0.1 | | |
| Sphalerite | 0.6 | | |
| Galena | 0.6 | | |
| | | Total Sulphides | 55 |
| Iron Oxides Iron Hydroxides | 1 | Total Iron (Hydr) Oxides | 1 |
| Calcite, Dolomite Ankerite, Siderite | 2.4 | Total Carbonates | 2 |
| Chlorites, Amphiboles, and other Basic Silicates | 9.5 | | |
| Orthoclase, Sericite, etc. | 7.5 | | |
| Plagioclase, Zoisite, etc. | } 12.4 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 19.9 | Total Silicates | 30 |
| Quartz Sulphates, Phosphates, etc. | 10 | | 10 |
| | | Total | 98 |

Specific Gravity 3.70
Particle Size 1.3.6.
Surface Area 106*

3.15. Analysis of a Tailings Sample Supplied by Mining Company No. 15

The mineralogical analysis of a tailings sample, supplied in 1971 by Mining Company No. 15 for preliminary percolation experiments, is included in this report for completeness. The mineralogical investigation of this sample, reported by Pinard⁽⁵⁾, was extended and the results were made comparable with those of the other analyses.

The results of the chemical analysis of the sample are listed in Table 52.

TABLE 52
Chemical Analysis of a Tailings Sample
from Mining Company No. 15*

| Composition in Wt % | | | |
|--------------------------------|-------|-----------------|-------|
| Na ₂ O | 0.04 | S | 33.60 |
| K ₂ O | 0.36 | SO ₄ | 1.44 |
| CaO | 1.72 | Cu | tr |
| MgO | 2.10 | Zn | 0.47 |
| Al ₂ O ₃ | 5.05 | Pb | - |
| SiO ₂ | 12.63 | Ni | |
| P ₂ O ₅ | | Co | |
| CO ₂ | 1.61 | Mn | |
| Fe | 35.63 | Cd | |
| Total | | | 94.65 |

The thermogravimetric analysis of the tailings sample indicated that the weight loss started at 460°C, continued gradually to the end of the run at 1150°C, and amounted to 28%. A part of this weight loss is due to the decomposition of pyrite; approximately 10% remains unaccounted for. It is possible that more CO₂ is present than is indicated by the chemical analysis,

*Chemical analysis by R.R. Craig, Chemist, Analytical Chemistry Section, Mineral Sciences Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa.

because of the difficulty in determining CO₂ in high-sulphide material. It seems unlikely, however, that the discrepancy could be so large.

The results of the screen analysis of the samples are listed in Table 53.

TABLE 53
Particle-Size Distribution in a Tailings Sample
from Mining Company No. 15

| Mesh Size | Wt % | |
|-----------|-------|------------------------------|
| +100 | 0.06 | |
| -100 +150 | 3.16 | Particle-Size Code 0.3.7. |
| -150 +200 | 2.49 | |
| -200 +270 | 13.30 | |
| -270 +325 | 6.94 | |
| -325 +400 | 42.03 | |
| -400 | | |

A description of the microscopy examination of the screen fractions is not available. It appeared, however, that the greatest part of the non-metallic minerals was concentrated into the plus 200-mesh fractions, and that the metallic minerals were concentrated into the minus 270-mesh fractions. Thin sections of products from gravity separations showed the presence of quartz and altered feldspar. A fair amount of quartz-feldspar intergrowths was present. Grains of amphibole, chlorite, zoisite, and iron hydroxides could be observed, and more carbonate than that indicated by the CO₂ content (determined chemically). Because a great part of the carbonate was concentrated into the >3-S.G. fraction, it is possible that more ankerite is present than is indicated in the final results. Because of the uncertainty of the composition of the minus 325-mesh fraction, however, the deviation from the chemically-determined CO₂ content has been assumed to be only about 1%, rather than 5 to 7%, as suggested by the T.G.A.

The results of the X-ray diffraction analysis indicated the presence of only pyrite with small amounts of quartz and sphalerite.

The specific gravity of the sample was determined to be 4.55 and the surface area exposed to water was 183* cm²/cm³.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 54.

TABLE 54

Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 15

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|------|-----------------------------|------|
| Pyrite, etc. | 54 | Total Sulphides | 64 |
| Pyrrhotite | 10 | | |
| Chalcopyrite | tr | | |
| Sphalerite | 0.1 | | |
| Galena | tr | | |
| Iron Oxides | 3 | Total Iron (Hydr) Oxides | 3 |
| Iron Hydroxides | | | |
| Calcite, Dolomite | 4 | Total Carbonates | 6.5 |
| Ankerite, Siderite | 2.6 | | |
| Chlorites, Amphiboles Amphiboles, and other Basic Silicates | 8.3 | Total Silicates | 11 |
| Orthoclase, Sericitc, etc. | 2.5 | | |
| Plagioclase, Zoisite, etc. | 0.3 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 2.8 | | |
| Quartz | 8.7 | | 9 |
| Sulphates, Phosphates, etc. | 1.4 | | 1 |
| | | Total | 94.5 |

Specific Gravity
4.55
Particle Size 0.3.7.
Surface Area 183*

3.16. Analysis of a Tailings Sample Supplied by Mining Company No. 16

The results of the chemical analysis of a tailings sample from Mining Company No. 16 are listed in Table 55.

TABLE 55

Chemical Analysis of a Tailings Sample from Mining Company No. 16

| Composition in Wt % | | | |
|--------------------------------|-------|----|-------|
| Na ₂ O | 0.029 | S | 38.9 |
| K ₂ O | 0.080 | As | 0.47 |
| CaO | 1.71 | Cu | 0.16 |
| MgO | 0.86 | Zn | 2.43 |
| Al ₂ O ₃ | 1.04 | Pb | 1.08 |
| SiO ₂ | 9.72 | Ni | 0.006 |
| P ₂ O ₅ | 0.10 | Co | 0.036 |
| CO ₂ | 2.56 | Mn | 0.14 |
| Fe | 38.7 | Cd | 0.004 |
| Total | | | 98.02 |

Exchange Cap.
0.08 m.equiv/100 g

The thermogravimetric analysis of the sample indicated that a weight loss of 22.8% occurred in the temperature range from 410°C to 1040°C. This weight loss was not completed at 1040°C and is assumed to originate principally in the decomposition of pyrite.

The results of the screen analysis of the sample are listed in Table 56.

TABLE 56
Particle-Size Distribution in a Tailings Sample
from Mining Company No. 16

| Mesh Size | Wt % | |
|-----------|------|------------------------------|
| +100 | 2.4 | |
| -100 +150 | 3.5 | Particle-Size Code 0.2.8. |
| -150 +200 | 6.5 | |
| -200 +270 | 3.4 | |
| -270 +325 | 9.0 | |
| -325 | 75.2 | |

The microscopy examination of the screen fractions indicated that opaque minerals were the major constituent. Quartz and altered feldspar were present in medium to small amounts, with some amphibole, chlorite, and very little carbonate. The opaque minerals increased in quantity in the minus 200-mesh fractions.

The results of X-ray diffraction analysis indicated the presence of pyrite, sphalerite, dolomite, calcite, quartz, amphibole, and amorphous material.

The specific gravity was reported to be 4.57 and the grain-surface area exposed to water was $127^* \text{ cm}^2/\text{cm}^3$.

The foregoing information was combined and produced the estimate of the mineral composition listed in Table 57.

TABLE 57

Estimated Mineral Composition of a Tailings Sample
from Mining Company No. 16

| Mineral Groups | Wt % | Final Estimate | Wt % |
|--|------|-----------------------------|------|
| Pyrite, etc. | 69.9 | Total Sulphides | 75 |
| Pyrrhotite | | | |
| Chalcopyrite | 0.5 | | |
| Sphalerite | 3.5 | | |
| Galena | 1.2 | | |
| Iron Oxides | 7.4 | Total Iron (Hydr) Oxides | 5 |
| Iron Hydroxides | | | |
| Calcite, Dolomite | 5.4 | Total Carbonates | 5 |
| Ankerite, Siderite | | | |
| Chlorites, Amphiboles and other Basic Silicates | 1.6 | Total Silicates | 3 |
| Orthoclase, Sericite, etc. | 0.6 | | |
| Plagioclase, Zoisite, etc. | 0.3 | | |
| Clay, Additional alteration | | | |
| Total Acid Silicates | 0.9 | | |
| Quartz | 8.7 | | 9 |
| Sulphates, Phosphates, etc | | | |
| | | Total | 97 |

Specific Gravity
4.57
Particle Size 0.2.8.
Surface Area 127*

4. DISCUSSION OF THE RESULTS OF THE MINERAL ANALYSIS

The principal aim of the mineral analyses was to obtain information about the range of differences in mineral composition of tailings produced from various ore deposits. The results of the analyses of all samples, listed in Table 58, show that, not only the mineral compositions, but also the particle-size distributions and the grain-surface areas of the tailings exposed to water, differ widely.

The reported specific gravities generally agreed well with the mineralogical composition. The presence of amorphous material, of which the specific gravity was not known, may account for discrepancies if estimates are based on the assumption that the tailings consisted solely of well-crystallized minerals.

Because of the difficulty in estimating the iron oxide (hydroxide) contents, the values in the final estimates tend to be lower than the maximum estimated from the results of the chemical analysis. This uncertainty, and the possible variations in the analyses in general, are expressed by the percentage unaccounted for in the "total" of the final estimate.

The analyses have been arranged in order of increasing sulphide content, except for the tailings samples from Mining Company No. 12 which were produced from one type of ore.

The pollution potential of a tailings depends, in the first place, on its mineral composition. Traditionally, the acidity of the drainage water from tailings ponds depends particularly on the oxidation of the sulphides, which is balanced by the solution of carbonates. Several chemical reactions have been formulated and could represent the foregoing process. However, the possibility of using these equations for estimating the acidity that can be expected to be produced by a certain mineral composition of a tailings still seems remote, disregarding all other factors.

By considering the approximate sulphide:carbonate ratio, it appears possible to group the tailings compositions qualitatively, as is shown in Table 59. The following kind of estimation

TABLE 58

A SUMMARY OF THE ESTIMATED MINERAL COMPOSITION OF THE TAILINGS SAMPLES

| Mining Company No. | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8.1 | | 8.2 | | 9 | |
|---|-----------|------|-----------|----|-----------|-----|-----------|----|-----------|----|-----------|----|-------------|------|-----------|------|-------------|-----|-----------|----|
| Pyrite, etc. | 0.2 | | 0.35 | | 0.7 | | | | 2.3 | | 4.5 | | 3.6 | | 4.9 | | 7 | | 0.5 | |
| Pyrrhotite | | | | | | | 2.5 | | 1 | | | | | | | | | | | |
| Chalcopyrite | 0.3 | | 0.2 | | 0.04 | | 0.1 | | 0.3 | | 0.06 | | 0.4 | | 0.07 | | 0.05 | | 7.3 | |
| Sphalerite | 0.01 | | 0.02 | | 0.02 | | 0.02 | | 0.02 | | 0.1 | | 1.8 | | 0.03 | | 0.005 | | 0.3 | |
| Galena | 0.01 | | | | 0.02 | | tr | | | | | | 0.2 | | 0.1 | | 0.02 | | 0.03 | |
| <u>Total Sulphides</u> | | 0.5 | | 1 | | 1 | | 3 | | 4 | | 5 | | 6 | | 5 | | 7 | | 8 |
| Magnetite, hematite | 15 | | 2.5 | | 7.2 | | 5 | | 10.4 | | 8.7 | | 4.7 | | | | | | 15 | |
| Iron hydroxides, limonite, etc | 3 | | 0.5 | | | 3.2 | | 3 | | | | | | | | | | | | |
| <u>Total Iron (Hydr) Oxides</u> | | 15 | | 3 | | 4 | | 6 | | 10 | | 5 | | 2 | | | | | | 10 |
| Calcite, dolomite | 7.7 | | 3.1 | | 3.1 | | 3.7 | | 4.9 | | 26.8 | | 2.6 | | 0.4 | | 1.6 | | 10.6 | |
| Ankerite, siderite | | | | | | | | | | | 1.6 | | | | | | | | | |
| <u>Total Carbonates</u> | | 8 | | 3 | | 3 | | 4 | | 5 | | 30 | | 2.5 | | 0.5 | | 1.5 | | 11 |
| Chlorites, amphiboles, pyroxenes, biotite, talc, etc. | | | | | | | | | | | | | | | | | | | | |
| Basic Silicates | 15.5 | | 11.8 | | 12.2 | | 38.2 | | 19.7 | | 3.0 | | 4.7 | | 0.8 | | <1 | | 14.5 | |
| Orthoclase, muscovite, sericite, etc. | 12.6 | | 22.5 | | 4.2 | | 14.8 | | 9.3 | | 4.8 | | 12.9 | | 19.2 | | 6.8 | | 8.1 | |
| Plagioclase, zoisite, etc. | 28.5 | | 23.6 | | 46.6 | | 9.5 | | 33.5 | | 34.9 | | 11.3 | | 4.7 | | 0.3 | | 11.9 | |
| Additional secondary minerals, clay, etc. | | | | | | | | | | | | | | | | 3.6 | | | | |
| <u>Total Acid Silicates</u> | 41.1 | | 46.1 | | 50.8 | | 24.3 | | 42.8 | | 39.7 | | 24.2 | | 27.5 | | 7.1 | | 25.0 | |
| <u>Total Silicates</u> | | 56.5 | | 58 | | 60 | | 63 | | 63 | | 43 | | 29 | | 28 | | 7 | | 40 |
| Quartz | 17.3 | 15 | 30.6 | 31 | 29.2 | 29 | 20.4 | 20 | 14.3 | 14 | 12.2 | 12 | 23.6 | 23.5 | 60.6 | 60.5 | 83.4 | 83 | 26.2 | 26 |
| Sulphates, phosphates, etc. | | | | | | | | | | | | | 34.5 | 34.5 | 2 | 2 | | | | |
| Total | 95 | | 96 | | 97 | | 96 | | 98 | | 95 | | 97.5 | | 96 | | 98.5 | | 95 | |
| Specific Gravity | 3.07 | | 2.73 | | 2.72 | | 2.83 | | 2.95 | | 2.88 | | 3.30 | | 2.81 | | 2.52 | | 3.02 | |
| Particle Size | 3.3.4. | | 2.3.5. | | 2.3.5. | | 0.3.7. | | 3.3.4. | | 0.0.10. | | 1.3.6. | | 1.3.6. | | 7.3.0. | | 3.3.4. | |
| Surface Area | 68 | | 99 | | 135 | | 327* | | 102 | | 114 | | 180 | | 149 | | | | 133 | |

TABLE 58 (Concluded)

| Mining Company No. | 10 | | 11 | | 12.1 | | 12.2 | | 13.1 | | 13.2 | | 14 | | 15 | | 16 | |
|---|--------|------|--------|----|--------|----|--------|----|--------|----|--------|------|--------|----|--------|------|--------|----|
| Pyrite, etc. | | | 1 | | 24 | | 0.9 | | 27 | | 40.7 | | 1.0 | | 54 | | 69.9 | |
| Pyrrhotite | 14.2 | | 34.2 | | 12 | | | | 5 | | 5 | | 53.6 | | 10 | | | |
| Chalcopyrite | 0.1 | | 0.4 | | 0.5 | | 0.04 | | 0.4 | | 0.6 | | 0.1 | | tr | | 0.5 | |
| Sphalerite | 0.01 | | 0.7 | | 0.2 | | 0.01 | | 0.9 | | 0.9 | | 0.6 | | 0.1 | | 3.5 | |
| Galena | | | 0.02 | | 0.02 | | tr | | 0.05 | | 0.2 | | 0.6 | | tr | | 1.2 | |
| <u>Total Sulphides</u> | | 15 | | 36 | | 36 | | 1 | | 34 | | 47 | | 55 | | 64 | | 75 |
| Magnetite, Hematite | 3.1 | | 2.8 | | 8 | | 4 | | 4 | | 6.6 | | 1 | | 3 | | 7.4 | |
| Iron hydroxides, limonite, etc. | | | 17.1 | | | | | | 6.5 | | | | | | | | | |
| <u>Total Iron (Hydr) Oxides</u> | | 5 | | 15 | | 6 | | 2 | | 5 | | 6 | | 1 | | 3 | | 5 |
| Calcite, dolomite | 2.6 | | 1.8 | | 10.1 | | 15.3 | | 4 | | 4.6 | | 2.4 | | 4 | | 5.4 | |
| Ankerite, siderite | | | | | | | | | 1 | | 0.7 | | | | 2.6 | | | |
| <u>Total Carbonates</u> | | 2.5 | | 2 | | 10 | | 15 | | 5 | | 5.5 | | 2 | | 6.5 | | 5 |
| Chlorites, amphiboles, pyroxenes, biotite, talc, etc. | 48.5 | | 5.2 | | 22 | | 16 | | 12.8 | | 13 | | 9.5 | | 8.3 | | 1.6 | |
| Basic Silicates | | | | | | | | | | | | | | | | | | |
| Orthoclase, muscovite, sericite, etc. | 2.4 | | 7.0 | | 4.9 | | 12.6 | | 6.0 | | 3.3 | | 7.5 | | 2.5 | | 0.6 | |
| Plagioclase, zoisite, etc. | 8.2 | | 5.6 | | 4.5 | | 20.7 | | 6.2 | | 3.3 | | 12.4 | | 0.3 | | 0.3 | |
| Additional secondary minerals, clay, etc. | | | | | | | | | | | | | | | | | | |
| <u>Total Acid Silicates</u> | 10.6 | | 12.6 | | 9.4 | | 33.3 | | 12.2 | | 6.6 | | 19.9 | | 2.8 | | 0.9 | |
| <u>Total Silicates</u> | | 60 | | 18 | | 33 | | 49 | | 25 | | 20 | | 30 | | 11 | | 3 |
| Quartz | 10.3 | 12 | 23.8 | 24 | 8.7 | 9 | 30.8 | 31 | 25.6 | 26 | 20.5 | 20 | 10 | 10 | 8.7 | 9 | 8.7 | 9 |
| Sulphates, phosphates, etc. | | | | | | | | | | | | | | | 1.4 | 1 | | |
| Total | | 94.5 | | 95 | | 94 | | 98 | | 95 | | 98.5 | | 98 | | 94.5 | | 97 |
| Specific Gravity | 3.21 | | 3.39 | | 3.45 | | 2.85 | | 3.27 | | 3.57 | | 3.70 | | 4.55 | | 4.57 | |
| Particle Size | 1.4.5. | | 1.4.5. | | 1.2.7. | | 2.3.5. | | 1.5.4. | | 1.3.6. | | 1.3.6. | | 0.3.7. | | 0.2.8. | |
| Surface Area | 85 | | 105 | | 216* | | 128 | | 78* | | 91* | | 106* | | 183* | | 127* | |

may represent the present state of knowledge, applied to problems involved in the acid drainage from tailings ponds.

TABLE 59
The Grouping of Tailings According to the Sulphide/Carbonate Ratio in Their Mineral Composition

| Tailings from Company No | Sulphide Content | Carbonate Content |
|--------------------------|------------------|-------------------|
| 2;3;4;5 | Low | Low |
| 1;6;12.2 | Low | Appreciable |
| 8;10;11;13.1 | Medium | Low |
| 9;12.1 | Medium | Appreciable |
| 13.2; 14;15;16 | High | Low |

It will be evident that the first five to six tailings have a similar low-sulphide content. Their carbonate content is probably sufficiently significant to balance the acidity produced by the sulphides. This group can be expected to produce non-acid drainage, taking only their mineral compositions into account. The same could be true for the tailings from Company No. 7, although the effect of the barite content is not known. Even tailings sample No. 9 might still be producing neutral, or possibly slightly acid, drainage, particularly because the iron sulphide is primarily pyrrhotite, which can be expected to decompose less rapidly than pyrite.

The tailings sample No. 8, however, which consists of rather coarse-grained quartz and very little carbonate, will probably produce acid drainage, notwithstanding its low pyrite content.

The carbonate content of tailings samples 10, 11, and 13.1 will probably be too low to offset the acidity produced by the sulphides. Samples No. 10 and 11 contain pyrrhotite which may not act in the same way as pyrite in the weathering process. Sample No. 10 contains, in addition, a large amount of basic silicates, dissimilar to all but Sample No. 4.

The carbonate content of Sample No. 9 will probably be sufficiently high to balance the acidity. Tailings sample 12.1 might constitute a case in which a limited flow and an appreciable amount of carbonate may still be able to balance the acidity produced by the sulphides. The tailings samples 13.2, 14, 15, and 16 will probably not have sufficient carbonates to offset the acid production.

The foregoing, however, is, in large measure, conjecture. The foregoing estimates lack any insight based on equations of chemical reactions that take place in the weathering process. Also, the extent to which these equations are perhaps affected by physical factors is not known. The only guideline in the estimations is that the solution of carbonates balances the acidity produced by the solution of the sulphides to an unknown extent. Thus, it is evident that knowledge on the weathering process in tailings ponds has to be supported by experiments in the laboratory and by field observations. When new mining operations are designed, the composition of the tailings to be expected is known only approximately, and it is not yet known to what extent and in which way this will affect the composition of the drainage water.

The values of the surface-area measurements are not clearly related to the reported particle-size distribution. It is very probable that this phenomenon originates in the distribution within the minus 325-mesh fraction which has not been taken into account in devising the three-number code.

Although some evidence has been obtained that grain-size distribution and subsequent grain-surface area exposed to water are both factors in the weathering process, in addition to the mineral composition and microbial activity, no information has yet been obtained about the proportions between the magnitudes of these factors. The polluting activity of a tailings pond depends on the amount of acid and toxic pollutants draining away in a certain period of time. It is feasible that fast drainage from a pond, consisting of coarse-grained tailings containing only a

few per cent of pyrite, may have greater pollution effects than an extremely slow drainage from a pond that contains very fine-grained tailings with a high pyrite content.

Obviously, factors in the topography and the construction of a tailings pond or pile can alter the flow through a coarse-grained tailings to the extent that the water may become stagnant, and then the drainage represents a kind of "overflow" situation. The possibilities of this and similar factors are being studied first in the laboratory and then in the field.

5. ACKNOWLEDGEMENTS

Thanks are due to all the mining companies that have contributed to the Mineral Sciences Division study on the weathering processes in tailings ponds by providing samples of their tailings to be used in the environmental projects of the Mines Branch.

Thanks are also due to the following members of the Mineral Sciences Division: to R.G. Pinard for starting the mineralogical analyses of four tailings samples; to A.L. Wilkins for preparing the screen- and super-centrifuge fractions and for measuring the grain-surface areas exposed to water; to W.S. Bowman for checking the values of the surface areas on the Mines Branch computer; to E.J. Murray for X-ray diffraction analyses; to R.H. Lake for differential thermal and thermogravimetric analyses, and to P. O'Donovan for preparing thin and polished sections.

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