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INTRODUCTION

The increased size of the present number of *Contributions to Canadian Mineralogy* is made possible by the enlarged membership of the Walker Mineralogical Club, by a special grant from the Royal Ontario Museum to defray the cost of printing the history of the Royal Ontario Museum of Mineralogy, and by a grant from the University of Toronto to defray the cost of printing the contributions from the Department of Mineralogy and Petrography in that institution.

The writer wishes here to express his thanks for this financial support. He would also ask the members of the Walker Mineralogical Club to lend their influence in enlarging the membership of the Club so as not only to provide for the publication of a larger number of papers from members of the Club but to secure a wider distribution of the publication.

For the hearty collaboration of those members who have assisted in the success of this issue by contributions of papers, the writer extends his heartfelt thanks.

A. L. PARSONS

THE ROYAL ONTARIO MUSEUM OF MINERALOGY

By A. L. Parsons
University of Toronto

The early history of the Royal Ontario Museum of Mineralogy deals with the development of collections of minerals and rocks in the University of Toronto, Victoria University, and the Ontario Provincial Museum.

University of Toronto

So far as the University of Toronto is concerned, this early history is practically unknown, except for the information that there was a collection of minerals and rocks which was destroyed in the fire of 1890. There are a few crystals which are supposed to go back to the time of the late Professor E. J. Chapman that remain in the teaching collection of the University of Toronto.

The real start of the Museum in its present form is marked by the purchase in 1894 by the University of Toronto of a large collection of minerals from Dr. W. F. Ferrier, then of Ottawa, on the advice of Professors E. J. Chapman and A. P. Coleman. This collection was put on display in the museum section of the Biology Building which at that time housed the Department of Mineralogy and Petrography.

In 1901 the Department of Mineralogy and Petrography came under the direction of Professor T. L. Walker who, from that time until his retirement from active service in 1937, was indefatigable in his efforts to improve the collections of minerals and rocks.

When the present Mining Building was built, the Departments of Mineralogy and Geology were transferred to it and a large basement room was devoted to the Museum of Mineralogy and Geology until better quarters could be secured. Originally it was intended to add a museum wing to the Mining Building, but in view of other museum projects the appropriation that had been granted for this purpose was transferred to the fund for a greater museum. Upon completion of the west wing of the present Museum, the collections of minerals and rocks were moved to the top floor in September, 1912. Here for the next eighteen months the early part of the task

of building a public museum around two fine taxonomic collections of minerals and rocks occupied a large portion of Professor Walker's time.

VICTORIA UNIVERSITY

At about this time, after a fire in the upper portion of the main building of Victoria University, the residue of the minerals and rocks in the collections of Victoria University was turned over to the Royal Ontario Museum of Mineralogy. The task of attempting to rescue museum material from the mixture of specimens and labels fell to the writer, with the result that 350 named specimens of rocks and 411 specimens of minerals were added from this source to the Museum's collections. Because of an unfortunate museum practice common in the latter half of the past century of having wall cases with steeply tilted shelves for the display of mineral specimens, there was a considerable portion of the collection that was no longer of value, for with the jarring of the cases either at the time of the fire or at some other time, a mixture of specimens was thrown forward against the doors, and on these being opened, many specimens went to the floor so that only such specimens as had proper marks of identification or were definitely recognized both as to nature and locality found a place in the Museum.

PROVINCIAL MUSEUM

With the close of the Ontario Provincial Museum in the Normal School in the spring of 1933, the collections of minerals were transferred to this Museum. The Hamilton Merritt collection and the Dillon Mills collection, which are rich in specimens from historic mines and mineral localities in Canada, were carefully numbered and labelled so that they are probably intact. At present these are stored in special cases for comparison and study, each collection being kept as a unit. These collections have a peculiar interest and value, being the careful work of intelligent private collectors in a special field. Of the remaining material the best has been incorporated in the systematic collection of minerals.

THE PERIOD FROM 1912 TO 1920

With the transfer of the University collections to the new Museum and an increased appropriation for purchase and collecting

expenses, the Director devoted his vacations to collecting minerals and rocks from all parts of Canada so as to have as complete a representation of Canadian minerals as possible. Having a keen appreciation of the fact that the rarest minerals could usually be secured only by exchange, he collected more than was needed for display and began a series of exchanges that added much to the Museum's resources. During this period more particular attention was paid to securing good display material, especially large specimens that could be put in the high cases with suitable descriptive labels, so that the casual visitor might gather information that could not be given in the taxonomic collections.

During this time the silver mines of Cobalt were in their greatest period of production, and large quantities of the associated minerals were turned over by the mining companies with no charge except for silver value or, in some cases, the cost of mining. In similar manner the newly developed gold mines of the Porcupine and Kirkland Lake districts, and the nickel mining companies of the Sudbury district, contributed most liberally.

Throughout this period the staff of this Museum consisted of the Director, one assistant for cataloguing and stenographic work, and a part-time preparator.

THE PERIOD FROM 1920 TO 1932

In the year 1920 the Honourable and Reverend H. J. Cody, Minister of Education, included in the appropriations for the University a sum of fifty thousand dollars to be devoted to research. Of this sum three thousand dollars was allotted to the Department of Mineralogy. As a result there was instituted a most intensive campaign of research which not only added to our knowledge of Canadian minerals but also increased in a great degree the exchange value of the materials thus investigated.

Inasmuch as there were few suitable organs for the publication of the results of these investigations, Dr. Walker issued the *Contributions to Canadian Mineralogy for 1921*, and continued this publication each succeeding year until he was incapacitated for active work.

At this same time the writer, who in the preceding period had worked as unofficial assistant in the work of the Museum, was

appointed Assistant Director, and to him was entrusted the greater part of the negotiation of exchanges during this period.

These three factors augmenting the resources of the Museum marked the beginning of the most active period of research and growth of the Museum. The spare time of the Director and Assistant Director was fully occupied with collecting in the summer, and research, exchange, and other routine work in the winter.

Up to this time the addition of new minerals to the collections was mainly by purchase of such newly described species as came into the hands of dealers. Correspondence with museums and individual workers in all parts of the world resulted in exchanges that not only enabled this Museum to fill many gaps in its collections but served to enrich the collections of our correspondents. Several of these institutions have established a series of continuing exchanges whereby we receive duplicates of newly described material in exchange for our best duplicate material.

This was not only the period of greatest growth in the systematic collection, but was also the time when the greatest quantity of good display material from Canada and good exchange material was accumulated.

The culmination of this policy occurred in the summer of 1931 when, in anticipation of the move to the new wing of the Museum, Dr. Walker made an extended European trip upon which, by personal contact, he was able to negotiate many important exchanges and secure by purchase the best available material in the hands of the dealers.

THE PERIOD FROM 1932 TO 1939

With the near completion of the east wing of the Museum in 1932 the collections of the mineralogical section were moved to the south half of the entrance floor of the new section where, with exhibition space increased by about fifty per cent, the Museum of Mineralogy assumed its present form, as shown in Fig. 1.

In view of this increase in space, involving about one-half more cases, it was necessary to handle practically every specimen, not only in the exhibition gallery, but in the exchange stock as well, so that the entire time of the staff was employed during the summer of 1932 in arranging the new display in the gallery, and in the proper arrangement of the duplicate material.

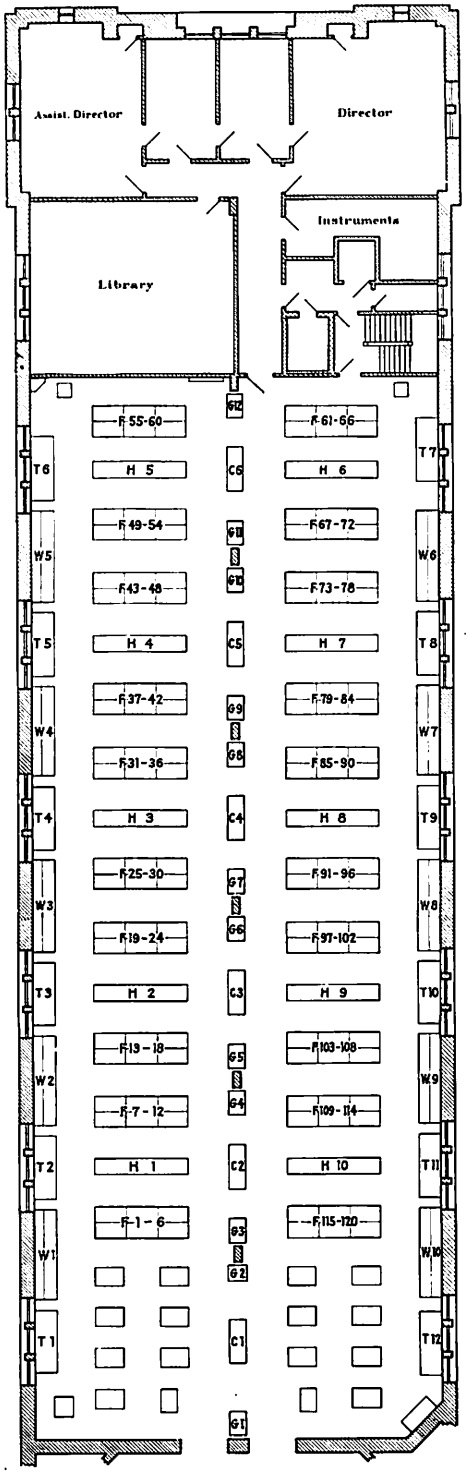

FIG. 1.—Plan of the Mineral Gallery, Royal Ontario Museum.

The completion of the new installation accompanied by the relief from serious strain marked the peak of the development of the Mineralogical Museum and the beginning of a transition period. Serious illness involving the Director or the Assistant Director for three successive summers interfered with the Museum's activities in a marked manner. The illness of the Director, which finally compelled him to give up his work in May, 1936, and eventually to resign, was a calamity which was an irreparable loss to the Museum. His greatest reward is the knowledge that he built a museum that is recognized as one of the outstanding museums of mineralogy in the world.

The Royal Ontario Museum of Mineralogy, which had its beginning in the purchase of the Ferrier collection of 3,595 specimens in 1894, has so grown that in February, 1939, there were 23,000 entries in the register.

THE COLLECTIONS

The Systematic Collection of Minerals

This collection, which contains specimens of all but the very rarest types of minerals, is displayed in table cases F.1–F.48 and F.73-F.120 and in high cases H.1–H.4 and H.7–H.10, and is one of the most complete collections on this continent. It has grown about the Ferrier collection which contained 997 named species and varieties of minerals, involving 3,595 specimens, and was unusually complete for a private collection at the time of its purchase. Additions have been made from the Victoria University collection, the William Morris collection, the Henry Montgomery collection, the Andre Dorfman collection, the Culbert collection of minerals from Cobalt, Ontario, and the Normal School collections, the most important of which are the W. Hamilton Merritt collection and the Dillon Mills collection of Canadian minerals.

It has been augmented by donations from mining companies in Canada and the United States. By far the greatest increase has come by the purchase of new minerals and fine specimens from dealers, and more particularly by exchange with museums in all parts of the world.

In the forty-five years that have elapsed since the purchase of the Ferrier collection there have been added 1,181 mineral species

and varieties. Of the 824 species recognized by Dana in 1892 there were lacking in the collection in 1921 eighty-four species. At present all but thirty-three of these have been secured.

From necessity, that portion of the collection which is displayed in the table cases is accompanied by very little explanatory material, but in the high cases the Director was able to develop his idea of the purpose of a museum. In these high cases each specimen is provided with an explanatory label, calling attention to certain features that are illustrated by the specimen, and in this way the visitor may gather most of the points emphasized in an elementary textbook of mineralogy. It was not enough that a specimen should be large or beautiful; it was necessary that there should be some feature that was worthy of attention either in its own physical properties, mode of occurrence, crystal form, or uses. In fact, in these cases, the important principle is developed that a museum, to be of great use, should consist of a collection of good descriptive labels illustrated by suitable specimens. In this respect this Museum occupies a leading position among the world's museums of mineralogy.

The Canadian Mineral Collection

In order that the visitor who is particularly interested in Canadian minerals may find them without hunting through the systematic collection, the Canadian mineral collection has been displayed separately in five wall cases (W.1–W.5). Nearly all known Canadian minerals are represented. Like the systematic collection, this is arranged according to the Dana classification.

In this collection the descriptive label is not employed, as the object of the collection is not to show the minerals of Canada as illustrating certain features, but to exhibit so far as possible a complete representation of the mineral species and varieties found in the country. At present 372 species and varieties are represented in the collection. Many of the specimens have been presented by mining companies, but as a whole, it represents the work of the former Director, Dr. T. L. Walker.

The Gem Collection

In the early days of the Museum's history it was felt that the expenditure of money for a collection of gems worthy of display in

the Museum was not warranted. At the opening of the Museum, however, in 1914, there was a collection showing the type of gem material that could be found in the bazaars of India, which was secured through the kind offices of Sir Henry Hayden, Director of the Geological Survey of India. Later a selection of Brazilian gems was presented by the Geological Survey of Brazil. As opportunity offered, good examples of some of the less expensive semi-precious stones were added by purchase or exchange, and a few of the more expensive gems were donated by Ryrie-Birks, while an exceptionally fine uncut black diamond was presented by Joseph Errington, Esq.

A bequest by Colonel Reuben Wells Leonard of St. Catharines, Ontario, made it possible to augment the growing collection by fine examples of the precious stones. There are exceptionally good examples of nearly every precious and semi-precious stone in the collection.

A feature of the collection consists of a special sub-collection of Canadian semi-precious stones which represent study and work by the Director and the Assistant Director. There are also two cases devoted to the display of synthetic gems.

The collection is displayed in eleven small cases (G.1, G.3–G.12) along the central aisle. To bring out the full beauty of the gems they are mounted on jeweller's wax set in cherry frames.

The Meteorite Collection

A small but representative collection of meteorites is displayed in a large table case (T.1). Typical specimens of the three principal classes, siderites or iron meteorites, siderolites or stony iron meteorites, and aerolites or stony meteorites are here shown.

Like the gem collection, this collection has been one of slow growth because of the feeling that the expenditure of large sums of money on this type of material was unwarranted after the main types were adequately represented.

There has been, however, a gradual growth by exchange and donation, and a few Canadian meteorites have been added by purchase.

Collections to Show the Paragenesis of Minerals

While a collection of minerals arranged in the manner of the systematic collection or by the so-called economic classification is

of prime importance to the student, there is in some ways an even greater attraction in collections showing the minerals that may be expected to be found together in the earth. In certain respects this is shown in collections of rocks, but the study of these to ascertain the minerals involved requires a microscopic examination.

Frequently when a mineral is found in a given locality it is to be expected that certain other minerals will be found nearby. To illustrate this tendency, eleven table cases (T.2–T.12) contain series of minerals and rocks that may normally be expected to occur together. These include the minerals of the silver-nickel-cobalt veins of Cobalt, Ontario; the minerals of the mica-apatite veins of Ontario and Quebec; the zeolites and associated minerals from various basalt regions; the minerals from the pegmatite dykes; the minerals from the nepheline syenites; the minerals of the gold-quartz veins; the minerals of the silver-lead-zinc veins; the minerals that result from the oxidation of chalcopyrite; the minerals in ultra-basic rocks; saline minerals; the radium minerals; and the rocks and minerals of the Sudbury nickel intrusive arranged along with a similar series from the Bushveld complex.

These collections are accompanied by labels descriptive of the particular association.

The Teaching Collection

One of the earliest special collections to be developed in the Museum was the so-called Teaching Collection or Beginners' Collection which occupies one of the wall cases (W.8). Here models, crystals, and minerals are arranged to illustrate the terminology used by the mineralogist.

The Collection of Useful Minerals from Ontario

In order that the casual visitor might have an opportunity of seeing the important mineral products of Ontario in collected form, four bronze cases (C.2–C.5) arranged along the central aisle are devoted to a display of the important minerals of Ontario that have been mined within the past forty years for their metallic content or for use in industry and the arts. Associated with these is a case (C.6) which is devoted to ornamental stones from Ontario.

An interesting feature in this exhibit is a model showing the hourly production of gold in the province from 1911 to date.

The Crystal Collection

Inasmuch as most minerals crystallize, the study of crystallography has for a long time been looked upon as an essential part of the study of minerals, and a collection of crystals should constitute a part of every mineralogical museum. For a public museum there is, however, the problem of presenting something of general interest rather than a collection that aims to show every possible form, group, or even unit cell. In view of this, the crystal collection is of a different type from those that are ordinarily displayed, and is contained in two wall cases (W.6 and W.7).

In one of these cases (W.6) specimens illustrating the different modes of formation of crystals, the habit of crystals, twinning and various types of distortion, exhibit phenomena which are the subject of much interest to the observer. A few models of typical unit cells illustrate the units which go to form the crystals. This case is accompanied by descriptive labels calling attention to the features of particular interest.

The other case (W.7) is devoted to minerals which normally develop large or beautiful crystals.

The Systematic Rock Collection

The rock collection is contained in twenty-four table cases (F.49–F.72) and two high cases (H.5–H.6). The collection begins with the igneous rocks (Cases F.49–F.65) which are followed by the sedimentary rocks (F.65–F.69), which in turn are followed by the metamorphic rocks (F.69–F.72).

In the high cases large specimens illustrating rock-forming processes and special features are accompanied by descriptive labels calling attention to the important features that are illustrated by the individual specimens.

The Large Specimen Bronze Cases

Just within the entrance to the mineral gallery are fourteen bronze cases devoted to large specimens. In some instances a single mineral occupies the case, but sometimes the specimen illustrates the association of minerals to be found at some particular mine and

is thus directly connected with the paragenetic collections of minerals and rocks. Here are displayed the following:

A large and fine group of crystals of quartz from Hot Springs, Arkansas, presented by Andre Dorfman, Esq.

A large specimen showing the gold and telluride minerals at the Lake Shore Mine, Kirkland Lake, Ontario, presented by the company through E. W. Todd, Esq.

A large specimen of gold quartz from the Vipond Mines, presented by the directors of the company.

Two large specimens illustrating different associations of gold in the Hollinger Mine, presented by the directors of the Hollinger Consolidated Gold Mines, Limited.

A large silver specimen showing the full width of the vein and the mineral association at the Miller Lake-O'Brien Mine at Gowganda, presented by the Honourable Senator M. J. O'Brien.

Two specimens of silver from the Frontier Mine, South Lorrain, Ontario.

One large vein specimen of silver from the Keeley Mine, South Lorrain, presented by Dr. J. Mackintosh Bell on behalf of the directors of the Keeley Silver Mines, Limited.

Vein specimens from the Lawson Mine and the O'Brien Mine, Cobalt, Ont.

A large specimen showing banded galena and sphalerite from the Sullivan Mine at Kimberley, B.C., presented by the Consolidated Mining and Smelting Company.

A large specimen of chalcopyrite from the Noranda Mine, Noranda, Quebec, presented by the company.

A large specimen of pyrrhotite and chalcopyrite from the Creighton Mine, presented by the International Nickel Company.

A large specimen of chalcopyrite, pentlandite, and pyrrhotite from the Frood Mine, accompanied by the metallic products to be obtained from such a block of ore, presented by the International Nickel Company.

Special Exhibits

Among the special exhibits may be mentioned a case (C.1) just within the entrance, devoted to showing the interesting range of colour in minerals. Immediately beyond this is an exhibit of fluorescent minerals which is a never-ending attraction. Being visible from the main rotunda, these serve to attract visitors who otherwise might not be inclined to visit the gallery.

In the north-east corner of the gallery is a unique feature in the shape of a mammoth compass consisting of a long mass of lodestone in a bronze tub which floats in water in an outer tub. After the mass has been turned by attraction to a bit of iron, it oscillates as a

compass needle, finally coming to rest in a north-south direction. This is one of the most popular exhibits in the gallery.

The most recent special exhibit is a reconstruction of a crystal cave. For this an opening was cut through the wall near the northwest corner of the gallery and a special room built. The crystals suspended from the roof and sides and lying on the bottom give a good representation of the way in which these crystals were found. The apparent size of the cave is increased by two mirrors suitably placed. The crystals were obtained by exchange with the New York State Museum and the cave is built on an adaptation of a plan used in such a reconstructed cave in the museum at Albany, New York.

On the north wall of the gallery on either side of the entrance are two cases, one containing a specimen of commercial phlogopite from the Lacey Mine, near Sydenham, Ontario, presented by the General Electric Company of Schenectady, New York, and the other a larger slab of black mica from Faraday Township, Ontario, presented by Dr. T. L. Gledhill.

Under the bronze table cases (T.1–T.12) are arranged a number of large specimens, some of which have a temporary interest. Here such things as slabs of the orbicular granite of Finland, a quarter-ton mass of lodestone, beryl-bearing pegmatite, and many others are provided with descriptive labels until such time as a better mode of display can be devised.

The Cases

Most of the cases in the mineral gallery are constructed of cherry (Series F, H, and W) although there are thirty-eight which have cherry bases and bronze tops, and six with marble bases and bronze tops. In general the warm tones of cherry give the pleasing character of the case display. The high cases and wall cases are provided with glass shelves, thus giving the maximum amount of light and an open appearance. An attempt has been made to secure dust-proof construction, and while perfection has not been secured, we have little difficulty with dust.

Most of the cases containing the systematic collection are provided with cupboard bases in which adequate space is secured for that part of the systematic series not used for exhibition. Similar

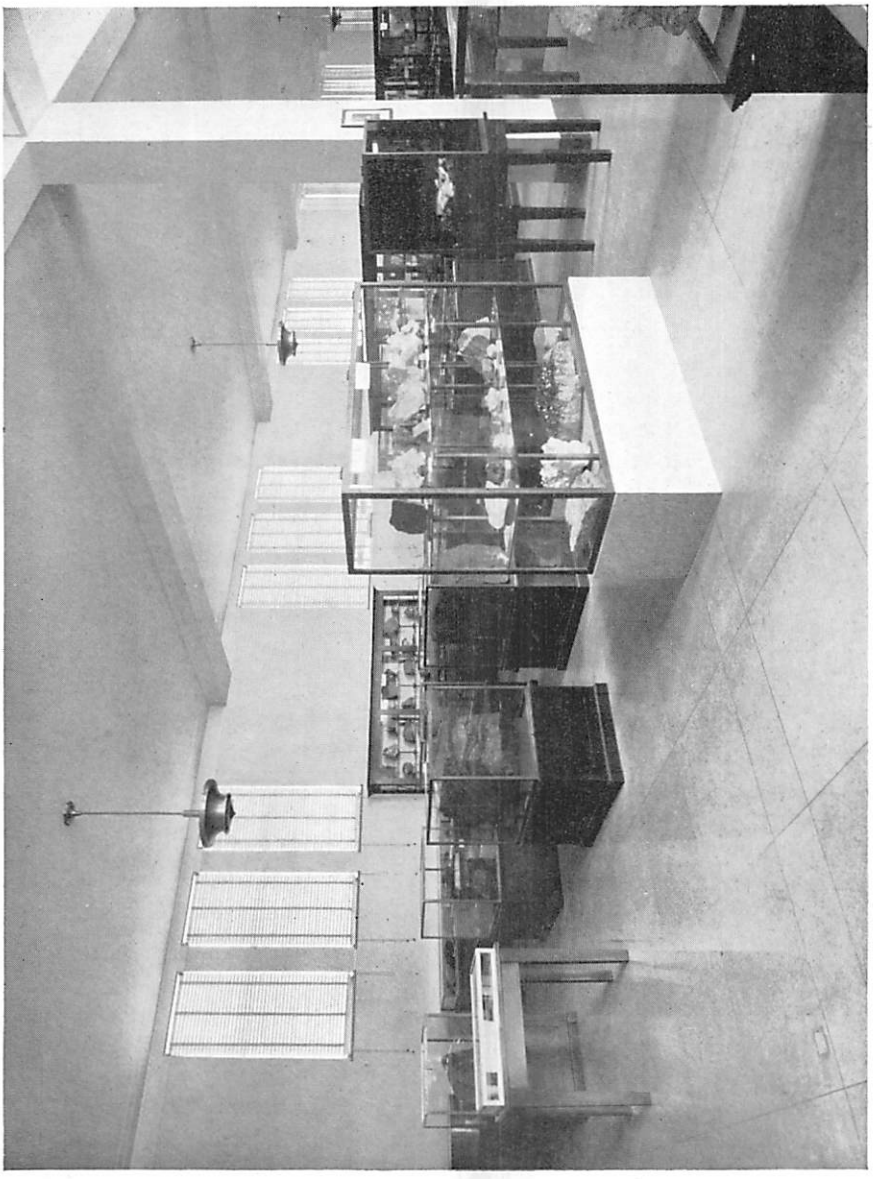

FIG. 2.—Part of the gallery of the Royal Ontario Museum of Mineralogy from the west side of the entrance. The large bronze case with marble base in the foreground is C.1 in Fig. 1.

provision is made in the rock cases and in the lower part of the wall cases for duplicates from the Canadian systematic series. In the illustrations (Figs. 2 and 3) the general type of cases may be observed, while the distribution of the cases in the gallery is shown in Fig. 1.

Temporary Exhibits

In every museum there is always the problem of making exhibits of material that for some reason has an intense popular but temporary interest such as results of exploration, recent major discoveries of minerals, minerals that have been found to have peculiar properties or uses, and many other similar types of material. In general these are best displayed as a temporary exhibit, to be later incorporated in the general collections.

From time to time such exhibits have been featured in this Museum, beginning with the collection of Indian semi-precious stones presented by Sir Henry Hayden, which was on display at the official opening of the Museum in 1914. At the same time a collection of rocks and minerals collected by the Scott Antarctic Expedition was given a prominent place.

At intervals collections of radium minerals, local collections like the Madoc fluorites, the Cobalt silver association, the Great Bear Lake silver-uraninite association, and others have been exhibited in the special cases. In most instances these temporary exhibits have been used later as a part of one of the larger special collections or have been absorbed in the systematic collections.

At present these temporary exhibits are for the most part displayed in two wall cases (W.9 and W.10) which are devoted to recent acquisitions from foreign countries and from Canada, respectively.

RESEARCH AND PUBLICATIONS

With the great quantity of minerals that have been collected by the staff of the Museum in the past twenty-five years, it is evident that extensive research must have been carried on so that these materials could be assimilated in the collections. There is, however, so far as this Museum is concerned, little outward evidence of this, for it is only recently that a laboratory has been equipped for the

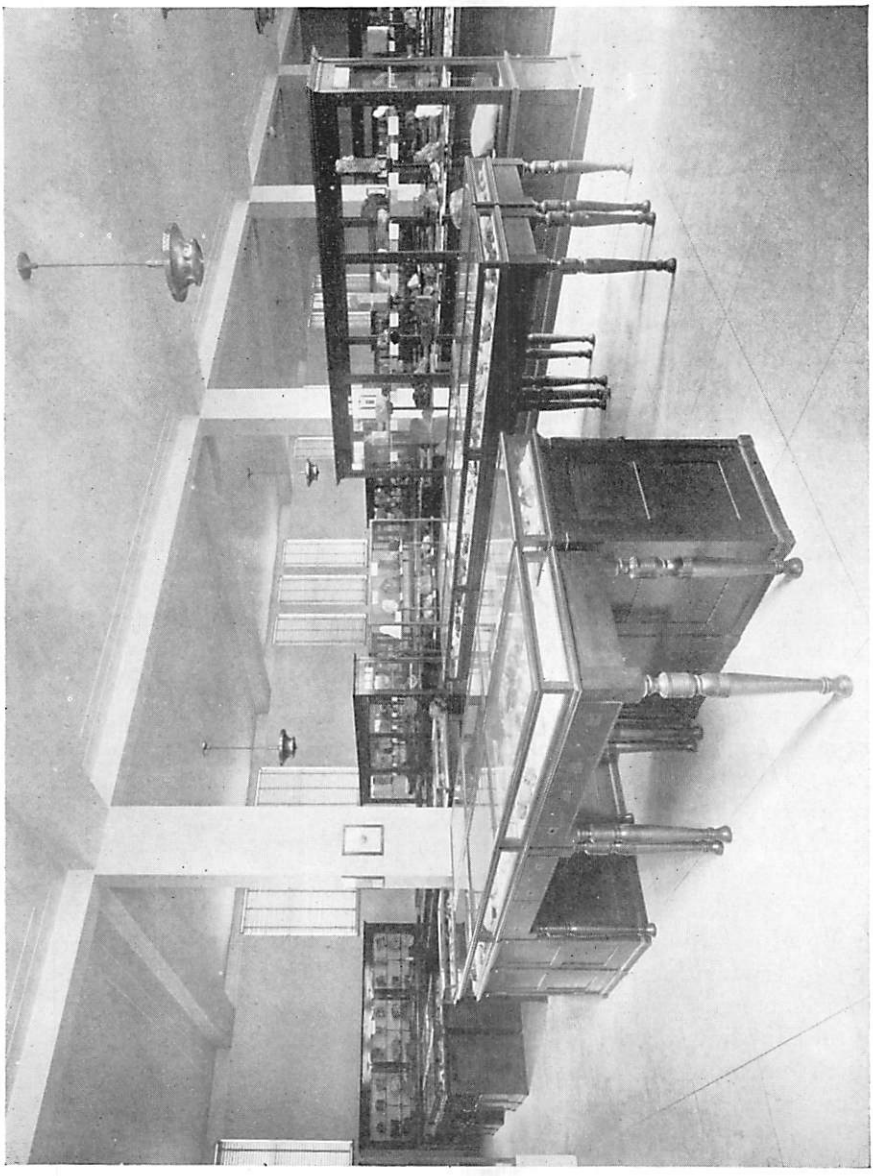

FIG. 3.—Part of the gallery of the Royal Ontario Museum of Mineralogy from the west side. The nearest cherry case is F.114 in Fig. 1.

chemical examination of minerals, and the Museum has no official organ for the publication of the results of research.

This anomalous condition is, however, not a true picture, and is due to the peculiar relations existing between the University of Toronto and the Royal Ontario Museum whereby most of the research connected with the Museum of Mineralogy has been carried on in the Department of Mineralogy in the University of Toronto. Until 1921 the results of research were published in journals in the United States and abroad, inasmuch as there was no suitable medium for such publication in Canada.

In order to provide for the publication of the results of our research, Dr. Walker issued the *Contributions to Canadian Mineralogy for 1921, from the Department of Mineralogy and Petrography of the University of Toronto*, which was continued annually until his retirement in 1937. This publication contains the most of the results of research on material in the Royal Ontario Museum of Mineralogy during this period.

As a fitting testimonial of their high personal and professional regard for Dr. Walker and his work, his colleagues throughout Canada, on invitation by the writer, united to form the Walker Mineralogical Club of the University of Toronto. This Club assumed a portion of the financial responsibility for the publication of *Contributions to Canadian Mineralogy for 1938 from the Department of Mineralogy and Petrography in the University of Toronto and from the Walker Mineralogical Club.* With the change in title, papers were received from colleagues in other institutions. With membership open to all who are interested in minerals, crystals, and rocks, the membership has increased so as to provide for a wider and more regular distribution of the publication. It also provides for a larger group of contributors from colleagues in other universities and in the government service where the article is of interest but not of sufficient magnitude to constitute a final report. The meetings of the Club have been held in the Museum with the result that many of the members have become interested in the welfare of the Museum, as shown by donations of minerals.

STUDIES OF MINERAL SULPHO-SALTS: 1—COSALITE FROM CANADA AND SWEDEN

By L. G. Berry
University of Toronto

The natural sulpho-salts form a large division of minerals consisting essentially of a metallic element combined in various proportions with sulphur and with arsenic, antimony, or bismuth. This division presents many uncertainties in crystallography, composition, and classification. Recent studies by Palache, Richmond, and Winchell (1938), Vaux and Bannister (1938), Bannister, Pabst, and Vaux (1939), and others, are beginning to clear up these uncertainties, revealing surprisingly large lattice dimensions and correspondingly complex cell contents. Much remains to be done, however, many species having not as yet been studied by modern methods.

Of the several groups of sulpho-salts the Jamesonite Group is one on which there is very little structural information. Minerals of this group, together with other species of acicular habit, were chosen for first study since promising material was available.

The Jamesonite Group of Dana (1892, p. 117) comprises a number of sulpho-salts with compositions conforming to the general formula: $2RS.(As, Sb, Bi)_2S_3$. From a structural point of view this general formula is better written $X_2Y_2S_5$, where X is lead, occasionally replaced by small amounts of copper or iron, and Y is arsenic, antimony, or bismuth with slight mutual substitutions.

The established species which appear to fall clearly into the Jamesonite Group are:

Dufrenoysite	$Pb_2As_2S_5$
Jamesonite	$Pb_2Sb_2S_5$
Cosalite	$Pb_2Bi_2S_5$

Minerals of less certain standing, which Dana includes as species in the Jamesonite Group, are:

Kobellite	$Pb_2(Bi, Sb)_2S_5$
Schapbachite	$PbAg_2Bi_2S_5$

Of the minerals of the Jamesonite Group only dufrenoysite and cosalite have been found in crystals sufficiently well developed to

establish their symmetry (orthorhombic) and geometrical elements. For jamesonite only the ratio $a:b$ has been determined. The available x-ray data on minerals of the Jamesonite Group are confined to cell dimensions of jamesonite derived from powder photographs and a rotation photograph about the needle axis, by Hiller (1938). Our experience shows that this procedure is likely to give untrustworthy results when applied to orthorhombic minerals with large cell dimensions.

MATERIAL

The material assembled for the present study consisted of the following specimens:

1. Cosalite (Royal Ontario Museum of Mineralogy, M/11147) from Mondoux claim, McElroy Township, Timiskaming district, Ontario. Slender needles described by Walker (1921) with analyses by Todd.

2. Cosalite (R.O.M.O.M., M/19544) from the Cariboo Gold Quartz Mine, Cariboo district, British Columbia. Slender needles. This occurrence is mentioned by Hansen (1935, p. 24) and described by Warren in this issue of the *Contributions to Canadian Mineralogy*.

3. Cosalite (R.O.M.O.M., M/19545) from the Island Mountain Mine, Cariboo district, British Columbia. Bent needles embedded in quartz. Also mentioned by Hansen (1935, p. 20).

4. Cosalite from Nordmark Mines, Värmland, Sweden. "Naturhistoriska Riksmuseum, Stockholm, yellow 4054." Slender columnar aggregate. Acquired in 1874 by A. E. Nordenskiöld. This is the mineral for which he proposed the name "bjelkite," identified with cosalite by Sjögren (1878).

5. Cosalite from Nordmark Mines, Värmland, Sweden. "Coll. Min. Hj. Sjögren, 129." Slender columnar aggregate and needles embedded in calcite.

For the use of the Canadian materials (1, 2, 3) preserved in the Royal Ontario Museum of Mineralogy I am indebted to the Director, Professor A. L. Parsons. Specimen 2 was recently received from Dr. H. V. Warren. The Swedish specimens (4, 5) were kindly supplied by Professor G. Aminoff in Stockholm at the request of Professor Parsons. I am also indebted to Professor M. A. Peacock for supervising the work and for many helpful suggestions, both in the course of the work and in the preparation of this paper.

STRUCTURAL CRYSTALLOGRAPHY

The most favourable material (specimen 1) was used for single crystal measurements leading to the structural lattice, space group,

and cell content. Observations on the remaining material were confined to x-ray powder photographs which were compared with the pattern of the fully studied specimen.

Due to the lead content of cosalite, all the photographs required long exposures for full development of the patterns with copper radiation: 1—9 KWH for rotations; 2—12 KWH for powder photographs filtered with nickel foil; 20—27 KWH or up to 5 days for Weissenberg photographs. Molybdenum and iron radiations were also tried but copper gave the best results.

Owing to the needle habit only one axis of adjustment was available. A sufficiently straight needle was difficult to obtain since the material is very flexible and usually deformed. The crystal finally selected for x-ray measurements was about 1.5 mm. long and not more than 0.05 mm. thick. On the reflecting goniometer a train of weak signals from the zone of the needle axis sufficed to orient the crystal. No terminal faces were seen on any of the specimens.

The rotation photographs showed widely spaced and closely occupied layer lines, indicating a relatively small lattice period in the needle axis and large transverse periods. With copper radiation the zero, first, and second layer lines appeared (Fig. 1); iron radiation gave only the zero and first layer lines.

Using both the α and β layer lines from two photographs with copper radiation and two with iron, twelve values for the period of the needle axis were obtained, giving:

$$c_0 = 4.047 \pm 0.01 \text{ Å}$$

The Weissenberg photographs (Figs. 2, 3) showed orthorhombic symmetry. The zero layer gave 24 orders of $h00$ and 30 orders of $0k0$, including the orders extinguished by the space group symmetry and the structure. The first layer Weissenberg showed a similar pattern. There are no systematic omissions in $hk0$ or $hk1$ and therefore the lattice is of the primitive mode (P). Deducting 0.1° from the ϑ values of the spots $h00$, $0k0$ to correct for the small crystal thickness the following lattice periods were obtained:

$$a_0 = 19.05 \pm 0.03 \text{ Å}; \qquad b_0 = 23.82 \pm 0.03 \text{ Å}$$

The systematically missing spectra conform to the conditions:

$0kl$ present only with k even
$h0l$ present only with $h+l$ even

and the special cases:

$h00$ present only with h even
$0k0$ present only with k even

These conditions are characteristic for the space groups:

$$D_{2h}^{16} = Pbnm \text{ or } C_{2v}^{9} = Pbn(2)$$

The structural lattice periods give the ratio:

$$a_0 : b_0 : c_0 = 0.800 : 1 : 0.170$$
$$p_0 : q_0 : r_0 = 0.212 : 0.170 : 1$$

The chosen orientation is the normal orthorhombic setting in which c_0 is the shortest and b_0 the longest edge of the rectangular lattice cell. As is usually the case, the shortest cell edge is the direction of morphological elongation. Jamesonite presents an extreme case of this common relation, the pronounced relative shortness of the vertical axis causing needle-like elongation in that direction.

The accepted geometrical elements of cosalite (Dana, 1892, p. 121) were derived by Flink (1886) from numerous measurements on terminated crystals from Nordmark, Sweden. In Flink's setting the needle axis was taken as b[010]. On the material used in the present study Walker retained Flink's orientation and noted thirteen forms in the needle zone, ten of them new, with measured angles in good agreement with the elements.

A correlation of the geometrical and structural crystallography gives the following reversible transformation:

Flink—Walker to Berry: $00\frac{1}{2}/100/0\frac{1}{2}0$
Berry to Flink—Walker: 010/006/200

Flink's elements transformed to the adopted setting, give:

$$a : b : c = 0.795 : 1 : 0.181$$

The ratio $a:b$, and consequently the angles in the main zone agree satisfactorily with the structural value, $a_0:b_0$; $c:b$, however, is only roughly similar to $c_0:b_0$. Table 1 shows the corresponding symbols of the forms noted on cosalite.

The structural setting (Berry) gives a natural series of symbols in the main zone [$hk0$]. For the terminal planes, however, the new symbols are no simpler than the old ones. This, coupled with the poor agreement in the ratio $c:b$, suggests that Flink's crystals may

not have corresponded in composition with the material from Nordmark analysed by Lundström (1874) and Sjögren (1878).

TABLE 1.—COSALITE: CORRELATION OF FORM SYMBOLS

Berry (1939)	Walker (1921)	Flink (1886)
100	001	*c* 001
010	100	*a* 100
001	—	*b* 010
160	301	—
140	201	—
130	302	—
380	403	—
250	504	—
120	—	*e* 101
230	304	—
340	203	—
110	102	—
430	308	—
320	103	—
210	104	*d* 104
032	—	*i* 140
301	—	*f* 011
332	—	*h* 142
3.12.2	—	*k* 221
632	—	*g* 144

COMPOSITION AND CELL CONTENT

The cell dimensions of the cosalite specimen 1, together with the

TABLE 2.—COSALITE, MCELROY TOWNSHIP, ONTARIO: ATOMIC CONTENT OF THE UNIT CELL

	1	2	3	4			5
Pb	38.68	0.3881	0.001871	14.07	16.47	31.78	16
Cu	2.02	0.0203	0.000319	2.40			
Bi	42.38	0.4252	0.002034	15.31			16
S	16.59	0.1664	0.005192	39.06			40
	99.67	1.0000					

1. Analysis by Todd (Walker, 1921). 2. Analysis reduced to the sum of unity. 3. Atomic proportions. 4. Numbers of atoms in the unit cell, obtained by multiplying the values under 3 by the molecular weight 7524. 5. Ideal cell content of cosalite.

specific gravity, $G=6.76$, measured by Todd (Walker, 1921), give the molecular weight of the cell content:

$$M = 7524$$

As shown in column 4 the cell content of the McElroy Township cosalite closely approaches $(Pb, Cu)_{16}Bi_{16}S_{40}=8[(Pb, Cu)_2Bi_2S_5]$. For a cell containing $Pb_{14}Cu_2Bi_{16}S_{40}$ the calculated specific gravity is 6.88, which is close to the measured value 6.76. For a cell with the ideal content $Pb_{16}Bi_{16}S_{40}$ the calculated specific gravity is 7.14.

TABLE 3.—COSALITE, NORDMARK, SWEDEN: ANALYSES REDUCED TO X+Y=32

	1		2		3	
	Anal.	Atoms	Anal.	Atoms	Anal.	Atoms
Pb	37.64		40.10		39.19	
Fe	5.13	32	0.67	32	1.32	32
Bi	39.40		41.55		41.86	
S	17.83	38.5	15.98	39.5	16.48	39.8
	100.00		100.49		98.85	

1. Containing some pyrrhotite; anal. Lundström (1874).
2. "Bjelkite," including 2.19 per cent insoluble; anal. Sjögren (1878).
3. "Bjelkite"; anal. Sjögren (1878).

In Table 3 the available analyses of Swedish cosalite("bjelkite") are given together with the atomic proportions reduced to X+Y=Pb+Fe+Bi=32, in accordance with the cell formula established above. In the case of the better analyses (2, 3) the values for S closely approach the ideal number 40. Even in analysis 1, representing impure material, the departure is not great.

X-RAY IDENTIFICATION OF CANADIAN AND SWEDISH COSALITES

An *x*-ray powder photograph of cosalite from McElroy Township gave the complex pattern in Fig. 4. Table 4 gives the uncorrected ϑ-values and the corresponding corrected lattice plane spacings (d), measured on two of the clearest films. The ϑ-values marked with an asterisk correspond to the more prominent powder lines.

TABLE 4.—COSALITE:
LATTICE PLANE SPACINGS FROM POWDER PHOTOGRAPHS

ϑ	d	ϑ	d	ϑ	d
10.15°	4.53 Å	23.0°	1.995 Å	37.8°	1.263 Å
11.4	4.02	23.4	1.962	38.1	1.254
12.1	3.78	*23.95	1.919	39.0	1.229
*13.0	3.52	25.0	1.841	41.95	1.156
*13.3	3.44	25.55	1.804	43.15	1.129
14.05	3.25	*26.7	1.731	54.05	0.952
14.6	3.13	27.45	1.686	56.2	0.927
*15.1	3.02	29.2	1.592	58.05	0.908
*16.05	2.84	32.15	1.457	60.85	0.881
18.1	2.52	33.0	1.423	63.1	0.863
19.8	2.31	*33.85	1.392	65.15	0.849
20.15	2.27	35.0	1.351	66.75	0.837
*21.15	2.17	35.6	1.330	69.95	0.818
*22.3	2.06	36.9	1.289	74.6	0.797

The spacings are corrected for thickness of sample by subtracting 0.4° from each ϑ-value, and deducting 0.25 per cent from each spacing. This procedure gave good values in calibration photographs on pure tungsten powder samples of similar thickness.

Figs. 5, 6, 7, 8 are powder photographs of the specimens numbered 2, 3, 4, 5, respectively, under the list of materials studied. From the complete correspondence of the powder lines from these materials and from the type material (Fig. 4), it is evident that the Swedish and Canadian minerals are structurally identical.

SUMMARY

Cosalite from McElroy Township, Timiskaming district, Ontario, for which a reliable analysis and density measurement were available, is orthorhombic; space group: $D_{2h}^{16}=Pbnm$ or $C_{2v}^{9}=Pbn(2)$. Cell edges: $a_0=19.05\pm0.03$, $b_0=23.82\pm0.03$, $c_0=4.047\pm0.01$ Å. The unit cell contains $8[(Pb,Cu)_2Bi_2S_5]$. Cosalite from the Cariboo Gold Quartz Mine, and the Island Mountain Mine, Cariboo district, British Columbia, and from Nordmark, Sweden, give powder photographs identical with that of the Ontario material.

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EXPLANATION OF FIGURES

X-ray photographs with copper radiation. Diameter of cameras = 57.26 mm. Figs. 1, 2, 3, unfiltered; Figs. 4, 5, 6, 7, 8, filtered with nickel foil.

FIG. 1.—Cosalite, Mondoux claim, McElroy Township, Timiskaming district, Ontario. Rotation about the needle axis [001], showing the zero, first, and second layer lines; 2 KWH.

FIG. 2.—The same. Zero layer Weissenberg photograph, showing $K\alpha_1$, $K\alpha_2$, $K\beta$ spots and also diffractions from a small sub-parallel individual; 21.8 KWH.

FIG. 3.—The same. First layer Weissenberg photograph, showing only $K\alpha_1$, $K\alpha_2$ diffractions; 26.9 KWH.

FIG. 4.—The same. Powder photograph; 1.9 KWH.

FIG. 5.—Cosalite from the Cariboo Gold Quartz Mine, Cariboo district, British Columbia. Powder photograph; 11.4 KWH.

FIG. 6.—Cosalite from the Island Mountain Mine, Cariboo district, British Columbia. Powder photograph; 12.5 KWH.

FIG. 7.—Cosalite from Nordmark Mines, Värmland, Sweden (Nordenskiöld's "bjelkite"). Powder photograph; 11.9 KWH.

FIG. 8.—Cosalite from Nordmark Mines, Värmland, Sweden (Sjögren's collection). Powder photograph; 7.0 KWH.

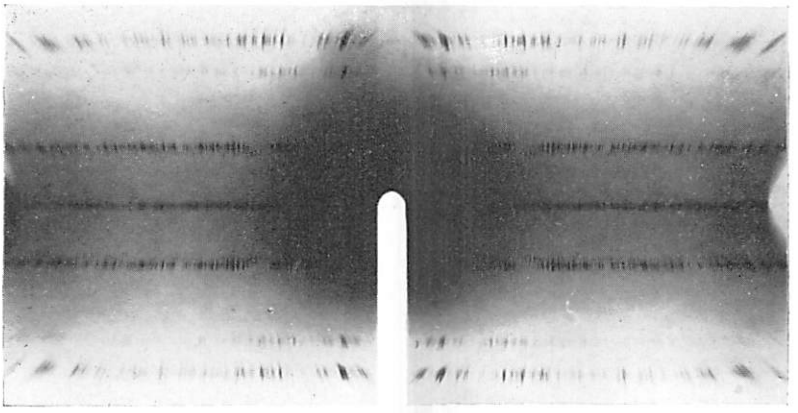


FIG. 1

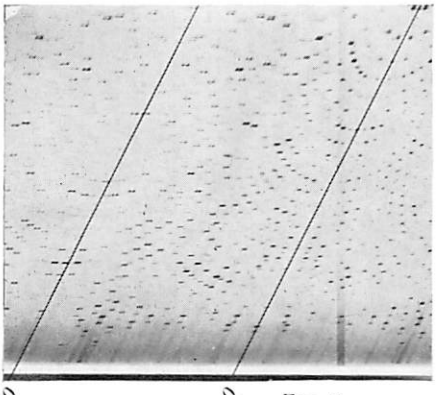


FIG. 2

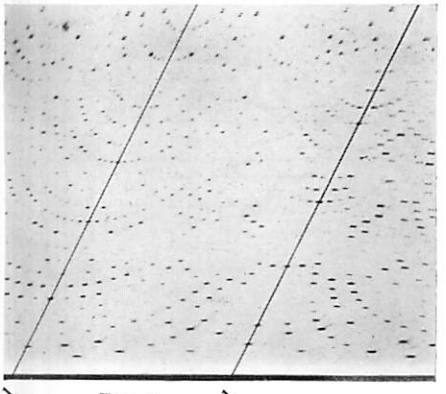


FIG. 3

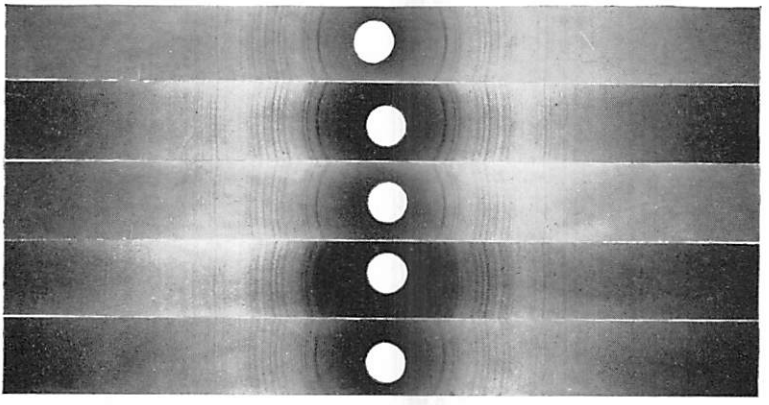


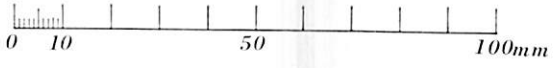
FIG. 4

FIG. 5

FIG. 6

FIG. 7

FIG. 8



TRANSPARENT GREEN PYROAURITE FROM ONTARIO

By H. V. ELLSWORTH
Geological Survey of Canada

Some time ago the writer examined samples of crystalline Precambrian dolomite collected by M. F. Goudge (1938) of this department from on or about lot 27, concession X, Calvin Township, three and a half miles east of Rutherglen.

Certain specimens of the dolomite were found to carry considerable quantities of brucite, others much magnetite, while still others carried numerous small, green, transparent, mica-like crystals that were found to have the optical properties and qualitative chemical composition of the rare mineral pyroaurite, though according to text-book descriptions of this mineral (Dana, Hintze, Larsen, Winchell, etc.), it is yellowish, yellow-brown, gold-like, sub-metallic, translucent, etc. Subsequent quantitative analyses have proved that the Ontario mineral is chemically pyroaurite, agreeing closely in composition with the material from Långsbanshytte, Sweden, described by Flink (1910, p. 107) and analysed by Mauzelius. In regard to the colour of the Långsbanshytte mineral, Flink states that the colour is light yellowish grey, sometimes almost pure white, most often earth-brown and *sometimes greenish*. Unfortunately, this statement as to the occurrence of greenish pyroaurite has not been reprinted in any of the recognized text-book descriptions of the mineral, though it seems likely that the greenish variety represents the mineral in its pure, unaltered state, the cloudy yellowish or brownish varieties being doubtless somewhat altered, probably more or less dehydrated forms of the originally transparent and almost colourless or slightly greenish mineral.

The Ontario mineral occurs as small barrel-shaped hexagonal crystals attached to the walls of tiny cavities in the dolomite or completely enclosed in it. As noted by Flink, the crystals often show step-like faces and taper towards the ends like phlogopite or corundum crystals. The crystals rarely exceed one millimetre in greatest diameter. They usually include minute crystals or grains of magnetite near the attached side or sides, and some are slightly altered on the outer surface. The pyroaurite crystals have been

found so far only at a depth of several feet below the surface outcrop. They have been entirely dissolved out of the upper part of the exposure leaving the dolomite rusty and porous at the surface, with an occasional cavity showing fragmentary residual limonitic pseudomorphs.

The crystals have very perfect basal cleavage, the laminae being flexible but not elastic. They are uniaxial negative with $\omega = 1.560$, and $\epsilon = 1.543$ both ± 0.003. ϵ was obtained as closely as possible on thin sections cut across the cleavage with a specially sharpened knife-blade under the binocular microscope, though it was not possible to obtain perfectly normal sections, and ϵ may be slightly lower than the figure given. Pleochroism strong; ω yellow to brown, ϵ nearly colourless. The mineral is a pale bottle or window-glass green and as transparent as glass. Thin cleavages are colourless under the microscope. On heating it becomes opaque and gold-coloured with a soft, velvety, almost metallic lustre much like etched gold, and very like the scales of gold-coloured, weathered biotite that are so common in sands and rock residues of Precambrian origin, and so often mistaken for gold by amateur prospectors. Pyroaurite has been very well named and the name is particularly apt for the Ontario mineral because of the complete change in appearance on heating. It further resembles mica in that upon heating the laminae separate and puff out accordion fashion to a certain degree, as do those of many micas. The mineral is more or less magnetic after heating, depending on the nature of the heat treatment. The behaviour on heating is so characteristic as to be almost sufficient alone to identify this mineral and distinguish it from all others, except possibly the variety brugnatellite.

Pyroaurite, of course, is readily soluble in mineral acids with visible effervescence and evolution of carbon dioxide. After ignition, it is still quite readily soluble in hydrochloric acid, less so in others.

PREPARATION OF ANALYTICAL SAMPLE

The small size of the crystals and the fact that they generally carry minute grains of magnetite made it very difficult to obtain pure material for analysis. The first sample (1) analysed consisted of crystals and cleavage fragments individually selected for purity

under the binocular microscope, and untreated chemically in any way. This sample still contained a small amount of magnetite, and the outer surface of the crystals in some cases was somewhat altered. In efforts to obtain a pure sample, it was found that by giving the pyroaurite material a short treatment with dilute hydrochloric acid, the magnetite grains became so loosened as to drop out readily, and all traces of alteration were dissolved from the outer surfaces. After much tedious work picking out grains under the binocular microscope, a sample of 0.35 gm. was finally obtained which was reduced by subsequent acid treatment and rejection of doubtful grains to 0.25 gm. of material in which no trace of impurities whatever could be seen under the microscope. This sample (2) after having been thoroughly washed in water, alcohol, and ether was dried at 100°C. and then allowed to stand in air at room temperature for a few days, and weighed for analysis in the air-dry condition, without grinding or further treatment.

ANALYTICAL METHODS AND RESULTS

The small samples available made it necessary to work on the semi-micro scale. The water, acid, and ammonia used were freshly redistilled as required. The apparatus was mostly fused silica and platinum with some pyrex. Weighings were made to 0.01 mg. or better on a micro balance using a similar platinum crucible as a counterpoise. The usual macro methods were applied with apparatus reduced to appropriate size. In each analysis, the main determinations of Fe, Mg, loss on ignition, were made on 100 mg., total H_2O on 20 to 40 mg. by direct weighing in a micro-Penfield tube. Loss on ignition was determined by heating a 100 mg. sample in a small platinum crucible of 4 c.c. capacity. Carbon dioxide was not determined directly but is calculated as the difference between loss on ignition and total H_2O. Owing to the simplicity of the operations, the special care taken in every way throughout the analysis, and as also indicated by the good agreement of the two determinations on the pure sample, the results are believed to be probably as accurate as the usual macro analysis made without similar precautions as to purity of reagents.

The analyses gave the following results:

TABLE 1.—PYROAURITE: SAMPLE 1

	Analysis		Less 0.41 per cent magnetite
Fe_2O_3 (total Fe)	23.24		23.33
FeO	(0.8)		——
Al_2O_3	None		——
MgO	35.50		35.64
CaO	None		——
MnO	0.01		0.01
H_2O at 110°	1.03	H_2O-	1.03
H_2O (total)	33.77	H_2O+	32.74
Ignition loss	41.11		——
CO_2 (Ign.—H_2O)	7.34		7.34
Magnetite	0.41	Total	100.09

In the above analysis H_2O at 110° and loss on ignition were first determined on a 100 mg. sample. The ignited material was then treated with HNO_3 in the hope of dissolving the pyroaurite with minimum attack on the magnetite. The magnetite residue was 0.41 per cent. Total Fe, Ca, Mg, Mn of the pyroaurite were determined on the resulting solution. Total H_2O was determined on a separate 20 mg. sample free from magnetite.

TABLE 2.—PYROAURITE: SAMPLE 2

	A	B
Fe_2O_3 (total Fe)	23.37	23.30
FeO	(0.2)	——
MgO	35.84	35.84
CaO	None	None
MnO	0.01	0.01
H_2O at 110°	(0.69)	——
H_2O (total)	33.66	——
Ignition loss	(40.96)	——
CO_2 (Ign.—H_2O)	7.30	——
	100.18	

In the above determinations H_2O at 110° and loss on ignition were determined on a 100 mg. sample (A) as before. This was then dissolved in HCl and total Fe, Mg, and Mn determined in the solution. Total H_2O was determined on a separate 40 mg. sample. Sample B of 100 mg. was dissolved directly in HCl without ignition; evaporated to dryness in a test for silica none was found. Total Fe, Mg, and Mn were determined as before in this solution. In all cases a little silica was found in the Fe_2O_3 after ignition, e.g. 0.17 mg. in sample B, the excess of which over SiO_2 of filter ash is assumed to have come from reagents or apparatus and has been deducted from the iron found. Filter ash was actually determined, found to be approximately three times the amount stated on the label, and also deducted from the weighed precipitates. FeO was found by dissolving duplicate 10 to 12 mg. samples in dilute H_2SO_4 in an atmosphere of CO_2 and titrating with N/100 permanganate from a micro burette. Although sample 1 certainly contained traces of magnetite, it does not seem possible that enough dissolved to cause the high result relative to that of sample 2. Possibly the drying of sample 2 at 100° resulted in oxidizing some of the ferrous iron. That some ferrous iron is really present was proved by the ferricyanide test on grains absolutely free from visible magnetite or other impurity. The presence of even this very small amount of ferrous iron along with the green colour suggests that at some time in its life-history the mineral may have contained more FeO than at present and that the present mineral may be relatively oxidized in respect to its original composition. Green ferric salts are rare; in looking through Dana the writer noticed only two, coquimbite and ferronatrite, that are said to be sometimes greenish. One would certainly expect this Ontario pyroaurite with 23 per cent Fe_2O_3 to be yellowish rather than green.

A spectrogram of sample 2 made by G. R. Giles on the large Hilger quartz spectrograph showed no Al, Cr, Sr, or Si, a trace of Mn, and a very faint trace of Ca. No precipitate of calcium oxalate could be detected in any of the analyses.

COMPOSITION AND FORMULA

Only the results on sample 2 are considered here as sample 1 contained a little magnetite. The results on sample 1 when recalculated agree closely with those on sample 2. A check of the actual weights of substances obtained in analysis 2A gives an idea of the accuracy to be expected, as follows:

Sample taken, 0.10017 g.

Ignition loss	0.04103 g.
Fe_2O_3	0.02341
MgO	0.03591
MnO	0.00001
	0.10036
Taken	0.10017
Difference	0.00019

Molecular ratios of the writer's analysis 2A, of Mauzelius' analysis on Långbanshytte material, and of analysis No. 3 by Černych (Kurnakov and Černych, 1927, p. 315) on pyroaurite from the Bashenowo, Ural, asbestos mine, are shown below for comparison.

TABLE 3.—PYROAURITE: ANALYSES AND MOLECULAR RATIOS

	Ontario 2A		Långbanshytte		Ural	
	Per cent	Mol. ratio	Per cent	Mol. ratio	Per cent	Mol. ratio
Fe_2O_3	23.37	0.1464	23.20	0.1453	23.49	0.1471
FeO	(0.2)	—	—	—	—	—
MnO	0.01	—	0.21	0.0030	—	—
MgO	35.84	0.8888	35.08	0.8700	34.50	0.8556
CaO	None	—	0.54	0.0096	—	—
$H_2O+110°$	32.97	1.8317	33.53	1.8628	33.92	1.8844
$H_2O-110°$	0.69	—	0.16	—		
SiO_2	—	—	0.29	—	—	—
CO_2	7.30	0.1659	6.91	0.1570	7.87	0.1788
	100.18		99.92		99.78	

TABLE 4.—PYROAURITE: MOLECULAR RATIOS AND FORMULAS

Ontario	Långbanshytte	Ural
Fe_2O_3. 0.1464 ÷ 1 =0.1464	0.1453 ÷ 1 =0.1483	0.1471 ÷ 1 =0.1471
MnO . —— ——	0.0030	
MgO . 0.8888 ÷ 6 =0.1481	0.8700 ÷ 6 =0.1466	0.8556 ÷ 6 =0.1426
CaO.. —— ——	0.0096	
H_2O+ 110° 1.8317 ÷12 =0.1526, ÷12.5=0.1465	1.8628 ÷12 =0.1522, ÷12.5=0.1490	1.8844 ÷12 =0.1570, ÷13 =0.1499
CO_2.. 0.1659 ÷ 1 =0.1659	0.1570 ÷ 1 =0.1570	0.1788 ÷ 1=0.1788

The ratios of all three analyses lead to $Fe_2O_3.6MgO.CO_2+12$, 12.5, or 13 H_2O as the simplest formula. The indicated H_2O content in the case of the Ontario and Långbanshytte minerals is very close to 12.5 molecules and, so far as the writer's analysis is concerned, considering that the determination of total loss of H_2O and CO_2 is probably quite precise even on the micro scale, but that there may be greater errors in dividing this loss into hygroscopic water, water of constitution and CO_2, the true combined H_2O content, as a matter of fact, is as likely to be 13 molecules as 12 if it is not 12.5. No published information is available as to how CO_2 was determined in the analyses by Mauzelius and Černych, but it is quite likely that the same procedure was used due to scarcity of material, and in any case their results show a similar tendency to high H_2O and CO_2. Any error in H_2O determination by the Penfield tube method is in the direction of low results, and any water so lost is calculated as CO_2. Thus all three analyses seem to indicate a water content of at least 12.5 molecules with a fair probability of 13 molecules. The formula with 12 molecules of H_2O commonly assigned to pyroaurite was apparently first proposed by Foshag (1921) in his study of the hydrotalcite group. He derived this result mainly from Mauzelius' analysis and also by analogy with other members of the group, i.e. hydrotalcite and stichtite. However, all the analyses cited, including those of hydrotalcite and stichtite, also

show excesses of H_2O and CO_2 over the 12 molecule formula and there seems little doubt that the formula should be written with 12.5 or 13 molecules of water.

Foshag also seems to have been the first to suggest that the CO_2 which had previously been regarded as due to impurities is an essential constituent and he proposed the formula

$$MgCO_3.5Mg(OH)_2.2Fe(OH)_3.4H_2O$$

This fits the quantitative data quite well except in regard to H_2O and CO_2 as just noted, but does not necessarily represent the actual constitution of the green mineral which may be very complex. It is difficult to understand how a mineral with such a high content of ferric hydroxide can have a pale green colour. However, Friend (1921, p. 125) states that "Ferric hydroxide can be obtained as a white precipitate on adding a freshly prepared and concentrated solution of a ferric salt to cooled ammonium hydroxide solution, but it rapidly becomes brown, due, it has been suggested, to molecular condensation or aggregation." It may be, therefore, that the ferric hydroxide is present in the uncondensed state in this mineral. Pure triferrion itself, of course, is almost colourless, but still slightly yellowish as shown by a strong nitric acid solution.

Not only is the green colour of this ferric mineral anomalous but the close association of magnesium with trivalent iron seems unnatural, whereas salts of diferrion and magnesium are very similar and in many cases isomorphous, and ferrous compounds have normally a greenish colour. For these reasons one cannot help but wonder whether the mineral may not be a ferric pseudomorph after an originally ferrous compound, which has in some way retained the colour of the original mineral. Meixner (1937, p. 370) mentions a white "Eisenbrucite" analysed by Kurnakov and Černych (1927, pp. 313-315) which contained 16.07 per cent FeO and 3.59 per cent Fe_2O_3 and which Meixner considers as ferropyroaurite—

$$MgCO_3.2Fe(OH)_2.5Mg(OH)_2.4H_2O$$

As previously mentioned, analyses of the Ontario pyroaurite indicate the presence of less than one per cent of FeO, but as magnetite is so intimately associated and may have been present in a highly dispersed form as traces in the material analysed, it is not absolutely certain that the FeO found can be considered as belonging to the

pyroaurite though that appears to be the case. This is a point that can be investigated further only when more material is obtained. It is interesting to note, however, that Foshag (1921) mentions that a FeO determination was made at the United States National Museum on pyroaurite from Langban, and 0.74 per cent was found, an amount of the same order as found in the Ontario mineral.

DEHYDRATION

A carefully prepared lot of the Ontario pyroaurite corresponding in purity to that analysed as sample 2 was used for dehydration tests. Because of the difficulty and tediousness of selecting individually pure flakes under the binocular microscope, this experiment was also conducted on the micro scale with 43.75 mg. of the flakes contained in a 4 c.c. platinum crucible. The mineral was not ground to powder but merely split up into as thin cleavages as possible because it was thought that grinding might alter the natural water content and, further, it had been found earlier that the mineral when ground stuck so firmly to the agate mortar and pestle as to be scarcely removable. The mineral contained in the small platinum crucible was heated at atmospheric pressure in an electric oven to temperatures from 105° to 300°C. over a period of 153 days, with weighings as a rule every 24 hours. Weight was lost very slowly and though the original intention had been to heat at each 10 degree increase in temperature until the weight became constant, it was found that this would require a very long time, and it was not strictly carried out over the whole range. Thus, as Mellor quotes figures (Johnston, 1908, p. 1363) for the vapour pressure of magnesium hydrate of 760 mm. at 160° approximately, the temperature was raised relatively quickly (6 days) to 150° where it was held until there was no further loss. Almost exactly 5 mols. H_2O was lost up to and at 150°, i.e. total 5.33 less 0.26 at 105° for hygroscopic H_2O, leaving 5.07 mols. for lost H_2O of constitution. From 150° upward heating was continued at each 10° increase up to 220° until the loss was 0.02 mg. or less per 24 hours. The heating at 220° was continued until the rate was reduced to 0.09 mg. per 24 hours and at 230° and succeeding 10° intervals up to 250° to a rate of 0.02 mg. or less per 24 hours. The mineral was kept at 270° until the rate of loss was less than 0.01 mg. per 24 hours. At this point all the

water and some CO_2 had been lost and the rate of loss (of CO_2) up to 300° was very small, less than 0.002 mg. per 24 hours average.

The net result of this experiment as shown by the curve (Fig. 1) seems to indicate a grouping of the H_2O as follows: 5, 2, 5 (or 5.5. or 6) molecules at about 150°, 220°, and 270° respectively. Johnston (1908) also gives the dissociation point of magnesium carbonate at atmospheric pressure as 230°(?).

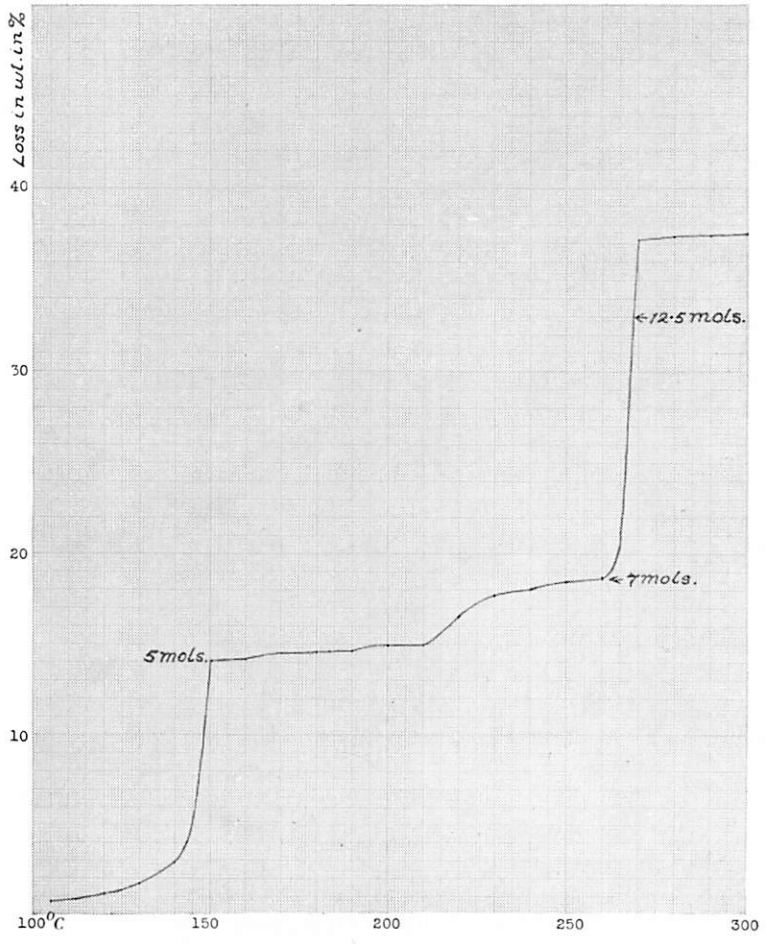


FIG. 1.—Pyroaurite: dehydration curve.

Kurnakov and Černych (1928, pp. 357-361) have made studies of the thermal decomposition of pyroaurite by means of an automatic registering apparatus.

APPEARANCE AND PROPERTIES OF DEHYDRATED PYROAURITE

As dehydration proceeded, the pyroaurite was examined from time to time under the binocular microscope, as tabulated below:

Percentage loss	Max. temp.	Time	Properties
2.40	140°	5 days	Pale yellowish, transparent
5.37	150°	10 days	Strong yellow, transparent
12.77	150°	22 days	Deep red brown, transparent

From this point onward to the end of the experiment, after heating for 153 days and up to 300°, the only change was a very gradual deepening of the rich brownish red colour. The final product after a loss of 37.44 per cent was examined as fine powder in oils under the microscope. It was a strong yellow to brownish-red colour depending on the thickness, and perfectly transparent under high power without any sign of cloudiness or any separated product. Most surprising, it was still uniaxial, cleavage flakes giving faint, blurred, uniaxial or very slightly biaxial figures the sign of which was indeterminable while grains normal to the cleavage showed parallel extinction. The index of refraction, of course, had greatly increased and was for ω greater than 1.745. Shrinkage was evident in the form of fine cracks which were most marked on the outside of original flakes before they were broken up. On igniting this product for several minutes at a bright red heat no further change occurred except that it perhaps became slightly darker in colour, when viewed in oil under the microscope, i.e. it was impossible to produce the characteristic gold-like appearance resulting from quick ignition. On examining some of the gold-like product in oil under the microscope by transmitted light, it was indistinguishable from the slowly dehydrated material. The shimmering gold-like appearance in reflected light evidently is caused merely by the separation and distortion of the cleavage flakes due to rapid evolution of steam during quick heating, by which air gets in between the cleavages. In the case of the slowly dehydrated product the loss of H_2O was so slow and gradual that the cleavages were not loosened up, the

material remained solid, and no golden effect was produced. It consists simply of dark brownish-red flakes.

The phenomenon of the dehydrated pyroaurite retaining its original crystal structure seems remarkable in view of the great change in composition, and the fact that periclase is isometric.

LOCALITIES AND ASSOCIATIONS

The Ontario pyroaurite is the first to be found outside of Europe. It occurs in Precambrian dolomite of the geological formation commonly known as the Grenville Limestone. An analysis of fragments of the dolomitic matrix of the pyroaurite carefully picked under the binocular microscope for freedom from visible impurities, but nevertheless not absolutely pure, yielded the writer the following results:

	Per cent
SiO_2	0.22
$(Fe, Al)_2O_3$	0.54
CaO	30.38
MgO	21.65
MnO	0.55

This represents nearly a theoretical dolomite with some impurities.

Some associated bands of the dolomite carry considerable quantities of iron-bearing brucite, which may be more or less altered to hydromagnesite, others carry much magnetite, still others contain serpentinous material.

The related mineral brugnatellite, identified by optical properties, was mentioned by E. Poitevin of this Department in a doctorate thesis submitted to the University of Montreal, as occurring in the form of minute brownish flakes associated with brucite in joint planes of the serpentine, at the Vimy Ridge and Consolidated Asbestos Mines, Megantic County, Province of Quebec.

Meixner (1937, pp. 369-371) summarizes the nine known European occurrences and associations of pyroaurite. The mineral there occurs variously in serpentine, dolomite, serpentinous limestone, and chromite.

The writer is much indebted to Mr. H. A. Leverin of this Department for translating Flink's paper on the Långban pyroaurite.

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THE STOCK OF "SUZORITE" IN SUZOR TOWNSHIP QUEBEC

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A quite unusual intrusive rock has been discovered by the writer when he was doing geological exploration work for the Quebec Bureau of Mines during the summer of 1936 (Faessler, 1937). For the reasons explained below this rock is termed "suzorite."

LOCALITY

The outcrop of "suzorite" lies in the region of Little Pichui River, in the Grenville area of the Township of Suzor, Laviolette County, Province of Quebec. It is best reached from the Quebec-Cochrane railway line, by leaving the railway track at milepost 106, one and three-quarter miles west of McCarthy station, which is 238.6 miles from Quebec City. From this point a two and one-half mile portage leads northwards to Lake Croche (Islands Lake, Lac des Iles) and after crossing this lake to its north-easternmost bay, a one-mile traverse brings one to Lake Lebrun (Second Dam Lake, Lac de la Deuxième Ecluse) on the Little Pichui River. The outcrop described here lies about 3,000 feet west of Lake Lebrun and about 3,000 feet north of the above bay of Lake Croche.

DESCRIPTION OF THE OUTCROP

The outcrop of "suzorite" constitutes a single mass forming a part of a ridge which rises about 200 feet above the level of Lake Lebrun. The ridge runs in a NE-SW direction. The outcrop of "suzorite" has an elliptical form in ground plan, the ellipse lying across the ridge. The diameters of the ellipse are 200 feet in the NE-SW direction and 1,100 feet in the NW-SE direction. The area covered by the outcrop is therefore somewhat over two acres. The outcrop, on both short sides of the ellipse, forms the vertical cliffs of the ridge; along the long sides of the ellipse the outcrop does not show any important topographic feature.

The contours of the outcrop are sharply defined as the surround-

ing rock is made up of superposed bands of paragneiss and granitic gneiss, so characteristic of Grenville areas, and the massive "suzorite" crosses straight through these bands. The real contact, however, could not be observed, for whenever attempts were made to find it, there was found a zone, about two feet wide, of highly altered and loosened rock material originating from both the country rock and the intrusion.

The mass seems to be a part of a volcanic vent. No other similar outcrop has been observed in this region.

DESCRIPTION OF THE "SUZORITE"

The "suzorite" from Suzor is a very massive rock showing not the slightest banding or foliation. It is dark brown in colour, very soft, coarse grained, and has very little mechanical strength. Its apparent specific gravity is about 2.9.

The most striking feature is its high content of dark brown mica which constitutes more than half of the rock. The mica is found in laminae up to 7 mm. across and in smaller flakes all of them in unoriented arrangement. Other megascopical constituents are red feldspar, which gives the rock a somewhat spotted appearance, greenish pyroxene, and a colourless mineral which, by microscopical and chemical tests, proves to be apatite.

Five thin sections were studied. In one of them biotite constitutes about 80 per cent of the slide; the others show about 60 per cent biotite. Feldspar coming next in quantity constitutes about 13 per cent. Augite makes up 11 per cent, apatite 10 per cent, and the remainder is formed of small quantities of calcite and a few grains of titanite, quartz, plagioclase, magnetite, and pyrite.

The *biotite* is found in flakes up to 6 mm. in length; it is highly pleochroic, the maximum absorption colour being deep brown; it is uniaxial.

The *feldspar*, in grains up to 4 mm. across, is mostly orthoclase, containing some decomposition products along cleavage traces. Innumerable minute needles of an undetermined mineral form inclusions in the feldspar which have parallel extinction and are length-slow. (Sillimanite?)

Some very small grains of plagioclase also are present; they have the optical properties of andesine.

The *pyroxene*. The large crystals of augite measure up to $3 \times 1\frac{1}{2}$ mm. They are greenish in colour and often include some brown biotite along their cleavage traces.

The *apatite* is found in colourless crystals up to 3 mm. in length, often wedge-shaped, filling the interstices between differently oriented tablets of mica.

Order of crystallization: biotite and augite seem to have crystallized simultaneously; they were followed by apatite and feldspar.

CHEMICAL ANALYSES OF "SUZORITE"[1]

Two chemical analyses were made on two different samples; No. 1 in the following table was taken at the centre of the intrusion, No. 2 near its border.

TABLE 1.—"SUZORITE": ANALYSES

	1	2
SiO_2	39.94	42.44
Al_2O_3	11.20	9.80
Fe_2O_3	1.46	1.09
FeO	3.92	4.53
MgO	10.62	11.80
CaO	12.25	9.68
Na_2O	1.31	1.03
K_2O	6.28	6.65
H_2O	—	0.18
H_2O	1.82	2.40
TiO_2	2.82	3.74
CO_2	1.91	1.41
P_2O_5	5.57	3.81
S	0.28	0.14
SO_3	0.45	0.35
Cl	—	0.16
F	—	0.02
Cr_2O_3	—	0.06
MnO	0.13	0.07
	99.96	99.36

[1]The chemical analyses were made in the Provincial Chemical Laboratories under the direction of Mr. M. Archambault. I am also indebted to Mr. R. Loranger of the same laboratories for the elaborate calculations of the norm.

CALCULATION OF THE NORM AND CLASSIFICATION

A study of the results of the chemical analyses shows that in spite of the rarity of quartz there is enough silica to neutralize the alumina, the soda, the potash, and a part of the lime; the remainder of the lime is fixed in non-feldspathic minerals. Therefore, "suzorite" has to be considered as a feldspathic rock of the calco-magnesian type with no feldspathoids.

TABLE 2.—"SUZORITE": NORMS

Normative minerals			1	2
or			34.75	39.31
ab			—	1.89
an			7.65	4.28
lc			1.88	—
ne			4.40	1.82
di			7.22	9.66
ol			16.98	18.29
mt			2.11	1.58
cm			—	0.07
il			5.37	7.11
ap			11.84	8.31
fr			—	0.04
pr			0.53	0.25
cc			4.34	3.20
hl			—	0.26
th			0.80	0.62
H_2O, etc.			1.89	2.46
Total			99.76	99.15
Classif.	Class	p	III	III
according	Order	q	6	5
to	Rang	r	2	1
C.I.P.W.	Subrang	s	2	1

COMPARISON WITH OTHER ROCKS

"Suzorite" with its high content in dark minerals resembles at a glance the ultrabasic rocks of the perknite group, that means peridotites with little or no olivine. Perknites with predominating

biotite are termed "glimmerites" by Larsen and Pardee (1929, pp. 101, 102, 104) or "biotitites" by Washington (1927, pp. 187-189), but the microscopic study reveals too high a content in alkaline feldspar which places the practically quartz-free "suzorite" in the syenite group.

Syenites rich in mafic minerals are termed "melasyenites" by Pirsson (1900, pp. 479-488), but according to Johannsen (1931-1938; melasyenite, vol. 3, p. 64; glimmerite, vol. 4, p. 441; durbachite, vol. 3, p. 86) melasyenites contain olivine.

A mica rich syenite ("Glimmersyenit") has been described by Sauer (1891) and named "Durbachit," but according to the norm calculated for "suzorite" (see Table 2) it could hardly be considered as a durbachite.

The norm calculated for "suzorite" gives the rock the average composition III, 5, 2, 2, according to the CIPW-system of classification (Cross, Iddings, Pirrson, and Washington, 1904). There is no rock described in the available literature corresponding exactly to such a formula. "Suzorite" by its deficiency in silica resembles somewhat the rocks of the shonkinite family, but the complete absence of feldspathoids brings it nearer to the alkaline syenites where it occupies an intermediate position between the plutonic and the lamprophyric facies.

The high content in apatite and calcite indicates perhaps a rather hybrid rock; both minerals may be introduced into the magma by adsorption of portions of the sedimentary wall rock.

To this rock which, both in norm and mode, occupies a position which heretofore has been unrepresented in any petrographic classification the name "suzorite" is given from the locality where it was first found.

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THE ASSOCIATION OF GOLD, TUNGSTEN, AND TIN AT OUTPOST ISLANDS, GREAT SLAVE LAKE

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INTRODUCTION

Of the many gold deposits throughout Canada one of the most interesting and difficult of interpretation from a mineralogic point of view is that at Outpost Islands in Great Slave Lake, N.W.T. There, minerals of tungsten, tin, copper, and molybdenum are associated with the precious metal in mineralized zones in which also are found quartz-mica lenses of pegmatitic aspect, containing staurolite and andalusite, the latter enclosing grains of blue corundum. The geology and many of the minerals of this deposit were described in this journal by Ellsworth and Jolliffe (1937). An examination of the property by the writer in 1936 permitted further field study, both on surface and underground, and the collection of specimens, which have since been investigated by Lazier (1938) under the writer's direction, in an endeavour to establish the genetic significance of the minerals. Additional specimens collected by Dr. Jolliffe were kindly placed at the writer's disposal by the Bureau of Economic Geology, Department of Mines and Resources, Ottawa, Canada.

The results herein reported can in no sense be considered as complete, and further field and laboratory studies are required before any final conclusion as to origin of the deposit is reached.

The map sheet of the eastern portion of Great Slave Lake, west half, No. 377a (Canada, Department of Mines) with geology by C. S. Stockwell (1936) shows the location and geologic setting of Outpost Islands, originally known as Isles du Large. The principal gold deposit is located on one of the smallest in the northernmost row of islands.

GENERAL CHARACTER OF DEPOSIT

The gold-bearing deposit which has been explored by underground workings is the only one of many mineralized zones found

to contain at all consistent and appreciable values in gold. The mineralized zones are in the nature of shears arranged *en echelon*, trending slightly north of east and dipping nearly vertically or steeply south. They occur in a series of micaceous quartzites or quartz-mica schists, which, in places, still exhibit well-preserved cross-bedding. Interbedded with these are minor conglomerates, purer quartzites, and stratigraphically above them, argillaceous beds, conglomerates with pebbles in an argillaceous matrix partially recrystallized to andalusite and staurolite, and more massive quartzites. The whole series strikes north of east and at the mine workings, dips steeply south at 70°-80°. The sediments have been correlated with the early Precambrian, Wilson Island sedimentary series of Great Slave Lake (Ellsworth and Jolliffe, 1937, p. 75).

Small, altered, hornblendic dykes, striking northerly, transect the sediments and at the eastern end of the islands one of these is cut by a narrow feldspathic pegmatite. Other possible intrusives consist of numerous lenticular bodies of white glassy quartz carrying chiefly biotite, muscovite, and specular hematite, and more rarely, coarsely crystalline andalusite. Some of these run parallel to, and others cut across, the bedding of the micaceous quartzite. In underground workings, particularly on the 123 foot level, several such bodies occur *en echelon*, are cut by the shear fractures, and are also mineralized. The nearest other intrusive is found on Butte Island, four miles to the north, where granite or related rocks are mapped by Stockwell.

The shear zones which may be traced intermittently across the islands from north-east to south-west are distinctly discontinuous. They are nowhere marked by intense schistosity and the shearing appears to have been distributed along several parallel planes, spaced closely over widths up to 20 feet, or to have given rise to a few fractures only, where the zone enters either more competent conglomeratic layers or quartzose bodies.

Mineralization of the shear zones is most marked where they occur in the micaceous quartzites and, as a whole, consists chiefly of the introduction of chalcopyrite, the weathering of which has given rise to a thin veneer of limonite. Other minerals found associated are ferberite, magnetite, specular hematite, probably ilmenite, pyrite, marcasite (of massive variety), bornite, chalcocite, covellite,

chlorite, sericite, and gold. Very minute quartz stringers, paralleling the schistosity, appear to accompany the mineralization and are noticeable underground where some of them resemble the purer interbedded quartzites in sugary texture and greenish cast. An unknown tin mineral, possibly cassiterite, is also present. Molybdenite is reported by Ellsworth and Jolliffe (1937, p. 71), and powellite, with disseminated limonite, appears in thin sections as a secondary mineral replacing blades of ferberite.

STATEMENT OF PROBLEMS

The more outstanding problems of a purely mineralogic and geologic character connected with these deposits are as follows:

1. The character and genesis of the quartzose bodies. Are they quartzose pegmatites or a product of metamorphic processes?
2. The peculiar occurrence and origin of blue corundum in some of the andalusite which is contained in the quartz bodies.
3. The paragenesis of the ore and its thermal significance.

Have we here an example of "telescoping" of high and lower temperature minerals ranging from a near-pegmatitic character with typical tin, tungsten, copper minerals to, finally, gold, or is the occurrence of the ferberite, sulphides, and gold entirely unrelated to the quartz bodies, and, where all occur together, is their association "merely fortuitous" as regarded by Ellsworth and Jolliffe (1937, p. 77)?

THE CHARACTER AND GENESIS OF THE QUARTZ BODIES

The many quartz bodies range in size from 1 to 10 feet in width and from 10 to 50 feet or more in length. Some parallel the enclosing sediments; others are lenticular and occupy typical gash-fractures up to 2 feet in width, crossing the sediments at small angles. Ellsworth and Jolliffe (1937) note that they occur also at the apices of folds. The majority have sharp contacts, save where an irregular and discontinuous mica selvage, 3-4 inches wide, intervenes between quartz and the wall rocks. Similar segregations of mica, muscovite, and biotite, locally altered to chlorite, are contained within the quartz. In addition, blocky segregations of red andalusite, in crystals attaining dimensions of 3-4 inches, are present

in some of the quartz bodies. Minor mineral constituents consist of magnetite, ilmenite, and specular hematite, most intimately associated with the micas, and, where the bodies are cut by later shears, as noted by Jolliffe, chalcopyrite, bornite, pyrite, and even gold may be present. Gold has actually been found with both mica and chlorite and in fractures in the andalusite, the latter in drill core from a point some 150 feet below the fourth level.

The general aspect of these bodies is very similar to that of many quartzose pegmatites such as those of Quebec with which molybdenite is associated, but they cannot be traced into more feldspathic dykes nor are any nearby major intrusives exposed to which they might be related.

On the other hand, Jolliffe, by personal communication, intimates that these bodies may be of metamorphic derivation. In this connection it is interesting to note that George (1908, p. 21), reporting on the tungsten deposits of Boulder County, Colorado, notes ". . . irregular bodies of pegmatite, mostly of finer texture [than normal pegmatites also present] which . . . are the result of a process of solution and recrystallization of the country rock along seams and fracture lines. These bodies never have well defined boundaries, but show a gradational transition to the texture and mineral composition of the country rock. The pegmatization frequently follows branching and rebranching fractures and penetrates the country rock irregularly."

Andersen (1931, p. 53) also considers certain pegmatites carrying garnet, cordierite or epidote, as "endemic in metamorphic rocks." These he regards as largely the result of recrystallization of country rock, but to explain their form as "injection bodies" he indicates the necessity of solutions "to form fluxes for the recrystallization."

The evidence bearing on the origin of the quartz bodies at Outpost Islands may be classified as mineralogic and geologic.

Mineralogic Evidence

Type of Quartz. The quartz in the masses under discussion is coarse-grained and has a glassy lustre and white colour. Etch tests on fragments mounted in bakelite with hydrofluoric acid after the method of Meen (1937), show in the majority of grains either a lack of twinning or simple types characteristic of α-quartz. A few grains

were found, however, which show twinned individuals the borders of which are much more irregular than the others, and on this basis may be interpreted as having been β-quartz. These lack, however, any intricate fracturing common to this form. The conclusion is reached that most of the quartz was deposited as α-quartz, with possibly small amounts of β-quartz.

Spectroscopic and Chemical Evidence

A spectroscopic analysis of a sample of quartz was made with a No. E 216 Hilger quartz spectrograph[1] and in so far as measurements of the spectra were completed, they yielded no indication of the rarer metals commonly associated with pegmatites.

Samples of micaceous selvage from one quartz mass on the 200 foot level of the mine were examined and separated into light and heavy fractions. Minerals found consisted of quartz, biotite, minor muscovite, chlorite, andalusite, tourmaline, staurolite, pyrite, chalcopyrite, magnetite, hematite, ilmenite, and powellite.

A spectroscopic analysis of the heaviest product (not including andalusite) was made after eliminating magnetite and any iron magnetically. Elements found to be present were calcium, chromium, cobalt, manganese, molybdenum, titanium, tungsten, and vanadium. Some indication of tin was expected, but none appeared in the range of lines measured.

Previously samples of quartz with a minor amount of mica and of the micaceous and chloritic selvage, had been assayed for tin and tungsten by the Mines Branch, Department of Mines and Resources, Ottawa, with the following results, which are compared in the following table with a bulk sample from the main gold ore zone on the 50 foot sub-level.

	Per cent tin	Per cent tungsten
Bulk sample—50 foot sub-level	0.20	1.20
Quartz with minor mica from quartz body on 200 foot level	0.05	nil
Micaceous and chloritic selvage from several quartz masses underground	0.11	0.15

[1]Assistance in this work was kindly given by Dr. E. L. Bruce.

A partial spectroscopic analysis was also made on a sample of micaceous quartzite occurring outside the mineralized zone, and besides silicon, the elements cobalt, titanium, and vanadium were identified, but no tungsten, tin, molybdenum, manganese, nor chromium were found.

From a study of thin sections, and the above spectroscopic evidence, it would appear that the quartz masses have the following minerals in common with the adjacent sediments: quartz, biotite, muscovite, chlorite, hematite, andalusite, staurolite, tourmaline, probably ilmenite, and the elements cobalt and vanadium. The quartz bodies with micaceous borders, in addition, contain tin, tungsten in either ferberite or powellite, molybdenum in powellite—$Ca(Mo,W)O_4$ or molybdenite, chromium, and manganese, the latter probably also in ferberite, all of which, as is shown by a study of the paragenesis given below, may have been introduced during the main period of mineralization and after the formation of the quartz masses.

Though searched for, no beryllium, zirconium, tantalum, nor columbium lines were found in spectra of the quartz bodies. (Beryl is known to occur in true pegmatites in the Yellowknife area to the north of Great Slave Lake.)[2]

The occurrence of vanadium with aluminum silicates, possibly the micas, in both the sediments and quartz bodies is not surprising. The manner of occurrence of traces of cobalt has still to be solved.

Geologic Evidence

From descriptions given above, it is clear that the quartz masses have been injected into gash vein openings, the crestal portions of folds or parallel to the schistosity, as witness their sharp boundaries with adjacent wall rocks. They, therefore, do not appear to have been derived from the immediately adjacent sediments.

Structurally some of them, such as the gash-fracture type, appear related to a shear couple which coincides, at least approximately, with that inferred to have produced the later shearing and fracturing, namely a movement to the north side east and down with respect to the south side. Though not positive evidence, this sug-

[2]Neil Campbell and W. T. Love, personal communication.

gests a relation in time between the tensional fracturing, the introduction of the quartz bodies, and the later shearing and fracturing which allowed the subsequent introduction of various ore minerals.

Contrast in Quartz of Large Masses and Small Veinlets

In contrast to the coarse-grained and obviously injected quartz, very minor quartz veinlets are found paralleling planes of schistosity in the micaceous quartzites, and following fractures crossing the sediments. These are much finer grained, have a mosaic structure akin to that of the quartz in the quartzites, and underground, in places, have a greenish cast, identical with the more massive and less micaceous quartzites.

It is in quartz very similar to this fine-grained type that brown coloured, wavy bands, ¼ inch to ½ inch wide, containing abundant fine laths of ferberite, occur suggesting nodular or concretionary forms. Much of this variety may well have been derived from or represent recrystallized sedimentary material. The contrast is sufficiently great to suggest a decidedly different origin for the two types of quartz.

Summary

Mineralogically the quartz bodies afford no positive evidence that they were derived from an igneous source rather than from nearby or sub-jacent micaceous quartzites by solution processes, unless it can be shown that a fairly intimate relation in time exists between the earlier quartz and the somewhat later tin, tungsten, copper, molybdenum, and gold mineralization which is considered as unquestionably of magmatic origin. The probable presence of even a small amount of β-quartz, the structural relation indicated between the quartz-filled, gash-fractures and the later shearing, and the association of metals having strong pegmatitic affiliations (Sn, W, Mo, and even Cu), however, suggest to this writer a probable magmatic origin for the quartz.

On the other hand, there is no question that some constituents now in the quartz bodies have been acquired by assimilation processes from the nearby sediments and particularly is this true of the andalusite, and probably of some of the mica and iron oxides occurring along the borders. Fine-grained quartz associated with the

ferberite is also inferred to be derived at least in part from contiguous quartzitic sediments.

Blue Corundum in Andalusite

The peculiar occurrence of blue corundum in some of the andalusite which is contained in a quartz body has been described by Ellsworth and Jolliffe (1937, p. 78), who note that nowhere is it in contact with quartz. A few additional facts regarding this occurrence are worthy of record.

A thin section made from a corundum-bearing specimen collected originally by Dr. Jolliffe, shows the corundum everywhere as described, but between each irregular to rounded grain of the mineral and the andalusite is a fringe of sericite or muscovite (visible only with crossed nicols), which is clearly seen to replace the andalusite, and also appears to replace in part the corundum. Where replacement of andalusite has been extensive, the grains of corundum enclosed by mica are largest and the mica, coarser in grain. Where small corundum grains are entirely enclosed in a single crystal of andalusite, they have invariably a narrow fringe of finer-grained mica about them.

Examination of several other thin sections of similarly disposed andalusite crystals shows a similar replacement of the andalusite by white mica, both fine and coarse, but no corundum.

Compared with the andalusite of the nearby sediments, that in the quartz masses is considerably different in being much coarser grained and practically free from included or undigested quartz grains. So far as is known, the andalusite in the sediments does not contain any corundum, and its presence there does not seem at all probable in view of the high content of included quartz in all such grains examined.

How best may this peculiar occurrence be explained? There seems no reason to doubt that the andalusite in the quartz has been derived from adjacent argillaceous sediments by the solution, hydrothermal or magmatic, from which the quartz bodies have been deposited. In being so acquired recrystallization and purification of excess quartz have taken place. Locally excess Al_2O_3 over that required for andalusite may have been present, though the abun-

dance of silica in both formations renders it difficult to understand how such excess Al_2O_3 could escape union with the SiO_2 under the metamorphic processes involved.

While the synthesis of andalusite has not yet been accomplished, Bowen and Greig (1924, p. 242) have investigated the SiO_2-Al_2O_3 system in which mullite ($3Al_2O_3.2SiO_2$), cristobalite, and corundum are the various crystal phases formed. Mullite ($3Al_2O_3.2SiO_2$) melts incongruently at 1810°C. to form corundum and silica liquid. Natural sillimanite (Bowen and Greig, 1924, p. 248) on heating above 1545°C. forms mullite and silica rich liquid, the mullite behaving as usual at still higher temperatures.

Bowen and Greig (1924, p. 238) also point out that corundum may form "from shales and related rocks when heated as a result of immersion in igneous magmas . . . even when the total compositions indicated an ample supply of silica to form sillimanite, $Al_2O_3.SiO_2$." Harker (1932) also notes the occurrence of corundum in metamorphosed bauxitic sediments, silica-poor rocks, and even in highly metamorphosed acid igneous rocks (p. 289) in the latter of which alumino-silicates are regarded as forming "cyanite, sillimanite, hercynite and corundum . . . due to the liberation of alumina in this process of dissociation, for the granulites contain no more alumina in their bulk analysis than a granite of like acidity."

The occurrences cited of corundum in rocks containing free silica as quartz, unlike that under consideration, suggest that very high temperatures must have prevailed, though probably temperatures not as high as are indicated in the laboratory synthesis. Granted that some of the quartz in the bodies containing the corundum-bearing andalusite was deposited as β-quartz, a temperature of around 575°C. for the reaction here is indicated.

If we follow the process suggested by the work of Bowen and Greig, we may conceive of the quartz-riddled andalusite of the nearby sediments being included in injected silica-rich liquids which undoubtedly were aqueous solutions as shown by the micaceous minerals present. We may even admit that the temperatures of these solutions may have been somewhat higher than 575°C. Such engulfed andalusite must then have undergone recrystallization, forming larger crystals, and at the same time undergoing purification by elimination of excess quartz. If in the presence of water, and at

the temperatures suggested, corundum could still form by dissociation of some of the andalusite, it is indeed difficult to understand how it could escape reacting with either the enclosing silica or that being expelled from within the quartz-rich andalusite grains. Lack of corundum in the quartz itself suggests that all such grains of this mineral have disappeared by such a reaction, and that the corundum within the andalusite never came in contact with the silica liquid or solution.

Two other possibilities suggest themselves, both of which require further laboratory investigation involving, first, the actual synthesis of andalusite and, secondly, its alteration by potash-bearing solutions. The first is this. Under hydrothermal conditions could the alumino-silicate forming in the quartz bodies have existed temporarily as mullite which subsequently might form andalusite and corundum as in the following equation?

$$\underset{\text{Mullite}}{3Al_2O_3.2SiO_2} \longrightarrow \underset{\text{Andalusite}}{2(Al_2O_3.SiO_2)} + \underset{\text{Corundum}}{Al_2O_3}$$

The second possibility, though perhaps incongruous, is suggested by the ever-present fringe of potash mica between all grains of corundum and enclosing crystals of andalusite. Could the hot alkaline solutions[3] which have clearly attacked the andalusite, on working their way into some grains, have become depleted of any dissolved silica and given rise to both muscovite and corundum according to the following reaction?

$$\underset{\text{Andalusite}}{6(Al_2O_3.SiO_2)} + K_2O + 2H_2O \longrightarrow \underset{\text{Muscovite}}{K_2O.3Al_2O_3.6SiO_2.2H_2O} + \underset{\text{Corundum}}{3Al_2O_3}$$

Both of the above suggestions require considerable confirmation before any idea of their validity can be entertained. The common association of white mica around grains and crystals of corundum found in syenites suggests that a study of their relations might well prove profitable.

[3]Since the preparation of this manuscript W. H. Tomlinson, Am. Mineral., vol. 24, May, 1939, pp. 339-343, notes the "possible formation of corundum deposits by high-temperature volatile reactions on calcic plagioclase."

The Paragenesis of the Ore and its Thermal Significance

The paragenesis of the gold ores at Outpost Islands in so far as determined on specimens available shows several peculiarities in departing from the usual order of deposition.

The earliest mineral in the shear zones and fractures appears to be quartz, which on the whole, omitting the bodies of pegmatitic appearance, is relatively scarce, both on surface and underground. Ellsworth and Jolliffe (1937, p. 80) describe "Silicified zones surrounding the original fragments of brecciated quartzites" in which brownish bands of fine ferberite occur and grade "outward into areas of drusy quartz, pyrite and chalcopyrite." The silicified zones appear to the writer as largely recrystallized quartzite. The drusy quartz, not noted underground, and the narrow quartz veinlets, with widths a fraction of an inch, observed in mine workings, are considered as possibly of the same source, the recrystallization having been aided possibly by the incoming ore-bearing solutions. In support of this idea is the apparent gradation of this quartz into the quartzites, its similar mosaic texture, fine grain, and greenish cast, where fresh.

No definite tin material has been identified. In a heavy concentrate from micaceous selvages of the quartz bodies a single grain of a highly birefringent mineral was suspected of being cassiterite, but exact optical data were not obtained. The association of the tin with the mica selvage (see analyses, this paper) suggests a relation which cannot be proven, as all the later ore minerals have penetrated these same bodies to various extents.

Of the metallic minerals specularite, with possibly some magnetite, is one of the earliest, and, as with the quartz, it may possibly have been derived from the adjacent sediments or introduced by the ore-bearing solutions.

Then follows ferberite, in bladed crystals, cutting and replacing specularite (Fig. 1), developing also "as nodules in the pegmatitic quartz," as small grains and aggregates replacing andalusite, and in an unknown manner in the micaceous selvage of the quartz bodies. Pyrite projects into blades of ferberite, and elsewhere has associated with it massive and beautifully twinned marcasite, as seen in a section supplied by Dr. Jolliffe. Chalcopyrite invades pyrite and mar-

casite, and in one section was found to contain a well-developed crystallographic intergrowth of what is interpreted as a solid solution of chalcocite and covellite. The latter mineral is anisotropic and gives film tests like chalcocite, but ordinary etch reactions like covellite. Where the blades cross, there is no widening and the texture is ascribed to ex-solution rather than replacement (Fig. 2).

Quartz clearly replaces chalcopyrite irregularly, but presents smooth boundaries to bornite which borders the chalcopyrite in places. Elsewhere bornite with included hair-like forms or shreds of covellite replaces chalcopyrite along well-defined fractures and around the edges of the grains, and would readily be ascribed to supergene solutions were it not for the nature of the minerals found cutting and replacing these, first of which is magnetite and possibly ilmenite as shown in Fig. 3. The magnetite invades chalcopyrite and makes embayments in both bornite and chalcopyrite which are concave towards the guest. This peculiar development of what is commonly a fairly high temperature oxide is perhaps not so odd in view of the still later development of an intimate mixture of sericite and chlorite. These two silicates not only penetrate magnetite, but also are found replacing chalcopyrite along crystallographic directions, possibly localized by "ex-solved" chalcocite, as well as invading the other earlier minerals.

The gold appears to be the last mineral introduced, and occurs as disseminated flakes in the fine-grained quartz, in fractures in the coarser "pegmatitic" quartz, cutting across flakes of chlorite, and even in fractures in andalusite. Tests show it contains little if any silver, either at surface where values are high or at depth where they are less.

The only minerals definitely of supergene origin consist of the thin limonitic gossan, sparse copper carbonates, and powellite. The latter contains many small segregations and specks of limonite, and is, in places, pseudomorphous after blades of ferberite. The original molybdenum mineral may have been molybdenite, none of which occurs in the sections studied.

The above sequence of minerals, the commonly high temperature oxides, magnetite, (probably) ilmenite, and specularite, the ex-solution texture in chalcopyrite, suggest an early mineralization at high temperatures, probably hypothermal. The ferberite, known

in other deposits of both hypo- and epithermal character, here occurs in disseminated blades in fine quartz, as brown wavy bands or zones, suggestive of lower temperature formation than either the oxides which precede or the chalcopyrite (and pyrite) which follow it.

Massive and twinned marcasite, replaced by chalcopyrite, is quite unlike near-surface development of this mineral.

Following the irregular replacement of chalcopyrite by quartz, decreasing temperatures are suggested by the distinct fracture and grain boundary control of the bornite and covellite replacement in chalcopyrite, but whether much of a drop in temperature occurred is not clear. At any rate the subsequent replacement of bornite and chalcopyrite by magnetite and the probably closely related chlorite and sericite, bespeak still elevated temperatures. As is so often the case, no indication is available as to the temperature of the gold mineralization, but there seems no good reason to place it much below that of the immediately preceding minerals. The scarcity of quartz definitely accompanying the metallic minerals throughout the period of mineralization is a most noteworthy feature, though the earlier injection of the numerous, and in many places, large quartz bodies may well account for this lack in the later solutions.

In conclusion, the writer hazards the opinion that the mineralization at Outpost Islands occurred over quite a wide range of temperatures, from the near pegmatitic stage to hypothermal and possibly even mesothermal, the lower temperature limit not yet being established. The complementary character of the earlier quartzose injections and the later quartz-poor, tungsten, tin, copper, iron, molybdenum, and gold mineralization, add some weight to the idea that the quartz masses are of magmatic origin and are to be regarded as quartzose pegmatites.

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EXPLANATION OF FIGURES

FIG. 1.—Ferberite (dark grey) cuts and replaces specularite (white).

FIG. 2.—Intergrowth of bladed chalcocite (with covellite in solid solution?) darker grey in chalcopyrite.

FIG. 3.—Magnetite (M), bornite (Bn), pyrite (Py), and specularite (Sp), quartz (Q). Magnetite appears to replace bornite.

FIG. 4.—Mica or sericite and chlorite (SC), chalcopyrite (Cp). The silicates appear to replace the chalcopyrite along crystallographic directions, possibly along former lamellae of chalcocite.

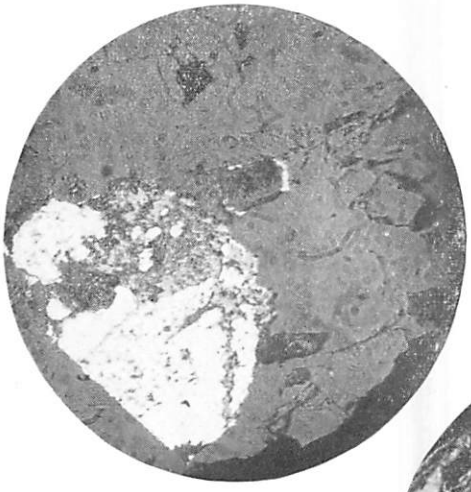

FIG. 1

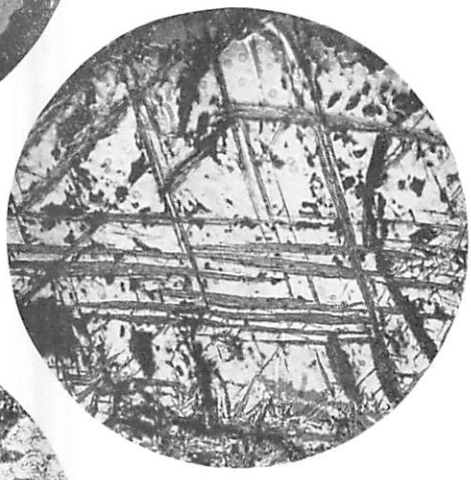

FIG. 2

FIG. 3

FIG. 4

VESUVIANITE FROM GREAT SLAVE LAKE REGION CANADA

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During the summer of 1938, Dr. A. S. Dadson discovered a small quantity of vesuvianite crystals in Precambrian sediments, near a granite contact, at Turnback Lake, about forty miles north of Great Slave Lake, Northwest Territories, Canada. He presented this material (M/19485) to the Royal Ontario Museum of Mineralogy. Since this is a new locality for vesuvianite, a description of the material may be of interest.

MORPHOLOGY

The material consists of four crystal groups, up to about 5×5×3 inches, and several single crystals up to one inch in length. The crystals, which are chocolate-brown with a greenish tint, are stout prismatic in habit. All but one of them show a broad base; one crystal is doubly terminated.

Three crystals, measured on the two-circle reflecting goniometer, show the forms in the first column of Table 1, in which the indices (Dana) refer to the usual setting of vesuvianite. Gottfried (1930) found that this setting corresponds to a base-centred structural cell (*C*). With reference to the simple cell (*P*), the indices of the observed forms shows a notable simplification as indicated in the last column.

The gnomonic projection of the observed forms in the preferred setting (*P*) (Fig. 1) shows a normal arrangement of face poles whereas a projection in the old setting reveals omissions due to the systematic halving of lattice plane spacings in the base-centred lattice.

The reversible transformations from the base-centred (*C*) to the simple lattice (*P*) are

C to *P*: $\frac{1}{2}\bar{\frac{1}{2}}0/\frac{1}{2}\frac{1}{2}0/001$
P to *C*: $110/\bar{1}10/001$

The long form series of vesuvianite might be transformed to the structural setting with advantage.

TABLE 1.—VESUVIANITE: FORMS ON CRYSTALS FROM GREAT SLAVE LAKE

Form	Old setting		New setting
	Dana	*C*	*P*
c	001	001	001
m	110	110	010
f	210	420	130
h	310	310	120
a	100	200	110
p	111	111	011
t	331	331	031
e	101	202	112
u	201	201	111
i	312	312	122
s	311	311	121
d	421	421	131
Total of indices	44	50	38

Fig. 2 is a portrait drawing of the crystal with the unusually small base. Fig. 3 is a symmetrical drawing showing the double termination and the usual broad base.

TABLE 2.—VESUVIANITE: OPTICS

Great Slave Lake	Larsen and Berman, 1934			
	p. 87	p. 88	p. 73	p. 192
Greenish-brown	Brown, with BeO	Greenish-blue, with CuO (cyprine)		
	ω 1.712	ω 1.712	ω 1.713	ω 1.716	α 1.715
					β 1.719
	ϵ 1.708	ϵ 1.700	ϵ 1.705	ϵ 1.721	γ 1.720
Sign	−	−	−	+	−
Abs.	$\epsilon > \omega$			$\omega > \epsilon$	
	faint	faint	faint	faint	faint

OPTICS

The indices of refraction, obtained on a refractometer, do not differ appreciably from the indices given for vesuvianite from other localities. Crystal grains are faintly pleochroic in shades of yellow. The first column of Table 2 gives the optical data for this vesuvianite. The other columns show the optical data for other vesuvianites listed by Larsen and Berman (1934, pp. 73, 87, 88, 192).

COMPOSITION AND ATOMIC CONTENT OF UNIT CELL

A chemical analysis of the material is given in Table 3, column 1. Adopting the cell dimensions of Warren and Modell (1931, p. 425), the volume of the unit cell is $V_0=2890$ cubic Å. The measured density of the material in hand is $G=3.432$ (suspension in Clerici solution). From these values, the molecular weight of the unit cell content is $M_0=6011$. Using this figure, the number of each kind of atom in the unit cell is given in column 2. The total of the oxygen equivalents is 157.1 which is reasonably close to the figure 152 derived from the structure by Warren and Modell (1931, p. 423) and Machatschki (1932, p. 148). The recalculation of the number of each kind of atom in the unit cell to 152 oxygen equivalents is shown in column 3.

Referred to 152 oxygen equivalents, the formula derived by Warren and Modell (1931, p. 425) is:

$$Ca_{40}Al_{16}(Mg, Fe''', Fe'', Ti, Zn, Mn)_8Si_{36}O_{136}(OH, F)_{16}$$

From a discussion of a large number of vesuvianite analyses, Machatschki (1932, p. 148) proposed a less restricted formula:

$$Y_{38}Y_{26}Z_{36}(O, OH, F)_{152}$$

where X = Ca (Na, K, Mn), Y = (Al, Fe''', Fe'', Mg, Ti, Zn, Mn), Z = Si.

From column 3, where the atoms treated as structurally equivalent have been grouped, the cell content of the vesuvianite from Great Slave Lake is:

$$(Ca,Mn, Na, K)_{37\text{-}73}(Al, Be, Fe'', Fe''', Mg, Ti)_{27\text{-}72}Si_{35\text{-}41}(O, OH, F)_{152}$$

If we assume that a small amount of the aluminium may replace silicon, then the formula may be written:

$$(Ca,Mn, Na, K)_{37\text{-}73}(Al, Be, Fe'', Fe''', Mg, Ti)_{27\text{-}13}Si_{36}(O, OH, F)_{152}$$

or nearly:

$$(Ca,Mn,Na,K)_{38}(Al,Be,Fe'',Fe''',Mg,Ti)_{27}Si_{35}(O,OH,F)_{152}$$

in excellent agreement with Machatschki's structural formula.

TABLE 3.—VESUVIANITE: ANALYSIS AND ATOMIC CONTENT OF UNIT CELL

1		2			3		
SiO_2.....	36.68	Si.....	36.62	36.62	Si.....	35.41	35.41
TiO_2.....	0.81	Ti.....	0.59		Ti.....	0.57	
Al_2O_3.....	15.62	Al.....	18.35		Al.....	17.75	
[1]BeO.....	1.07	Be.....	2.56	28.14	Be.....	2.48	27.22
Fe_2O_3.....	2.81	Fe'''....	2.10		Fe'''....	2.03	
FeO.....	2.96	Fe''.....	2.46		Fe''.....	2.38	
MgO.....	1.39	Mg.....	2.08		Mg.....	2.01	
MnO.....	0.46	Mn.....	0 39		Mn.....	0.38	
CaO.....	35.88	Ca.....	38.38	39.00	Ca.....	37.13	37.73
Na_2O.....	0.10	Na.....	0.19		Na.....	0.18	
K_2O.....	0.03	K.....	0.04		K.....	0.04	
H_2O+.....	0.84	H.....	5.59		H.....	5.41	
H_2O-.....	0.04						
[2]F.....	2.03	F.....	6.40		F.....	6.18	
O for F_2.....	-0.85	O.....	-3.18	157.10	O.....	-3.08	152.00
	99.87		151.09			146.19	

1. Vesuvianite, Great Slave Lake, Northwest Territories, Canada. Analyst V. B. Meen. [1]Determined by 8-hydroxyquinoline method. [2]Determined after method of Merwin (1909, pp. 124-125).

2. Number of atoms in the unit cell with $M_0=6011$.

3. Number of atoms in the unit cell reduced to the sum of 152 oxygen equivalents.

EXPLANATION OF FIGURES

FIG. 1.—Vesuvianite: Gnomonic projection of forms on crystals from Great Slave Lake, in the structural setting.

FIGS. 2 and 3.—Vesuvianite: Measured crystals.

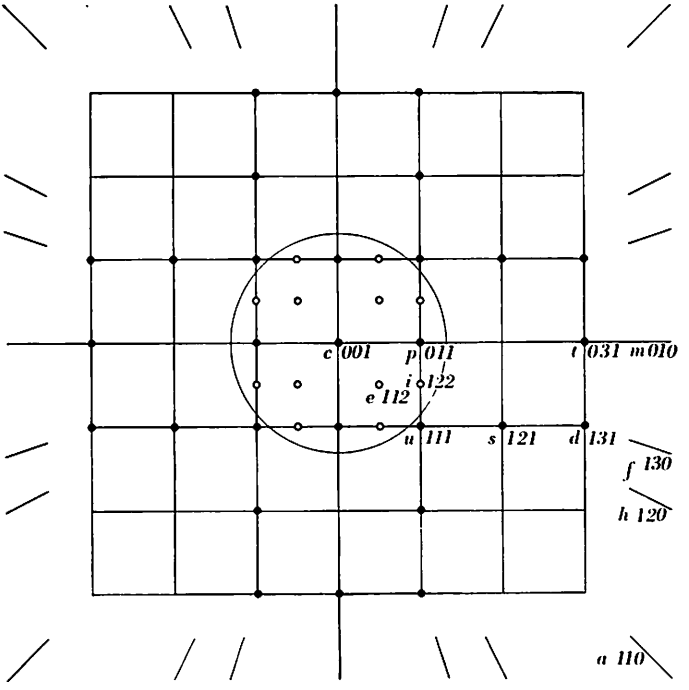

FIG. 1

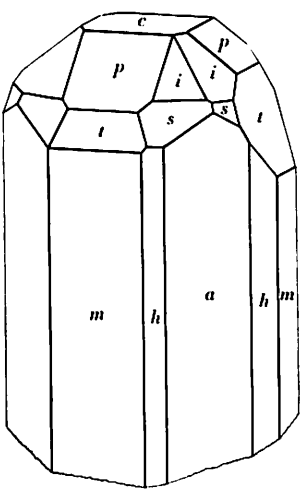

FIG. 2

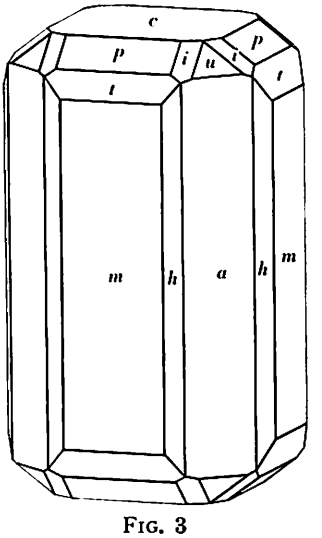

FIG. 3

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MAGNESIOCHROMITE FROM CARIBOU PIT COLERAINE TOWNSHIP, QUEBEC

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About ninety years ago T. Sterry Hunt (1849) analysed chromite from a vein at Bolton, Quebec, and from a boulder near the outlet of Lake Memphremagog. Both of these chromites were unusually rich in magnesia and may be classed as magnesiochromite[1] or picrochromite.[2] Similar materials with higher alumina and lower chromic oxide are called picotite and chrome-picotite. More recent work by Poitevin (1931) and Denis (1932) has shown that in general the chromites from Quebec are relatively high in magnesia and that the chromite from the Caribou pit contains approximately 50 per cent $MgCr_2O_4$ and should therefore be classed as magnesiochromite or picrochromite.

Through the courtesy of the Asbestos Corporation Limited, a considerable quantity of the chromite ore from the Caribou pit was obtained by the Royal Ontario Museum of Mineralogy in 1935. A sample for analysis and *x*-ray examination was prepared by taking the largest fraction separated by Clerici solution. This was then put through a Hallimond magnetic separator which removed the magnetite; the material picked up by the second magnet, which was the largest fraction, was taken for the purpose of this study. Under the microscope the material was found to be isotropic and coffee-brown in colour.

An analysis (Table 1, column 1) was made by Dr. E. B. Ellestad. The sample was dissolved in concentrated sulphuric acid in a sealed tube so as to obviate any change in the state of oxidation of the iron. Analyses of material from the same locality, by Connor and Fabry (2) (Poitevin, 1931, p. 19) and Archambault (3) (Denis, 1932, p. 47) are given for comparison.

[1]According to Dana (1892, p. 228) the current variety name *magnesiochromite* is a variant of *magnochromite* (Bock, 1868).

[2]*Picrochromite* was proposed by Simpson (1920, p. 103) as a species name, and in a more restricted sense as a sub-species name for magnesium bearing chromite with $MgO:FeO > 3:1$ and $Al_2O_3:Cr_2O_3 < 1:3$.

TABLE 1.—MAGNESIOCHROMITE: ANALYSES FROM THE CARIBOU PIT, QUEBEC

	1	2	3
SiO_2	0.24	—	0.61
TiO_2	0.17	0.22	n.d.
Al_2O_3	14.03	15.63	13.70
Cr_2O_3	55.51	52.21	54.62
MgO	14.83	17.62	15.71
CaO	0.11	tr.	0.44
Fe_2O_3	3.79	6.56	5.79
FeO	11.35	8.70	9.93
MnO	0.14	nil	—
NiO	—	0.13	—
H_2O+	0.07	—	—
H_2O-	0.02	—	—
	100.26	101.07	100.80

The three analyses are much alike, the magnesia values comparing fairly well with that of the original magnochromite (magnesiochromite) of Bock which gave MgO 14.00.

Hitherto spinel analyses have usually been calculated and discussed in terms of theoretical molecules of the spinel form, $R''R'''_2O_4$. A more realistic interpretation is obtained by expressing the analyses in terms of the atomic content of the structure cell. This has been done in Table 2, in which the columns correspond to the analyses in Table 1. The numbers of atoms have been reduced to 32 oxygen atoms in keeping with the known cell content of the spinels, $R''_8R'''_{16}O_{32}=8[R''R'''_2O_4]$, first determined by W. H. Bragg (1915).

TABLE 2.—MAGNESIOCHROMITE: ANALYSES REDUCED TO ATOMIC CONTENTS OF THE STRUCTURE CELL

	1		2		3	
Si	0.06		—		0.15	
Ti	0.06		0.04		—	
Al	4.13	15.97	4.50	15.97	3.85	15.88
Fe'''	0.72		1.20		1.06	
Cr	11.00		10.05		10.82	
Fe	2.38		1.78		2.05	
Ni	—		0.03		—	
Mn	0.03	8.03	—	8.29	—	7.96
Mg	5.59		6.48		5.79	
Ca	0.03		—		0.12	
Oxygen	32.00		32.00		32.00	

Adding the small amounts of Si and Ti to R‴, all three analyses give structurally equivalent totals close to the ideal numbers R″ = 8, R‴ = 16, the new analysis (1) showing the closest approach.

X-ray powder photographs of the magnesiochromite from the Caribou pit were made by L. G. Berry, using a powder camera of 57.26 mm. diameter with chromium radiation. Dr. M. A. Peacock kindly measured these films which showed only the lines of the face-centred cubic lattice of the spinel structure. Applying a correction which gave accurate values on standard substances the cube edge $a_0 = 8.247 \pm 0.005$Å was obtained.

TABLE 3.—MAGNESIOCHROMITE: CALCULATED CUBE EDGE

	a_0		Chemical proportions		Partial values
$MgAl_2O_4$	8.02 Å	×	0.195	=	1.564
$MgCr_2O_4$	8.29	×	0.440	=	3.648
$FeCr_2O_4$	8.34	×	0.307	=	2.560
$FeFe_2O_4$	8.37	×	0.044	=	0.368
			0.986		8.140
Magnesiochromite			1.000 a_0	=	8.255 Å (calc.)
					8.247 Å (meas.)

The cube edge of the magnesiochromite was calculated from the known values for the four artificial spinels which may be considered as contributing partial values according to their chemical proportions (Table 3). The values for the artificial spinels were selected as the most probable values from the numerous measurements recorded in Hermann, Lohrmann, and Philipp (1937). The calculated cube edge agrees well with the measured value.

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X-RAYS IN MINERALOGY: DESIGN OF A SERVICEABLE APPARATUS[1]

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THE INFERENCE OF CRYSTAL STRUCTURE

The present basis of systematic mineralogy. Minerals, with few exceptions, are the chemical elements and compounds found in Nature in the crystalline condition; mineralogy is concerned with the properties of minerals. In answer to the question: "What is the principal property that distinguishes one mineral from another?" one might say: the crystal form; another: the chemical composition. Yet a moment's reflection would show that neither answer is satisfactory. Rock salt—NaCl and fluorspar—CaF_2 are both found in cubic crystals and thus the cubic form is not a distinguishing property; again diamond—C and graphite—C both consist wholly of carbon atoms and therefore the chemical composition does not distinguish one from the other. A considered reply to the foregoing question would be: crystal form and chemical composition are jointly the principal distinguishing properties of a mineral. This has long been the accepted answer and the basis of every system of descriptive mineralogy.

Theory of crystal symmetry. The regular form of a crystal has always been recognized as an expression of a regular internal arrangement of its constituent particles. The facts of observation (constancy of interfacial angles; symmetry of seven kinds; simple rationality of intercepts) were explained by assuming that this regular internal arrangement could be represented, in the first place, by a space lattice, that is an unlimited periodic arrangement of points in space. In such an arrangement a line drawn through any two points contains an endless succession of equally spaced points; and the whole system comes to coincidence (identity) on translation from any point to any other point. It was found that there are fourteen possible lattice types (translation groups) giving seven (holohedral) symmetry types (crystal systems).

[1]Based on an address to the Walker Mineralogical Club, Toronto, March 23, 1939.

To explain the additional (merohedral) symmetry types shown by crystals it was inferred that the regular internal arrangement must be of the nature of a three dimensional pattern of points (motif) surrounding each lattice point or, what is the same thing, occupying the parallelepiped (unit cell) outlined by eight contiguous lattice points. It was shown that the symmetry of the motif gives thirty-two types (point groups, crystal classes) based on the possible combinations of axes and planes of symmetry; and that the possible combinations of all imaginable symmetry operations yield the full and final number of two hundred and thirty types of symmetry (space groups).

Structural and systematic implications. This theory of crystal symmetry, completed nearly fifty years ago, was more than sufficient to explain the facts of observation. Measurements on the reflecting goniometer gave an axial ratio defining the geometrical form of a possible lattice cell. The crystal forms and certain physical properties might indicate the correct crystal class. Few crystallographers saw the possibility of finding the lattice type; and the thought that the space group symmetry might find expression in the observable characters of crystals was never entertained. The teaching and practice of crystallography continued to rest mainly on the simple conception of an axial cross belonging to one or another of the crystal systems, to which the observed forms of a crystal were referred with the simplest rational symbols.

The theory of crystal symmetry was at the same time a theory of crystal structure. If the crystal motif had any reality its constituent points must represent particles with spherical symmetry, and therefore the atoms themselves. Since the crystal was built of a periodic succession of identical motifs, the motif must consist of a whole number of atoms of the kinds and in the proportions given by the chemical composition of the species. Crystal structure might already have been defined as a definite periodic arrangement of known atoms. From this definition crystal form and crystal composition are functions of crystal structure. And therefore, in answer to our original question: "What is the principal distinguishing property of a mineral?" a bold answer would have been: the crystal structure. This will soon be the accepted answer and the philosophi-

cally founded system of descriptive mineralogy of tomorrow will rest on a structural basis.

This line of thought must have been followed in the past, but it would have remained unfruitful so long as the reality of crystal structure could not be demonstrated. Based on crystal form and chemical composition, both immediate properties of crystal structure, the systematic mineralogy of the past rested on the best available foundation. The structural system of the future will be an improvement of the existing system rather than an entirely new arrangement.

THE REALITY OF CRYSTAL STRUCTURE

Results of x-ray measurements. The momentous discovery of the diffraction of x-rays by a crystal (1912) led to two fruitful fields of physical enquiry: the spectroscopy of x-rays and the analysis of crystal structures. These researches, at first wholly in the domain of physics, became of increasing interest to mineralogy. They brought the utterly unexpected demonstration of the reality of crystal structure, with actual determinations of the atomic arrangements in simpler cases. The neglected full theory of symmetry with its implied theory of structure was adopted unchanged as the essential working theory in the new field of research. It was seen that the accumulating structural information was not only of intrinsic value as an addition to the specific properties of minerals, but brought important clarification to some basic mineralogical conceptions, leading to better descriptions of species and an improved systematic arrangement. The study of crystal structures, so far as it contributes to mineralogy as a branch of Natural History, has thus become an essential part of the work of an institute contributing to the present-day progress of mineralogy.

The full structural determination of a crystal species gives:

(1) The absolute dimensions of the unit cell; in general three lengths (cms. $\times 10^{-8}$) and three angles defining the elementary parallelepiped containing the structural pattern (motif).

(2) The space group; this also defines the crystal system, lattice, and class.

(3) The atomic content of the unit cell; the number of each kind of atom or ion constituting the structural pattern.

(4) The atomic or ionic positions; given by coordinates referred to the cell edges as axes.

The complete structural information can be obtained only in favourable cases. With suitable apparatus and material the items (1), (2), (3) can always be determined, the space group being limited to a few alternatives if not uniquely determined. The determination of the atomic positions (4) may prove difficult, however, or practically impossible; and in any case the work and results in this last stage appear to be more in the field of crystal physics than in mineralogy. For this reason the new *System of Mineralogy* of Dana, now in preparation, will include items (1), (2), (3), when available, but not (4).

As mentioned above the results of structural studies have modified and clarified some basic mineralogical conceptions; their contribution in this direction is perhaps as important as the direct addition they have brought in the way of specific data. In the following we shall briefly consider some of the effects of structural results on the crystallographic, chemical, physical, and systematic aspects of mineralogy.

Relation to geometrical crystallography. In some cases the crystal lattice indicated by the study of its forms proves to be geometrically similar to the structural lattice, in others it is a multiple lattice of the structural lattice. If properly determined we must accept the structural lattice and describe the forms and structure with reference to one and the same lattice cell. The structural worker usually chooses the smallest permissible cell, which in most cases gives the best morphological presentation (simplest face symbols). Considerations of pseudo-symmetry, which are likely to be structural as well as geometrical, may suggest the adoption of a multiple cell for both purposes. As regards the orientation of the lattice cell, if the structural worker will set his shortest cell edge vertical when there is a choice, he will usually meet the morphologist's preference in having the axis of the main zone vertical.

The knowledge of the structure of many species has also opened a fascinating field of pure crystallographic enquiry, namely the relations of form and structure. A neglected hypothesis relating crystal habit to the (inferred) lattice is finding remarkable confir-

mation; and a new enquiry seeking the relation between crystal habit and space group symmetry is making promising progress.

Relation to mineral chemistry. *X*-ray measurements do not, of course, indicate the kinds of atoms in the structure; on the contrary the determination of the atomic content rests on the best obtainable chemical analysis made on material representing the measured crystal. Given the volume of the unit cell and the specific gravity of the crystal a simple calculation yields the molecular weight of the cell contents. This number in conjunction with the analysis yields the number of atoms of each kind in the unit cell. In simple cases the cell content amounts to a simple multiple of the empirical chemical formula, the factor (Z) often being 1, 2, 3, 4, 6, 8, rarely a larger number. When the chemical analysis does not yield a simple rational formula, which commonly occurs, the calculation of the cell content yields numbers some of which are clearly not integral. The fractional values can, however, be collected into one or more groups giving integral totals in keeping with the symmetry of the crystal. This indicates that atoms of different kinds occupy equivalent positions in the structure. An element represented by a fractional number per unit cell must be distributed statistically through the crystal, giving successive unit cells which are not strictly identical. This is the picture we now have of a mixed crystal or "solid solution" as it was called. An atom of one kind may occupy the position of an atom of another kind if their structural radii are similar; equality of chemical valence is not necessary.

Such considerations lead to the view that the chemical composition of a mineral is in fact the atomic content of the unit cell. The mineral "molecule" has significance only if it represents the cell content or an aliquot part of it. Many of the complex mineral "molecules" and mixtures of "molecules" derived from analyses of minerals with complex structures, such as the silicates, do not correspond to the cell content and should therefore be abandoned.

Relation to physical properties. The physical properties of a mineral, such as cleavage, hardness, specific gravity, and the optical properties observed in transmitted or reflected light, are likewise functions of the crystal structure, and notable progress has been made in relating these properties to the structure of some crystals. The exact measurement of specific gravity has become a necessity,

since the determination of cell content involves this value. The long-standing problem of measuring the specific gravity of a small single crystal too heavy to float in any convenient liquid, has recently been solved by Berman (1939), using a specially adapted micro torsion balance which gives excellent results. Reliable tests for pyroelectricity and piezoelectricity have also become necessary since a positive effect of either kind is the best proof of the absence of a centre of symmetry. This in turn permits a unique determination of the space group which cannot be reached by x-ray effects alone.

Relation to systematic mineralogy. Although the full effect of structural information on the systematic arrangement of minerals cannot as yet be foreseen, certain trends are apparent. Minerals showing closely similar crystallographic, chemical, and physical properties, constituting the so-called "isomorphous," or better named homeomorphous groups of the existing system, have in most cases proved to be isostructural, and in these cases x-ray measurements have confirmed the existing arrangement. Minerals which were grouped mainly on chemical grounds, without close similarity of form and physical properties, have usually been found to have unlike structures. Thus on the whole the results of structural studies appear to be subdividing the existing system rather than integrating it into larger divisions. On the other hand, interesting structural similarities are appearing among minerals which were formerly regarded as unrelated. A re-grouping of such minerals may prove to be desirable, if it can be done without gross violation of mineralogical proprieties; but changes in this direction must await the accumulation of further structural information.

LITERATURE

A vast literature has already grown around the subject of x-rays and crystal structure. All the original papers on crystal structure are abstracted in the *Strukturbericht*, a supplementary serial to the *Zeitschrift für Kristallographie* (Leipzig). The entire current literature of mineralogy, including structural work, is briefly noticed in the *Mineralogical Abstracts*, a supplementary serial to the *Mineralogical Magazine* (London). The number of treatises in English is not large. A good introduction to the subject is given by Bragg (1928), a fuller treatment by Bragg and Bragg (1933). In Bragg (1937)

the mineralogist will find a judicious selection and clear presentation of the data on mineral structures.

THE RECENTLY COMPLETED *X*-RAY INSTALLATION IN THE DEPARTMENT OF MINERALOGY

To assist others, especially in Canada, in designing a serviceable *x*-ray equipment for work in mineralogy, the following brief description is given of the recently completed installation in the Department of Mineralogy. In the space available only the general arrangement can be outlined, with some details on the auxiliary apparatus which presents a few novelties. Only a few purely engineering details are given since the individual worker will eventually plan these according to his own preference and resources.

General considerations. An apparatus for the pursuit of work of the kind outlined above should be capable of continuous service and able to produce the necessary variety of *x*-radiation and *x*-ray photographs. Such an apparatus cannot as yet be bought as a unit. Industrial installations are available but their usefulness is limited; furthermore the initial cost of such units is high, and expensive replacements may be necessary from time to time. The desired combination of reliability, general usefulness, and long range economy can be reached by choosing *x*-ray tubes and cameras of successful types, made in small numbers by a few instrument makers, and designing the necessary auxiliary apparatus to be made commercially at moderate cost.

X-ray tubes. Of the available types of *x*-ray tubes the Ksanda form of the ion tube[2] was chosen as best suited for the purpose of the installation. This tube was designed and described by Ksanda (1932); continued use of the original tubes in the Geophysical Laboratory in Washington, D.C., has suggested only slight improvements which are incorporated in the latest models. The principal features of the Ksanda tube are: rapidly interchangeable targets giving the desired variety of *x*-radiation; horizontal target surface, giving beams of *x*-rays of equal intensity from three ports; cold cathode, from which there can be no contamination of the target;

[2]Made by the American Instrument Company, 8010-8020 Georgia Avenue, Silver Spring, Maryland, and described in the Company's Bulletin 1045, 1938.

simple seals with plain rubber gaskets at the joints which are opened when changing the target or the cathode or demounting a tube from the post; perfect needle valves for controlling the passage of air to or from the tube; stainless steel body, head and cap; "Pyrex" glass cylinder. The life of the tube is practically unlimited. After several hundred running hours the aluminum cathode becomes pitted, with reduction in the efficiency of the tube. A new cathode is quickly installed. After about a thousand hours of heavy duty we have found it desirable to replace the glass cylinder which became permanently stained and etched. Unless overloaded the targets do not depreciate. The tube runs satisfactorily under a range of conditions: air pressure, 0.005 to 0.020 mm. of mercury; voltage, 35-45 KV; current (half wave rectified), 5-20 MA. Ksanda twin tubes are shown in place in Figs. 1 and 2. The left tube is connected ready for use, the right tube is disconnected.

Electrical system. The main transformer (Fig. 1, *a*)[3] is a single-phase transformer, rated at 2 KW continuous output. The line supply, 110 volts, 25 cycles,[4] is transformed to high tension, with autotransformer taps at 25, 30, 35, 40, 45, 50, 55 KV. The instrument panel (*b*) is also provided with start and stop buttons, red indicator light, voltmeter (0-100 V) and kilowatt-hour metre in the primary, and ammeter (0-50 MA) in the secondary. Behind the panel is an adjustable solenoid cut-out set to break the primary circuit if the current should exceed 10 amps. This corresponds to a current of about 24 MA at 45 KV in the secondary circuit. The main switch, with 25 ampere fuse and 4 ohm-20 ampere rheostat[5] are not shown. The body of the transformer is grounded.

From the insulator (*c*) the high tension current is carried by the conductors (*d d d*) through the thermionic valve (*j*) to the cap of the *x*-ray tube, which is in metallic connection with the cathode. The target is in metallic contact with the body of the tube which is grounded. The conductors (*d d*) shown as 3/16 inch brass rod,

[3]Designed and constructed by the Moloney Electric Company of Canada, 213 Sterling Road, Toronto, Ontario.

[4]The system works very well with the 25 cycle supply; a 60 cycle supply is preferable.

[5]Good rheostats in a variety of ratings are made and sold by the Zenith Electric Company, Villiers Road, Willesden Green, London, N.W. 2.

have been replaced with advantage by ½ inch copper tube. The insulators (*k k*) are made of 1-inch round fibre projecting 10 inches from a wooden base.

The valve (*j*) is a Philips Glass Valve[6] with a peak rating 125 KV-300 MA, many times greater than the maximum continuous load. The valve gives half wave rectification of the high tension current. The filament of the valve is heated from the secondary circuit of the transformer (*f*),[7] the correct voltage at the filament terminals, read on the voltmeter (*h*), being attained by adjustment of the rheostat (*e*) in the primary circuit of the transformer (*f*). The secondary winding of the transformer (*f*) is insulated against 100 KV to ground.

Cooling system. The target and body of the *x*-ray tube, which are at ground potential, require to be cooled by a copious flow of water. The main water supply, at City pressure, passes through the main valve (*l*), and the needle valve (*m*), through the target and the body of the tube, back by the return pipe (*n*), through the outflow control valve (*q*) to the drain (*w*). To guard against failure in this cooling system, due either to interruption of the City supply or a break in the system, a "Pressuretrol" (*o*)[8] is connected to the outflow pipe, ahead of the visible water column (*p*) and the valve (*q*). This device is essentially a mercury switch which will break the line supply to the main transformer (*a*) when the water pressure in the return pipe (*n*) falls below a chosen critical value. A pressure corresponding to a head of 5 feet, obtained by adjusting the valve (*q*) and observed in the gauge-glass (*p*), gives a brisk flow without undue pressure on the rubber connections.

The cathode, which is at high potential, is cooled by a slower stream of water passing through the needle valve (*s*), along the pipe (*t t*), through one side of the glass-water resistance (*u*), through the cathode, and back through the other side of the glass-water resistance (*u*) and the pipe (*v v v*) to the drain (*w*). A safety device on

[6]Supplied by the Burke Electric and *X*-Ray Company, 61-63 Yorkville Avenue, Toronto, Ontario. In a personal communication (Oct. 4, 1938), Mr. Ksanda suggests the use of a General Electric "Kenotron" valve, type FP-84, peak rating 70 KV-200 MA.

[7]Made by the Burke Electric and *X*-Ray Company.

[8]Made by the Minneapolis-Honeywell Regulator Company, 117 Peter Street, Toronto, Ontario.

this cooling circuit does not appear to be necessary. The length of the glass-water resistance is determined by the electrical conductivity of the local tap-water. In the present case it was found that the electrical loss, due to the conductivity of the column of cooling water, was reduced to 5 per cent with 65 feet of glass tubing, 5/32 inch inside diameter, in each branch of the glass-water resistance.

Vacuum system. Unlike other open *x*-ray tubes which require a mercury diffusion pump in addition to a mechanical pump, the Ksanda tube runs well in direct connection with a vacuum tank and standard rotary vacuum pump. The adopted arrangement is shown in Fig. 3. A "Cenco-Hyvac" pump (Fig. 3, *b*)[9] capable of producing a vacuum of 0.0003 mm., draws on the main vacuum tank (*g*) through a glass connection provided with a "Pyrex" vacuum cock (*e*). The main tank is similarly connected to the auxiliary vacuum tank (*h*). The main tank is connected to the post of the *x*-ray tubes by a brass tube with a short flexible section (*i*).[10] The auxiliary tank is connected by a copper tube (*j*) to the nipple of the inlet valve (Fig. 2, *c*) of the *x*-ray tubes. The auxiliary tank is also provided with a narrow bore "Pyrex" cock (Fig. 3, *k*) with a short fine jet. The tanks are commercially made,[11] of plain 1/8 inch sheet steel with welded seams, provided with standard iron pipe flanges ("spuds") to receive the specially made turned brass nipples (*f f f f f*). The main tank is 12 inches in diameter and 24 inches high; the auxiliary tank has the same diameter with a height of 18 inches.

The vacuum connections, except the copper tube (*j*), are not less than ¼ inch inside diameter; the connections (*d d d*) are of rubber vacuum tubing made tight with sealing wax or vacuum wax; glass to metal joints are sealed with sealing wax, metal to metal joints are soldered. In use, the pressure in the main tank is kept somewhat lower than that required by the tubes; the pressure in the

[9] Supplied by the Central Scientific Company of Canada, 119 York Street, Toronto, Ontario.

[10] "Sylphon" bellows, made by the Fulton Sylphon Company, Knoxville, Tennessee.

[11] By the Canadian John Wood Manufacturing Company, 101 Hanson Street, Toronto, Ontario.

auxiliary tank is maintained at a slightly higher value. As the tube "hardens" with time air is admitted to the tubes very gradually by slightly opening the inlet valve (Fig. 2, *c*). The cock (Fig. 3, *k*) permits small amounts of air at atmospheric pressure to be admitted to the tank (*h*), if required.

Table and cameras. The table consists of a marble slab, $36\times48\times1\frac{3}{8}$ inches, on an angle-iron frame 42 inches high, with legs $2\times2\times\frac{1}{8}$ inches and ties $1\times1\times\frac{1}{8}$ inch. These dimensions give a convenient working height with small chance of accidental contact with the parts at high voltage. Two cameras serve most purposes. Single crystal photographs are made on the equi-inclination Weissenberg *x*-ray goniometer (Fig. 2, *m*)[12] which has been adapted to give Laue photographs as well as rotation and Weissenberg pictures; photographs on crystalline powders are made on the powder camera (*l*).[13]

Of the several types of film that have been used, the Eastman "No-Screen" *x*-ray film has given the best results.

Performance. Since completion (November, 1938) the *x*-ray installation has given continuous satisfactory service, the log showing nearly 2,000 running hours (June, 1939). Replacements were limited to an unsuitable thermionic valve, which failed soon after installation, one "Pyrex" cylinder, and six cathodes which depreciated in the normal way. Apart from experimental photographs the apparatus has been used mainly to obtain new or improved structural data on imperfectly known minerals. Some of the results of this work appear elsewhere in this issue of the *Contributions to Canadian Mineralogy*.

ACKNOWLEDGMENTS

The writer is widely indebted for the valued opportunity of assembling a modern installation for research in structural mineralogy, conducting such work, and introducing others to this fruitful field. His thanks are due principally to President Cody, who recognized the increasing importance of the subject and obtained

[12]Made after the design of Buerger (1936A) by C. L. Berger and Sons, 37 Williams Street, Boston, Massachusetts.

[13]Made after the design of Buerger (1936B) by the Physics Workshop, University of Toronto.

the necessary funds for the fundamental apparatus; to Professor Parsons, for constantly encouraging the work; to Professor Burton, for authorizing many services by the Physics Workshop; to Professor Ireton, for indicating reliable manufacturers and dealers in Canada, and for the temporary use of sundry appliances; and to Mr. Berry for much cheerful and skilful assistance.

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EXPLANATION OF FIGURES

FIG. 1.—General arrangement. *a*—main transformer; *b*—instrument panel; *c*—insulator; *d d d*—high tension leads; *e*—rheostat; *f*—filament transformer; *g*—insulator; *h*—voltmeter; *i*—socket; *j*—thermionic valve; *k k*—insulators; *l*—main water valve; *m*—needle valve controlling flow to target and body of *x*-ray tube; *n*—flow from target and body of *x*-ray tube; *o*—"Pressuretrol"; *p*—visible water column; *q*—valve controlling outflow; *r*—overflow pipe; *s*—needle valve controlling flow to cathode; *t t t*—flow to cathode; *u*—glass-water resistance; *v v v v*—flow from cathode; *w*—drain.

FIG. 2.—*X*-ray tubes and cameras. *a*—marble table top; *b*—hollow post and air passage connecting *x*-ray tube and main vacuum tank; *c*—needle valve controlling air from auxiliary vacuum tank; *d*—needle valve controlling passage of air to and from *x*-ray tube; *e*—rubber pressure tubing leading water to and from target and body of tube; *f*—body of tube; *g*—lead cap covering unused port; *h*—"Pyrex" glass cylinder; *i*—aluminium cathode; *j*—rubber pressure tubing leading water to and from cathode; *k*—copper tubing leading from valve *c* to auxiliary vacuum tank.

FIG. 3.—Vacuum system. *a*—motor; *b*—vacuum pump; *c c*—soft rubber seats; *d d d*—rubber vacuum tubing; *e e*—"Pyrex" glass cocks, ground for high vacuum; *f f f f f f*—turned brass connections; *g*—main vacuum tank; *h*—auxiliary vacuum tank; *i*—brass tube with flexible metal section leading to hollow post of *x*-ray tube; *j*—copper tube leading from auxiliary vacuum tank to valve *c* (Fig. 2); *k*—narrow bore "Pyrex" cock with fine short jet.

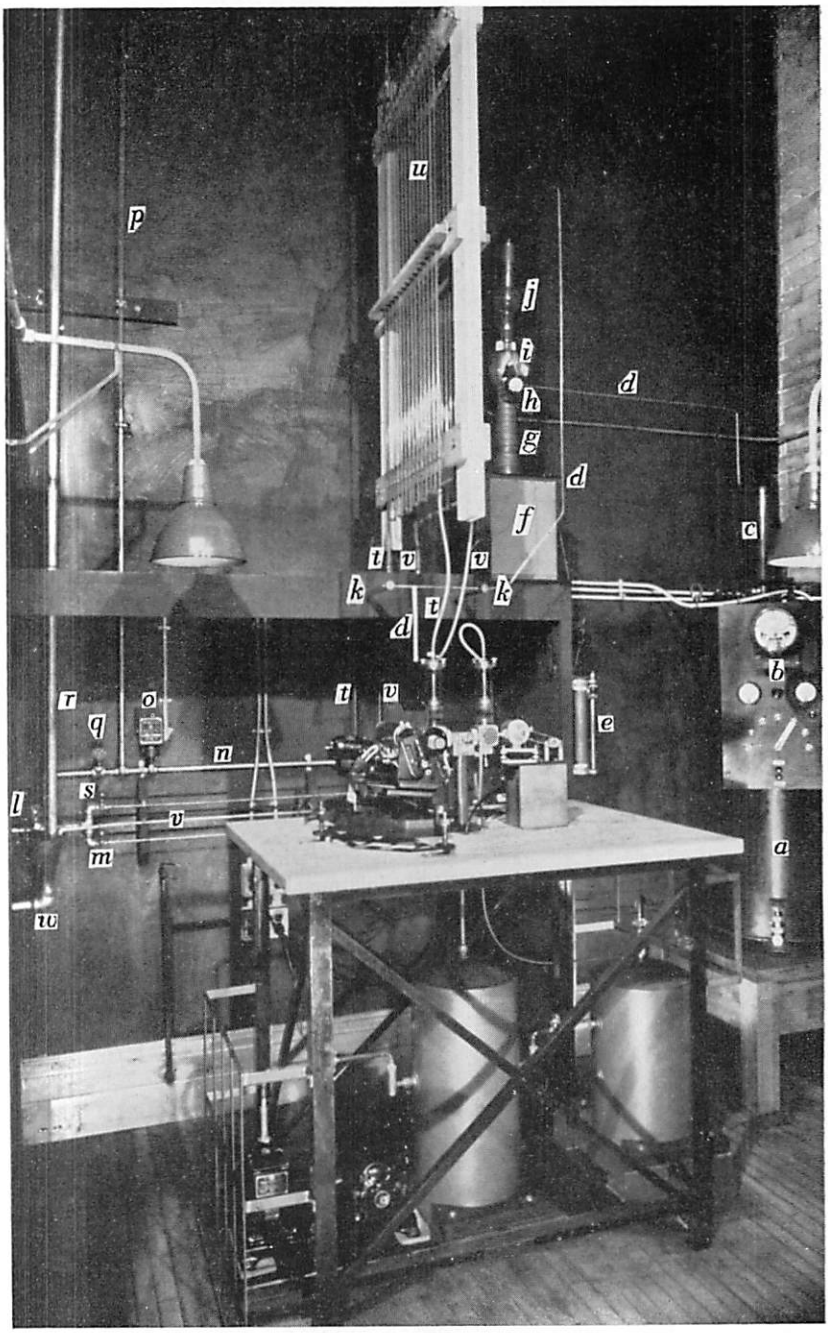


FIG. 1

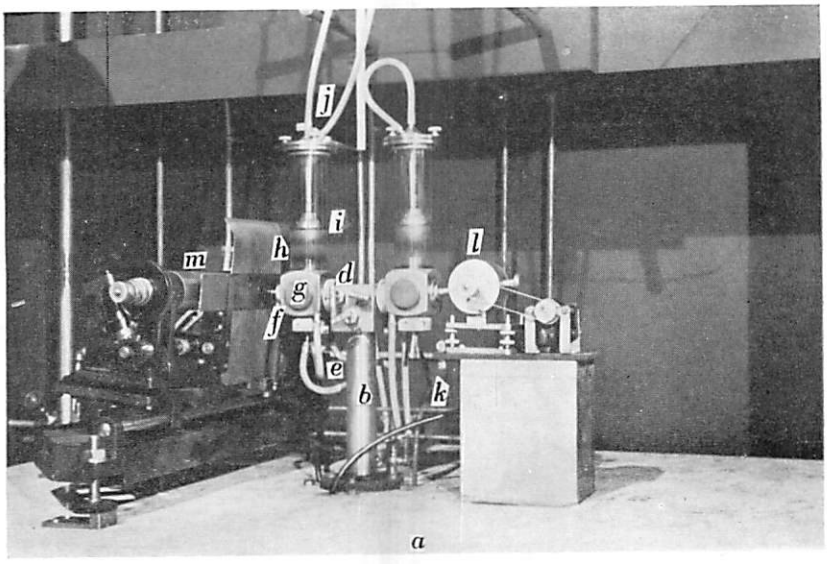


FIG. 2

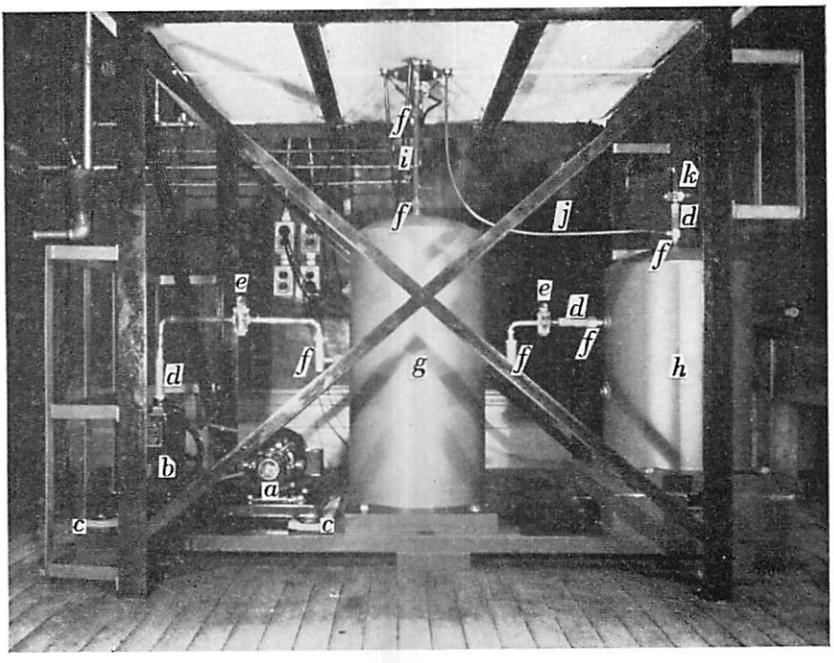


FIG. 3

ON RAMMELSBERGITE FROM ONTARIO

By M. A. PEACOCK, *University of Toronto*
and C. E. MICHENER, *International Nickel Company of Canada*
Copper Cliff, Ontario

In the course of a study[1] of the nickel arsenide named maucherite by Grünling (1913) and temiskamite by Walker (1914), a re-examination was made of the abundant material from the Moose Horn Mine, Elk Lake, Ontario, the type locality for temiskamite. In this material was found a single specimen that lacked the pinkish hue of typical temiskamite. This specimen was first examined closely by Doctor Harcourt who clearly showed, in a personal communication (March 8, 1939), that it differed essentially from maucherite whose properties we later found to be identical with those of temiskamite.

Doctor Harcourt suggested further study of the specimen in question. This was undertaken by the present authors, who found that the exceptional specimen from Elk Lake agreed in its chemical, physical, and structural properties with material from Cobalt, Ontario, identified by Walker and Parsons (1921) as rammelsbergite, the orthorhombic diarsenide of nickel. Our observations are given in some detail since they lead to goniometric and röntgenographic measurements which have not as yet been made on rammelsbergite of established chemical and physical purity.

MATERIALS AND ACKNOWLEDGMENTS

The materials used in the present study were kindly placed at our disposal by Professor A. L. Parsons, Director of the Royal Ontario Museum of Mineralogy.

1. Rammelsbergite, ROMOM, M/12411, Moose Horn Mine, Elk Lake, Gowganda, Ontario. Compact, fine-grained, tin-white mass, with attached calcite, 1½ inches in size. The specimen has a rudely platy structure and a delicate iridescent tarnish on old fracture surfaces.

2. Rammelsbergite, ROMOM, M/11772, Hudson Bay Mine, Cobalt, Ontario. Compact tin-white mass with attached calcite, 2 inches in size. The

[1]By the first-named author in collaboration with Dr. G. A. Harcourt of the International Nickel Company of Canada, Copper Cliff, Ontario. The results of this work will be communicated on another occasion.

specimen shows very little tarnish; on old weathered surfaces it is coated with a greenish white bloom. Described by Walker and Parsons (1921) with notes on a polished section by Thomson and an analysis by Todd.

We are also indebted to Dr. G. A. Harcourt for assistance in the study of polished sections; to Professor F. E. Beamish for supervising an analysis by Mr. G. W. Rogers in the Department of Chemistry; and to Dr. George Tunell of the Geophysical Laboratory in Washington, D.C., for advice on space-group notation.

OBSERVATIONS ON POLISHED SECTIONS

Specimen 1—Elk Lake

A polished section of the Elk Lake material (Fig. 1) shows a white mineral with no trace of the pink shade characteristic of maucherite, containing 2-3 per cent of niccolite finely and evenly

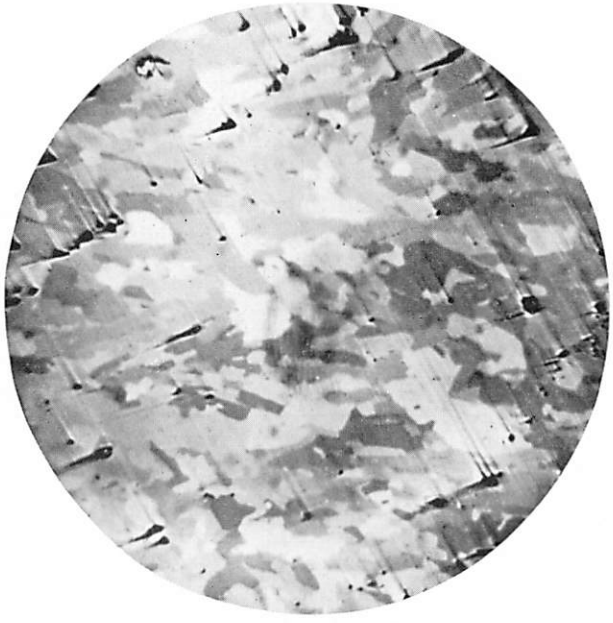


FIG. 1.—Rammelsbergite, Moose Horn Mine, Elk Lake, Ontario. Vertical illumination; crossed nicols; ×85. The field consists wholly of granular anisotropic rammelsbergite. The small black areas are pits; the shaded lines are due to polishing.

distributed as the only impurity. The white mineral is strongly anisotropic giving the polarization colours: salmon, buff, grey, greenish grey. Polarized light shows the mineral to be a uniform interlocking mosaic of grains averaging 0.06 mm. in diameter. The niccolite gives more brilliant polarization colours. Talmage hardness, E.

Another section from the same specimen, kindly examined by Professor J. E. Thomson, showed small sparse cubes of a mineral, presumably cobaltite, which was unattacked by nitric acid. Most areas are free from this mineral whose total amount appears to be less than one per cent of the section.

Etch tests: HNO_3, effervesces instantly and blackens; HCl, negative; KCN, negative; $FeCl_3$, stains light brown, brings out grain boundaries; KOH, negative; $HgCl_2$, slowly stains brown.

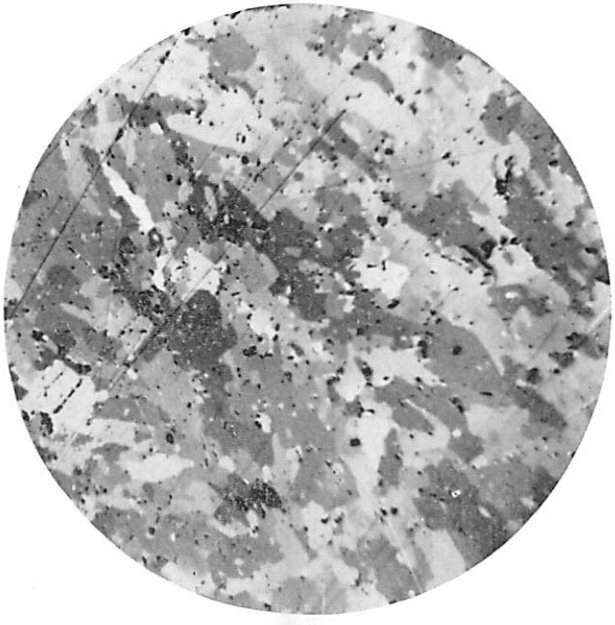


FIG. 2.—Rammelsbergite, Hudson Bay Mine, Cobalt, Ontario. Vertical illumination; crossed nicols; ×85. The field consists wholly of granular anisotropic rammelsbergite. The small black areas are pits.

Specimen 2—Cobalt

A polished section of this specimen (Fig. 2) consists of a remarkably pure, uniformly white mineral containing occasional minute white grains which are unaffected by nitric acid and make up less than one per cent of the surface. The white mineral is strongly anisotropic, the polarization colours being: buff yellow, salmon, grey, dark greenish grey. Under polarized light the mineral is seen to consist of fairly uniform interlocking grains with an average diameter of 0.05 mm. Talmage hardness, E.

Etch tests: HNO_3, effervesces instantly and blackens; HCl, negative; KCN, negative; $FeCl_3$, stains light brown; KOH, negative; $HgCl_2$, slowly stains brown.

Thus, in polished sections, the two specimens are practically identical in their properties which agree very closely with those given for rammelsbergite by Short (1934).

CHEMICAL COMPOSITION

An analysis[2] of the Elk Lake rammelsbergite is given in Table 1, together with Todd's analysis[3] of the material from the Hudson Bay Mine, Cobalt. For comparison the best of the three early analyses[4] of rammelsbergite from Schneeberg is taken from Dana. All three analyses agree well with the percentage composition of $NiAs_2$, the Elk Lake material containing the least impurity. The nearly homogeneous appearance of the polished section of this material, together with the lack of iron and the small amount of cobalt in the analysis, indicates that the Elk Lake rammelsbergite comes closer to the ideal composition than most specimens, in which considerable mechanical or isomorphous admixture of other compounds is assumed (Walker and Parsons, 1921; Schneiderhöhn and Ramdohr, 1931, p. 209).

[2]Made by preference on a sample of about 50 mg. Time was taken to develop a method which gave accurate recovery of arsenic and nickel from a standard solution.

[3]This analysis is quite similar to Todd's four analyses of rammelsbergite from the Silver Bar Mine (Walker and Parsons, 1921, pp. 28, 29).

[4]The remaining two analyses of rammelsbergite in Dana (1892, p. 101) are unsatisfactory. One of them, dating from 1832, sums to 102.27; the other is reduced to the sum of 100 after deducting 5.11 per cent bismuth.

TABLE 1.—RAMMELSBERGITE: ANALYSES

	1	2	3	4
Ni	28.1	27.08	26.65	28.1
Co	0.4	1.94	trace	——
Fe	none	0.56	2.06	——
Cu	none	0.16	trace	——
Bi	——	——	2.66	——
Sb	——	0.91	——	——
As	68.5	65.78	68.30	71.9
S	2.6	3.05	trace	——
	99.6	99.48	99.67	100.0
G	7.12	7.02	7.19	

1. Elk Lake (Specimen 1); anal. G. W. Rogers.
2. Cobalt (Specimen 2); anal. E. W. Todd, in Walker and Parsons (1921, p. 30).
3. Schneeberg, Saxony; anal. Hilger, 1871 (Dana, 1892, p. 101).
4. $NiAs_2$.

CRYSTALLOGRAPHY

The existing crystallographic data on rammelsbergite are meagre and conflicting; a special effort was therefore made to obtain both goniometric and röntgenographic measurements on the nearly pure Elk Lake material. In the first place *x*-ray powder photographs were made on samples from the Elk Lake and Cobalt specimens. The two materials gave identical complex patterns, described later.

Careful inspection of the Elk Lake specimen revealed a small part of the natural surface in which the grain size increased to a maximum of 0.5 mm. Here the individual grains presented a roughly rectangular, terraced, tabular appearance due to the oscillation of the plane of tabular development with narrow and imperfect crystal facets. The plane of tabular development proved to be a plane of perfect and easy cleavage, apparently pinakoidal, offering the possibility of obtaining a single crystal fragment which could be oriented on the *x*-ray goniometer. Eventually such a fragment was secured, a squarish tablet 0.4 mm. in greatest width and 0.08 mm. thick. One broad surface consisted wholly of a cleavage plane; the other was made up of a crystal face parallel to the cleavage, in oscillatory combinations with minute facets from which a few identi-

fiable reflections were obtained on the optical goniometer. The normal to the cleavage proved to be a rational crystallographic direction and thus it was possible to obtain rotation and Weissenberg photographs leading to the space group, cell dimensions, and cell content of the substance.

Measurements on the Reflecting Goniometer

The crystal fragment was adjusted with the broad crystal face in polar position. With reference to the axial ratio subsequently obtained from x-ray measurements

$$a_0 : b_0 : c_0 = 0.988 : 1 : 1.963$$
$$p_0 : q_0 : r_0 = 1.987 : 1.963 : 1$$

the visible facets, from which feeble reflections were obtained, were identified as in Table 2. The adopted orientation brings out the pronounced pseudo-tetragonal character of the orthorhombic lattice, the plane of tabular development and cleavage becoming {001}.

TABLE 2.—RAMMELSBERGITE FROM ELK LAKE: FORMS AND ANGLES

Forms	Measured		Calculated	
	ϕ	ρ	ϕ	ρ
c 001	——	0°00′	——	0°00′
d 104	90°00′	25 58	90°00′	26 25
e 304	90 00	55 15	90 00	56 08
p 113	45 37	42 48	45 21	42 57½
q 112	45 37	53 35	45 21	54 23½

The agreement between the measured and calculated values is only fair, but the identification of the forms may be considered certain since the optical and röntgenographic measurements were made on one and the same crystal.

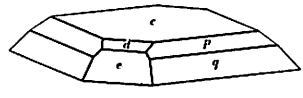


FIG. 3.—Rammelsbergite. Drawing showing the habit of the measured crystal.

Fig. 3 shows the habit of the fragment, with the upper part symmetrically restored and the oscillations between the base and the terminal planes neglected. The bottom of the crystal is bounded by the basal cleavage. Comment on these geometrical results in relation to those previously reported on rammelsbergite will be offered later.

Measurements on the X-Ray Goniometer

A rotation photograph (Fig. 4), with copper radiation, about the normal to the cleavage, the axis [001], gave the layer lines, 0, 1, 2, 3, 4, 5, from which was obtained the value:

$$c_0 = 11.405 \pm 0.03 \text{ Å}$$

Weissenberg photographs were made of the zero (Fig. 5), first (Fig. 6), second and third layer lines about the same axis; a zero-layer Weissenberg was also made about the axis [110] in order to obtain the systematic extinctions of planes $\{00l\}$ and further information on the tenor of the intensities to assist in indexing the powder photographs.

Measurement of the films gave the remaining lattice periods:

$$a_0 = 5.74 \pm 0.01 \text{ Å}; \quad b_0 = 5.81 \pm 0.01 \text{ Å}$$

As it may not be easy to secure another measurable crystal, a condensed tabulation of the observed reciprocal lattice points may be of value. Without attempting to estimate the relative intensities closely, we shall simply distinguish the prominent spots with an asterisk. The films showed orthorhombic symmetry in regard to the positions of the spots. At the same time some serious departures from orthorhombic equivalence of intensities were noted, indicating a lower true symmetry such as Buerger (1937) has found in the Arsenopyrite Group. For the present purpose, however, the orthorhombic treatment will suffice since the films may be completely indexed with reference to a simple rectangular lattice.

Zero layer Weissenberg about [001]

—	—	*020	—	—	—	060
—	—	—	—	—	—	—
*200	210	220	*230	—	*250	260
—	—	—	—	—		
*400	—	420	—	440		
—	—	—	—			
*600	610	*620	*630			

First layer Weissenberg about [001]

—	—	*021	—	*041	—	061
—	111	*121	*131	141	*151	161
—	*211	221	—	241	—	—
—	311	321	331	341	351	361
—	411	—	—	*441		
—	511	521	—	541		
—	*611					

Second layer Weissenberg about [001]

—	—	*022	—	—	—	062
—	—	*122	—	—	152	162
—	*212	—	232	—	252	
—	*312	322	—	—	352	
—	—	422	—	—	452	
—	512	522				
—	612					

Third layer Weissenberg about [001]

—	—	*023	—	—	—	063
—	—	*123	133	—	153	163
203	*213	—	233	—	253	—
303	*313	323	—	—	—	363
—	—	423	—	—	—	463
503	513	523				
603	613					

Zero layer Weissenberg about [110]

—	—	220	—	—
—	111	221	331	—
—	—	—	—	—
—	*113	223	333	443
*004	114	224	*334	
—	*115	225	—	
—	*116	—	—	
—	117	—	*337	
*008	118	228	—	
—	119	—	339	
—	*1.1.10	—	—	
—	*1.1.11	—	3.3.11	
0.0.12	—	2.2.12		
—	1.1.13	2.2.13		
—	1.1.14			

From the foregoing tabulation we obtain the following statement of systematic spectral omissions:

hkl present in all orders
0*kl* present only with *k* even
*h*0*l* present in all orders
*hk*0 present only with *h* even

and the special cases:

*h*00 present only with *h* even
0*k*0 present only with *k* even

These conditions are characteristic of the space groups $D_{2h}^{11} = Pbma$ (holohedral) and $C_{2v}^{5} = Pb2a$ (hemimorphic). Without information on the crystal class we cannot choose between these alternatives.

In addition to these omissions which conform to space group conditions the tabulation shows further systematic and random extinctions due to the structure:

00*l* present only with $l = 4n$
*hk*0 with $h = 4n$ present only with *k* even
*h*0*l* absent except with $l = 3$

Powder Photographs

The powder photograph[5] of the material from Elk Lake is reproduced in Fig. 7; the material from Cobalt gave the photograph in Fig. 8. The patterns are identical as regards the positions and relative intensities of the lines. An interesting feature of the photographs appears in numerous pairs of barely separated lines resulting from the near equality of the cell edges: $a_0 \doteqdot b_0 \doteqdot c_0/2$.

Table 3 gives for each pair of powder lines: (1) the uncorrected glancing angle ϑ, as given by half the distance between corresponding lines in mm.; (2) the corresponding corrected spacing, *d* (meas.), as given by a formula derived from calibration photographs:

$$d \text{ (meas.)} = 0.9975\lambda/2 \sin (\vartheta - 0.4°)$$

(3) the indices *hkl* of the powder line;[6] (4) the calculated spacing from the quadratic form:

$$\frac{1}{d^2 \text{ (calc.)}} = \frac{h^2}{a_0^2} + \frac{k^2}{b_0^2} + \frac{l^2}{c_0^2}$$

[5]The mounts were prepared in the very serviceable manner described by Harcourt (1937, p. 518).

[6]In finding the indices a graphical method (Peacock, 1938) proved useful.

EXPLANATION OF FIGURES 4—8

Rammelsbergite. *X*-ray photographs with unfiltered copper radiation. Diameter of cameras, 57.26 mm. The scale of Figs. 4—8 is such that the horizontal distance between the slanting lines (Figs. 5, 6) equals 45 mm. on the films.

FIG. 4.—Moose Horn Mine, Elk Lake, Ontario. Rotation photograph about [001], normal to the cleavage; 1.1 KWH.

FIG. 5.—The same. Zero layer Weissenberg photograph about [001]; 8.5 KWH.

FIG. 6.—The same. First layer Weissenberg photograph about [001]; 10.0 KWH.

FIG. 7 (above).—The same. Powder photograph; 1.5 KWH.

FIG. 8 (below).—Hudson Bay Mine, Cobalt, Ontario. Powder photograph; 1.4 KWH.

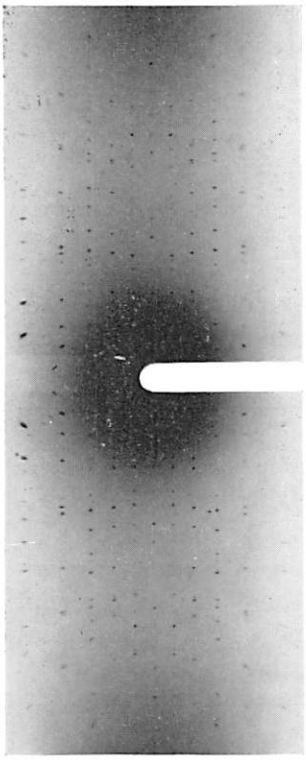


FIG. 4

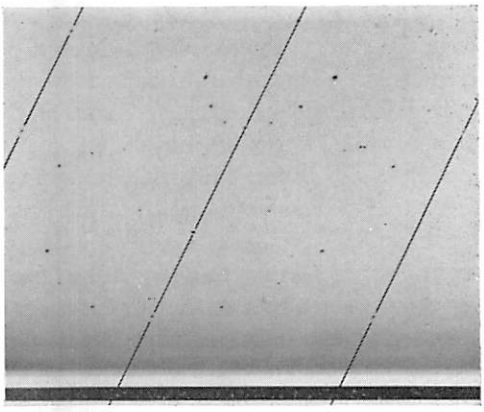


FIG. 5

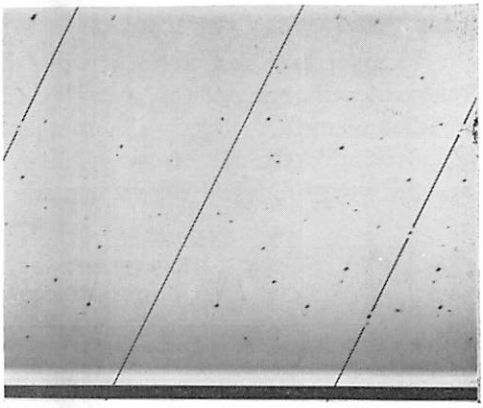
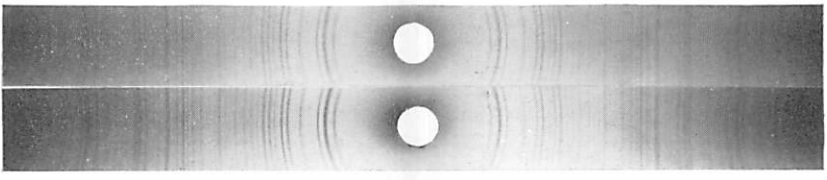


FIG. 6



FIGS. 7 and 8

The lines which are barely separated are indicated by braces around the ϑ-values. *P* indicates a prominent powder line; *W* a prominent Weissenberg spot; *w* a weaker Weissenberg spot. Indices not marked lie beyond the range of the Weissenberg photographs taken. The indexing may be regarded as certain except for a few cases where several possible reflecting planes have spacings very near the measured value. In such cases the plane with the nearest spacing and greatest Weissenberg intensity was assumed to have contributed mainly to the powder line. The nickel in the mineral appears to act as an efficient filter for the β-radiation in a powder photograph. Only the first line is perhaps the β-line of the next (triple) line. For the β wave-length the first line gives d (meas.) = 2.52 Å corresponding to d (calc.) = 2.53 Å for the set of planes (121). Even with known lattice elements the complete discussion of the powder photograph proved difficult and convinced us that there would be little chance of finding the correct indices and elements from the powder picture alone.

This presentation of the powder diagram will serve for subsequent identification of this material. The complete indexing, with good agreement between the measured and calculated spacings, also excludes the remote possibility that the single crystal and powder measurements were not made on the same substance.

TABLE 3.—RAMMELSBERGITE FROM ELK LAKE: POWDER PHOTOGRAPH

	$\vartheta°$	d(meas.)Å	*hkl*	d(calc.)Å
P	16.0	2.85	*W* 004	2.85
P	17.55	2.60	*W* 022	2.59
P	17.95	2.54	*W* 121	2.53
P	18.15	2.51	*W* 211	2.51
P	19.2	2.38	*W* 122	2.36
P	22.4	2.05	*w* 220	2.04
P	22.8	2.01	*w* 221	2.01
P	25.2	1.828	*W* 131	1.811
P	25.6	1.801	*w* 223	1.799
P	26.6	1.737	*W* 312	1.732
P	27.9	1.661	*w* 224	1.660
P	28.1	1.650	*W* 313	1.640

TABLE 3.—*Continued*

	$\vartheta°$	d(meas.)Å	hkl	d(calc.)Å
P	28.8	1.612	W 230	1.605
P	29.1	1.597	w 321	1.582
P	30.0	1.552	134	1.543
P	30.4	1.534	w 322	1.538
	31.6	1.480	w 233	1.478
P	32.4	1.447	W 041	1.441
P	32.8	1.431	W 008	1.423
	34.0	1.386	w 411	1.382
	35.8	1.324	W 313	1.313
	37.9	1.260	w 422	1.255
P	39.0	1.229	W 334	1.228
P	39.3	1.221	w 423	1.218
	40.1	1.200	244	1.180
	42.8	1.137	W 151	1.133
	43.5	1.122	w 511	1.120
	44.1	1.110	w 512	1.105
	44.6	1.100	W 1.1.10	1.098
	45.6	1.081	W 250	1.077
P	46.4	1.066	w 521	1.063
	47.5	1.047	W 337	1.044
	48.1	1.037	w 253	1.036
P	49.1	1.021	w 440	1.021
P	49.6	1.013	W 441	1.017
	51.4	0.987	w 351	0.987
	52.3	0.974	w 060	0.968
	53.7	0.956	W 600	0.957
	55.0	0.941	W 611	0.941
	56.0	0.929	w 339	0.927
	58.0	0.908	W 620	0.909
	59.7	0.892	w 541	0.898
	63.5	0.860	W 630	0.858
	65.7	0.844	w 363	0.842
	66.9	0.836	448	0.830

ATOMIC CONTENT OF THE UNIT CELL

From the empirical formula, $NiAs_2$, with the molecular weight $m=208.55$, together with the cell volume, $V_0=a_0b_0c_0=380.4$ cubic Å, and the measured specific gravity, $G=7.12$ (Peacock), the number of empirical molecules in the unit cell is:

$$Z=V_0G/1.65\ m=7.87 \text{ or nearly } 8$$

For a cell containing 8[$NiAs_2$], with molecular weight $M=1668.4$ the calculated specific gravity is:

$$G_0=1.65\ M/V_0=7.24$$

The range of specific gravities reported on rammelsbergite is 6.9-7.2 (Dana, 1892).

Or, we may proceed from the molecular weight as given by the measured cell volume and specific gravity:

$$M_0=V_0G/1.65=1641$$

and apply this to the analysis of the measured material to obtain the atomic cell content, as shown in Table 4.

TABLE 4.—RAMMELSBERGITE FROM ELK LAKE: ATOMIC CONTENT OF THE UNIT CELL
$M_0=1641$

	1	2	3	4	
Ni.....	28.1	0.279	0.00475	7.8	7.9
Co.....	0.4	0.004	0.00007	0.1	
As.....	68.5	0.690	0.00921	15.1	16.5
S.....	2.6	0.027	0.00083	1.4	
	99.6	1.000			

1. Analysis (Table 1, column 1). 2. Reduced to a sum of unity after deducting 2 per cent of niccolite. 3. Atomic proportions. 4. Atoms in the unit cell.

Again the cell content is close to $Ni_8As_{16}=8[NiAs_2]$, in which a small amount of sulphur takes the place of arsenic.

DISCUSSION OF RESULTS

In the foregoing description we have given chemical, physical, geometrical, and structural data on an orthorhombic diarsenide of nickel from two occurrences in Ontario. The new analysis comes closer to the ideal composition of rammelsbergite than any previous analysis. The appearance of the polished section, the anisotropism, the hardness, the specific gravity, and the etch reactions likewise lie within the range of properties of materials referred to rammelsbergite. Thus far it would appear that the Ontario material was indisputably identified with rammelsbergite.

On comparing our observations on cleavage, crystal form, and crystal structure with those reported on rammelsbergite we find certain differences, even when the uncertainties of the previous observations are taken into account. In contrast to our excellent pinakoidal cleavage that of rammelsbergite is given as prismatic (Dana, 1892, p. 101); that of the related species safflorite—$CoAs_2$, however, is given as pinakoidal. The crystal form attributed to rammelsbergite is prismatic similar to that of arsenopyrite—FeAsS, with a prism angle $(110):(1\bar{1}0) = 56\text{-}57°$. The habit of our material, so far as it is developed, is tabular parallel to the cleavage and the unit prism angle would be close to a right angle due to the pseudo-tetragonal geometry.

On minute imperfect crystals doubtfully referred to rammelsbergite on the basis of blowpipe tests, Palache and Wood (1904) obtained the axial ratio:

$$a : b : c = 0.5722 : 1 : 1.1545$$

with the forms: {010}, {120}, {110}, {210}, {014}, {013}, {012}, {021}, {102}. The prism angle is $(110):(1\bar{1}0) = 59°34'$. No mention is made of cleavage. We can find no simple relation between these elements and forms and those that we have found.

A few years later Dürrfeld (1911) obtained some poor measurements on crystals of *Weissnickelkies* from Riechelsdorf, an accepted locality for rammelsbergite. The crystals were prismatic with the forms {110}, {011}, {101}, giving the ratio:

$$a : b : c = 0.6798 : 1 : 1.1622$$

which is close to the accepted ratio for arsenopyrite. Again there is no simple relation between these data and ours.

The only x-ray work reported on rammelsbergite is by de Jong (1926), who found that the cell edges of rammelsbergite—$(Ni,Co,Fe)As_2$ from Schlaggenwald, Styria, are the same as those of safflorite—$(Co,Fe)As_2$ and löllingite—$FeAs_2$ from Saxony:

$$a_0 = 6.35 \qquad b_0 = 4.86 \qquad c_0 = 5.80$$

with $Z = 4$ and $G_0 = 7.75$, in poor agreement with the measured values, 6.9-7.2. On löllingite—$FeAs_{1.78}$ from Franklin, New Jersey, Buerger (1932) obtained values very different from those of de Jong whose data for rammelsbergite therefore do not appear to be reliable.

Turning to x-ray work on related species we find some interesting

analogies. No measurements have been made on chloanthite,[7] the cubic form of $NiAs_2$; on pyrite, cobaltite, and gersdorffite, however, Ramsdell (1925) obtained the cube edges:

Pyrite	—FeS_2	a_0	5.38 Å
Cobaltite	—CoAsS		5.58
Gersdorffite	—NiAsS		5.68

which are comparable to our values:

$$a_0 = 5.74 \qquad b_0 = 5.81 \qquad c_0/2 = 5.70$$

This suggests that the structure of rammelsbergite may be similar to that of these related cubic species.

In a series of papers, 1931-7, Buerger[8] has given structural data from single crystal measurements on several members of the Marcasite Group of Dana (1892, p. 94), and has proposed an orientation and classification (1937, p. 54) of these minerals based on structural symmetry. The data in Table 5 are extracted from this tabulation.

TABLE 5.—MARCASITE GROUP OF DANA: ABBREVIATION OF BUERGER'S CLASSIFICATION

Marcasite Group	Orthorhombic	Marcasite 2[FeS_2]	a_0 4.44	b_0 5.39	c_0 3.37 Å
Löllingite Group	Orthorhombic	Löllingite 2[$FeAs_2$]	5.25	5.92	2.85
		Safflorite $CoAs_2$	——	——	——
		Rammelsbergite $NiAs_2$	——	——	——
Arsenopyrite Group	Gudmundite Type Monoclinic ($\beta = 90°$)	Gudmundite 8[FeSbS]	10.04	5.93	6.68
	Arsenopyrite Type Triclinic ($\alpha = \beta = \gamma = 90°$)	Arsenopyrite 8[FeAsS]	9.51	5.65	6.42
		Glaucodot 8[$\left\vert\begin{matrix}Co\\Fe\end{matrix}\right\vert$ AsS]	9.62	5.73	6.67
		Wolfachite Ni $\left\vert\begin{matrix}As\\Sb\end{matrix}\right\vert$ S	——	——	——

[7]From smaltite-chloanthite—(Ni,Co,Fe)As_2 Ramsdell (1925) obtained too complicated a powder diagram for structural determination. This suggests that his material was not isometric.

[8]See Buerger (1937).

The seemingly coherent Marcasite Group of Dana appears to divide into sub-groups and types almost as numerous as the species themselves. It will be seen that the Ontario rammelsbergite does not come close to any of the structurally studied species. On the basis of its cell edges and cell content our mineral fits better in the Arsenopyrite Group of Buerger than in the Löllingite Group; but even there the Ontario mineral is distinguished by a simple lattice, a cell ratio of nearly 1:1:2 (2:1:1), and an apparent orthorhombic space group which is not among those indicated by Buerger.

Finally, after the work on the Ontario material was finished, a rapid examination was made of materials named rammelsbergite from other localities; the combined observations were then compared with notes and x-ray films on rammelsbergite in Doctor Harcourt's possession. The assembled information presented a diversity which demands further detailed study. At present we can say that if rammelsbergite is defined as the orthorhombic or pseudo-orthorhombic diarsenide of nickel, then our material is rammelsbergite of unusual purity; if it can be shown, however, that the original or typical rammelsbergite (if such can be obtained) is a homogeneous mineral essentially different from ours, then the Ontario mineral is a distinct substance. We propose to pursue this question in the near future.

SUMMARY

A nickel arsenide of unusual purity, from Moose Horn Mine, Elk Lake, Ontario, is pseudo-orthorhombic; $a_0:b_0:c_0=0.988:1:1.963$ (from single crystal x-ray measurements). Habit, tabular $\{001\}$; forms $c\{001\}$, $d\{104\}$, $e\{304\}$, $p\{113\}$, $q\{112\}$. Space group, $Pbma$ or $Pb2a$; cell edges, $a_0=5.74\pm0.01$, $b_0=5.81\pm0.01$, $c_0=11.405\pm0.03$Å; cell content, Ni_8As_{16}. Cleavage, $\{001\}$, perfect and easy; H (Talmage) = E; $G=7.12$ (meas.), 7.24 (calc.). Hand specimen, tin white, massive, in part minutely crystallized. Polished sections, pure white, strongly anisotropic; fine granular, homogeneous, with about 2 per cent niccolite and less than 1 per cent cobaltite. Analysis, Ni 28.1, Co 0.4, Fe 0.0, Cu 0.0, As 68.5, S 2.6 = 99.6.

Rammelsbergite from Hudson Bay Mine, Cobalt, Ontario, is similar in composition and physical properties and gives an identical x-ray powder pattern.

The physical and chemical properties of the Ontario mineral agree well with those given for rammelsbergite; the morphological and structural observations, however, do not agree closely with the existing uncertain data reported on rammelsbergite.

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CALCIUM DIBORATE HEXAHYDRATE FROM A MORTAR OF PORTLAND CEMENT AND COLEMANITE

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In connection with a study of Portland cement aggregates,[1] mortar briquettes consisting of one part Portland cement and four parts colemanite ($Ca_2B_6O_{11}.5H_2O$) were prepared in the usual manner and stored in distilled water. After fourteen months, when the tensile strength of the briquettes was determined, large crystals were found attached to the briquettes; groups of similar crystals lay on the bottom of the sealed container in which the briquettes had been stored.

The crystals were clear and colourless except on the attached surfaces which were white and opaque due to the inclusion of debris. Qualitative analysis showed the crystals to be a hydrated calcium borate, but the optical properties proved to be different from those of colemanite or of any other naturally occurring calcium borate. Clear crystals were selected and analysed and found to correspond closely to hexahydrated calcium borate, $CaB_2O_4.6H_2O$. The formation of this compound by the reaction of Portland cement and colemanite in presence of water may be regarded as following the reaction:

$$\underset{\text{Colemanite}}{Ca_2B_6O_{11}.5H_2O} + Ca(OH)_2 + 12H_2O \rightarrow 3\underset{\substack{\text{Calcium diborate}\\\text{hexahydrate}}}{(CaB_2O_4.6H_2O)}$$

giving the most highly hydrated compound of the system, $CaO\text{-}B_2O_3\text{-}H_2O$.

According to Mellor (1924, p. 88), Ditte first prepared a salt, which he regarded as heptahydrated calcium diborate, by adding borax to a solution of a calcium salt and treating the precipitate with an excess of calcium hydroxide solution. The crystals that gradually formed were described as six-sided prisms or hexagonal plates. They were stable in presence of atmospheric carbon dioxide but rapidly dehydrated at 80°C. The crystals dissolved in water at 10°C. to the extent of two grams per litre, giving an alkaline

[1]Conducted by Dr. T. Thorvaldson, at the University of Saskatchewan.

solution. Van't Hoff and Meyerhoffer showed that Ditte's compound was hexahydrated calcium diborate, $CaB_2O_4.6H_2O$, which Meyerhoffer prepared by the action of boric acid on calcium chloride in an aqueous solution of potassium hydroxide.

Since nothing is known of the crystals of calcium diborate hexahydrate, beyond the suggestion of hexagonal form, which proves to be erroneous, a fairly detailed study was undertaken, especially since the material proved suitable for exact crystallographic measurements. In the present account the first-named author is responsible for the morphological and röntgenographic description; the second-named author recognized and analysed the substance and determined the physical properties and indices of refraction of the crystals. We are indebted to Mr. L. G. Berry for an independent determination of the optical properties of the crystals, and to Mr. K. J. McCallum for measuring their density.

CHEMICAL PROPERTIES

The composition of the crystals was established by the following analysis (1) which compares closely with the theoretical values (2) corresponding to the formula $CaO.B_2O_3.6H_2O$.

	1	2
CaO	23.97	23.99
B_2O_3	30.39	29.78
H_2O at 550°C	45.86	46.23
	100.22	100.00

The sample yielded 37.1 per cent water at 120°C., as compared to 37.8 per cent required by $5H_2O$ in the formula. The crystals thus lose five molecules of water at 120°C., the balance at red heat. They are slightly soluble in water, readily soluble in dilute acids. The crystals are stable in air at room temperature and not affected by the carbon dioxide of the atmosphere.

PHYSICAL PROPERTIES

The crystals are colourless and transparent, with brilliant vitreous lustre; brittle, with uneven fracture; one perfect cleavage, taken as basal {001}; hardness $2\frac{1}{2}$; specific gravity 1.884 ± 0.005 (Peacock, by suspension in bromoform and alcohol), 1.881 ± 0.005

(McCallum, on a 2 gm. sample in carbon tetrachloride and xylene); fusibility 1.

OPTICAL PROPERTIES

The crystals are biaxial, negative, with low refringence and moderate birefringence. The optic axial angle is large with perceptible dispersion, $r>v$. The optic axial plane is normal to the monoclinic symmetry plane. The acute bisectrix is parallel to B[010]; the obtuse bisectrix is inclined to C[001] at 3° in the acute axial angle β (Fig. 1). The following statement of the optical properties includes the principal indices of refraction as measured by Vigfusson and the complete optical data by Berry.

	n (Vigfusson)		n (Berry)		
$X=B$	1.505	±0.002	1.506	±0.002	Negative
$Y : C=+87°$	1.511		1.511		$r>v$
$Z : C=-3°$	1.515		1.514		
$2V$ (calculated)	79°±5°		76°±5°		

CRYSTALLOGRAPHY

Morphology. The material available for crystallographic study consisted of several large crystals of fair quality and some groups of smaller crystals from which a few individuals of excellent quality and convenient size (1 to 3 mm.) were selected for measurement on the two-circle goniometer.

Most of the crystals are thick tables flattened parallel to the plane of perfect cleavage and bevelled by planes of pyramidal aspect (Fig. 2); a few approach an equidimensional form due to large growth of the pyramidal planes with reduction of the plane of the cleavage (Fig. 3). On inspection the crystals appear to be monoclinic with a plane of symmetry normal to the plane of cleavage. In the absence of a prismatically developed zone the crystals were adjusted and measured with reference to the axis normal to the symmetry plane. In this position (Fig. 1) the two-circle angles for a monoclinic crystal are ϕ_2, azimuth measured clockwise from the great circle through a(100) and b(010), and ρ_2, polar distance from b(010).

Gnomonic projections of four measured crystals show monoclinic symmetry and clearly indicate the proper choice of the recip-

rocal lattice. The plane of cleavage might be taken as basal {001}, or front pinakoidal {100}. The first choice is adopted since it gives a satisfactory appearance to all the crystals. With the second choice the crystals of the common tabular habit would entirely lack a vertical zone.

The geometrical elements:

$$p_0 : q_0 : r_0 = 0.8554 : 1 : 0.8550;\ \mu = 75°49'$$
$$a : b : c = 1.2058 : 1 : 1.2063;\ \beta = 104°11'$$

were derived from one crystal (No. 3), shown in Fig. 3, which gave nearly perfect reflections from all its faces. The other measured crystals (Nos. 1, 2, 4), of the type shown in Fig. 2, gave less constant measurements. The elements a and c are nearly alike; indeed they may be equal. Consequently the lattice cell with (010) centred is nearly or perhaps exactly rectangular. The crystal habit, the x-ray photographs, and the optical orientation all show, however, that the crystals are monoclinic and not orthorhombic.

Table 1 gives the forms observed on all the measured crystals together with the measured and calculated angles on crystal 3 and

TABLE 1.—CALCIUM DIBORATE HEXAHYDRATE: FORMS and ANGLES

Form	Measured on crystal 3		Calculated for crystal 3		Measured on crystals 1, 2, 4	
	ϕ_2	ρ_2	ϕ_2	ρ_2	ϕ_2	ρ_2
c 001	75°56′	90°00′	75°49′	90°00′	75°00′— 75°16′	90°00′
b 010	—	0 00	—	0 00	—	—
a 200	0 02	90 00	0 00	90 00	0 00	90 00
m 110	0 01	40 32½	0 00	40 32½	0 00	40 50—41°00′
d 011	75 45½	40 30½	75 49	40 32	—	—
e 021	—	—	75 49	23 09½	74 30	23 16
f $\bar{2}01$	151 14	90 00	151 05½	90 00	—	—
p 111	37 54	53 27½	37 54	53 27½	36 51 — 38 27	53 30—54 11
q $\bar{1}11$	127 54½	46 26	127 55½	46 25½	127 43 —128 22	46 18—46 42
r $\bar{1}12$	—	—	104 45	59 44½	103 44 —103 53	60 00—60 08

the range of measurements obtained from crystals 1, 2, 4. It will be seen that the agreement between the measured and calculated angles on crystal 3 are exceptionally good.

Before the x-ray measurements were undertaken, an attempt was made to determine the mode of the crystal lattice and the space group from the Law of Bravais in its classical form and in the generalized form due to Donnay (1937; 1938). This did not lead to a definite result, perhaps owing to conditions which the Law of Bravais cannot take into account, namely, important variations of habit and merohedry. The space group, as determined by x-ray measurements, is *Pa* (monoclinic, domatic; primitive lattice; a-glide plane) in which all indices are possible except ($h0l$) with h odd. The effective lattice plane spacings (d), determined graphically by a recently described method (Peacock, 1938), are therefore as in Table 2.

TABLE 2.—LATTICE PLANE SPACINGS FOR SPACE GROUP *Pa*

hkl	*d*(Å)	Forms on tabular crystals	Forms on pyramidal crystals
001	7.72	*c*	*c*
010	6.61	—	*b*
110	5.03	*m*	*m*
011	5.03	—	*d*
$\bar{1}11$	4.53	—	*q*
111	3.94	*p*	*p*
200	3.86	*a*	*a*
$\bar{2}01$	3.86	—	*f*
210	3.34	—	—
012	3.34	—	—
$\bar{1}12$	3.34	*r*	—
$\bar{2}11$	3.34	—	—

For the common tabular crystals the correspondence between lattice plane spacing and form importance is unsatisfactory. The cleavage $\{001\}$ follows the lattice planes with the greatest spacing; but the absence of $b\{010\}$, $d\{011\}$, $q\{\bar{1}11\}$, with relatively large spacings, and the presence of $r\{\bar{1}12\}$, with a relatively small spacing, constitute irregularities. For the pyramidal crystals, on the other

hand, the correspondence is much better. The condition ($h0l$) present only with h even nicely explains the absence of $\{101\}$ and $\{\bar{1}01\}$; but the theoretical importance of $b\{010\}$ is out of keeping with the fact that the form was observed only once with a small face.

Almost every crystal shows a belt of striations or narrow steps running parallel to $\{001\}$ and dividing the crystal roughly in halves. The two parts are in contact on (001) and often mutually displaced along [100]. The symmetry of such a crystal pair is monoclinic, holohedral—$2/m$. These relations indicate twinning according to the law: twin axis [010]; composition plane (001). If [010] is an axis of twinning it cannot be an axis of symmetry of the structure. The crystal class is thus monoclinic, domatic—m, which has only a mirror plane of symmetry. The twinning is an example of twinning by merohedry (Friedel, 1926), in which the element of twinning is an element of symmetry of the lattice but not of the crystal structure. The individual crystals are merohedral while the twinned pair has holohedral symmetry.

X-ray measurements. The structural lattice, space group, and cell content were determined by x-ray measurements on a small cleavage fragment showing the planes (001) and (100) meeting in the edge [010]. Excellent films were obtained with short exposures using unfiltered copper radiation.

A rotation photograph about [010] showed the layer lines: 0, 1, 2, 3.

A zero-layer Weissenberg photograph about [010] showed the diffractions:

—	200	—	400	—	600	—	800	—
001	002	003	004	005	006	007	008	009

and diffractions $h0l$ only with h even.

A first-layer Weissenberg about [010] showed:

110	210	310	410	510	610			
011	012	013	014	015	016	017	018	019

and all diffractions $h1l$.

A zero-layer Weissenberg photograph about [100] gave:

010	020	030	040	050	060	070	080	
001	002	003	004	005	006	007	008	009

and all diffractions $0kl$.

The axial angle β was obtained from the distances between the slanting rows /00l/, /h00/, /00$\bar{l}$/, on the zero-layer Weissenberg photograph about [010].

Measurement of the films gave the lattice parameters:

$$a_0 = 7.970 \pm 0.01 \text{ Å}$$
$$b_0 = 6.614 \pm 0.01 \text{ Å}$$
$$c_0 = 7.977 \pm 0.01 \text{ Å}$$
$$\beta = 104°25' \pm 15'$$

The ratio:

$$a_0 : b_0 : c_0 = 1.2051 : 1 : 1.2061; \quad \beta = 104°25'$$

agrees well with the goniometric ratio:

$$a : b : c = 1.2058 : 1 : 1.2063; \quad \beta = 104°11'$$

The only systematically missing spectra are those which do not conform to the condition: ($h0l$) with h even. In the domatic class —m the space group is therefore $C_s^2 = Pa$, using the notation appropriate to the adopted setting of the crystals.

The volume of the unit cell is:

$$V_0 = a_0 b_0 c_0 . \sin \beta = 407.3 \text{ Å}^3$$

The molecular weight of the empirical formula $CaB_2O_4.6H_2O$ is $m = 233.7$. The specific gravity is $G = 1.884$, using the higher of the similar measured values. The number of empirical molecules in the unit cell is therefore:

$$Z = V_0 G / 1.65\, m = 1.99 \text{ or nearly } 2$$

The unit cell of calcium diborate hexahydrate thus contains $Ca_2B_4O_8.12H_2O$, which has the calculated specific gravity 1.894. The near approach of the value of Z to an integral number affords a verification of the analysis, the specific gravity, and the lattice parameters.

SUMMARY

Crystals of calcium diborate hexahydrate, $CaB_2O_4.6H_2O$, from a mortar of Portland cement and colemanite, are monoclinic, domatic; $a : b : c = 1.2058 : 1 : 1.2063$; $\beta = 104°11'$. Forms: $a\{200\}$, $b\{010\}$, $c\{001\}$, $m\{110\}$, $d\{011\}$, $e\{021\}$, $f\{\bar{2}01\}$, $p\{111\}$, $q\{\bar{1}11\}$, $r\{\bar{1}12\}$. Combinations: $p\ r\ c\ a\ m$; $p\ a\ f\ d\ c\ q\ m\ b$. Twins common; twin axis [010]; composition plane (001). Space group Pa. Structure cell: $a_0 = 7.970$, $b_0 = 6.614$, $c_0 = 7.977$ all ± 0.01 Å; $\beta =$

104°25′; contains $Ca_2B_4O_8.12H_2O$. Cleavage: {001} perfect. $H=2\frac{1}{2}$. $G=1.881$; 1.884 (meas.); 1.894 (calc.). $F=1$. Colourless, transparent. Biaxial, negative; $X=B$; $Z:C=-3°$; $nX=1.505$, 1.506; $nY=1.511$, 1.511; $nZ=1.515$, 1.514 ± 0.002; $2V$ (calc.) $=79°$, 76°; $r>v$. Analysis: CaO 23.97, B_2O_3 30.39, H_2O at 550°, 45.86 = 100.22: H_2O at 120° 37.1 ($5H_2O$).

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EXPLANATION OF FIGURES

FIG. 1.—Calcium diborate hexahydrate. Stereographic projection on the symmetry plane (010), showing the observed forms and the optical orientation. The face-poles with form letters are in normal position; those without letters are twinned by 180° rotation about [010].

FIG. 2.—Crystal of the common bevelled tabular habit, with twin striations.

FIG. 3.—Crystal of pyramidal habit from which the geometrical elements were obtained.

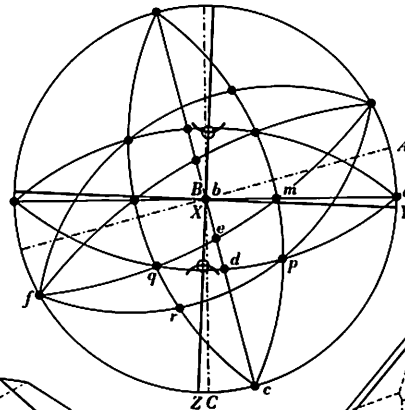

FIG. 1

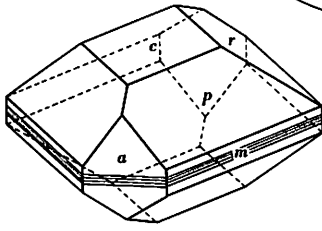

FIG. 2

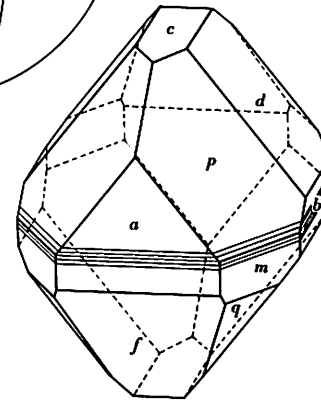

FIG. 3

ANTHRAXOLITE FROM SOUTH NAHANNI RIVER NORTHWEST TERRITORIES

By R. L. RUTHERFORD
University of Alberta

In 1935 A. E. Cameron (Cameron and Warren, 1938) brought in three specimens from the South Nahanni River which were identified as anthraxolite. This anthraxolite is said to come from Meilleur Creek, a tributary of the South Nahanni. One specimen about the size of a 2 inch cube, consists of brittle anthraxolite with numerous small fractures filled with quartz. The analyses given below were made from this specimen. The other two specimens apparently represent the width of a vein and are about $1\frac{1}{2}$ inches thick. In these the purer anthraxolite occurs as a thin irregular band occupying a medial part of the vein. The greater part of these two specimens is composed of a fine-grained mixture of anthraxolite, calcite, quartz, and indeterminable dark-coloured fine-grained material. Fine-grained iron sulphide, pyrite, or marcasite, is also present as disseminated grains and occasionally concentrated into layers.

The anthraxolite is brittle and breaks with pseudo rectangular cleavage into small chunks. Iron oxides commonly form a yellow stain along the fracture planes. Some surfaces show iridescent lustre.

The term anthraxolite was first used by Chapman as a name for coal-like material as end products resulting from the metamorphism of petroleum. The well-known occurrences near Sudbury, Ontario, were first described by Coleman (1896). The chemical analyses of the Sudbury anthraxolite was first reported by Ellis (1896). In his report Ellis included the following: a proximate analysis given earlier by Chapman for the Sudbury anthraxolite, an analysis by Hoffman on a specimen from Ungava district, and an ultimate analysis of a specimen from an occurrence in a barite vein near Kingston, Ontario. Because of frequent reference to coal in the Precambrian, Coleman (1928) again discussed the Sudbury occurrence.

The following is a table of analyses of anthraxolite from three localities. For purposes of comparison the "Calculated—Dry Ash Free" values are included in the table.

TABLE 1.—ANTHRAXOLITE: ANALYSES

Proximate Analyses

	1 Sudbury a	1 Sudbury b	2 Great Slave Lake	3 Nahanni (as received)
Moisture	——	——	1.35	1.9
Vol. matter	5.3	5.3	4.08	6.0
Fixed carbon	74.2	64.7	93.27	85.9
Ash	20.5	30.0	1.30	6.2

Ultimate Analyses

	1	2	3 (dry basis)
Carbon	94.92	94.25	87.50
Hydrogen	0.52	1.26	1.75
Nitrogen	1.04	0.78	——
Oxygen	1.69	1.97	——
Sulphur	0.31	0.42	——
Ash	1.52	1.32	6.3

Calculated—Dry Ash Free

	1 a	1 b	2	3
Fixed carbon	93.3	92.4	95.8	93.5
Vol. matter	6.7	7.6	4.2	6.5
Carbon	96.40		95.50	93.40
Hydrogen	0.55		1.30	1.90

1. Sample from Sudbury district, Ontario. Analysis given by Coleman (1928).

2. Sample from Union Island, Great Slave Lake, N.W.T. Analysis given by Rutherford (1928).

3. Sample from South Nahanni River, N.W.T. Analysis by W. A. Lang, Department of Industrial Research, University of Alberta.

The proximate analyses, Sudbury (a) and (b), were not made from the same sample used for the ultimate analysis (1). The high ash content of the Nahanni sample is due largely to the difficulty of separating the anthraxolite from the quartz which occurs as numerous thin fracture fillings. The similarities of the anthraxolite from

the three sources are best indicated when the analyses are compared on the "calculated—dry ash free" basis.

Anthraxolite from near Port Arthur, Ontario, is reported by Ellsworth (1934) to be slightly radioactive and nickeliferous. The specimen from Nahanni River showed no reaction when tested with the electroscope. It shows a qualitative chemical test for traces of titanium but no vanadium or nickel. The geological age of the anthraxolite from the South Nahanni River has not been determined. The other occurrences referred to are in rocks of Precambrian age.

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COPPER-TOURMALINE-HEMATITE VEINS AT HIGHLAND VALLEY, B.C.[1]

By JOHN S. STEVENSON
British Columbia Department of Mines

At four of the properties that lie within an area approximately two miles in diameter in the Highland Valley copper area east of Ashcroft, the copper veins contain extraordinarily large amounts of tourmaline and specular hematite. Considerable underground work has been done, principally between the years 1901 and 1906, on three of these properties, but the copper content of the veins was too low for profitable operation.

Several copper-tourmaline ore deposits have been described in the literature (Lindgren, 1933, pp. 684-686; McLaughlin, 1933, pp. 566-568), but of those described only a few appear to contain tourmaline and hematite in large quantities. Of these, the most important is the Cactus Mine, Utah, which has been fully described by Butler (1913, pp. 119-129).

In British Columbia, deposits that contain abundant tourmaline are rare, and those carrying tourmaline and hematite are unreported. A fissure vein that contains galena and abundant black tourmaline has been described from the Lardeau area (Walker, Bancroft, and Gunning, 1929, pp. 21, 31, 33, 34); this vein cuts metamorphic rocks and a quartz gabbro-diorite dyke, but is probably related to granite of the Kuskanax batholith. A vein in tuffs three miles from a granodiorite mass has been described from the Hazelton area by O'Neill (1919, p. 24); this vein contains principally chalcopyrite but tourmaline is also present in large amounts.

QUARTZ DIORITE

The rock formation in the vicinity of the veins in Highland Valley is quartz diorite. This rock constitutes the north-easterly corner of a large area of granitic rocks that extends fifteen miles westward and twenty-five miles southward. The copper-tourmaline veins lie three miles southward from an intrusive contact on the

[1]Published by permission of the Honourable Minister of Mines for British Columbia.

east and one mile eastward from a contact with overlying later lavas on the north.

The quartz diorite is massive and possesses an inequigranular, fine-grained texture. The mode of the rock as determined from a Rosiwal determination on a fairly typical section, is as follows:

	Per cent	Grain size in mm.
Quartz	20	0.2 −0.5
Orthoclase	2	1.0
Oligoclase ($Ab_{80}An_{20}$)	52	0.75×3.0
Biotite (thoroughly altered to chlorite)	25	1.0 ×2.0

Rock of the above composition corresponds to quartz diorite or tonalite, 228 P of Johannsen (1931, p. 155). If nomenclature is based on texture alone, the fineness of grain of this rock would indicate the name dacite; however, in this paper the rock will be referred to as quartz diorite.

Alteration of the quartz diorite has been moderate. A few of the feldspars show only slight alteration, but many grains have been changed to fine-grained aggregates of white mica and are so badly altered that determination of the feldspar is impossible; only small amounts of epidote were noted. In most cases the biotite has been completely altered to chlorite. Close to the veins a few isolated crystals of tourmaline have formed in the quartz diorite.

VEINS

Size and Texture

The veins are discontinuous in length and variable in width. Individual veins range from 6 feet to 60 feet in length and from a knife-edge to 4 feet in width, although a width of 10 inches is most common. The vein-filling is commonly brecciated, with fragments consisting of either wall rock or those minerals formed early in the sequence of hydrothermal mineralization.

Their extreme variability in both length and width, abundance of brecciated material, lack of gouge and crushed zones, suggest that the veins occupy tension joints rather than faults within the quartz diorite mass.

Mineralogy

The vein-filling consists of both hypogene and supergene minerals. The hypogene minerals listed in order of abundance, include: tourmaline, quartz, specular hematite, magnetite, chalcopyrite, pyrite, and chlorite. The supergene minerals include: chalcocite, malachite, azurite, and limonite. Tourmaline, by far the most abundant mineral in the veins, forms from 5 to 90 per cent of the vein matter.

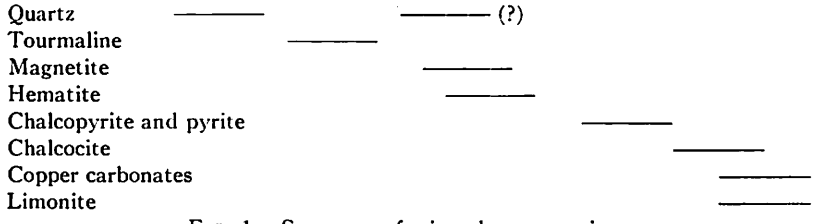

FIG. 1.—Summary of mineral paragenesis.

The paragenesis of the minerals is shown graphically in Fig. 1. In general, the sequence of primary mineralization has been: silicates and quartz—magnetite and hematite—sulphides.

Tourmaline. Tourmaline is the most abundant and characteristic mineral in the veins. It occurs principally as black, irregular masses of small, closely packed crystals. In thin-section it is seen to occur as areas of closely packed grains forming a filling between brecciated fragments of vein quartz (Fig. 3), and as clean-cut veinlets filling fractures in vein quartz (Fig. 4), or, more rarely, as well-shaped crystals protruding into quartz grains. The grains range from irregular fragments 0.1 mm. in diameter to well-shaped, tabular crystals measuring 0.2 mm. by 0.05 mm.

The optical properties of the tourmaline are given below:

Uniaxial Negative

$$\omega_D = 1.6865$$
$$\epsilon_D = 1.6500$$
$$\omega_D - \epsilon_D = 0.0365$$
$$\omega_F - \omega_C = 0.0218$$
$$\epsilon_F - \epsilon_C = 0.0200$$

All indices given are ± 0.0005.

In an average thin-section, 0.03 mm. in thickness E = very light brown, O = dark green.

A graph of the indices for light of different wave-lengths, as determined by the Emmons double variation method, is given in Fig. 2.

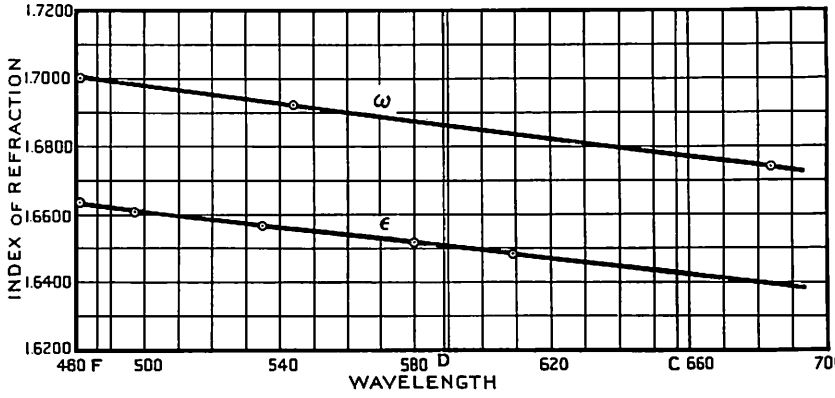

FIG. 2.—Variation of indices of refraction with wave-length for Highland Valley tourmaline, variety schorlite.

Winchell's graphs (1932, p. 475; 1933, pp. 303, 305) showing the relations between composition and optic properties in tourmalines, indicate that the Highland Valley tourmaline approximates schorlite. In composition it corresponds closely to a tourmaline containing almost 100 per cent of the end compound schorlite, $H_8Na_2Fe_6B_6Al_{12}Si_{12}O_{62}$, in which the iron and sodium molecules are important.

Quartz. Brecciated quartz, apparently the first vein mineral formed, is a common constituent of the veins. It occurs as very angular fragments sealed together by the other vein minerals (Figs. 4, 5). Because of the forces responsible for the brecciation this fragmental quartz possesses pronounced strain shadows.

Lenses of even-grained, non-brecciated quartz occur occasionally in the veins. The quartz grains in these lenses do not show strain shadows, and it is evident that fracturing had ceased before its deposition. No vein minerals were seen cutting or replacing this unstrained quartz, and it is, therefore, assumed to be late in the sequence of mineral deposition.

Chlorite. Hydrothermal chlorite has been seen within and close to the veins as rosettes of radial fibres and as veinlets definitely transecting the minerals of included fragments of quartz diorite. The optical properties of this chlorite are as follows: biaxial negative, optic angle almost zero, $\beta = 1.620$, and abnormal birefringence showing dark purple interference colours. This chlorite corresponds most closely to the ferriferous clinochlore, diabantite of Winchell (1933, p. 283); the indices are somewhat too high for the ferriferous penninite, delessite, of both Winchell (1933, p. 282) and of Larsen and Berman (1934, p. 169).

Hematite and magnetite. In some vein-sections specular hematite is abundant, either as the only vein-filling surrounding brecciated fragments of wall rocks, or in association with minor amounts of magnetite replacing both the quartz and later tourmaline (Fig. 5). In polished sections of this vein-matter, hematite is seen to replace magnetite as irregular veinlets which lack any well-defined pattern.

Chalcopyrite and pyrite. Chalcopyrite occurs as isolated grains and as narrow veinlets transecting all the hypogene vein minerals. Pyrite was seen only as isolated grains probably contemporaneous with the chalcopyrite.

Oxidation

The products of oxidation or supergene minerals include chalcocite, limonite, and copper carbonates. Polished sections of the sulphides show progressive alteration of chalcopyrite to chalcocite from a few hair-like stringers of chalcocite in chalcopyrite, to masses of chalcocite with only a kernel of chalcopyrite remaining; etching with dilute nitric acid brings out the granular grain pattern characteristic of rhombic supergene chalcocite (Lindgren, 1933, p. 840). Limonite has extensively replaced the chalcocite and the copper set free in such oxidation has wandered freely and become fixed in fractures within the vein as the copper carbonates, malachite, and azurite.

CONCLUSIONS

These veins are hypothermal. That deposition of the minerals occurred at high temperatures is shown first by their location within an intrusive rock, quartz diorite, and secondly by their characteristic mineralogy, namely abundant tourmaline and specular hematite.

The abundant tourmaline indicates that large amounts of boron, most probably as the weak boric acid, must have accompanied the ore-bearing solutions and, therefore, that the mineralization solutions were, by Schmedeman's definition (Schmedeman, 1938, p. 797) alkaline.

In their formation, the veins are quite probably related to the magma from which their host rock, quartz diorite, crystallized.

ACKNOWLEDGMENTS

The writer wishes to thank Dr. John F. Walker and Mr. Philip B. Freeland, of the British Columbia Department of Mines, for their critical reading of the manuscript.

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EXPLANATION OF FIGURES 3—5

FIG. 3.—Characteristic habit of closely packed tourmaline crystals (Plane polarized light).

FIG. 4.—Tourmaline veinlets in badly fractured quartz (Plane polarized light).

FIG. 5.—Hematite and magnetite (black) replacing fractured quartz (white) and tourmaline areas (grey) (Plane polarized light).

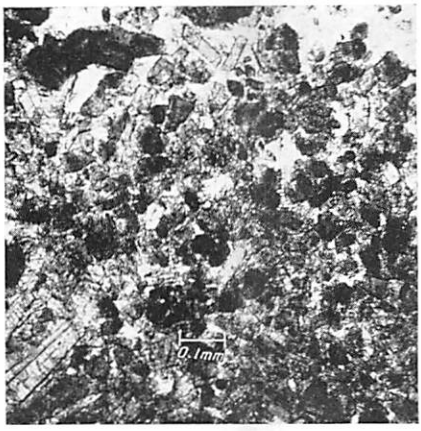

FIG. 3

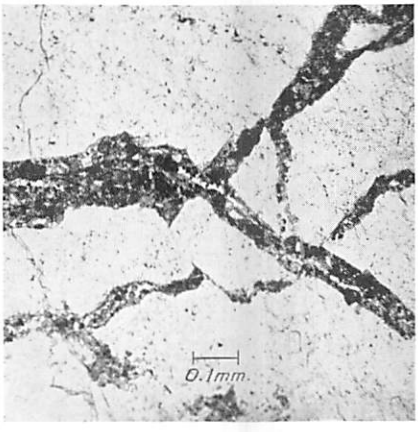

FIG. 4

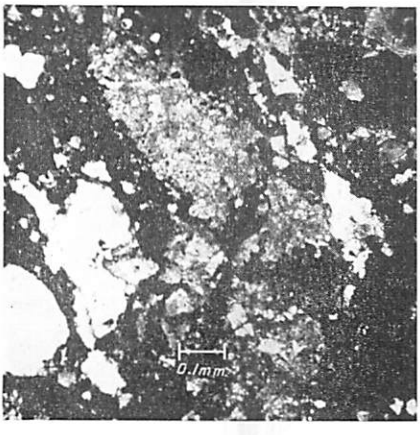

FIG. 5

NICKELIFEROUS PYRITE FROM THE DENISON MINE SUDBURY DISTRICT, ONTARIO

By Ellis Thomson and J. S. Allen
University of Toronto

In a previous paper by one of the writers (Thomson, 1938) a preliminary description of this material was given under the heading " 'beyrichite' ore." This material was determined, in part, as nickeliferous pyrite; but it was felt that chemical and röntgenographic observations would be necessary to establish the exact nature of the substance. Professor Peacock kindly made the necessary *x*-ray photographs and offered some suggestions which we have adopted in the description and discussion of this material. The authors also wish to record their grateful appreciation of the cordial co-operation extended to them by Dr. E. B. Dane, Jr., and Dr. Harry Berman of Harvard University. They are indebted to Doctor Dane for the hardness determinations and one of the photomicrographs and to Doctor Berman for helpful advice and for a specific gravity determination of this material.

At the time the previous paper was written it was recognized that "beyrichite" was an inappropriate name, since beyrichite is a discredited synonym for millerite. Also the suggestion that the mineral is a mixture, possibly of pyrite and bravoite, is not confirmed. The senior author has re-examined the material in polished sections, as a result of which the following description is given to revise and supplement the previous observations.

In hand-specimens this material is seen to differ slightly in colour from the ordinary pyrite, a faint violet shade modifying the usual colour of common pyrite. Its mode of occurrence, as seen in polished section under the microscope, has already been described in the previous paper by the senior author (1938, p. 72), mention being made of a nickeliferous pyrite mixed very intimately with other pyrite (Fig. 1 of the present paper). Sometimes these two pyrites occur as outer and inner zones in the same crystals (Fig. 2). It was deemed advisable to examine this material once more in the light of new evidence presented by *x*-ray and chemical studies. These crystals generally consist of two portions, both creamy in

colour but with one showing a modifying violet shade. Between these two portions there is sometimes to be found another portion about half-way between the other two in colour. All three portions are isotropic and show the same hardness, F+ (Talmage), which is greater than that of pyrite. A specific gravity determination was made of portions of one of the crystals by Dr. E. B. Dane, Jr., and Dr. Harry Berman on the Berman Torsion Micro-Balance. The result obtained, namely 4.81, was distinctly low due to inclusions of gangue material which are fairly abundant throughout.

For convenience of reference the creamy type will be called A, the violet cream type C, and the type intermediate in colour between these two B. In reflected light the three types show the following colours: A, cream; B, light violet cream; C, violet cream. All three types have the same hardness and give the same etch reactions: hardness, F+; HNO_3, light brown, differential, remains after rubbing; HCl, negative; $FeCl_3$, negative; KCN, negative; KOH, negative; $HgCl_2$, negative. It will be noted that these etch reactions are different from those of ordinary pyrite. This fact, taken in conjunction with the difference in colour, makes it seem probable, although definite proof is lacking, that all three of these portions contain nickel and that the variation in colour is proportional to the amount of nickel present in each portion.

Part of a specimen consisting largely of A, the creamy portion, whose appearance in polished sections is described above, was crushed into fragments of about 0.5 mm. diameter. From this material a sample was prepared by picking grains which appeared to be homogeneous and free from other minerals. A polished section of a part of this picked sample showed that it consisted chiefly of A, the creamy type, with minor quantities of C, the violet cream type. An analysis of the picked sample gave the values under 1 in the following table; previous analyses of similar materials from the Sudbury district are given under 2, 3, 4.

The material from the Denison Mine is somewhat richer in nickel than the similar previously analysed materials from Sudbury, named "blueite," "whartonite," and "nickeliferous pyrite." Reduced to 8 atoms of sulphur in keeping with the cell content of pyrite, Fe_4S_8, the nickel in the Denison material amounts to about half an atom per unit cell, in random replacement of iron.

X-ray powder photographs were made from the picked sample of the Denison material and from a fragment taken from a cube of common pyrite (Figs. 3, 4). The diagrams are identical as regards the positions and intensities of the powder lines. This confirms the fact that the Denison material is pyrite, whose cube edge and structure are not appreciably affected by the presence of some nickel in the place of iron.[1]

TABLE 1.—NICKELIFEROUS PYRITE FROM THE SUDBURY DISTRICT: ANALYSES

	1	1a		2	3	4
Fe	38.54	3.44	3.99	38.8	42.90	39.70
Ni	6.50	0.55		3.5	5.40	4.34
Cu	none	—		—	—	traces
S	51.39	8.00		(52.3)	45.00	49.31
Insol.	3.80	—		5.4	4.80	5.76
	100.23			100.0	98.10	99.21

1. Denison Mine; anal. J. S. Allen. 1a. Atomic proportions reduced to 8 atoms of sulphur contained by the unit cell of pyrite.

2. "Blueite," "Jack's Tin," found notably at Emmens Metal Company, associated with niccolite, gersdorffite, pyrrhotite, and chalcopyrite; anal. Emmens (1892, p. 208).

3. "Whartonite," Shepherd Mine, in cellular masses lined with minute cubic crystals; anal. Emmens (1892, p. 210).

4. "Nickeliferous pyrite," Murray Mine; massive material associated with small cubes containing nickel and having the properties of pyrite; includes moisture 0.10; As none; anal. Walker (1894, p. 313).

The foregoing observations have confirmed the occurrence of nickel-bearing pyrite at the Denison Mine and have shown it to be a nearly homogeneous mineral with the chemical and structural properties of pyrite. It must be remembered, however, that the word homogeneous is here used only in the limited sense in which this term is applied to composite crystals of the smaltite-chloanthite type. It is possible that these crystals were originally truly homogeneous and have since separated into different portions by exsolution. Or they may be the result of some kind of rhythmic precipitation. But whatever the mechanism that may have

[1]The very slight difference of spacings shown in the reproductions could not be confirmed on the films.

brought about the present intimate association of the component parts of these crystals, it would seem certain that this mineral is not an individual species but a well-defined variety of pyrite, as understood by Dana (1892) and the authors of the new Dana now in preparation. Our observations might justify the revival of *blueite* or *whartonite* of Emmens (1892) as a name for this variety; but since these names have already been discredited by Penfield (1893) it seems better to follow Penfield (1893) and Walker (1894) and retain *nickeliferous* or *nickelian pyrite* to describe this variety.

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EXPLANATION OF FIGURES

FIG. 1.—Nickeliferous pyrite, showing cubic outlines and intimate intergrowth of the violet cream type (C), and the cream type (A). Plain reflected light.

FIG. 2.—Nickeliferous pyrite, showing a core of the cream type (A) and an outer zone of the violet cream type (C); a small amount of the intermediate light violet cream type (B) is visible. Plain reflected light; × 110.

FIG. 3.—Nickeliferous pyrite, mainly the cream type (A). *X*-ray powder photograph with copper radiation; 0.8 KWH.

FIG. 4.—Common pyrite, fragment of clean crystal. *X*-ray powder photograph with copper radiation; 0.8 KWH.

FIG. 2

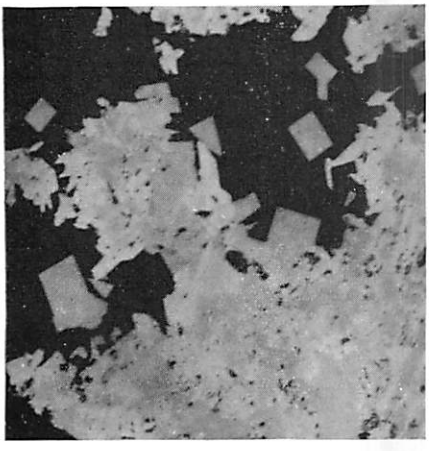

FIG. 1

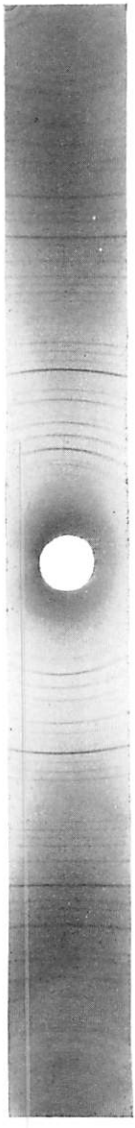

FIG. 3

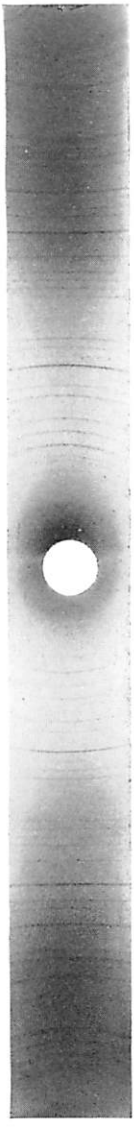

FIG. 4

VESICULAR CARBONACEOUS SEDIMENTS IN LAKE OF THE WOODS REGION

By JAS. E. THOMSON
Ontario Department of Mines

Lawson (1885, pp. 58, 29) described a peculiar type of vesicular carbonaceous rock associated with Keewatin lavas on Corkscrew Island in Lake of the Woods. Later Parsons (1913, pp. 221-222) and Greenland (1913, pp. 584-597) discussed this occurrence. In recent years the writer has found this rock type at a number of places around Lake of the Woods (1937, pp. 11-14) and eastward along the extension of the same belt of lavas and sediments on Sucan and Lower Manitou Lakes (1935, pp. 9-11).

The carbonaceous rock contains a sufficient amount of carbon, generally in the form of graphite, to soil the fingers on handling. The weathered surface of the vesicular type somewhat resembles a gas-blown slag of ordinary dark-coloured coal "clinkers." The field relationships and chemical and petrographic characteristics indicate that the rock is of sedimentary origin. This raises an interesting question as to the source of the carbon and the presence of vesicles in a Keewatin sedimentary rock.

OCCURRENCES ON LAKE OF THE WOODS

Five exposures of the vesicular graphitic rock were observed throughout the north-central part of Lake of the Woods. The rock is quite soft and weathers easily so that exposures are rarely found except along steep cliffs or in test pits. By far the best outcrops occur about twelve miles south-west of the town of Kenora on the north-west corner of Corkscrew Island (Thomson, 1937, map 45b). Here, a band of sediments up to 25 feet in thickness is interbedded with sheared acid and basic lavas. The sediments outcrop at intervals over a length of almost half a mile and show a transition from black chert with vesicular phases to massive chert and lean iron formation along the strike.

A detailed section across a 25 foot width of the sedimentary band at one point showed six vesicular chert zones with intervening non-vesicular material. The vesicular zones vary from 1 to 8 feet in

width. Samples of typical vesicular chert and the non-vesicular variety were taken from this location for analyses and their composition is recorded in Table 1. A few of the vesicles were filled with rounded pyrite balls but this condition is rare. Occasionally a few pyrite crystals are found in or near narrow silicified zones in the adjoining chert.

Freshly broken samples of the vesicular chert show a dense black groundmass with spherical cavities of varying sizes occupying irregular zones throughout the rock. Some samples are full of holes and resemble pumice in texture. The cavities range from half an inch in diameter to microscopic dimensions. The greater number of these are empty but some are partly filled with rounded masses of graphite; others contain a framework of delicate graphite flakes and fibres. The larger cavities are often enclosed or partly enclosed by a narrow rim of quartz.

Thin sections of the black chert show the rock to be composed of tiny quartz grains with delicate wisps of carbonaceous material interlaminated between bands of quartz. There are also traces of sericite. The vesicular graphitic chert consists of the same mineral assemblage but the graphite particles are often so numerous that they make parts of the section almost opaque. The primary quartz and graphite of the groundmass appear to have been deposited simultaneously. Secondary quartz often appears as small veinlets which run in all directions through the groundmass, and also as small columnar crystals arranged in a radial fashion around the rim of the vesicle.

Chemical tests of the carbonaceous material show that it is largely in the form of graphite. The soft carbonaceous material that fills the cavities, when heated over a Bunsen flame, is partially burnt, showing that a small amount is amorphous carbon. When the rock material is boiled in aqua regia, however, no noticeable amount goes into solution, showing that by far the greater proportion is crystalline graphite.

OCCURRENCES ON MANITOU AND SUCAN LAKES

Vesicular graphitic sediments of similar appearance and composition to those described above were observed between Lower Manitou Stretch and Alonghill Lake, and on the south and east

sides of Sucan Lake (Thomson, 1935, map 43a). These locations are about twenty-six miles north of the town of Fort Frances. Both occurrences lie at or near the contact between a sedimentary series (Temiskaming) and Keewatin lavas, but the exact relationship could not be determined. The rock is exposed only in test-pits. A chemical analysis of the unaltered rock from a test pit on the portage between Lower Manitou Stretch and Alonghill Lake is given in Table 1, no. 3.

TABLE 1.—ANALYSES OF CARBONACEOUS SEDIMENTS

	1	2	3
SiO_2	96.87	94.01	92.14
Al_2O_3	1.61	2.27	2.61
Fe_2O_3	0.03	0.59	0.13
FeO	0.02	Nil	1.58
CaO	Nil	Nil	0.33
MgO	0.22	0.32	0.30
Na_2O	0.32	0.16	0.14
K_2O	0.22	0.42	0.25
H_2O	0.13	0.56	0.29
TiO_2	Nil	Nil	0.05
P_2O_5	0.05	0.07	Trace
MnO_2	Nil	Nil	0.02
CO_2	0.09	0.11	0.30
S	—	—	0.35
FeS_2	0.13	0.28	—
C	0.40	1.38	1.98
	100.09	100.17	100.47
Specific gravity	2.655	2.112	—

1. Black chert, Corkscrew Island, Lake of the Woods. Analysis by Provincial Assay Office, Ontario, 1936.

2. Vesicular graphitic chert, Corkscrew Island, Lake of the Woods. Analysis by Provincial Assay Office, Ontario, 1936.

3. Graphitic chert, Lower Manitou Stretch. Analysis by Provincial Assay Office, Ontario, 1934.

The analyses show the similarity in chemical composition between the vesicular and non-vesicular graphitic chert. The composition of both rock types checks closely with that of cherts from various parts of the world (Clarke, 1924, p. 551). Other analyses

of the carbonaceous rocks on Corkscrew Island show considerably more carbon than found in the samples taken by the writer. Lawson (1885, p. 59) states that a sample was found on analysis to contain 5.77 per cent carbon, and an analysis by Greenland (1913, p. 587) on similar material showed 8.24 per cent carbon.

ORIGIN OF THE VESICULAR GRAPHITIC CHERT

It is difficult to find a satisfactory explanation of the origin of this rock. Lawson has suggested that the confining of gas may have been responsible for the formation of the spherical cavities. Parsons's explanation is as follows (1913, p. 222): "The vesicular structure can probably be best explained by the expansion of gaseous matter in the rock, and is probably due to the coking of carbon compounds, which may have been coal-like deposits or an asphalt vein filling."

Greenland (1913, pp. 588-597) suggests that the vesicles were formed by the removal of pyrite crystals and the subsequent infiltration of silica, and that the carbonaceous matter is of inorganic origin and introduced by hot solutions. The quartz is believed to form an incomplete pseudomorph after pyrite. This partially filled the cubic or diamond-shaped cavities and produced the spherical vesicles.

While the theory of removal of pyrite by solution to produce the cavities may have some merit, there are several points it does not explain satisfactorily. In some parts of the rock there are no quartz rims around the cavities and yet they are perfectly spherical. It would seem well-nigh impossible completely to remove pyrite by solution without leaving some iron oxide in the rock, yet scarcely a trace of this can be found in the empty vesicles or groundmass. Moreover, some of the vesicles are filled with carbon or a network of carbon fibres which could scarcely have been introduced after the removal of pyrite without at least some evidence of intense hydrothermal alteration of the rock. As pointed out by Lawson and Parsons, the evidence strongly suggests that the cavities were formed by the confining of gases in an unconsolidated rock. It is very probable that the pyrite now found in some of the vesicles was introduced long after their formation.

If it is then assumed that the vesicles and most of the carbon are primary, some other explanation for their occurrence is necessary. The writer would suggest three ways in which they might be formed, although it is possible that these processes, as described below, could be carried out simultaneously and be inter-related.

(1) *Confining of gases produced by the decay of organic material.* Silica, derived by the weathering of adjacent igneous rocks, may have been transported as colloidal silica and deposited in local shallow ponds. This mode of solution and transportation would be similar to that suggested for the Keewatin iron formation by Moore and Maynard (1929). It has already been stated that the graphitic chert passes into lean iron formation along the strike on Corkscrew Island. Moore and Maynard postulate the presence of organic matter in the solutions carrying iron and silica, this organic matter preventing the iron and silica from mutually precipitating one another until they are finally deposited by the electrolytes of the sea. In the case under discussion, the solutions were almost devoid of iron but rich in silica. The precipitation and consolidation of the silica along with the closely associated organic matter would form the black cherts. These contain a relatively small amount of carbon. At intervals, however, a large amount of organic material may have been collected with the silica to form a thick ooze. It may be within the realm of possibility that gases, such as carbon dioxide, methane, and other hydrocarbons formed by the decay of the organic material under these conditions could be entrapped, and produce the bubble holes or vesicles. The subsequent breaking down of these confined gases could produce the carbon now found within the vesicles. In support of this idea it may be pointed out that in the analyses (Table 1) the vesicular chert contains between three and four times the amount of carbon found in the ordinary chert. According to this explanation the vesicular phases of the chert would represent horizons where a proportionately large amount of organic material was entombed. Most of the carbon would be altered to graphite during the subsequent folding of the Keewatin series and the granitic intrusion. At that time, also, the secondary quartz and pyrite could have been introduced into the cavities.

(2) *Confining of gases emanating from lava flows.* It is possible that the vesicles may be due to gaseous emanations from the lavas

overlying the cherty beds. Studies of modern volcanoes have shown that gases are given off during the eruption and cooling of lava flows (Clarke, 1924, pp. 261-271). Analyses indicate that water vapour or steam makes up about 99 per cent of these gases. The remainder consists of many other substances, including a small amount of carbon monoxide, carbon dioxide, and methane. It seems quite possible that hot lavas flowing over a bed of unconsolidated mud could give off gases that would circulate through the sediment and form the vesicles. However, it seems extremely doubtful that the lava could supply sufficient vaporized carbon to account for the content of this element in the graphitic rock. It would, therefore, be more reasonable to assume that the carbon was an original constituent of the sediment, probably of organic origin, but that the vesicular structure might be due to the introduction of gases, chiefly water vapour, from the lava flows that covered the carbonaceous sediments before they were completely consolidated. Cooke (1922, p. 28) suggests that amygdaloidal cavities in muds adjacent to lavas were formed in this way in the Larder Lake district.

Under such circumstances, the graphite could be formed by the reaction of the water vapour from the lavas with the organic carbon in the chert. Winchell (1911) has pointed out that carbon combines with water vapour at temperatures above 500° to 650°C. as shown by the following equations:

$$C+2H_2O=CO_2+2H_2$$
$$2C+2H_2O=2CO+2H_2$$

The gases thus produced could circulate throughout the sediment and be concentrated in the vesicles. Winchell further demonstrates that under 900°C. the reaction $2CO+2H_2O \rightleftharpoons 2CO_2+2H_2$ tends to produce CO_2 and hydrogen. Below 500°C. the CO_2 and hydrogen thus produced tend to react to produce water and graphite. This would explain the formation of graphite in the vesicles by reaction of the confined gases on cooling.

(3) *Vaporization of connate water in the sediments by adjacent hot lava flows.* The vesicles may have been formed by the vaporization of connate water within the sediments. Lava flowing over a wet, unconsolidated mud bed could provide sufficient heat to vaporize the water indigenous to the sediment. The flow would also provide an impervious capping that would prevent the escape of steam thus

formed. The chemical reactions discussed under hypothesis (2) could still take place and produce graphite both within the vesicles and in the groundmass of the chert. If the overlying lava were a viscous flow, it might not give off sufficient vapour to circulate throughout the sediments and form all the vesicles. However, these hot gaseous emanations could aid in vaporizing the connate water of the sediments. In other words, hypotheses (2) and (3) could be closely interrelated.

All the above hypotheses postulate the presence of life in Keewatin time, probably in the form of primitive plants or animals. It would be impossible to prove the presence of lowly organisms in this case, but several geologists (Moore and Maynard, 1929, p. 523) have expressed the opinion that such forms probably existed at that time. It seems more logical to assume the presence of organisms during the Keewatin period than to seek an explanation through the introduction of the carbon from magmatic sources, for which there is no particular evidence.

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ERRATUM

On page 141, line 12 should read "gas-blown slag *or* ordinary dark-coloured coal 'clinkers'."

EXPLANATION OF FIGURES

FIG. 1.—Index map showing location of vesicular carbonaceous sediments. Scale, 60 miles to 1 inch. 1.—Corkscrew Island. 2.—Lower Manitou Stretch. 3.—Sucan Lake.

FIG. 2.—Specimen (one-half natural size) of vesicular graphitic chert from Corkscrew Island, Lake of the Woods. Most of the vesicles are empty but a few are filled with carbon.

FIG. 3.—Specimen (one-half natural size) of vesicular graphitic chert obtained from the portage from Lower Manitou Stretch to Alonghill Lake.

FIG. 4.—Photomicrograph of vesicular graphitic chert shown in Fig. 3. Vesicles (grey) are surrounded by a rim of quartz (white). The dark groundmass consists of graphite and fine-grained quartz. (Partially crossed nicols ×8.)

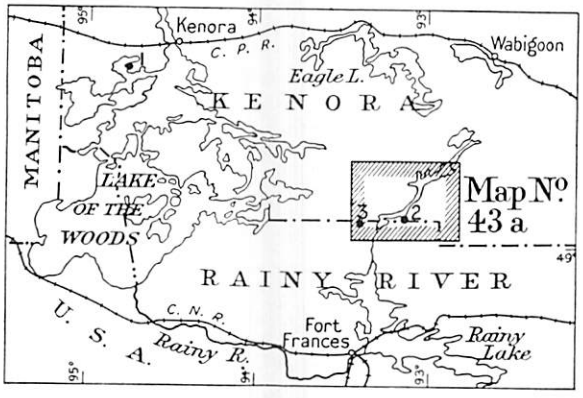
Kenora
C. P. R.
Eagle L.
Wabigoon
KENORA
MANITOBA
LAKE
OF THE
WOODS
Map No.
43 a
RAINY RIVER
C. N. R.
U. S. A.
Rainy R.
Fort
Frances
Rainy
Lake
95°
94°
93°
49°

FIG. 1

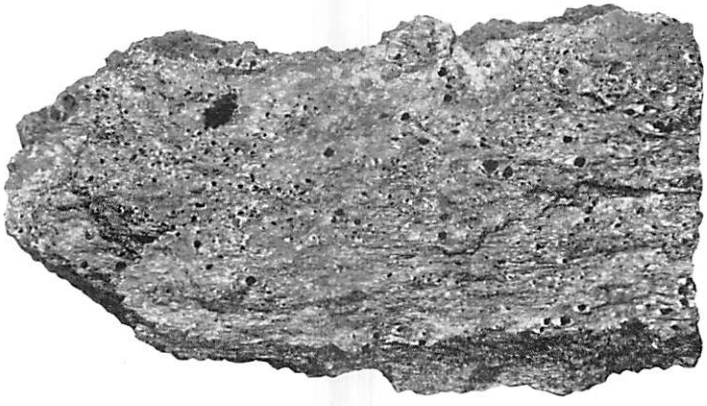

FIG. 2

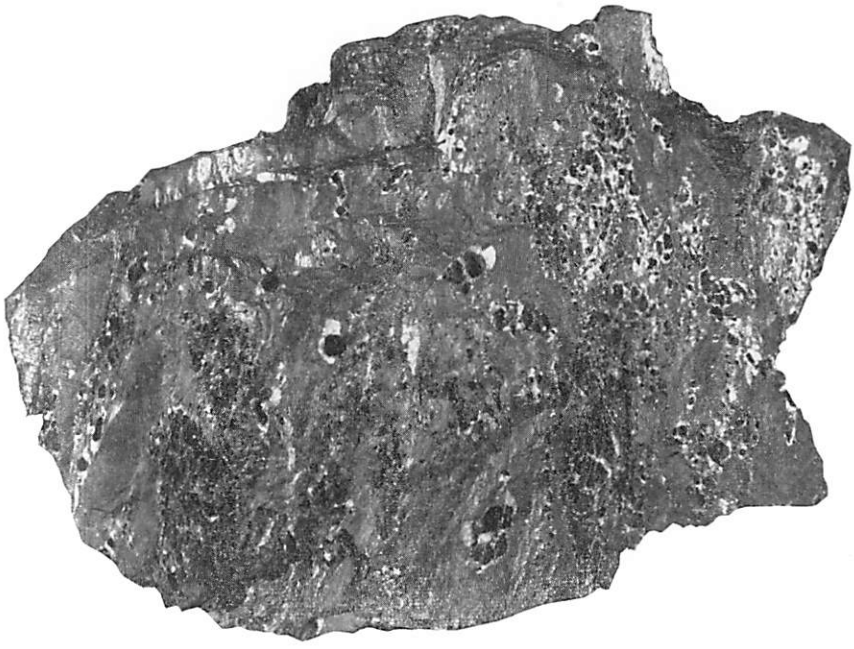

FIG. 3

FIG. 4

AN OCCURRENCE OF COSALITE IN BRITISH COLUMBIA

By H. V. Warren
University of British Columbia

Introduction

In the Cariboo Gold Quartz Mine there are some ore shoots which contain visible gold. In many places this visible gold is accompanied by a fibrous metallic mineral approximating galena in colour: this mineral was generally referred to as "a telluride" or as stibnite, but has now been identified as cosalite, a lead bismuth sulphide.

History

In 1932 small samples containing this so-called telluride were sent to Professor A. L. Crawford at the University of Utah[1] and to Dr. M. Haycock of the Department of Mines at Ottawa. Largely on the basis of etch and microchemical tests—supplemented by Dr. Haycock with a spectrographic analysis on some impure material—the mineral was tentatively identified by Professor Crawford as lillianite, and by Dr. Haycock as aikinite or benjaminite. Dr. Haycock found copper in his spectrographic analysis and this undoubtedly turned him against cosalite. However, the $3\frac{1}{2}$ per cent of copper found present by chemical analysis can most conveniently be considered as replacing some of the bismuth in cosalite and is not sufficient to suggest the presence of aikinite which carries 11 per cent of copper. Benjaminite carries twice as much bismuth as lead, lillianite carries 32 per cent of bismuth, and consequently all these determinations, reasonable though they were in the light of the information then available, may be discarded.

Moreover, both Professor Crawford and Dr. Haycock said that their determinations were tentative and stated that quantitative chemical analyses on large amounts of purer material than was available to them would be required to identify satisfactorily this mineral, recognized by both as being essentially a lead bismuth sulphide. Furthermore, Dr. Haycock discovered in his polished sections that this needle-like mineral was closely related to another

[1]Personal communication.

mineral which resembled the cosalite in all its properties except that it was massive in habit. This massive mineral is now known to be galenobismutite. It is believed that numerous conflicting reports on the etch tests for each of these minerals have resulted from testers not realizing the intimate association of this galenobismutite and cosalite.

In 1934 Eric Johnson, working under the author's direction, isolated both of these soft grey minerals and, under the supervision of the late Professor H. N. Thomson, analysed them. The needles proved to be cosalite and the massive material galenobismutite.

As both these minerals are rarely found, and in order that no doubt should remain as to their identification, the author, after obtaining some satisfactory samples, picked out under binoculars, a "clean" product which Mr. G. S. Eldridge kindly undertook to analyse. Both of the previous determinations were confirmed satisfactorily and the following description of this occurrence of cosalite is offered for the records.

ASSOCIATION AND OCCURRENCE

The cosalite found at the Cariboo Gold Quartz Mine is usually in close and often in intimate association with galenobismutite and native gold. All these three minerals have been deposited at about the same time and later than the quartz and pyrite with which they are closely associated. A carbonate gangue mineral, probably ankerite, is frequently found near the cosalite but is not abundant.

Galena, sphalerite, and chalcopyrite also occur in minor quantities associated with the cosalite, galenobismutite, and gold.

The presence of vugs into which needle-like and much twinned crystals of cosalite project together with the occurrence of arsenopyrite and scheelite in nearby ore and the widespread auriferous pyrite suggest that possibly the deposit represents one in which the earlier minerals were laid down at greater temperatures than were the later minerals. Furthermore, it is worthy of mention that no important masses of intrusive rocks have been found anywhere near the Cariboo Gold Quartz Mine. The deposit may in the light of present information be described as mesothermal with the reservation that "telescoping" of the mineral deposition may have played an important part in the forming of the deposit.

COMPOSITION

Two analyses have been made of this cosalite. Analysis 1 represents material picked out and analysed by Mr. E. W. Johnson. Analysis 2 was made on that picked out by the author and analysed through the courtesy of Mr. G. S. Eldridge.

It is not possible to get sufficient material for a complete analysis of all the minor elements such as silver which may be present in small amounts. Nevertheless, the two analyses check closely and approximate the analyses made on the original material (Dana, 1892, p. 121) from Cosala, Mexico.

	1	2
Pb	41.20	41.29
Bi	39.35	38.28
S	16.40	15.80
Cu	3.60	—
Insol.	—	1.79
	100.55	97.16

Assuming that the copper replaces some of the bismuth, calculation gives us the formula $Pb_2Bi_2S_5$ or $2PbS.Bi_2S_3$.

As in this occurrence gold is found in such important quantities wherever cosalite occurs, an assay was run from what appeared megascopically to be pure material. The assay ran 0.15 per cent Au. Three other assays of less carefully selected cosalite ran in gold: 1.12, 1.90, 10.10 per cent.

However, as native gold could be seen in nearly all polished sections containing cosalite, it is doubtful if any gold occurs chemically combined, particularly when it is noted that the most carefully selected cosalite ran only 0.15 per cent gold. Owing to the erratic occurrence of the gold in the cosalite it was not possible to estimate satisfactorily the amount of native gold contained in any one sample before assaying.

The above assays show clearly why cosalite has come to be regarded as an indicator of good gold values in the Cariboo Gold Quartz Mine.

MEGASCOPIC CHARACTERISTICS

As a result of having such small quantities of pure material with which to deal, it is not possible to do more than state that the most conspicuous physical property of this cosalite was one perfect pinacoidal cleavage parallel to the long axis of the crystals. The crystal faces are all much striated parallel to their elongation, so much so that it has so far proved impossible to measure any of the angles in the zone parallel to this elongation. The hardness is close to 2.5. Its fibrous character is conspicuous and serves to distinguish it from the associated galenobismutite from which it cannot otherwise be distinguished by megascopic examination.

MICROSCOPIC CHARACTERISTICS

Colour in polished sections—creamy grey. Strongly anisotropic. Hardness—low.

Etch tests: HNO_3, rapidly turns grey, effervescence sometimes noted. HCl, KCN, $FeCl_3$, KOH, $HgCl_2$—negative.

It is to be noted that these etch tests do not agree with those given for cosalite by Professor M. N. Short (1931, pp. 74 and 81). The author suggests that independent tests should be made on the Cariboo Gold Quartz needles so that the reason for these differences in behaviour may be explained. Incidentally, the cosalite which was tested by Professor M. N. Short came from Ontario.

CONCLUSIONS

The lead grey mineral which occurs conspicuously in fibrous form and occasionally in long needle-like crystals at the Cariboo Gold Quartz Mine is cosalite. Its chemical composition and physical properties agree closely with those ascribed to cosalite described from Cosala, Mexico. Differences in etch tests performed on this cosalite and that from Ontario have yet to be reconciled.

ACKNOWLEDGMENTS

Besides those already mentioned the author wishes to thank the officials of the Cariboo Gold Quartz Mine for their ready co-operation in obtaining specimens and for permission to publish these

results. Mr. W. B. Burnett, President, and Mr. R. R. Rose, General Manager, were particularly helpful. Mr. Roy Maconachie also assisted in collecting some of the material.

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THE WALKER MINERALOGICAL CLUB

Officers for 1938-1939

Honorary President.....Professor T. L. Walker
President.....Professor A. L. Parsons
Secretary-Treasurer.....Mr. W. E. Chantler
Councillors for Members.....Mr. D. E. Craigie
Mr. H. C. Rickaby
Councillor for Department of Mineralogy.....Professor M. A. Peacock
Councillor for Student Members.....Mr. E. O. Chisholm

At the first meeting of the year 1938-1939 held on October 27, 1938, at 4.30 o'clock in the Theatre of the Royal Ontario Museum, the Secretary-Treasurer presented an interim report showing that the membership consisted of two honorary members, 157 members, and 11 student members. After expenses were paid there was a surplus of $45.00, or a cash balance of $29.50 in the treasury. Up to that date sixteen members were still owing dues.

The Council then reported to the Club the election of the Honourable and Reverend H. J. Cody as Honorary Member of the Club for the great service that he rendered to the sciences of Mineralogy and Petrography while acting as Minister of Education for Ontario, in providing funds for research in Mineralogy and Petrography and other sciences in the University of Toronto. By this appropriation it was made possible to carry on the research, the results of which were published in the early numbers of *Contributions to Canadian Mineralogy.*

The Secretary was instructed to send a copy of the report to Dr. Cody with the announcement of his election.

The Committee appointed to nominate officers for the Walker Mineralogical Club for the year 1938-1939 nominated the following officers:

President.....Professor A. L. Parsons
Secretary-Treasurer.....Mr. W. E. Chantler
Councillor for Members.....Mr. D. E. Craigie
Councillor for Department of Mineralogy.....Professor M. A. Peacock
Councillor for Student Members.....Mr. E. O. Chisholm

It was moved by Mr. Rickaby that the Secretary-Treasurer be instructed to send out ballots for the election of officers and that the poll close on Monday, December 5, and that the Council be instructed to canvass the ballot and announce the results thereof immediately.

On motion by Professor Thomson the Club passed the following by-law:

"The Secretary-Treasurer or the President shall be authorized to draw cheques on the bank account of the Club for the payment of bills."

Notice of motion was given by Professor Thomson that the Constitution of the Walker Mineralogical Club be amended as follows:

Under *Officers*, that the clause "A Councillor to represent the Members" be amended to read "Three Councillors to represent the Members, one to retire each year."

That the clause "These Officers shall constitute the Council of the Club" be amended to read "These officers together with the first past president shall constitute the Council of the Club and shall be authorized to fill vacancies in the Council for the year and to perform such duties as ordinarily fall to a council."

Under *Meetings*, that the paragraph which reads "The meetings of the Club shall be on the fourth Thursday of October, December, February and March" shall be amended to read "The meetings of the Club shall be on the Fourth Thursday of October, February and March and on the Second Thursday of December."

On motion by Professor Thomson, the Secretary-Treasurer was instructed to send to each member the proposed amendments to the constitution and that the result of the ballot be reported to the Club at the February meeting.

The Council was then authorized to arrange a meeting of a social character in lieu of the regular December meeting.

At five o'clock an open meeting was held which was addressed by Professor R. P. D. Graham of McGill University on "Some Non-Metallic Minerals of Quebec" in which the speaker discussed the origin, mode of occurrence, and use of the serpentine, talc, chromite, and kaolin deposits of Quebec.

On invitation by the Chairman and the Board of Trustees of the

Royal Ontario Museum, the Club, with their wives and friends, was privileged to be present at the formal opening of the Crystal Cave in the Royal Ontario Museum of Mineralogy on December 9, 1938, and afterwards a reception was given by the Chairman and the Board of Trustees in honour of the Walker Mineralogical Club. Dr. J. B. O'Brian, Mrs. H. D. Warren, and Professor A. L. Parsons received the guests. Presiding at the tea table in the library of the Museum of Mineralogy were Lady Falconer, Mrs. H. J. Cody, Mrs. Sigmund Samuel, and Mrs. E. S. Moore. Those assisting were Miss Harriet Parsons, Mrs. V. B. Meen, Mrs. R. B. Burgess, Mrs. Jack Satterly, Mrs. George Langford, Miss Ruth Moore, Dr. Madeline Fritz, Mrs. L. S. Russell, Mrs. V. J. Okulitch, and Mrs. M. A. Peacock.

The third meeting of the year was held in the Lecture Room of the Royal Ontario Museum on February 23, 1939, at 5 o'clock at which time Major G. M. Thomson of Gypsum, Lime and Alabastine, Canada, Limited, addressed the Club on the "Growth of Gypsum Crystals." The lecture was illustrated with slides and moving pictures exhibiting the growth of the gypsum crystals during the hydration of plaster-of-paris.

At the meeting of March 23, 1939, in the Lecture Room of the Royal Ontario Museum, on motion of Professor Thomson, seconded by Dr. Okulitch, the President was empowered to appoint a committee to nominate officers for the coming year. This committee which was later appointed consists of the Council with the addition of Professor A. MacLean and Mr. W. C. Ringsleben.

Professor M. A. Peacock then presented a paper on "The Use of *X*-rays in Mineralogy," describing the various methods employed for the study of minerals and crystals by means of *x*-rays and giving a description of the new laboratory for *x*-ray study of crystals in the Department of Mineralogy and Petrography in the University of Toronto.

The membership of the Club as on June 1, 1839, is as follows:

Honorary members	3
Members	221
Student members	17
Total	241

One member, Mr. A. Dempster, was lost by death during the year.

FINANCIAL STATEMENT OF THE WALKER MINERALOGICAL CLUB FROM JANUARY 14, 1938, TO JUNE 1, 1939

RECEIPTS

Dues paid for 1937-1938	$168.50	
Dues paid for 1938-1939	173.50	
Dues paid in advance	44.00	
Bank interest	.32	
Refund from University Press	5.40	
Sale of back number of Journal	1.25	
Contribution from Honorary Member, R. A. A. Johnston	5.00	
Unrecorded receipts	1.13	
Total cash receipts		$399.10

Unpaid dues $64.00 shown in Statement of Surplus.

EXPENDITURES

November 21, 1938, University of Toronto Press	$5.04	
December 8, 1938, University of Toronto Press	5.40	
January 7, 1939, University of Toronto Press	148.82	
March 23, 1939, University of Toronto Press	4.79	
March 23, 1939, Superintendent, University of Toronto	1.75	
April 5, 1939, University of Toronto Press	5.14	
Bank charge	.31	
Total expenditures	$171.25	
Cash on hand and in bank	227.85	
		$399.10

SURPLUS as of June 1, 1939

Cash on hand and in bank	$227.85	
Unpaid dues for 1937-1938	1.00	
Unpaid dues for 1938-1939	63.00	
		$291.85

LIABILITIES

None	0.00	
Total surplus		$291.85

THE WALKER MINERALOGICAL CLUB

May 10, 1939

Honorary Members

Dr. H. J. Cody — Dr. R. A. A. Johnston — Dr. T. L. Walker

Ordinary Members

Airey, H. T.
Allan, J. A.
Allan, J. D.
Allen, J. S.
Armstrong, J. E.
Ashcroft, F. N.
Atchison, D. W.
Austin, F.
Badian, A. M.
Baker, J. M.
Ball, S. H.
Bandy, M. C.
Barrington, J. D.
Barth, T. F. W.
Bateman, G. C.
Beamish, F. E.
Beattie, J.
Bell, A.
Bell, J. W. N.
Berman, H.
Berry, L. G.
Blomfield, A. L.
Bradfield, A. R.
Brigham, A. F.
Brigstocke, R. W.
Britton, G. C.
Brown, E. L.
Brown, W. L.
Brownell, G. M.
Bryce, R. A.
Buddington, A. F.
Buisson, G. J. A.
Burns, A. G.
Burwash, E. M.
Campbell, A.
Campbell, A. D.
Campbell, I.
Campbell, N.
Carlyle, E. J.
Carveth, W. A.
Chantler, W. E.
Chudoba, K.
Cole, A. A.
Cole, L. H.
Combs, R. H.
Costain, H. H.
Coultis, S. G.
Craigie, D. E.
Dadson, A. S.
Davis, N. B.
Dawson, J. A.
Day, B.
DeLury, J. S.
Denis, T. C.
Derry, D. R.
Dickenson, J. G.
Dolmage, V.
Donnay, J. D. H.
Dougherty, E. Y.
Douglas, G. V.
Drury, C. W.
Dufresne, A. O.
Dupuis, G. E.
Dyer, W. S.
Eardley-Wilmot, V. L.
Ellsworth, H. V.
Emery, V. H.
Errington, J.
Fabry, R. J. C.
Faessler, C.
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