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A STUDY OF THE MINERAL COMPOSITION OF MINE DUST

By T. L. Walker

In November, 1933, Mr. E. W. Todd, Superintendent of the Lake Shore Mines Limited, suggested to the writer the desirability of a study of mine dust with a view to finding out the proportions of the common minerals, particularly of quartz and muscovite. As is well known, persons, whose work requires them to spend much time in an atmosphere vitiated by certain types of rock dust, are prone to silicosis. As the trouble has been worst in mines and quarries where the rock contains a high percentage of quartz, it has been commonly held that the disease was due principally to the large proportion of quartz in the dust which they inhale. More recently W. R. Jones[1] has maintained that the offending mineral is sericite, a fine scaly variety of muscovite. Under the circumstances it became very necessary to determine as accurately as possible the mineral composition of the dust, particularly in the air of the gold mines of northern Ontario.

On the suggestion of the writer mine dust was collected from several mines by using a vacuum cleaner, which after several days' continuous operation commonly collected a few ounces of dust. On material so gathered experiments have been carried out with a view to the solution of the problem.

The dust in the samples studied is largely made up of particles less than 3 microns in diameter. The larger grains are mostly either carbonate or very thin flakes of green-brown mica which occasionally reach a diameter of 35 microns.

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[1] Jones, W. R. Jour. of Hygiene, vol. XXXIII, 1933.

The earliest attempts to secure qualitative and quantitative data as to mineral composition of such dusts were usually carried out by the microscopic methods developed by petrographers. The grains of the different minerals were counted and some account taken as to the relative sizes. In this way after much tedious work results were obtained which did not claim any great accuracy. Recently Ross and Sehl[2] have proposed a modified petrographic method using liquids of known indices of refraction for mounting the dust on the microscopic slide. In 1933 Knopf[3] proposed a method for the determination of quartz in dusts based on the solubility of silicates in fluosilicic acid in which quartz is only slightly attacked. The writer has had experiments conducted to test the rate at which quartz is lost while the silicates are being broken up. For this purpose three samples whose quartz content had been determined by the X-ray method described later were treated as follows: half a gram of dust was treated with 15 c.c. hot hydrochloric acid for 15 minutes; the residue washed and burned in a platinum crucible; treated with fluosilicic acid for 89 hours at 20-22 C. after which the residue was treated with 15 c.c. strong hydrochloric acid, washed and weighed. The percentages of quartz found were in all cases lower than those obtained from X-ray determinations. Analysis of the quartz residues obtained after 89 hours' treatment shows that the titanium in the dust is not completely eliminated by this process. Such an analysis showed the residue to contain 95.91 per cent. of silica and 1.75 per cent. of titanic acid.

Half gram samples of rock crystal ground to pass through 200 mesh when treated with fluosilicic acid, were found as a result of four repetitions on the same material under identical conditions, to lose on an average 0.0004 grams for each hour's duration of the treatment. The results were very uniform. The rate of loss for quartz of mine dust, being very much finer, will probably be much greater. Possibly for such dust the rate of loss may be established by comparison with

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[2] Ross, H. L. and Sehl, F. W. Ind. and Eng. Chem., vol. VII, p. 30, 1935.

[3] Knopf, Adolph. Pub. Health Repts., no. 1560, 1933.

X-ray data. If so, by use of an appropriate factor satisfactory data may be obtained by this modification of the Knopf method.

CHEMICAL ANALYSES OF DUST

Two complete chemical analyses were made, I on dust collected by a vacuum cleaner, and II, a sample representing mill feed at the same time. The analyses are followed by the *norm* or calculated percentages of the principal minerals. Such calculations are commonly made by petrographers from chemical analyses of rocks. The true composition or *mode* is often very different. The principal and striking difference between the two analyses is the greater amount of silica in II and the correspondingly greater percentage of quartz in the *norm* as compared with that of I. If it be safe to assume that the dust was derived from the break-up of material like that in II, then it is apparent that quartz

CHEMICAL ANALYSES

	I	II
Silica	48.74	58.12
Alumina	13.47	13.24
Ferric Oxide	1.21	1.01
Ferrous Oxide	4.01	4.36
Lime	6.92	4.80
Magnesia	4.30	3.00
Soda	1.72	2.13
Potash	4.17	4.39
Carbon Dioxide	7.86	5.48
Water−110°	0.34	0.04
Water+110°	2.36	1.47
Oxide of Titanium	0.63	0.53
Oxide of Manganese	0.12	0.10
Phosphorus Pentoxide	0.89	0.41
Sulphur	1.17	0.94
Loss on ignition (excess of water and carbon dioxide)	2.78	0.33
	100.69	100.35
Less O equiv. of S	.59	.47
	100.10	99.88

CALCULATION OF THE *Norm*

		I	II
Apatite		2.24	1.12
Ankerite	Calcite	10.20	7.60
	Magnesite	6.47	3.78
	Siderite	1.62	1.39
Albite		15.20	16.25
Orthoclase		25.60	26.70
Ilmenite		1.08	.77
Metasilicates		27.93	24.47
Quartz		6.63	15.55
Balance (water, sulphur, *etc.*)		3.03	2.37
		100.00	100.00

does not remain in suspension so long as the other principal minerals, possibly on account of its breaking into equidimensional fragments due to its exceedingly poor cleavage in contrast to the feldspars, micas, hornblendes, calcite, and pyroxenes, the other principal minerals in the rock, most of which are remarkable for the well-developed cleavage which renders them more likely to appear in flat or acicular form. The chemical analyses I and II were made at the laboratory of the Ontario Department of Mines.

THE EVIDENCE OF THIN SECTIONS

Sections were made of eight pieces selected from mill feed supplied by the Company. As is well known, all or nearly all the quartz is vein quartz which along with a greater volume of country rock makes up the mill feed. The old rock now much altered and crushed is on the whole an intermediate igneous type quite porphyritic in texture, with plagioclase less abundant than the orthoclase. The latter mineral is much altered with the development of fine micaceous scales, sericite. In some sections this is abundant. The dark mineral in the porphyritic rock was often biotite which formed porphyritic crystals now much altered. There are, therefore, two sources of micaceous minerals, one derived from orthoclase, the other from old phenocrysts of dark mica. Calcite and sericite are the most abundant secondary minerals, followed by leucoxene and chlorite.

MICROSCOPIC EXAMINATION OF THE DUST

Most of the particles are less than 3 microns in diameter, so that at times it is difficult or impossible to determine the minerals. The larger ones are mostly calcite, or a green-brown biotite from the old porphyritic crystals of the rock. These occasionally reach a diameter of 35 microns. Most of the quartz particles must be very small, few greater than 3 microns in diameter. Muscovite is quite frequent in flakes and scales always small but often distinctly determinable. The feldspars which according to the chemical and X-ray analyses are present must occur in very small particles as they are seldom determinable. It would be tedious to attempt a quantitative estimate of the proportions of the different minerals by this method, nor does the writer feel that any very accurate data can be obtained in this way. The qualitative determination of the dust may be settled without great difficulty.

X-RAY METHODS FOR THE ANALYSIS OF DUST

Knowing that rapid progress was being made in quantitative determination of chemical elements by spectroscopic methods it occurred to the writer that in a similar way quantitative results might be obtained for the proportions of the minerals in the mine dust, using X-ray diffraction patterns and the microphotometer curves derived from them.

The writer was very fortunate in securing the co-operation of Professor G. L. Clark of the University of Illinois who kindly undertook to make diffraction patterns and microphotometer curves for specimens sent him. It was hoped that in a mixture of two or more minerals the relative intensities of the lines would be found to vary directly with the proportions in which the minerals giving these lines were present. When the curves were examined it seemed as if this could not be so. On the invitation of Professor Clark the curves and films were returned, when he undertook to make films from more finely ground samples. The difficulty arose from the spotting of the lines due to the coarseness of a few particles. He constructed a small ball mill and after finer grinding, clearly defined patterns were obtained from which very characteristic curves were prepared. The details of his work are contained in the following paper. Professor Clark is of the opinion that this method with the best technique is capable of giving the quantity of quartz in dust within 10 per cent. of the quartz present.

The per cent. of quartz has been determined by the X-ray method in five samples of mine dust as follows:

Sample No. 1, 24.5% Lake Shore Mine, Nov. 1933
" " 22, 13.2% 2,450 level Lake Shore Mine, March 11, 1935
" " 24, 16.7% Lake Shore Mine, March 18, 1935
" " 25, 13.8% Lake Shore Mine, March 18, 1935
" " 26, 13.8% Porcupine District

A test was also made on a finely powdered sample of the mill feed at the Lake Shore Mine in 1933 with the following result:

Sample No. 2, 31.5%

In order to check the accuracy of this method for quartz determination two additional samples were submitted. These samples were made by taking part of a sample already determined and adding to it a known amount of rock crystal crushed to pass 200 mesh:

Sample No. 2 with added quartz, quartz found 37.0%, expected 35.5%
" " 22 with added quartz, quartz found 54.6%, expected 56.6%

This method for the direct determination of the percentages of crystalline substances in a finely divided powder may be useful over a wide field when further developed. Standards similar to those already set up for quartz may also be worked out for the other common minerals in the mine dust, such as muscovite, biotite, orthoclase, calcite, and plagioclase. The proportions of these minerals may then be determined from the graph which is used for the quartz determination. Possibly in the future some such method may be useful to the petrographer who at present has to be content with the artificial *norm* calculated from chemical rock analyses. Possibly one of the most apparent advantages may be the determination of the coefficient to be used in connection with the Knopf method so as to approximate more closely to the true amount of quartz in the dust. The method provides a way by which mine dusts may be studied for the determination of all the principal minerals and gives information on which the many research workers in medical science may build more surely than has been possible in the past.

The writer wishes to express his warmest thanks to Professor Clark for his co-operation in testing out the original suggestion as to whether quartz could be accurately determined by X-ray studies.

AN X-RAY DIFFRACTION METHOD FOR THE ESTIMATION OF QUARTZ IN A MIXTURE OF SILICATE ORES

By George L. Clark and Dexter H. Reynolds
(X-ray Laboratories, Department of Chemistry,
University of Illinois, Urbana, Illinois.)

The quantitative estimation of quartz and other minerals in naturally occurring materials is of great interest to geological, mineralogical, and metallurgical sciences. The mineralogical analysis of dusts is of particular importance in relation to the study of silicosis among mine workers, and others who work in dust-laden atmospheres. Two methods have been proposed and used for the estimation of quartz in mineral mixtures. The first[1] is a chemical method depending upon the relative ease of reaction of free and combined silica with fluosilicic acid. The time required for the analysis varies from 24 to 72 hours. The difficulties in the way of success by this method are great. Quartz in a finely divided state, as it may be in a dust, may be very reactive, and the silicate minerals vary greatly in the ease with which they are decomposed. The method is not applicable to the determination of constituents other than quartz. The second method[2] is a microscopic method, in which the area of the quartz grains in the powdered sample is measured. The volume of free silica, and from this the weight of free silica, is taken as proportional to the area measured. The method is rapid, but is limited to materials which are known to be free of minerals which may have the same index of refraction as quartz. Extremely fine particles may be missed, while large particles may lead to erratic results because of non-uniformity of shape.

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[1] Knopf, Adolph. U.S. Pub. Health Repts., no. 48, p. 183, 1933.

[2] Ross H. L. and Sehl, F. W. Ind. and Eng. Chem. (anal. ed.), vol. VII, p. 30, 1935.

The investigation of the possibilities of an X-ray diffraction procedure for the estimation of quartz in mixtures was undertaken at the suggestion of Dr. T. L. Walker, Director of the Royal Ontario Museum of Mineralogy, who suggested that results might be obtained which would be comparable with those obtained for elements by means of the quartz spectrograph. It is fundamental to the diffraction of X-rays by a crystalline powder[3] that lines will be obtained in the diffraction pattern which are characteristic of each crystallographic species present in the sample. For this reason it is possible by means of X-ray diffraction to analyse a powdered mixture qualitatively for the actual chemical compounds present in the mixture. The densities of the diffraction lines of a substance in a mixture have long been used as a rough measure of the relative amount of the substance present. Examination of the literature has failed to disclose any attempt to make the method more exact by application of the principles and technique developed for quantitative analysis for the elements with the quartz spectrograph. The following report is the record of preliminary work on an adaptation of the "internal standard method" of spectral analysis[4] to the quantitative analysis of mineral mixtures by means of a photometric comparison of X-ray diffraction lines of the substance sought with those of a foreign substance added to the mixture in known amount as an internal standard. All the work so far has been directed towards the estimation of quartz, but experiments are projected for the extension of the method to other minerals.

The relationship between the densities of diffraction lines and the relative amount of the substance present in the irradiated sample is not necessarily a simple one. It has been observed repeatedly that in the case of a salt of a heavy metal, as lead sulphate, a much more prominent lead sulphate

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[3] For a full discussion of X-ray diffraction by crystalline powders, see G. L. Clark Applied X-rays (2nd ed. McGraw-Hill), 1932. Specific mention of quantitative analysis by X-ray diffraction is made on p. 227.

[4] Scheibe, G. Chemische Spektralanalyse, Phys. Meth. der Anal. Chemie (Akad. Verlag. M.B.H., Leipzig, 1933), vol. I, p. 108.

pattern is obtained if the sample is diluted with 60 to 80 per cent. of zinc oxide or other substances composed of elements of low atomic weights, than can be obtained from pure lead sulphate. Luckily for the early success of this investigation, the principal lines of quartz may be obtained easily and quickly. The other minerals which may be present ordinarily in naturally occurring silicate ores have low absorption coefficients for X-rays, since they are composed of elements with relatively low atomic weights. For this reason they do not interfere greatly with diffraction by the quartz. As will be shown, the relative densities of the quartz diffraction lines compared to those of an internal standard, vary linearly with the relative amount of quartz present in the sample being examined.

PREPARATION OF SAMPLE AND DIFFRACTION PATTERNS

The first series of standard samples was prepared from powdered quartz and fluorite, with the quartz content varying from 10 to 60 per cent. To 2 grams of each of the samples prepared, half a gram of zinc oxide powder was added as an internal reference standard. In later work, the standard series was prepared from powdered quartz and calcite, with fluorite added as reference standard. Fluorite has the advantage over zinc oxide as a reference standard in that it has a strong line very close to the principal quartz line, and no lines were found in the ore samples submitted which interfered with the fluorite line. The resulting mixtures were subjected to the same grinding operations and other treatment as were the natural ores and mine dust samples submitted for analysis.

The natural ores and mine dust samples submitted had been pulverized to pass a 200-mesh screen. Typical patterns for these are shown in Plate I, figures 1 and 2. It may be seen that the average particle size of the samples, even of the mine dust samples, is too large to give smooth diffraction lines. It was necessary to resort to some method of reducing the average particle size, for, unless smooth lines are obtained, photometer curves of the patterns would be meaningless. For this reduction a cylindrical steel ball mill charged with ball bearings was used, with a high boiling petroleum ether as a suspending medium to prevent caking of the sample. The mill is of such size that it will handle samples of from 1 to 5 grams without appreciable loss. Twenty-four hours' grinding was required to reduce satisfactorily a sample of quartz which already had been crushed to pass 200-mesh. Enough steel was present in the ground product to impart a gray colour, but the amount was found to be insufficient to give lines for iron in the diffraction patterns during the exposure times used.

In the preliminary work, a thin pyrex glass capillary of about 0.3 millimetre internal diameter, drawn from a 15 millimetre thin glass test tube, was filled with the pulverized sample, and mounted at the centre of a cylindrical X-ray diffraction camera, with a photographic film held tightly against the outside circumference of the camera at a distance of 6.42 centimetres from the sample. The sample was then irradiated with X-rays from a Müller fine-structure X-ray tube with a copper target. The beam was filtered through a 0.01 millimetre thickness of nickel foil, to render it homogeneous with a predominant wave-length of 1.54 A.U., and was defined by a series of lead pinholes 0.030 inch in diameter. An exposure time of exactly four hours was used with the tube operating at 25 ma. and 30 K.V.P. Developing, fixing, and washing of films were kept as uniform as possible.

In later work, a sample holder was built which would hold the tip of a wedge-shaped block of the sample at the centre of the camera. The angle at which the X-ray beam struck the surface of the wedge was varied until a uniformly fogged background was obtained on the diffraction pattern. This resulted in photometer curves with horizontal base lines, which allowed easier and more accurate measurement of the curves. The wedge has the added advantage of giving sharper diffraction lines than the capillary, hence better resolution of the lines, with less chance for confusion in interpreting the patterns.

Prints of some of the diffraction patterns are shown in Plate I, figures 3 to 8. A shorter exposure and development time was used for the patterns to be measured photometrically than for the others, because it was desirable that none of the lines approach maximum blackening of the film emulsion.

MEASUREMENT OF THE RELATIVE INTENSITIES OF THE DIFFRACTION LINES

The portion of each film containing the principal lines of quartz and zinc oxide, or of quartz and fluorite, was photometered using a Moll type photographically recording photometer. From six to ten curves were made of each pattern at various points along the lines in order to get fair and dependable average measurements. A series of typical photometer curves with the principal lines marked is shown in figure 1.

The density of a photographically recorded X-ray diffraction line may be considered as proportional to the height of its photometer curve above the general background of the

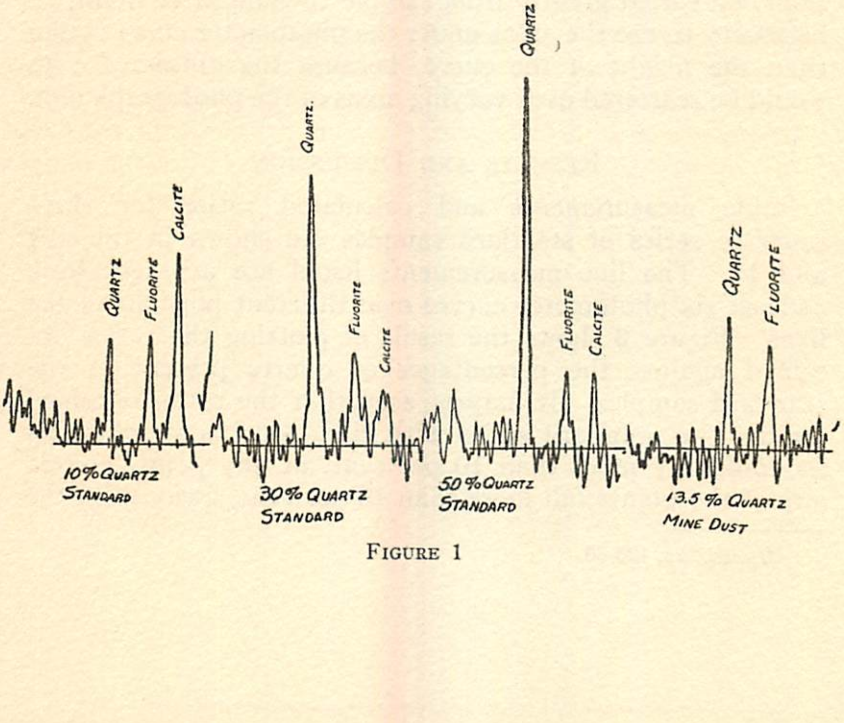

FIGURE 1

pattern. If, for a series of samples of similar composition, it is considered that particle size is uniform, that the portions of sample bathed by the X-ray beam are of uniform size and shape, and that all conditions surrounding the making of the pattern are constant, the relative intensities of a given line appearing in all the patterns may be considered as proportional to the relative densities of the line, and, therefore, proportional to the heights of the respective photometer curves. The first two conditions are, within certain limits, fairly easy of attainment, but the conditions surrounding the making of the patterns are not easily controlled satisfactorily. The measurements may, however, be reduced to the same basis by dividing the density of the line by the density of a line of a standard substance present in each sample in equal amount. The ratios thus obtained are proportional to the relative intensities of the line. The theory underlying the above discussion is fully developed by Scheibe[5] in his excellent treatment of quantitative analysis with the quartz spectrograph.

If the particle size of the samples was of colloidal dimensions, or varied greatly from sample to sample, it would be necessary to use the areas under the photometer curve rather than the height of the curve, because the diffracted rays would be scattered over varying areas of the photograph film.

RESULTS AND DISCUSSION

Line measurements and calculated ratios for three separate series of standard samples are shown in tables I and II. The line measurements listed are averages from at least six photometer curves over different portions of the lines. Figure 2 shows the result of plotting the ratios obtained against the percentages of quartz present in the standard samples. It may be seen that the ratios obtained for the two standard series with zinc oxide as standard do not differ by more than 10 per cent. at any point, nor do any of the points fall more than 10 per cent. away from the

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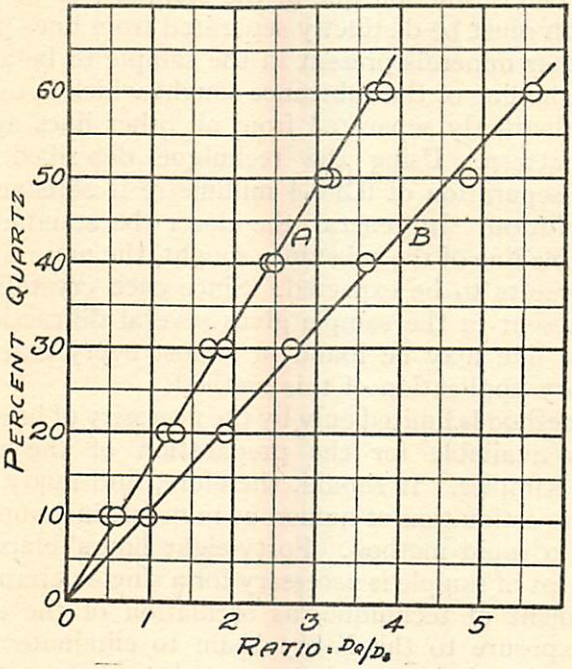
[5] *Op. cit.*, pp. 125-30.

straight lines. Ten per cent. may then be taken as the precision of the method. Since the method is entirely empirical, 10 per cent. may also be considered its accuracy. This compares favourably with most work done on the quartz spectrograph. It is expected that further refinements in technique and procedure will increase the accuracy and precision to 5 per cent., which corresponds to the best spectrograph determinations.

Some of the results obtained upon samples submitted for analysis are listed in table III.

It should be observed that this method cannot be considered to estimate *free silica*, but only that part of the free silica which is present as quartz. If a sample contains silica in any other crystal form or as a glass, this silica will not be



D_Q = Density of Quartz Line D_S = Density of Standard Line
A – ZnO Standard, B – Fluorite Standard.

FIGURE 2

found by this method. This may explain the discrepancy between the results by the X-ray method and the petrographic immersion method on the three starred samples listed in table III. These three samples were obtained from the Research Laboratory of the Aetna Life Insurance Company, Hartford, Connecticut, and were examined there by the microscopic method.

The lowest amount of quartz which can be definitely determined by X-ray diffraction has been determined to be about 1 per cent. The region above 60 per cent. quartz has not yet been investigated, but it should fall into line with the above results by increasing the relative amount of standard substance added to the samples.

Care must be observed in the choice of a reference substance. The diffraction line of the standard to be used for comparison must be distinctly separated from lines produced by the other minerals present in the sample to be analysed. Likewise the line of the substance sought which is to be used must be distinctly separated from all other lines appearing in the pattern. Using the technique described in this report, a separation of 0.3-0.4 millimetre is satisfactory for good resolution. In general, the closer the standard line is to a suitable line of the substance sought, the more consistent are the results to be expected. Since each crystalline substance present in the sample gives several diffraction lines, a suitable line may be found in almost every case for the satisfactory application of this method.

The method is limited only by the necessity of having pure materials available for the preparation of the series of standard samples. It should, therefore, find ready application to the estimation of numerous minerals in complex ores. It is not a rapid method. Forty-eight hours' elapsed time from receipt of sample is necessary for a single determination. Improvement of technique, as oscillation of the specimen during exposure to the X-ray beam to eliminate the long grinding operation, may be expected to reduce the time required appreciably. The apparatus used is necessarily expensive, but no more so than the apparatus required for dependable analysis with the quartz spectrograph.

TABLE I.—Standard Series with Zinc Oxide Standard

Sample	%Quartz	Qtz. line	ZnO line	Ratios—$\frac{\text{qtz}}{\text{ZnO}}$	
				A	B*
CS 2	10	1.7	3.0	0.6	0.5
CS 3	20	2.4	2.1	1.2	1.3
CS 4	30	3.6	2.1	1.7	1.9
CS 5	40	4.3	1.8	2.4	2.5
CS 6	50	7.2	2.3	3.1	3.2
CS 7	60	9.2	2.4	3.8	3.7

*Ratio B was obtained with a second series of standards.

TABLE II.—Standard Series with Fluorite Standard

Sample	%Quartz	Qtz. line	Fluo. line	Ratio—$\frac{\text{Quartz}}{\text{Fluorite}}$
KS 4	10	2.3	2.3	1.0
KS 5	20	5.3	2.7	2.1
KS 6	30	6.1	2.2	2.8
KS 7	40	6.4	1.8	3.6
KS 8	50	8.2	1.7	4.8
KS 9	60	9.1	1.6	5.8

TABLE III.—Results Obtained with Samples Submitted by T. L. Walker for Quartz Analysis

Sample	Material	%Quartz X-ray Method	%Quartz Microscopic Method
1	Mine dust	24.5	....
2	Mine ore	31.5	....
4	Mine ore (qtz added)	37.0	....
7*	Feldspar	26.0	33.8
..*	Corundum	less than 1	0.8
..*	Abrasive wheels	less than 1	8.3
21	Commercial feldspar	3.5	....
22	Mine dust	13.2	....
23	" "	54.6	....
24	" "	16.7	....
25	" "	13.8	....
26	" "	13.4	....

*These samples were obtained from the Aetna Life Insurance Company, Hartford, Connecticut, and had been examined by them for quartz by the microscopic method.

SUMMARY

An empirical method for the estimation of quartz in a mixture of silicate ores using X-ray diffraction is described. A crystalline compound which is not present in the ore sample is added to it in a definite ratio. The densities of a quartz line and of a line of the added substance on the resulting diffraction pattern are compared photometrically. From the ratio the amount of quartz may be determined by reference to a curve in which ratios are plotted against per cent. quartz, the curve being prepared using synthetic standard samples. Duplicability of results is within 10 per cent. of the amount of quartz present. Zinc oxide and fluorite were used as internal standards, the latter being more satisfactory. The method was applied only to quartz-silicate ore mixtures, ranging between 1 and 60 per cent. quartz, but should prove applicable to many other minerals over the entire composition range.

MAGMATIC DIFFERENTIATION AS SHOWN IN THE NICKEL-INTRUSIVE OF SUDBURY, ONTARIO

By T. L. Walker

For over forty years petrographers and geologists have studied the igneous rocks in connection with which the world's principal nickel deposits are found. During that period many observations have been made and many theories proposed. Through this long period most observers have seen in these rocks one of the best examples of magmatic differentiation. In a paper recently published, Dr. W. E. Collins gives an account of his observations in this field from 1928 to 1934.[1] With the exception of the five analyses of rocks from the Blezard Mine section which, in 1897,[2] suggested to the present writer that the complex was due to magmatic differentiation, the paper contains a complete collection of the chemical analyses of rocks from the nickel intrusive, a detailed description of the transition zone between the norite and the micropegmatite, and a new theory to account for the facts observed. Dr. Collins assumes that there was only one intrusion which, while still in the fluid condition, separated into three liquid magmas, the heaviest, below, giving rise to the norite, the lightest, on top, forming the micropegmatite, while from the magma of intermediate density a transition zone, which in the field varies from 250 to 800 feet in width, was produced.

The present writer has nothing new to contribute so far as field observations are concerned, not having done any work in the Sudbury region since 1928, but as one of the earliest workers on the Sudbury problem, takes liberty in the following pages to suggest an advance in our theory as to the differentiation of the nickel eruptive. These suggestions

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[1] Collins, W. H. Trans. Roy. Soc. Can., sect. IV, p. 123, 1934.

[2] Walker, T. L. Quart. Jour. Geol. Soc., vol. LIII, p. 55, 1897.

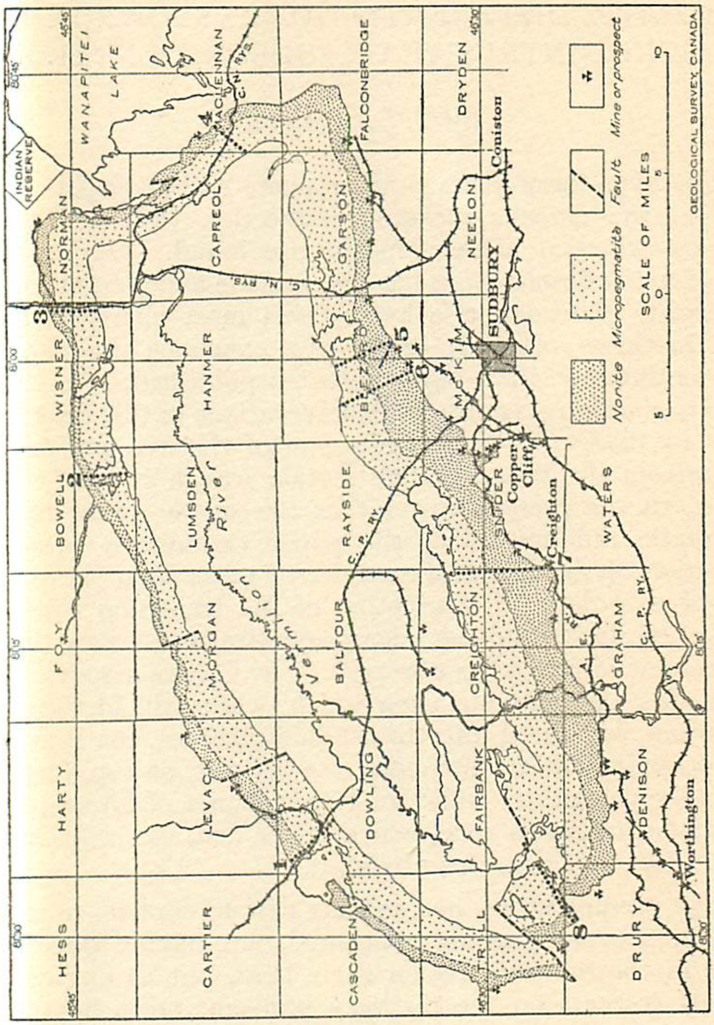

FIGURE 1.—Index map of the Sudbury nickel basin (after Collins).

seem to follow from some of the detailed observations of Collins.

Collins[3] finds that differentiation by the early formation of crystals of heavy minerals and their sinking to the lower part of the magma is not tenable on account of the general distribution through all phases in approximately equal concentration of certain heavy minerals known to have been among the earliest to crystallize out. He says:[4]

> Apatite must have been one of the first minerals to begin to crystallize, for it is found embedded in the plagioclase and dark minerals. Its specific gravity is about 3.2. Since the difference between 2.70 and 2.85 was effective in separating norite from micropegmatite, apatite should have sunk quickly to the bottom. Actually, however, this mineral is fairly uniformly distributed throughout the irruptive. Titaniferous magnetite also began to crystallize early. It has a density of about 4.5 and should have gone to the bottom quickly and completely. A few small concentrations have actually been found around the outer edge of the irruptive, and magnetite also occurs in some of the sulphide ore-bodies; but the greatest concentration of titaniferous magnetite is near the top of the norite, and it is disseminated throughout the micropegmatite and norite fairly uniformly, as shown by the TiO_2 column of the chemical analyses. According to the fractional crystallization theory, a greater downward concentration might also be expected of pyroxene, especially of the orthorhombic species.

In the splendid series of complete analyses of rocks from the nickel intrusive assembled by Collins there are 55 of which the specific gravity and percentages of TiO_2 and P_2O_5 are known. If the rocks be divided into three groups corresponding to norite, specific gravity greater than 2.82, transition, specific gravity from 2.70 to 2.83, and micropegmatite, specific gravity less than 2.71, and the average content of TiO_2 and P_2O_5 taken for the different densities, it appears that there is a gradually increasing content of these oxides with increase in density.

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[3] *Op. cit.*

[4] *Idem.* p. 160.

Average Content of TiO_2 and P_2O_5

S.G.	TiO_2	P_2O_5
2.66–2.70	.58%	.18%
2.71–2.82	.90%	.25%
2.83–2.96	1.63%	.74%

The above percentages are not averages of all rocks falling within the density ranges indicated, but an average of the averages corresponding to each density. In the first group there are 14 analyses, in the second 25, and in the third 16. All densities from 2.66 to 2.96 are represented except 2.86 and 2.92. The corresponding values for the average of all analyses within the ranges indicated are as follows:

S.G.	TiO_2	P_2O_5
2.66–2.70	.59%	.19%
2.71–2.82	.82%	.22%
2.83–2.96	1.69%	.72%

While there is little difference between the two sets of percentages, the former represents more accurately the variation of composition with density, being free from the chance indicated by there being five analyses for rocks of the same density, 2.82. To the writer the gradual increase in the percentages of TiO_2 and P_2O_5 is reasonably in accord with what might be expected for differentiation due to sinking of heavy early formed minerals. As no other phosphate mineral has been recognized in the Sudbury eruptive, it seems probable that the increase of P_2O_5 indicates a regular concentration of apatite in the heavier rocks. As titanite has been reported only as a very subordinate mineral, it is probable that the TiO_2 percentage gives a fair indication as to the concentration of ilmenite.

Since the heavy minerals apatite and ilmenite are found to be most abundant in the heaviest rocks and least abundant in those with low specific gravity, there does not appear to be so much ground for the assumption of Collins as to the differentiation of the one-time homogeneous intrusive magma into three liquid portions, from which the three types of rock crystallized.

Collins has made a most important contribution to our knowledge of the transition zone which lies between the micropegmatite and the norite. He shows that in this zone which varies from 250 to 800 feet in width there is a *gradual* downward increase in density of the rock types. The heaviest part is in contact with the norite and the lightest in contact with the micropegmatite. Mineralogically the transition is gradual with two minerals characteristic of the zone—epidote and chlorite. This detailed study of the transition zone has done much to strengthen the arguments for magmatic differentiation of the nickel eruptive.

Figure 2 shows the variation in specific gravity of the rocks in eight sections across the eruptive. A very striking feature in the graphs is the fact that the heaviest rocks lie in the *upper* part of the norite and in the lower part of the transition. Where the width of the norite is narrow, the graph rises to a sharp peak near the lower contact of the transition, but where the norite is wide, the highest density is reached in the norite some distance below the contact. The greater the width of the norite the flatter is the curve as it rises and falls. The number of points plotted for each curve is so great that the gravity variation may be assumed to be definitely established.

There is no suggestion as to the reason for the above characteristics in Collins's article. The three liquid phases postulated by him give no explanation as to why the denser type of norite lies above the less dense. Can the arrangement of the rock types as recorded by Collins be satisfactorily accounted for on the basis of three liquid magmas, separated from a homogeneous intrusive? As no explanation has been offered, the writer wishes to indicate how such a result might be reasonably expected on the basis of the sinking of heavy minerals which crystallize early from an originally homogeneous liquid intrusion.

If there be showers of heavy crystals from such a magma it will be agreed that the lowest layer will become a mixture

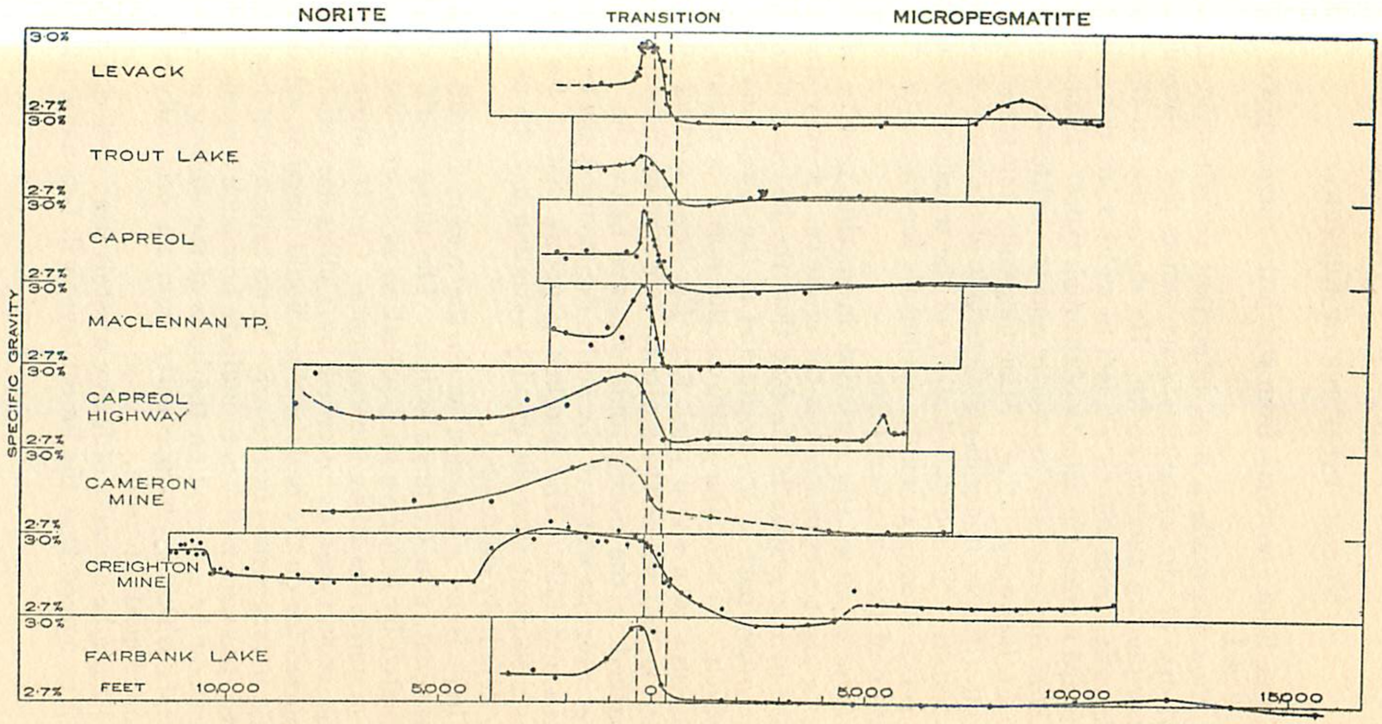

FIGURE 2.—Curves Showing Variation in Specific Gravity across the Nickel Eruptive (after Collins).

of such crystals with the spaces between the crystals filled with molten material. As the deposit increases in thickness the weight of the solid part will gradually squeeze out most of this liquid. At the very bottom due to early cooling from proximity of the cold floor the period during which this process—liquation—can operate must be shorter than in overlying layers, thus producing in the *lowest* part, a rock not quite so heavy as may be formed above where owing to the greater weight of solid crystal burden and longer period of fluidity for the entrapped liquid, the liquation may be more complete. It has frequently been stated that the norite at the lowest contact is not the heaviest in the section.[5]

If the process continue it will in time be supplemented by another disturbing element. The norite often contains some blue quartz and a micrographic intergrowth of quartz and feldspar, representing the last minerals in the norite to crystallize. This last crystallization must liberate great quantities of water and probably other liquid and volatile constituents which, mingling with the entrapped magma in the overlying zone, will increase its fluidity and so permit a more complete squeezing out of the magma with the formation of a rock still richer in heavy minerals than that formed below. When the bottom part finally freezes and consolidates, this process begins and is shown in the graphs by the increase in density in the rocks at a stage that bears some relation to the thickness of the underlying norite mass. This is shown in the Capreol Highway, Cameron Mine, and Creighton sections where the gravity curve begins to rise not far from the centre of the norite. In the other four, the norite is so thin that the rise in the curve begins in the very top of the norite (figure 2). This process continues till the showers of heavy crystals diminish and finally stop, due either to the still molten upper part of the intrusive having attained a viscosity too great to permit crystals to sink, or to the chemical composition of the mass no longer permitting further separation of heavy minerals. The greatest fluidity

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[5] Coleman, A. P., Moore, E. S., and Walker, T. L. Univ. Tor. Studies, Geol. Ser. no. 28, p. 34.

of the entrapped magma would give rise to the zone of rocks of highest density. From this point, due either to increasing viscosity of the micropegmatite magma or to chemical inhibition, the precipitation *gradually* comes to an end and during that time the transition zone is formed. The two characteristic minerals in this zone mentioned by Collins, epidote and chlorite, are said by him to be derived by alteration of hornblende, pyroxene, and biotite. This characteristic alteration is reasonably in accord with the action of mineralisers such as the final consolidation of interstitial quartz and graphic intergrowth in the norite would provide.

The writer feels that the processes outlined require few assumptions apart from a homogeneous liquid intrusive with an orderly crystallization and sinking of heavy minerals. The field and laboratory observations as to the distribution and character of the rock types are accounted for. Can they be accounted for by two intrusions as suggested by Phemister,[6] or by the three liquid magmas formed in place from one magma, as suggested by Collins? Any theory which has no explanation for the regularities shown in figure 2 cannot be accepted as satisfactory.

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[6] Phemister, T. C. Ont. Bur. Mines, vol. XXXIV, pt. 8, 1925.

AN UNUSUAL TYPE OF QUARTZ

By T. L. Walker

The Royal Ontario Museum of Mineralogy recently obtained some specimens of quartz which show so many unusual characteristics that it seems desirable to present a brief description. The mineral comes from a gold mine in the Okanagan district of British Columbia and was presented by Mr. D. A. Taylor.

The index of refraction is in agreement with that recorded for quartz while the specific gravity was found to be 2.63. The mineral in hand specimens is translucent and milky white in colour. Mr. V. Ben Meen has kindly etched polished surfaces of this quartz and finds that it is the low temperature type, alpha-quartz. It is very cleavable and on the cleavage surfaces frequently shows parallel lines so that at first sight it might be mistaken for plagioclase (Plate II, figure 1). It is reported that in the mine such continuous cleavage surfaces at times cover several square feet. On the specimen illustrated may be seen one well-marked series of parallel lines and another less prominent cutting the first at angles of about 75°. It breaks readily so as to show two good cleavages such as might be observed on a feldspar. The angles between these two cleavages measured on a two circle goniometer are 91° 56′ and 88° 04′.

The cleavages are nearly in the position required for twinning on the rhombohedron *r* $(10\bar{1}1)$. Commonly it shows well in only two of the three directions but as in the illustration all three are at times apparent. The angle between *r* and *r*′ in quartz, 85° 46′, does not quite agree with that recorded above.

Cleavage which follows twinning planes is usually referred to as parting, which is said to differ from true cleavage in that the separation takes place only along certain planes of a given direction, in contrast to cleavage where it is equally cahedron (110) are 2a, 2a, ∞a, and for the trapezohedron (211) are 3a, 6a, 6a.

It will thus be seen that the rhombic dodecahedron can be formed before there are enough unit cells to provide the necessary volume for the trapezohedron (211) and that much additional material must be present before the trisoctahedron (332) or (996) can be formed.

X-ray studies have shown that atomic planes with the indices (332) are not uncommon. This merely means that for every atom in the plane (996) as an origin there is a similar atom on the perpendicular to the plane that can be located by the indices ($\bar{3}\,\bar{3}\,\bar{2}$). These latter atoms lie in a plane which will give X-ray reflections but does not have integral structural parameters when referred to the same origin as (996) and is impossible as an external form for a regular crystal network of unit cells.

The relative scarcity of crystal forms with large indices is easily understood if both indices and parameters are integral multiples of the dimensions of the unit cell, otherwise it is difficult to understand.

MINERALIZATION OF THE LITTLE LONG LAC AND STURGEON RIVER AREAS

By Ellis Thomson

Of the many new mining districts recently discovered in the province of Ontario, none has aroused more interest than those in the vicinity of Little Long Lac and Sturgeon River which are adjacent to the stations of Hardrock, Geraldton, and Jellicoe on the Sudbury-Long Lac branch of the C.N.R. It seemed desirable, therefore, that some fairly complete record should be made of the mineralization of these two fields, with particular emphasis on the ore minerals. With this end in view a considerable number of specimens was collected, polished, and examined under the reflecting microscope. Thin sections were also prepared to give information as to the transparent minerals present. In all, 70 polished sections and 16 thin sections were examined, 46 polished and 10 thin sections from the Little Long Lac area and 24 polished and 6 thin sections from the Sturgeon River area.

Since more specimens were examined from the Little Long Lac field, the description of the sections from this region will be given first.

Description of Specimens

Little Long Lac Area

Bankfield Gold Mines. In the eight sections examined from this mine the main metallic minerals present are pyrite, arsenopyrite, chalcopyrite, and magnetite in the order of prevalence. Gold, sphalerite, pyrrhotite, and limonite appear in subordinate quantities, the first two as minor constituents in two of the sections and the last two as minor constituents in but one. The metallic mineralization is partly in veins with quartz and carbonate and in part is present as impregnations in a chlorite schist or altered gabbro.

Dikdik Mine. But two sections were examined from this mine. In these sections pyrite was the chief metallic mineral, but they contained also a considerable quantity of chalcopyrite and galena, as well as smaller amounts of sphalerite, gold, and pyrrhotite. The native gold in these sections is noticeably lighter in colour than that from other mines in the district. This is probably due to an admixture of silver.

Hardrock Gold Mines. Only one section was examined from this mine. The chief metallic minerals in this section are arsenopyrite and gold, but minor quantities of pyrite, pyrrhotite, chalcopyrite, galena, and tetrahedrite also occur.

Hutchison Property. Two sections were examined of material from this mine. One of these consisted of highly-rusted quartz vein material carrying gold, limonite, and pyrite sparsely scattered through the gangue. Only one pyrite crystal was seen in the section but evidently this iron sulphide is the source of most of the limonite. The other section showed fair quantities of galena and limonite. This second section was also coated with iron hydroxide.

Lac Development Company. In the five sections examined from this mine, the following ore minerals, given in order of prevalence, were noted: pyrite, chalcopyrite, sphalerite, galena, pyrrhotite, and gold. Of these minerals the first two predominated largely in quantity over the other four.

Lafayette Property. In the one specimen examined from this property small quantities of gold, pyrite, and chalcopyrite were noted in vein-material.

Langmuir Long Lac Mines. Eight sections were prepared of specimens from this mine. In these sections chalcopyrite and pyrrhotite were the predominant metallic minerals with pyrite, sphalerite, hematite, limonite, and native gold present in minor quantities.

Little Long Lac Mines. From the many specimens supplied from this mine fifteen polished sections were prepared and examined. In these sections pyrite and arsenopyrite predominated largely with the following minerals present in subordinate quantities and in about the order of prevalence as listed: gold, limonite, berthierite, pyrrhotite, chalcopyrite, galena, sphalerite, tetrahedrite, hematite, magnetite. Gold occurs as a minor constituent in six of the sections while the rare sulphantimonide, berthierite, appears as a major constituent in two of the sections.

McLeod-Cockshutt Gold Mines. Four sections were prepared from material available from this mine. In these four sections the following metallic minerals were present in about the order of prevalence listed: pyrite, chalcopyrite, sphalerite, arsenopyrite, and gold. Of these the last two were present as minor constituents in but one section while the other four appeared in two or more sections.

Occurrences

While there are minor differences in the metallic minerals listed from each of the properties in the Long Lac field, they occur in much the same forms at these different properties. It was, therefore, deemed advisable to summarize this part of the paper. The minerals present will be taken in alphabetical order:

Arsenopyrite. For the most part this mineral occurs as isolated crystals of short prismatic habit scattered through the gangue material. Occasionally these crystals are aggregated together in small masses.

Berthierite. This mineral which is present in but two sections from the Little Long Lac mine, occurs in needle-like crystals generally aggregated together as fillings of tiny cracks in the gangue material (Plate III, figure 1) and to a lesser extent as isolated crystals scattered through the gangue.

Chalcopyrite is generally found either as small vein-like or bleb-like forms in the gangue material or in the larger pyrite and arsenopyrite crystals or in massive form filling large fracture cracks in the gangue. In the sections from the Dikdik Mine it occurs also as tiny inclusions in the larger sphalerite areas.

Galena is not abundant in this field. It was encountered in minor quantities at the Dikdik, Hardrock, Hutchison, Lac Development, and Little Long Lac Mines. It occurs as short vein-like or bleb-like forms chiefly in the gangue material and to a lesser extent in the pyrite or arsenopyrite crystals.

Gold was found in small amounts in at least one specimen from each mine. It occurs uniformly in short veins or tiny blebs chiefly in the gangue and to a lesser extent cutting the larger crystals of pyrite and arsenopyrite.

Hematite is a comparatively rare constituent of the ore from this field, being present in but two sections from the Langmuir Long Lac Mines. It appears in short vein-like forms cutting the quartz gangue, sometimes associated with limonite.

Limonite is fairly common as an alteration product of the iron minerals and occurs as tiny veinlets or small inclusions either cutting the gangue or the other iron minerals.

Magnetite appears in small quantities, in ores from the Bankfield and Little Long Lac Mines, as small granular areas generally associated with the gangue material, less often with pyrite or arsenopyrite.

Pyrite is the commonest metallic mineral in the district and occurs in nearly all sections examined. It is found generally in disseminated crystal form scattered through the gangue material, sometimes with the crystals aggregated together in massive form. Some of the larger crystals show a rough cubic cleavage. A later pyrite occurs in vein-like forms or, as in specimens from the Langmuir Long Lac Mine, as replacements of chalcopyrite or pyrrhotite (Plate III, figure 2).

Pyrrhotite is present usually as short veins or tiny bleb-like inclusions in the arsenopyrite, pyrite, or gangue. In the ores from the Langmuir Long Lac Mine there are fair-sized masses of this mineral, associated with chalcopyrite and a later pyrite, segregated in fracture openings of the quartz gangue material.

Sphalerite is fairly widespread in minor quantities. It occurs generally as tiny inclusions in chalcopyrite, pyrite, arsenopyrite, berthierite, or gangue, or in short veins or bleb-like masses in the gangue or in the larger pyrite crystals.

Occasionally it appears in small granular masses filling fractures in the gangue.

Tetrahedrite is a very minor constituent of the ores of this district being found in subordinate amounts at the Hardrock and Little Long Lac Mines. It occurs as short veins or tiny blebs in arsenopyrite, chalcopyrite, or the gangue material.

In order that the distribution of the different minerals may be observed more readily a table has been prepared showing for each of the minerals the locality and type of occurrence as well as whether it is a major or minor constituent of the ore. This table follows:

TABLE I

Minerals	Mines	Maj. Const,	Min. Const.	Occurrence
Arsenopyrite	Bankfield, Hardrock, Little Long Lac	x		isolated crystals, crystal masses
Berthierite	Little Long Lac		x	veins, prismatic crystals
Chalcopyrite	Dikdik, Hardrock, Lafayette		x	veins, blebs
	Hutchison		x	veins
	Lac Devel., Little Long Lac, McLeod-Cockshutt		x	massive, veins, blebs
	Langmuir Long Lac	x		massive, veins, blebs
Galena	Dikdik, Hardrock, Hutchison, Lac Devel., Little Long Lac		x	veins, blebs
Gold	All nine		x	veins, blebs
Hematite	Langmuir Long Lac		x	veins, blebs
Limonite	Bankfield, Hutchison, Langmuir Long Lac, Little Long Lac		x	veins
Magnetite	Bankfield, Little Long Lac		x	small granular areas
Pyrite	All nine	x	x	isolated crystals, crystal masses
Pyrrhotite	Bankfield, Dikdik, Hardrock Lac Devel., Little Long Lac		x	veins, blebs
	Langmuir Long Lac	x		massive
Sphalerite	Bankfield, Dikdik, Lac Devel., Little Long Lac, Langmuir Long Lac		x	veins, blebs
	McLeod-Cockshutt		x	massive, veins, blebs
Tetrahedrite	Hardrock, Little Long Lac		x	veins, blebs

Gangue Minerals. The gangue material in most of the sections examined is predominantly quartz with minor quantities of carbonate and chloritized mica. Tourmaline was found in one of the sections from the Little Long Lac Mine. Two of the specimens from the Bankfield Mine were a chlorite schist and an altered gabbro impregnated with the metallic minerals.

Mineral Genesis. It is not within the scope of this paper to discuss in any great detail the genesis of the ore in this field. Without the field relations it is dangerous to be too dogmatic about its history. Nevertheless, from a microscopic study some information of a reliable kind may be obtained as to the relative order of deposition of the mineral constituents, and this is set out very briefly in the following paragraph.

In general the order of mineral deposition would appear to have been as follows: (1) quartz, pyrite, arsenopyrite, magnetite; (2) quartz, pyrite, arsenopyrite, pyrrhotite, chalcopyrite, sphalerite, carbonate; (3) carbonate, pyrite, berthierite, sphalerite; (4) galena, gold, tetrahedrite; (5) limonite. It will be noted that there is considerable overlapping in times of deposition, quartz being deposited during stages 1 and 2 and pyrite during stages 1 to 3. In two of the specimens there is to be seen a beautiful replacement of chalcopyrite and pyrrhotite by a later pyrite (Plate III, figure 2).

Sturgeon River Field

Twenty-four sections were prepared from specimens taken from this area. These are distributed as follows:

Agaura Exploration Company	15
Casey Contact Mines	4
Oliver Severn Mines	2
Springer Exploration Company	3

The mineralization at these properties will be listed in the above order.

Agaura Exploration Company. In the fifteen sections examined, the following metallic minerals were found to be present: pyrite, sphalerite, chalcopyrite, galena, gold, and magnetite. Of these sphalerite, chalcopyrite, and pyrite predominate largely; galena is present in fair quantity, while magnetite and gold are minor constituents.

Casey Contact Mines. In this ore the metallic minerals present, given in order of prevalence, are pyrite, chalcopyrite, galena, sphalerite, magnetite, limonite, and gold. Of these the first three predominate largely over the last four.

Oliver Severn Mine. Of the two sections examined from this mine one consisted almost entirely of metallic minerals, while the other contained considerable gangue. In the former specimen pyrite and galena were the predominant metallic minerals with subordinate quantities of sphalerite, chalcopyrite, hematite, and gold, while the latter specimen showed chalcopyrite as the common metallic mineral with pyrite and hematite in minor amounts.

Springer Exploration Company. Three sections were examined from material supplied by the above company, one from the Maloney Sturgeon Gold Mines. The main metallic mineral in these sections is pyrite, but they contain also minor quantities of chalcopyrite, galena, sphalerite, gold, and limonite.

Occurrences

Chalcopyrite occurs generally as short veins or tiny bleb-like inclusions, the former in the gangue or the sphalerite, the latter in sphalerite, pyrite, or gangue. Occasionally it appears in massive form.

Galena is fairly common as a minor constituent of many of the sections. It appears generally as short veins or bleb-like inclusions in the gangue or in the larger areas of pyrite or sphalerite. Less often it is found in small granular masses in the gangue.

Gold is found as a minor constituent in five of the twenty-four sections examined. It occurs uniformly as tiny bleb-like inclusions or short veinlets in the gangue or in the larger pyrite crystals.

Hematite is present as a minor constituent in the two specimens examined from the Oliver Severn property. It is found as small prismatic crystals either scattered through the gangue material or cutting it in veins.

Limonite appears as an alteration product of the other iron minerals in four sections from the Casey Contact Mines and the Springer Exploration Company's properties. It occurs in subordinate amounts in the usual vein-like forms.

Magnetite, another minor constituent, was found in small granular areas in three of the sections examined.

Pyrite is the commonest metallic mineral in this district, occurring in nearly all the sections examined. It is found in the same forms as in the Little Long Lac area. It shows a rough cubic cleavage the cracks of which are sometimes filled with other metallic minerals or gangue material.

Pyrrhotite is a rare mineral in this district being found in but one section of the Springer Sturgeon Gold Mines as a minor constituent, appearing in the form of tiny bleb-like inclusions in some of the larger pyrite crystals.

Sphalerite is a fairly common constituent of the ores from this area, being present as a major constituent in the Agaura Exploration Company's properties and as a fairly constant minor constituent in the ores from the other four properties. It is most frequently found in massive form or in small granular areas in the gangue, less often in short veins or bleb-like inclusions in the pyrite or in the gangue.

A table, showing distribution and mode of occurrence for the metallic minerals of this district is on opposite page.

A consideration of table II shows some marked divergences between the mineralization in this field and that of the Little Long Lac area. It will be noted that arsenopyrite, berthierite, and tetrahedrite are lacking in the Sturgeon River ores, and pyrrhotite is very rare, while galena is fairly common.

Gangue Minerals. The gangue material is predominantly quartz, but considerable carbonate is also present as well as minor quantities of a secondary biotite, frequently changed to chlorite.

Mineral Genesis. The order of mineral deposition, in so far as it could be deduced from a microscopic examination of the specimens available, appears to have been as follows:

(1) quartz, pyrite, magnetite; (2) quartz, pyrite, hematite, sphalerite; (3) sphalerite, chalcopyrite, pyrrhotite, galena, carbonate; (4) carbonate, chalcopyrite, galena, gold, hematite; (5) limonite. As in the mineral deposition in the Little Long Lac area there has been considerable overlapping in times of deposition. This is especially noticeable in cases of quartz, pyrite, sphalerite, chalcopyrite, galena, and carbonate.

TABLE II

Minerals	Mines	Maj. Const.	Min. Const.	Occurrence
Chalcopyrite	Agaura Expl. Co.	x		massive, blebs, veins
	Casey Contact		x	veins, blebs
	Oliver Severn	x		veins, blebs
	Springer Expl. Co.		x	veins, blebs
Galena	All four		x	veins, blebs
Gold	Agaura Expl. Co.		x	blebs
	Casey Contact		x	blebs
	Springer Expl. Co.		x	blebs
Hematite	Oliver Severn		x	crystals, veins
Limonite	Casey Contact, Oliver Severn, Springer Expl. Co.		x	veins
Magnetite	Agaura Expl. Co., Casey Contact		x	veins
Pyrite	All four	x		crystals, crystal aggregates
Pyrrhotite	Springer Expl. Co.		x	blebs
Sphalerite	Agaura Expl. Co.	x		massive
	Casey Contact		x	veins, blebs
	Oliver Severn		x	veins, blebs
	Springer Expl. Co.		x	massive

In conclusion the writer wishes to acknowledge the assistance rendered by the officers of the mines mentioned in this paper. Their prompt and efficient co-operation, in placing at his disposal an adequate supply of specimens, has made possible the preparation of this paper, and is deeply appreciated.

BIGSTONE BAY, LAKE OF THE WOODS, ONTARIO

Tellurides were reported from this locality in 1930[1] but no specific mention was made at the time as to the telluride mineral present. The chief metallic minerals in this section are tetradymite, calaverite, and petzite (Plate III, figure 4) but it contains also considerable pyrite as well as minor amounts of gold, chalcopyrite, and hessite. These metallic minerals are associated chiefly with a quartz gangue and to a lesser extent with carbonate. They occur in the following forms: pyrite in isolated crystals in the gangue; the remaining metallic minerals in short veins or as tiny blebs in the gangue.

Genetic Relationships. From the microscopic evidence available the order of mineral deposition would appear to have been as follows: (1) pyrite, (2) quartz, and (3) remaining metallic minerals and carbonate.

MCWATTERS MINE, ROUYN TOWNSHIP, QUEBEC

Telluride minerals have been reported from this mine by Hawley[2] who records the presence of hessite. Since the telluride examined by the writer was bismuth telluride, it seemed worth while recording it along with the hessite mentioned by Hawley. The main metallic mineral in the section examined is tetradymite, along with minor quantities of chalcopyrite and gold (Plate III, figure 5). These metallic minerals are associated with a predominant quartz gangue, which is cut in places by a later carbonate. They occur in the following forms: pyrite as a few isolated crystals scattered through the gangue or the larger areas of tetradymite; the other two metallic minerals as short veins or small bleb-like forms in the gangue.

Genetic Relationships. From evidence available to the writer it appeared that the order of mineral deposition was as follows: (1) pyrite, (2) quartz, and (3) carbonate, tetradymite, gold.

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[1] Suffel, G. G. Ont. Dept. Mines, vol. XXXIX, pt. 3, p. 69.

[2] Hawley, J. E. Que. Bur. Mines, Ann. Rep., pp. 40-1, 1933.

In conclusion the writer would like to acknowledge the kindness of Dr. M. E. Hurst, Dr. James E. Thomson, and Mr. E. V. Neelands, who made available material for this investigation.

THE INFLUENCE OF POTENTIAL IN ORE DEPOSITION

By A. S. Dadson

It is recognized that when two metallic minerals in contact are covered by a suitable liquid reagent an electric current is generated owing to the so-called difference of potential of the minerals. In consequence the solution of the one of lower potential is accelerated and of the other retarded.

The writer sought by this method to demonstrate potential differences in the ore minerals of Cobalt, Ontario. The minerals concerned are arsenopyrite, breithauptite, chloanthite, cobaltite, gersdorffite, loellingite, niccolite, rammelsbergite, safflorite, skutterudite, smaltite, temiskamite, and silver. These minerals are commonly intergrown with a great variety of combinations and specimens of pure mineral are scarce. Whether a certain amount of isomorphism takes place or whether they occur as distinct chemical individuals is not definitely known. Ellsworth[1] came to the conclusion that true molecular isomorphous mixtures in the Cobalt minerals are rare.

The minerals mentioned in this paper gave characteristic etch reactions, and chemical tests showed that each contained at least a preponderance of the metal indicated as essential to its composition.

Professor Ellis Thomson kindly gave access to his collection of polished ores for typical specimens and certain combinations.

The Action of Silver Sulphate Solution

The common etch reagents did not offer much hope of success in the matter of finding potential differences. At the suggestion of Dr. T. L. Walker, silver sulphate solution

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[1] Ellworth, H. V. Ont. Bur. Mines, vol. XXV, pt. 1, pp. 220-43, 1916.

rather coarser silver on the breithauptite. Non-granular silver formed over niccolite. After ten minutes all the precipitated silver wiped off easily, when it was seen that niccolite was the only mineral etched.

4. *Niccolite, safflorite, rammelsbergite, skutterudite, cobaltite*

The orthorhombic crystals of safflorite were intergrown with niccolite.

The niccolite etched immediately with formation of much feathery silver. Bright granular silver was deposited on the safflorite, skutterudite, and cobaltite. The rammelsbergite also etched quickly and became coated with adherent non-granular silver. Only the niccolite and rammelsbergite were etched, the former much more deeply.

5. *Rammelsbergite, niccolite, skutterudite*

Rammelsbergite formed the main mass of this section. Niccolite was a nest surrounded by cubic crystals of skutterudite. There were also some cubic inclusions of skutterudite in the rammelsbergite. The niccolite etched immediately with deposition of bright silver on the surrounding skutterudite. The skutterudite included in the rammelsbergite was seen to coat with silver before the rammelsbergite was visibly etched.

6. *Rammelsbergite, skutterudite, smaltite, chloanthite, niccolite*

In this specimen rammelsbergite formed central areas and was surrounded by scattered niccolite, zoned skutterudite-smaltite-chloanthite, and skutterudite in the order named. The rammelsbergite and niccolite etched quickly and became coated with non-granular silver. Bright granular silver was deposited on the other minerals. After five hours some of the smaltite-chloanthite was etched just enough to indicate zonal structure.

7. *Safflorite, loellingite, rammelsbergite, skutterudite, niccolite, tetrahedrite, chalcopyrite, bornite*

The rammelsbergite formed numerous small central areas surrounded by cubic skutterudite and then radiating intergrown safflorite and loellingite. At one end of the section there was a little niccolite and it was possible to test this separately. The copper minerals formed small inclusions in the gangue. Similar results were observed when the drop was covering the niccolite and when it was not. The rammelsbergite, and niccolite, when covered, quickly etched and coated with non-granular silver. Bright granular silver was deposited on the other minerals. After forty minutes the safflorite-loellingite was etched just enough to indicate radiating structure. The tetrahedrite was not etched, but on account of the smallness of the particles it was difficult to decide whether the chalcopyrite and bornite were etched or not.

8. *Loellingite, safflorite, skutterudite, cobaltite*

The loellingite and safflorite formed radiating intergrowths with a core of skutterudite. Cobaltite was in small scattered inclusions. Formation of silver could first be observed after half an hour. After one hour considerable silver had formed in the shape of thin flat crystals about ¼ millimetre in diameter growing perpendicularly from the etched loellingite and safflorite. These two minerals were etched uniformly brown. The others were not etched.

9. *Silver, cobaltite, safflorite, loellingite, skutterudite*

After half an hour numerous thin flat crystals of silver had formed, mostly growing perpendicularly from the etched safflorite and loellingite, but some also growing from the unetched skutterudite. A few of the silver areas had a loose granular deposit of silver.

10. *Smaltite, cobaltite, arsenopyrite*

After one hour very little silver had formed. After three hours considerable silver was growing as small flat crystals from the etched smaltite and also the unetched cobaltite and arsenopyrite.

11. *Smaltite-chloanthite, skutterudite, cobaltite, chalcopyrite, bornite, tetrahedrite, chalcocite*

The copper minerals formed small inclusions in the central parts of large zoned crystals of smaltite-chloanthite. Cobaltite and skutterudite were intergrown forming irregular inclusions in the smaltite-chloanthite. Silver was first noticeable after four minutes—loose granular crystals formed over the whole surface but most thickly about the chalcocite inclusions. After half an hour much coarse silver was growing from etched and unetched minerals. The smaltite-chloanthite had etched differentially. The chalcocite had etched deeply and apparently also the bornite and chalcopyrite. The other minerals were not etched.

12. *Temiskamite, niccolite, cobaltite*

The niccolite formed a narrow rim at the margin of a mass of temiskamite. The temiskamite and niccolite both etched immediately. Apparently the niccolite was attacked more strongly.

13. *Silver, loellingite, safflorite, cobaltite, skutterudite, temiskamite*

The temiskamite was in small inclusions in the silver areas. The silver areas were concentrically surrounded by skutterudite and radiating intergrown safflorite and loellingite. The temiskamite etched immediately and bright granular silver was deposited on silver and skutterudite. After five minutes the loellingite-safflorite started to etch with growth of rather coarse flat crystals of silver.

The other sections tested showed no variations from the ones described. Where calcite gangue was present it was always deeply dissolved but had no apparent effect on the reactions.

In order to test the effect of a larger amount of solution certain of the above sections were set in wax in the bottom of a small dish so that only the polished surface was exposed. 10 cc. of the solution was added and left for 15 hours. The resulting solutions were analysed quantitatively. The specimens after washing off the loose silver presented the same appearance in regard to deposited silver as has been described above.

Section	Minerals Etched	Minerals not Etched	Analysis of Solution
2.	Niccolite	Breithauptite	0.0018 g As
		Cobaltite	0.0021 g Ni
		Skutterudite	no Sb.
4.	Niccolite	Safflorite	0.0025 g As
	Rammelsbergite	Cobaltite	0.0018 g Ni
		Skutterudite	0.0002 g Co
7.	Rammelsbergite	Skutterudite	0.0031 g As
	Niccolite	Tetrahedrite	0.0005 g Ni
	Loellingite	(Chalcopyrite?)	0.0003 g Co
	Safflorite	(Bornite?)	0.0008 g Fe

In section 4 the safflorite has evidently been protected by the niccolite. In section 7 the rammelsbergite has not been effective in protecting the loellingite and safflorite, possibly because the adherent silver formed on it slows up its solution.

THE EFFECT OF HYDROFLUORIC ACID IN SILVER SULPHATE SOLUTION

With the assumption that, in the case of the niccolite and breithauptite the breithauptite was protected by a coating of insoluble antimony oxide, a little hydrofluoric acid was added to the silver sulphate solution in the proportion of 3:10. This solution strongly attacked breithauptite while niccolite in the same specimen was not visibly etched. Even after exposing the section to 15 cc. of the solution overnight the niccolite was not etched although in places it had swelled up and cracked.

A small specimen about 3 grams in weight consisting of breithauptite, niccolite, and cobaltite, with all the calcite gangue removed, was placed in a platinum basin with 20 cc. of the silver sulphate solution and 3 cc. of hydrofluoric acid. Silver immediately began to precipitate on the specimen and on the sides and bottom of the basin. After leaving overnight all the silver had been precipitated as a dark botryoidal coating over specimen and dish. The solution on analysis gave 0.0096 g Ni, 0.0131 g Sb, 0.0002 g As, trace Fe.

Continuing the etching experiments with the silver sulphate-hydrofluoric acid solution, niccolite without breithauptite was strongly attacked with formation of rather adherent silver. In specimens in which niccolite was in contact with rammelsbergite the niccolite was etched immediately and the whole surface of the section under the drop was covered with an impalpable coating of silver. After half an hour all the silver was precipitated from the solution and no etching on the rammelsbergite was detected. In the typical specimen of rammelsbergite there was instantaneous formation of a very compact layer of silver when the reaction apparently stopped. On scraping off the silver the surface was again instantly protected by a very thin layer of fresh silver, but after half an hour no etching was observable on the rammelsbergite. Two specimens of rammelsbergite with cobaltite-skutterudite rims showed strong etching with formation of non-granular coatings of silver and also deposits of bright granular silver on the rim minerals.

It is possible that in certain specimens of rammelsbergite a protective coating of silver is formed which stops the reaction. It is also possible that rammelsbergite acts as a positive pole to niccolite and is protected from solution. It is hoped that further work along this line will clear up the point.

Loellingite, safflorite, smaltite, and chloanthite showed similar reactions to those observed in the straight silver sulphate experiments except that the reactions started immediately or at least within a minute.

It is evident that the hydrofluoric acid has some other action than simple solution of the antimony oxide. If a piece of niccolite or niccolite and breithauptite is placed in a platinum basin with the silver sulphate solution alone only a very little silver forms on the sides of the basin in contrast to the large amount when hydrofluoric acid is present

SUMMARY

Considering the action of silver sulphate solution the minerals can be placed in three groups:

I. Niccolite, rammelsbergite, and temiskamite are quickly attacked.

II. Loellingite, safflorite, smaltite, chloanthite, and skutterudite are slowly attacked.

III. Arsenopyrite, cobaltite, gersdorffite, silver, and breithauptite are not attacked.

When a mineral of group I is in contact with one or more members of the other two groups it will form the negative pole of a voltaic cell with generation of considerable e.m.f. as shown by the precipitation of silver on the other minerals. In the succeeding groups the production of an e.m.f. is not so evident but is indicated by the fact that silver crystals grow from the unetched as well as the etched minerals. Since skutterudite was found not to be attacked when in contact with other minerals of groups I and II, it evidently will come below them in a potential series.

The addition of hydrofluoric acid to the silver sulphate solution gives a further division. Breithauptite is most strongly attacked and niccolite in contact with it is protected. Niccolite alone is strongly attacked. Rammelsbergite, when in contact with niccolite is apparently protected.

Possibly further experiments will separate these minerals more completely.

If we assume that the silver in the Cobalt ores came in later it is evident that the solutions would exercise considerable selection in the matter of replacing minerals. On account of electrolytic action, with the solution of one mineral others may be protected.

Niccolite, rammelsbergite, temiskamite, and under certain conditions breithauptite would be most readily replaced. Furthermore with the solution of these minerals considerable e.m.f. is set up which could cause the silver to precipitate wherever a positive pole existed. This would explain the growth of silver into fractures and openings made through solution.

Examination of polished sections shows many cases of partial replacement of niccolite and breithauptite by silver. A very common form in which silver occurs is as central areas surrounded by concentric rims of arsenides, which usually are one or more of skutterudite, safflorite, loellingite. It is significant that this is also the form in which rammelsbergite commonly is found. It does not require much imagination to consider the silver, occurring in these forms, to have completely replaced the rammelsbergite without replacing the surrounding minerals.

THE TEMPERATURE OF FORMATION OF QUARTZ AND SOME ASSOCIATED MINERALS

By V. B. Meen

In a previous paper[1] the writer gave an account of the results obtained by etching polished basal sections of quartz. The method used by Wright and Larsen[2] was revised and the etch-pits, so obtained, were much more satisfactory. The study of quartz, by this revised procedure, has been continued and the associated minerals have been noted. Almost all the specimens examined were of vein origin but, contrary to the statements of Wright and Larsen,[3] they were not all of the low-temperature type.

There is some confusion in the literature regarding the value of the crystallographic inversion temperature for alpha to beta quartz and in the use of the terms low-temperature, high-temperature, alpha quartz, and beta quartz. In the following pages, the temperature of inversion is assumed to be 575° C., low-temperature and high-temperature refer respectively to temperatures below and above 575° C. and alpha and beta quartz are low-temperature and high-temperature forms respectively.

Specimens were obtained from the Royal Ontario Museum of Mineralogy, Canadian mines, and from the collection of the writer. No attempt was made to select grains from the specimens and polish basal sections. Each specimen was broken up into fragments of 2 to 5 millimetres in diameter, and then treated with hot hydrochloric acid to remove carbonate which in many cases was present intersticially. The fragments were then mounted in bakelite briquettes as

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[1] Meen, V. B. Univ. Tor. Studies, Geol. Ser., no. 36, pp. 37-43, 1934.

[2] Wright, F. E. and Larsen, E. S. Amer. Jour. Sci., ser. 4, vol. XXVII, pp. 421-47, 1909.

[3] *Op. cit.*, p. 446.

previously described.[4] Before polishing, it was necessary to grind away some of the face of the briquette in order to expose the maximum area of the fragments.

Due to the leaching out of the carbonate, fragments are frequently left in a porous condition. It is essential that these holes be filled before the specimen can be polished mechanically. Sealing-wax, Canada balsam, powdered resin, and liquid resin were experimented with as filling media.[5] The latter gave the most satisfactory results. The briquette is placed in an oven and heated to 130° C., liquid resin is spread over the surface and allowed to cure, at 130° C., for at least two hours. The resin, which is then quite hard and tough, is ground away to the original surface of the briquette. This resin fills all cavities, prevents particles from chipping out and scratching, and does not smear during the polishing operation.

For convenience, the specimens have been grouped as follows:

1. Quartz from veins with no associated minerals—two specimens.
2. Quartz from veins which contained gold, visible or invisible—thirty-three specimens.
3. Quartz from veins which contained gold and tourmaline—five specimens.
4. Quartz from veins which contained tourmaline and no gold—six specimens.
5. Quartz from veins which contained some mineral other than those mentioned above. In this group is included the quartz of two specimens of greisen—twelve specimens.

GROUP 1. QUARTZ WITH NO ASSOCIATED MINERALS

A specimen of "bull" quartz and a specimen of rose quartz were examined. Both were made up of grains at least 1 centimetre in diameter as seen in thin section and were alpha quartz.

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[4] Meen, V. B., *op. cit.*, p. 41.

[5] Powdered and liquid resin are supplied by the Bakelite Corporation.

GROUP 2. QUARTZ WITH GOLD BUT NO TOURMALINE

The size of the grains of these quartzes varied from 1 millimetre to 1 centimetre or greater. Pyrite and calcite occurred in almost all of them. Other minerals seen in some of these veins were chalcopyrite, pyrrhotite, tellurides, arsenopyrite, galena, sphalerite, and sometimes a little sericite, biotite, or chlorite. Both low and high-temperature quartz were represented in this group. Thirty-one specimens were of the alpha type and two of the beta type. These two specimens were obtained from McKenzie Red Lake Gold Mines and Gold Eagle Gold Mines, both in the Red Lake area of Ontario.

GROUP 3. QUARTZ WITH GOLD AND TOURMALINE

Of the five specimens examined, three showed low-temperature and two showed high-temperature characteristics. The low-temperature specimens were obtained from Siscoe Gold Mines, Siscoe, Quebec, Buffalo-Ankerite Gold Mines, South Porcupine, Ontario, and Northern Empire Mines, Empire, Ontario. The high-temperature specimens were obtained from Howey Gold Mines, Red Lake, Ontario, and Lafayette Long Lac Gold Mines, Little Long Lac, Ontario. Pyrite and calcite occur in all the samples, galena and sphalerite are known to occur in the ore from the Howey, and arsenopyrite was present in the samples from Northern Empire and Lafayette Long Lac.

GROUP 4. QUARTZ WITH TOURMALINE BUT NO GOLD

In this group also, both types were represented. The only specimens available were obtained in the neighbourhood of Little Long Lac, Ontario. Three specimens showed low-temperature and three showed high-temperature characteristics.

GROUP 5. QUARTZ WITH SOME MINERAL OTHER THAN THOSE MENTIONED ABOVE

For convenience, these occurrences have been listed in the following table.

Occurrence	Associated Minerals	No. of Localities	Type of Quartz
Vein	Galena, Sphalerite	3	Alpha
Vein	Argentite, Silver	1	Alpha
Vein	Chalcopyrite	1	Alpha
Vein	Scheelite	2	Alpha
Vein	Axinite, Fouqueite	1	Alpha
Vein	Rutile	1	Beta
Pebble	Cassiterite	1	Beta
Greisen	Cassiterite	2	Beta

During the course of the examination of the material described in the foregoing pages, twelve specimens were studied on which no determinations could be made. After etching, the surfaces of these were saccharoidal in appearance. When an examination of thin sections was made, it was found that these specimens fell into two very distinct classes. By coincidence, there were six examples of each class. The one type was made up of very fine grains which were less than 0.2 millimetre in diameter. The acid attacked most readily along the boundaries of grains and hence the polished grains were completely removed from the fragment. The other type consisted of coarse-grained quartz but the grains were full of minute inclusions. The acid acted first by way of these inclusions and riddled the surface with holes and undermined it with tunnels. Plate II, figures 3 and 4, are photomicrographs of thin sections which illustrate these two types.

The literature contains many descriptions of mineral occurrences in which the terms "low-temperature" or "high-temperature" are used. In most of these, nothing more definite regarding the temperature of formation is given. Lindgren,[6] in a description of veins of the Alpine type, says: "Another, in the French Alps, yields axinite, titanite, ilmenite, and many other minerals which indicate deposition at high temperature." On another page,[7] he says: "High-temperature minerals like tourmaline, topaz, magnetite, and

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[6] Lindgren, W. Mineral Deposits, p. 611, 1933.

[7] *Op. cit.*, p. 121.