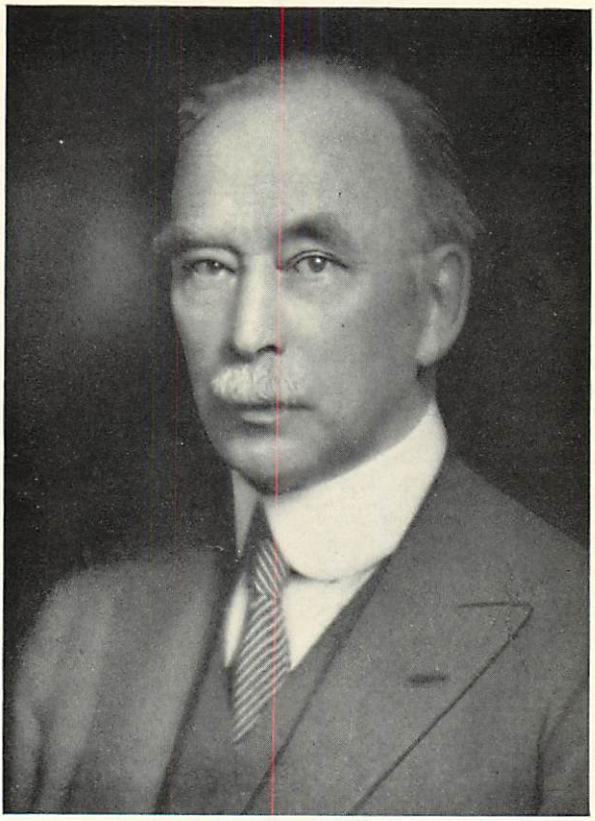

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PROFESSOR OF MINERALOGY AND PETROGRAPHY
IN THE
UNIVERSITY OF TORONTO
1901-1937

DIRECTOR OF THE ROYAL ONTARIO MUSEUM OF MINERALOGY
1912-

AN OUTSTANDING CONTRIBUTOR TO OUR KNOWLEDGE OF THE
MINERALOGY AND PETROGRAPHY OF CANADA

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FOREWORD

By A. L. Parsons

The present issue of Contributions to Canadian Mineralogy marks a decided change in the policy that has prevailed in the past, for colleagues and former students in other institutions have contributed articles as a special expression of their high esteem upon the premature completion of the active work of Professor Thomas Leonard Walker, Ph.D., as head of the Department of Mineralogy in the University of Toronto. When, in May, 1936, he was suddenly forced to give up active work, the work that was being done by students under his direction was nearly finished but had not been put in its final form for publication. It was also hoped that certain other papers which were planned by Dr. Walker could be prepared after he had a period of rest, but up to the present this has not been possible.

This series of studies was started by Dr. Walker in 1921 so as to have an outlet for an increased number of articles dealing principally with mineralogical and petrographical researches that were made possible for several years by a special grant for scientific research in the University of Toronto by the Provincial Government of Ontario. The ramifications of such studies have in some cases extended to other branches of science: chemistry, geology, physics, botany, and zoology, but unless another more suitable medium of publication were readily available, the results have been incorporated in this series.

In the editing of the Contributions, the writer was most intimately connected with Dr. Walker, and no statement was allowed to be published until we were perfectly agreed that the point at issue was reasonably proven. Theories that were not well based on facts were considered entirely out of place.

Although many articles by Dr. Walker and his colleagues have been published elsewhere, Contributions to Canadian

Mineralogy from 1921 to 1937 constitute the best part of the work of the most fruitful period of Dr. Walker's academic career, including not only his own researches but those of his colleagues and students who worked under him. It was the period when he inspired all who were with him to accomplish the best work of which they were capable.

In order that permanent credit may be given to Dr. Walker for establishing and directing this series of studies, an index has been prepared and incorporated in this study so as to mark as a unit this part of the series, which it is hoped may be continued by his successors.

The writer wishes to express his thanks to all those who have assisted at this time in the preparation of a Study that is worthy of being dedicated to our friend, colleague, and teacher, Thomas Leonard Walker.

INSECTS AND ARACHNIDS FROM CANADIAN AMBER

By F. M. Carpenter, J. W. Folsom, E. O. Essig, A. C. Kinsey, C. T. Brues, M. W. Boesel, and H. E. Ewing

INTRODUCTION

By F. M. Carpenter

Up to the present time our knowledge of the insect fauna of the Cretaceous period has been almost negligible. Apart from a few fragments of very dubious affinities, only about a dozen specimens have been described from strata of that horizon. Since there is every indication that most of the existing families of insects arose during the Cretaceous, the paucity of such fossils has been very disconcerting. It was lamented many years ago (1917) by Professor Cockerell, who asserted then that nothing would throw more light on the relationships of living insects than the discovery of a rich Cretaceous fauna. During the twenty years which have passed since then, no such fauna has been uncovered. But a little more than two years ago a deposit turned up which gives promise of filling in this extensive gap in the geological record of the insects, and the fact that this deposit is amber adds enormously to its significance. The existence of such a deposit came to my attention solely as a matter of chance. In the course of a routine perusal of geological literature in January, 1935, I happened to come upon a short abstract of a paper read by Dr. T. L. Walker at the fifteenth annual meeting of the Mineralogical Society of America, in which brief reference was made to the amber and insect inclusions.[1] In reply to my request for further information, Dr. Walker sent me a

[1]Proc. Geol. Soc. Amer., 1934: 418.

copy of his published paper[2] in which he refers to the discovery of the insects as follows: "In the course of the examination of the specimens [of amber] with the microscope, it was observed that some of the specimens showed remains of insects, often fragmental, but at times perfectly preserved even to the most delicate structures shown by the antennæ and wings. . . . There seems to be a great variety not only of insects but of spiders and other small forms. There is here an important fauna for the palæontologist and entomologist to which, so far as the writer is aware, attention has not previously been directed." As soon as the amber was prepared for shipment, twenty-seven pieces containing nineteen insects were sent to me, and in the fall of 1935 seventy-five more pieces including sixty-eight insects were also forwarded to me by Dr. Walker. A preliminary note on the first lot has already been published[3] and the present paper is an account of the eighty-seven insects represented in these two collections.[4]

Since several orders and families were represented in this assemblage and all of them belonged to groups in which I have done no systematic work, I felt that it was advisable and even necessary to enlist the aid of various other entomologists in order to obtain authentic accounts of the insects included. The parasitic Hymenoptera were accordingly referred to Professor C. T. Brues; the Chironomidæ to Professors O. A. Johannsen and M. W. Boesel; the Cynipidæ to Professor A. C. Kinsey; the Collembola to Dr. J. W. Folsom; the Aphididæ to Professor E. O. Essig; and the mites to Dr. H. E. Ewing. The manuscripts prepared by these specialists have been brought together and form the descriptive part of the present paper. I acknowledge with many thanks my indebtedness to these fellow entomologists for their indispensible co-

[2]Univ. Tor. Studies, Geol. Ser., no. 36, Contributions to Canadian Mineralogy 1934: 5-10.

[3]Carpenter, F. M. 1935. Univ. Tor. Studies, Geol. Ser., no. 38: 69.

[4]Since this paper was finished, the writer and C. T. Brues accompanied by Mrs. Brues, Alice M. Brues, and Mr. C. T. Parsons have collected about four hundred pounds of the amber at Cedar Lake for the Museum of Comparative Zoology.

operation. To Dr. Walker we all are more than grateful for the opportunity to study these remarkable fossils—an opportunity made possible not only by his courtesy in loaning the specimens but also by his discovery of the insects in the amber. We are also indebted to Dr. F. P. Ide, University of Toronto, for finding some of the insects in amber in his possession; to Mr. A. S. Fuller, Toronto, for collecting some of the amber at Cedar Lake; and to Mr. G. W. Allan of the Hudson's Bay Company for his assistance in obtaining most of the amber. My own part in the preparation of this paper has been confined to various routine tasks, such as grinding and polishing the pieces of amber so that the insects could be seen clearly, sending the specimens to the several specialists already mentioned, and editing the manuscripts.

Although insects have thus only recently been found in the amber, the existence of this deposit has been known for nearly half a century. In 1890 Mr. J. B. Tyrrell, while making a geological survey of the vicinity of Grand Rapids, Manitoba, reached the Chemahawin Indian Reservation at Cedar Lake. Here an Indian showed him a piece of amber, which he stated was found in that region. In company with the Hudson's Bay Company officer, Mr. W. C. King, Tyrrell examined the place where the amber had been found, on the west shore of Cedar Lake, near the mouth of the Saskatchewan River. Tyrrell's report on his observations follows:[5]

"[The amber] occurs mixed with sand and many fragments of partly decayed wood, on a low beach behind a gradually shelving shore and along the face of a deep wet spruce swamp. The pieces were for the most part smaller than a pea, but could be readily seen glittering among the sand and vegetable debris. Some pieces were found as large as a robin's egg, and Mr. King informed me that he had collected pieces very much larger. It has evidently been washed up on the shore by the waves, but its exact age has not yet been positively determined. . . .

"It is difficult to make an accurate estimate of the quantity of amber on this mile beach, but it may confidently be said

[5]Summary Rept., Geol. Surv. Can. 1890, 1891: 22. Also Ann. Rept., Geol. Surv. Can., N.S., vol. V, 1890-1: 30-1 A.

to be found throughout the distance in a band thirty feet wide, with a minimum depth of two feet. This band has thus a total bulk of 316,800 cubic feet. A number of specimens collected from various parts of it showed an average of a little over ten percent. of amber, which, in natural fragments, weighed 46 pounds to the cubic foot. The amount of amber on this strip of beach would, therefore, be about 31,680 cubic feet, or 1,457,280 pounds."

The following year, 1891, Tyrrell made a second and more extended trip to Cedar Lake, this time for the specific purpose of obtaining additional data on the occurrence of the amber. Although no other extensive deposits of the amber were found, grains of the amber were seen on the shores of several small lakes in the vicinity of Chemahawin, and to the north and east of Cedar Lake. From his observations on the geology of the region, Tyrrell was led to believe that the amber had been derived from the Cretaceous rocks in the prairie through which the Saskatchewan River flows and that it had been deposited in the delta formed by the river where it enters Cedar Lake.

It is surprising that no reference is made in these published notes to the presence of insects in the amber, especially since interest in fossil insects was very general among the geologists at about that time. I have been unable to find any mention of these inclusions, however, and since no other papers on the amber have been published prior to Dr. Walker's, he is the first to refer to the occurrence of the insects.

Inasmuch as the present place of deposition of the amber is obviously a secondary one, its geological age is difficult to determine. But a study of a geological map of Canada contributes materially to this problem. It may be assumed without question, I think, that the amber has been derived from some region west or north-west of Cedar Lake, following the present general drainage of the area. Cedar Lake itself, and the Saskatchewan River for fully 150 miles up from the lake, is situated in a Silurian formation, and above that for at least 700 miles the river and its branches (North and South Saskatchewan Rivers) flow through Cretaceous beds only.

A few hundred miles beyond this interval, approximately a thousand miles from Cedar Lake, the Saskatchewan River has its source in the Rocky Mountains of Alberta, in a series of formations considered to be either upper Cretaceous or lower Tertiary.[6] It is of interest in this connection that amber, or at least some form of fossil resin, has been found in lignitic beds in various parts of British Columbia (Nanaimo coalfields, Nechako River, Peace River, Frances River), but these regions are close to the Pacific Ocean and have probably always had a westerly drainage, away from the vicinity of Cedar Lake. Fossil resin has also been found in the very southern part of Saskatchewan, in a relatively small bed of Cretaceous lignite. In this connection it is interesting to note that the Cedar Lake amber differs in structure from the Baltic amber. The most complete chemical analysis was made by Harrington, who examined some of the pieces collected by Tyrrell.[7] He found that unlike Baltic amber it did not contain succinic acid, that it was more resistant to heat than Baltic amber, and that it had a somewhat different ultimate composition. He proposed the name Chemawinite to distinguish it from the other retinites, such as Krantzite, Jaulingite, *etc.*, and concluded that "though the origin of this substance is not certainly known, there is little doubt that it has been derived from one of the Tertiary[8] or Cretaceous lignites occurring on the Saskatchewan. Some of these are known to contain resins, one of which, examined by the writer, was not essentially very different from the Cedar Lake material." It is also pertinent to note that amber has been found in Cretaceous lignites in various parts of North America, such as New Jersey, Delaware, Staten Island (New York), Martha's Vineyard, and Colorado. One piece of this

[6]This is the "Laramaie" formation, as that term was used by Dawson in 1882 (Rept. of Progress, Geol. Surv. Can., 1880-1882: 48).

[7]On the So-Called Amber of Cedar Lake, N. Saskatchewan, Canada. Amer. Journ. Sci., (3) 42, 1891: 332-338.

[8]At the time when Harrington's paper was written, much of the area through which the Saskatchewan River flows had not been surveyed and its geological age was not certain. Since then surveys have shown all these regions to be Cretaceous, not Tertiary.

Cretaceous amber, from Hardin County, Tennessee, contained a caddis-fly, *Dolophilus præmissus* Cock., the first and only amber insect described from North America up to the present time.

The most striking indication of the age of the amber is provided by the insect inclusions. Our knowledge of the insect fauna of the Tertiary is much more complete than that of any other geological period, owing to a large extent to the thousands of specimens preserved in the Baltic amber. By comparing the insects present in the Canadian amber with those belonging to the same orders or families of the Tertiary fauna, especially in the Baltic amber, we can obtain some idea of the geological level of the Canadian amber. In the present paper twenty-two new species, seven new genera, and two new families are described from the Canadian amber. It will be apparent from the descriptions and discussions given below that the new genera and families are particularly striking because of their primitive or generalized characteristics, and because of their intermediate position between various existing families. As an example we might take the Collembolan described below as *Protentomobrya walkeri* by Folsom, which represents a new family, Protentomobryidæ. In contrast to this, all the twelve species of Collembola which have been described from the Baltic amber belong to *existing genera*! The whole picture presented by the Canadian amber species does not fit at all with our understanding of the Baltic amber (Oligocene) fauna. Of course a more extensive series of the insects will be needed to furnish conclusive proof of the age of the amber, but I believe that in view of the nature of the insects which we now have and the geology of the region, we are justified in assuming that it is Cretaceous.

Because of the small number of known Cretaceous insects, even the twenty-two species described in this paper contribute materially to our knowledge of the fauna of that period. Until now, aside from obscure fragments of uncertain family position, one dragon-fly, four cockroaches, one stone-fly, three possible midges, and a few beetles have comprised the known Cretaceous fauna. In this paper species of six existing

families are described from the Canadian amber and these constitute not only the first record of all six families in the Cretaceous but also their earliest geological occurrence.

In addition to the species described below, several others are included in the collection of amber, but the specimens are not well enough preserved to permit generic or, in some cases, even family position. There are two specimens of Coleoptera (Nos. 27A and 70), family uncertain; two specimens of Diptera Brachycera, possibly Empidids; and several Homopterous nymphs, apparently in the first stage. Since additional collecting of the amber will probably yield better specimens of these species, we have not attempted to describe them.

INSECTA

ORDER COLLEMBOLA

By J. W. Folsom[1]

The single peculiar specimen at hand represents a new family of Collembola.

The most remarkable characteristic of the Collembolan is the primitive condition of the furcula, or spring, on the fourth abdominal segment. The furcula (figure 1) consists simply of a pair of long slender diverging stylets, each swollen basally. No division into manubrium, dentes, and mucrones (as in recent forms) was detected.

In ventral aspect, under strong overhead illumination, the form of the furcula showed clearly in white, against the dark background of the abdomen.

On the whole, the affinities of this species are with Entomobryomorpha, particularly Entomobryidæ, as shown in the reduced, concealed pronotum, the reduced first abdominal segment, and the clothing. On the other hand, the third abdominal segment is not reduced, being almost as long as the fourth (as 14: 17), and in this respect suggests the genus *Orchesella*. Furthermore, the fifth abdominal segment is not reduced. The anterior limits of the sixth abdominal segment are obscure, though there is a dorsal subtriangular appendage, or suranal valve, and underneath this a subtriangular subanal valve. These two valves are separated from each other in the specimen by a bubble that projects from the rectum.

The antennæ, however, which are relatively short, with short stout segments, are not of the entomobryid type, but are such as are characteristic of Poduromorpha (Poduridæ and other families).

A new family is necessary for the reception of this species. That is something unusual, for the twelve species of Col-

[1]Bureau of Entomology and Plant Quarantine, U.S. Dept. Agr.

lembola hitherto known from amber have all been referable to recent genera (*Hypogastrura* 2, *Isotoma* 2, *Entomobrya* 1, *Tomocerus* 1, *Lepidocyrtus* 1, *Orchesella* 1, *Sminthurus* 1, *Allacma* 3), according to Handschin,[2] who has revised them.

Those twelve species, from Baltic amber, are from the Oligocene, however; while the species described here is apparently Cretaceous.

Our specimen is essentially as represented in figure 1. The parallel-sided condition of the abdomen is abnormal; on the ventral side are irregular folds which indicate that the abdomen has shrunk laterally. Probably the abdomen was normally fusiform.

The number of eyes on each side of the head could not be made out clearly. None could be seen on the right side, but there were apparently at least six on the left side. Since the area of the eye spot is not reduced (as compared with that of recent forms), and since the area is greater than is necessary for six eyes, it is possible that there were eight eyes on each side, as in most of the recent species.

The legs were contracted in confusion under the body, and the claws could not be studied. A ventral tube could be seen obscurely. A tenaculum was not seen.

PROTENTOMOBRYIDÆ Folsom, n. fam.

Body elongate. Pronotum probably membranous and naked, concealed under the mesonotum. Abd. 1 reduced. Abd. 3 almost as long as abd. 4, which is but slightly enlarged. Abd. 5 not reduced. Abd. 6 with suranal and subanal valves. Furcula present, consisting of a pair of long simple stylets. Antennal segments four, short and stout. Integument smooth. Clothing setaceous.

PROTENTOMOBRYA Folsom, n. gen.

The generic characters are contained in the preceding diagnosis of the family. They cannot, however, be listed

[2]Handschin, E. 1926. Revision der Collembolen des baltischen Bernsteins. Ent. Mitt., bd. 15: 161-185, 211-223, 330-342, figs.

separately, with only one species at hand. It may be said, though, that in the family Entomobryidæ the number of antennal segments, the relative lengths of abd. 3 and abd. 4, and the character of the clothing (whether setaceous or scaly) are characters of generic value.

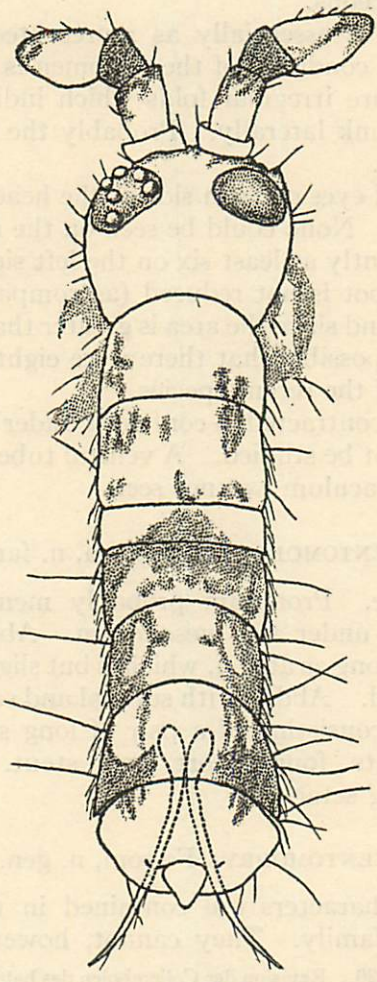

FIGURE 1.—*Protentombrya walkeri* Folsom, n. sp. Drawing of type.

Protentomobrya walkeri Folsom, n. sp.

Figure 1

Ground colour probably pale yellow or white, with blackish markings. Ant. 2 black apically; ant. 2 black throughout. The colour pattern of the body is partly indefinite, but abd. 1 shows a black median triangle; abd. 2 is mostly black except along the posterior border; abd. 3 is black laterally, with an elongate pale spot on each side; and abd. 4 has a black band across the posterior third (interrupted in the figure). Eye spots not reduced, and eyes at least 6 and possibly 8 on each side. Antennæ relatively short, with short stout segments, in relative lengths as 3:12:7:17 (right side) and 2.5:11:8:15 (left side). Clothing of dense, short, reclinate setæ and long, outstanding tactile hairs. Furcula with sparse, short, stiff setæ. Integument smooth. Length, 0.64 mm.

Holotype: No. 64, Royal Ontario Museum of Mineralogy, Toronto.

Locality: Cedar Lake, Manitoba, Canada.

Named for Dr. T. L. Walker, Director of the Royal Ontario Museum of Mineralogy, Toronto, to whom we are indebted for the opportunity to study these amber insects.

ORDER HOMOPTERA

FAMILY APHIDIDÆ

By E. O. ESSIG

The fossil aphid referred to me for determination is of special interest because of its geologic age. Since the Aphididæ have not previously been found earlier than the Baltic amber (Oligocene), this specimen is by far the oldest known member of the family.

An examination of the published descriptions and illustrations of the fossil aphids reveals an amazing and confusing situation. In the first place the described specimens appear

to be unusually well preserved considering the extremely delicate and fragile nature of these small insects. This is specially surprising of the large number of genera and species taken in the shales of Florissant, Colorado, and described by S. H. Scudder and G. B. Buckton. Those of the Baltic amber do not appear to be in such good condition if we are to judge by the illustrative material available. In the second place the taxonomic work, while done by eminent and thorough paleo-entomologists, reveals a lack of general knowledge of the Aphididæ as a group and the genera and species individually. Therefore, there is usually lacking in the descriptions certain characters that are now most used in the classification of the insects. The wings, which are best preserved, form the general basis for classifying fossil aphids, and there seems to be some confusion as to the exact use of the venation in erecting sub-families and genera. It is also difficult to conclude whether certain of the named species actually lacked cornicles, sensoria, and other organs now used in classification, or whether perhaps these were either destroyed during the process of preservation or do not show in the fossil specimens. My researches of the literature gave no helpful clue to the problem of naming the particular aphid at hand.

The individual herein described is preserved in a small piece of amber which is mounted in Canada balsam under a cover glass on a microscopic slide. With the use of our best microscopes it is impossible to locate secondary sensoria and cornicles. The thickness of the amber prevents the use of high magnifications, and it may be possible in the future, with better equipment, to see things which are wholly indiscernible by me.

Subfamily *Aphidinæ*

The question of the proper subfamily for this new species is a difficult one, since in modern classification certain habits and characters are used which cannot be ascertained for a fossil specimen. There is at present no way to relegate fossil aphids to suitable subfamilies without studying at first hand the various previously described species. If one is to follow

the broadest interpretation in the erection of subfamilies, this species would fall in the Aphidinæ from the fact that the media (third discoidal or cubitus) is twice-branched.[1] Most of the modern definitions of the subfamily are much more elaborate and comprehensive. However, such a designation as this accords with the present view that this subfamily Aphidinæ is the most primitive of the Aphididæ.

Canadaphis Essig, n. gen.

Wings with characteristic aphis-type venation; abdomen prolonged posteriorly into a tail-like cauda; antennæ six-segmented; cornicles absent.

Canadaphis carpenteri Essig, n. sp.

Figure 2

This small aphid lies embedded in a small bit of amber in the position shown in the accompanying illustrations in figure 2. The body is somewhat pigmented and too dense to permit careful study. The head is indeed quite unusual and the front appears like an extended two-lobed process. The antennæ, especially the apparently perfect left member, are clearly segmented, as are also the legs. The compound eyes are evident, but the facets are not well defined. There are indications of ocular tubercles. The wings are beautifully preserved in a most remarkable manner and are not unlike those of modern living specimens. Both pairs are visible; the venation is distinct; the stigma prominent, but short; the surfaces are covered with the characteristic cuticular scales; the fore wings are furnished with the anal folds which were engaged in flight by two humuli on the distal front margin of the hind wings. The legs are quite normal in size and the tarsi are two-segmented; the first segment very small and the

[1]Even this single character is too broad a statement since such a modern authority as A. C. Baker states: "In the typical forms of this subfamily the media of the fore wing is twice branched, but it is very commonly branched only once, and it is rarely simple" (Generic Classification of the Hemipterous Family Aphididæ. U.S. Dept. Agr. Bull. 826, 1920: 11).

second unusually long. There are indications of permanent sensoria on antennal segments V and VI, but no secondary sensoria are visible on III, a condition found in practically all modern alate individuals. It is possible that they are not discernible. The segmentation of the antennæ is quite modern in aspect.

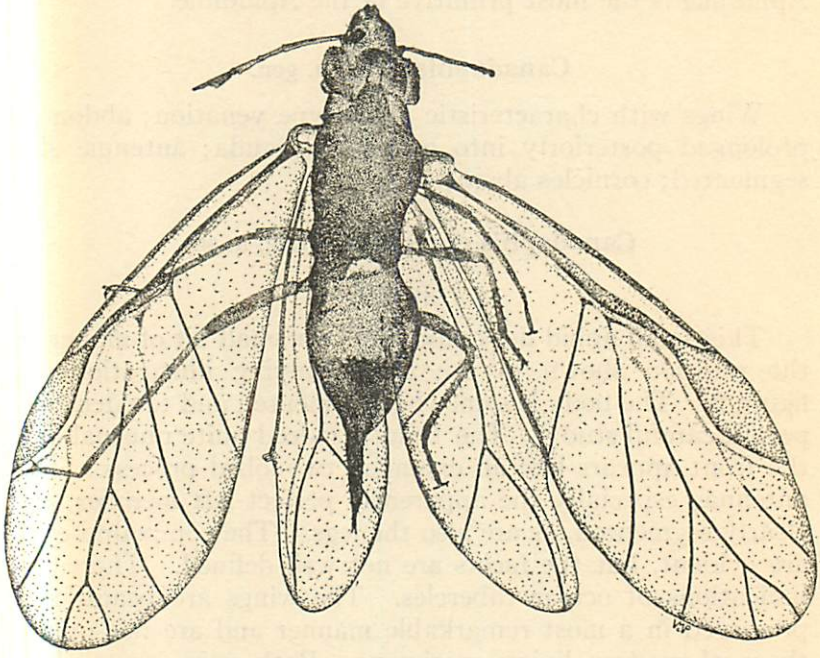

FIGURE 2.—*Canadaphis carpenteri* Essig, n. sp. Drawing of type by Virginia McPheter.

The most striking feature of the insect is the long pointed extension of the abdomen into what may be a cauda, but which bears little resemblance to that organ in present-day forms. Whether it is a natural condition or a forced prolongation of the body during the embedding process cannot be ascertained, but the presence of two small spines at the pointed apex suggests a natural condition. It includes about one-fifth of the entire length of the body. Camera lucida

measurements give lengths as follows: body, including cauda, 1.25 mm.; cauda 0.25 mm.; fore wing 1.43 mm.; stigma of fore wing 0.35 mm.; hind tarsi 0.15 mm.; antenna—I, 0.02 mm.; II, 0.03 mm.; III, 0.16 mm.; IV, 0.06 mm.; V, 0.07 mm.; VI, 0.11 mm. (base 0.04 mm.; unguis 0.07 mm.); total 0.46 mm.

The new species is named in honour of Dr. F. M. Carpenter.

Type: No. 30, Royal Ontario Museum of Mineralogy, Toronto.

ORDER HYMENOPTERA

FAMILY CYNIPIDÆ

By ALFRED C. KINSEY[1]

There are only seven fossil Cynipoids described to date. Several other references to Cynipoids in the paleontological literature are too vague to be ascribed with any assurance to this group (*see* Kinsey, 1919).[2] The acceptable species are the following:[3]

Figites solus, Brues 1910, Miocene, Florissant, Colo.
Protoibalia connexiva, Brues 1910, Miocene, Florissant, Colo.
Aulacidea progenitrix, Kinsey 1919, Miocene, Florissant, Colo.
Aulacidea ampliforma, Kinsey 1919, Miocene, Florissant, Colo.
Aulacidea succinea, Kinsey 1919, Oligocene, Baltic amber.
Rhodites vetus, Cockerell 1921, Oligocene, Isle of Wight.
Andricus vectensis, Cockerell 1921, Oligocene, Isle of Wight.

It is to be observed that all the species previously described are Miocene and Oligocene in origin. Consequently the discovery of the Cretaceous specimen described below pushes

[1]Contribution from Dept. Zool., Indiana Univ., no. 251 (Entomological Ser. no. 12).

[2]Kinsey, A. C. 1919. Fossil Cynipidæ. Psyche, 26: 44-49.

[3]Brues, C. T. 1910. The Parasitic Hymenoptera of the Tertiary of Florissant, Colorado. Bull. Mus. Comp. Zool., 54: 1-125.

Cockerell, T. D. A. 1921. Fossil Arthropods in the British Museum. V. Oligocene Hymenoptera from the Isle of Wight. Ann. & Mag. Nat. Hist., (9) 7: 1-25.

the known history of the group back a very long way. It is remarkable that the new species is clearly cynipoid, even at that remote horizon; and that it is only a little more primitive than the Oligocene and Miocene species and, indeed, than some of the simpler present-day genera of the families Figitidæ and Cynipidæ.

One of the species described from the Oligocene of the Isle of Wight by Cockerell is assigned to *Andricus* and another to *Rhodites*; but there seems nothing in the published records of the two that would rule them out of the present-day tribe Aulacini. It is in that tribe that all of the other described fossils clearly belong; and it is also with the Aulacini that the new, Cretaceous species has most of its affinities. This continued relation of the fossils with the most primitive of the present-day tribes may have some significance. It is possible that the more specialized genera which constitute the bulk of our recent gall wasp fauna have all come into existence since the early Miocene; but the fossil record is much too scant to warrant drawing such a conclusion from it alone.

Protimaspis Kinsey, n. gen.

With the characters found in the Cretaceous fossil described below. Closest to the present-day genera *Timaspis* and *Phanacis*, and not far removed from *Aulacidea*. Differs from these in having the abdomen more lenticulate in profile, the second segment of the abdomen larger, the terminal segment lacking on the subcosta, the second abscissa of the radius nearly straight, the radial cell more narrow at base, the areolet larger, the nervulus peculiarly modified, and the whole wing a bit shorter (with a wing-body ratio of 0.94, instead of 1.05 or more as found in the present-day genera).

Genotype: *Protimaspis costalis* n. sp., from the Cretaceous amber of Cedar Lake, Manitoba, Canada.

Protimaspis costalis Kinsey, n. sp.

Figures 3A and 3B

Female (?). Entire body dark to black (as seen in the fossil!). Head about as wide as thorax, slightly widened

behind cheeks; antennæ 14- (or 15-) segmented, somewhat moniliform, with segments 4-13 subequal, with segment 3 only slightly longer (and slightly incised?), with segment 14 nearly twice as long as 13 and with a more or less obscure division. Thorax rather slender and elongate (the other details not evident in the fossil). Abdomen essentially sessile, slender,

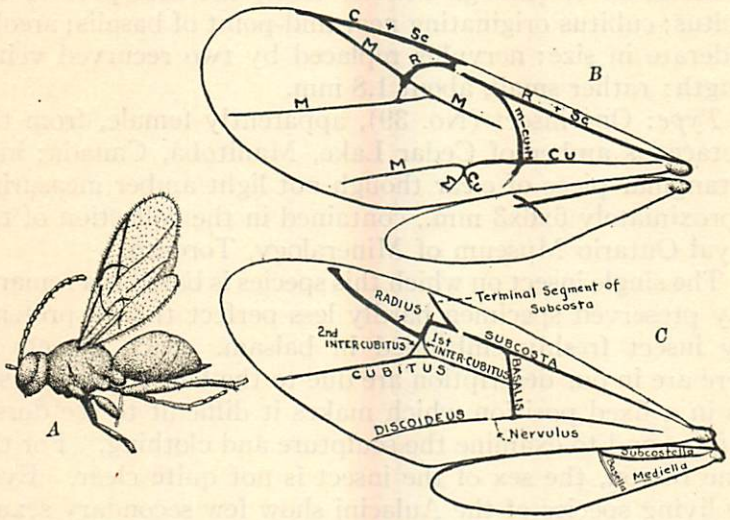

FIGURE 3.—A. *Protimaspis costalis* Kinsey, n. sp. Drawing of type specimen in the position in which it was found, and without any reconstruction.

B. *Protimaspis costalis* Kinsey, n. sp. Detail of front wing, indicating possible homologies in venation. C=costa, Sc=subcosta, R=radius, M=medius, Cu=cubitus.

C. *Cynips sp.* Detail of front wing, with current nomenclature for veins.

elongate, lenticular in profile, with segment 2 covering more than one-third, but the other segments sub-equal; the hypopygium without a spine. Legs usual; tarsal claws simple. Wings normal, but only 0.94 of the body in length; ciliate over the entire surface and on every margin (unless lacking on part of the anal margin of the fore wing); veins only moderate in weight, those about the radial cell heaviest;

subcosta straight, not extending beyond usual break in vein, not turned up toward margin; a vein along entire margin of radial cell, closing it and extending a bit beyond it in both directions; radial cell long triangulate, twice as long as its width at base; first abscissa of radius well curved but not angulate; second abscissa of radius fairly straight, a direct continuation of (though heavier than) the first part of the cubitus; cubitus originating near mid-point of basalis; areolet moderate in size; nervulus replaced by two recurved veins. Length: rather small, about 1.8 mm.

Type: One insect (No. 39), apparently female, from the Cretaceous amber of Cedar Lake, Manitoba, Canada; in a rectangular piece of clear though not light amber measuring approximately 6x6x3 mm., contained in the collection of the Royal Ontario Museum of Mineralogy, Toronto.

The single insect on which this species is based is a remarkably preserved specimen hardly less perfect than a present-day insect freshly embedded in balsam. Such defects as there are in our description are due to the fact that the fossil lies in a fixed position which makes it difficult to see dorsal surfaces and to examine the sculpture and clothing. For the same reason, the sex of the insect is not quite clear. Even the living species of the Aulacini show few secondary sexual characters, and without an opportunity to move the fossil from its embedded position we cannot be certain what we see. The antennal count, 14-15, is that of normal males, and one more than that usually found in the females of the Aulacini; but the Cretaceous insect might very well have had more segments than the present-day species. There is a suggestion of an incision in the third segment of the antenna, and this is a male character; but the embedded specimen cannot be turned into a position which makes this character certain. The abdomen is narrowed more or less as in males of the Aulacini, but it is large for a male. Moreover, the terminal organs look like ovipositor sheaths with a protruding ovipositor, and this character is so clear that we are inclined to consider the specimen a female.

The wing venation of the insect is somewhat more primitive than that found in any of the living Cynipidæ. It is

suggestive of the venation found in the Ibaliidæ and in some of the simpler Figitidæ. It may prove significant when we come to consider the origins of these three families from the ancestral stocks. Since the Chalcidoidea also appear to have had their origin in this same cynipoid stock, it will be interesting to secure more fossils of the group. The present species is closest to the primitive, weed-stem gall makers of the genera *Timpaspis* and *Phanacis*, which belong to the tribe Aulacini in the family Cynipidæ. But *costalis* is not so far removed from some of the simpler parasitic cynipoids; and we cannot be certain whether the fossil represents a parasite in the family Figitidæ or a gall maker in the family Cynipidæ. No certain interpretation of the wing venation of the fossil can be made until we have more elaborate studies of homologies in the Hymenoptera in general, and of a wide range of species in the present-day Cynipidæ. Pending such a study we can, however, note the observable differences between *Protimaspis* and the more specialized cynipid wings.

Referring to the accompanying figures, it will be seen that what we commonly call the "subcosta" terminates at the break near the base of the radial cell. There is no "terminal segment to the subcosta". The connection between the marginal vein and the first abscissa of the radius looks more like a fusion between veins than like the terminal segment of the subcosta. If the subcosta really continues beyond the break in the vein, the "first abscissa of the radius" would appear to be the true continuation.

The remarkable vein on the margin of the radial cell extends beyond that cell at both ends, suggesting that it is the long-lost costa, and not the continuation of the subcosta which we usually consider any vein that closes that cell.

The vein which is ordinarily called the "second abscissa of the radius" appears to be directly continuous with the first (the basal) portion of the "cubitus"; and since other studies of the hymenopterous wing[4] seem to show this basal portion

[4]Bradley, J. C. 1931. A Laboratory Guide to the Study of the Wings of Insects. Daw, Illston and Co., Ithaca, N.Y.: 28-32, plates 38-58, 67.

Comstock, J. H. 1918. The Wings of Insects. Comstock Publ. Co., Ithaca, N.Y.: 362-381.

to be the medius rather than the cubitus, it is possible that the "second abscissa of the radius" is also part of the medius. The terminal half of the so-called "cubitus" also appears to be the medius, just as Comstock and Bradley have interpreted it.

WING VEIN NOMENCLATURE

Current in systematic literature	In Comstock 1918	In Bradley 1931	In Protimaspis
Subcosta			
Basal portion	Sc+R+M	R+M	Sc (+R?)
Terminal segment	Sc+R	Sc+R	fusion between C and R
Extension on margin	R (?)	Sc+R	C (+Sc?)
Radius			
First abscissa	R	R	R
Second abscissa	R	R	M
Cubitus			
Basal portion	M	M	M
Terminal portion	M	M	M
Discoideus			
Basal half	Cu	Cu	Cu
Terminal half	M	Cu	M
Basalis	m−cu+M	m−cu+M	m−cu+M

What passes for the basal portion of the "discoideus" in descriptive literature is probably, at the base of the wing, really the cubitus, as Comstock and Bradley are again agreed. But the peculiar arrangement near what should have been

the nervulus in *Protimaspis* makes it look as if the true cubitus ended at that point, while the terminal half of the discoideus seems to represent another vein which may be another branch of the medius.

Our figure 3B shows a wing of *Protimaspis* with the interpretations which we have just suggested. For comparison the wing of the present-day species of *Cynips*, bearing the nomenclature current in taxonomic descriptions, is shown in figure 3C. A further comparison of several interpretations of cynipid wings is given in the table above. The fragmentary nature of Bradley's publication leaves it uncertain whether we have fairly interpreted his views on the subject.

None of the available studies of hymenopterous wings, nor our suggested interpretation of this wing of *Protimaspis*, makes us feel confident that we have yet found the correct homologies for the cynipid wing veins. Until we can make an extensive study of gall wasp wings, we are not warranted in using anything but the current nomenclature in descriptive word with the group. Meanwhile every fossil will contribute materially to our further interpretations of the group.

SUPERFAMILIES ICHNEUMONOIDEA, SERPHOIDEA, AND CHALCIDOIDEA

By CHARLES T. BRUES

The present small collection contains only nine species, but is extremely interesting as it includes several remarkable forms. There are representatives of three well-known families, Braconidæ, Scelionidæ, and Mymaridæ, and still another, the Serphitidæ, which is proposed as new. The latter is based on a highly anomalous form which presents characters that must exclude it from any family heretofore recognized although it shows resemblances to several widely distinct modern groups. Several of the species are referable to modern genera, but others, such as *Proteroscelio* and *Bæomorpha*, are strikingly different from the modern representatives of the family to which they belong. There is some

similarity to the fauna of the Baltic amber, but obviously this resemblance is not close. It is, of course, not possible to make any generalized statements on the basis of such meagre material. However, this Cretaceous amber fauna gives promise of furnishing very important evidence on the relationships of the families of the parasitic Hymenoptera, and it will quite probably be found to include types that throw light on the origin and relationships of some of the larger groups of this order.

FAMILY BRACONIDÆ

SUBFAMILY DIOSPILINÆ

Diospilus Haliday

Diospilus (*sens. lat.*) **allani** Brues, n. sp.

Figure 4A

This is represented by an incomplete specimen in which most of the head and thorax, the base of the abdomen, part of the legs, and the complete antennæ and wings are preserved. The antennæ are long, filiform, 20-jointed; scape short, pedicel very short; base of flagellum thinner than the middle, with the first joint longer than the scape, the joints beyond gradually shorter, those near the middle more than twice as long as wide; the entire antenna two-thirds longer than the head and thorax together. The head is not preserved in the oral region so that the clypeus and mouthparts cannot be seen. The head in dorsal view shows a very sharp black edge to a reflecting band which indicates that the occiput is margined; head strongly transverse, just about twice as wide as thick; the eyes large, but not bulging out beyond the rounded lateral contour of the head; seen from above twice as broad as the temples behind them. Thorax distinctly less than twice as long as high, including the prothoracic neck; mesonotum strongly convex in front, with deep parapsidal furrows; propodeum showing some elevated tooth-like projections and evidently at least partly areolated. Anterior and middle coxæ small, hind ones obovoid, as long as the posterior slope of the propodeum. Legs rather slender,

the posterior tibiæ with two very short spurs. Abdomen preserved only at the extreme base, sessile, with the first segment rounded above in profile. Basal side of stigma apparently slightly longer than the apical side. First discoidal cell with a very short petiole above, *i.e.*, the cubitus arises from the basal vein; nervulus postfurcal, entering the first discoidal cell at its basal third; anal cell with an in-

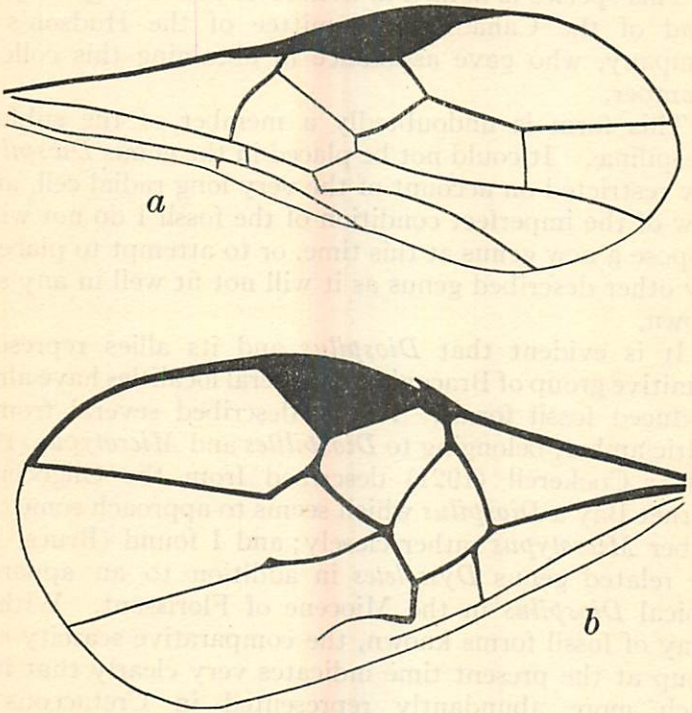

FIGURE 4.—A. *Diospilus* (*sens. lat.*) *allani* Brues, n. sp. Wing of type.
B. *Pygostolus patriarchicus* Brues, n. sp. Wing of type.

complete cross-vein, just before the nervulus, extending halfway to the wing margin; radial cell extending almost to the wing-tip, the first section of the radius about half as long as the second; third considerably longer than the second. Second cubital cell scarcely narrowed apically, the recurrent nervure entering it near the base; second discoidal cell rather im-

perfectly closed at apex, the nervellus arising below the middle of the cell. Hind wing with the basal cell complete, the median and discoidal of about equal length, incomplete below; radiellan cell not indicated apically.

Type: from Cretaceous amber, Cedar Lake, Manitoba, Canada; No. 3, Royal Ontario Museum of Mineralogy, Toronto.

This species is named in honour of Mr. George W. Allan, Head of the Canadian Committee of the Hudson's Bay Company, who gave assistance in obtaining this collection of amber.

This form is undoubtedly a member of the subfamily Diospilinæ. It could not be placed in the genus *Diospilus* as now restricted on account of the very long radial cell, and in view of the imperfect condition of the fossil I do not wish to propose a new genus at this time, or to attempt to place it in any other described genus as it will not fit well in any so far known.

It is evident that *Diospilus* and its allies represent a primitive group of Braconidæ as several localities have already produced fossil forms. I have described several from the Baltic amber, belonging to *Diospilites* and *Microtypus* (Brues, 1933); Cockerell (1921) described from the Oligocene of Gurnet Bay a *Diospilus* which seems to approach some of the amber *Microtypus* rather closely; and I found (Brues, 1910) the related genus *Dyscoletes* in addition to an apparently typical *Diospilus* in the Miocene of Florissant. With this array of fossil forms known, the comparative scarcity of the group at the present time indicates very clearly that it was much more abundantly represented in Cretaceous and Tertiary times.

SUBFAMILY BLACINÆ

Pygostolus Haliday

Pygostolus patriarchicus Brues, n. sp.

Figure 4B

♀. Length 2.1 mm.; ovipositor 0.5 mm. Light coloured in the specimen, except for the eyes, apices of antennæ, most

of thorax, and apical half of abdomen. This is probably due to fading at least in part, as the stigma and wing veins are paler than usual. Antennæ 21-jointed; scape oval, about the length of the first flagellar joint which is somewhat less than four times as long as thick; second flagellar joint about as long as the first; third to last progressively shorter, becoming more or less moniliform after the ninth which is decidedly longer than thick. Head of normal form although the temples and vertex are slightly elongated antero-posteriorly as in *Electroblacus* Brues.[1] Eyes small, ovate, the cheeks, temples, and malar space consequently larger than usual. Mandibles small, curved, acutely pointed at tips. Mesonotum with such very deeply impressed parapsidal furrows that it appears trilobed anteriorly. Propodeum very strongly areolated above. Abdomen (in lateral view) apparently rather narrowly sessile, arcuately arched above, and apparently strongly bicarinate; second tergite about as long as the first, slightly longer than the propodeum; following segments together somewhat less than half the length of the abdomen. Ovipositor stout, curved slightly downwards just beyond the middle, a little more than half the length of the abdomen. Stigma broad, triangular, its basal and apical sides equal; second section of radius one-third longer than the first and about one-fifth the length of the third; cubital vein arising at the upper fifth of the basal vein, the first discoidal cell therefore petiolate above; recurrent nervure interstitial with the first transverse cubitus; nervulus postfurcal, entering the second discoidal cell at its basal third; the latter cell open below at apex; radial cell attaining the tip of the wing. Legs slender, the hind pair stouter.

Type: from Cretaceous amber, Cedar Lake, Manitoba, Canada; No. 16, Royal Ontario Museum of Mineralogy, Toronto.

This species is a quite typical *Pygostolus*. The genus is already known from Baltic amber by a similar species, *P. clavatus* Brues, from which the present form differs in the form of the antennal joints and the insertion of the recurrent nervure.

[1]A genus known from Baltic amber.

Neoblacus Ashmead

Neoblacus facialis Brues, n. sp.

♂. Length 1.4 mm. Black, with the abdomen reddish brown, except at tip; legs brownish, especially the front pair; wings hyaline or very slightly infuscated. Head strongly transverse, the temples narrowed behind the eyes. Antennæ slender, except for the rather stout scape; about 16-jointed, inserted somewhat below the middle of the face on a distinct elevation, below which the face recedes obliquely to the mouth; first and second flagellar joints of about equal length, the first more slender, fully four times as long as thick; following joints growing gradually thicker, but very little shorter, those near the apex more than twice as long as thick. Mandibles small, narrow, strongly bidentate at tips. Upper side of thorax not very clearly visible, apparently smooth, with the parapsidal furrows deep and the scutellum deeply foveate at base. Abdomen long and narrow, the sides nearly parallel, except at the base; nearly as long as the head and thorax together; first segment apparently furrowed at the base. Legs stout, the femora and tarsi noticeably thick, the first joint of the hind tarsi longer than the two following joints together. Stigma long and narrow, fully four times as long as wide; the radius arising well before the middle of the stigma, its first section nearly perpendicular to the costa, slightly longer than the width of the stigma; second and third sections of approximately equal length, the radius slightly angulate at the middle although the second transverse cubitus is absent; first cubital and first discoidal cells fused as the base of the cubitus is present only as the faintest trace which, however, is sufficiently indicated to show that it arises from the basal vein rather than the costa; recurrent nervure entering the extreme base of the second cubital cell although almost obsolete at its upper end; second and third sections of cubitus complete; nervulus strongly postfurcal; nervellus arising rather high up, the second discoidal cell open at apex. Radiellan vein in hind wing absent.

Type: from Cretaceous amber, Cedar Lake, Manitoba,

Canada; No. 46, Royal Ontario Museum of Mineralogy, Toronto.

From the general form of the body, legs, and wings, this species is evidently a member of this group and fits quite well in the genus *Neoblacus* which has already been found fossil in Baltic amber.

SUPERFAMILY SERPHOIDEA

SERPHITIDÆ Brues, n. fam.

Figure 5A

Abdomen petiolate, inserted at the apex of the propodeum slightly above the hind coxæ, the petiole composed of two slender joints and the gaster large, oval, composed of six segments; convex above; more or less flat below, with the tergites extending slightly inwards in ventral view to form a lateral carina on each side of the sternites. Fore wings with large stigma, the costa and subcosta separated, enclosing a well-developed costal cell. Antennæ 10-jointed, with long scape, pedicel and clavate flagellum; mandibles large, trifid. Prothorax short, scarcely visible from above; tegulæ present; mesonotum and scutellum separated by a deep groove; the axillæ small, widely separated. Trochanters probably one, possibly two-jointed; coxæ of moderate size, legs rather slender, the tarsi of the usual form. Wing venation considerably reduced; median and submedian cells closed, second discoidal open below; radius and cubitus indicated, but weak apically.

Type: *Serphites* n. gen.

Serphites Brues, n. gen.

Figure 5A

Head rather large, considerably broader than thick; eyes large, extending close to the base of the large mandibles; mandible on right side with three long curved teeth directed inwards, toward the median line; ocelli present. Antennæ inserted below the middle of the face, the scape not reaching

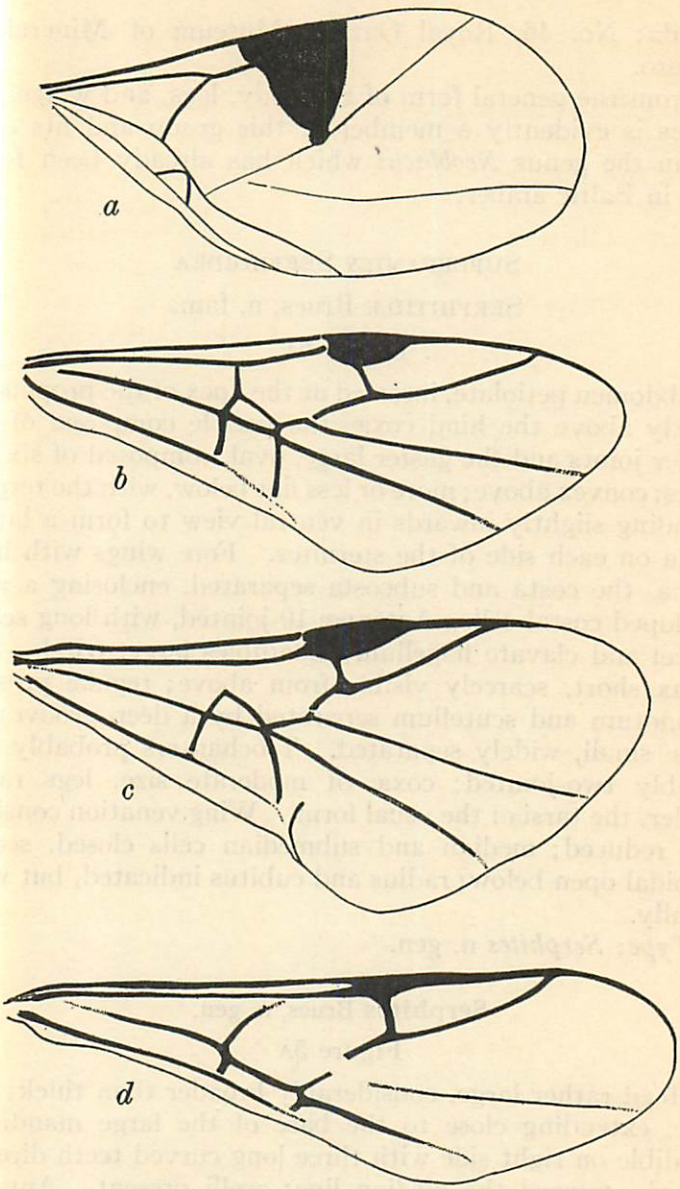

FIGURE 5.—A. *Serphites paradoxus* Brues, n. sp. Wing of type.
B. *Vanhornia aucnemidarum* Crawford, wing.
C. *Helorus anomalipes* Panzer, wing.
D. *Acanthoserphus albicoxa* Dodd, wing.

to the vertex; pedicel rather long, oval; flagellum gradually clavate. Mesonotum with complete, widely separated weakly impressed parapsidal furrows; scutellum large, elongate, strongly convex, with a deep crenate furrow at base. Propodeum evenly sloped behind, short and narrowed to apex. Abdominal petiole about as long as the width of the thorax; its first joint twice as long as the second, cylindrical, about one-fourth as wide as long, the second segment slightly curved downward toward the tip. Body of gaster about as long as, and slightly wider than, the thorax, its first segment rounded at base when seen from above, about as long as the second, third and following successively shorter, the last very small. Femora slightly thickened near the middle; middle and hind tibiæ with short, delicate spurs. Fore wing with large triangular stigma, the costal margin slightly shorter than either of the other two sides; costal vein slightly thicker than the subcostal; basal vein sharply bent at middle; submedian cell much longer than the median; first cubital and first discoidal cells fused; second discoidal open apically, the third discoidal open below; the costal, subcostal basal and median veins (except base and apex of latter) stout; other veins thin basally and very weakly indicated in the apical part of the wing; radial cell narrow and short, about as long as the stigma along the wing margin; radial vein straight weak, at its base with a small dark, rounded swelling which extends as a thick stub into the cubital area and presumably represents the upper end of the first intercubital vein. Hind wing apparently with a submarginal and basal vein, enclosing a cell, but without radiellan vein.

Type: *S. paradoxus* n. sp.

Serphites paradoxus Brues, n. sp.

Figure 5A

♂. Length 1.2 mm. Apparently uniformly black or dark coloured, with hyaline wings, the antennæ possibly lighter brown or yellowish; middle and hind legs yellowish on the trochanters, the knees, the tibiæ and tarsi. Sculpture

of face and front obscured in the type; mesonotum and scutellum shagreened; abdomen smooth, the genitalia extruded as a small quadrangular projection in vertical view, no conspicuous valves.

Type: from Cretaceous amber, Cedar Lake, Manitoba, Canada; No. 7. A second specimen, No. 71, shows only the thorax, legs, and abdomen. Both specimens are in the Royal Ontario Museum of Mineralogy, Toronto.

The type specimen is fairly well preserved and shows very clearly the form of the antennæ, mandibles, thorax, wings, legs, and abdomen. These parts exhibit several discordant characters and peculiarities that are utterly impossible to reconcile with any modern family of Hymenoptera. The wing venation is much reduced, even near the base of the wing. Aside from the stigma, it resembles more or less closely that of *Brachygaster* of the family Evaniidæ except that the apical veins are less completely atrophied. This similarity is probably not of much significance on account of the tendency noticeable in many insects with simplified venation whereby particular veins tend to disappear earlier than others and produce similar patterns which have no common phyletic origin. The large, triangular stigma at once recalls the genus *Serphus* and its allies but this alone undoubtedly indicates no relationship as it is not a general character of the group. Other serphoid characters of definite nature are lacking, however, in the wing, although there seems to be nothing there to exclude it from that group. The longer pointed radial cell occurs in even more elongate form in the Australian genus *Acanthoserphus* of the family Serphidæ. As no figure of the wing of this genus has been published, one is here included (figure 5D). In wing venation *Acanthoserphus* shows also a great similarity to *Ropronia*, *Helorus* (figure 5C), and *Vanhornia* (figure 5B), representatives of the three other related families Roproniidæ, Heloridæ, and Vanhorniidæ, although its body structure is fundamentally that of *Serphus*. So far as the venation is concerned *Serphites* has the stigma and marginal cell and second discoidal cell nearest to that of *Acanthoserphus* or of *Austroserphus* another recently de-

scribed Australian genus. The petiolate abdomen, with its distinctly two-jointed pedicel, occurs among Hymenoptera only in ants, and there in its completely binodal form is characteristic of the highly specialized subfamily Myrmicinæ. Obviously there can be no significance to this similarity in the abdominal petiole as the general form is entirely different from that of any ant and, moreover, no other part of the body is in any way similar to the Formicidæ. The form of the head and its appendages is certainly not ant-like and among recent Hymenoptera finds its closest counterpart in the superfamily Chalcidoidea. In fact the shape of the head in front view, strong, tridentate mandible and antennæ would pass perfectly well for a pteromalid or other chalcid-fly. The same is in general true of the thorax and abdomen. Except for the fact that the petiole consists of two joints, the form of the abdomen is not dissimilar from that of the subfamily Sphegigastrinæ of the Pteromalidæ. The legs do not appear to offer any peculiarities which would suggest relation with any particular family or superfamily.

Thus, I have been unable to place this peculiar form satisfactorily in any family. I believe it should be regarded as a primitive, although degenerate form which shows in general, particularly in wing venation, the closest affinity with certain Serphoidea, especially *Helorus* (figure 5C), Acanthoserphus (figure 5D), and the otherwise rather different Families Vanhorniidæ (figure 5B) and Roproniidæ.[2] That these groups are old is evidenced by the presence of a perfectly typical genus of Heloridæ, *Mesohelorus*, described by Martynov from the Jurassic in Turkestan.[3]

There are, therefore, close similarities in venation between Serphites and several members of the superfamily Serphidæ and no good reasons for excluding the fossil from this group. The thorax is of a generalized type that would not be anomalous for almost any group of Clistogastra.

For the reasons set forth above, this insect has been made

[2]I have previously called attention to the close similarity between *Ropronia*, *Vanhornia*, and *Helorus* in Psyche, 34, 1927: 81.

[3]Bull. Acad. Sci., U.R.S.S., 1925: 758.

the type of a new family in the superfamily Serphoidea. Its relationship to the several more similar families of this group is not easily indicated.

I do not believe that it can possibly be associated with the peculiar Oligocene genus *Pelecinopteron* recently described by me from Baltic amber.[4] *Pelecinopteron* shows characters that lead one to think that it forms more or less of a transition between the Stephanidæ and the Pelecinidæ and Monomachidæ, but I can discern absolutely no stephanid-like characters in *Serphites* and if the latter furnishes any evidence on the origin of modern forms, it certainly does not in any way relate to the Pelecinidæ which would seem from the present state of our knowledge to bear little relationship to the Heloridæ and other serphoids. However, the many peculiarities of *Serphites* indicate that it is not very near to the line of descent of any living Hymenoptera.

FAMILY SCELIONIDÆ

Baryconus Förster

Baryconus fulleri Brues, n. sp.

♀. Length 1.4 mm. Apparently entirely black, with the wings hyaline, the wing venation moderately dark brown. Antennæ 12-jointed; scape long, slightly curved, extending well above the level of the vertex; pedicel obovate, with very narrow base, about one-half longer than its greatest thickness; first four joints of flagellum small, of about equal size and more or less moniliform, scarcely half as thick as the terminal club which includes six closely attached joints; the latter are of nearly equal length, the first slightly longer and rounded at the base and the last conically narrowed to tip, the middle four club-joints each fully one-half wider than long. Mesonotum rather flat, slightly shagreened, or at least dull; scutellum with a broad, deep, and apparently crenulate furrow at the base; its apex, and also the postscutellum rounded, simple, and without spines or projections. Abdomen not so very

[4]The Parasitic Hymenoptera of the Baltic Amber. Part I. Bernstein-Forschungen, Heft 3, 1933: 19.

clearly visible in dorsal view, apparently rather narrow at the base and seemingly with rather close-set longitudinal carinæ, at least toward the base of the first segment; body of abdomen elongate oval, shining and without distinct sculpture, at least near the sides, nearly twice as long as broad. From below, the abdomen is seen to be very strongly margined laterally, the third tergite very much longer than the others, longer than either the first and second combined, or the more apical ones taken together. Legs slender, of the usual form. Marginal vein short, about twice as long as thick, about half as long as the stigmal vein which is slender with a distinct knob at the tip.

Type: from Cretaceous amber, Cedar Lake, Manitoba, Canada; No. 51, Royal Ontario Museum of Mineralogy, Toronto.

This species is named in honour of Mr. Archie S. Fuller of Toronto, who collected a large part of the amber considered in this paper.

This species is certainly a true *Baryconus* or closely allied although certain details are not clearly to be made out in the specimen. There is no indication of a tubercle at the base of the abdomen and the lateral angles of the propodeum may be produced. However, such differences occur among the three subgenera of *Baryconus* that are recognized by Kieffer.

Proteroscelio Brues, n. gen.

Figure 6A

A member of the subfamily Scelioninæ, but differing from all described members of the Scelionidæ in having the antennæ 14-jointed. Head considerably flattened; seen from above it is nearly four times as broad as thick; much lengthened below, with the malar space about as long as the eyes. Eyes small, set at the sides of the head, the lower border angulate (at an angle of about 70°), upper border rounded; seen from above occupying the full thickness of the head; back of head flat, the occiput long as the head rises far above the occipital foramen; lateral ocelli rather close to the eyes. Antennæ

14-jointed, the scape reaching about to the vertex, distinctly flattened but not really widened; remainder of antennæ flattened, especially the pedicel and first two flagellar joints which form together with the rest of the flagellum a long, flattened club. Pronotum long, more or less neck-like; mesonotum and scutellum nearly flat, separated by a narrow groove; no parapsidal furrows. Abdomen elongate, fusiform; second tergite longest, but not greatly exceeding the others; lateral carina strong. Legs slender. Wings with the marginal, postmarginal, and stigmal veins well developed, also a weakly defined radial vein enclosing a narrow radial cell.

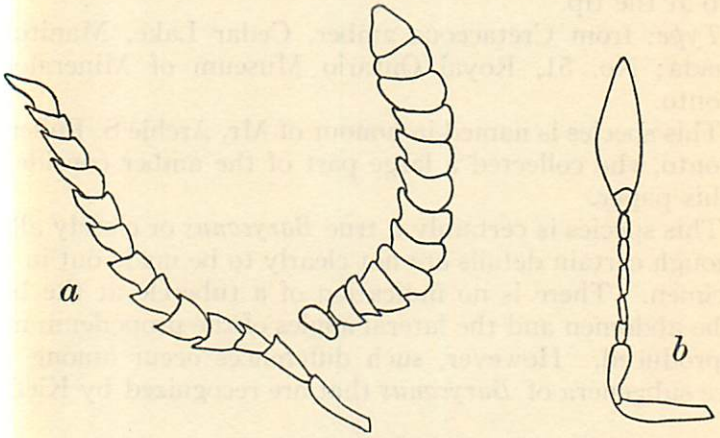

FIGURE 6.—A. *Proteroscelio antennalis* Brues, n. sp., antennæ.
B. *Bæomorpha dubitata* Brues, n. sp., antenna.

Type: *P. antennalis* n. sp.

Among living genera *Proteroscelio* resembles the remarkable Austromalayan genus *Platyscelio* somewhat in the form of the antennæ and in the less strongly flattened head and thorax, but it is much less highly modified.

Proteroscelio antennalis Brues, n. sp.

Figure 6A

♀. Length 1.5 mm. Apparently entirely dark coloured or black; wings hyaline with deep brown veins. Front and

vertex finely rugulose or shagreened, face and cheeks more smooth and shining; ocelli in a nearly equilateral triangle, the lateral ones closer to the eye than to one another. Pedicel of antennæ elongate, very slender at base, much flattened and widened apically where it is nearly as wide as long, but its thickness at apex is only about one-third its length; first flagellar joint shorter, of the same thickness and nearly as long as the pedicel; first flagellar joint wider and shorter; following broad, about one-half wider than long, last more or less conical; in side view the antennal club appears serrate as the third and following joints of the flagellum project tooth-like at the apical angle below. Thorax smooth or minutely punctulate above. Abdomen smooth both above and below.

Type: from Cretaceous amber, Cedar Lake, Manitoba, Canada; No. 56, Royal Ontario Museum of Mineralogy, Toronto. A photograph of this specimen was published by Walker, without name, as figure 2 on Plate 1 of his paper.[5]

This peculiar form differs from all living Scelionidæ in having fourteen joints in the antennæ instead of twelve or the lesser number which occurs in a few genera. There is, however, an undescribed species in Baltic amber with fourteen joints, but the latter is otherwise very different from the present form.

FAMILY SCELIONIDÆ (?)

Bæomorpha Brues, n. gen.

Figure 6B

Antennæ inserted high up on the face, far above the clypeus, set in slight broad depressions; arising at about the level of the middle of the eyes; consisting of eight joints and a solid, fusiform club which is more or less connate with the preceding (sixth) flagellar joint; no frontal ridge or prominence below the insertion of the antennæ, but there is apparently a short median carina between them. Head more or less rounded, the eyes oval, rather small; malar space long;

[5]Univ. Tor. Studies, Geol. Ser., no. 36, Contributions to Canadian Mineralogy 1934: Plate I, fig. 2.

mandibles apparently projecting forward, but their minute structure is not preserved. Abdomen short. Legs of typical scelionid type, rather slender. Wings ample, extending well beyond the abdomen; with the submarginal vein about one-third the length of the wing; marginal vein long, nearly as long as the submarginal, twice as long as the curved stigmal which is very slightly thickened at apex and gives off a spur representing the base of the radial vein extending toward the wing margin; this spur is distinctly curved, concave apically and behind; postmarginal vein thin, but distinctly defined, nearly twice as long as the marginal; basal vein strong, extending directly downwards from the base of the marginal vein.

Type: *B. dubitata* n. sp.

This insect has the habitus of a typical member of the subfamily Bæinæ of the Scelionidæ, but the insertion of the antennæ which shows very clearly in the type is entirely different from any known scelionid, as all the members of this family have the antennæ arising very low down on the head at the edge of the clypeus. In this respect it resembles the Diapriidæ and Belytidæ, except that in the latter groups there is always a transverse, elevated ridge or shelf just below the antennæ. On account of the consolidation of the apical antennal joints into an unsegmented club, the number of joints in the complete antenna cannot be stated; however, by reflected light two indistinct sutures appear on the club in addition to six clearly defined flagellar joints which would make a total of eleven joints in the antennæ. In all described Bæinæ there are only four free flagellar joints in addition to the completely fused club in the female, although the male has the 12-joints characteristic of most Scelionidæ. So far as wing venation is concerned, *Bæomorpha* might fall in the subfamily Teleasinæ on account of the long marginal vein, or in the Scelioninæ by reason of the long postmarginal. It is therefore an extremely anomalous form.

Bæomorpha dubitata Brues, n. sp.

Figure 6B

♀. Length 0.6 mm. Apparent colour: head and antennæ black; thorax in great part pale brownish or yellowish;

abdomen with some yellowish at sides, base and apex; legs black; wings hyaline. Antennal scape short, not reaching quite to the vertex; pedicel obovate, much thicker and more than half as long as the scape; first five flagellar joints very small, distinctly longer than wide, and of subequal length; sixth flagellar joint of the same length, but broader and quite closely fitted to the club which is as long as the five preceding joints together.

Type: from Cretaceous amber, Cedar Lake, Manitoba, Canada; No. 37, Royal Ontario Museum of Mineralogy, Toronto.

FAMILY CALLICERATIDÆ

Lygocerus Förster

Lygocerus (?) **dubitatus** Brues, n. sp.

♀. Length 0.9 mm. Black or very dark coloured, the legs apparently more or less pale basally; wings considerably infuscated, the large stigma dark brown. Head nearly twice as wide as thick in dorsal view. Antennæ 10-jointed, distinctly enlarged near the middle and then tapered to a point apically; scape extending only about halfway to the vertex from its insertion near the lower margin of the face; pedicel one-half longer than wide, much expanded apically, with the apical corner triangularly produced on one side; first flagellar joint short; very strongly transverse, with one apical corner acutely produced; second and third joints increasingly larger and with the produced corner less acute; joints four to seven cylindrical, each about as long as thick, eighth (terminal) joint more slender, pointed, more than twice as long as thick. Surface of head and thorax above apparently smooth and polished. Wings with the stigma very large, twice as long as wide, its lower margin evenly curved; marginal vein weakly curved, reaching the margin of the wing; the marginal cell one-half longer than the stigma.

Type: from Cretaceous amber, Cedar Lake, Manitoba, Canada; No. 69, Royal Ontario Museum of Mineralogy, Toronto.

This species is undoubtedly very similar to the large modern genus *Lygocerus*, but as the female antennæ are 10-jointed as in certain other genera with linear stigma, its position here is questionable, as the antennæ are uniformly 11-jointed in *Lygocerus* and related genera. As the type is not so perfectly preserved as might be wished, I have hesitated to propose a new generic name.

SUPERFAMILY CHALCIDOIDEA

FAMILY MYMARIDÆ

Ooctonus Haliday

Ooctonus (?) **minutissimus** Brues, n. sp.

♀. Length 0.4 mm. Apparently entirely dark, the wings hyaline. Antennæ 10-jointed, the club one-jointed; pedicel nearly half the length of the scape, pedunculate at base, greatly widened apically and several times as thick as the basal flagellar joints; these are all slender except the last two before the club which are gradually broader, the last submoniliform; club elongate oval, three times as long as thick, obtusely pointed at tip. Wings strongly widened apically, the submarginal hairs at least as long as the width of the wing in front and those that extend from the posterior border considerably longer.

Type: from Cretaceous amber, Cedar Lake, Manitoba, Canada; No. 54, Royal Ontario Museum of Mineralogy, Toronto.

This is an extremely minute species, which although very well preserved is very difficult to study. The antennæ appear to be 10-jointed, but as they are slightly shrivelled near the base of the flagellum, nine may perhaps be the correct number. Otherwise the species fits very well in *Ooctonus*.

ORDER DIPTERA

FAMILY CHIRONOMIDÆ

By M. W. BOESEL

With a single possible exception, all the fossil Chironomids which have been described and given specific names have come

to light within the last one hundred years. It was not until 1904 that Meunier published his extensive work on the Baltic amber midges and other Diptera, and this was followed in 1916 with a supplementary work.[1] Of the 119 fossil midges named specifically to date, 85 are from the rich Baltic amber of the early Oligocene and of these Meunier has named 77. Naturally enough, 105 species have been described from the Palearctic whereas only four have been recorded from the Nearctic. There are seven Ethiopian species and one each for the Neotropical, Oriental, and Australian regions. Of the four North American forms, three were described by Scudder (1890) from the Eocene (Green River) and one by Cockerell (1916) from the Miocene (Florissant).[2] The foregoing discussion does not take into account the fact that some of the above species are probably not Chironomids.

Compared with the Baltic amber fauna, the Cretaceous species described below present little variety, being mostly Ceratopogoninæ. The three non-biting species all belong to the Orthocladiinæ. In the Baltic amber the latter subfamily constitutes over one-third of the described species, the Chironominæ and Ceratopogoninæ each about one-fourth, and the Tanypodinæ nearly one-tenth. In all probability when a larger series of Chironomids from the Cretaceous amber has been studied a more diversified fauna will be found. The chief significance of the present collection of fossil midges is that it comprises some of the oldest known members of the family.

The writer wishes to express his indebtedness to Dr. O. A. Johannsen of Cornell University for a list of generic determinations covering this series of amber Chironomidæ.

[1]Meunier, Fernand. 1904. Monographie des Cecidomyidæ, des Sciaridæ, des Mycetophilidæ et des Chironomidæ de l'ambre de la Baltique. Ann. Soc. Scient. de Bruxelles 28: 12-275.

————————1916. Sur quelques dipteres (Bombylidæ, Leptidæ, Dolichopodidæ, Conopidæ et Chironomidæ) de l'ambre de la Baltique. Tijdschr. Ent. 59: 274-286.

[2]Cockerell, T. D. A. 1916. Some American Fossil Insects. Proc. U.S. Nat. Mus., 51: 89-106.

Scudder, S. H. 1890. The Tertiary Insects of North America. Rept. U.S. Geol. Surv., 13: 1-734.

SUBFAMILY CERATOPOGONINÆ

Lasiohelea Kieffer

Lasiohelea cretea Boesel, n. sp.

Figures 7A, 7F, and 8

Female. Head with numerous hairs about one-third to one-half as long as width of head. Antennæ with second segment subapically attached to first (figure 7A); segments 2 to 9 wider than long, 10 to 14 longer than wide; terminal

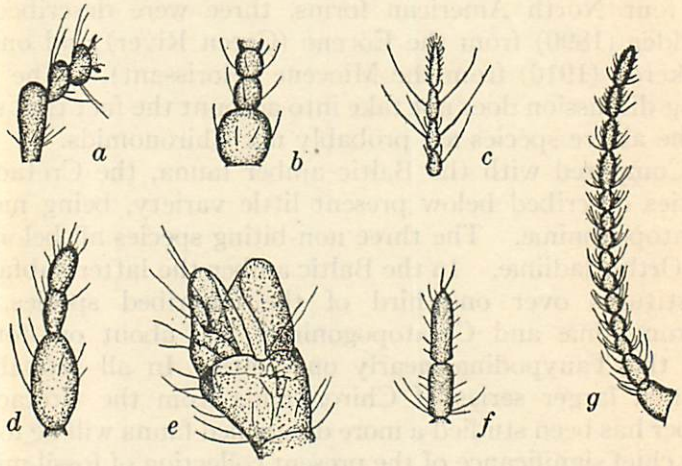

FIGURE 7.—A. *Lasiohelea cretea* Boesel, n. sp., female, basal segments of antenna.
B. *Lasiohelea globosa* Boesel, n.sp., female, basal segments of antenna.
C. *Metriocnemus cretatus* Boesel, n. sp., female terminal segments of antenna.
D. *Lasiohelea globosa* Boesel, n. sp., female, terminal segments of palp.
E. *Spaniotoma conservata* Boesel, n. sp., male, hypopygium in dorsolateral view.
F. *Lasiohelea cretea* Boesel, n. sp., female, terminal segments of antenna.
G. *Protoculicoides depressus* Boesel, n. sp., female, antenna.

segment not distinctly enlarged or thickened (figure 7F). Relative lengths of antennal segments from base to tip, 77: 33: 25: 21: 22: 23: 28: 29: 60: 65: 62: 55: 75. Antennal style short, indistinct. (Some of the antennal segments in a

paratype are swollen but it is significant that the enlargements on the right antenna do not agree with those on the left.) Palps apparently 4-segmented with second segment longest and somewhat thickened; third segment very short, about half as long as fourth. Thorax moderately hairy. Tibio-tarsal proportions of foreleg, 30: 19: 9: 6: 6: 5: of midleg, 40: 17: 10: 5: 5: 4: of hindleg, 35: 22: 10: 6: 5: 5. Wing as in figure 8A; microtrichia covering entire surface. Total length, 1.4 mm.

Specimens: holotype, female; No. 36, paratype, female; No. 4, Royal Ontario Museum of Mineralogy, Toronto.

Lasiohelea globosa Boesel, n. sp

Figures 7B and 7D

Female. Head with short hairs. Antennæ 14-segmented; second segment attached apically to first, which is globose (figure 7B); terminal joint in the only available specimen enlarged but probably not naturally so. Relative length of antennal segments from base to tip approximately as follows: 60: 35: 30: 30: 32: 30: 33: 30: 65: 50: 60: ?: ?. Terminal joints apparently about as long as the three preceding but difficult to measure accurately. Second segment of palp distinctly enlarged and twice as long as each of the succeeding segments (figure 7D). Thorax hairy. Tibio-tarsal proportions of foreleg, 45: 23: 12: 9: 6: 7; of midleg, 52: 25: 11: 7: 6: 6; of hindleg, 48: 32: 13: 8: 7: 6. Wing (which is slightly imperfect) very similar to that of *L. cretea* except for the following details: the basal portion of the anterior margin is hairy; there is no apparent "break" in the anterior margin just distad of the end of costa. Total length, 1.7 mm.

Specimen: holotype, female; No. 47, Royal Ontario Museum of Mineralogy, Toronto.

Atrichopogon Kieffer

Atrichopogon canadensis Boesel, n. sp.

Figure 8B

Female. Antennæ slender with approximate proportions of segments 2 to 14 as follows: 4: 3.5: 4: 3.5: 3.5: 3.5: 3.5:

4: 4.5: 6.5: 6: 5.5: 8.5; maximum diameter of these segments, 2. No antennal style evident. Palps with segments in approximately the following proportions: 3: 6: 2: 2; second segment distinctly swollen. Tarsal claws apparently uncleft. Tibio-tarsal proportions of midleg, 40: 22: 8: 5: 4: 4. Wing as shown in figure 8B: microtrichia covering entire

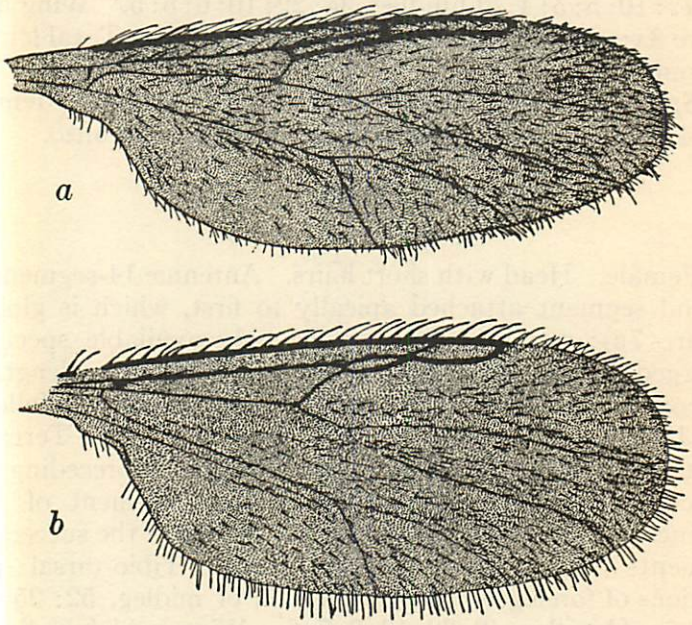

FIGURE 8.—A. *Lasiohelea cretea* Boesel, n. sp., female, wing.
B. *Atrichopogon canadensis* Boesel, n. sp., female, wing.

surface; macrotrichia numerous, except proximally. Total length, 1.7 mm.

Specimen: holotype, female; No. 35, Royal Ontario Museum of Mineralogy, Toronto.

Dasyhelea Kieffer

Dasyhelea tyrrelli Boesel, n. sp.

Figure 11A

Male. Eyes apparently base. Second joint of antenna over twice as long as wide; segments 3 to 8 about as long as

wide; segments 10 and 11 slightly longer; segments 12 and 13 flask-shaped with a circlet of about 10 hairs around the bulge at the base; segment 14 wider than the several preceding segments, pointed apically and covered with short hairs but lacking circlet of large hairs; relative lengths of last four segments, 4.5: 10.5: 8: 8. The antennæ of the specimen at hand are not in perfect condition and the exact nature of segment 9 is doubtful. Antepenultimate segment of palp nearly as long as penultimate and last segments combined. Wing as in figure 11A, microtrichia covering entire surface. The veins in all except the base of the wing are exceedingly vague. The anterior veins in the figure are shown as much more distinct than is warranted by the type specimen. The base of the wing, which is best preserved, indicates, however, that the anterior veins were originally very distinct. Furthermore, loose hairs in the amber indicate that many hairs of the wing were lost. In the unfigured wing of the other side of the type, the fringe hairs on the anal angle are hardly longer than are those at other points along the posterior margin of the wing. Proportions of segments of midleg, 40: 21: 9: 4: 4.5. Abdomen turned ventrally in type so as to make any details exceedingly obscure. Total length, about 1.5 mm. Length of wing, 1.1 mm.

Specimen: holotype, male; No. 28, Royal Ontario Museum of Mineralogy, Toronto.

Ceratopogon Meigen

Ceratopogon aquilonius Boesel, n. sp.

Figure 9A

Female. Antennæ slender, composed of 14 segments, as long as combined length of head and thorax. Basal segment about three times as wide as second segment. All segments longer than wide. Proportions of antennal segments, 8: 4: 3.5: 3: 3.2: 3.5: 4: 3.5: 3.5: 3: 3: 3.5: 4.5: 5.2. Terminal segment of palp at least twice as long as preceding, but slightly shorter than antepenultimate segment. Wing as in figure 9A.

Legs and abdomen in exceedingly poor position for observation. Total length, about 0.8 mm.

Specimen: holotype, female; No. 61, Royal Ontario Museum of Mineralogy, Toronto.

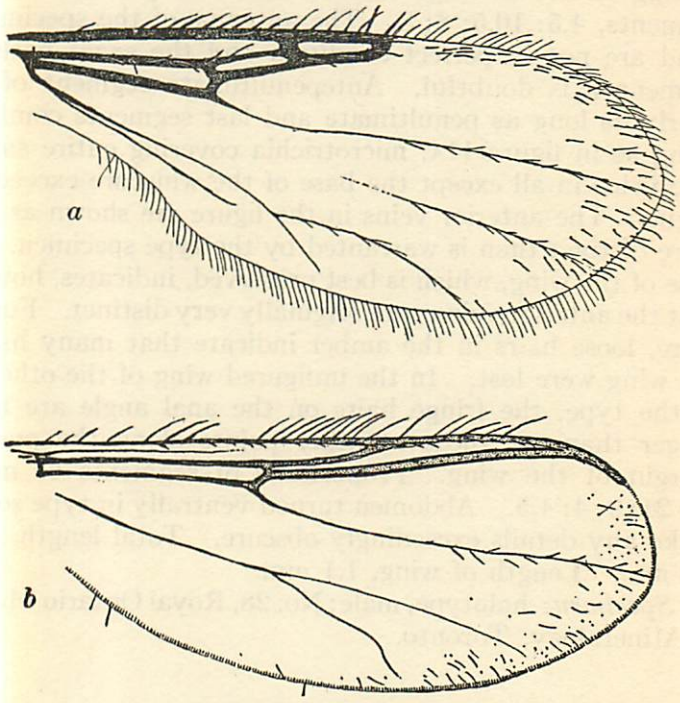

FIGURE 9.—A. *Ceratopogon aquilonius* Boesel, n. sp., female, wing.
B. *Metriocnemus cretatus* Boesel, n. sp., female, wing.

Protoculicoides Boesel, n. gen.

Eyes bare. Antennæ of female with segments 3 to 10 snort, 11 to 14 cylindrical. Humeral pits present. Wings with microtrichia present over entire surface; macrotrichia absent on wing membrane; radius extending distinctly beyond middle of wing. Empodia apparently lacking; tarsal claws of female equal; hind femora not very noticeably larger than fore and mid femora.

Genotype: *P. depressus* n. sp.

This genus seems to be closely related to the modern *Culicoides* as indicated especially by the very evident humeral pits. As regards the radius it is distinctly more primitive than *Culicoides*: R_{4+5} ends about midway between R_1 and M_{1+2}, causing the second radial cell to be sharp apically rather than blunt; in *Culicoides* R_{4+5} ends nearer R_1, usually not far from the middle of the anterior wing-margin and the second radial cell appears blunt apically. It is not to be inferred, however, that this genus is directly ancestral to *Culicoides*. The extremely depressed nature of the thorax and abdomen (if this is natural), the absence of subcosta, and perhaps other features seem to be marks of specialization.

Protoculicoides depressus Boesel, n. sp.

Figures 7G and 11B

Female. Head about twice as wide as long. Antennæ 14-segmented; segments 3 to 10 short, 11 to 14 elongate, as in figure 7G; second segment joined subapically to first. Thorax depressed; mesonotum only slightly convex, lateral margins flaring, slightly raised; area anterior to scutellum depressed. Humeral pits distinct, parallel with anterior mesonotal margin. Approximate tibio-tarsal proportions as follows: foreleg, 60: 25: 10: 8: 7: 9; midleg, 55: 30: 13: 10: 7: 7. Tarsal proportions of hindleg, 33: 14: 8: 7: 7. (Difficulties in making these measurements have made them somewhat doubtful.) Tarsal claws on all legs equal. Wing as in figure 11B: microtrichia present over entire surface; macrotrichia confined to costa, radius, and the wing margin. Anal area of wing and part of cubitus not clear in the single available specimen. Abdomen extremely depressed. (The flattened nature of the thorax and abdomen may not be natural.) Total length, 2.2 mm.

Specimen: holotype, female; No. 6, Royal Ontario Museum of Mineralogy, Toronto.

SUBFAMILY ORTHOCLADIINÆ

Metriocnemus van der Wulp

Metriocnemus cretatus Boesel, n. sp.

Figures 7C and 9B

Female. Antennæ apparently 6-segmented, with last four segments as shown in figure 7C. Tibio-tarsal proportions approximately as follows: foreleg, 33: 19: 12: 9: 4; midleg, 35: 12: 7: 5: 4: 4; hindleg, 34: 19: 11: 9: 4: 4. Wing as in figure 9B: hairs evidently once present on R_1, R_{3+4}, and along nearly the entire length of costa; fringe of hairs on wing margin also almost entirely absent although undoubtedly present originally. Length of wing, 1 mm. Almost entire abdomen of holotype absent.

In the paratype, the palps are apparently 4-segmented. The fringe of the wing is fairly complete, the hairs on the posterior margin being at least 1½ times as long as those along the costa but more slender; one particularly long hair originates in the margin below the posterior arculus and extends parallel with the wing margin among the fringe hairs to a point in the margin about opposite crossvein *r-m*; squama with a few short hairs. This specimen has macrotrichia along the branches of *M* near the wing-apex but none on the wing-membrane. Total length of paratype, 0.8 mm.

Specimens: holotype, female; No. 59 (two specimens on slide; the specimen with three complete legs is the holotype; the second very incomplete specimen on the slide seems to belong to the same species but is not included in the type series), paratype, female; No. 13, Royal Ontario Museum of Mineralogy, Toronto.

Spaniotoma Philippi

Spaniotoma conservata Boesel, n. sp.

Figures 7E and 10B

Male. Eyes minutely hairy. Palps very long and slender (poorly preserved); proportions of last three segments about 9: 9: 11. Dorso-central thoracic hairs suberect. Tibio-tarsal ratios as follows: foreleg, 60: 33: 23: 15: 7: 6; midleg,

58: 26: 10: 9: 5: 5; hindleg, 60: 35: 19: 14: 9: 8. Wing as in figure 10B. Hypopygium shown in figure 7E. Total length, 1.8 mm.

Female. Proportions of antennal segments as follows: 6: 6: 6: 5: 7. First four segments with whorl of about 5 hairs nearly twice as long as the antennal segments; the basal segment with an additional partial whorl near its base; terminal (fifth) segment with scattered short hairs. Wing

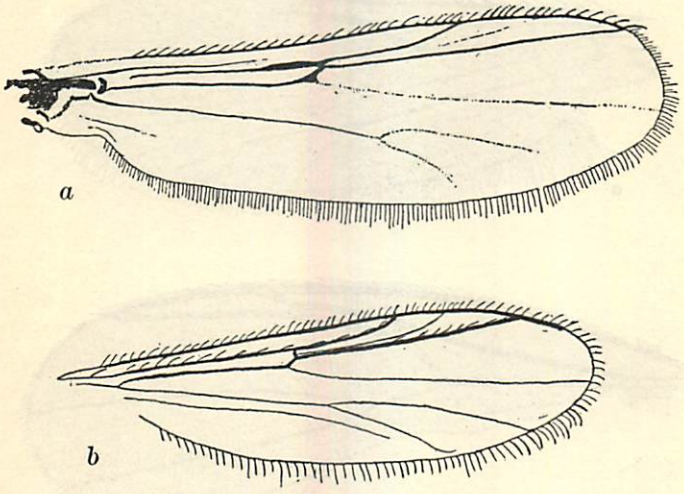

FIGURE 10.—A. *Spaniotoma* (*Smittia*) *veta* Boesel, n. sp., male, wing.
B. *Spaniotoma conservata* Boesel, n. sp., male, wing.

similar to that of male but broader; R_{2+3} almost straight; R_{4+5} toward the tip curving gracefully posteriorly and meeting *C* nearer the wing-apex; *C* produced nearly to the apex. Total length, 1.3 mm.

Specimens: holotype, male; No. 31, allotype, female; No. 31, Royal Ontario Museum of Mineralogy, Toronto.

Spaniotoma (Smittia) veta Boesel, n. sp.

Figure 10A

Male. Length of longest antennal plumes about equal to width of head. Terminal segment of antenna of same dia-

meter as others. Eyes apparently bare. Palps elongate, slender, not clearly visible in holotype. Wing as in figure 10A, with a distinct thickening of *R* near *fR* and of *r* especially at its point of union with *M*. Ends of media and cubitus very indistinct. No microtrichia present. Tibio-tarsal proportions approximately as follows: foreleg, 35: 25: 19: 16: 11: 6; midleg, 32: 16: 7: 5: 4: 4. Fourth tarsal segment of hindleg

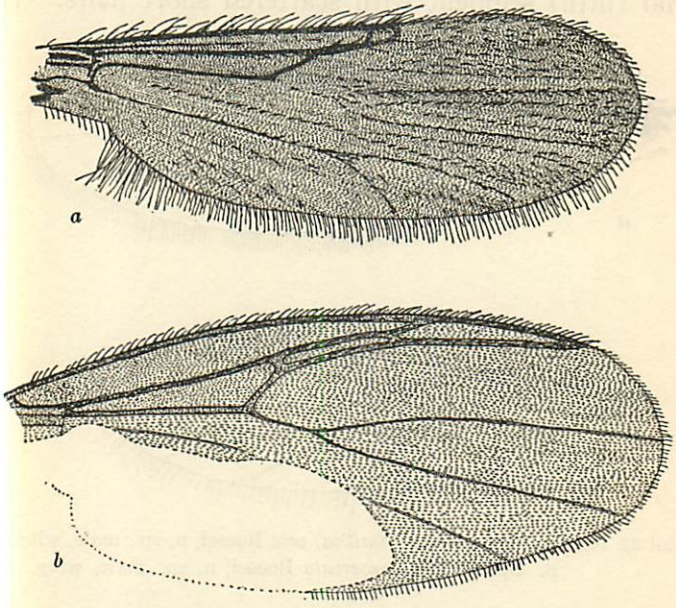

FIGURE 11.—A. *Dasyhelea tyrrelli* Boesel, n. sp., male, wing.
B. *Protoculicoides depressus* Boesel, n. sp., female, wing. (Details of anal area not shown.)

cylindrical, slightly longer than fifth. Eighth abdominal segment slightly more than twice as wide at apex as at base; spur apparently slender and well-developed. Total length, 1.3 mm.

A rather incomplete male specimen has so many features in common with the holotype that I am regarding it as a paratype. The venation at the base of the wing especially coincides with that of the type. The last three segments of

the palp have proportions about as follows: 2.5: 5: 9. The wing differs from that of the holotype as follows: the thickenings of *R* and *r* are not evident; subcosta extends to near wing margin about as far from R_1 as R_1 is from R_{2+3}; the tips of media and of cubitus are more distinct.

Specimens: holotype, male; No. 45, paratype, male; No. 68, Royal Ontario Museum of Mineralogy, Toronto.

ARACHNIDA

ORDER ACARINA

By H. E. Ewing[1]

Two species of mites have been found in the Cretaceous amber from Canada, one being a new species of *Bdella* (family Bdellidæ) and the other a larva of an undetermined genus of Erythræidæ.

Among the fossil arachnids described in the past the mites have been well represented, but not before the Tertiary Period. Apparently the only species to be described for an earlier period is *Protacarus crani* Hirst. This species was described in 1923 from Rhynie Chert (Devonian).[2] It belongs to the family Eupodidæ, a family regarded by some as the most generalized of all those of the order Acarina.

It is of interest to note that the two species of mites described in this paper belong to families abundantly represented by living species and that the three families represented by the oldest known fossil mites all belong to the suborder Prostigmata.

Most of the described fossil mites have come from amber[3]

[1]Bur. Entomology and Plant Quarantine, U.S. Dept. Agr.

[2]Hirst, S. 1923. On Some Arachnid Remains from the Old Red Sandstone (Rhynie Chert Bed, Aberdeenshire). Ann. & Mag. Nat. Hist., ser. 9, 12: 455-474, text figs. 1-13, Pls. XI-XV.

[3]Karsch, F. 1884. Neue Milben in Bernstein. Berl. Ent. Zeitsch., Bd. 28, Heft 1, s. 175-176, figs. 1-3.

Koch, C. L. and Berendt, G. C. 1854. Die im Bernstein befindlichen Crustaceen, Myriapoden, Arachniden und Apteren der Vorwelt. From Die im Bernstein befindlichen Organischen Reste der Vorwelt, Bd. 1, Abt. 2, 124 s., 17 tab.

Sellnick, M. 1918. Die Oribatiden der Bernstein-sammlung der Universität Königsberg i. Pr. Schr. Physiköhonom Gesells. Königsberg i Pr., Jahrg. 59, s. 21-42, 23 text figs., 1 T.

————————1931. Milben im Bernstein. Bernstein-Forschungen (Berlin und Leipzig), Heft 2, s. 148-180, figs. 1-39.

(Koch and Berendt, 1854; Karsch, 1884; Sellnick, 1918, 1931; and others) but of a later date than those described in this paper. They belong for the most part to the suborder Cryptostigmata, or beetle mites. Scudder[4] (1890) described from the Green River beds of Wyoming (Tertiary) a fossil arachnid as *Ixodes tertiarius*. Commenting on this fossil he says, "Its size makes it tolerably evident that it belongs to the Ixodidæ." The length given by Scudder is 3.5 mm. It is very doubtful if this fossil represents a tick. We have several living mite species in the United States that are longer than it is. However, to the present writer, the description and figure given by Scudder suggest a primitive phalangid (Cyphophthalmi) rather than either a tick or a mite.

A few species of the genus *Bdella* have been described from European amber deposits. One of these, *Bdella lata* Koch and Berendt, 1854, belongs to the genus *Scirus* according to our present classification. Two of the others are said to have conspicuous markings on the back, thus differing from the species described in this paper. Another species is so inadequately described that it is impossible to recognize it.

In 1909 the present writer described[5] as *Bdella lata* a living mite species from Illinois. As this name is preoccupied by *Bdella lata* Koch and Berendt just mentioned, the name *Bdella recens* is here suggested to take its place.

The specimen of the genus *Bdella* in the Cretaceous amber rests with its dorsal side nearest the ground surface. The appendages are spread out much as they would be in a resting position. The tarsal claws and pulvillus of each leg, except for the second left leg, can be easily seen and are in good condition. The sutures between the segments of the palpi and the legs are easily detected. The eyes are well preserved on the left side but cannot be seen on the right. All of the larger setæ are represented on one or both sides. Some

[4]Scudder, S. H. 1890. The Tertiary Insects of North America. Rept. U.S. Geol. Surv., 13: 1-734, 28 pls.

[5]Ewing, H. E. 1909b. A Systematic and Biological Study of the Acarina of Illinois. Univ. Ill. Bull., vol. 7, no. 14 (Univ. Studies, vol. 3, no. 6): 1-120, 6 text figs., 8 pls.

structures cannot be made out. Thus most of the smaller setæ of the appendages cannot be detected. Also the groove between the beak and the rest of the cephalothorax and that between the latter and the abdomen cannot be observed because of the opacity of the body itself. The plumose setæ on the tarsi are not visible. The new species of *Bdella* is here described.

Bdella vetusta Ewing, n. sp.

Figure 12

Beak long, slender, reaching to tip of segment III of palpus, slightly swollen near base; median groove not visible; only a single pair of setæ detected, each seta of which is situated laterally at about one-third the distance from tip to base of beak.

Palpi reaching beyond beak by about one-third their length; segment I slightly broader than long; segment II about equal in length to all other segments taken together and bearing a small dorsolateral seta near its base; segment III very short, but longer than broad; segment IV slightly shorter and slightly narrower than III; last segment about equal in length to III and IV taken together, and bearing distally two tactile setæ, the outer being twice as long as the inner and equal in length to segments II, III, and IV taken together.

Cephalothorax as broad as broadest part of abdomen; eyes two on each side, submarginal, equal, situated about diameter of either from each other; rostral setæ slightly curved, about as long as femur I; posterior dorsal setæ very large, equal in length to last three segments of leg I taken together.

Abdomen long, fully twice as long as greatest width, broadly rounded behind, and bearing at least four pairs of posterior marginal setæ, the inner of which is longest. Other abdominal setæ not observed, although they must originally have been present.

Legs slender, posterior pair longest. Tarsus I slightly longer than tibia; tibia I about one and one-half times as long as patella I. Tarsus IV long, slender, longest of all tarsi;

tibia IV very much shorter than tarsus IV; patella IV about two-thirds as long as tibia IV. Most of setæ of legs not detected. Claws and pulvillus of each leg as shown in figure. Total length, 0.665 mm.; greatest width, 0.215 mm.

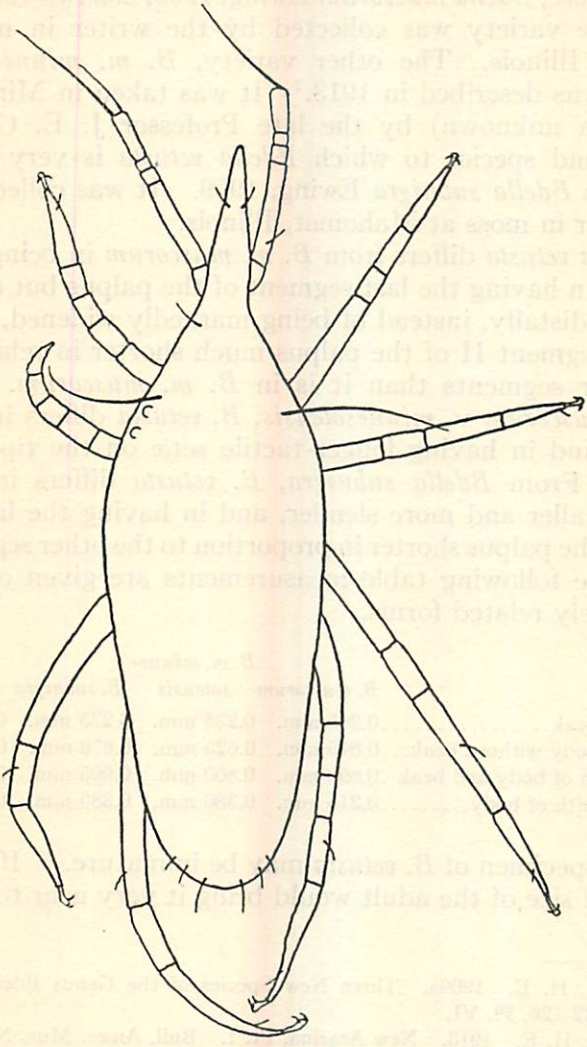

FIGURE 12.—*Bdella vetusta* Ewing, n. sp. Drawing of type.

Holotype: Royal Ontario Museum of Mineralogy, Toronto.
Type locality: Cedar Lake, Manitoba, Canada.

Remarks: *Bdella vetusta* is very closely related to two living species of *Bdella* described some years ago by the writer. One of these, *Bdella muscorum* Ewing, 1909, has two varieties.[6] The type variety was collected by the writer in moss at Muncie, Illinois. The other variety, *B. m. minnesotensis* Ewing, was described in 1913.[7] It was taken in Minnesota (situation unknown) by the late Professor J. E. Guthrie. The second species to which *Bdella vetusta* is very closely related is *Bdella subnigra* Ewing, 1909. It was collected by the writer in moss at Mahomet, Illinois.

Bdella vetusta differs from *B. m. muscorum* in being much smaller, in having the last segment of the palpus but slightly widened distally, instead of being markedly widened, and in having segment II of the palpus much shorter in relation to the other segments than it is in *B. m. muscorum*. From *Bdella muscorum* v. *minnesotensis*, *B. vetusta* differs in being smaller and in having longer tactile setæ on the tip of the palpus. From *Bdella subnigra*, *B. vetusta* differs in being much smaller and more slender, and in having the last segment of the palpus shorter in proportion to the other segments.

In the following table measurements are given of these four closely related forms.

	B. muscorum	*B. m. minnesotensis*	*B. subnigra*	*B. vetusta*
Length of beak	0.245 mm.	0.235 mm.	0.235 mm.	0.175 mm.
Length of body without beak	0.645 mm.	0.625 mm.	0.670 mm.	0.490 mm.
Total length of body and beak	0.890 mm.	0.860 mm.	0.905 mm.	0.665 mm.
Greatest width of body	0.315 mm.	0.380 mm.	0.385 mm.	0.215 mm.

The specimen of *B. vetusta* may be immature. If so, the increased size of the adult would bring it very near to *Bdella subnigra*.

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[6]Ewing, H. E. 1909a. Three New Species of the Genus Bdella. Can. Ent., 41: 122-126, Pl. VI.

[7]Ewing, H. E. 1913. New Acarina, Pt. I. Bull. Amer. Mus. Nat. Hist., 32, art. 5: 93-121, text figs. 1-9, Pls. VII-VIII.

LARVAL MITE

(Family Erythraeidæ; genus unknown)

The larval mite mentioned earlier in the paper rests in a doubled-up position and must be studied in a side view. Thus the characters of the dorsal plate and the mouth-parts cannot be studied properly. In fact, the former cannot be seen.

Beak swollen at base. Palpus slightly longer than beak; segment I not longer than broad; segment II about one and one-half times as long as broad, curved upward; segment III slightly arched, equal in length to all other segments taken together; segment IV almost half as long as III and ending in a slender, downwardly curved, bifurcate claw; segment V (thumb) short, swollen. Abdomen rather small, slightly swollen (probably due to partial engorgement at time of death); studded dorsally with prominent, simple, almost straight, spinelike setæ. Dorsal plate and eyes not visible. Legs very slender and similar. Each tarsus swollen near base, attenuated distally and bearing two lateral, strongly-curved, sharp, simple, subequal claws and a single middle claw much more slender and somewhat longer than lateral ones. Tarsus I slightly shorter than tibia I; tibia I about one and one-half times as long as patella I; patella I subequal to femur I.

Length of beak, 0.140 mm.; length of abdomen, 0.335 mm.; total length of body + beak, 0.475 mm.; greatest thickness of body, 0.145 mm.

Specimen number: No. 8, Royal Ontario Museum of Mineralogy, Toronto.

Remarks: Some workers might place this larval mite in the genus Erythraeus Latreille. It has the palpal characters of *Erythraeus*,—slender segments, very short thumb, slender bifurcate palpal claw, *etc.*, but differs from species of *Erythraeus* in having both lateral tarsal claws simple, instead of one of them being pectinate. Eventually it may be possible to place this specimen to genus, but at present our knowledge of the larval forms of the Erythraeidæ is not sufficient.

The somewhat swollen condition of the abdomen of this specimen indicates that it had attached and fed upon some arthropod host. It probably became detached from its host when the latter was caught in the liquid amber. The head and legs of a midge-like fly of the suborder Nematocera are imbedded in the amber deeper down below the mite. This dipteron seems too small to have been the host of the larval mite.

THOMSONITE FROM THE EASTERN TOWNSHIPS, QUEBEC

By Eug. Poitevin[1]

The mineral thomsonite was collected by the writer several years ago. It occurs at the following asbestos pits: Jacob, King, Johnston, Beaver, Martin Bennett, and also at the Caribou Chrome Pit. This species is found as minute crystals filling vugs in somewhat altered leucocratic rocks such as aplite and pegmatitic granites.

At the Caribou pit, thomsonite was associated with albite and grossular garnets, while at the other localities in Thetford Mines this mineral was always found closely associated with fibrous diopside, which is the older of the two. In some of the Thetford dykes, which show extreme alteration, large dog-tooth calcite crystals are impregnated with extremely minute crystals of thomsonite. As a rule the thomsonite crystals are under two millimetres in diameter. They are colourless or milky-white. Crystals from every known locality were studied and no appreciable differences could be observed between the physical, optical, and chemical properties of specimens from the various localities.

Thomsonite crystals from the Johnston asbestos pit were the best of those collected and they were used for the following studies:

All crystals of thomsonite exhibit parallel growth and this is visible especially along the base $c(001)$ as shown by the accompanying drawing (figure 1). The crystallography of the mineral is simple; only the three fundamental pinacoid faces are present—$a(100)$, $b(010)$, and $c(001)$. As shown on the drawing the c pinacoid is curved inward, some crystals, where the curvature is extreme, displaying hour-glass form. Many of the parallel growths were examined to ascertain whether they were natrolite but with negative results. The mineral is

[1]Chief, Mineralogical Section, Geol. Surv. Can., Ottawa.

optically positive. The acute bisectrix is normal to the base while the axial plane is parallel to $b(010)$. The refractive indices were carefully measured and found to be as follows:

$$\left.\begin{aligned}\alpha &= 1.528\\ \beta &= 1.530\\ \gamma &= 1.541\end{aligned}\right\} \pm 0.002,\ 2V = 50^\circ \text{ (measured)}.$$

The Specific Gravity of the mineral is 2.36-2.37.

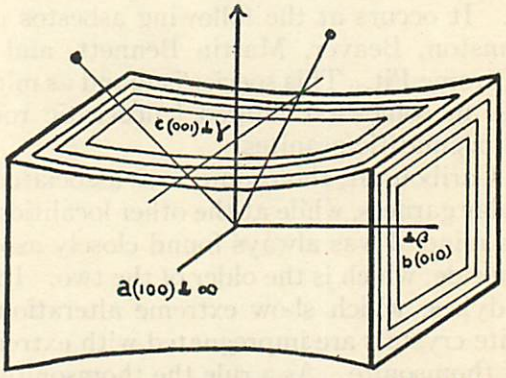

FIGURE 1.—Thomsonite crystal showing curvature and parallel growth together with the optical character.

Carefully selected crystals containing no visible impurities gave R. J. C. Fabry the following results on chemical analysis:

SiO_2	38.10	.635	
Al_2O_3	28.98	.284	
Fe_2O_3	.38	.002	.286
CaO	13.61	.243	
MgO	.38	.009	.252
Na_2O	5.28	.085	
K_2O	.22	.002	.087
H_2O	12.76	.708	
	99.71		

The above ratios do not lead to any simple formula.

A few years ago, Samuel G. Gordon[2] made a detailed study of the composition of thomsonite and he came to the con-

[2]Gordon, S. G. The Composition of Thomsonite, Proc. of Acad. Nat. Sci. of Philadelphia, vol. LXXVI, 1924.

clusion (provided the chemical analyses could be trusted) that the thomsonite series could be "interpreted as mixed crystals of the end members:

$CaO.\ Al_2O_3.\ 2SiO_2.\ 3H_2O$ (Calciothomsonite)
$Na_2O.\ Al_2O_3.\ 3SiO_2.\ H_2O$ (Natrolite with 1 H_2O)."

A study of the ratios derived from the above analysis indicates that the Thetford Mines thomsonite is composed of these two end members in the proportion of about 1 to 1. Gordon calculated in terms of Na_2O as 1.00, the formula ratios of a large number of analyses. These gave a large number of possibilities between the following extreme figures:

Na_2O	CaO	Al_2O_3	SiO_2	H_2O
1	1.00	2.36	5.09	5.68
1	5.97	6.83	18.31	19.97

Thomsonite from Thetford Mines gave ratios as follows:

Na_2O	CaO	Al_2O_3	SiO_2	H_2O
1	2.89	3.27	7.30	8.13

It is interesting to note that thomsonite in common with other zeolites is present only in those aplite dykes which occur in the vicinity of asbestos deposits, whereas an examination of hundreds of pits opened for chromite has failed to reveal the presence of thomsonite or other zeolites in dykes connected with chromite deposits, except in the one instance noted.

AN UNUSUAL HYPERSTHENE FROM LAKE ATHABASKA, SASKATCHEWAN

By H. C. Cooke[1]

In August, 1936, nickeliferous pyrrhotite was discovered 24 miles due north-east of Goldfields village, which lies about the middle of the north shore of Lake Athabaska. On September 7 the writer was taken to the discovery by airplane, but the visit, unfortunately, was limited to about five hours. The time was sufficient only for examining the pyrrhotite body, and for collection of a small suite of specimens.

The mineralized area is a breccia of rock fragments cemented and partly replaced by pyrrhotite.[2] The rock fragments range from a fraction of an inch to several feet in diameter, averaging 4 to 8 inches. They are gray in colour, equigranular, with grain size 1/2 to 1 mm., and at first sight are readily mistaken for some of the gneisses of the region. Thin sections, however, show them to be norites, made up almost wholly of hypersthene and the feldspar $Ab_{55-60}An_{45-40}$, with a few grains of accessory biotite and garnet. In some specimens the feldspar and pyroxene are somewhat altered, in others both are perfectly fresh. A considerable range in composition occurs, some specimens containing as little as 30 per cent. of feldspar, others being nearly all feldspar.

The pyroxene, the subject of this paper, has some peculiarities. In the specimen it is medium to light gray in colour, in thin section clear and colourless. Much of it has well-developed schiller structure. Some crystals of the thin sections exhibit an extremely faint pleochroism, but in most none is discernible. The intermediate index of refraction, determined by the immersion method, is 1.70 to 1.71. Maximum birefringence is .015 to .016, minimum about .003. The mineral

[1]Geologist, Geol. Surv. Can., Ottawa.

[2]For a full description of this occurrence, see Preliminary Rept. Geol. Surv. Can., Paper 37-3, 1937.

is optically negative, and elongation is (+). The optic angle, which appears small, was kindly measured for me by Dr. J. F. Henderson, and determined by him as 61° to 63°. The extinction, perfectly parallel to the cleavage in most crystals having parallel cleavage, lies at a small angle to it in others (2° to 13°). This feature, which at first appeared anomalous, eventually proved due to the incomplete development of one cleavage in crystals so cut that the angle between the two cleavages is small.

It will be observed that while the lack of colour and pleochroism in this mineral suggest enstatite, the other characters are those of hypersthene. It was decided, therefore, to obtain its chemical composition. From a sample of which the thin section showed no alteration two more sections were cut as a check. None of these showed decomposition in the pyroxene, and, accordingly, the sample was crushed and treated with heavy solutions. This operation was carried out by Mr. F. J. Fraser, who has specialized in this type of work for some years. By crushing to 80-mesh, and by repeated treatment with the solutions, some 4 or 5 grams of pyroxene were eventually obtained, beautifully fresh and clean, and contaminated only by a very few grains of some black, opaque, non-magnetic mineral. The total impurity, as estimated under the microscope, would not exceed 1/2 per cent. This material was then sent for analysis to Mr. R. J. C. Fabry, analyst to the Department of Mines, who reported as follows:

SiO_2	48.91	per cent.
Al_2O_3	3.50	" "
Fe_2O_3	.30	" "
FeO	24.16	" "
CaO	.59	" "
MgO	19.59	" "
Na_2O	.01	" "
K_2O	.12	" "
H_2O+	.99	" "
H_2O-	n.d.	
TiO_2	.83	" "
MnO	.16	" "
CO_2	nil	
Total	99.16	" "

Disregarding the minor constituents, it is evident that the mineral is a slightly aluminous silicate of magnesia and ferrous iron. Turning the above percentages into formula weights, we obtain:

SiO_2	.8151 formula weight
Al_2O_3	.0343
FeO	.3355
MgO	.4897

Combined, the formula weight of the ferrous iron and the magnesia amount to .8252, a reasonably close approximation to that of the silica with which they are combined. The mineral is, therefore, a metasilicate $(FeMg)SiO_3$. More precisely, its formula may be written (3/5 MgO.2/5 FeO).SiO_2, a type of hypersthene.

The chemical analysis emphasizes the unusual character of the mineral. Nineteen analyses of hypersthenes quoted in Dana's "System of Mineralogy" (6th ed., 1904) range from 10 to 28 per cent. in ferrous iron; of these only 6 have ferrous iron above 20 per cent., and only 4 are higher than the mineral here described. This mineral, therefore, is one of the most ferruginous of known hypersthenes. The text-books commonly state that the depth of colour in the mineral, and its pleochroism, are roughly proportional to the ferrous constituent: yet this mineral is colourless and almost non-pleochroic.

The writer wishes to express his sincere appreciation of the help so willingly given by his colleagues, Dr. Henderson, Mr. Fraser, and Mr. Fabry, without whose co-operation the problem would not have been solved.

SOME RECENTLY-DISCOVERED MINERALS OF THE GREAT SLAVE LAKE AREA, N.W.T.

By H. V. ELLSWORTH[1] and F. JOLLIFFE[2]

A.W.

The Precambrian region around the eastern part of Great Slave Lake, although still only partly explored, is already known to contain a wide variety of minerals, some of which are described more particularly in this paper. Among minerals mentioned in earlier publications may be noted: Cordierite[3] from south-east of Great Slave Lake, sodalite and nephelite on the Snare River, lepidolite in tourmaline pegmatite on the Emile River, spodumene in pegmatites east of Yellowknife Bay, and stibnite in quartz veins on Yellowknife Bay.[4] More recently ferberite, molybdenite, and cassiterite(?) have been found in gold-bearing zones on Outpost Islands, andalusite in quartz-biotite schists in the Yellowknife area and with staurolite-bearing schists on Outpost Islands, also blue corundum enclosed in a matrix of andalusite in pegmatitic quartz bodies in both these regions.

Andalusite

Since 1929 numerous occurrences of andalusite have been found by field parties of the Geological Survey in the Precambrian region around the eastern part of Great Slave Lake.[5] The mineral occurs in two associations: (1) in metamorphosed Early Precambrian argillaceous sediments; and (2) in "peg-

[1]Mineralogist, Geol. Surv. Can., Ottawa.

[2]Associate Geologist, Geol. Surv. Can., Ottawa.

[3]Optically Positive Cordierite from the Northwest Territories, Canada. Am. Min., vol. 18, p. 216, 1933.

[4]Jolliffe, F. Yellowknife River Area, Northwest Territories. Preliminary Rept., Geol. Surv. Can., Paper 36-5, 1936.

[5]*Cf.* Stockwell, C. H. Great Slave Lake-Coppermine River Area, Northwest Territories. Summary Rept., Geol. Surv. Can., 1932 C, pp. 37-64, 1933.

Jolliffe, F. Yellowknife River Area, Northwest Territories. Preliminary Rept., Geol. Surv. Can., Paper 36-5, 1936.

A.W.

matitic" quartz bodies with muscovite, biotite, chlorite, and locally corundum, apatite, and metallics.

Geological field work in the Precambrian region near Great Slave Lake, though it has been almost entirely of a

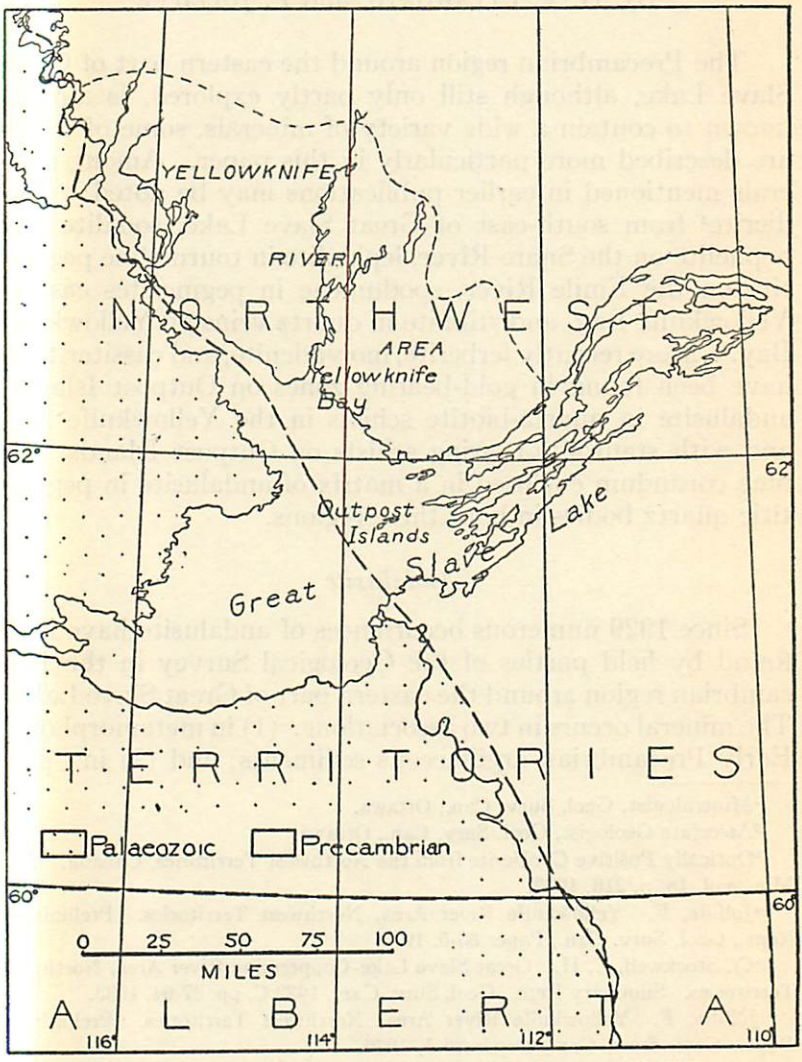

FIGURE 1.—Yellowknife River-Outpost Islands Areas, N.W.T.

reconnaissance type, has indicated at least two areas throughout which the mineral andalusite is widely distributed—the Yellowknife River area and Outpost Islands (see index map). The former includes about 10,000 square miles lying northeast of the North Arm of Great Slave Lake, and the latter is a group of islands marking the most westerly extension of the archipelago in the East Arm.

Yellowknife River Area

One of the most striking features of this part of the Canadian Shield is the large areal extent of Early Precambrian sediments. Approximately 30 per cent. of the whole Yellowknife area is underlain by these sediments, and a further 10 per cent. by similar beds mixed with granitic intrusives. Probably half the beds over this whole area of sediments contain grey to brown nodules up to 2 or 3 inches long (Plate I, figures 1 and 2). Most of the nodules on a fresh surface are seen to be merely segregations of quartz or biotite or both. Some, however, in thin section show a skeleton framework of andalusite enclosing the quartz and mica, and a few consist almost entirely of andalusite. Locally, pure crystals of the variety chiastolite up to 3 inches long occur in these nodular argillaceous schists.[6] Nearly 200 miles north of the Yellowknife River area on Lac de Gras other andalusite-bearing sedimentary schists of this general character have been noted.[7]

Throughout many of the andalusite-bearing beds, and particularly in the vicinity of granitic intrusives, irregular milky quartz masses generally only a few feet in length occur. Although feldspar appears to be scarce or lacking in these, they may be termed "pegmatitic", as they are characteristically coarse to very coarse in grain and show a moderately high temperature mineral association. Practically all these masses carry muscovite, biotite, and andalusite. Some crystals of the latter mineral contain tiny transparent blue "eyes" similar to those found in andalusite from Outpost Islands which were later determined as corundum. In a few

[6]Stockwell, C. H. *Op. cit.*, p. 50.
[7]Stockwell, C. H. *Op. cit.*, p. 49.

places green apatite crystals up to 1/2 inch long were found within these quartz "pegmatites".

A specimen of andalusite occurring in quartz-andalusite pegmatite, 55 miles N.N.E. of Yellowknife Bay, was studied in some detail. It is slightly pinkish in colour, is glassy, much less altered to muscovite than the Outpost Islands material, and more free from impurities in general. The sample as prepared for analysis on microscopic examination appeared to be practically free from impurities with the exception of traces of muscovite. It had S.G. = 3.137 at 20.57°C. This material showed exactly the same indices of refraction as the Outpost Islands sample, *i.e.*, $\alpha = 1.629$, $\beta = 1.633$, $\gamma = 1.639$, within the limits of accuracy of the oil immersion method. An analysis by H. V. Ellsworth yielded the following results:

SiO_2	36.86
Al_2O_3	61.46
Fe_2O_3	.60
MnO	<.01
TiO_2	.04
CaO	.20
MgO	.22
H_2O+	.64
H_2O-	.08
	100.11

The analytical sample did not appear to carry a sufficient amount of visible impurities to account for the presence of calcium and magnesium found by analysis, and these must be in part at least actual constituents of the andalusite.

Spectrograms of this andalusite and of the Outpost Islands andalusite made on the large Hilger quartz spectrograph by G. R. Giles showed strong gallium lines at 4172, 4033, and 2943, the strongest being 4172. The lines for the Yellowknife mineral appeared to be from 50 to 100 per cent. stronger than those of the Outpost Islands specimen analysed. No indium lines were visible in either case.

Outpost Islands

The rocks on Outpost Islands are a conformable series of interbedded sandy and argillaceous sediments cut by a few

basic dykes and later quartz-mica-andalusite "pegmatites". The sediments have been correlated on lithologic and structural evidence with the Archaean (?) sediments of the Wilson Island group found in the East Arm of Great Slave Lake.[8] The geological sequence on Outpost Islands is as follows:

	Approx. thickness in feet
9. "Pegmatites" (andalusite-bearing)	
8. Basic dykes	
7. Upper quartzite with andalusite-bearing conglomerate beds	1,000+
6. Andalusite schist and biotite schist	300
5. Middle quartzite	75
4. Conglomerate andalusite schist	175
3. Lower quartzite	250
2. Conglomerate, locally andalusite-bearing	450
1. Quartz-mica schist and gneiss, locally conglomeratic	1,700+

Andalusite occurs in four of the sedimentary formations as well as in the "pegmatites" but is present in by far the greatest concentrations in the conglomeratic andalusite schist. This latter formation contains a few beds of impure quartzite up to 2 feet thick and some pebbles uniformly but sparsely distributed. The matrix of this lean conglomerate contains quartz, biotite, sericite, andalusite, staurolite, chlorite, iron oxides, and apatite. The weathered surface would suggest that the grey to purple-brown nodules, which are up to 2 inches across, make up about 10 per cent. of the rock (Plate II, figure 1). However, in thin section these nodules are seen to consist of a mere skeleton of andalusite with much included quartz and biotite. Staurolite is likewise widely distributed through this formation although most of the crystals are only a fraction of an inch across. This mineral shows the same sieve texture as the andalusite with abundant inclusions of quartz and iron oxides.

An analysis of this andalusite- and staurolite-bearing rock not including any large pebbles gave the following results:[9]

[8]Stockwell, C. H. *Op. cit.*, p. 52. See also maps 377A, 378A, Geol. Surv. Can., 1936.

[9]Analyst, H. V. Ellsworth.

	Per cent.
SiO_2	69.97
Al_2O_3	15.63
Fe_2O_3	1.94
FeO	4.07
MgO	3.37
CaO	.41
Na_2O	.03
K_2O	2.86
H_2O+	1.01
H_2O-	.21
TiO_2	.55
P_2O_5	.01
MnO	.03
	100.08

F = .05

This chemical composition indicates a rock somewhat higher in silica and lower in lime than the average shale.[10]

Andalusite-Bearing Quartz Pegmatites

The previously mentioned irregular, coarse-grained masses of pegmatitic quartz, containing micas and andalusite, cut all the sediments and basic dykes on Outpost Islands (Plate II, figure 2). These preceded the metallic mineralization of the ore zones (ferberite, pyrite, chalcopyrite, bornite, chalcocite, and gold) and are probably not genetically related to it. Their distribution is erratic and comparatively few were seen within the massive quartzite formations. The greatest concentrations occur along zones of structural weakness—within shear zones, at the apices of folds in the sediments, and adjacent to contacts between competent and incompetent formations. The intricate outlines of most of the bodies signify no other structural control over their emplacement. In a few places, however, they do occur with sharp rectilineal boundaries along joint or fault planes as apparent fissure fillings, but these are generally only a few inches wide.

[10]Clarke, F. W. Data of Geochemistry. U.S. Geol. Surv., Bull. 770, pp. 552, 631, 1924.

The most abundant mineral present, and the only one in some cases, is milky quartz locally showing a poorly developed coarse comb structure. The next most abundant mineral is a pearly-grey to light green muscovite, much of which apparently has developed through hydrothermal alteration of andalusite and corundum. The andalusite occurs as aggregates up to 2 feet across with individual crystals of the mineral showing prism faces up to 1½ inches across and 4 inches long (Plate III). This andalusite is mauve to pink to brown in colour and in places contains transparent blue corundum crystals up to ½ inch across. Some of these "pegmatites" contain chlorite and a few carry biotite. The occurrence of metallic minerals is apparently restricted to "pegmatites" lying within those shear zones which elsewhere carry these metallics. Thus, at the shaft of Slave Lake Mines, a quartz-andalusite-mica vein carries younger ferberite, pyrite, chalcopyrite, bornite, chalcocite, and gold (Plate III). Again, in another zone on this property, visible gold occurs in pegmatitic quartz and between plates of muscovite. The occurrence of these metallics within the "pegmatites" is regarded as merely fortuitous and due to the position of these bodies along a shear zone later mineralized. The almost complete absence of feldspar in these masses is noteworthy. In only three of the innumerable "pegmatites" examined was any seen. In each case salmon-red stringers of orthoclase (?) up to ½ inch wide cut across all the other minerals including the muscovite and chlorite. In the great number of these "pegmatites" examined on Outpost Islands, no masses of andalusite exceeding 2 feet in length were seen on the surface.

A specimen of typical andalusite from the quartz pegmatites, Outpost Islands, was selected for analysis. It was brownish red in colour and showed considerable alteration to scaly muscovite. A piece selected for purity was crushed to small fragments and picked over under the binocular microscope to eliminate as far as possible small amounts of muscovite, chlorite, and magnetite which were present. The sample thus obtained for analysis had S.G. = 3.139 at 20.82°C. Examination of the purest grains in oils gave optical properties

as follows: biaxial negative. $\alpha = 1.629$, $\beta = 1.633$, $\gamma = 1.639$, $\pm .002$. An analysis by H. V. Ellsworth yielded the following results:

	Per cent.
SiO_2	36.58
Al_2O_3	60.16
Fe_2O_3[1]	1.82
MnO	< .01
TiO_2	.05
CaO	.22
MgO	.16
Na_2O	.03
K_2O[2]	.22
H_2O+	.86
H_2O-	.08
	100.19

(1) All Fe as Fe_2O_3.

(2) A 2-hour ignition by the Lawrence Smith method gave 99.08 per cent. decomposition of the andalusite.

The presence of small amounts of muscovite, chlorite, and magnetite no doubt accounts for the presence of potassium and to a certain extent for the greater percentage of iron in this variety.

Blue Corundum

Blue corundum occurs sparingly in patches up to one-half inch diameter embedded in andalusite in the quartz pegmatites at Outpost Islands. The specimens so far obtained are not quite of gem quality though some are more or less transparent and of a good deep cobalt-blue colour. There is a thin white margin of muscovite surrounding the corundum in most cases. Examined as crushed fragments in oils under the microscope, the corundum is seen to be more or less altered in places and the colour varies in intensity in different grains. The mineral is pleochroic, biaxial negative, with 2V estimated at 10° to 15°, $\alpha = 1.760$, $\gamma = 1.768$, $\pm .002$. Cleavage is well developed on crushing.

The occurrence of corundum in connection with quartz bodies is most unusual and, according to the generally ac-

cepted theory, impossible. However, in this case the corundum occurs in a matrix of andalusite which in turn is enclosed in the quartz bodies. No corundum is directly enclosed in quartz.

Ferberite

This mineral was first identified as a fragment of a small rounded mass originally about ½ inch in diameter, embedded in andalusite-bearing pegmatitic quartz from the dump at the shaft of Slave Lake Mines, Outpost Islands. The ferberite nodule was enclosed in a paper-thin envelope composed chiefly of chlorite with a little scaly muscovite, which allowed it to be removed easily from the enclosing quartz. This coating was removed as completely as possible by scraping and grinding and the sample of .3902 g. thus obtained gave on analysis the following results:[11]

FERBERITE FROM QUARTZ PEGMATITE, SHAFT OF SLAVE LAKE MINES, OUTPOST ISLANDS

	Per cent.	M.W.
FeO[(1)]	23.02	.322
MnO[(2)]	.49	.007
WO_3[(3)]	74.50	.321
Al_2O_3	.51	
CaO	.10	
MgO	.97	
SiO_2	.41	
Ti, V	Not deted.	
Undet. Ta, Sn?[(4)]	.10	
	100.10	

(1) Total iron determined as Fe_2O_3 and calculated to FeO.

(2) The Mn determination was checked by a very careful colorimeter determination on a separate .05 g. sample, which indicated a content of .52 per cent. MnO.

(3) Tungsten determined by the cinchonine method.

(4) Small amounts of impurities, not Fe, probably mostly Ta, possibly some Sn, obtained in purifying the WO_3.

The Al, Ca, Mg, and Si found are due in part at least to traces of chlorite and sericite associated with the ferberite.

[11]Analyst, H. V. Ellsworth.

The analysis shows that the mineral is nearly pure iron tungstate, the proportion of hübnerite molecule present being 2.12 per cent. if all the manganese is calculated as $MnWO_4$. The molecular ratios show a slight preponderance of bases as do most ferberites.[12]

A small amount of iron is doubtless contributed by traces of chlorite or other impurities present. However, it would appear that probably at least some portion of the minor constituents, more particularly MgO, may be actually combined in the ferberite.

Ferberite as pure as this has not previously been found in Canada, the nearest approach to it being a manganiferous variety carrying 2.75 per cent. of MnO (or about 12 per cent. hübnerite molecule) described by T. L. Walker[13] from the Kootenay Belle Mine near Salmo, B.C.

The ferberite is brownish black in colour with dark brown streak. It sometimes shows an iridescent bluish tarnish resembling that of copper minerals. Hardness 4-5, brittle, cleavage sometimes well developed, sometimes little noticeable. It is almost opaque in small grains or thin section under the microscope.

Further search for ferberite in specimens from Outpost Islands revealed that this mineral occurs in at least half of the eight gold-bearing zones so far developed.

The specimens examined show three modes of occurrence: (1) As nodules or crystals up to ½ inch across in pegmatitic quartz of the gold-bearing zone. (2) As clusters of tiny grains and aggregates up to 1 mm. across with magnetite, within and replacing andalusite, at the shaft, Slave Lake Mines (Plate III). (3) As minute needles and plates and in aggregates up to 3 mm. across disseminated in early-deposited quartz of the gold-bearing zones (Plate IV). The ferberite is mostly concentrated in silicified zones surrounding the original fragments of brecciated quartzites, while these ferberite zones pass outwardly into areas of drusy quartz, pyrite, and chalcopyrite.

[12]Hess, F. L. and Schaller, W.T. U.S.G.S., Bull. 583, Colorado Ferberite and the Wolframite Series.

[13]Walker, T. L. Tungsten Ores of Canada, Mines Branch, 25, 1909.

The identity of the mineral in all these cases was confirmed by preparing nearly pure concentrates of the mineral which were tested chemically by quantitative methods.

An analysis by the Ore Testing Laboratory, Department of Mines, Ottawa, of a half-ton shipment of ore from the 50-foot level, Slave Lake Mines, indicated a content of 1.18 per cent. WO_3 with 0.18 per cent. Sn besides gold, silver, and copper. That the tin is present as cassiterite, however, has not yet been proved.

Geochemistry

From the results of examination so far, it appears that the area here considered is characterized by a vast development of altered sedimentary rocks rich in Si and Al but remarkably poor in Ca, Na, and Mn. Feldspars and calcium minerals are almost entirely absent. The appearance of W as ferberite rather than as scheelite or wolframite might be expected under these conditions.

DIVERSIFICATION OF IGNEOUS ROCKS

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Introduction

Igneous rocks show an amazing degree of compositional diversity when viewed collectively or in a world-wide way. Their parent magmas come from regions more or less remote from the surface, so that at first glance diversity might be thought of as a reflection of similar compositional variation in magma sources. That this interpretation is reasonable in explanation of the larger and more uniform masses of igneous rock, is indicated by evidences from several sources that earth material is more or less delicately arranged into compositionally different and concentric shells. The lithosphere appears to grow gradually more basic with increasing depth. This kind of compositional layering in the earth can be most reasonably accounted for by assuming that the planet was originally liquid and homogeneous, and that differentiation was effected during cooling and congelation. While considerations like these may explain large-scale diversification of igneous material, they by no means account for certain local and minor kinds of diversity, nor for certain extreme compositional types. For many of the latter instances much evidence goes to show that magma, which was originally more or less homogeneous, has given rise to diverse products. Processes of differentiation and assimilation undoubtedly account for some diversifications. However, the importance assigned to these processes has grown to such an extremity that in recent years there is a tendency to account for all diversity by appealing solely to magmatic processes, and to lose sight of the evidence that the earth is compositionally zoned and therefore heterogeneous in magma sources. In this tendency the writer sees a danger of losing reality in the pursuit of a tempting phantom.

A solution of the problem of diversification is vital to the formulation of fundamental principles in several branches of physical geology. For instance, the question is involved with sources, migrations, and intrusions of magma, and assumes added importance in view of the fact that continental masses have been built during geologic time almost essentially by igneous processes. Moreover, intrusion and deformation are inseparably linked in earth history, so that a correct analysis of the causes of deformation might throw light on diversification. Uncertainty about these and related problems exists because of insufficient knowledge of conditions which govern in the earth's interior. Were these conditions known, they would likely lead directly to an explanation of diversification. Instead, igneous effects have been studied and used to designate conditions that should hold in the interior.

To be specific, evidences of community of origin of compositionally different igneous products, and of serial diversity, or compositional gradation between diverse types, are taken to indicate consanguinity, which in turn gives rise to the concept of a common parent magma. This further suggests that heterogeneity is derived from a parent of less heterogeneity, and so the concept of homogeneity of parent magma has gradually evolved. This view is sometimes expanded to the extremity that nearly all compositional varieties of igneous rock are regarded as having been derived from a single kind of homogeneous magma, one of basaltic composition being the most favoured. In this view diversity is brought about by differentiation processes. To permit the operation of the favoured processes, assumptions of enormous chambers of primary magma, and of passive intrusion, are required. Commonly there is an added inference that a permanent weak shell of potential magma must exist in the earth to provide a continuously available supply. It is important to bear in mind, however, that there are no positive and direct evidences of differentiation on a large scale. The more positive the evidence, the smaller is the scale of operation indicated. To sum up, it is apparent that minor and local effects have been used to build an elaborate hypothesis designed to explain not only

diversification, but as well the sources of magma and the manner of its intrusion. The same hypothesis places restrictions on assimilation as an effective process and narrows speculation on the causes of deformation.

Serial diversity and other indications of consanguinity may be results of assimilation. In this process "mixing" is appealed to instead of "unmixing" as in differentiation. A relatively homogeneous magma might, for example, be contaminated in varied degree in its different parts and so give rise to serial diversity. The common view of diversification, however, favours differentiation as the dominant process, though it is generally admitted that assimilation is not altogether negligible.

It should be emphasized that, notwithstanding convincing evidences of processes of both differentiation and assimilation, these evidences are positive only in a minor and local way. To explain wholesale diversification dependence has been placed on far-reaching extrapolation from local and positive indications. It might be wondered why extrapolation of differentiation evidences has satisfied petrologists so widely to the more or less exclusion of possibilities from assimilation. Advocates of differentiation saw the needs of their process and boldly decreed the necessary magmatic conditions in depth. On the other hand, the possibilities of other magmatic conditions favourable to assimilation have not received the attention they deserve. Obviously, the relative values of the evidences supporting each of the two kinds of diversification should be carefully weighed. Is it possible that the dominant process leaves less positive local evidences than does the one of minor importance?

In answer the writer holds that evidences of differentiation are likely to be preserved and consequently to be obvious, and that those of assimilation, though not destroyed, are in general not easily interpreted and are correspondingly not obvious. Differentiation in its more appealing processes is favoured by quiescence in the crystallizing magma chamber, and there is a multitude of igneous units available for examination, which were formed under these conditions in the so-called "second-

ary" magma chambers. The best evidences of the favoured processes of differentiation are supplied by these units, yet relatively few of them supply good evidence. If differentiation is the dominant process, it is surprising that it has left so few evidences. In contrast, evidences of assimilation are not expected to be apparent in any degree commensurate with the possible importance of the process. Certainly they are not expected in those units of intrusion where differentiation is favoured. Passive intrusion and quiescent magmas do not favour assimilation. It may well be that magmas are not passive agents, but active, migrating bodies which grow by assimilation.[1] With this concept it is obvious that effects of assimilation in producing diversity will be remote from the scene of the process. The effects are there but are not easily interpreted, and are therefore less obvious than those from differentiation. The more obvious effects of assimilation will be found in igneous bodies formed from magmas chilled at the scene of assimilation. There are many signs of assimilation along the margins of intrusives, but such evidences are interpreted as being on too small a scale to account for wholesale diversification. However, it may be that these signs record only a momentary phase of what may be a long drawn-out process. There seem to be ample grounds, therefore, for the view that differentiation has won favour as a concept because its evidences are more obvious.

It becomes more and more apparent that the correct interpretation of magmatic activities and sources is necessary for the solution of the problem of diversification. Thermal evidences have forced the writer to adopt views of conditions in the earth's interior which are entirely opposed to the extrapolations from differentiation evidences. From an inductive process conclusions were drawn (1) that magma is generated initially as a horizontally disposed and relatively thin sheet, (2) that the sheet is forced to migrate, and (3) that the volume of the initial sheet is increased many fold by frictional heat

[1]DeLury, J. S. Magmas from Subsidence. Amer. Journ. Sci., vol. XXIII, pp. 357-68, 1932.

——— The Magmatic Wedge. *Ibid.*, vol. XXVIII, pp. 341-352, 1934.

developed in forceful migration.[2] These conclusions plainly favour assimilation as a means for rock diversification. The part played by the processes of differentiation would be largely limited to the time following the final emplacement of the magma, though it is conceivable that some of its processes might contribute to diversification during migration.

The explanation sought specially in this paper is that of mass diversity in the continent as a whole. It is usual in attempts to explain diversification to emphasize local and minor evidences. However, it seems to the writer that regional evidences might be more dependable in approaching the problem than those derived from local effects. After all, it is abundantly evident in geological literature that local and shallow effects observed in a physically and chemically heterogeneous outer lithosphere have led to entirely opposing concepts of ultimate causes. Earth-wide and secular evidences may be more trustworthy. An attempt will be made, therefore, to weigh the broad implications of past and present igneous activities and to show their bearing on the problem of diversification.

Secular Igneous Activity

Continental masses are made up essentially of granitic rocks which appear to be the cores of a long succession of mountain systems. In oceanic regions, on the other hand, rocks of basaltic composition appear to dominate, and more exclusively so in the deeper basins where the only lands are volcanic islands. Other igneous activities of the ocean basins are more conjectural. If, however, it is permitted to judge the past from present indications, it might be safely inferred that igneous processes have dominated in suboceanic regions as they more obviously have in continents.

The continental mass consists in the main of granite and allied quartzose rocks, which are collectively referred to as *sial*. This material may be regarded as forming a discontin-

[2]DeLury, J. S. Geologic Deductions from a Thermal Equation. Journ. Geol., vol. XLIV, pp. 479-495, 1936.

uous shell which is thickest in the continents, thin in oceanic areas, and may be almost or entirely lacking under the deepest parts of the oceans. The prevalence of basaltic rocks in the latter regions, coupled with the evidence that similar material is available from beneath continents, suggests that a continuous shell of basaltic material, known as *sima*, underlies the continental *sial* and forms the floor of the oceanic deeps. Geodetic evidence supports the view that the continents ride high because of the low density of *sial* as compared with *sima*, and seismological interpretations add further confirmation. Perhaps the most positive evidence of a persistent and compositionally homogeneous shell of *sima* comes from the history of basaltic intrusion and extrusion. From earliest geologic time abundant flows of basalt have poured out in continental and oceanic regions, and the composition, especially in the larger flows, is remarkably uniform from time to time and from place to place. Here is not only evidence of a high degree of compositional layering in the earth, but as well of a diversification established at the beginning of the record.

Sialic magmas were equally persistent throughout geologic time and gave rise to the granitic rocks which largely compose the continents. The view has grown in recent years that sialic rocks are differentiates of basaltic magmas and that all recent granites entering the continents are so formed. Opposed to this concept is the evidence of compositional layering established from the beginning. Originally differentiated *sial* may always be the main source of granitic magmas. The view that *sial* differentiated in large part from *sima* during the geologic record, implies that continents have been formed by vertical segregation. On the other hand, if an original and more or less continuous shell of *sial* was inherited, a horizontal segregation must be called upon to explain continents. Of great importance to both conjectures is the evidence that continental *sial* has all been emplaced by intrusion during the geologic record. Original sialic rock is nowhere recognized.

Vertical segregation of *sial* suggests passive intrusion, thick magma chambers, and differentiation. Horizontal segregation indicates active migration of magma and favours

assimilation. It appears, therefore, that the problem of diversification is related to the manner in which continental *sial* has been segregated. Before dealing with geologic evidences of the manner of segregation of *sial*, there are other features of igneous activity which should be indicated.

With few doubtful exceptions the products of igneous intrusion have been much the same from time to time throughout the geologic record. Similarly, there are no profound differences to be noted in the relative prominence of different and abundant types of magma. Moreover, there is no indication of any important secular waning of igneous activity. Indications are, therefore, that magmas have tapped about the same levels in the earth throughout. On these and other grounds there are reasons for assigning relatively shallow depths to magma sources. Abundant magmas have compositions similar to those commonly assigned to outer shells. With dependence for magmatic heat placed on the heat of the interior alone, more and more basic would magma become with the passage of time, and, of greater importance, there would be important waning of igneous activity, and probably extinction of magma. These considerations together seem to imply that a shallow and persistent source of heat must be available constantly for magma generation. Radioactivity is the probable source.

Manner of Segregation of Sial

Igneous activity is not, and probably never has been, restricted to continental areas, so that if formation of continents by vertical segregation is assumed, it is not apparent why *sial* has not been segregated to some extent at least in the regions of the deeper oceans. It might be claimed in support of some measure of vertical segregation that continents and oceans were permanently established from the beginning, that original *sial* was segregated from earliest time into the present continental nuclei, and that these nuclei exercised a determining influence on the locus of later segregation by differentiation. While these possibilities must be weighed, there are no compelling evidences in their support. Moreover,

the assumption of permanent continents and oceans, though widely held, is by no means convincingly established. It may well be that the present continental outlines were roughly established by the beginning of Palaeozoic time, but little is known of terrestrial geography in Precambrian time, which probably embraces three-fourths of the record. It is unsafe to assume that the geography of the earliest ages remotely resembled that of the present.

Even in Palaeozoic time, when it is commonly and more definitely assumed that *sial* segregation was brought about by vertically operating processes, it seems highly probable that horizontal segregation was the dominant process. Consider the history of the Appalachian region. It is generally accepted that its Palaeozoic geosyncline was filled with sediments derived from a high and presumably extensive borderland lying to the eastward in Atlantic areas considerably beyond the present coastline. At the close of the Palaeozoic era the borderland disappeared, and new material, represented by the now exposed granitic core, came from somewhere to take up a new position beneath the folded sediments and floor of the geosyncline. Great subsidence in the borderland region accompanied great elevation in the mountain belt. To explain the close and significant relations between (1) salients in the axes of the folds, (2) effects of overthrusting, and (3) amount of intrusive *sial*, Keith[3] drew the conclusion that batholithic material came from the Atlantic region. He definitely favours the view of horizontal segregation as opposed to vertical.

The same arguments apply to Pacific regions and the building of the Cordilleran region. Here is evidence from comparatively modern times that the continents have been built by a process of skimming *sial* from oceanic regions. The concept offers reasonable possibilities for a general explanation of the origin of continents. Difficulties face the explanation of the common arcuate forms in continental trend lines by appealing to interactions of strong and rigid units of a so-

[3]Keith, Arthur. Outlines of Appalachian Structure. Bull. Geol. Soc. Amer., vol. XXXIV, pp. 309-380, 1923.

called "crust" or of a strong lithosphere. Arcuate forms definitely suggest, on the other hand, the existence of mobility in underlying regions and differential flow as a cause of deformation, and these would be supplied by forceful migration of magma in horizontal directions. A close association of deformation and intrusion would be predicted.

If the batholithic core of a mountain range is accumulated by the migration of a horizontal sheet of magma, and if the earth is compositionally layered in magma sources, it would follow that the batholith will reflect the composition of those earth layers which contributed to magma generation. A batholith of uniform composition would therefore suggest an origin from a homogeneous layer. A composite batholith would similarly indicate that the migrating sheet had involved compositionally different layers, and would imply either horizontal heterogeneity in the earth or a change of horizon on the part of the sheet. Heterogeneity of the batholith would also be increased by a "mixing" process akin to assimilation.

Since regional rather than local evidences are being emphasized, the history of intrusion throughout a large comagmatic section of the earth might permit interesting conclusions. A valuable analysis of the history of igneous activity in the Cordilleran region was made by Lindgren. His summary, in part, reads:

> The conditions outlined . . . , even with the broadest allowance for processes of differentiation, seem to call for magma basins, or magma beds, of several kinds.
>
> It seems to me that the study we have just completed strongly tends to support the hypothesis that the outer crust of the earth consists of zones in which with depth the basic constituents of the magma gradually increase.[4]

An authoritative interpretation of regional intrusion has led in this instance to the conclusion that igneous diversity on a large scale is related to inherited compositional layering of the earth. Again, regional evidences conflict with local indications.

[4]Lindgren, W. The Igneous Geology of the Cordilleras and its Problems. Problems of American Geology, Yale Univ. Press, chap. V, pp. 278 and 286, 1915.

Volcanic Evidences

Volcanic products provide another means for diagnosis of the problem of diversification. The typical continental volcano shows diverse lavas, and commonly signs of consanguinity of the different flows. It has become almost habitual to explain this diversity by appealing in each instance to differentiation in a parent magma chamber "below". However, many lava sequences are disturbing to this concept. More often than not the sequence is not "normal".

Diversity is also ascribed to differentiation in many oceanic islands, where all lavas are relatively basic but still show some compositional variation.[5] Without questioning this possibility, the writer makes the claim again that local evidences may be vastly outweighed by broad evidences. A world-wide survey of volcanic products may lead to more trustworthy views on diversification.

Daly made a valuable statistical survey of available evidences pertaining to the compositions of rocks in Pacific islands.[6] His study permitted the conclusion that:

> . . . The deep-sea islands are chiefly made of basalt, a rock with a density of about 3.0, and therefore heavier than granite. Most of these islands are volcanic, and many of them witnessed violent explosions. Numerous fragments of rocks, exploded out from considerable depths, have been found. Nearly all of the solid fragments are crystallized basalt or derivatives of basalt; fragments of rocks characteristic of the continents are usually conspicuous for their absence. Particularly, not a cubic inch of granitic rock has ever been found in the hundreds of volcanic islands which dot the region of the central Pacific, one fourth of the area of the whole globe. So far as they go, these facts suggest that the suboceanic crust is composed of rocks decidedly different from the rocks constituting the continents.[7]

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[5]Daly, R. A. Magmatic Differentiation in Hawaii. Journ. Geol., vol. XIX, pp. 289-316, 1911.

[6]Daly, R. A. Petrography of the Pacific Islands. Bull. Geol. Soc. Amer., vol. XXVII, pp. 325-344, 1916.

[7]Daly, R. A. Our Mobile Earth. Charles Scribner's Sons, pp. 97-98, 1926.

These facts serve to show the ineffectiveness of differentiation for the production of *sial* in an important way, and, therefore, as a means of explaining wholesale diversification. This conclusion seems final in view of the evidence that the typical continental volcano nearly always shows a conspicuous development of sialic lavas. It seems safe to say that in general volcanoes show in their products the same diversity that exists more or less in those portions of the heterogeneous earth which were melted to produce their parent magmas. Differentiation may contribute to diversity, but is probably greatly eclipsed by assimilation.

Summary

The problem of diversification could be most satisfactorily solved by securing accurate information of conditions in the earth's interior. Owing to uncertainty concerning these conditions, most interpretations of the problem have been arrived at from a study of igneous effects. The writer emphasizes the diagnostic value of secular evidences and regional effects, as opposed to those of a minor and local nature, with the result that the following conclusions seem to be permitted:

(1) An igneous rock body with relatively large mass and considerable uniformity of composition has probably been formed from a magma derived by the melting of an earth layer of similar composition.

(2) Diverse lavas from a single vent, compositional variation in a large unit of intrusion, and a group of intrusives showing community of origin, probably reflect in each instance original heterogeneity in the parent magma, which is regarded as resulting from a "mixing" or assimilation process. Differentiation processes may contribute to diversity in these groups.

(3) Differentiation is of minor quantitative importance, though its effects may be locally conspicuous. This process definitely accounts for the derivation of exceptional compositional types of rock, notably, extremely acid and basic varieties, those with unusual concentrations of any elements, but

especially the rare ones, and perhaps best explains the origin of monomineralic rocks.

The habitual explanation of diversification by postulating differentiation in a chamber of homogeneous magma "below" seems to be unjustifiable.

A REVIEW OF THE OCCURRENCE OF TELLURIDES IN CANADA

By Ellis Thomson

For many years the writer has been interested in recording localities reported for telluride minerals in the Dominion of Canada. With the rapid development of gold mining in this country during the past ten years, the occurrence of small quantities of these minerals has now been listed from many points in the Province of Ontario, as well as from a good many other parts of Canada. It seemed desirable, therefore, at this time to effect a compilation of these records within the confines of a single article, so that some idea might be gained as to the relative abundance of these rather rare minerals.

This brief article must, then, be considered rather as a gathering together of the results of past investigations than as a recording of new localities. It must also be borne in mind that this compilation, like any other, is necessarily incomplete. The writer was able to find twenty-one references in the literature, but feels quite certain that there are more. It is to be hoped, however, that any omissions may not greatly affect the completeness of this record up to 1937.

The earliest record that could be found of the occurrence of tellurides in this country is to be found in the "Report of the Royal Commission, Mineral Resources of Ontario"[1] published in 1890. The locality mentioned is the Huronian Mine, Moss Township, in Western Ontario. The telluride found there was given as sylvanite, and with it were associated native gold, galena, pyrite, chalcopyrite, and sphalerite.

In 1895 A. P. Coleman, in his report on the "Gold Fields of Western Ontario",[2] records the occurrence of the silver telluride, hessite, at Gold Creek, Pine Portage Bay, in Ontario, associated with pyrite and chalcopyrite, and also mentions

[1]Report of Royal Commission, Mineral Resources of Ontario, 1890, p. 25.
[2]Coleman, A. P. Ont. Bur. Mines, vol. V, p. 105, 1895.

the occurrence of nagyagite at the Huronian Mine.

Then, after a lapse of some sixteen years, two articles by D. D. Cairnes and Robt. Harvie, Jr., were published in the same issue of the "Journal of the Canadian Mining Institute"[3] on "Canadian Tellurium-Containing Ores" and "Notes on a Discovery of a Telluride Gold Ore at Opasatica and its Probable Relations to the Gold Ores of the Porcupine and Neighboring Districts". In the first of these Dr. Cairnes reviews the occurrence of tellurides in many localities in the Province of British Columbia, as well as a few in the Yukon Territory, and mentions also those few localities that have already been cited for the Provinces of Ontario and Quebec. The tellurides mentioned are altaite, sylvanite, hessite, petzite, calaverite, tetradymite, and nagyagite. In the interests of brevity, and for convenience of reference, these occurrences are given with details as to locality, tellurides, and associated metallic minerals in table 1 below.

The paper by Dr. Harvie notes the occurrence of sylvanite associated with native gold, pyrite, and chalcopyrite in Pontiac County, Opasatica District in the Province of Quebec.

The next reference to the occurrence of tellurides in Canada appears in 1912 and 1914, when Burrows and Hopkins[4] identified hessite on the Powell claim in Deloro Township, and analysed a telluride of gold from the Labine-Smith claim in the north part of Maisonville Township in Ontario. This last mentioned mineral proved to be petzite, with pyrite and native gold as the associated metallic minerals. The same two workers are responsible for the identification of tellurides in several other Ontario localities during the years 1915-20.[5]

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[3]Cairnes, D. D. Journ. Can. Min. Inst., vol. XIV, pp. 185-200, 1911.
Harvie, Robt., Jr. *Ibid.*, vol. XIV, p. 166, 1911.

[4]Burrows, A. G. Ont. Bur. Mines, vol. XXI, pt. 1, pp. 229-231, 1912.
———— and Hopkins, P. E. Ont. Bur. Mines, vol. XXIII, pt. 2, pp. 34-35, 1914.

[5]Hopkins, P. E. Ont. Bur. Mines, vol. XXIV, pt. 1, pp. 180, 183, 1915.
Burrows, A. G. *Ibid.*, vol. XXIV, pt. 3, p. 36, 1915.
———— and Hopkins, P. E. *Ibid.*, vol. XXV, pt. 1, p. 256, 1916.
———— *Ibid.*, vol. XXVI, p. 250, 1917.
———— and Hopkins, P. E. Ont. Dept. Mines, vol. XXIX, pt. 4, pp. 23-24, 1920.

TABLE 1

Locality	Tellurides	Assoc. Met. Minerals
Yukon Territory		
Gold Reef Claim	Sylvanite, hessite, petzite, telluric ochre	Pyrite, gold
Buffalo Hump Group on Mount Stevens	Sylvanite	Galena, gold
British Columbia		
1. Engineer Mines, Atlin Min. Div.	Calaverite	Gold, bismuth, pyrite
2. Valdez Island, Nanaimo Min. Div.	Gold tellurides	
3. Nickel Plate Mine, Osoyoos Min. Div.	Tetradymite	Gold, arsenopyrite
4. Near Osoyoos Lake, Osoyoos Min. Div.	Hessite, petzite	Gold
5. Long Lake Camp, Greenwood Min. Div.:		
(*a*) Jewel Mine	"Rich tellurides"	Pyrite, chalcopyrite, gold
(*b*) Lakeview Claims.	Altaite, hessite, tellurium	Gold, copper, chalcocite, chalcopyrite, pyrrhotite
(*c*) North Star Claim.	Hessite	Gold, pyrite, galena, chalcopyrite
(*d*) Enterprise Claim.	Petzite	Gold, galena, pyrite
(*e*) Rhoderick Dhu Claim	Tetradymite, altaite	
6. Olive Mabel Claim, Gainor Creek, Trout Lake Min. Div.	Nagyagite	Gold
7. Liddle Creek, Kaslo River, W. Kootenay District	Altaite	
8. Pay Roll Mine, near Cranbrook, Fort Steele Min. Div.	Altaite	Gold
Ontario		
Gold Creek, Pine Portage Bay	Hessite	Pyrite, chalcopyrite
Huronian Mine, Moss Tp.	Sylvanite, hessite, nagyagite	Gold, galena, pyrite, chalcopyrite, sphalerite
Quebec		
Pontiac Co., Opasatica District	Sylvanite	Gold, pyrite, chalcopyrite

All of these localities reported during the interval from 1914 to 1920 are listed in the following table.

TABLE 2

Locality	Tellurides	Assoc. Met. Minerals
1. Deloro Tp., Ont.....	Hessite.....	
2. Maisonville Tp., Ont...	Petzite.....	Gold, pyrite
3. Painkiller Lake, Ont...	Tetradymite, calaverite?	Gold, pyrite
4. Tough - Oakes Claim, Kirkland Lake.....	Altaite, tetradymite, hessite, calaverite.....	
5. Miller Independence Mine, Pacaud Tp.,Ont.	Tetradymite and other tellurides.....	Pyrite, chalcopyrite, hematite, galena
6. Benoit Tp., Ont.....	Petzite.....	Gold, pyrite
7. Kirkland Lake Area, Ont.....	Altaite, calaverite, coloradoite, kalgoorlite?, tetradymite?, hessite? ..	Gold, pyrite

The writer then took up the investigation of tellurides starting in 1922 and continuing in 1928 and from 1931 to 1935.[6] The results of his investigations are set out in the next table.

Finally, petzite was recorded from the Hollinger Mine in the Porcupine District by Walker and Parsons,[7] tetradymite and calaverite with associated matildite, sphalerite, and chalcopyrite from Smithers, B.C., by Pratt,[8] hessite with associated pyrite and arsenopyrite from the McWatters Mine Gold Belt, East Rouyn and Joannes, Que., by Hawley,[9] and

[6]Thomson, E. Univ. Tor. Studies, Geol. Ser., No. 14, pp. 91-98, 1922.
———— *Ibid.*, no. 27, pp. 11-14, 1928.
———— *Ibid.*, no. 30, pp. 51-54, 1931.
———— *Ibid.*, no. 32, pp. 27-31, 1932.
———— *Ibid.*, no. 36, pp. 33-36, 1934.
———— *Ibid.*, no. 38, pp. 47-49, 1935.

[7]Walker, T. L. and Parsons, A. L. Univ. Tor. Studies, Geol. Ser., no. 20, p. 39, 1925.

[8]Pratt, G. M. Univ. Tor. Studies, Geol. Ser., no. 30, pp. 55-56, 1931.

[9]Hawley, J. E. Que. Bur. Mines A.R., part C, pp. 40-42, 1933.

TABLE 3

Locality	Tellurides	Assoc. Met. Minerals
Painkiller Lake, Tp. of Beatty, Ont.	Tetradymite	Gold
Kirkland Lake District:		
Kirkland Lake Mine	Altaite	Gold, pyrite, chalcopyrite, sphalerite
Teck-Hughes Mine	Altaite	Gold, pyrite
Lake Shore Mine	Altaite, coloradoite	Gold, chalcopyrite
Tough-Oakes Mine	Altaite, coloradoite, petzite, calaverite, melonite	Gold and sulphides
Boston Creek	Calaverite, tetradymite, petzite	Pyrite, gold, chalcopyrite, sphalerite
Robb - Montbray Claim, Montbray Tp., Que.	*Tetradymite, altaite, krennerite*, petzite	Pyrrhotite, gold, pyrite, chalcocite, sphalerite
Moss Mine, Moss Tp.,Ont.	*Petzite*, altaite, coloradoite	Gold, chalcopyrite, pyrite, sphalerite, hematite
Ashley Mine, Bannockburn Tp., Ont.	Altaite, krennerite	Pyrite, galena, gold, chalcopyrite, sphalerite, hematite, magnetite, pyrrhotite
Straw Lake, near Fort Frances, Ont.	Tetradymite	Gold, pyrite, galena, chalcopyrite, sphalerite, magnetite
Eureka Mine, Tiblemont Tp., Que.	Tetradymite	Gold, galena, sphalerite
Gold Shore Mine, Red Lake, Ont.	Tetradymite	Gold, chalcopyrite, pyrite, galena
McWatters Mine, Rouyn Tp., Que.	Tetradymite	Gold, chalcopyrite

altaite with associated pyrite, galena, and gold from the Three Ladies Mine, Lake of the Woods District, Ontario, by James E. Thomson.[10] These last four occurrences are listed in the next table.

[10]Thomson, James E. Ont. Dept. Mines, vol. 45, pt. 3, 1937.

TABLE 4

Locality	Tellurides	Assoc. Met. Minerals
Hollinger Mine, Porcupine District, Ont.	Petzite	
Smithers, B.C.	Tetradymite, calaverite	Matildite, sphalerite, chalcopyrite
McWatters Mine, East Rouyn and Joannes, Que.	Hessite	Pyrite, Arsenopyrite
Three Ladies Mine, Lake of the Woods, Ont.	Altaite	Pyrite, gold, galena

In order that some idea may be obtained of the relative abundance of these telluride minerals, a summary of the records of the four tables above is given in the next table, but with those localities omitted where the telluride mineral has not been identified, and with the omission also of the associated metallic minerals.

TABLE 5

Locality	Tellurides
British Columbia	
Engineer Mines	Calaverite
Nickel Plate Mine	Tetradymite
Osoyoos Lake	Hessite, petzite
Lakeview Claims	Altaite, hessite, tellurium
North Star Claim	Hessite
Enterprise Claim	Petzite
Rhoderick Dhu Claim	Tetradymite, altaite
Olive Mabel Claim	Nagyagite
Liddle Creek	Altaite
Pay Roll Mine	Altaite
Smithers	Tetradymite, calaverite
Ontario	
Gold Creek	Hessite
Huronian (Moss) Mine	Petzite, sylvanite, hessite, nagyagite, altaite, coloradoite
Deloro Tp.	Hessite
Maisonville Tp.	Petzite

TABLE 5—*Continued*

Locality	Tellurides
Ontario	
Painkiller Lake	Tetradymite, calaverite
Kirkland Lake	Altaite, coloradoite, petzite, calaverite, hessite, melonite
Boston Creek	Tetradymite, calaverite, petzite
Benoit Tp.	Petzite
Ashley Mine	Altaite, krennerite
Straw Lake	Tetradymite
Gold Shore Mine	Tetradymite
Hollinger Mine	Petzite
Three Ladies Mine	Altaite
Quebec	
Opasatica District	Sylvanite, hessite
Montbray Tp.	Tetradymite, altaite, krennerite, petzite
Tiblemont Tp.	Tetradymite
Rouyn Tp.	Tetradymite, hessite
Yukon Territory	
Gold Reef Claim	Sylvanite, hessite, petzite, telluric ochre
Mount Stevens	Sylvanite

A brief consideration of the above table indicates fairly clearly that altaite, hessite, petzite, and tetradymite are the most abundant, that calaverite and sylvanite are next in importance, while coloradoite, krennerite, melonite, nagyagite, native tellurium, and tellurium ochre are relatively scarce.

SERICITE FROM THE TAYLOR-WINDFALL MINE, BRITISH COLUMBIA

By James M. Baker

Introduction

During the summer of 1935, Dr. V. A. Dolmage presented to the Royal Ontario Museum of Mineralogy a very interesting suite of mineral specimens from the Taylor-Windfall Mine, on Battlement Creek, twelve miles west of Taseko Lake, in the Clinton Mining Division, British Columbia. Dr. T. L. Walker, Director of the Royal Ontario Museum of Mineralogy, very kindly placed this suite at the writer's disposal, to enable him to make a more detailed investigation of the mineral associations of the gangue and ore.

Geological Setting

A short view of the geology of the immediate vicinity, at this point might be advisable to give as complete a picture as possible. No great detail is given in any of the reports to which reference has been made.[1]

The rocks in the vicinity of the workings are tuffs which overlie the Coast Range granitic rocks to an estimated depth of between 800 to 1,000 feet. These beds dip at a low angle of 20° to the north, are silicified in sections, and are exposed for 10 miles or more east of the deposit. At many places throughout its length the tuff has been almost completely altered to silica and the original dark green colour changed to pinkish-white. The silicification has been confined to wide bands, some of which are vertical and others parallel to the bedding of the pyroclastic. The only other rocks in the vicinity are

[1]Report of Minister of Mines of British Columbia, pp. F24-25, 1934.
Report of Minister of Mines of British Columbia, pp. C204-206, 1927.
Summary Rept., Geol. Surv. Can., pt. A, p. 73, 1924.

two intrusive dykes of quartz porphyry, averaging about 12 feet in width.

The tuff is well mineralized, both in the unsilicified and silicified sections, with well-formed pyrite crystals.

The ore mineralization apparently follows a certain line of fracturing which varies from east to north-east in strike. The open-cut working of the original discovery consisted of rich pockets in oxidized silicified sections of tuffs with tourmaline in some of the fractures. Individually these ore bodies were of small extent, the largest being under 12 feet in length, but in general 6 to 8 feet in length, and lesser depth, all without any appreciable continuity. Apparently these are of a vuggy nature.

The occurrence of gold is confined to eluvium and a small 2 to 6-inch tourmaline vein within an area of about 120 feet square, which is situated on the south-east side of the canyon of Battlement Creek.

In the underground development a new ore-body was discovered which is somewhat distinct from that at the surface. It consists of an alteration and filling along a fracture in the tuffs of a dark green chloritic gangue yielding values of 1 to 2 ounces over a 1 to 1½-foot width.

A certain amount of sericite is contained particularly in the hanging wall, and pockets of massive iron and copper sulphides, tetrahedrite, and sometimes barite. In the diamond drill holes and in the lower section of the winze, a silicified foot-wall and typical hydrothermal alteration in the hanging wall are apparent. The values seem to exist outside of the irregular masses of metallics and in the apparently barren gangue itself.[2]

Sericite

The sericitic material, which was evidently obtained from the hanging wall side of the vein zone, was made a special subject of study. The specimens, in the main, are composed of a fine, white, micaceous mineral, disseminated crystals and

[2]Information from the files of the Northern Miner, Toronto.

nests of perfect, pyritohedral crystals of pyrite, and tetrahedral crystals of tetrahedrite.

Physical Properties. Even in the hand specimen, this mineral is visibly micaceous, with a fine, silky lustre, and distinctly greasy to the feel. The pure mineral is in snow-white, very soft, and crumbly, thin laminae, or plates, which are flexible but not elastic. This type grades into a more compact, light greenish material which, in thin section, reveals itself to be mainly of the same material.

Several pieces were selected for their purity and freedom from metallic minerals, averaging approximately 4 grams in weight, on which the specific gravity was determined with Jolly's balance. Average specific gravity obtained was 2.79. The material prepared for chemical analyses, as described later, was used to obtain a more accurate value for the specific gravity with the aid of a constant-volume pyknometer.[3] The specific gravity found at 20°C. = 2.803.

Optical Properties. The optical properties of the mineral were determined with the aid of immersion liquids (glycerine and Thoulet's solutions), using the standard method as given by Larsen.[4]

β was easily determined, owing to the perfect basal cleavage, and α and γ with more difficulty. Cleavage flakes showed a perfect biaxial interference figure, the acute bisectrix being normal to the cleavage. The sign of the double refraction is negative. The angle 2E was found by measuring the distance between the optic axes by means of a micrometer ocular. A value for E was then obtained by Mallard's formula, $D = K \sin E$, the value of K for the microscope being determined with the aid of a muscovite of known optic axial angle. The mean of several determinations gave $2E = 36°$ for yellow light. Very minute, reddish-brown grains and hair-like inclusions with high relief were observed in some of the plates. These were determined to be rutile in later work.

[3]Ellsworth, H. V. A Simple and Accurate Constant-Volume Pyknometer. Min. Mag., vol. XXI, p. 431, 1926.

[4]Larsen, E. S. The Microscopic Determination of the Non-opaque Minerals. U.S. Geol. Surv., Bull. 848.

COMPARISON OF DATA FOR OPTICAL PROPERTIES OF SERICITE,[5] MUSCOVITE,[6] AND MINERAL STUDIED

1 Sericite (Ross)	2 Muscovite (Larsen)	3 Mineral in question
Biaxial Negative $2V=25°$ X=c	Biaxial Negative $2V=42°$ X=c	Biaxial Negative $2V=22°$ X=c
Indices: $\alpha=1.550\pm.003$ $\beta=1.585\pm.003$ $\gamma=1.587\pm.003$	Indices: $\alpha=1.560$ $\beta=1.593$ $\gamma=1.598$	Indices: $\alpha=1.552\pm.003$ $\beta=1.587$ $\gamma=1.589\pm.003$
Birefringence =.037	Birefringence =.038	Birefringence =.037

Pyrognostics. When heated before the blowpipe, a small fragment fused with some difficulty to a white enamel. This property is important, since muscovite and kaolinite are commonly listed as infusible.[7]

Qualitatively the mineral gave chemical reactions for potassium, sodium (little), alumina, silica, and water.

Composition and Chemical Properties. Extreme care was taken in selecting and preparing material for chemical analysis. Only the soft, pure white material was used, and to separate it from the fine grains of sulphides, and possibly quartz, the following procedure was used. The mineral was ground in a steel diamond mortar, and then in an agate mortar until it passed the 60-mesh and rested on the 80-mesh screen. A property of the components was utilized in the purification, in that the scaly, white mineral had a tendency to be more difficultly powdered, whereas the metallic sulphides, being of a brittle nature, powdered more easily, with the result that much of the sulphides and sulpho-salts were removed in the

[5]Shannon, E. V. Notes on the Mineralogy of Three Gouge Clays. Proc. U.S. Nat. Mus., art. 15, vol. LXII, p. 6, 1923.

[6]Larsen, E. S. *Op. cit.*, p. 237.

[7]Dana, E. S. Textbook of Mineralogy, 4th ed., p. 660, p. 680, 1932.

first treatment. Then the sample was thoroughly washed and slimed to eliminate all dust particles. The final product was dried in the electric oven at 110°C.

The final stage of purification was done in a separatory funnel with bromoform (specific gravity = 2.85). The first fraction was drawn off after stirring and allowing to settle; this, as shown by microscopic analysis, consisted mainly of sphalerite, pyrite, and a little tetrahedrite. Then, by the addition of benzol, the specific gravity of the liquid was lowered so that the major portion of the white material was in a state of suspension. Specific gravity of liquid at this stage = 2.779 (by Westphal's balance). This fraction was well washed with benzol, then ethyl alcohol, and finally dried at 110°C. For the analysis it was necessary to grind to −200 mesh. The analysis of this sample is labelled A.

A second sample was prepared by a slightly different method. Small pieces, adjudged free of metallics, under the low-power microscope, were ground to −200 mesh, dried at 110°C., and this sample was labelled B.

Water (−) was determined on a sample from the original material and total water (+) was determined on .5 gram samples by the modified Penfield method. Total alkalies were found by the Lawrence Smith method. Other constituents were found quantitatively by fusing .5 gram samples with C.P. sodium carbonate, using the procedure and technique of Hillebrand and Washington.[8]

The fluorine content was determined by a slightly modified method, based on the colorimetric method.[9] In general, fluorine determinations are very unsatisfactory. This method depends upon the bleaching action of fluorine on titanium solutions, oxidized by hydrogen peroxide. Into two 50 cc. Nessler tubes, 10 cc. of standard titanium solution (.00102 grams per cc.) were pipetted into each and 5 cc. of hydrogen peroxide added. Then, into one of these was poured a small

[8]Hillebrand, W. F. The Analysis of Silicate and Carbonate Rocks. U.S Geol. Surv., Bull. 700.

Washington, H. S. The Chemical Analysis of Rocks.

[9]Journ. Amer. Chem. Soc., vol. XXX, p. 219, 1908.

volume of solution, about 20 cc., containing the fluorine in the form of fluorides. From the data of the number of grams of fluorine that bleached a certain per cent. of the titanium present, the amount of fluorine in the sample can be determined. This is done by finding the amount of titanium solution necessary to bring the solution that contains the fluorine back to the original colour, shown by comparison with the solution in the second Nessler tube, and hence deducing the amount of titanium bleached.

ANALYSIS AND RATIOS OF SAMPLE A

	Per cent.			Ratios		
	1	2	Average			
SiO_2....	48.38	48.36	48.37	.8062	.8062	1.0x2
TiO_2....	.62	.64	.63 (a)			
Al_2O_3...	36.90	36.44	36.67	.3602	.3602	.90x1
MnO ...	trace	trace	trace			
FeO, Fe_2O_3..	trace	trace	trace			
CaO....	trace	trace	trace			
MgO ...	.21	.25	.23	.0057		
K_2O....	8.93	8.93	8.93	.0950	.3819	.95x1
Na_2O...	.45	.45	.45	.0073		
H_2O....	4.93	4.93	4.93	.2739		
F.....	trace	trace	trace			
	100.42	100.00	100.21			

(a) Not a constituent part of sericite, but derived from included rutile.

The ratios yield the formula $(H, K)_2O.Al_2O_3.2SiO_2$ quite closely, with the univalent bases potash, sodium, and hydrogen—replaced very slightly by magnesia. Molecularly, the ratio of water to alkalies is 2.72:1.00. Further, the analysis shows ratios which correspond fairly closely to an orthosilicate.

Analyses of sericite are not numerous in the literature, and in only a few cases were the optical properties included. The mineral in question appears to have a higher silica content

COMPARISON OF ANALYSIS WITH ANALYSES OF MUSCOVITE AND SERICITE

	Per cent.			
	1A	2[10]	3[11]	4[12]
SiO_2	48.37	46.51	46.58	45.54
TiO_2	.63(a)	..	..	..
Al_2O_3	36.67	36.58	37.46	37.15
Fe_2O_3	trace	.51	.80	..
FeO		.48	..	..
CaO	trace	.44	trace	..
MgO	.23	.46	1.16	.38
K_2O	8.93	7.84	6.38	10.70
Na_2O	.45	1.77	.64	.90
H_2O-	..	.11	.30	4.80
H_2O+	4.93	5.03	6.06	
F	trace	..	n.d.	..
	100.21	99.73	99.38	100.26
S.G.	2.803	2.798	..	..

(a) From rutile inclusions.

ANALYSIS AND RATIOS OF SAMPLE B (MEAN OF TWO ANALYSES)

	Per cent.	Ratio		
SiO_2	47.80	.7933	.7933	1.00x2
TiO_2	.65 (a)			
Al_2O_3	37.70	.3704	.3704	.92x1
MgO	.17	.0042		
CaO	trace			
FeO	trace			
Fe_2O_3			.3788	.94x1
MnO	trace			
K_2O	8.65	.0920		
Na_2O	0.34	.0055		
H_2O-	4.97	.2761		
	100.28			

(a) From rutile inclusions.

[10]Hutchinson, A. and Smith, W. C. Min. Mag., vol. XVI, 1912.

[11]Shannon, E. V. U.S. Nat. Mus., Bull. 131, p. 372.

[12]Hillebrand, W. F. Hand. d. Mineralchemie, Bd. 2, Ab. 2, p. 419.

than in the analyses to which reference was made. Although the material in Sample A appeared perfectly homogeneous under the low-power microscope, Sample B was prepared as described above, and analysed for the presence of quartz, previously overlooked.

The analysis shows the absence of free quartz in the selected material, and the result again gave ratios identical with Analysis A.

Dehydration Experiments on Sericite. Little work has been done on the dehydration of this mineral. As suggested by Miss Meyer, such dehydration curves might prove characteristic of the mineral.[13]

A sample of 5 grams was placed in an evaporating dish so that the depth of material did not exceed an eighth of an inch. This sample, selected from the original material, was ground to −80 mesh, and heated at 25°C. intervals for 24 hours at each temperature in an electric oven between the temperatures 110-275°C.

Two other samples, each weighing approximately 1 gram, from Sample A, were heated at various intervals in an electric muffle. The experiment was repeated with .5 gram samples of Sample B. Each set was averaged and tabulated in table I.

The temperatures of the muffle were obtained with a pyrovolter. The pyrovolter was carefully calibrated by taking a reading on the millivoltmeter of the melting point for several pure substances. These readings were plotted against the melting points of the substances and the best curve drawn. The curve was practically a straight line, but with a slight convexity towards the abscissa. The temperatures of the muffle were then read from this curve. The probable error was within ±5°C.

The graph on page 112 shows the loss of water at temperatures between 110°C. and 1000°C. This last temperature is the approximate temperature of the blast. The water lost up to 110°C. is probably absorbed water and therefore not a constituent part of the sericite.

Between the temperatures 110° and 450°, and between

[13]Meyer, D. B. Amer. Min., p. 384, May, 1935.

DEHYDRATION DATA FOR SERICITE

(1) Wt. of sample = 5.0028 g. (60 mesh)				(1a) Average of 2 samples = .9515 g. (100-200 mesh)				(2) Average of 2 samples = .5494 g. (100-200 mesh)			
Temp. °C.	Time hrs.	Per cent. loss	Total per cent. loss	Temp. °C.	Time hrs.	Per cent. loss	Total per cent. loss	Temp. °C.	Time hrs.	Per cent. loss	Total per cent. loss
110	24	.19	.19	459	2	.65	.65	434	2	.70	.70
125	24	No loss		493	2	.45	1.10	500	2	.95	1.65
150	24	.02	.21	534	2	.33	1.43	561	2	.83	2.48
175	24	.03	.24	538	2	.39	1.82	601	2	.84	3.32
200	24	No loss		588	2	.77	2.59	672	2	1.41	4.73
225	24	.04	.28	631	2	1.06	3.65	783	2	.02	4.89
250	24	No loss		730	2	1.07	4.72	Highest temp. reached in muffle			
275	20	.03	.31	792 (a)	2	.07	4.79	1000 (approx.)	1	.04	4.93
Highest temp. reached in oven				1000 (approx.)	1	.06	4.85	Constant weight			
				Constant weight							
				(a) Highest temp. reached in muffle							

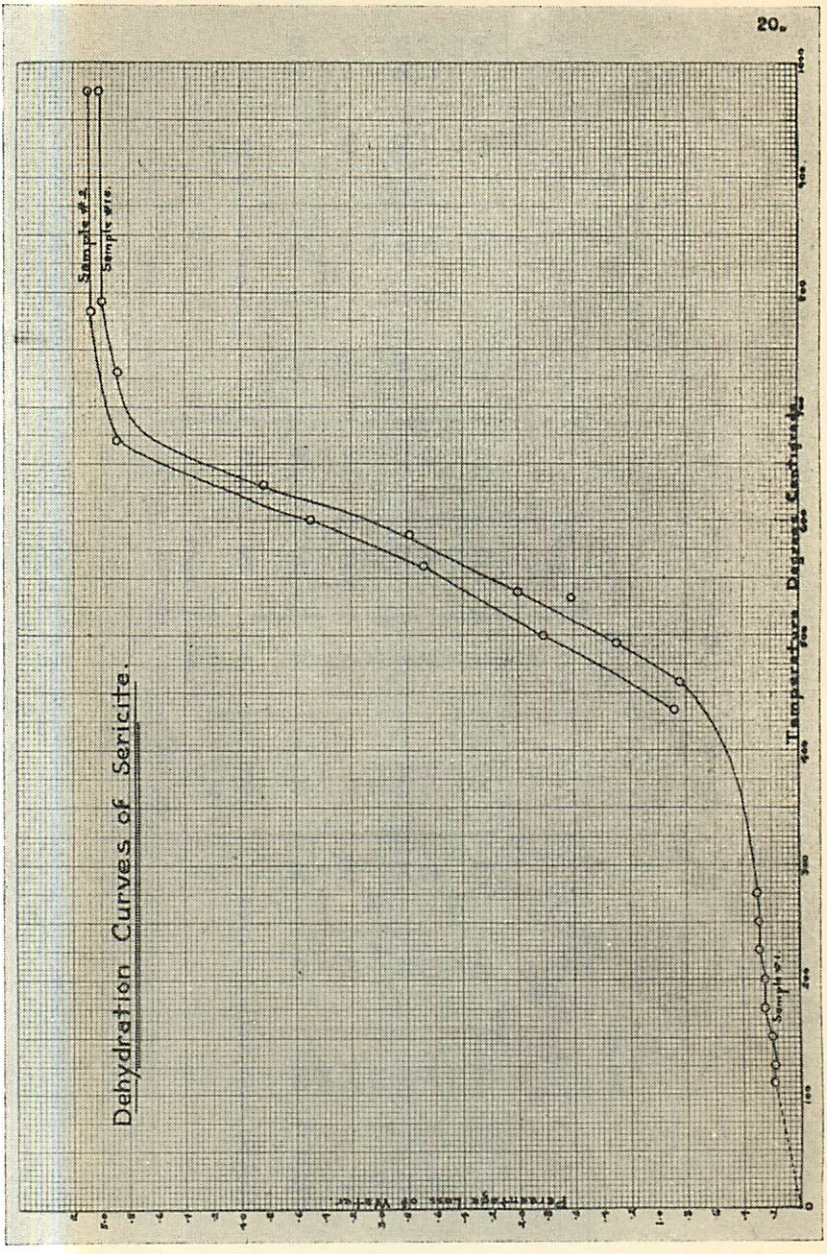
Dehydration Curves of Sericite.
Sample #2
Sample #16.
Sample #17.
Temperature Degrees Centigrade.
Percentage Loss of Water.

FIGURE 1

650° and 1000°, very little water was given off. Between 450° and 650°C. the water came off rapidly. The resulting curves are very similar to a sericite[14] experimented on in a like manner. Although these curves are quite comparable to the dehydration curves of several clay minerals,[15] there is a distinct difference in the way in which the last part of the water is given off.

"Recent data suggest that sericite contains less potash and more water and has a smaller optic angle than ordinary muscovite."[16] This is quite true of the optical properties of the mineral; on the other hand, so far as the chemical composition is concerned, there is very little difference between it and the muscovite analyses on the whole.[17]

From the above data of its physical, chemical, and optical properties the mineral undoubtedly belongs to the muscovite-mica group, and is sericite.

Summary and Conclusions

(1) Sericite is similar to muscovite in chemical composition, but differs slightly in optical properties and probably origin.

(2) Sericite gives off its main water content at a lower temperature than muscovite; dehydration curves are characteristic for sericite as of the kaolin minerals, and this property may be made use of in the determination of this mineral.

Acknowledgment

In conclusion, the writer would like to express his thanks to Dr. T. L. Walker, Professor A. L. Parsons, and Professor J. E. Thomson, in particular, and the other members of the Department of Mineralogy, for their helpful advice and interest.

[14]Meyer, D. B. *Ibid.*, p. 386.

[15]Ross, C. S. and Kerr, P. F. U.S. Geol. Survey., Prof. Paper 165E, pp. 166-167, 1931.

[16]Winchell, A. N. Elements of Optical Mineralogy, pt. II, p. 363.

[17]Doelter, C. Hand. d. Mineralchemie.

A POTENTIAL SERIES OF SOME MINERALS FROM THE TIMISKAMING DISTRICT, ONTARIO

By A. S. Dadson

Introduction

It has long been known that metallic minerals may act like metals in forming the electrodes of galvanic batteries.

Certain reactions observed when etching polished specimens of arsenides from the silver mines of the Timiskaming District, Ontario, suggested that there might be some connection between the potentials of the minerals and the occurrence of native silver. The investigation outlined in this paper was undertaken to see if such could be shown to be the case.

The members of the family of minerals forming the dominant metallic constituents of the veins of the district in question are, with their recognized chemical composition and crystal system, as follows:

arsenopyrite	FeAsS	orthorhombic
breithauptite	NiSb	hexagonal
chloanthite	$NiAs_2$	isometric
cobaltite	CoAsS	isometric
gersdorffite	NiAsS	isometric
loellingite	$FeAs_2$	orthorhombic
niccolite	NiAs	hexagonal
rammelsbergite	$NiAs_2$	orthorhombic
safflorite	$CoAs_2$	orthorhombic
skutterudite	$CoAs_3$	isometric
smaltite	$CoAs_2$	isometric
temiskamite	Ni_4As_3	tetragonal

To these might be added ullmanite, glaucodot, and nickel-skutterudite, but so far as the writer is aware, they have not been proved to exist as individual minerals in the ores.

In this paper other minerals found with the above will be considered as accessory.

Lists of the vein minerals which have been reported from

the district have been compiled by Walker and Parsons[1] and Thomson.[2]

Isomorphism

To what extent isomorphism is a factor in these minerals is not known. They are usually so intimately intergrown that deviation from the theoretical composition can be explained as due to mechanical mixtures of different minerals.

It is known that arsenopyrite, breithauptite, niccolite, and temiskamite do occur with practically the composition indicated by their formulae, and from their uniform appearance in polished section it seems likely that this is always the case.

In the specimens examined by the writer, loellingite and safflorite were found, characteristically, as radiating intergrowths, at least two different minerals being shown by etching. These two minerals may be present as individual iron diarsenide and cobalt diarsenide, but there is no proof that isomorphism does not exist. It seems fairly certain, however, that in the one iron predominates, and in the other cobalt. In some of the specimens considerable nickel was found with the iron and cobalt, the minerals having the same characteristic structure as the loellingite-safflorite intergrowths. As these showed properties and mode of occurrence different from typical rammelsbergite, they will be described as nickeliferous loellingite. As a matter of fact, a third mineral was not recognized in these cases.

Rammelsbergite is characterized by the rapidity with which it oxidizes to nickel bloom in a moist atmosphere. If a polished specimen is placed in such an atmosphere, the alteration is observable in a very few hours. In a week's time the colour of the bloom is quite distinct.

Three specimens treated in this manner showed the following characteristics:

In number 461 prismatic crystals of rammelsbergite were in a ground-mass of niccolite. They oxidized to a bright green bloom. The niccolite was also considerably altered, but did not show any bloom.

[1]Walker, T. L. and Parsons, A. L. Univ. Tor. Studies, Geol. Ser., no. 20, p. 59, 1925.

[2]Thomson, J. Ellis. Econ. Geol., vol. XXV, p. 642, 1930.

In number 484 rammelsbergite was of a radiating to subradiating structure with a rim of intergrown gersdorffite and cobaltite at the contact of the gangue. Most of the rammelsbergite oxidized to a pale green bloom, but towards the rim it was distinctly rose-coloured, with, however, bits of green mixed with it. Etching had shown the mineral to be all rammelsbergite though not of a uniform texture, some being well crystallized while the rest was of the nature of a fine-grained groundmass. The rose-coloured bloom seemed to be mostly from the more poorly crystallized material.

Number 482 had a concentric structure. Rammelsbergite graded into an intimate mixture of rammelsbergite and niccolite. This was followed by another zone of rammelsbergite, then one of niccolite and finally a rim of cobaltite and gersdorffite at the contact of the gangue. After oxidation the central part of the second zone of rammelsbergite had a faint pink bloom. The rest of the rammelsbergite was coated with a bright green bloom.

Walker and Parsons,[3] from analyses of blooms from Cobalt, Ontario, present the following table:

TABLE 1

	CoO	NiO	
I	34.11	.52	Deep peach blossom
III	16.33	17.37	Pale rose
IV	6.43	29.30	White
V	3.40	33.82	Greenish white

It is seen that a pale rose-coloured bloom contains almost equal quantities of nickel and cobalt.

In connection with some other experiments, specimen 484 was immersed in paraffin wax in a small dish so that only the polished surface was exposed. A small inclusion of niccolite was coated with the wax. It was then covered with a solution of silver sulphate and left overnight. Only the rammelsbergite was visibly attacked by the solution, which, on analysis, was found to contain .0033 grams of nickel and .0007 grams of cobalt, a ration of approximately 5:1.

[3]Walker, T. L. and Parsons, A. L. Univ. Tor. Studies, Geol. Ser., no. 17, p. 13, 1924.

These experiments indicate that in rammelsbergite considerable cobalt may be isomorphous with nickel though not uniformly so in a given mass.

None of the other minerals exhibits such rapid oxidation as rammelsbergite. The typical safflorite such as described by Todd from the Miller Lake O'Brien Mine, Gowganda, is relatively very stable.[4]

Smaltite, chloanthite, and skutterudite are generally considered to form an isomorphous series. Frequently, zoned crystals showing two or three different components are found. Walker has shown that in such crystals from the Timiskaming Mines, Cobalt, the most resistant component approaches the composition $CoAs_3$.[5]

Short suggests that skutterudite and a cobalt monarsenide form the end members of the isomorphous series and that zoning in the crystals does not necessarily represent materials of different composition.[6] It is certain, however, that smaltite and chloanthite are rarely found with the composition indicated by their formulae, arsenic being in excess.

In the specimens examined crystals were found both with and without the composite structure shown by zoning. They were distinguished as skutterudite, smaltite, chloanthite, or smaltite-chloanthite according to the etch tests to be described, and to their apparent content of Ni and Co. Where the composite structure was prominent the fact will be mentioned.

Identification

Through the kindness of Dr. J. Ellis Thomson, a number of polished specimens from described material were available to the writer for use as standards. They are listed here as a matter of record.

No. 477. Cobaltite crystals from the Columbus Mine, Cobalt, described by DeLury.[7]

[4]Todd, E. W. Ont. Bur. Mines, vol. XXXV, pt. III, p. 68, 1926.
[5]Walker, T. L. Amer. Min., vol. VI, p. 54, 1921.
[6]Short, M. N. Econ. Geol., vol. XXV, pp. 764-771, 1930.
[7]DeLury, J. S. Amer. Journ. Sci., ser. 4, vol. XXI, pp. 275-276, 1906.

No. 451. Gersdorffite from the Nipissing Mine, Cobalt, described by Thomson.[8]

No. 1115. Gersdorffite from the type locality at Lobenstein in Thuringen.

No. 2121. Loellingite from the Keeley Mine, South Lorrain, described by Bell and Thomson.[9]

No. 4102. Safflorite from the Miller Lake O'Brien Mine, Gowganda, described by Todd.[10]

No. 2126. Rammelsbergite from the Keeley Mine, South Lorrain, described by Thomson.[11]

No. 2111. Temiskamite from the Moosehorn Mine, Elk Lake, described by Walker.[12]

No. 2127. Skutterudite from the Frontier Mine, South Lorrain, similar to the material described by Walker.[13]

For identification of the unknown minerals, a scheme, based on the description of J. Ellis Thomson, was adopted.

Niccolite, breithauptite, and usually the accessory minerals could be identified on sight and confirmed if necessary by the common etch reagents.

The rare mineral, temiskamite, was distinguished from niccolite by its paler colour, and tetragonal crystallization as brought out by etching and by the polarizing microscope.

The remaining nine, hard, white minerals which are so alike in appearance and so intimately mixed, were separated as follows:

1. Division into orthorhombic and isometric groups by the polarizing microscope and by crystal outline.

2. Testing with saturated ferric chloride solution one minute (usually the whole surface was covered). Only rammelsbergite and loellingite are etched, the rammelsbergite much more deeply. This test is very definite except in the presence of niccolite. When niccolite was found in contact with rammelsbergite the etching of the latter was always less than the standard, and in several specimens in which niccolite and rammelsbergite were intimately intergrown no etching

[8]Thomson, J. Ellis. Econ. Geol., vol. XXV, p. 495, 1930.

[9]Bell, J. M. and Thomson, J. Ellis. Univ. Tor. Studies, Geol. Ser., no. 17, pp. 31-32, 1924.

[10]Todd, E. W. Ont. Bur. Mines, vol. XXXV, pt. 3, p. 68, 1926.

[11]Thomson, J. Ellis. Econ. Geol., vol. XXV, pp. 483-484, 1930.

[12]Walker, T. L. Amer. Journ. Sci., ser. 4, vol. XXXVII, p. 170, 1914.

[13]Walker, T. L. Univ. Tor. Studies, Geol. Ser., no. 20, pp. 49-50, 1925.

whatever could be seen on the rammelsbergite. A few sections in which niccolite was in contact with loellingite showed the same effect.

3. Testing with saturated potassium permanganate for one minute (usually the whole surface of the section was covered). A cubic mineral stained brown indicates gersdorffite.

4. Testing with 1:1 nitric acid—a test drop being applied by a loop on the end of a platinum wire and allowed to remain one minute. Rammelsbergite effervesces strongly; loellingite and safflorite etch deeply, usually without effervescence; arsenopyrite characteristically stains brown to iridescent before etching; smaltite and smaltite-chloanthite as described in this paper etch slowly to a rough surface—in the composite crystals usually the central part etches more readily, it presumably being more nickeliferous than the outer zones; chloanthite when fairly pure etches instantly; gersdorffite usually etches quietly to a rough surface and frequently shows a zonal structure; skutterudite and cobaltite are negative.

5. Testing with concentrated nitric acid, the test drop being allowed to remain one minute. This etches skutterudite and leaves cobaltite unetched.

After some practice much information could be obtained from the unetched surface of the section. The high relief, rough polish, and pinkish colour of cobaltite and gersdorffite are often evident. Rammelsbergite takes a very fine polish and is considerably whiter than the other minerals. To the writer's eye arsenopyrite appears rather creamy in colour when in contact with loellingite and safflorite and also usually shows its characteristic crystal outlines.

The readiness with which gersdorffite tarnishes in a moist atmosphere was used at times to confirm this mineral.

Confirmation of the content of nickel, cobalt, and iron was made by the potassium mercuric thiocyanate test as described by M. N. Short.[14]

Usually it was found sufficient to transfer the 1:1 nitric acid etch drop to a glass slide by means of a capillary tube and test directly. In cases where it could not be decided what

[14]Short, M. N. U.S. Geol. Surv., Bull. 825, 1931.

minerals had supplied the elements found in the tests, recourse was had to gouging out a bit of the mineral powder by means of a bevelled needle.

Etching Experiments

In the identification of minerals in polished ore specimens by etch reactions, it is sometimes observed that when certain minerals in contact are covered by the test drop the characteristic etching of one fails to form. As mentioned above, ferric chloride solution often fails to etch rammelsbergite when the latter is in contact with niccolite.

Two such minerals form a galvanic couple with increased attack on the more electronegative and consequent protection of the other.

Etching with solutions of silver salts gave some results which are of interest in regard to possible application to theories of deposition of silver in the ores.

A. Silver Sulphate Solution (approximately 1/40 normal)

A number of specimens were first tested with small drops applied by means of a loop on the end of a platinum wire. Niccolite, rammelsbergite, and temiskamite etched immediately with precipitation of silver. The other members of the family showed no action in the time it took for the drop to dry up.

Next, larger drops were placed on the sections and examined through the binoculars. For observation over a period of time the sections were placed in an ordinary chemical desiccator with a piece of wet sponge in the bottom to prevent evaporation of the drop.

Application of this method to some thirty specimens served to place the minerals in groups:

1. Niccolite, temiskamite, rammelsbergite.
2. Loellingite, safflorite, smaltite-chloanthite, skutterudite.
3. Gersdorffite, arsenopyrite, cobaltite.
4. Breithauptite.

Typical specimens of niccolite, temiskamite, and rammelsbergite etched immediately with formation of much silver, the first formed usually being fine grained and adherent.

Typical specimens of the minerals of group 2 etched more slowly, silver first being observed in from one-half to two and one-half hours. In these the silver was usually in the shape of thin, flat crystals growing perpendicularly to the etched surface.

Gersdorffite, arsenopyrite, and cobaltite showed no reaction even after ten days.

Breithauptite, which was always intergrown with niccolite, darkened in colour and at times showed very faint etching but evidently did not react further with the solution.

When a mineral of group 1 was in contact with minerals of the succeeding groups, the existence of considerable electromotive force was demonstrated. With the etching of the former much of the silver was precipitated on the latter as a bright crystalline deposit in sharp contrast to the rather impalpable looking silver which usually formed over the etched mineral.

Rammelsbergite when etched was coated with impalpable looking silver in contrast to the bright crystalline deposit which was precipitated on the unetched smaltite-chloanthite and cobaltite.

Considering the rate at which the minerals of group 2 react, it is impossible to say to what extent they are protected by the etching of minerals of group 1 in contact with them, as these soon displace all the silver from the solution.

In group 2 the two components of the loellingite-safflorite intergrowths appeared to etch equally. Smaltite in contact with loellingite was etched to a lesser degree than the latter.

Chloanthite was found only as the central core of composite smaltite-chloanthite crystals. It etched more readily than the outer smaltite zones but its relation to loellingite and safflorite could not be determined.

In one specimen some skutterudite in contact with loellingite and safflorite showed very faint etching. In several other specimens with the same relationship it showed no sign of etching.

In this group 2 the existence of electromotive force was indicated by the fact that the silver crystals grew from the unetched minerals as well as from the etched minerals in contact.

In group 1 niccolite in contact with rammelsbergite was more deeply etched than the latter. In some specimens an unetched zone of rammelsbergite was left at the contact. In two specimens in which rammelsbergite was intimately intergrown with the niccolite it did not etch but received a deposit of silver as if it were a member of group 2.

In the one specimen in which niccolite was found in contact with temiskamite, it could not be decided which was the more strongly attacked.

B. Silver Sulphate Solution Acidified with Hydrofluoric Acid

With the assumption that in the case of breithauptite and niccolite the breithauptite was protected by a coating of insoluble antimony oxide, a solution was made up of 1/40 normal silver sulphate and hydrofluoric acid in the proportion of about 10:3. Hydrofluoric acid is a very effective solvent of antimony oxide.

As before, experiments were carried out, using large drops of the solution. This solution attacked breithauptite strongly while niccolite in the same section showed no sign of etching. Niccolite alone was strongly attacked. Niccolite and temiskamite in contact appeared to etch equally. Where both niccolite and rammelsbergite were covered by the drop, the rammelsbergite did not etch. Rammelsbergite without niccolite etched strongly.

Typical specimens of loellingite-safflorite and smaltite-chloanthite etched immediately or at least within a minute. Where loellingite and safflorite were in contact with smaltite, the former etched deeply while the latter was scarcely attacked. Skutterudite was not found to etch when in contact with any of the last-named minerals. Loellingite and safflorite when in contact with rammelsbergite showed only very faint etching. In the loellingite-safflorite intergrowths one component etched first. In specimen 46 in which the two components were clearly discernible, the one which etched first

was that which had been identified as loellingite. Indeed, the safflorite member only started to etch visibly after two minutes.

In these tests the silver was usually precipitated over the whole surface covered by the drop as a coarse-grained or fine granular deposit, most voluminous in the minerals of group 1. In a few cases, however, the two different types, as described in the straight silver sulphate experiments, were observed.

It is evident that the hydrofluoric acid has some other effect than just solution of the antimony oxide. If a piece of niccolite is put in a platinum basin with some of this acidified solution, the sides and bottom of the basin soon become covered with a large deposit of silver in contrast to the small amount precipitated on the platinum when neutral silver sulphate is used.

C. Silver Sulphate Solution Acidified with Sulphuric Acid(20:3)

With the exception of the niccolite-breithauptite combination, this solution gave results practically identical with the silver sulphate-hydrofluoric acid solution, indicating that the acidity causes the acceleration observed.

With niccolite and breithauptite the silver formed such an adherent deposit that it was difficult to see what minerals had been affected. By scraping off the silver it was found that the breithauptite was etched strongly. Niccolite was possibly slightly etched but it was not very definite.

The tables on the next few pages list the experiments from which the above generalizations have been made. The abbreviations used are:

arseno.—arsenopyrite
chl.—chloanthite
gersd.—gersdorffite
nic.—niccolite
saffl.—safflorite
sm.—smaltite
ct.—chalcocite
bn.—bornite
immed.—immediately
brei.—breithauptite
cob.—cobaltite
loel.—loellingite
ram.—rammelsbergite
skut.—skutterudite
tem.—temiskamite
cp.—chalcopyrite
tetr.—tetrahedrite

A number of other solutions were tested as etching reagents but not to any extent.

TABLE 2

ETCHING EXPERIMENTS

A. Silver Sulphate Solution

Spec.	Time	Formation of silver	Minerals etched	Minerals not etched	Remarks
27	10 min.	immed.	nic.	brei., cob., skut.	brei. darkened in colour
464	10 min.	immed.	nic.	brei., cob., skut., Ag	brei. darkened in colour
0	2 hrs.	immed.	nic.	brei., cob., skut., Ag	brei. darkened in colour
29	10 min.	immed.	nic.	cob.	
2111	10 min.	immed.	tem., nic.	cob.	
11	30 min.	immed.	ram.	sm.-chl., cob.	
484	10 min.	immed.	ram., nic.	gersd., cob., skut.	
45	24 hrs.	immed.	ram., nic., loel.	sm.-chl., cob.	an inclusion of loel. in sm.-chl. etched faintly
482	10 min.	immed.	ram., nic.	ram., gersd., cob., skut.	ram. intimately intergrown with nic. not etched
485	10 min.	immed.	ram., nic.	cob., skut., tetr.	
10	1 min.	immed.	ram., nic.	ram., gersd., sm.-chl.	a rim of unetched ram. next the nic.
10	11 min.	immed.	nic.	ram., gersd., sm.-chl.	a crystal of ram. included in nic. unetched
2121	15 hrs.	2½ hrs.	loel., saffl.	cob.	
4102	15 hrs.	2½ hrs.	saffl., loel.	cob., arseno., skut.	
26	15 hrs.	½ hr.	loel., saffl., skut.	cob., arseno., skut.	some skut. faintly etched

TABLE 2—*Continued*

ETCHING EXPERIMENTS—*Continued*

Spec.	Time	Formation of silver	Minerals etched	Minerals not etched	Remarks
416	½ hr.	15 min.	loel., saffl.	skut., Ag	
4103	15 hrs.	10 min.	loel., sm.	gersd.	loel. etched more deeply than sm.
67	3 hrs.	½ hr.	loel., saffl., sm., chl.	cob., arseno., tetr.	chl. as cores of composite sm.-chl. etched more deeply than the sm.
171	15 min.	3 min.	ct., bn., sm.-chl.	cob., tetr., cp.	sm. chl. etched after 10 min., tiny inclusions of ct. and bn. etched in 3 min.
386	4 hrs.	1½ hrs.	sm.	cob., arseno.	
453	½ hr.	immed.	ram., loel., saffl., chl.	skut., sm., cob., tetr.	loel., saffl., etched very faintly, chl. as core of composite sm.-chl. crystal etched
80	24 hrs.	immed.	nic.	loel., saffl., sm.	
493	5 min.	immed.	tem., loel., saffl.	skut., cob., Ag	tem. as inclusions in Ag etched immed., loel. and saffl. etched after 5 min.
2127	15 hrs.	2½ hrs.	skut.	cob.	
2	10 days	—	—	arseno.	
481	4 days	—	—	arseno.	a small bit of Ag formed from the cracks after 1 day but did not increase
451	10 days	—	—	gersd.	a tiny bit of silver formed in cracks
1115	4 days	—	—	gersd.	a small bit of Ag formed in cracks
477	10 days	—	—	cob.	

TABLE 2—*Continued*

ETCHING EXPERIMENTS—*Continued*

B. Silver Sulphate Solution Acidified with Hydrofluoric Acid

Spec.	Time	Formation of silver	Minerals etched	Minerals not etched	Remarks
464	3 min.	immed.	brei.	nic., cob., skut., Ag	
27	5 min.	immed.	brei.	nic., cob., skut.	
29	2 min.	immed.	nic.	cob.	
482	2 min.	immed.	nic.	ram., cob., gersd., skut.	
485	4 min.	immed.	nic.	ram., skut., tetr.	
10	5 min.	immed.	nic.	ram., sm.-chl., gersd.	
484	7 min.	immed.	nic., ram.	cob., gersd., skut.	nic. was in a very small inclusion in the ram.
2126	15 min.	immed.	ram.	skut.	ram. only slightly etched as the silver formed a protective coating
453	15 min.	immed.	ram., loel., saffl.	sm.-chl., cob., tetr.	loel. and saffl. etched very slightly
454	10 min.	immed.	ram.	loel., saffl., sm.	
26	3 min.	immed.	loel., saffl.	cob., skut., tetr., cp.	loel. and saffl. etched differentially
2121	1 min.	1 min.	loel., saffl.	cob.	
46	2 min.	immed.	loel.	saffl.	
46	10 min.	immed.	loel., saffl.		
67	2 min.	immed.	loel., saffl.	sm.-chl., cob., skut.,tetr.	
171	3 min.	immed.	sm.-chl., bn., ct.	cob., tetr., cp.	
2111	1 min.	immed.	tem., nic.	cob.	

TABLE 2—*Continued*

ETCHING EXPERIMENTS—*Continued*

C. Silver Sulphate Solution Acidified with Sulphuric Acid

Spec.	Time	Minerals etched	Minerals not etched	Remarks
73	½ min.	brei., nic. (?)	cob.	nic. possibly slightly etched
8	2 min.	brei., nic. (?)	cob.	" " " "
74	10 min.	brei., nic. (?)	skut., cob.	" " " "
27	15 hrs.	brei.	nic., skut., cob., Ag	
29	½ min.	nic.	cob.	
461	3 min.	nic.	ram., gersd.	
461	3 hrs.	nic.	ram., gersd.	
53	3 hrs.	nic.	ram., gersd.	
454	5 min.	nic.	ram., loel., saffl., skut., cob.	
454	40 min.	nic., ram.	loel., saffl., cob., skut.	ram. slightly etched where not in contact with nic.
49	2 hrs.	nic., ram. (?)	loel., saffl.	ram. possibly slightly etched
49	2 min.	ram.	loel., saffl.	drop not covering nic.
65	5 min.	ram.	chl., gersd.	
68	25 min.	loel., saffl.	sm., cob., arseno.	
67	90 min.	loel., saffl.	sm., sm.-chl., tetr., cp.	

D. Silver Sulphate Solution with Tartaric Acid

Niccolite in contact with breithauptite was not etched while the breithauptite was strongly attacked.

E. Silver Bi-carbonate Solution

When a drop was placed on a section the reaction was obscured by the formation of yellow silver carbonate, which, however, soon dissolved. The results obtained on a few sections are given in the following table:

TABLE 3

Spec.	Time	Minerals etched	Minerals not etched	Remarks
27	30 min.	nic.	brei., skut., cob., Ag	
29	3 hrs.	nic.	cob.	
482	1 hr.	nic.	ram., skut., cob., gersd.	fine sooty silver precipitated over whole surface
11	30 min.	ram.	sm.-chl., cob.	bright crystalline silver on unetched minerals; impalpable on ram.

TABLE 3a

SOLUTION OF .2g. OF SILVER CARBONATE IN 25 CC. OF 1:4 AMMONIA WATER

Spec.	Time	Silver formed	Minerals etched	Minerals not etched	Remarks
27	15 min.	immed.	nic.	brei., skut., cob.	very adherent on brei.
51	24 hrs.	immed.	ram.	sm. - chl., gersd., loel.	unetched minerals silver plated
485	7 min.	immed.	ram., nic.	skut., tetr.	
453	90 min.	immed.	ram.	loel., saffl., sm.	
39	15 hrs.	not in first 30 min.	loel., saffl., skut.(?)	arseno.	the skut. stained but etching questionable

F. Mercurous Nitrate (saturated)

The material used for this solution had partially decomposed so that it gave an acid solution. It is not fair to say,

therefore, that the minerals displaced mercury from the solution, as with the exception of skutterudite and cobaltite, they are all attacked by dilute nitric acid.

These two minerals were not affected by the solution while the others etched with displacement of mercury. The significant point is that the typical specimen of skutterudite was only superficially tarnished in the twelve days the drop was allowed to remain.

G. Copper Sulphate Solution (saturated)

This solution was tried on typical specimens of the minerals. In the twenty-four hours the drops remained, no copper was visibly precipitated. Niccolite and rammelsbergite were superficially stained, but this was evidently due to oxidation. The others showed no sign of etching.

Effect of a Larger Volume of Solution

In these etching experiments with drops of the solution it is to be remembered that the reactions observed are significant only for the small amounts of solution used.

To test the effect of a larger amount of solution, certain of the sections were immersed in paraffin wax in small dishes, so that only the polished surfaces were exposed. A quantity of solution was added to let stand for a period of time.

B. Silver Sulphate Solution Acidified with Hydrofluoric Acid

Several specimens of the niccolite-breithauptite combination were tested, using 20-25 cc. of the solution and from five to fifteen hours' time.

The breithauptite dissolved deeply. The niccolite, although it did not visibly etch, swelled up and cracked along certain zones. Very little arsenic went into solution.

It is evident from these experiments with a larger quantity of solution that niccolite is effective in protecting rammelsbergite from attack by silver sulphate solution. Rammelsbergite, however, is not so effective in protecting loellingite, safflorite, and smaltite-chloanthite.

TABLE 4

A. Silver Sulphate Solution

Spec.	Volume of sol.	Time	Minerals etched	Minerals not etched	Remarks
464	20 cc.	5 hrs.	nic., brei.	skut., cob., Ag	brei. very slightly etched
27	20 cc.	15 hrs.	nic.	brei., skut., cob., Ag	brei. darkened in colour; no Sb. in solution
482	10 cc.	15 hrs.	nic., ram.	ram., skut., gersd., cob.	ram. intimately intergrown with nic. unetched; other ram. slightly etched.
484	25 cc.	15 hrs.	ram.	skut., gersd., cob.	an inclusion of nic. had been coated with wax; solution contained .0033g Ni; .0007g Co.
11	25 cc.	5 hrs.	ram., sm.-chl.	cob.	
453	10 cc.	15 hrs.	ram., nic., loel., saffl., chl.	sm., skut., cob., tetr.	nic. was only in minor amounts; centres of a few sm.-chl. crystals etched; tetr. silver plated
4102	5 cc.	15 hrs.	saffl., loel.	skut., cob., arseno.	
171	25 cc.	15 hrs.	sm.-chl., bn., ct.	cob., tetr., cp.	solution contained .0003g Ni; .0015g Co; .0042g As.
386	10 cc.	15 hrs.	sm.	cob., arseno.	solution contained .0085g Co; .0189g As.

Breithauptite is very effective in protecting niccolite from attack by silver sulphate solution acidified with hydrofluoric acid.

Summary of Etching Experiments

The experiments described on the last few pages demonstrate that there is a notable difference of potential between certain of the minerals. This property was noted before by Ellsworth,[15] who used it with considerable success in separating certain of the minerals for analysis.

According to the experiments, the minerals can be arranged in a potential series with the most electronegative at the top:

1. Breithauptite
2. Niccolite and Temiskamite
3. Rammelsbergite
4. Loellingite
5. Safflorite
6. Smaltite and Smaltite-chloanthite
7. Skutterudite
8. Gersdorffite, Arsenopyrite, Cobaltite.

Assuming a solution that will dissolve antimony oxide, a comparatively large difference of potential was indicated between breithauptite and niccolite, and between niccolite and rammelsbergite. The difference between rammelsbergite and the other diarsenides was not so great, but still evidently considerable. The few specimens in which loellingite and safflorite were in contact with smaltite or smaltite-chloanthite, indicated that the former were the more electronegative. Since skutterudite was scarcely attacked by the solutions when in contact with the preceding minerals, its position is evident.

The sulpharsenides form a group by themselves as they were not attacked at all by the silver solutions. It seems likely that they come below silver in the potential series, and therefore should have a lower potential than skutterudite.

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[15]Ellsworth, H. V. Rept. Ont. Bur. Mines, vol. XXV, pt. 1, 1916.

The measurements of electromotive force described on the next few pages were made to see if a more quantitative expression of the potentials of these minerals could be obtained.

MEASUREMENTS OF ELECTROMOTIVE FORCE

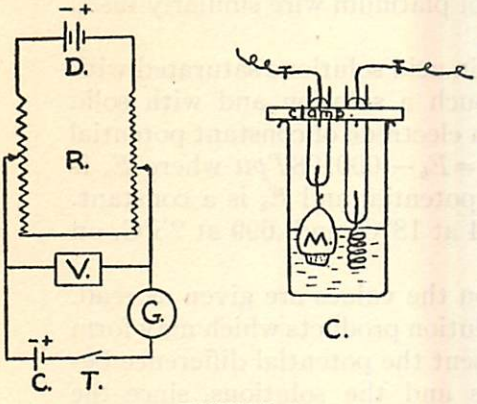


FIGURE 1

D—Two dry cells.
R—Resistance coils.
V—Voltmeter.
G—Galvanometer.
T—Tapping key.
C—Cell, the E.M.F. of which is to be determined. The mineral electrode M is attached to platinum wire and the contacts coated with paraffin wax. It is hooked on to platinum wire fused into a glass tube. The opposing electrode is a coil of platinum wire fused into a glass tube. For connection to the system the tubes are filled with mercury. Leads of platinum wire are used at the tops of the tubes.

The set-up used for these measurements is shown in figure 1. By adjusting the resistance coils the current from the dry cells is balanced against that from the unknown cell. When the galvanometer shows no current flowing, the value of the electromotive force is read on the voltmeter.

The galvanometer used was of such sensitivity that the cells could be balanced within about .003 volts, which was as close as the third decimal place in the voltmeter readings could be estimated.

In the figures in the following tables it will be understood that there is an error of $\pm .002$ in the estimation of the third figure of the voltmeter readings.

The minerals used for measurement were from material which had been examined microscopically. All carbonate gangue was removed by dilute hydrochloric acid. Platinum wire was wound securely around the fragments and the contacts coated with paraffin wax. Enough wax was used to give

plenty of clearance between the bare wire and the solution. The areas of the minerals exposed varied from about two square millimetres to two square centimetres.

For measurement, the mineral electrodes thus made were hooked on to a piece of platinum wire fused into a glass tube, connection to the system being made through mercury. The opposing electrode was a coil of platinum wire similarly fused into a glass tube.

Measurements were made in acid solutions saturated with quinhydrone. Platinum in such a solution and with solid quinhydrone present, forms an electrode of constant potential according to the equation $E_h = E_k - .000198 T p_H$ where E_h is the observed single electrode potential and E_k is a constant. Biilman determined E_k as .704 at 18°C. and .699 at 25°C. on the hydrogen scale.[16]

For purposes of comparison the values are given as read. Neglecting the effect of any solution products which may form from the minerals, they represent the potential difference between the mineral electrodes and the solutions, since the platinum has a constant potential. As it is practically impossible to get pure specimens of the minerals, it was necessary to use mixtures. In the tables the dominant minerals in each specimen are italicized.

Certain of the mineral electrodes will bear further mention here. No. 2126 rammelsbergite, No. 451 gersdorffite, and No. 2111 temiskamite, were specimens listed on page 119.

No. 73 was prepared by treating a specimen of breithauptite, niccolite, and cobaltite with hot 1:4 nitric acid. This strength of acid will dissolve niccolite while the breithauptite is protected to a certain extent by a coating of antimony oxide. Since in this specimen the cobaltite was only associated with the niccolite, a small fragment of rather pure breithauptite with a few inclusions of niccolite was obtained. The antimony oxide was removed with hydrofluoric acid.

No. 1 was a crystal of cobaltite from the same lot which had been described by DeLury.

[16]Clark, W. M. The Determination of the Hydrogen Ions, 2nd ed., pp. 291-292.

No. 46 was from a specimen part of which was analysed by the writer. Microscopic examination showed only loellingite and safflorite with some tiny inclusions of chalcopyrite.

Analysis

Fe	19.99
Co	8.59
As	71.51
Cu	.28
S	.31
Insol	.17
	100.85

Table 5 records the measurements made in normal hydrochloric acid saturated with quinhydrone, the solution being contained in a small beaker as shown in figure 1. The mineral electrodes were measured successively in the same solution, it taking from 1 to 2 minutes to balance the system. Certain minerals were returned from time to time as a check. In the table the figures in the same division represent these repeated measurements. Before making each reading, the mineral was rubbed with emery paper and wiped with a handkerchief to remove dust.

Measurements were made on different days with fresh lots of the same solution.

The variations in the readings shown in the table are too great to be explained by differences in temperature which did not amount to more than four degrees. For most of the specimens there is a constant drop over the period of days. A few, however, show a rise.

After the mineral electrodes were removed from the solution, they were rinsed with water and allowed to dry in the air. There is bound to be some oxidation under these circumstances. Due to the removal of the carbonate gangue most of the specimens were porous to a certain degree. Oxidation products formed in these pores would not be removed by rubbing with emery paper. It is possible that a film of solution formed by these oxidation products, when the mineral is placed in the acid, caused the variations.

TABLE 5

POTENTIALS IN NORMAL HYDROCHLORIC ACID SATURATED WITH QUINHYDRONE

Spec.	Locality	Minerals	Readings in volts				
			1st day	2nd day	3rd day	4th day	5th day
73	Hudson Bay, Cobalt	*breithauptite*, niccolite	.398 .400	.400 .398	.402	.402	.384
37	Nipissing, Cobalt	*breithauptite*, *niccolite*, cobaltite, skutterudite, silver	.420 .400			.350 .370	.376
74a	Nipissing, Cobalt	*breithauptite*, *niccolite*, cobaltite, skutterudite, silver				.380	.360
74b	Nipissing, Cobalt	*breithauptite*, *niccolite*, cobaltite, skutterudite, silver					.396
47a	Silver Bar, Cobalt	*niccolite*, smaltite, chloanthite, cobaltite, skutterudite	.338	.320 .324			
47b	Silver Bar, Cobalt	*niccolite*, smaltite, chloanthite, cobaltite, skutterudite	.360 .356	.330 .338	.338 .338		.344
78	Cobalt	*niccolite*, cobaltite		.310 .336	.330	.340	

TABLE 5—*Continued*

Spec.	Locality	Minerals	Readings in volts				
			1st day	2nd day	3rd day	4th day	5th day
71	McKinley, Cobalt	*niccolite*, skutterudite, gersdorffite		.370 .340	.376	.380	
2111	Moosehorn, Elk Lake	*temiskamite*, cobaltite	.350 .350	.336 .370	.358		
343	Moosehorn, Elk Lake	*temiskamite*, cobaltite			.340	.344	.352
2126	Keeley, S. Lorrain	*rammelsbergite*	.240	.230	.224		
11	Hudson Bay, Cobalt	*rammelsbergite*, cobaltite, smaltite-chloanthite	.190 .166	.144	.130		
65	Hudson Bay, Cobalt	*rammelsbergite*, chloanthite, gersdorffite	.204	.180	.168		
45	Cobalt Lake, Cobalt	*rammelsbergite*, *niccolite*, smaltite-chloanthite, cobaltite		.266	.258		
46	Keeley, S. Lorrain	*loellingite*, *safflorite*	.170		.156		

TABLE 5—*Continued.*

Spec.	Locality	Minerals	Readings in volts				
			1st day	2nd day	3rd day	4th day	5th day
42		*loellingite*, *safflorite*, skutterudite, cobaltite, arsenopyrite	.260	.140 .140	.126		
68	Coniagas, Cobalt	*loellingite*, *safflorite*, smaltite-chloanthite, arsenopyrite, tetrahedrite			.160		
171	Frontier, S. Lorrain	*smaltite-chloanthite*, cobaltite, arsenopyrite, bornite, chalcopyrite					.170
1	Columbus, Cobalt	*cobaltite*	.040	.040 to .0(a)			
451	Nipissing, Cobalt	*gersdorffite*	.071 to .020	.060 to .020(a)			
481	University, Cobalt	*arsenopyrite*	.020	.040 to 0.20(a)			

(a) In the case of the three sulph-arsenides—cobaltite, gersdorffite, and arsenopyrite—the electromotive force dropped so quickly that a balance could only be made at the lower figures given, which were constant for a minute. None of the other minerals showed this drop.

Table 6 records the measurements made in normal sulphuric acid saturated with quinhydrone. For these the mineral electrodes were washed with hot water, rubbed with emery paper, and fresh paraffin was put over the contacts. As before, measurements were made on different days with fresh lots of the same solution. The minerals were tested one after the other, then immediately repeated in the same order in the same solution.

The high value for wire silver as compared to c.p. silver foil is likely due to a content of mercury and antimony which is common to most of the silver from the district.

It is to be noted in this last table that the values for the specimens containing breithauptite are not higher than those of niccolite. In the etching experiments with silver sulphate solution, it was found that breithauptite was not attacked by the neutral solution, while if a little hydrofluoric acid was added it was strongly attacked.

The following measurements were made, using a beaker well coated with paraffin, and as solution, 50 cc. of the normal sulphuric acid with approximately 2 cc. of hydrofluoric acid mixed with it. This solution was saturated with quinhydrone.

It is a question why breithauptite should not show a higher value than niccolite in sulphuric acid as in the etching experiments silver sulphate acidified with sulphuric acid attacked breithauptite while niccolite in contact was protected.

In tables 6 and 7 the position of copper and silver is to be noted. In the etching experiments arsenopyrite, cobaltite, and gersdorffite did not displace silver from its solutions while none of the minerals displaced copper from copper sulphate solution.

It is a noteworthy fact that in practically all the measurements the potentials of the three sulpharsenides dropped so quickly that a balance could only be obtained at the lowest readings recorded, which were constant for a minute. This behaviour was not noted with any of the other minerals.

To test to what extent constancy was obtainable, certain of the mineral electrodes were cleaned and set up in cells as shown in figure 1. The mineral fragments were attached to a

TABLE 6

POTENTIALS IN NORMAL SULPHURIC ACID SATURATED WITH QUINHYDRONE

Spec.	Locality	Minerals	Readings in volts	
			1st day	2nd day
73	Hudson Bay, Cobalt	*breithauptite*, niccolite	.300 .300	.272 .320
37	Nipissing, Cobalt	*breithauptite*, *niccolite*, cobaltite, skutterudite, silver	.264 .280	.292 .320
47c	Silver Bar, Cobalt	*niccolite*, smaltite, chloanthite, cobaltite, skutterudite	.300 .300	.330 .330
78	Cobalt	*niccolite*, cobaltite	.300 .310	.320 .324
2111	Moosehorn, Elk Lake	*temiskamite*, cobaltite	.330 .320	.316 .316
343	Moosehorn, Elk Lake	*temiskamite*, cobaltite	.312 .320	.324 .324
2126	Keeley, S. Lorrain	*rammelsbergite*	.240 .240	.250 .250
11	Hudson Bay, Cobalt	*rammelsbergite*, cobaltite, smaltite-chloanthite	.190 .170	
46	Keeley, S. Lorrain	*loellingite*, *safflorite*	.160 .154	
171	Frontier, S. Lorrain	*smaltite-chloanthite*, cobaltite, arsenopyrite, chalcopyrite, bornite	.144 .144	
1	Columbus, Cobalt	*cobaltite*	.030 to 0	.040 to 0(a)
451	Nipissing, Cobalt	*gersdorffite*	.080 .080	.090
481	University, Cobalt	*arsenopyrite*	.020	.050 to .020(a)

TABLE 6—*Continued*

Spec.	Locality	Minerals	Readings in volts	
			1st day	2nd day
X	Keeley, S. Lorrain	Wire Silver	.172 .172	.170
	Assay Department	c.p. silver foil		.092 .094
	Merck	c.p. copper foil	.432	.430
	Merck	c.p. arsenic metal	.280	.280

(a) As in the measurements in hydrochloric acid, the potentials of cobaltite and arsenopyrite dropped so quickly that a balance could only be made at the lower figure given. Gersdorffite, however, remained constant long enough to make a reading at the higher figure.

TABLE 7

Spec.	Minerals	Readings, T-21.3°C.
73	breithauptite, *etc.*	.436
37	breithauptite, *etc.*	.400
47c	niccolite, *etc.*	.350
78	niccolite, *etc.*	.350
2111	temiskamite, *etc.*	.346
343	temiskamite, *etc.*	.350
2126	rammelsbergite	.284
46	loellingite, *etc.*	.220
171	smaltite, *etc.*	.154
1	cobaltite	.060 to .024 (a)
451	gersdorffite	.160 to .100 (a)
481	arsenopyrite	.080 to .060 (a)
	c.p. silver foil	.120
	c.p. copper foil	.430

(a) balance only at lower figure.

Here breithauptite is in its proper position.

platinum wire fused into a glass tube and the contacts covered with paraffin wax.

The solution used was hydrochloric acid 1.01 normal at 22°C. It was shaken up with an excess of quinhydrone in a stoppered flask and allowed to stand for an hour. The solution was then poured into a cell, the electrodes placed in position, and the first reading made immediately. Readings were made at frequent intervals during the first day and then daily for six days. After the first few readings the cells were sealed with paraffin wax.

The results are recorded on the accompanying graph. They are not strictly comparable to the last set of measurements for, since the solution was decanted into the cells, the only solid quinhydrone present was that which may have remained in suspension. However, the results indicate that the platinum retained a constant potential. The temperature varied between 19°C. and 24°C., but as it showed no relation to the values, was not plotted on the graph.

The values for breithauptite, temiskamite, and niccolite remained remarkably constant from the start. The values for the other minerals dropped quickly during the first hour and from then were very constant.

At the end of the week the solutions were found to contain solution products of the minerals. In the case of breithauptite, niccolite, temiskamite, and loellingite-safflorite they were abundant; gersdorffite had dissolved to a greater extent than smaltite, while arsenopyrite and cobaltite were only slightly dissolved. All the minerals showed a visible alteration on the surfaces.

As a check on the solution, some measurements were made in beakers, the conditions otherwise being the same—that is, though the solution was apparently saturated with quinhydrone there was no solid quinhydrone visible. Between readings the beakers were covered.

One would expect that the drop in potential shown by the minerals is caused by the increasing concentration of the solution products. The solution may be due to direct attack by the acid, but is more likely due to the electrolytic action of the

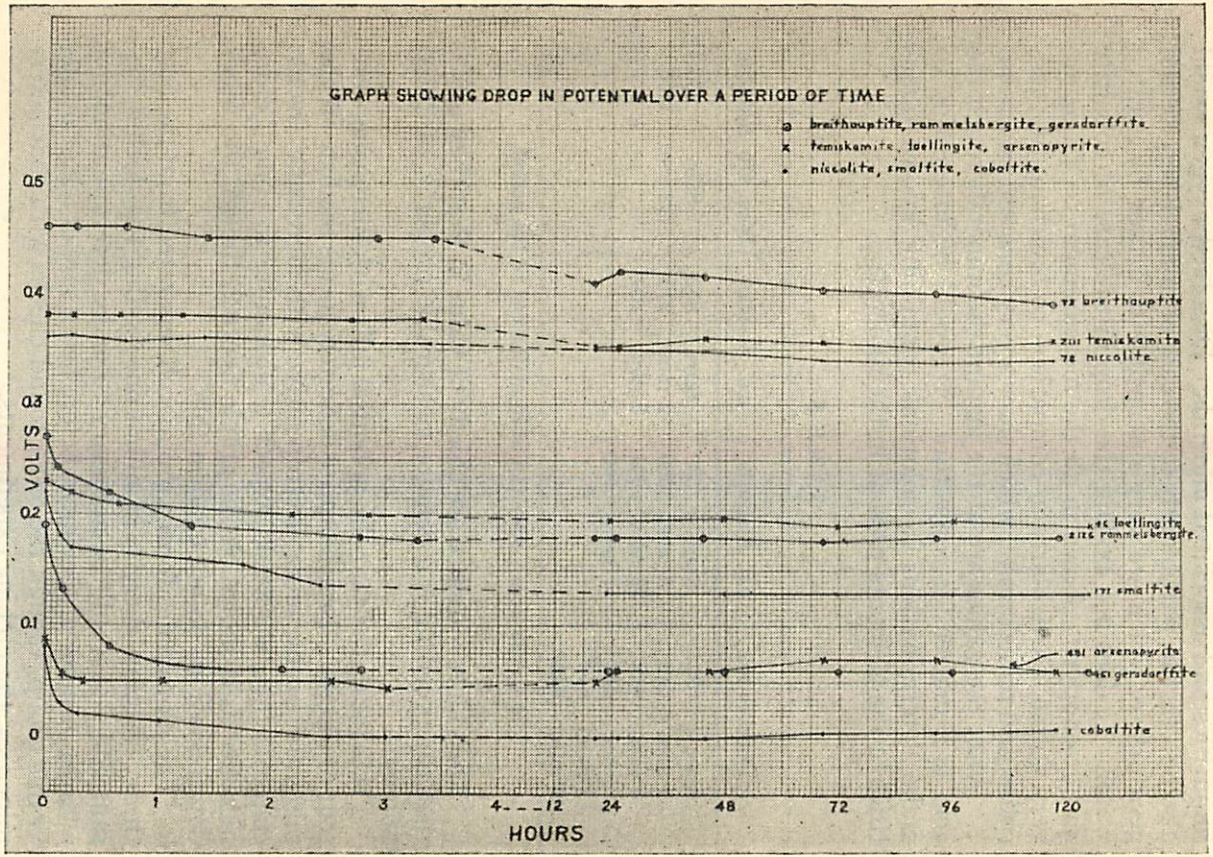

GRAPH SHOWING DROP IN POTENTIAL OVER A PERIOD OF TIME
breithauptite, rammelsbergite, geradorffite.
temiskamite, loellingite, arsenopyrite.
niccolite, smaltite, cobaltite.
VOLTS
0.5
0.4
0.3
0.2
0.1
0
HOURS
0
1
2
3
4
12
24
48
72
96
120
72 breithauptite
211 temiskamite
78 niccolite
45 loellingite
216 rammelsbergite
171 smaltite
481 arsenopyrite
461 geradorffite
1 cobaltite

FIGURE 2

impurities and associated minerals. Dissolved oxygen would also be a factor, particularly in the case of rammelsbergite and gersdorffite, which are very susceptible to attack by aerated water. It does not explain the drop in the case of cobaltite and arsenopyrite shown in all the measurements. These are very stable, particularly in comparison to breithauptite, niccolite, and temiskamite, which show a very constant potential.

What the values are at the instant the minerals touch the acid is a matter for conjecture. It would be interesting to make determinations in solutions containing known quantities of the elements present in the minerals.

TABLE 8

c.p. Copper foil		c.p. Bismuth		c.p. Arsenic		Spec. 47b Niccolite	
Start	.632	Start	.550	Start	.302	Start	.350
2 min.	.640	3 min.	.560	2 min.	.310	12 min.	.350
4 min.	.642	26 min.	.564	5 min.	.330		
9 min.	.642	17 hrs.	.560				
18 min.	.642						
39 min.	.642						

The metals were visibly tarnished at the end of the period.

The values obtained are chiefly of value in that they prove that the potential is a definite measurable property of these minerals.

It is indicated that the potential falls with increasing content of arsenic. Breithauptite definitely heads the list. If the minerals become more electropositive with increasing arsenic content, then we would expect temiskamite to come before niccolite as is shown on the graph, figure 2, though the other determinations do not confirm this.

The diarsenides form a group well separated from the first three. Rammelsbergite in all but one reading tops loellingite-safflorite. It would be necessary to make determinations on a larger number of specimens before being sure of the positions in this group, though the order found checks with that determined by the etching experiments.

The sulpharsenides form a third group in the order gersdorffite, arsenopyrite, cobaltite. This checks with their order of susceptibility to attack by dilute nitric acid.

Combining the results of the etching experiments and the measurements of electromotive force we obtain the potential series:

Copper
- Breithauptite
- Niccolite and Temiskamite
- Rammelsbergite
- Loellingite and Safflorite
- Smaltite and Smaltite-chloanthite
- Skutterudite

Silver
- Gersdorffite
- Arsenopyrite
- Cobaltite

The position of chloanthite was not determined, but from its reactions with the common etch reagents it seems likely that it comes between rammelsbergite and loellingite.

Application to Ore Deposition

More work could profitably be done both in the etching experiments and in the measurements of electromotive force, but it is of interest first to see if this potential series of minerals fits in with any relationships found in the ores.

The geological features of the silver mines of the Temiskaming District have been well described. It is sufficient to mention here that the veins occupy narrow fissures connected with both the lower and upper horizons of the Nipissing diabase sill. Most of the productive veins are in the Huronian sediments but are also found in the diabase itself and to a certain extent in the Keewatin greenstone. The metallic minerals occur in calcitic and dolomitic veins and also in the wall rock.

It is generally considered that the silver belongs to a later period of mineralization than the arsenides and it has been suggested that the arsenides were responsible for the deposition of the native silver.

Palmer[17] worked out the quantitative relationships of the reactions of certain of these arsenides with silver sulphate solution, and in a companion paper Bastin[18] presented significant mineralogical relationships which seemed to prove that the arsenides had caused the precipitation of the silver.

Later, Bastin,[19] from a study of the ores of South Lorrain and Cobalt, came to the conclusion that the arsenides had not been responsible for the precipitation of the silver. He based his opinions on the fact that he invariably found the arsenides to maintain their own crystal faces when in contact with silver.

The writer had seen a few specimens in which there seemed to be no doubt that the silver had replaced the arsenides, and there is a possibility that the presence of euhedral crystals of an arsenide in contact with silver means that a more electronegative member of the family has been replaced.

Palmer presents the following equations for the reactions of the arsenides with silver sulphate solution:

1. *Tetranickel Triarsenide* (Temiskamite or Maucherite)
   $2Ni_4As_3+17Ag_2SO_4+9H_2O=8NiSO_4+3As_2O_3+9H_2SO_4+34Ag$
2. *Niccolite*
   $2NiAs+5Ag_2SO_4+3H_2O=2NiSO_4+As_2O_3+3H_2SO_4+10Ag$
3. *Smaltite*
   $CoAs_2+4Ag_2SO_4+3H_2O=CoSO_4+As_2O_3+3H_2SO_4+8Ag$
4. *Loellingite*
   (*a*) $FeAs_2+4Ag_2SO_4+3H_2O=FeSO_4+As_2O_3+3H_2SO_4+8Ag$
   (*b*) $2FeSO_4+Ag_2SO_4=Fe_2(SO_4)_3+2Ag$
5. *Sulpharsenides*—Do not react.

The equations show an equivalent quantity of silver displaced for both elements present in the minerals.

The following two experiments were performed by the writer with a view to confirming that both elements of the minerals act in displacing silver from its solutions.

1. A specimen from the Keeley Mine, South Lorrain, consisting largely of rammelsbergite, with a little cobaltite,

[17]Palmer, Chase. Econ. Geol., vol. XII, p. 207, 1917.
[18]Bastin, E. S. *Ibid.*, p. 219.
[19]Bastin, E. S. Econ. Geol., vol. XX, p. 1, 1925.

skutterudite, and loellingite, and free of silver, was crushed to 20-60 mesh and cleaned with hydrofluoric acid to remove any oxidation products. It was washed and dried. A sample weighing .5042 grams was placed in an Erlenmeyer flask and the air displaced by clean carbon dioxide. Approximately 400 cc. of silver bi-carbonate solution, made by passing carbon dioxide through a mixture of silver carbonate and water, was filtered into the flask, which was then corked and set aside for twelve hours. It was then filtered and both filtrate and residue analysed. Considerable silver had been displaced and the filtrate was slightly acid to litmus.

		Analysis	Molecular proportions
Ag displaced		.1731 g.	160
Filtrate	As	.0314	42
	Ni	.0089	15
	Co	.0018	3
Residue	As	.3087	
	Ni	.0741	
	Co	.0536	
	Fe	.0055	
	S	.0189	
	Insol	.0035	
		.5065	
Weight taken		.5042	
Error		.0023	

Multiplying the molecular proportions for arsenic by three, and those for nickel and cobalt by two, it is seen that practically an equivalent quantity of silver has been displaced for the arsenic, nickel, and cobalt that went into solution.

2. A sample, 100-200 mesh, of niccolite with small amounts of smaltite, chloanthite, and skutterudite, from analysed material, was cleaned with dilute hydrochloric acid, washed, and dried. Samples were placed in Erlenmeyer flasks and the air displaced with carbon dioxide. With the carbon dioxide still running, a solution, made by dissolving silver car-

bonate in strong ammonia, was filtered into each flask. It was necessary to filter, as some of the silver carbonate had decomposed to an insoluble material. The solutions were diluted to about 100 cc., the flasks corked and set aside, one for twelve hours, the other for five days. At the end of these periods considerable silver had been displaced and the solutions were deep blue in colour. There also appeared to be a small amount of an insoluble greenish flocculent substance formed. The solutions were filtered off and analysed. In the first lot, after filtering and washing, 30 cc. of 1:2 sulphuric acid was passed through the residue twice to give acid washings.

(*a*) .5009 g.—niccolite—.80 g. silver carbonate+10 cc. ammonia—12 hours.

		Analysis	Molecular proportions
Ag displaced		.6284 g.	582
Filtrate	As	.0867	116
	Ni	.0679	116
Acid washings	As	.0015	2
	Ni	.0010	2

Multiplying the proportions of arsenic by three and of nickel by two, we get a quantity 590.

(*b*) .5037 g.—niccolite—.50 g. silver carbonate+5 cc. ammonia—5 days.

	Analysis	Molecular proportions
Ag displaced	.3872 g.	359
As	.0617	82
Ni	.0454	77

Multiplying as above, we get a quantity 400.

In (*a*) there is a slight excess of nickel and arsenic equivalent to the silver displaced, and in (*b*) there is a large excess which would be still greater if the acid washings had been analysed. It was later found by digesting niccolite in a corked flask with 1:1 ammonia, that the niccolite was slowly dissolved, to what extent was not determined. What action carbonic acid has on rammelsbergite was not investigated. Until these matters are investigated, too much weight should not be placed on these experiments. However, they indicate that nickel, as well as the arsenic, acts in displacing silver

from its solutions. The nickel does not merely go into solution by action of acid set free.

Assuming that the silver was precipitated by the arsenides in the ores, then, if the equations on page 142 held, there would be a great excess of silver over that which filled the space previously occupied by the replaced mineral. We can imagine this excess being deposited by electrolytic action wherever the proper connections existed to form a positive pole to the mineral dissolving. The silver would grow by deposition on itself if there was open space.

It is significant that much of the silver in the wall rock is in the form of threads and leaves, showing no particular relation to the arsenides, while in the veins proper it is intimately associated with the arsenides.

Summary

The arsenides and sulpharsenides of nickel, cobalt, and iron, which are the principal metallic constituents of the veins of the silver mines of the Timiskaming District, Ontario, can be arranged in a potential series analogous to the potential series of the metals.

By etching polished specimens with solutions of silver salts and by measurement of the electrode potentials of selected specimens in acid solutions, the following series was worked out:

Copper
- Breithauptite
- Niccolite and Temiskamite
- Rammelsbergite
- Loellingite and Safflorite
- Smaltite and Smaltite-chloanthite
- Skutterudite

Silver
- Gersdorffite
- Arsenopyrite
- Cobaltite

This series may be of help in explaining some of the problems connected with the ores.

It is generally supposed that the silver is of a later period of mineralization than the arsenides, and that the arsenides were responsible for its deposition. If this is so, we might expect the silver to replace the arsenides selectively according to the above series. That is, one high in the series would be replaced before one below it, provided, of course, that an electric circuit was present. Selective replacement has been noted by various authors. However, in those days the complete series of the minerals was not recognized in the ores of the district.[20]

Electromotive force would explain the growth of silver into cracks and fissures in the wall rock and in the gangue. Silver could be deposited on any mineral acting as a positive pole to the mineral being dissolved by the silver-bearing solution.

It is hoped that a study of a number of representative polished sections will show if these hypotheses can be applied.

The writer wishes to thank Professor J. Ellis Thomson for his help in the identification of the minerals and for the loan of many fine specimens; Professor Burt-Gerrans for his advice on the measurements of electromotive force and loan of apparatus; and Professor T. L. Walker and Professor A. L. Parsons for their many helpful suggestions.

[20]Bastin, E. S. Econ. Geol., vol. XII, 1917.
Schlossmacher, K. Zeit. f. Praktische Geol., p. 131, 1921.

THE TEMPERATURE OF FORMATION OF VEIN QUARTZ AND SOME ASSOCIATED MINERALS

By V. B. Meen

Abstract of a thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy in the University of Toronto

In two previous papers[1] the writer has given an account of a study made on quartz of various occurrences. In the earlier of these papers, the method, by which distinction could be made between quartz of low-temperature origin and quartz of high-temperature origin, was gone into in detail. In the later paper, the results of a study, by this method, of quartz of vein origin, were briefly recounted and some conclusions were reached. Since the publication of these papers, some further investigations have been made into the genetic relationships of the minerals associated with the various specimens of quartz. On account of these further investigations, it is here intended to give a brief résumé of the two previous papers and to draw together as a whole the conclusions which have been reached.

Some changes were made in the procedure[2] for obtaining and studying etch-pits on polished basal sections of quartz. Larger etch-pits, spaced farther apart, were obtained by using a more dilute solution of hydrofluoric acid for a correspondingly longer period of time than were obtained by following their procedure. A 6.5 per cent. solution of hydrofluoric acid with an immersion period of 46 hours was found to give excellent results. The etch-pits are more readily examined by using an *Ultropak* illuminator, which furnishes oblique inci-

[1]Meen, V. B. Univ. Tor. Studies, Geol. Ser., no. 36, pp. 37-43, 1934.
———— *Ibid.*, no. 38, pp. 61-68, 1934.

[2]Wright, F. E. and Larsen, E. S. Amer. Journ. Sci., ser. 4, vol. XXVII, pp. 421-447, 1909.

dent light, than by using transmitted or vertically reflected light. This permits the mounting of the specimen in bakelite or some other rigid, acid-resisting medium which prevents disintegration of the high-quartz during etching and the subsequent handling.

The writer agreed with Wright and Larsen in their conclusions that low-quartz, if twinned at all, twins regularly and in large areas, and that high-quartz is badly fractured and heterogeneously twinned in small areas. The boundaries of the individuals in twinned low-quartz are, for the most part, straight and parallel to the horizontal crystal axes. Wright and Larsen said that the twinned areas in high-quartz showed no apparent relationship to the crystal directions. The writer found, however, that the cracks, which often form the boundaries between twin individuals, appear to be roughly parallel to the horizontal crystal axes, which is in agreement with the statement made by Mügge[3] that the fractures are parallel to the unit rhombohedron $(10\bar{1}1)$. Where twins are not bounded by cracks, there appears to be no relationship between these boundaries and the crystal directions. It is, therefore, seen that there is a tendency for the twins to form boundaries according to a definite orientation, but this is not complete on account of the rapidity of the inversion from the high-temperature form to the low-temperature form at the temperature of approximately 573°C. The boundaries of the etch-pits were found to be parallel to the horizontal crystal axes in both types of quartz.

In extending the examination to quartz of vein origin, it was found that both low- and high-temperature varieties occur. This is contrary to the statements of Wright and Larsen. The majority of veins are, however, of the low-temperature type, that is, they were formed below 573°C. It was also found that gold occurs in both types of quartz. Many minerals were found associated with these specimens of quartz, and studies were undertaken to determine the genetic relationships of these minerals to the quartz. The results are tabulated below. Minerals which were found to be later than

[3]Mügge, O. Neues Jahrb. Festband, pp. 181-196, 1907.

the low-quartz in which they are embedded can be said to have crystallized below 573°C. Those which were formed prior to the crystallization of the surrounding high-quartz can be said to have crystallized above 573°C. In cases where the mineral crystallized prior to low-quartz or later than high-quartz, no conclusion could be reached and such minerals are classed as indeterminates. The numbers in the three columns indicate the number of specimens examined.

TABLE 1

Mineral	Temperature of Crystallization		
	Below 573°C.	Above 573°C.	Indeterminate
Argentite	1	.	.
Arsenopyrite	2	.	2
Axinite	.	.	1
Carbonate	32	.	5
Cassiterite	.	3	.
Chalcopyrite	14	.	1
Fouquéite	.	.	1
Galena	9	.	.
Gold (free)	17	.	1
Magnetite	.	.	1
Pyrite	31	1	5
Pyrrhotite	6	.	.
Rutile	.	1	.
Scheelite	1	.	1
Silver	1	.	.
Sphalerite	11	.	.
Tellurides	4	.	.
Tourmaline	3	4	6

Argentite, galena, pyrrhotite, silver, sphalerite, and tellurides were found to have crystallized only below the inversion-temperature of quartz. Arsenopyrite, carbonate, chalcopyrite, free gold, and scheelite crystallized below the inversion-temperature of quartz but in each case there were one or more examples of an indeterminate nature. These minerals may be said to crystallize below the inversion-temperature of quartz but it is possible that they also may crystallize above it. Axinite, fouquéite, and magnetite were indeterminate

because, in each case, the mineral had crystallized earlier than the surrounding low-quartz. Cassiterite and rutile, in the specimens examined, were formed only above the inversion-temperature, but the number of available specimens was small. Ahlfeld[4] has stated that the cassiterite from Uncia-Llallagua crystallized below 573°C. Of the eighteen minerals, listed in the table, only pyrite and tourmaline definitely showed the ability to crystallize both above and below the inversion-temperature of quartz. For such minerals as these the writer would suggest the term *low-high*.

Of the thirty-eight specimens of gold-bearing quartz, thirty-four were of low-temperature and four were of high-temperature origin. The latter were obtained from McKenzie Red Lake Gold Mines Limited, Gold Eagle Gold Mines Limited, Howey Gold Mines Limited, and Lafayette Long Lac Gold Mines Limited. All four of these mines are situated in north-western Ontario. In all, specimens of gold-bearing quartz from twelve mines in this section of Ontario were examined. Eight were of low-temperature origin and four, those mentioned above, were of high-temperature origin. If conclusions can be based on so small a number of determinations, it would appear that one-third of the gold-bearing veins of north-western Ontario are of the high-temperature type. Since, however, three of these mines lie within five miles of each other, it is probable that the proportion for the whole area is not so great. From the observations of the writer, all the vein quartz which was examined from the gold mines of northern Quebec, Porcupine, Kirkland Lake, and northern Manitoba is low-quartz.

Since most of the specimens which were available for study were obtained from gold mines, it has been impossible to determine the frequency of occurrence, over a large area, of high-temperature veins which contain no gold. The ratio of barren high-quartz veins to barren low-quartz veins would be of interest but also could not be determined. The question of the preference of gold for one type of quartz rather than the other cannot be answered until the above-mentioned ratio is known.

[4]Ahlfeld, F. Econ. Geol., vol. XXVI, p. 246, 1931.

LUMINESCENCE IN MINERALS

By W. L. Brown

Summary of a thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy in the University of Toronto[1]

After an investigation of most of the available mineral specimens at the Royal Ontario Museum of Mineralogy as well as the University of Toronto, a large number were found to show luminescence under the ultra-violet lamp. Of these the following were not previously listed as reacting to ultra-violet light in this way: apatite, bolivarite, berzeliite, celestite, cerussite, gilpinite, jurapaite, leadhillite, matlockite, mesolite, phosgenite, scolecite, uranocircite, uranosphaerite, valleite, zippeite.

Photo-phosphorescent minerals are classified according to the duration of their phosphorescence as follows: *momentary*—phosphorescence lasts one or two seconds; *vanishing*—phosphorescence lasts 20-60 seconds; *persistent*—phosphorescence lasts longer than two minutes. This last group was investigated by means of the photographic method and a number of striking examples found. Many fluorites showed persistent phosphorescence, the lighter coloured portions of the purple varieties giving a stronger action than the darker coloured portions. Various scapolites react strongly after exposure to sunlight, particularly in the altered portions. A striking similarity was found in the photo-phosphorescent properties and the bleaching action by sunlight between a pink evanescent sodalite and a light violet coloured fluorite. Both of these minerals suffer a bleaching action on exposure to sunlight, the pink sodalite being much more sensitive in this respect than the

[1]The results of the essential part of the work covered have already been published in Univ. Tor. Studies, Geol. Ser., no. 35, pp. 19-35; and Geol. Ser., no. 36, pp. 45-54.

fluorite. The photo-phosphorescence is much fainter in the bleached varieties than in the naturally coloured minerals. Some yellow varieties of calcite show photo-phosphorescence, also phenacite, sphalerite, danburite, and scheelite.

The wave lengths causing persistent phosphorescence were investigated by means of a special exposure block, using the spectrum of the carbon arc in the quartz spectrograph. The active wave lengths were found to range continuously from below 2500 Å to above 7000 Å units. The relative absorption of the fluorite controlled to a certain extent the exciting power of the various wave lengths.

In a study of the variation of the intensity of phosphorescence with interval of time the fluorite was exposed to sunlight, it was found that maximum value was obtained in 60 seconds, any increase in exposure causing a decrease in phosphorescence. This result corresponds closely to that obtained by Iimori and Iwase working with the quartz-mercury lamp.

The reddish-orange fluorescence of calcites was found to be dependent upon the presence of manganese in suitable proportions. Iron also acts in this way but to a lesser degree. The reddish-orange fluorescence of calcites rises to a maximum intensity and then gradually dies out with the increase in percentage of manganese carbonate. There is a regular increase in refractive index ω and specific gravity, and a decrease in molecular volume with increasing percentages of manganese and iron carbonates. Considering the relative sizes of the replacing atoms and that of calcium in the calcite structure, an explanation is given for the relation existing between the intensity of fluorescence and the percentage of manganese carbonate present in calcites. The condition in which the atoms of a suitable impurity are present in the crystal structure of the host mineral determines whether or not that mineral will fluoresce.

In conclusion, the writer wishes to thank Dr. T. L. Walker and Professor A. L. Parsons for their sustained interest in the work. The other members of the staff of the Department of Mineralogy also rendered assistance which was greatly appreciated.

EXPLANATION OF PLATES

Plate I

Figure 1.—Nodular structures in metamorphosed early Precambrian greywacke, 50 miles north-north-east from Yellowknife Bay, Great Slave Lake.

Figure 2.—Concentration of andalusite crystals along certain horizons of interbedded slate and greywacke, 25 miles north-east of Yellowknife Bay, Great Slave Lake.

Plate II

Figure 1.—Andalusite metacrysts developed in conglomeratic andalusite schist in south-western part of Outpost Islands, Great Slave Lake.

Figure 2.—Near south-west corner Outpost Islands. "Pegmatitic" quartz mass 60 feet long and 10 feet wide.

Plate III

"Pegmatite" from shaft, Outpost Islands, Great Slave Lake. Prismatic crystals of andalusite (grey, An) and biotite (black, Bi) in milky quartz. Pyrite and chalcopyrite (rough grey, PyCp) fill comb-lined vugs in quartz and andalusite. Ferberite and magnetite (black, FbMt) occur within and replacing andalusite. All the metallic mineralization is much later than the formation of the "pegmatite".

Plate IV

Brecciated impure quartzite from west zone Outpost Islands. Fragments of quartzite (medium-grained banded in larger specimen) cemented by quartz and metallics in the following order of deposition: (1) cherty quartz (light grey); (2) cherty quartz with disseminated ferberite (black); (3) cherty and drusy quartz with pyrite and chalcopyrite (mottled).

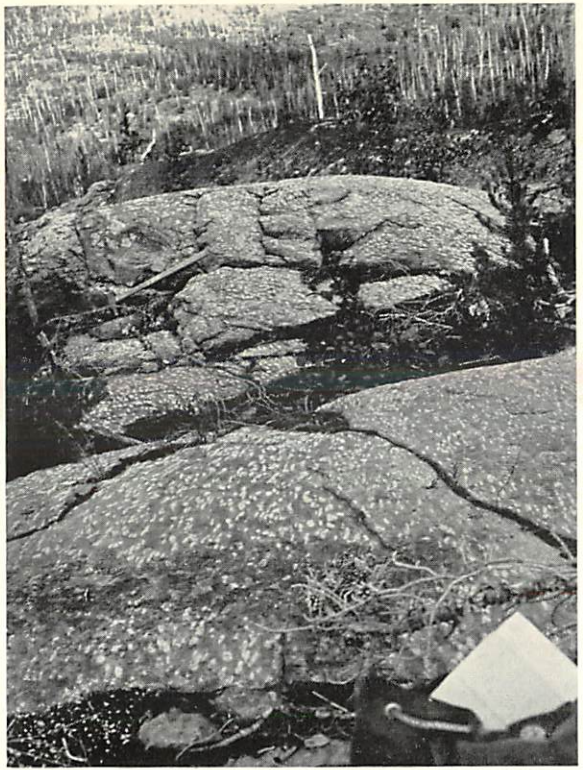


Figure 1

Figure 2

PLATE II

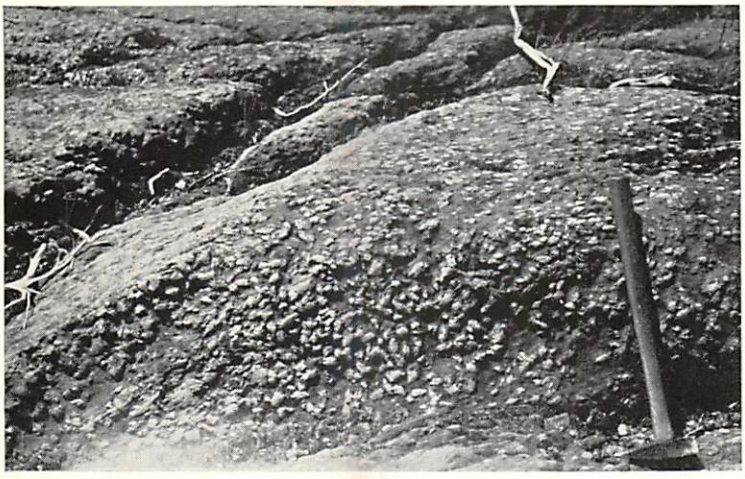
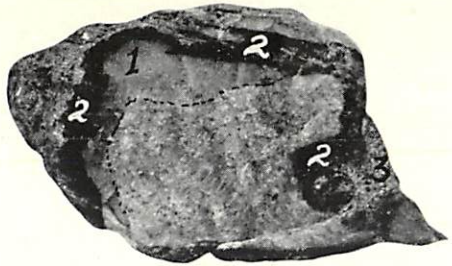


Figure 1

Figure 2

PLATE III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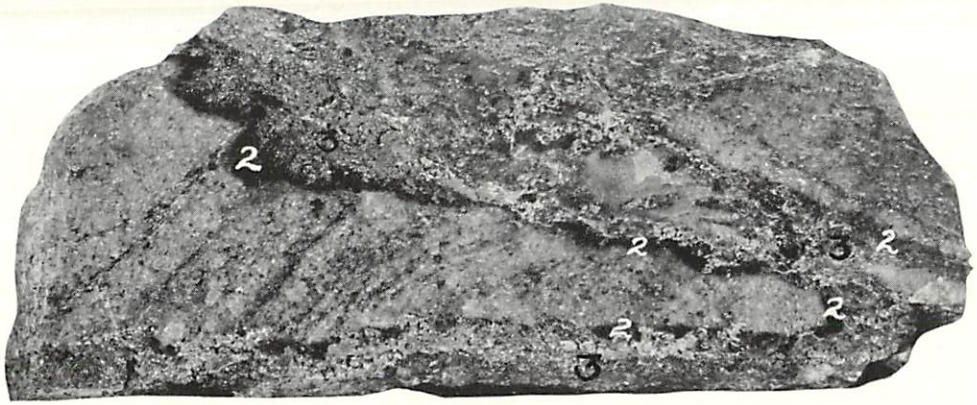
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