Technical and Bibliographic Notes / Notes techniques et bibliographiques

The Institute has attempted to obtain the best original copy available for filming. Features of this copy which may be bibliographically unique, which may alter any of the images in the reproduction, or which may significantly change the usual method of filming are checked below.

- [x] Coloured covers / Couverture de couleur
- [x] Covers damaged / Couverture endommagée
- [ ] Covers restored and/or laminated / Couverture restaurée et/ou pelliculée
- [ ] Cover title missing / Le titre de couverture manque
- [ ] Coloured maps / Cartes géographiques en couleur
- [ ] Coloured ink (i.e. other than blue or black) / Encre de couleur (i.e. autre que bleue ou noire)
- [ ] Coloured plates and/or illustrations / Planches et/ou illustrations en couleur
- [ ] Bound with other material / Relié avec d'autres documents
- [ ] Only edition available / Seule édition disponible
- [ ] Tight binding may cause shadows or distortion along interior margin / La reliure serrée peut causer de l'ombre ou de la distorsion le long de la marge intérieure.
- [ ] Blank leaves added during restorations may appear within the text. Whenever possible, these have been omitted from filming / Il se peut que certaines pages blanches ajoutées lors d'une restauration apparaissent dans le texte, mais, lorsque cela était possible, ces pages n'ont pas été filmées.
- [x] Additional comments / Commentaires supplémentaires: Part of cover title is missing. Various pagings.

L'Institut a microfilmé le meilleur exemplaire qu'il lui a été possible de se procurer. Les détails de cet exemplaire qui sont peut-être uniques du point de vue bibliographique, qui peuvent modifier une image reproduite, ou qui peuvent exiger une modification dans la méthode normale de filmage sont indiqués ci-dessous.

- [ ] Coloured pages / Pages de couleur
- [ ] Pages damaged / Pages endommagées
- [ ] Pages restored and/or laminated / Pages restaurées et/ou pelliculées
- [x] Pages discoloured, stained or foxed / Pages décolorées, tachetées ou piquées
- [ ] Pages detached / Pages détachées
- [x] Showthrough / Transparence
- [x] Quality of print varies / Qualité inégale de l'impression
- [ ] Includes supplementary material / Comprend du matériel supplémentaire
- [ ] Pages wholly or partially obscured by errata slips, tissues, etc., have been refilmed to ensure the best possible image / Les pages totalement ou partiellement obscurcies par un feuillet d'errata, une pelure, etc., ont été filmées à nouveau de façon à obtenir la meilleure image possible.
- [ ] Opposing pages with varying colouration or discolourations are filmed twice to ensure the best possible image / Les pages s'opposant ayant des colorations variables ou des décolorations sont filmées deux fois afin d'obtenir la meilleure image possible.

This item is filmed at the reduction ratio checked below /
Ce document est filmé au taux de réduction indiqué ci-dessous.

10x		14x		18x		22x		26x		30x	
	12x		16x		20x		24x ✓		28x		32x

The copy filmed here has been reproduced thanks to the generosity of:

National Library of Canada

The images appearing here are the best quality possible considering the condition and legibility of the original copy and in keeping with the filming contract specifications.

Original copies in printed paper covers are filmed beginning with the front cover and ending on the last page with a printed or illustrated impression, or the back cover when appropriate. All other original copies are filmed beginning on the first page with a printed or illustrated impression, and ending on the last page with a printed or illustrated impression.

The last recorded frame on each microfiche shall contain the symbol → (meaning "CONTINUED"), or the symbol ▽ (meaning "END"), whichever applies.

Maps, plates, charts, etc., may be filmed at different reduction ratios. Those too large to be entirely included in one exposure are filmed beginning in the upper left hand corner, left to right and top to bottom, as many frames as required. The following diagrams illustrate the method:

L'exemplaire filmé fut reproduit grâce à la générosité de:

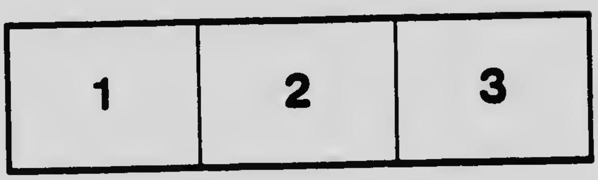
Bibliothèque nationale du Canada

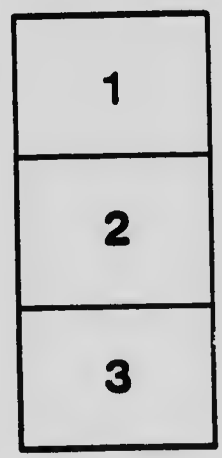
Les images suivantes ont été reproduites avec le plus grand soin, compte tenu de la condition et de la netteté de l'exemplaire filmé, et en conformité avec les conditions du contrat de filmage.

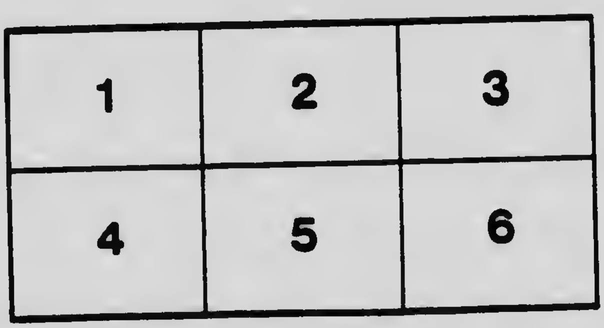
Les exemplaires originaux dont la couverture en papier est imprimée sont filmés en commençant par le premier plat et en terminant soit par la dernière page qui comporte une empreinte d'impression ou d'illustration, soit par le second plat, selon le cas. Tous les autres exemplaires originaux sont filmés en commençant par la première page qui comporte une empreinte d'impression ou d'illustration et en terminant par la dernière page qui comporte une telle empreinte.

Un des symboles suivants apparaîtra sur la dernière image de chaque microfiche, selon le cas: le symbole → signifie "A SUIVRE", le symbole ▽ signifie "FIN".

Les cartes, planches, tableaux, etc., peuvent être filmés à des taux de réduction différents. Lorsque le document est trop grand pour être reproduit en un seul cliché, il est filmé à partir de l'angle supérieur gauche, de gauche à droite, et de haut en bas, en prenant le nombre d'images nécessaire. Les diagrammes suivants illustrent la méthode.

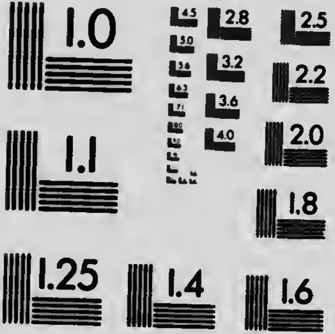






MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



CANADA
DEPARTMENT OF MINES
GEOLOGICAL SURVEY
HON. ROBERT ROGERS, MINISTER; A.P. LOW, DEPUTY MINISTER;
R. W. BROCK, DIRECTOR.

MEMOIR No. 22

PRELIMINARY REPORT

ON THE

S[illegible]TINE AND ASSOCIATED ROCKS

OF

SOUTHERN QUEBEC

BY

JOHN A. DRESSER.

OTTAWA
GOVERNMENT PRINTING BUREAU
1913.

No. 1190.

Frontispiece

Plate I

Photo. Amalgamated Asbestos Corporation, Ltd.

View from Black Lake, showing asbestos mines in the foreground and the Notre Dame hills in the distance.

View from Black Lake, showing asbestos mines in the ..eground and the Notre Dame hills in the distance.

CANADA

DEPARTMENT OF MINES

GEOLOGICAL SURVEY

HON. ROBERT ROGERS, MINISTER; A.P. LOW, DEPUTY MINISTER,
R. W. BROCK, DIRECTOR.

MEMOIR No. 22

PRELIMINARY REPORT

ON THE

SERPENTINE AND ASSOCIATED ROCKS

OF

SOUTHERN QUEBEC

BY

JOHN A. DRESSER.

OTTAWA
GOVERNMENT PRINTING BUREAU
1913.

11159—A

No. 1190.

To R. W. Brock, Esq.,
Director, Geological Survey,
Department of Mines,
Ottawa.

Sir,—I beg to submit the following preliminary report on the Serpentine and associated rocks in southern Quebec.

I have the honour to be,
Sir,
Your obedient servant,
(Signed) **John A. Dresser.**

April 28, 1911.

CONTENTS.

	Page
Introductory	1
General statement	1
Location and area	2
History	2
General history	2
Previous work	3
Bibliography	4
Summary and conclusions	6
General geology	6
Economic geology	6
General character of the district	9
Topography	9
General account	9
Regional	9
Local	11
Detailed account	11
Relief	11
Drainage	12
Climate	13
Agriculture	14
Transportation and communication	14
General geology	15
General statement	15
Regional	15
Local	17
Sedimentary rocks	17
Igneous rocks	18
Table of formations	19
Description of formations	19
Sedimentary	19
Distribution	19
Lithological characters	20
L'Islet	20
Sillery	20
Farnham	21
Quaternary	22
Structural relations	23
Internal	23
External	23
Relations between Ordovician and Cambrian	24
Mode of origin	24
Cambrian	24
Ordovician	24
Age and correlation	25
Cambrian	25
Ordovician	25
Igneous	25

	Page
Thetford phase	25
Distribution	25
Lithological characters	26
Peridotite	27
Serpentine	28
Pyroxenite	30
Gabbro	31
Diabase	32
Porphyrite	33
Granite	33
Aplite	35
Broughton phase	35
Distribution	35
Lithological characters	35
Serpentine	35
Soapstone	36
Greenstone schists	36
Structural relations	36
Internal	36
Foliation	37
Faulting	37
Jointing	38
Breccia	39
Amygdaloid	42
External	42
Relative to older formations	42
Mode of origin	42
Age and correlation	50
Data	50
Conclusions	51
Geological structure of the region	52
Geological history	53
Economic geology	54
Asbestos	54
General character and distribution	54
Production	55
History	57
Relations of the deposits to the country rock	58
Deposits of the Thetford type	58
Evidence	58
Summary of evidence	61
Theoretical	61
Review of previous opinions	62
Conclusions	65
Deposits of the Broughton type	67
Evidence	67
Summary of evidence	68
Theoretical	69
Mining and milling	70
Mining	70
Handling and dressing	71
Uses	72

	Page
Status and possibilities of the industry	72
Occurrences of asbestos	73
Chromite	74
Production	74
History	75
Development in Canada	75
Characters of the ore	76
Minerals associated with chromite	80
Magnetite	80
Vesuvianite	80
Diamonds	82
Molybdenite	84
Relations to the country rock	85
Genesis	88
Evidence	88
Theoretical	88
Review of previous opinion	89
Conclusions	90
Mining	91
Concentration	91
Uses	91
Occurrences of chrome iron ore	92
Status and possibilities of the industry	92
Antimony	95
Character of deposit	95
Talc	96
Platinum	96
Copper	97

ILLUSTRATIONS.

Photographs.

Plate	I.	General view, Black lake	Frontispiece
"	II.	Sketch, Danville slate quarry	22
"	III.	Big Ham mountain	26
"	IV.	Microphotograph—peridotite	26
"	V.	Microphotograph—serpentine	26
"	VI.	Peridotite containing serpentine and asbestos in veins	58
"	VII.	Microphotograph—asbestos vein	60
"	VIII.	King mine, Thetford mines	70
"	IX.	Ling mine, East Broughton	70
"	X.	Mill and tramline, Frontenac mine, East Broughton	70
"	XI.	Microphotograph—chromite	76

Drawings.

Fig.	1.	Diagrammatic section across the serpentine belt, Cleveland township, Que	38
"	2.	Diagrammatic section across the serpentine belt, Melbourne township, Que. (Range VI.)	39

PAGE

FIG. 3. Diagrammatic section across the serpentine belt, Melbourne township, Que. (Range I.) 40
" 4. Diagrammatic section across the serpentine belt, Brompton township, Que 41
" 5. Sill of diabase, pyroxenite, and serpentine, Garthby township, Que 44
" 6. Diagrammatic section along power line between Thetford river and Bisby creek 46
" 7. Diagram showing relations of asbestos, serpentine, and peridotite at Black lake 59

Maps.

No. 1154 (23A) Map of Thetford-Black Lake mining district .... END
" 1184 (38A) Map of Danville mining district .... "
" 1202 (52A) Map of northeast part of serpentine belt, Quebec ...... "

PRELIMINARY REPORT ON THE SERPENTINES AND ASSOCIATED ROCKS IN SOUTHERN QUEBEC.

INTRODUCTORY.

General Statement.

The district described in this report is distinguished for the production of asbestos and chromite. It includes all the mines at present producing these minerals in Canada, and furnishes about three-fourths of the world's supply of asbestos. It also embraces larger areas which are being vigorously prospected, and others of less probable value which it has been necessary to study in order to find out the extent and relations of the mineral deposits, and to ascertain the geological structure of the series to which they belong. The report, therefore, deals, primarily, with the economic resources; but some attention is also given to the petrography and structural geology of the district.

The work has been greatly facilitated by assistance freely and courteously rendered by the managers of the various mines of the district. Access to the mines and concentrating mills, and much information derived from the long and successful experience of many of the pioneer managers has been readily given, which, it is needless to say, has been of great assistance in conducting the investigation.

The field work upon which this report is principally based was carried on during the seasons of 1907 and 1909. In the first season the mode of occurrence of the mineral deposits was studied; chiefly in and near the working mines; in the second, the distribution and extent of the known deposits and of the rock formations containing them, was traced, and material for a preliminary map obtained.

The Eastern Townships map of the Geological Survey series, enlarged to a scale of 1 mile = 1 inch, was used as a basis; and the surveys were principally made by compass and chain. In a few places where greater accuracy was required, transit and stadia surveys were made.

Alex. MacLean, and R. Randal Rose, acted as field assistants in 1907; and in 1909, Mr. MacLean again assisted. It is a pleasure to acknowledge the efficient services of these gentlemen.

Location and Area.

The district to which this report relates is in the Province of Quebec, south of the St. Lawrence, between the St. Francis and Chaudière rivers. The area over which work was done is less than 10 miles in width, and about 80 miles in length. The northern extremity, near Beauceville, is 40 miles from the St. Lawrence river, and the most southerly point to which the work has been carried is near Richmond about 60 miles from the St. Lawrence.

History.

General History.—The close of the French régime in Canada—1763—saw many parts of the St. Lawrence plain opened for settlement; but the highlands were as yet untouched, and remained so for a generation later. Following the separation of Upper Canada (Ontario) from Lower Canada (Quebec) in 1791, a more vigorous colonization policy was adopted by the latter Province, and the survey of the highlands was begun. By the mode of survey then adopted, the land was divided into townships, approximately square; and these were subdivided into ranges and lots. The shape thus given to land holdings distinguished the district from the portions previously surveyed in the plain, in which long ranges parallel to some line of travel were subdivided into long, narrow farms. From the mode of survey and the location of the district, it gained the name of the Eastern Townships.

The earliest settlements were made about the beginning of the 19th century by emigrants from the neighbouring New England States; a portion of whom were United Empire Loyalists. The first lands occupied were those along Lakes Memphremagog and Massawippi, and in the valley of the St. Francis river.

In order to connect these early settlements with the city of Quebec—both for commercial and strategic purposes—a road, which still bears his name, was projected by Governor Craig in 1805. It was afterward built from Quebec to the St. Francis river, at Richmond. By means of this road and the Gosford road, which was built some years later, farther to the eastward, emigrants from the British Isles rapidly occupied the northern part of the district.

Between 1850 and 1855 the main line of the Grand Trunk railway was built from Montreal to Portland; thus crossing the district from west to east, and also a branch from Richmond to Lévis, paralleling Craig's road. About 1880 the Quebec Central railway was completed from Sherbrooke to Lévis, running for nearly half its length closely parallel to or across the serpentine belt; and since that date the Canadian Pacific railway has extended lines across and to various parts of the district. The Lotbinière and Megantic railway has connected the Grand Trunk branch with the St. Lawrence river at St. Jean des Chaillons, and a third line between Sherbrooke and Quebec is now projected.

Meanwhile, the tide of immigration from the British Isles has been diverted to western Canada, and the English speaking settlers of the Eastern Townships are rapidly following it. But the steadily increasing French-Canadian population having occupied the St. Lawrence plain, has extended to the highlands, and now forms much the greater part of the population.

Previous Work.—The first descriptions of this district were by Sir William Logan, in several of the early reports of the Geological Survey, and were later embodied in the Geology of Canada, published in 1863. In these, the distribution of the serpentines and related rocks was described with the admirable care and accuracy which characterized Logan's work; but the scale of the maps issued at that time did not admit of showing them in the atlas accompanying the general report of 1863.

Mineralogical and lithological examinations accompanied by chemical analyses were made at the same time by T. Sterry Hunt, and the results were published in conjunction with those of Logan's field work. According to the views of the Uniformitarian school of geology, which at that time was in the ascendancy, the serpentines of this district were supposed to be altered sediments derived largely from magnesian limestone. They were assigned to a certain horizon of the stratified rocks, and were often correlated with neighbouring beds of dolomite.

The sedimentary origin of these rocks was questioned by the late Dr. A. R. C. Selwyn—who succeeded Sir William Logan as Director of the Geological Survey of Canada in 1869. A small suite of specimens from the district, the first rocks to be examined in Canada by modern microscopic methods, was determined in 1882 by Dr. F. D. Adams—then lithologist to the Geological Survey—and the serpentines were shown to be altered igneous, not sedimentary rocks.[1] The newly acquired information as to the origin of the rocks necessitated a review of the stratigraphy, which was carried out by Dr. R. W. Ells. Dr. Ells revised the areal geology of the entire Eastern Townships and published reports with maps on a scale of 4 miles = 1 inch. Those which relate to this district appeared in the annual volumes of the Geological Survey for the years 1886, 1887, and 1894.

Numerous other related publications, which have been issued from both official and private sources, will be referred to in the bibliography.

Bibliography.

1849. Hunt, T. S.. .. .. ..*Report of Progress, Geological Survey*: describes serpentines and associated minerals from Richmond and Beauce counties.

1850. Logan, Sir W. E.. ..*Report of Progress, Geological Survey*: describes the rocks of the St. Francis and Chaudière valleys; and mentions the chromite deposits of Ham.

Hunt, T. S.. .. .. ..Mineral determinations and analyses from the same localities.

1856. Hunt, T. S.. .. .. ..*Report of Progress, Geological Survey*: chemical analyses of rocks and minerals from the serpentine belt.

1858. Logan, Sir W. E.. Hunt, T. S., and Richardson, James.... ..*Report of Progress, Geological Survey*: presents separate reports on the geological structure, rock varieties and their distribution in the Eastern Townships.

1863. Logan, Sir W. E., assisted by Hunt, T. S. *Geological Survey, Canada*. In a general report entitled 'Geology of Canada' is given a description of the serpentines, with chemical analyses, and observations on their economic importance and geological relations.

1875. Harrington, B. J. ..*Report of Progress, Geological Survey*: gives analyses of serpentines from Bolton and Melbourne, showing them to contain chromium, nickel, and cobalt.

1876. Hunt, T. S.. .. .. ..*Report Second Geological Survey of Pennsylvania*; includes the rocks of this district, in a discussion on the 'Azoic Rocks and Trap Dykes' of Pennsylvania.

1878. Selwyn, A. R. C.. ..*Report of Progress, Geological Survey, Part A*: discusses the geological structure of the Quebec Group.

1882. Selwyn, A. R. C.. ..*Report of Progress, Geological Survey, Part A*: a further discussion of the Quebec Group.

1882. Adams, F. D... .. ..*Report of Progress, Geological Survey, Part A*: Appendix. Announces the igneous origin of the serpentines and several associated rocks.

[1] Geological Survey, Canada, 1880-1-2. Part A.

1886. Ells, R. W.. .. ..*Annual Report, Geological Survey.* Report on the geology of the district covered by the Sherbrooke map sheet, or the southeast quarter sheet of the Eastern Townships map.

1887. Ells, R. W... .. .. ..*Annual Report, Geological Survey.* Report on the geology of the district covered by the Quebec map sheet, or the northeast quarter sheet of the Eastern Townships map.

1888. Ells, R. W... .. .. ..*Annual Report, Geological Survey.* Report on the mineral resources of the Province of Quebec, containing a review of the economic geology of the district described in the last two preceding reports.

1894. Ells, R. W... .. .. ..*Annual Report, Geological Survey.* Report on the geology of the district covered by the Montreal map sheet, and the southwest quarter sheet of the Eastern Townships map.

1903. Ells, R. W... .. .. ..*Bulletin on Asbestos, Geological Survey.* Reviews the history and progress of the asbestos industry.

1904. Merrill, G. P... .. ..*Bulletin, Geological Society of America.* Discusses the mode of occurrence of asbestos.

1905 Cirkel, F. .. ..*Report of Mines Branch: Department of the Interior.* Discusses the mode of occurrence of asbestos, and describes methods of mining and concentrating.

1905. Dresser, J. A.. .. ..*Bulletin, Geological Society of America.* A general description of the igneous rocks of the Eastern Townships with a discussion of their genetic relations.

1898–1908. Obalski, J. .. ..*Reports of the Department of Mines of Quebec.* In several reports—especially those for the years mentioned—the progress in mining asbestos and chromite is described, and the distribution of the mineral deposits noted.

1909. Cirkel, F... .. .. ..*Report of Mines Branch: Department of Mines, Canada.* Discusses the mode of occurrence, mining, concentration, and uses of chromite.

1909. Dresser, J. A.. .. ..'*Economic Geology.*' *New Haven, Conn., Vol. IV. No. 2.* Describes mode of occurrence of asbestos, and discusses its origin.

1909. Dresser, J. A.. .. ..*Journal, Canadian Mining Institute, Vol. XII.* Reviews the mineral resources of the Serpentine belt, and discusses the mode of occurrence of asbestos and chromite.

1910. Barlow, A. E.. .. ..*Journal, Canadian Mining Institute, Vol. XIII.* Discusses the mode of origin of asbestos.

1910. Dresser, J. A.. .. ..*Journal, Canadian Mining Institute, Vol. XIII.* Discusses the geology of the asbestos deposits.

1910. Dresser, J. A.. .. ..*Summary Report of the Geological Survey for 1909;* reprinted as a separate. Describes the geology and mineral resources of the asbestos district of southern Quebec.

1912. Barlow, A. E... .. ..*Geology and Mineral Resources of the Chibougamau Region.* Bureau of Mines, Quebec.

SUMMARY AND CONCLUSIONS.

General Geology.

The serpentine belt of the Eastern Townships of Quebec consists of a series of igneous rocks of basic composition, which are intrusive through sedimentary strata of Palæozoic age. In the district covered by the accompanying maps, the sedimentary rocks are upper Cambrian and lower Ordovician; but, in adjacent areas to the south, Silurian and early Devonian strata are also thought to be intruded by the igneous rocks of the serpentine belt.

A small portion of the serpentine belt, found in the township of Broughton, presents some features that make it probable that it is older than the greater part of the series; but it is, at least, post-L'Islet in age, and so may have been intruded in late Cambrian time.

The rocks in this district are, therefore, principally post-Ordovician in age, and possibly were intruded in Devonian time: which was a period of igneous activity in the northern Appalachian region.

Economic Geology.

While serpentine owing to its greater economic importance gives its name to the belt, it is really the least abundant of the principal rocks of the series. It does not form large bodies like the other principal rocks, but occupies only small areas where peridotite or possibly pyroxenite has been altered to serpentine.

Asbestos occurs in serpentine of two varieties, which are thought to be of different ages. The two classes of asbestos may be conveniently called the Thetford and the Broughton types, and the rocks in which they occur, the Thetford and the Broughton phases, from townships in which they are well known.

Asbestos of the Thetford type occurs in veins, and is generally longer and stronger than that of Broughton. Chromite also occurs in the Thetford phase. The asbestos of Broughton occurs principally as 'slip' fibre, or fibre arranged parallel to the cleavage faces of the rock. It is more cheaply mined than that at Thetford, but being shorter and of less tensile strength, it has a lower market value. The Broughton asbestos deposits are often associated with talc or soapstone, which is not found in any important amount at Thetford. There are no deposits of chromite in the serpentine of Broughton.

In both quantity and quality of the minerals produced, much the greater value is obtained from the serpentine of the Thetford phase. It is found in all the principal parts of the serpentine belt, and contains the mines of Thetford, Black Lake, and Danville, with their smaller deposits in the intervening areas, and also extends southward beyond the St. Francis river.

The Broughton serpentine contains the mines and prospects of East Broughton and the vicinity of Robertson. The property of the D'Israeli Mining Company, Limited, in Garthby, and some prospects in ranges I, II, and III, of Tring, also belong to this class.

The production of asbestos has increased steadily from the beginning of mining in the district thirty years ago, to the present time. It now has an annual value of $2,500,000.

Chromite occurs in workable deposits in the Thetford serpentine, but not, as far as known, in that of Broughton. The value of the annual production for several years was about $80,000.

Soapstone or talc is found in important quantities associated with the Broughton serpentine; but not with that of Thetford. Some shipments were made from these deposits over twenty years ago, but a stable industry has not yet resulted.

The serpentine of the Thetford phase has been derived by alteration from peridotite. It is thought that the Broughton serpentine has been derived from pyroxenite, a closely allied rock.

In both cases the original rock was a member of a series of intrusive rocks differentiated from a single magma. The series comprises peridotite, pyroxenite, gabbro, diabase, porphyrite, and hornblende granite, the latter sometimes passing into aplite. The granite has usually been injected a little later than the other members of the series, and, therefore, in many places forms dykes and sills or intrusive sheets. These probably had a favourable influence in the formation of asbestos deposits, especially in the vicinity of Thetford Mines.

The igneous complex may be regarded as a batholith, or thick laccolith, in the area between Thetford and Danville, where it presents many isolated stocks. Elsewhere it is chiefly in sheets or sills. The serpentine of the Thetford type occurs both in sills and stocks, while the serpentine of Broughton is only in sheets or sills.

The different rock varieties are arranged in order of decreasing density: in sills from the base upwards; in stocks from the centre outward. This order is peridotite, pyroxenite, gabbro, diabase, and porphyrite. The peridotite alters to serpentine, and the serpentine being purest, is most likely to carry asbestos near the base of a sill, or the centre of a batholithic mass.

A result of this arrangement of the igneous rocks is, that when the structure is known, the location of the purest serpentine may be determined. Most of the sheets dip towards the southeast, and in such areas the best prospecting ground is along the northwest side of the igneous belt. Where the sills dip to the northwest, the best prospecting ground is near the southeast border.

In stocks the serpentine is exposed only by erosion of the original rock masses. This has been most effective on the northeast side of the hills, as that is the side against which the ice moved in the glacial period.

Besides the purity of the original peridotite—which is necessary that pure serpentine may form—the degree of alteration of peridotite to serpentine is an important factor in the formation of asbestos. The degree of alteration is indicated by the relative hardness of the rock. If the original rock were a pure peridotite—that is, composed essentially of olivine—the more completely it is altered to serpentine the softer the resulting rock, and the better the prospect for asbestos. But, if the original rock contained a considerable amount of pyroxene which has been altered to soapstone, the resulting rock may be softer than the purest serpentine, but will be unlikely to contain asbestos. Therefore, soft rock is a good indication of asbestos if there is no soapstone present.

The presence of granite, also, seems to have a bearing upon the occurrence of asbestos veins. The granite rock has generally been injected later than the other rocks; it fills fissures formed in the solid peridotite and forms dykes and sills. The fissuring and the action of heated waters accompanying the granite which filled the fissures probably aided in forming asbestos.

Since the parent rock of the serpentine was a deep-seated one, and since the alteration to serpentine as well as intrusives of granite may occur at great depths, there appears to be no reason why the asbestos deposits also may not continue to as great depths—perhaps to the limits of profitable mining. To determine the depth of any particular deposit, the structure of the sill or stock to which it belongs should be examined in detail.

The chromite occurs in segregated masses that are believed to be primary, in the outer part of the peridotite or serpentine portions of the stocks, near the pyroxenite zone.

Chalcopyrite and pyrite occur in bodies of possible importance, in the diabase of Garthby and other places in the district. They are thought to be primary segregations.

Antimony occurs in South Ham, as a contact deposit in schists, adjacent to serpentine and diabase. The deposit contains native antimony, kermesite, valentinite, and a little stibnite.

Platinum is known to occur in the drift, and this has come from the direction of the chromite deposits, which are the probable source of the metal. Several assays of chromite ore for platinum, made by Mr. Harold Leverin of the Mines Branch, have, however, yielded negative results.

Diamonds of good quality, but too small to be of value as gems, occur in the chromite. There is as yet too little known about their occurrence to indicate whether or not they may be found of commercial value.

GENERAL CHARACTER OF THE DISTRICT.

Topography.

GENERAL ACCOUNT.

Regional.—That portion of the Province of Quebec which lies south of the St. Lawrence river consists of two parts which are quite distinct in their topographic features, the St. Lawrence valley and the Appalachian highlands. The St. Lawrence valley is so nearly level as to present to the eye the appearance of a plain. It, however, rises in altitude from 100 feet above sea-level along the river to 400 feet near the foot of the highlands, and thus is properly regarded as a broad, flat valley, though it is often suitably referred to as a plain. Its breadth on the south shore varies from 50 miles near the southern boundary of the Province, to 4 or 5 miles a short distance northeast of the city of Quebec, where the highlands and river channel closely converge.

The Appalachian highlands, sometimes known as the Notre Dame hills, are an extension of the Green mountains of Vermont and of the White mountains of New Hampshire, which are the bordering states on the south of the Province of Quebec. The highlands consist of ridges of subdued hills (see frontispiece) which have a northeasterly trend, and rather broad intervening valleys whose altitude is well above that of the St. Lawrence plain. The hills form three principal ridges, or ranges, which are about 25 miles apart. The largest of these is the Sutton range which borders on the St. Lawrence plain. In Sutton mountain near the Vermont State line, it rises to a height of 3,100 feet—the highest point in the district. Farther to the northeast, in the counties of Megantic, Arthabaska, and Wolfe, this range is some 15 miles in width and considerable portions of it have an altitude of more than 1,500 feet. The second range, in a depression of which the city of Sherbrooke stands, forms the Capelton and Stoke hills and the hills of Weedon. The highest point in this range is Bald Peak at the northeast end of Stoke mountain, which is about 2,400 feet above sea-level. The third or Lake Megantic range lies only partly in Canada, and forms the boundary line between the Province of Quebec and the State of Maine. Where crossed by the Canadian Pacific railway it has an elevation of 1,852 feet, but rises considerably higher at other points.

Besides these larger features of relief, there are numerous hills—many of them being of the butte type—which are due to igneous intrusions, and are less regularly distributed over the region. In the St. Lawrence plain the series known as the Monteregian hills furnish the only exception to the even surface. They are eight in number, and occur as abrupt, isolated hills, in a roughly straight line across the valley. In the basins between the Sutton and Lake Megantic ranges, there are six or seven granitic hills of similar form to the Monteregians although differing from them in other features. Also on the southeast side of the Sutton range and running near and parallel to it, there is the series of intrusive hills forming the serpentine belt with which this report essentially deals. These last present various topographic forms and may be better considered under a detailed description of the relief.

The region as a whole is drained to the St. Lawrence river by means of the Richelieu, Yamaska, St. Francis, Nicolet, Becancour, and Chaudière rivers and their tributaries.

These streams cross the Sutton and in some cases the Sherbrooke hills as well, in courses generally at right angles to the trend of the ridges. The valleys are somewhat narrower and have steeper slopes where the rivers cut through the ridges, but no falls or even important rapids are formed.

Viewed broadly, therefore, the region may be regarded as a section of an old coastal plain, which was formed around the edges of the Pre-Cambrian upland in early Palæozoic times and was later deformed by the folding of the Appalachian uplift. The St. Lawrence river in the Province of Quebec occupies the position of a subsequent stream running parallel to the Laurentian old land, and not far from it. The belt of higher land along the boundary line between the Province of Quebec and the State of New York represents an ancient cuesta, now well worn down in that vicinity, and which is lost in the Appalachian folding and faulting farther to the northeast. The main rivers which drain this region are thus obsequent streams flowing northwesterly to the St. Lawrence down the inward sloping face of the old and deformed cuesta. Their tributaries, on the other hand, flow either northeasterly or southwesterly under the influence of the folding of the region, and are often modified by glacial action. The tributaries more frequently have falls or rapids, and thus give rise to the principal water-powers of the district. They are, therefore, thought to be later than the rivers into which they empty.

Local.—The particular district in which this investigation has been carried on lies on the southeast slope of the Sutton range, and between the St. Francis and Chaudière rivers. The country on the southeast presents a uniform, nearly level, surface, the skyline being broken only by the profiles of the hills of the Sherbrooke or Lake Megantic ranges in the distance. On the northwest, however, the hills of the Sutton range rise almost immediately from the boundary of the serpentine belt to a height greater than is reached by most of the hills of that series, and usually limit the view to a distance of 3 or 4 miles, or less.

DETAILED ACCOUNT.

Relief.—The country underlain by the serpentine belt has a rather distinctive relief. The hills have abrupt profiles and sometimes steep, or even overhanging, faces due to different rates of erosion of the various rocks of the series. They are thus in marked contrast to the gentle slopes and subdued outlines of older hills which compose the main ranges.

The Quebec Central railway, which follows the course of the serpentine belt throughout the greater part of the distance between the St. Francis and Chaudière rivers, has an altitude at Sherbrooke of 485 feet. At D'Israeli station the altitude is 869 feet; at Black Lake 940 feet; at Robertson 1,205 feet; at East Broughton 1,224 feet, and at Beauce Junction on the Chaudière 491 feet. Above this the hills of the serpentine belt rise from 100 feet to 1,000 feet. The surface of the belt is, therefore, arched along its length in this district in agreement with a pronounced dome structure in the Sutton range. The summit of this dome, which should be opposite Broughton station, has been removed by erosion probably aided by faulting and is now replaced by the transverse valley of a branch of the Thames river, a tributary of the Beçancour. Consequently, Broughton station at an altitude of 1,106 feet, is 100 feet lower than Robertson, 4 miles to the southwest; or East Broughton, an equal distance to the northeast. The sides of this transverse valley, northwest of the railway, are steep, and rise some 800 feet above the bed of the stream, exposing sills of serpentine.

Drainage.—The northern part of the district—except for a short distance from the Chaudière—is drained by the Beçancour river. The Thames rising on the southeast side of the Sutton range crosses it through the gap at Broughton mentioned above, and joins with the Clyde at Lloyds Mills in the township of Inverness to form the Beçancour. The Thetford river rises in Beçancour lake in the southern part of Thetford, and enters Black lake. Thence, under the name of Black stream it crosses the Sutton range by a gap in the townships of Ireland and Halifax, in which a series of lakes are formed: Trout lake, Lake William, and the Adderly lakes. From these to its junction with the Thames, it is known as the Clyde.

The Nicolet rises in Nicolet lake in the township of Garthby, and runs northwesterly to the St. Lawrence. It is joined on its course by several branches bearing the same name, one of which expands to form the Little Nicolet lakes near Asbestos.

The remainder of the district is drained by the St. Francis which runs in a southwesterly direction, parallel to the Sutton and Sherbrooke ranges, for the upper 50 miles of its course, and then turning at right angles near Sherbrooke, takes a northwesterly course, and crosses both ranges of hills on its way to the St. Lawrence.

There is a marked difference in the valley of the St. Francis in these two parts of its course. In the upper portion there are several lakes having very irregular outlines, occasional rapids, and frequently the sides of the valley are steep. It has the general characteristics of a rather young river. But in the lower part, from Sherbrooke to its entrance to the St. Lawrence, there are no lakes, although there are a few rapids. The valley is wide, and has low or gently sloping sides, except where it passes through the principal folds of the strata which it crosses. It thus has the general aspect of a valley, older than the upper portion. The tributaries which enter from the northeast or southwest agree in character with the upper rather than the lower portion of the St. Francis river. They have narrow or irregular valleys, occasional lakes, and many rapids. This is important, inasmuch as they furnish the principal powers of the district.

The Magog enters the St. Francis river at Sherbrooke by a cascade, giving a fall of 100 feet in about a fourth of a mile; which supplies water-power for the principal industries and utilities of the city. The Ouatopekah joins the St. Francis at Windsor Mills, and by a nearly similar descent on the northeast side furnishes power for the industries which give rise to that town. The upper St. Francis river in Westbury has a rapid—where the river is confined in a deeply entrenched channel—which is about to be developed for power purposes; while at East Angus the water-power furnished by the river has led to the establishment of the mills of the Royal Pulp and Paper Company; and at Herring rapids, power is obtained by the St. Francis Hydraulic Company, and transmitted to many of the mines of the district. Other tributaries of the larger river furnish small water-powers; but in nearly all instances they are in streams running northeast or southeast, or parallel to the folding of the ranges of hills.

Climate.

The average temperature of the district is about 40° F. Extremes of summer heat rarely rise above 90° F., while the temperature in winter only occasionally falls below 25° F. The average temperature for July and August is 65° F., for January and February 15° F.

There is an annual precipitation of about 40 inches, of which as much as 30 inches fall as rain. The remainder calculated as snow gives a total snowfall of 90 to 100 inches. The amount and frequency of snowfalls is an important factor in the cost of mining operations, which are largely carried on by open-cut methods.

Agriculture.

The summer season is not long, but is one of rapid vegetation. Seeding is usually done in May; hay is cut in July; grain harvested in August, and root crops early in September.

Mixed farming and dairying are the agricultural occupations. In the intervals between necessary farming operations farm labourers often find employment in the mines. This practice is probably growing less owing to improved methods of farming, and more especially to the constant occupation occasioned by the dairying industry.

Transportation and Communication.

The building of the railways of the district was mentioned in the historical sketch which forms an earlier part of this report. The greater part of the district is served by the Quebec Central railway, now a portion of the Canadian Pacific Railway system. The principal shipping stations for the mines on this line are Thetford Mines, Black Lake, and East Broughton. Thetford Mines is 76 miles from Quebec, 67 miles from Sherbrooke, and 168 from Montreal. Black Lake is 4 miles south of Thetford Mines and East Broughton, 18 miles to the north. Sidings or short spurs lead to the principal mines.

The mines at Asbestos are reached by a line of 4 miles owned by the Danville Asbestos and Asbestic Company, Limited, which connects the mines with the Grand Trunk railway at Danville, 88 miles from Montreal and 86 miles from Quebec.

Public roads reach all parts of the district. These are generally located on range lines, but frequently are adjusted to the topography of the district, or to give suitable access to the railway. The best of these roads are maintained in a condition that can be described as only tolerably good. The majority of them are poor. The custom of repairing roads by statute labour still obtains, and little if any permanent road building is done.

Telephone and telegraph communication can be had throughout the district.

GENERAL GEOLOGY.

General Statement.

REGIONAL.

North of the St. Lawrence valley the Pre-Cambrian of the great continental protaxis extends northward and northwestward to Hudson straits and the Arctic ocean. The St. Lawrence valley is underlain by strata of Palæozoic age which range from Cambrian to Devonian. From the edge of the Pre-Cambrian to about the middle of the valley the strata are in ascending order and little disturbed in position. The general dip is towards the southeast, at an angle rarely more than ten degrees, and generally about five or six. The Potsdam, Calciferous, Chazy, Trenton, Utica, and Lorraine, are successively exposed without—as far as known—any time break in the series. This portion of the valley is separated from the eastern part by a fault running from the head of Lake Champlain to the St. Lawrence river near Quebec city, whence it continues in or near the river channel far to the northeastward. The total length of this dislocation was estimated by Sir William Logan at not less than 900 miles. The plain is heavily drift covered, and there is rarely, if ever, any topographic expression of this fault in the Province of Quebec south of Quebec city. But the rocks in the eastern side of the fault are distinguished from those of the western part of the valley plain by their being highly folded and greatly disturbed from their original position, also by palæontologic and lithologic differences.

The lithologic differences, besides those due to dynamic metamorphism, are such as to indicate in general, shallow water deposits on the eastern side of the fault. The palæontologic features which distinguish the eastern from the western part of the valley denote colder water in the former and are interpreted by Schuchert and Ulrich[1] as indicating a narrow barrier in early Ordovician time

[1] Ulrich and Schuchert, 'Paleozoic Seas and Barriers,' N.Y. State Museum Bulletin 52, pp. 633-663, 1902.

running northeasterly through the central part of the present valley. The diastrophic differences denote that the Champlain and St. Lawrence fault took place near the western limit of the Appalachian uplift.

The strata in the eastern part of the valley are regarded as nearly contemporaneous with those in the western part. As the highlands, formed by the greater uplift along the main anticlinal ridges, are approached, however, the lower formations are more largely exposed.

The central portions of the main ranges of the highlands consist of highly metamorphic rocks. A part of these are altered volcanics, porphyries, and greenstones—which are thought to be of Pre-Cambrian age. Another considerable portion is made up of altered sediments, and perhaps pyroclastic rocks, whose age is extremely uncertain. Occupying the basins between the main ranges, flanking the ridges, and in places almost completely covering them, are sediments of Palæozoic age similar to those of the eastern part of the plain. Here, however, there are distinct evidences of an erosional unconformity between the Ordovician and the Cambrian: while no time break is thought to have occurred in the deposition of the strata west of the Champlain and St. Lawrence fault.

Through the sediments of both the plain and the highlands there have been considerable intrusions of igneous rocks. Across the plain the intrusions of the alkaline rocks of the Monteregian series form eight conspicuous buttes. In the highlands isolated intrusions of granite occur chiefly in the trough between the Sherbrooke and the Lake Megantic ranges; the intrusives of the serpentine belt are in the trough between the Sherbrooke and the Sutton ranges, near and parallel to the latter. With the exception of a part of the serpentine belt chiefly developed in the township of Broughton, all these intrusives appear to be of about the same age; their intrusion being assigned to late Devonian time, which is known to have been a period of igneous activity in the Appalachians north of New York.

Outlying remnants of sediments high up on the hills of intrusive rocks indicate that the region has been deeply eroded, and that the surface has been considerably lowered by subsequent denudation. Small occurrences of Devonian strata at Lake Memphremagog and Montreal show that that system had some distribution within the region and has now been all but completely removed. Rocks of Silurian age are somewhat widely distributed, but in small areas;

while Ordovician sediments on Mount Royal and Shefford mountains of the Monteregian series, indicate that the surface of the St. Lawrence plain has been eroded, at least, to a depth of 600 feet to 1,000 feet.

Heavy glaciation has come from the north-northwest, and the resulting land forms are modified in places by later local glaciation in which there has been ice movement from the east of north generally following the structural valleys of the region. The St. Lawrence plain is heavily drift-covered and the same may be generally said of the troughs between the main ranges of hills. At lower levels the drift has been reassorted by water showing submergence since the latest glacial period. In the St. Lawrence valley marine fossils up to 615 feet above present sea-level show that the submergence extended to the ocean. Terraces in the valleys of the highlands are found at a higher level, but evidence has not been found that the waters by which they were formed were marine.

LOCAL.

Sedimentary Rocks.—The district occupied by the serpentine belt and the rocks associated with it lies on the southeast side of the Sutton range. This range has an anticlinal structure, and consequently the strata of the district, with local exceptions, dip towards the southeast. The stratified rocks in the district consist broadly of slates, quartzites, and sandstones, all of which have been greatly deformed and altered by regional metamorphism. Those rocks which border on the serpentine series in the part of the district thus far studied, are all considered to be of Cambrian age and the oldest in the district with the possible exception of some outlying occurrences of serpentine at some distance northwest of the main belt.

The Cambrian strata consist of a coarse feldspathic sandstone or greywacke and red and green slates, underlain by quartzites and grey or greenish grey schists and slates. The red slate and sandstone are a southward extension of the Sillery formation, which occurs typically at Sillery cove near Quebec city, and farther down the St. Lawrence river. The quartzites and grey slates are similar to the rocks which underlie the Sillery in the region between the Chaudière river and Rivière du Loup, for which the name L'Islet formation has been proposed, from its extensive occurrence in that county. It appears to underlie the Sillery conformably, but is distinguished from it in the original character of the rocks, in the degree of alteration, as well as by stratigraphical position.

The Cambrian is overlain on the southeast by altered black slates of Ordovician age, which are referred to the Farnham series or lowest Trenton. They have not yet been found in actual contact with the intrusive rocks in this district, but a short distance to the south they are cut by the intrusives of the serpentine belt.

On the northwest or underlying side, the grey slates and quartzites are succeeded by quartzose and sericitic schists. It is not known with certainty whether these belong to the same, or to an older formation. But as the question is of no economic importance, and the rocks in question occupy a very small part of the area, they are not distinguished on the accompanying map, in which all the sediments are shown as undifferentiated Palaeozoics.

Igneous Rocks.—All the igneous rocks, with the possible exceptions mentioned above, have been intruded into the Cambrian formation.

The area occupied by them may be conveniently called the serpentine belt, since the serpentine, although not the most abundant in it, is the rock which contains the principal mineral deposits. In this district there are two phases of the igneous rocks in the serpentine belt which differ in economic importance; in degree of alteration, and, possibly, also in age. They are distinguished as the Thetford phase and the Broughton phase, from townships in which they are characteristically developed.

All the igneous rocks are in the form of sills, or of larger intrusive masses which are either batholiths or thick laccoliths. The different rock varieties are generally differentiates from single intrusions. The granites, and in some cases portions of the porphyrites, have apparently been intruded a little later than the other rocks of the series. The rocks of an individual intrusion usually become less basic from the base of a sill upward, or from the centre of a stock outward. Accordingly peridotite and serpentine are usually found near the base of sills and towards the central part of stocks.

TABLE OF FORMATIONS.

Sedimentary.

Quaternary		Sands and gravels. Stratified clay. Boulder clay.
Ordovician	Farnham	Black slates. Conglomerate.
Cambrian	Sillery	Red and green slates, and sandstones.
	L'Islet	Quartzose, grey schists, and quartzite.

Igneous.

(Intrusive and of different ages).

Post-Sillery; in part at least, Post-Farnham and possibly later than lower Devonian.	
Thetford Series	Peridotite, altering to serpentine; pyroxenite, gabbro, diabase, and porphyrite; granite and aplite.
Post-L'Islet Series Broughton.	Serpentine. Soapstone. Greenstone schists.

Description of Formations.

Neither the scale of the map accompanying this report, nor the facilities for preparing it admit of a separation of the sedimentary formations from one another. Nor does the economic reason—for which this investigation has principally been made—require such a separation. Consequently, in considering the distribution of the various formations enumerated in the preceding table, they may be grouped as sedimentary, and igneous.

SEDIMENTARY.

Distribution.

Along the northwestern part of the district there are highly metamorphic rocks, which are possibly older than the Cambrian; but they cannot, with certainty, be distinguished as such, in the area examined. The Cambrian, as exposed, forms a band on each side of the serpentine belt throughout the district. The igneous rocks are intruded in some places in the Sillery; at others in the L'Islet formation; and again in others they have been injected in the transition rock between them. The entire Cambrian is usually from 4 to 5 miles wide, but, in places, much exceeds that breadth. This includes a large number of overlying areas of Ordovician which commonly occupy the troughs of minor folds in the Cambrian.

The Ordovician, in general, occupies the southeastern part of the district as a continuous formation.

The Quaternary formation covers much the greatest part of the area, which is heavily drifted, especially in the less elevated portions.

Lithological Characters.

L'Islet.—The rocks of this formation are grey, quartzose schists, and quartzites. The schists have a considerable range in colour; from dark to light grey according to the amount of quartz in them. The quartz is in grains as a constituent of the rock and in veins of secondary origin. In places, the veins are very numerous. Besides quartz the rock shows mica (sericite), and in places, chlorite, and some grey material which is indeterminable in the hand specimen. The quartzite is in places fairly pure, and has a nearly white colour. In other parts, feldspar grains can be seen, also small flakes of sericite.

In thin section the schist is found to consist essentially of quartz, feldspar, and sericite. Grains of iron oxide are occasionally found. With the increase of quartz the schist passes into schistose quartzite; and where the amounts of feldspar and mica are relatively small, into quartzite.

Sillery.—The rocks which compose the Sillery formation are red and green slates, and sandstone.

The slates are rather siliceous rocks, generally, with a good cleavage. As compared with the schists of the L'Islet formation they have a finer texture, better cleavage, are less broken, and have many less veins of quartz. The green variety shows a considerable amount of chlorite in the microscope sections; the red carries minute grains of hematite. Both contain quartz and feldspar in rounded grains and mica in shred-like forms.

The following chemical analysis of reddish slate from Kingsey, range I, lot 4, just outside of the present map sheet, shows the general composition.

Analysis of Sillery slate, by T. Sterry Hunt[1]:—

SiO_2	54·80
Al_2O_3	23·15
FeO	9·58
MgO	2·16
CaO	1·06
K_2O	3·37
Na_2O	2·22
H_2O	3·90
	100·24

The sandstone in the counties of Beauce, Megantic, and a part of Wolfe, has the general aspect of the Sillery sandstone of the type locality near Quebec city. The hand specimen shows feldspar and quartz as the principal minerals. Under the microscope it shows the same minerals with the addition of grains of iron ore cemented together by a finely crystalline mineral probably quartz. It is typically an arkose. In the southern part of the area under description, the sandstone has a chloritic cement and the rock becomes properly a greywacke. In some phases it is highly feldspathic, and contains very little quartz. Leucoxene is quite abundant in this phase.

The term sandstone has been used in a generic sense for these two varieties, since they form a single stratigraphic unit, and frequently pass by gradation from one stage to the other.

Farnham.—The principal rock of the formation is a soft, fissile, argillaceous slate, of steel grey colour. In places, it contains noticeable amounts of graphite, and in many cases magnetite is quite plentiful in microscopic grains. Near igneous intrusions and in places that have been especially altered, it has developed a small amount of secondary mica (sericite) and so becomes a true phyllite. Quartz stringers and veins are common in this rock, and the veins frequently contain small amounts of crystalline calcite interlocking with the quartz. Lenses or possibly small beds of feldspathic quartzite are occasionally found in these slates. The following are chemical analyses[2] of two specimens of this rock from the Danville slate quarry.

[1] Report Geol. Surv., Can., 1852-3.
[2] B. J. Harrington, Report Geol. Survey, Canada, Vol. VIII, 1895, p. 60J.

Analysis of slate from Danville:—

SiO_2	55·75	67·85
Al_2O_3	17·87	9·10
FeO	9·07	11·14
MnO	0·70	0·79
MgO	5·81	3·23
CaO	1·14	0·98
K_2O	2·97	0·44
Na_2O	1·12	1·80
H_2O	5·26	4·55
	99·69	99·88

The base of the Farnham formation consists of pebbles of greywacke, sandstone, and quartzite of the underlying Sillery and L'Islet, in a matrix of the black slate just described. The pebbles are usually well rounded, probably waterworn, and rarely exceed 3 or 4 inches in diameter. They are not, as a rule, closely packed together, but frequently form about one-fourth of the whole rock mass. In places, this conglomerate has a thickness of 100 feet, or more. It is a very constant feature of the lower part of this formation for 2 or 3 miles northwest of the original occurrences of theso rocks.

Quaternary.

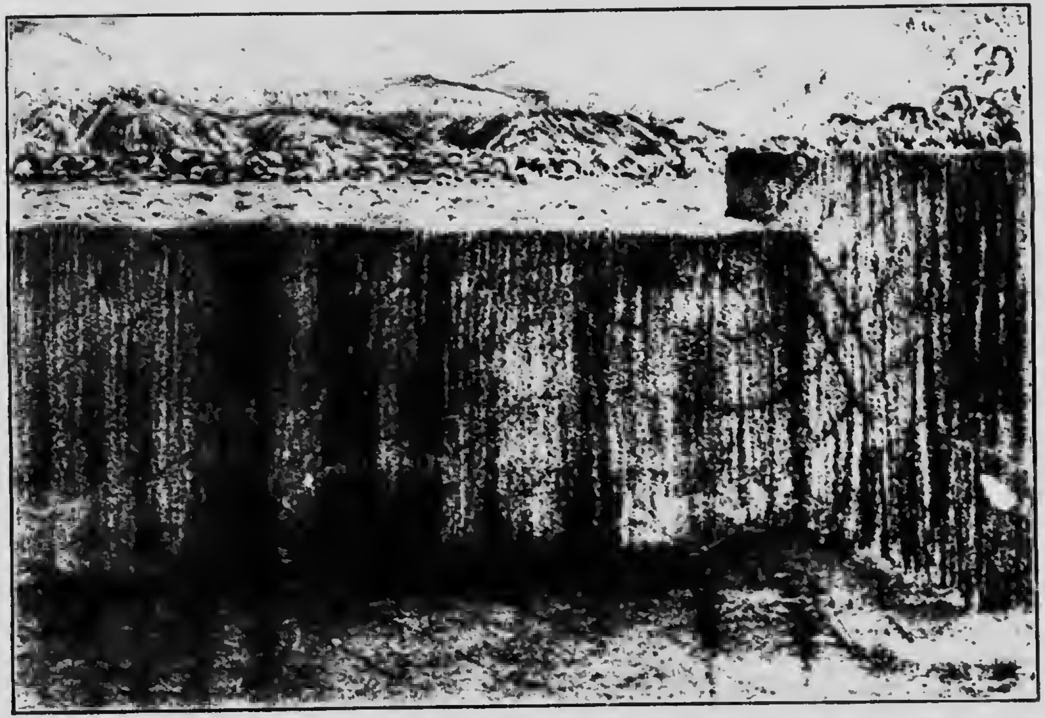
Glacial movement that came from the east-northeast, appears to have been later and lighter than that from the north-northwest.

A considerable portion of the drift of this area consists of stratified clays. These have a thickness in places of 100 feet and are wide-spread and occur up to an altitude of about 500 feet.

There are also thick deposits of sands and gravels locally stratified, as in the vicinity of the Little Nicolet lakes near Danville. In this instance they are probably a delta deposit of the Champlain period. In other places they occur as terraces around lakes, or along river channels. Like the clays, the sand and gravels are largely products of the assorting of the boulder clay by water action since the last glacial period.

Boulder clay is frequently found resting on the solid rock where exposures are suitable for showing it. It consists, as usual, of unassorted glacial débris, the boulders representing widely different rock formations. Boulders of Laurentian granite and gneiss and other rocks characteristic of the Pre-Cambrian highlands north of the St. Lawrence river, are quite common, but are not numerous. The greater number of erratics are from formations that occur on

Plate II



Sketch of southwest wall of the old Danville slate quarry, showing the crumpling and the dip of Ordovician slates to the southeast. The vertical wall shown is 30 feet high.

11159—p. 22

the south shore of the St. Lawrence river, and many are of local origin.

A general glacial movement from the north-northwest is evidenced by numerous striæ and scorings in the solid rocks, and by the distribution of Laurentian and other erratics from that direction. There has also been local glaciation governed by the present topography. Striæ from east-northeast are common, and distinctive boulders, such as serpentine and pyroxenite, are frequently found for a distance of 3 or 4 miles south and west of occurrences of these rocks in place.

Structural Relations.

Internal.—The sedimentary rocks are all foliated, the degree of foliation varying with the susceptibility of the rock to deforming agencies. The quartzites and sandstones show the least evidences of compression, but even they in places have quite a distinct cleavage. The argillaceous rocks are generally reduced to finely fissile slates, and are sometimes folded and wrinkled in a very intricate manner.

The cleavage of the rocks roughly coincides with the bedding in strike, seldom differing from it by as much as 20°. In dip, however, there is no general agreement between bedding and cleavage. The dip of the cleavage is usually at high angles or nearly vertical, and where the strike agrees with that of the bedding, the dip of the latter is often obscured.

External.—The relations between the sedimentary and the igneous rocks will be described in the consideration of the latter.

In this district there are no strata later than the Ordovician, except the Quaternary, which, of course, overlies it unconformably. The rocks of the region—which are older than the L'Islet formation—are not sufficiently developed in this district to show decisively their relation to that formation. No conglomerate or other indication of unconformity, such as might denote the base of the Cambrian system, has been found.

The only structural feature in the relation of the sedimentary formations to one another that calls for description, therefore, is the relation between the Ordovician and the Cambrian.

Relations between Ordovician and Cambrian.—Near their base the Ordovician slates contain pebbles of quartzite or sandstone similar to the underlying Cambrian. The pebbles are larger and more numerous nearer the contact.

In the township of Ham, south and west of Little Ham mountain, where there are numerous narrow bands of Ordovician overlying a rather wide area of Cambrian, there is a discordance in the bedding of the two formations. The Cambrian strikes quite uniformly N. 55° to 60° E., while the Ordovician as constantly strikes due east, or a few degrees to the north of east. The dips are too far obscured to be reliable evidences in this locality. But the basal conglomerate and the discordant bedding indicate that an erosional, and in this locality, at least, a stratigraphic unconformity exists between the Cambrian and the Ordovician.

The conglomerate is a general feature, and may be found in all occurrences of the formation. The difference in strike was clearly observed only in the townships of Ham, Wotton, and a part of Shipton; that is, in the vicinity of that part of the serpentine belt which swerves to the eastward, out of the general direction of the belt.

Mode of Origin.

The solidified sediments of the district were originally sandstones and shales, and accordingly are regarded as shallow water deposits.

Cambrian.—The Pre-Cambrian old lands, comprising the porphyry-greenstone ridges and possibly some early sediments, have doubtless furnished much of the material of the sandstone or greywacke, which are distinguished from their equivalents farther to the northward and near the Laurentian, by a chloritic or muddy cement. But this source was probably not adequate to supply the material of the shales of the period. These are generally similar to those of the lower St. Lawrence, and are probably derived in considerable measure, at least, from off shore detritus of the Laurentian.

Ordovician.—The conglomerate at the base of the Ordovician consists of pebbles of sandstone and quartzite that are identifiable with beds in the Cambrian, in a matrix of black shales. The shales are composed of material that might have been derived from the

Cambrian slates, with the addition of subordinate amounts of carbonaceous, ferruginous, and calcareous matter.

Age and Correlation.

Cambrian.—The L'Islet and Sillery formations are identified in this district by their lithological characters and stratigraphical relations to each other and to the overlying formation. They have also been traced to the type occurrence of the Sillery near Quebec city where they contain fossils, and have been much studied by earlier investigators. They are assigned to the upper Cambrian, on the determinations of that age for the Sillery by Ells and Ami.[1] No fossils have been found in the district in which this investigation has been carried on.

The determination of the age of these strata, therefore, depends on the previous determination of the Cambrian near Quebec, on their identification by lithologic and stratigraphic evidences in the intervening distance; and on the assumption that sediments of similar lithologic character were deposited at the same time in parts of the Lévis trough, 100 miles apart.

Ordovician.—The age of the rocks of this system has been determined by Ells and Ami on the evidence of fossils which were found by Dr. Ells, at Castle brook, in the township of Magog in Stanstead county.[2] The fossils at this locality occur near the base of the formation which is [illegible]ed by the basal conglomerate consisting of pebbles of the [illegible]g sandstone and quartzite in a matrix of Farnham slate. The conglomerate, which is of wide-spread occurrence, is the most important datum line in working out the stratigraphy of the district.

IGNEOUS.

Thetford Phase.

Distribution.—The igneous rocks in this district south of Wolfestown form a narrow belt, seldom reaching a mile in width. They extend from the St. Francis river at Corris station on the Grand Trunk railway in the county of Richmond northeasterly to the mines of the Asbestos and Asbestic Company near Danville, a

[1] Annual Report, Geological Survey Canada, 1887.
[2] Annual Report, Geological Survey, 1894, Part J.

distance of 12 miles. It is a marked feature of this section that the northwestern side of the belt is always serpentine, the southeastern generally diabase or pyroxenite. This arrangement is characteristic of a sill which dips to the southeast. After a drift covered interval of about a mile in which the bed-rock cannot be determined, the igneous rocks appear in range I of Shipton and continue in an almost unbroken band to Little Ham mountain in the county of Wolfe. This is a distance of about 10 miles and in a course only slightly north of east. Diabase is the prevailing rock in this section, although areas of serpentine are exposed here and there on the north-northwest side of the belt. The igneous rocks next appear, in Big Ham mountain, 5 miles to the southeast, the interval being occupied by Cambrian and Ordovician sediments. From the southwest end of Big Ham mountain the igneous belt again takes a northeasterly trend, and extends with one or two minor interruptions to the road leading from Coleraine station on the Quebec Central railway, to Wolfestown. In this section the belt is in places more than a mile in width. The distance is 18 miles.

In the next 10 miles to the east-northeast, the serpentine belt is very irregular, and in places becomes much wider. These are batholithic, or laccolithic masses, and comprise the area which contains the important mines of Thetford and Black Lake. Broadly described, there are two nearly parallel belts for a short distance here, each 2 or 3 miles wide, and 2 miles apart: the hills from Wolfestown to Thetford mines form one; while the ridges running from the vicinity of D'Israeli to Adstock mountain, form the other; but they are very irregular. Farther to the northeast the igneous rocks are chiefly diabase, and form a nearly connected but narrower belt past Clapham lake, and thence to Broughton mountain, a distance of 12 miles from Thetford Mines.

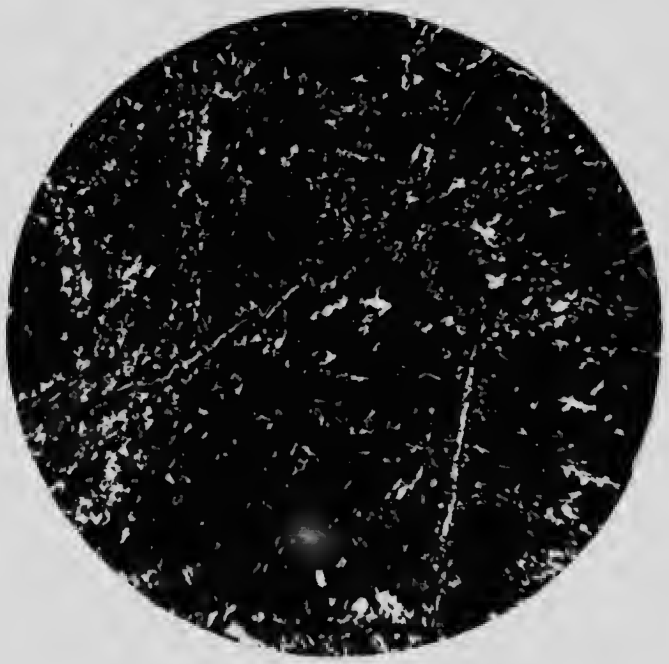
Lithological Characters.—The essential features of the two phases of igneous rocks can be best shown by a comparative view of the rocks which compose them:—

Big Ham mountain, from a distance of six mi.. This profile is characteristic of the hills that are composed of diabase and other less basic rocks of the serpentine belt.

Plate IV

Microphotograph of peridotite (Specimen 2048). The rock consists essentially of grains of olivine slightly serpentinzed around their edges.

Plate V



Microphotograph of serpentine (Specimen 2049).

11159---p. 26

Thetford phase.	Broughton phase.
Peridotite partially altered to serpentine.	Serpentine.
Pyroxenite.	Soapstone.
Gabbro.	Greenstone schists.
Diabase.	
Porphyrite.	
Granite.	
Aplite.	

The most noticeable difference between the rocks as seen in the field is the degree of alteration. While all are highly metamorphosed, the rocks of the Thetford phase are fresh and well preserved in comparison with those of Broughton. The serpentine of the Broughton phase is much more shattered than that of Thetford: peridotite, and pyroxenite are not found in the Broughton phase, while the greenstone schists of Broughton are a mass of igneous rocks, so altered that, the original rock varieties cannot be distinguished with any degree of certainty.

Peridotite.—Peridotite is dark green in colour, on a fresh surface, and weathers to a dull, or sometimes rusty brown. Grains of iron oxide, and the glistening faces of pyroxene crystals, can occasionally be distinguished in the hand specimen.

The rock consists essentially of olivine, with minor amounts of pyroxene, and accessory magnetite and chromite. In places, the pyroxene is present only in accessory amounts and the rock becomes a [illegible]ite. With an excess of pyroxene over olivine it becomes pyroxenite.

The olivine is usually reduced to serpentine in thin films covering the faces of crystals, and in consequence the serpentine and peridotite rocks look so much alike that in the field it is difficult and often impossible to distinguish them except on weathered surfaces. The differences in their mineralogical composition and structure can be seen in the accompanying microphotographs shown in Plates IV and V.

The olivine is in crystals of fairly uniform size, which appear to have been formed at about the same time. Iron ore, where present, is the only earlier constituent. Pyroxene forms larger crystals than the olivine which they are sometimes found to enclose.

The following chemical analyses show the composition of typical specimens of the dunite variety:—

—	1.	2.	3.	4.	5.	6.
SiO_2	38·16	38·24	42·80	29·81	43·87	38·40
TiO_2	none.	none.	......	2·20	tr.	......
Al_2O_3	0·63	0·70	......	2·01	1·64	0·29
Fe_2O_3	3·32	3·50	......	5·16	8·94	3·42
FeO	4·76	4·25	9·40	4·35	2·60	6·69
MgO	41·84	41·92	47·38	32·41	27·32	45·23
CaO	0·68	0·68	......	7·69	6·29	0·35
K_2O	0·20	0·20	......	0·29	0·50	0·08
Na_2O				0·11		
$H_2O-110°$	0·47	0·60	0·57	......	1·08	......
H_2O+110	9·63	9·76	*	*8·92	*7·64	4·11
	99·69	99·85	......	......	......	......

* Also minor amounts of rare constituents.

(1) Near Black Lake station (Specimen 2048). Analysis by M. F. Connor.

(2) Ireland, range II, lot 28 (Specimen 3291). Analysis by M. F. Connor.

(3) Dun mountain, New Zealand.

(4) Peridotite, Elliott county, Kentucky. Described by J. S. Diller. Analysis by T. M. Chatard.

(5) Lherzolite, Baltimore. Described by G. H. Williams. Analysis by T. M. Chatard.

(6) Dunite, Tulameen, B.C. Described by J. F. Kemp, and later by C. Camsell. Analysis by W. F. Hillebrand.

It will be seen by comparison of these analyses that, the nearest analogue of the dunite of southern Quebec is that from Tulameen, B.C.

Serpentine.—The serpentine is dark olive green in colour, and often weathers to a cream colour. It shows no crystalline structure itself, but contains occasional crystals of pyroxene, and grains of iron oxide. The rock is frequently fractured and slickensided, showing movement of the different parts of the rock against one another. In the thin section remnants of olivine are rarely found, though outlines of olivine crystals altered to serpentine can more frequently be seen. Minute veins of asbestos are frequently found running in courses that suggest the characteristic lines of parting along which serpentinization is often seen to begin in partially altered crystals of olivine in peridotite (*see* Plate IV).

The following analyses show the composition of serpentine from this district and from several other localities:—

—	7.	8.	9.	10.	11.	12.
SiO_2	40·08	37·66	39·14	37·82	41·13	43·40
TiO_2	none.	tr.	....	....	....	....
Al_2O_3	2·11	1·61	2·08	0·61	0·84	....
Fe_2O_3	1·13	6·15	4·27	7·92	3·86	....
FeO	1·70	1·87	2·04	1·15	2·77	3·60
MgO	*37·90	38·66	39·84	37·94	41·88	40·00
CaO	0·20	0·22	tr.	none.	tr.	....
K_2O / Na_2O	0·10	0·20	....	tr.	....	....
$H_2O - 110°$	1·35	0·75	12·70	0·75	10·88	13·00
$H_2O + 110°$	13·89	12·49		12·50		
	98·76	99·61	100·18	....	101·36	100·00

* MgO probably low,

(7) Serpentine near Black Lake station. Analysis by M. F. Connor.

(8) Serpentine, Garthby, range II, lot 40. Analysis by M. F. Connor.

(9) Serpentine, Greenville, Plumas Co., California. Described by J. S. Diller.

(10) Serpentine said to be derived from enstatite, Granville, Mass.

(11) Serpentine from dunite. Le Bonhomme Vosges. Cited from Rosenbusch "Elemente Gesteinslehre."

(12) Serpentine, Ham, range II, lot 4, Wolfe county. Analysis by Hunt.

Regarding the origin of serpentine, the late T. Sterry Hunt,[1] basing his observations on experiments by Daubrée on the crystallization of feldspar, said:—

"The solution of silica by carbonate of soda and the conversion of carbonates of lime, magnesia and iron into silicates, by its aid, may be effected at the heat of boiling water...................... The various siliceous minerals of crystalline or metamorphic rocks may then be regarded as having been formed either by the crystallization and rearrangement of silicates occurring in the sedimentary

[1] Geology of Canada, p. 584.

strata, or by the union of silica, uncombined, or united with an insufficient amount of base, with oxides existing in the sediments, generally in the state of carbonates. In these reactions are included the formation from the materials of sedimentary rocks, of feldspars, micas, scapolite, epidote, garnet, tourmaline, kyanite, andalusite, staurotide, chlorite, pyroxene, hornblende, olivine, serpentine and talc."

The relation of serpentine to peridotite, as seen, both megascopically and microscopically in this and other parts of the world, has caused the opinion of Hunt and others who held like views, to be long since abandoned. The constant association of serpentine with igneous rocks, and the ample evidences of the alteration of peridotite and allied rocks to serpentine abundantly prove it to be an altered igneous rock, and not of sedimentary origin.

Pyroxenite.—This is a dark, green rock, holocrystalline, and often very coarse in texture. Pyroxene crystals, a small amount of interstitial serpentine, and grains of iron oxide can be seen in the hand specimen. The microscopic section shows little more. Remnants of olivine are occasionally found in the serpentine, and portions of the pyroxene are sometimes altered to talc, and other decomposition products. The pyroxene, which is by far the most abundant mineral, is largely diallage although numerous crystals have the optical characters of enstatite, and others of augite. It frequently occurs in very large crystals, in places showing cleavage faces as large as 5 inches by 8 inches. The following analysis, No. 13, is of pyroxene from a pyroxenite hill, a short distance south of the Danville Asbestos mines. The analysis was made by Mr M. F. Connor, Mines Branch, Department of Mines, Ottawa.

Chemical analyses of diallage:—

—	13.	14.	15.
SiO_2	50·36	47·20	50·41
Al_2O_3	4·42	3·40	4·05
Cr_2O_3	0·47	trace.	0·60
FeO	3·34	8·91	6·57
MgO	18·21	24·53	15·33
CaO	20·85	11·36	21·34
K_2O	not det.	—	0·42
Na_2O	"	......	0·55
H_2O − 110°	0·37	......	0·88
H_2O + 110°	1·11	5·80	0·37
	99·13	101·20	101·60

(13) Diallage, near Danville Asbestos Mines, Richmond county, Que.

(14) " Ham, Wolfe county, Geol. Canada, 1863, p. 469.

(15) " Wildschönau, Dana System of Mineralogy, VI edition, p. 369.

The rock pyroxenite being composed so largely of pyroxene minerals, its composition, as might be expected, bears a general resemblance to that of pyroxene. The presence of a subordinate amount of olivine or serpentine lowers the content of silica and lime and increases the magnesia iron.

Chemical analyses of pyroxenite.

—	16.	17.	18.
SiO_2	46·30	52·55	46·30
TiO_2	trace.	0·14	
Al_2O_3	2·58	2·71	5·27
		Cr_2O_3 0·44	
Fe_2O_3	3·45	1·27	2·59
FeO	3·57	4·90	2·92
MgO	23·18	20·39	22·42
CaO	15·20	16·52	17·30
K_2O, Na_2O	0·15	0·27	
		MnO 0·24	
H_2O −110°	0·66		
H_2O +110°	4·77	1·09	4·02
	99·86	....	100·32

(16) Pyroxenite, Garthby, range II, lot 40. Analysis by M. F. Connor.

(17) " var. Websterite, Baltimore, Md., U.S.A.

(18) " var. Diallagite Gaispfadpa B, Oberwallis. Cited by Rosenbusch "Elemente Gesteinslehre," p. 222.

Gabbro.—Coarse textured rocks consisting essentially of diallage and plagioclase, which are commonly found between pyroxenite and diabase, are referred to the gabbro family. In places, they are much altered, and with, or instead of diallage, contain colourless hornblende, which is apparently secondary, and the aggregate of decomposition products known as saussurite. In such cases the rock is conveniently called gabbro diorite in the sense that the term was used by G. H. Williams[1] to indicate the history as well as the composition of the rock.

A specimen of gabbro from the township of Garthby where the rock is well developed and is especially well preserved, was described by Dr. F. D. Adams[2] as follows: 'This rock occurs associated with the serpentine. It is composed of diallage and plagioclase. The diallage is for the most part tolerably fresh, though in places it is decomposed. In addition to the prismatic cleavages, it has the usual perfect cleavage or 'theilbarkeit' parallel to the orthopinacoid. In most of the crystals occurring in the section which show this cleavage, the axes of elasticity make an angle with it; but several grains were found which were cut in a direction approximating the base or an orthodome, and in which, consequently, the extinction almost or quite coincided with the cleavage. By examining the axial figure seen in such sections, the plane of the optic axes was found to be at right angles to the cleavage, thus proving that the mineral was really diallage and not a rhombic pyroxene. The plagioclase in the section is now entirely decomposed, principally to a dull translucent mass with aggregate polarization (saussurite?). Numerous very minute scales of oxide of iron are scattered through the rock.'

'It bears a very close resemblance to a gabbro found near the head of the Upsalquitch river in New Brunswick.'

Diabase.—This is a fine grained rock, greyish-green in colour. Streaks and spots of epidote can be frequently seen in it. In the thin section little can be seen of the primary character of the rock. Chlorite, epidote, quartz, calcite, and leucoxene, all secondary minerals, are now the principal constituents. Actinolite forms tuft-like aggregates of fine crystals in a few places. Pyrite, and in places magnetite, are common accessory minerals. Specks and strings of chalcopyrite are not uncommon.

In occasional sections, however, some primary plagioclase remains, and its relations to decomposition products of pyroxene indicate that the rock was originally diabase.

A specimen taken on lot 40, range II of Garthby, Wolfe county, analysed by Mr. M. F. Connor, Mines Branch, Department of Mines, Ottawa, showed the composition given under No. 19.

[1] Bulletin No. 28, U.S. Geological Survey.
[2] Report Geological Survey, Canada, 1880-82, p. 12A.

Chemical analyses of diabase:—

—	19.	20.	21.
SiO_2	42·96	45·46	46·68
TiO_2	0·66	—	—
Al_2O_3	17·45	19 94	17 12
Fe_2O_3	2·29	15·36	2·18
FeO	11·04	—	7·61
MgO	9·77	8·71	10·34
CaO	6·80	10·12	13·46
K_2O	1·51	3·21	trace.
Na_2O	1·93	2·12	1·75
$H_2O - 110°$	9·47		
$H_2O + 110°$	4·75	2·20	0·88
	99·63	....	100·02

(19) Diabase, Garthby, range II, lot 40. Analysis by M. F. Connor.
(20) " Ausable Forks, N.Y. Analysis by J. F. Kemp. .
(21) " Gabbro-diorite. Windsor Road, Baltimore, Md. Analysis by L. McCay.

The analysis No. 21, which is introduced for comparison, is from a gabbro-diorite near Baltimore which has been described by G. H. Williams.[1] In the Baltimore area, Williams found the gabbros and gabbro-diorites to have the same general composition. In the district being described, the diabases and gabbros are thought to differ in structure due to conditions of cooling of the magma rather than to original differences in chemical composition. The similarity between analyses No. 19 and No. 21 supports this view.

Porphyrite.—Marginal phases of the diabase just described are frequently found which in the thin section exhibit the characters of porphyrite. The structure is plainly porphyritic. The groundmass is chiefly chlorite and epidote in fine granular condition, and phenocrysts of plagioclase can be discerned. It is well shown on the south side of Shipton Pinnacle and in many places along the upper margin of sills. Although it is not an important rock of the series in regard to the area it occupies, it is noteworthy as it marks the acid extreme of differentiation in many places.

Granite.—The granite of the serpentine belt is rather light in colour, and consists essentially of quartz, orthoclase, plagioclase, and hornblende. A little iron oxide is generally present. In places,

[1] U.S. Geological Survey, Bulletin 28.

biotite occurs even in essential amounts, but in general it does not occur at all. It is most abundant in the central parts of the larger bosses of granite such as are found between the Poudrier road and Thetford Mines. In such places it is also noticeable that the granite is often porphyritic.

There is a curious lithologic feature of this rock which seems worthy of note. The relation of the hornblende to the quartz indicates either an unusual mode of alteration of the former, or some form of magmatic corrosion between them. It was first observed in the granites of this belt from the township of Shipton, by Dr. F. D. Adams.[1] Dr. Adams thus described it: "The rock is no longer fresh. The feldspar, of which a very considerable proportion is plagioclase, is a good deal decomposed, and the hornblende is altered in a very peculiar and hitherto unobserved manner. Three stages of alteration can be clearly distinguished. (1) The hornblende changes to a scaly mass having all the appearance of chlorite. This zone is not always present. (2) There is a zone of fine needles, generally in tufts, with parallel extinction, and which have a brown or yellow colour. This colour, however, probably does not belong to the needles themselves, but is due to the separation of hydrated oxide of iron on the decomposition of the hornblende molecule. (3) Running out from these tufts are long and exceedingly fine, hair-like needles which penetrate the quartz. These are colourless, and probably the same as those of the yellow zone, but longer and finer. Dr. George Williams, of John Hopkins University, remarks the curious fact of the 'constant relation existing between a hornblende and a quartz; while the edge of a hornblende crystal in contact with feldspar is quite sharp and fresh, or at most only fibrous, the edge of the same crystal in contact with quartz almost always presents the phenomena described.' Dr. Williams considers that there has been a mutual reaction of these two minerals on each other, in a way exactly similar to that so often observed between plagioclase and olivine in the Scandinavian olivine diabases, in which a zone of silicates of undetermined character is formed along a line of contact between the two minerals."

This peculiar relation of hornblende to the quartz is a very constant one in the granites of the serpentine belt.

---

[1] Annual Report of the Geological Survey, Canada, 1880, 1881, 1882, p. 8 A.

Aplite.—Aplite occurs as dykes and small intrusive bodies apparently connected with the granite. It contains no iron-magnesia minerals, but consists of quartz and orthoclase, and is so fine in texture that these minerals cannot be distinguished in the hand specimen. The total amount of this rock is small, but like the porphyrite, it is important as being an extreme acid differentiate.

Broughton Phase.

Distribution.—The Broughton phase is of less extent than the Thetford series. It consists chiefly of an upturned sill, or series of sills, which run with some interruptions from lot 13, range III, of Broughton, to lot 17, range IV, of Thetford, a distance of 13 miles. In width it rarely exceeds 300 feet. On this sill are situated the mines of East Broughton and Robertson. Several isolated occurrences of serpentine in Ham, Leeds, and Tring, probably also belong to this series.

Lithological Characters.—Serpentine.—The serpentine of the Broughton phase is lighter in colour than that of Thetford, and contains little, if any, iron ore. Much of it is finely fractured, and soft, and has a 'soapy' feel. There is a coating of slip fibre asbestos on most of the fractured surfaces. Under the microscope, occasional sections are found which show the cleavages of pyroxene in serpentine. Almost the entire rock is fibrous in places; but the mesh work of reticulating veinlets of asbestos that is often seen in serpentine derived from olivine in the rocks of the Thetford phase is not found here.

The differences in toughness and hardness of the two phases of rock is shown in the working of the mines. The amount of blasting that is necessary to remove the rock from the pits of Broughton is much less than at Thetford, while the cyclones used in the final pulverizing of the rock wear several times longer in the concentrating mills of Broughton than in those of Thetford.

In parts of the Broughton serpentine which are not fractured there is no asbestos and the rock is harder and tougher. Thin sections from such parts, which are generally near the foot of the sills, usually show the rock to be wholly reduced to serpentine, or occasionally to serpentine and chlorite. The only primary mineral that has yet been found in this rock is pyroxene, in the form of a few remnants of crystals, except at pit 17 of the Robertson mine, where there are portions of original olivine, and the character of the rock as a whole becomes more like that of Thetford.

Soapstone.—Soapstone or steatite, in places containing veins or strings of talc, has a considerable development amongst the rocks of the Broughton phase. It is distinguished by its light grey colour, and by its soft, unctuous feel. On the weathered surface it sometimes shows a rusty-brown coating, which indicates a higher content of iron than is usual. A few specks of pyrite are occasionally seen in the rock but these are rare. No chemical analyses have been obtained from the soapstone in this immediate vicinity; but from very similar material in the serpentine belt in the township of Potton, T. Sterry Hunt[1] obtained the analysis given under No. 22.

	22.	23. Theoretical composition of pure talc.
SiO_2.......	59·60	62·8
MgO........	29·15	33·5
FeO........	4·50	Usually contains a little iron replacing MgO.

Greenstone Schists.—These rocks, which occupy the position in the Broughton series taken by gabbro, diabase, and porphyrite amongst the rocks of the Thetford phase, are so far altered that their original characters cannot be definitely determined. They consist principally of chlorite and epidote, with a smaller amount of quartz. In colour they are green or greyish green. They have been intensely foliated and narrow bands of epidote and chlorite run parallel for several feet without interruption. Their composition, and the fact that they form breccias with overlying sediments, show that they are of igneous origin. They are, therefore, regarded as highly altered equivalents of the diabases and nearly related rocks of the Thetford phase that are mentioned above.

Structural Relations.

Internal.—The different varieties of igneous rocks are rarely found to be sharply distinguished from one another. In passing

[1] Geology of Canada, 1863, p. 470.

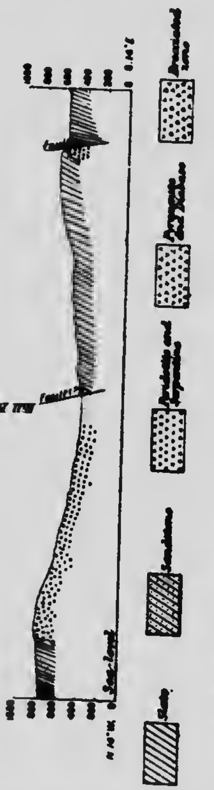
upward from the base of a sill, or outward from the centre of a stock the general order of the rocks is peridotite, pyroxenite, gabbro, diabase, and porphyrite. In places, porphyrite passes into a fine grained granite or aplite. Granite is frequently intrusive in the basic rocks, but in some places appears to have been differentiated from them. In the margins and dykes of acid intrusions granite frequently passes into aplite. Where there has been greater metamorphism peridotite has become serpentine; pyroxenite has become soapstone; and the other basic rocks are represented by greenstone schists. Where one rock greatly exceeds the others in small intrusions, the arrangement is not at all complete, but where all, or several of the varieties are present, they occur in the order of arrangement given above.

Foliation.—In the Thetford phase, foliation, evidently due to regional compression, is observable, but is not so pronounced a feature as in the rocks of the Broughton phase. In the latter the greenstones are reduced to regularly laminated schists, and the serpentine to a finely fissile condition. This alteration of the serpentine is probably due, in part at least, to the forces set up by hydration, as has been noted in the discussion on serpentinization.

Faulting.—Faults of small displacement are numerous throughout the serpentine, but are less frequently found in the other igneous rocks. Many are due to small movements, such as seem to have produced the abundant slickensiding; but displacements of several feet indicating movement of rock masses, are also frequently found. The asbestos veins are rarely, if ever, faulted.

One fault of regional importance occurs in the southern part of the district under description, and extends for a greater distance southward, beyond the St. Francis river. It forms a well-marked trench from the Shipton Pinnacle in the county of Richmond, to the south end of Long lake in the township of Orford, Sherbrooke county, a distance of 25 miles, and is traceable for 8 miles farther northeast, to the Little Nicolet lakes—a total distance of 33 miles. Throughout much of this distance, the fault trench is from 200 feet to 400 feet deep, by 200 feet to 300 feet wide at the bottom, and has a steep wall on the southeast side. The vertical displacement has not been less than 400 feet near the line between ranges XII and XIII in Cleveland. The downthrow is on the northwest side, and an extensive sill of peridotite, serpentine, pyroxenite, diabase, etc., is exposed by the fault. Figs. 1, 2, 3, and 4 show several sections taken across the fault.

Jointing.—Joints in the peridotite have determined the position of many of the larger serpentine bands. In other cases the shattered condition of the serpentine obscures the joint system. The other rocks



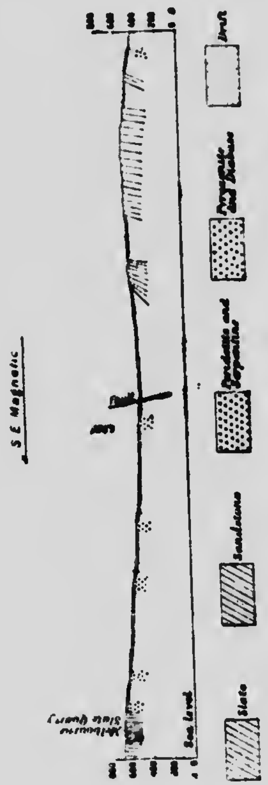
DIAGRAMMATIC SECTION ACROSS THE SERPENTINE BELT

In range XIII, township of Cleveland, between lots 5 and 9

Scale. 1600 feet to 1 inch.

Fig. 1.

of the igneous group are, as a rule, very distinctly and regularly jointed. The inclination of the joints nearest the horizontal appears to vary somewhat in different intrusive masses, and excellent examples of joint planes, determined by the shape of the intrusive body, have been noted in a few places. Broughton mountain is an intrusive mass of diabase which rises amongst strata having a general dip of 75° to the northwest. In it the joints nearest the horizontal have a dip to the southeast of 15°. They are very clearly marked on a cliff face on the southwest side. In lot 13, range IV, of Broughton an intrusive sheet, or sill, of serpentine dips to the southeast at an angle of 30°, while the joint plane nearest the horizontal has an



DIAGRAMMATIC SECTION ACROSS THE SERPENTINE BELT

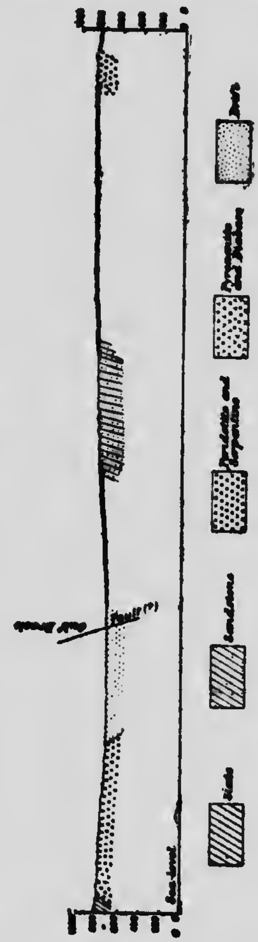
in range VI, township of Melbourne, between lots 18 and 22.

Scale, 1600 feet to 1 inch

Fig. 2.

equal dip to the northwest. The jointing in both cases is, as would be normally expected, at right angles to the cooling sides.

Breccia.—Several instances have been observed in which there have been successive intrusions of diabase or gabbro. Good examples may be seen where the Garthby road crosses Mount Louise. The older rock, here, is gabbro which has been shattered and recemented by fine-grained greenstone, probably diabase. Similar relations between these rocks are shown along the road between South Ham and Vezine corners, near the north end of Nicolet lake. The included fragments are angular and the contacts in all cases are closely



DIAGRAMMATIC SECTION ACROSS THE SERPENTINE BELT

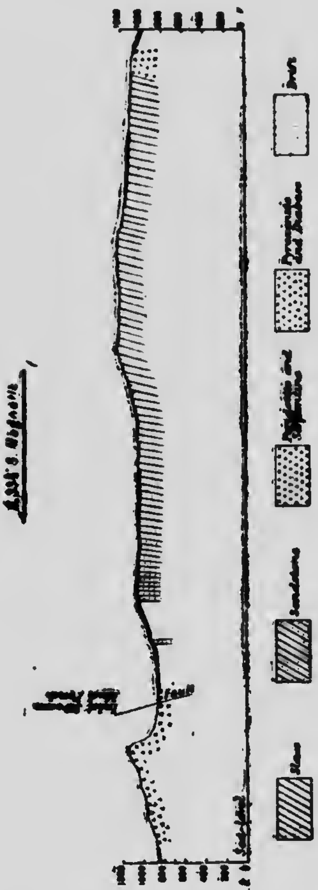
in range I, township of Melbourne, between lots 21 and 26.

Scale, [illegible] feet to 1 inch.

Fig. 3.

welded, indicating that the earlier rock was still in a heated condition when the later was intruded. These rocks are, therefore, considered not as representing separate periods of intrusion, but stages in a single period of igneous activity.

Similar phenomena may be seen at the northwest side of Shipton Pinnacle.



DIAGRAMMATIC SECTION ACROSS THE SERPENTINE BELT

in ranges X and XI, township of Brompton, between lots 14 and 16.

Scale. 1800 feet to 1 inch.

Fig. 4.

At the last mentioned locality, but on the southwest side of the Pinnacle, the fine-grained diabase is nodular in places. Some of the nodules are as large as three-fourths of an inch in diameter, and are not deformed by later pressure, as is the case of amygdules in the older effusive rocks of the region. In areas of a few feet in extent, the nodules occupy a considerable proportion of the rock.

Amygdaloid.—Occurrences of amygdaloidal structure in diabase were noted near Corris station on the Grand Trunk railway, at Little Ham mountain, and in a few other localities. As several of these occurrences are found well within the border of the igneous intrusion, they are thought to indicate that the diabase was, in places, brought in by successive injections, as was pointed out in the last paragraph, and that it was locally under very light pressure.

External.

Relative to Older Formations.—The contact of the porphyrite or diabase with the sediments is generally a brecciated one. Fragments of sedimentary rocks are found in places for a distance of 1,000 feet inward horizontally from the contact; but the position of the contact in overlying portions now removed by erosion cannot be told. It is not probable that the brecciation extends to this depth from the roof of the intrusion. The depth of the brecciated zone in sills appears to vary with the thickness of the sill. Actual thicknesses of 100 feet may be seen in different places. Dykes are rarely, if ever, present. The sediments near the contact and the fragments in the breccia zone are frequently found to be greatly altered and are probably much changed in chemical composition.

On the whole the contact of the igneous with the sedimentary rocks is clearly intrusive, and indicates an intrusion that proceeded slowly and without violent dynamic action.

There are no solid formations younger than the igneous rocks which come in contact with it in this district.

Mode of Origin.

The various rocks of the serpentine belt have been formed by differentiation from a common magma, which has been intruded into the sedimentary rocks from unknown depths. The arrangement of the different classes of rocks with reference to one another depends principally upon the shape of the body of igneous rocks in any particular locality. The shapes of the igneous bodies are ascertained by the outline of the surface exposures, the attitude of the surrounding rocks, and in some cases by cross sections that are actually exposed by erosion or by mining operations.

The igneous bodies tend to take one or other of two shapes: one is exposed in a long narrow band running parallel to the strike of the sediments which dip towards it on one side, and away from it on the other. Where exposed in cross section it can be plainly seen to be a sill, or intrusive sheet, as the other structural features would indicate.

The other type shape is elliptical or irregular in surface section, the strata dip away from it, or stand vertical, locally. The alteration of the sediments and occasional cross sections show that such bodies widen in all directions with depth. Such bodies are thought to be either stocks or thick laccoliths. For convenience they will be referred to as stocks or batholithic masses.

The arrangement of the various rocks is quite regularly distinct in these two classes of intrusive bodies. The rocks are arranged in order of decreasing basicity, viz., serpentine or peridotite, pyroxenite, gabbro or diabase, porphyrite, and sometimes aplite, in sills from the base upwards: in stocks from the centre outwards. Where one variety of rock is greatly in excess of the others, as occurs in some places, it may occupy any part or form the whole of an intrusion. But where different varieties are found they seem, invariably, to occupy the relative positions indicated above.

Also where there are two sheets running parallel the upper is more acid than the lower. Thus in ranges X and XI of Broughton where two sheets are exposed at intervals for 2 or 3 miles, the lower is composed of serpentine and a little soapstone; and the upper of soapstone and a smaller amount of greenstone schist—probably an altered diabase. Little if any serpentine is found in the upper sheet; no diabase in the lower. The sheets are from 50 feet to 75 feet in thickness, and about 75 feet apart vertically.

Between the Shipton Pinnacle and the St. Francis river—a distance of 8 miles—the serpentine belt is in the form of a thick sill dipping to the southeast at a high angle. Serpentine occurs along the northwest or footwall side, and diabase wherever present is on the southeast side or upper side. The mines at Asbestos are in similar position with regard to the pyroxenite and diabase hills on the southeast, and may be on the northeasterly extension of the same sheet.

Fig. 5. Sill of diabase, pyroxenite, and serpentine, Garthby, range II, lot 40.

Several exposures in Broughton show talc or soapstone in the upper and serpentine in the lower parts of a sheet, the soapstone representing original pyroxenite. In Garthby, range II, lot 40, where a thick sheet dips to the north at 65°, serpentine, pyroxenite, diabase, and porphyrite may be seen in unbroken succession on an exposure some 1,500 feet in breadth.

This arrangement of the rocks agrees with the relative average density of the principal minerals, and with the order in which they generally crystallize:—

Order of crystallization.	Specific gravity.	Rocks formed.
1. Olivine..................	3·32	Peridotite. (Serpentine).
2. Pyroxene................	3·20	Pyroxenite. (Soapstone).
3. Feldspar	2·70	With pyroxene forms diabase and related rocks.

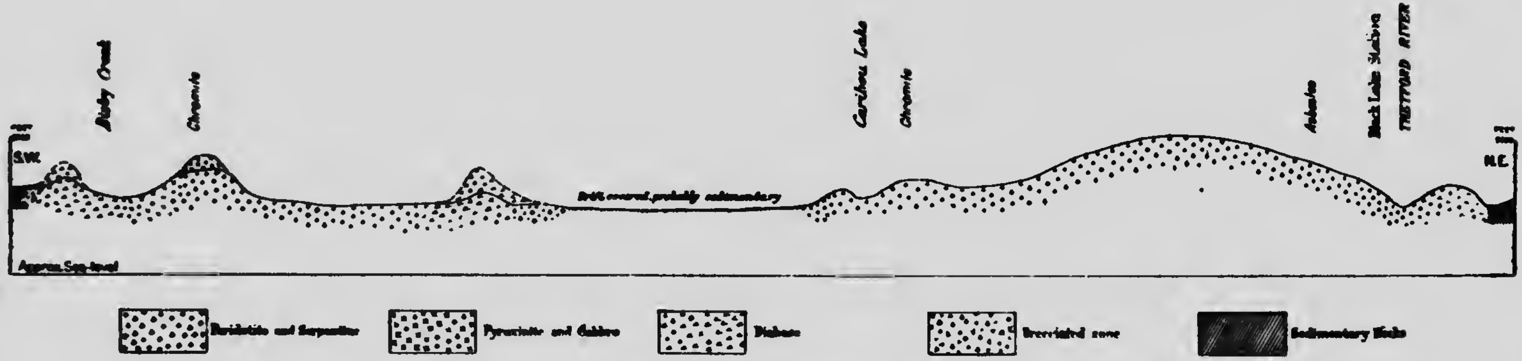
Olivine crystallizing would, in the lighter portion of the magma remaining fluid, first settle towards the bottom of the sheet, even if it had a high dip, and form the peridotite, which later has been altered to serpentine. Closely following olivine, pyroxene crystallized, and likewise settled, forming pyroxenite. By later alteration this has become soapstone.

Where pyroxene and olivine became mixed together through crystallizing simultaneously, they formed the harder unproductive variety of serpentine in the Thetford series, or the talcose serpentine of the Broughton series.

Where pyroxene mixed with feldspar which crystallized next in general order, diabase and the related rocks were formed.

This separation would be more nearly complete, the more slowly the cooling took place.

Granite has been found in sheets in only two cases. In one, on lot 24, range I, of Tring it occurs as a differentiate at the top of the sheet. In the other instance, in the townships of Cleveland and Danville, it appears to have been injected later than the serpentine, in which it occurs principally as dykes.



DIAGRAMMATIC SECTION ALONG POWER LINE OF ST. FRANCIS HYDRAULIC CO, BETWEEN THETFORD RIVER AND BISBY CREEK

Horizontal scale: 1 mile to 1 inch
Vertical scale: 2640 feet to 1 inch

Fig. 6.

In uncovered portions of stocks, such as the hill between Thetford Mines and Black Lake, or between the side of Black Lake and the Wolfestown road, the Belmina road or the area about Little Lake St. Francis, serpentine occurs in the central part and is partially or wholly enclosed by pyroxenite which in turn is generally bordered by a vein-like body of diabase. The outer edge of the diabase usually contains fragments of the adjacent sediments, and so passes into breccia (Fig. 6). The accompanying cut shows the arrangement of the rocks as seen along a section from the Thetford river to Bisby creek. The section follows the power line of the St. Francis Hydraulic Company from the property of the Dominion Asbestos Company southward.

A mile northwest of the northern end of this section the sediments dip towards the southeast at an angle of 70°, and within a few yards of the contact 4 miles northwest of the section the dip is 75° in the same direction. The first igneous rock is diabase which in the outer portion sometimes contains fragments of sediments and thus forms breccia. The diabase may be seen near the Roman Catholic church in Black Lake. The section is there drift covered until the serpentine is reached near Black Lake station, but on the lake road below the house of J. Johnston, about 400 yards west of the station, gabbro approaching pyroxenite in composition is exposed. Following the line of section the serpentine continues southward across the hill above the Standard and Dominion mines, though with a considerable amount of pyroxene in the higher and southern part of the hill; and passes beneath heavy covering of drift. West of the last exposure of serpentine, and near the Quebec Central railway, 560 yards north of Chrome siding, there is an exposure of pyroxenite and diabase at the south side of the same serpentine area. The drift extends for 2 miles along the line of section where the second area of igneous rocks is met. These in succession are breccia, diabase, serpentine, diabase and breccia. The succeeding sediments stand vertically for half a mile south of the contact, and at a distance of 2 miles dip towards the southeast at an angle of 75°. It will be noted that Thetford river and Bisby creek occupy similar positions in erosion valleys cut in the transition rock between the diabase and serpentine; that the general dip of the sediments on either side of the belt is southeasterly; and that the dip though practically vertical near the contact on either side is generally higher on the southeast than on the northwest.

No sediments have been found in the drift covered part of the section. Three miles west of the section, the nearest exposure, sedimentary slates strike through this area nearly at right angles to the line of section. They dip away from each of the igneous ridges thus indicating a synclinal trough between them, which has been deeply filled with drift.

The structure of the serpentine belt, as shown in this section, suggests a thick laccolith similar to that which contains the nickel deposits at Sudbury; but closer investigation does not support the comparison very well. Parallel ridges such as occur here are not common, being found in only a few instances in the distance of 100 miles thus far examined. Such cases seem to represent the dying out of one ridge and the beginning of another near and parallel to it.

The arrangement of the rocks in the two ridges is the same, while if they were parts of one laccolithic sheet they should appear in reversed order in the two ridges. It, therefore, seems probable that the igneous ridges are formed along two lines, perhaps minor anticlines, which have afforded an easier ascent for the magma. They may be connected at no great depth beneath the sediments, yet they diverge sufficiently to permit of similar effects from differentiation taking place in each.

The arrangement of the rocks by which the most basic is at the centre and the mass becomes more acid towards the outer edge is a common one in igneous intrusions of this class. It is theoretically accounted for by differentiation according to gravity taking place in a slowly rising magma thus bringing the more acid material of the diabase and related rocks in contact with the sediments. As the intrusion gradually rises the acid margin is carried upward forming an envelope over the advancing stock or batholith This is seen in the district in such hills as Broughton, Adstock, or Big Ham mountains, which rise in cone or saddle shapes and are encased in diabase in the upper portions. Near the base the diabase passes into gabbro, and where erosion has been especially heavy, pyroxenite and sometimes serpentine are exposed.

An excellent example of differentiation in a sill is to be seen in lot 40 of range II of Garthby (Fig. 5). Here a sill is exposed with horizontal breadth of 1,600 feet. The sediments on the upper side dip to the northwest at an angle of 65°. The dip of the sediments on the underlying side of the sill could not be found at the contact, but half a mile distant along the strike it was found to be also 65° in the same direction.

The rock at the northwest side, the top of the sheet, is diabase; near the southeast side, pyroxenite; and at the southeast edge, 30 feet lower vertically, serpentine. The following are analyses of the specimens taken at the points shown in the accompanying diagram:—

—	No. 19.	No. 16.	No. 18.
SiO_2	42·96	46·30	37·66
TiO_2	0·66	trace.	trace.
Al_2O_3	17·45	2·58	1·61
Fe_2O_3	2·29	3·45	6·15
FeO	11·04	3·57	1·87
MgO	9·77	23·18	38·66
CaO	6·80	15·20	0·22
K_2O	1·51	0·16	0·20
Na_2O	1·93		
$H_2O - 110°$	0·47	0·66	0·75
$H_2O + 110°$	4·75	4·77	12·49
	99·63	99·86	99·61

The above analyses have been already cited in the foregoing pages in the paragraphs treating of the classes to which these rocks are most closely allied. All the rocks are extremely altered. Under the microscope, however, No. 19 still shows the general characters of a gabbroid diabase; No. 16 is found to consist essentially of pyroxene, much of which is probably diallage; and No. 18 is serpentine.

The higher alumina and alkalies in No. 19 may be taken to indicate its content of feldspar. Lime seems to vary directly with the amount of pyroxene (diallage) in the rock, while magnesia increases regularly towards the base of the sill. Ferric iron increases in going downwards, and ferrous iron, in going upwards.

The rocks are too much decomposed to admit of reliable quantitative calculation of the minerals of which they were originally composed. There is, however, evidence of a distinct increase of the silicates of lime, iron, and magnesium, that is of the heavier minerals, in passing from the top to the bottom of the sill.

Age and Correlation.

Data.—The formations here referred to the Cambrian system are distinctly separated from those belonging to the Ordovician by a conglomerate consisting of pebbles of the former in a matrix of the latter. This conglomerate is of very general occurrence, and is an important feature in the stratigraphy of the district, as it provides a datum line for working out the succession of strata above and below it.

The lithological characters of the rocks above and below the conglomerate are also quite distinctive. The calcareous and argillaceous rocks of the upper system are dark iron-grey or nearly black; while the slates, schists, and sandstones underlying them are grey-green and red, or sometimes nearly black. In this case the dark schists of the L'Islet may be distinguished from the black slates of the Farnham by the fact that, while both are argillaceous, the Farnham carries nodules of grey limestone which are not found in the L'Islet.

There is, also, a difference in the strike of the bedding between the rocks of the two systems in some parts of the district, especially in the townships of Ham and Wotton in the county of Wolfe. Where they are exposed near together or in contact: as near the southeast end of Little Ham mountain, the Farnham slates strike nearly due east, while the rocks of the older series have a strike 30° north of east.

The only fossils that have been found in the area covered by the accompanying map are a few obscure forms in the Ordovician on lot 14 of range XII of the township of Cleveland in Richmond county. No full description of these has ever been published; but they were referred to by Sir J. W. Dawson[1] in an article on the "Silicification of Palæozoic Fossils," as indicating the lower Silurian (Ordovician) age of the rocks. At present only a few fragments of crinoid stems could be found.

At Castle brook in the township of Magog, 25 miles south of the limits of the accompanying map, there is a rich graptolite area of lower Trenton (Quebec City) age[2]. This locality is on the

---

[1] Q. J. G. S., Feb., 1879, p. 62.

[2] R. W. Ells, Report Geol. Surv., Canada, 1894, Part I, p. 38.
H. M. Ami, Appendix to the above.

extension of the black slates which constitute the Ordovician of this district and only a few feet above the conglomerate which forms its base.

Near the city of Quebec, 35 miles north of the limits of this map, the Sillery formation contains fossil evidences of Cambrian age[1], and is believed by Dr. Ells to pass beneath the Lévis. The Lévis has been determined on palæontological evidence to be of Beekmantown[2] (Calciferous) age.

The L'Islet underlies the Sillery apparently conformably and to the south of this district, the Georgia (lower Cambrian) emerges from beneath the L'Islet near the boundary line of the state of Vermont.

The igneous rocks are all intrusive through, and hence younger than the sedimentary rocks with which they are in contact. The rocks of the Thetford phase alter Ordovician strata in this district, and 40 miles south of the district igneous rocks of the same series cut strata which underlie lower Devonian sediments, it is thought conformably.

The igneous rocks of the Broughton phase penetrate sedimentaries of the L'Islet formation, but are not found in contact with any rock of later age. The Broughton phase shows greater alteration than the Thetford phase. It is fractured mechanically to a greater degree, and the serpentinization is more complete.

Conclusions.—From the data set forth above, it may be safely concluded that the highest sedimentary formation, except the Pleistocene, is of Ordovician age, and was deposited in early Trenton time; and that there is a pronounced unconformity between this and the next underlying formations. While it is not certainly proven, it is at least very probable that the underlying formations are of Cambrian age.[3]

The igneous rocks of the Thetford phase are from evidence in the district, certainly post-Ordovician, and if the similar rocks 40 miles to the southward were intruded at the same time, they may be later than early Devonian.[4] The Broughton phase is possibly of the same age as the Thetford phase, but the latest sediments that

[1] R. W. Ells, Geol. Surv., Canada, 1887, pp. 63-68 K.
[2] Lapworth, Trans. Royal Society of Canada, 1886.
[3] R. W. Ells, Report Geol. Surv., Can., 1887, p. 63 K.
[4] Further evidence of the age of these intrusives might be found on the east side of Lake Weedon in Wolfe county, a locality that was not satisfactorily examined during this investigation.—J.A.D.

are cut by them are the L'Islet, and they have suffered greater deformation and alteration than the Thetford phase. It is, therefore, considered advisable to state their age only as post-L'Islet.

Geological Structure of the Region.

In the part of the St. Lawrence plain which lies west of the St. Lawrence and Champlain fault, the sediments form a conformable series from the Potsdam to the Lorraine or Hudson river. They have been only locally disturbed from the position in which they were originally deposited.

Broadly speaking, the structural features of the region east of the fault are three anticlinal folds separated by broad basins which have a general synclinal structure. The anticlinal folds form the principal ranges of hills in the district, the structure being thus far expressed in the topography. In general, the strata are in ascending order from the crests of the ranges to the central portions of the valley basins. But minor folding and faulting, and differential erosion, bring about many exceptions. This is the case on the west side of the Sutton anticline, which is the most westerly of the three great folds, and is from 15 to 20 miles east of the St. Lawrence-Champlain fault, where the succession of formations is somewhat irregular.

The most easterly or Lake Megantic anticline, forms the boundary line between Canada and the United States, consequently a description of the eastern side of this fold is not included in this sketch. The middle or Sherbrooke anticline divides the area between the Sutton and the Lake Megantic folds into two nearly equal basins of about 5 miles in breadth.

In the central parts of the main folds, igneous rocks of volcanic character, and older than the sediments, are exposed so generally as to strongly suggest that they generally form the axial ridges. Later intrusions of granite in the basin between the Sherbrooke and Lake Megantic anticlines, and of alkaline rocks—the Monteregian hills—occur in the St. Lawrence plain, but their distribution bears no apparent relation to the general structure of the region. On the other hand the basic intrusives of the serpentine belt closely follow the trend of the Sutton anticline, and are always on the southeast side.

Geological History.

(1) At the close of Pre-Cambrian time the present main axes of the Appalachian folding in this region must have been determined and the extrusion of the porphyry and greenstone magma had taken place. These had probably been considerably eroded, and sedimentary rocks may have already been solidified, at least along the flanks of the igneous masses. To what height above the general surface the axes had been raised it is, of course, impossible to say, nor can it be shown through what kind of walls the volcanic rocks were extruded.

(2) A period of sedimentation followed; but there is as yet no evidence to show that the submergence which brought it about took place before the later part of Cambrian time. It seems to have continued to the close of the Cambrian, when the region was again raised above sea-level. It was, perhaps, at the time of this uplift that the Broughton series of igneous rocks was intruded.

(3) The region was then subjected to a period of erosion, probably remaining above the sea until early Trenton (Farnham) time.

(4) A submergence followed, and the muddy sediments of the Farnham series were deposited, and probably without interruption, the Silurian and lower Devonian, of which remnants are found in the region. These probably covered the Pre-Cambrian ridges.

(5) The elevation which brought this period of sedimentation to a close was accompanied or soon followed by a period of igneous activity. The Thetford series comprising a large part of the serpentine belt was intruded at this time; also the granites of the southern part of the Eastern Townships and the Monteregian hills of the St. Lawrence plain. Probably the St. Lawrence-Champlain fault was formed about this time.

(6) These successive uplifts and depressions of the valley basin probably indicate steps in the elevation of the main ranges. The forces which produced the elevation seem to have ceased to act soon after the intrusions of latest igneous rocks, since these show little evidence of lateral compression.

(7) There is no record of the geological history of the region from Devonian time to Pleistocene, and sub-aerial erosion may be supposed to have advanced steadily and continuously during this long interval.

(8) In the Pleistocene glacial period the country was swept and planed down by heavy glaciation which affected every part of the region. The troughs between the main ranges received accumulations of drift sometimes 100 feet or more in thickness and the crests of the resistant ridges were swept bare of all residual soil. The courses of the smaller streams—those running transversely to the main ice movements—were changed, and lakes and rapids formed, and the surface now took on much of its present topography.

(9) The retreat of the glacier was accomplished by a period of submergence (Champlain period). The boulder clay was in part assorted, and the stratified clays, sands, and gravels were separated and re-deposited, giving the submerged areas a rather uniform surface.

(10) An uplift followed, probably of not less than 600 feet, and since that time erosion and local deposition have given the land surface its present features.

ECONOMIC GEOLOGY.

The minerals of economic value that have been found in the serpentine belt are asbestos, chromite, talc, antimony, and copper. Platinum has also been found in gravels which probably had their origin in the rocks of the serpentine belt. Asbestos is much the most important of the minerals here found and chromite is next in value. Both of these are being mined at present. Antimony and talc have been mined, and there has been some development of copper. Platinum is known only as a rare mineral occurrence.

Asbestos.

GENERAL CHARACTER AND DISTRIBUTION.

The asbestos of this district is wholly of the chrysotile variety, that is, a hydrous silicate of magnesium, and occurs only in the serpentine rocks to which it is essentially similar in chemical composition. There are two distinct forms of asbestos known as 'cross fibre,' and 'slip fibre.' The cross fibre asbestos occurs in veins and consists of minute fibres, or crystals, arranged parallel to one another, and cross-wise of the vein. It is the principal form of asbestos found in the serpentine of the Thetford phase, which is the country rock of the mines of Thetford Mines, Black Lake, Coleraine, Wolfestown, and Danville. The length of the fibre is usually less than the width of the vein, and rarely exceeds 2½ inches. The slip fibre asbestos does not form veins, but occurs in serpentine without any definite arrangement, and in places makes up a large proportion of the rock. Slip fibre is usually shorter than average cross fibre. It is the principal product of the serpentine of the Broughton phase in which the mines of East Broughton are situated.

Although slip fibre occurs principally in the Broughton phase and cross fibre is the chief product of the Thetford phase of serpentine, the rule of occurrence is not invariable, as both kinds of fibre are found to some extent in both classes of rock.

PRODUCTION.

The asbestos mines of this district are the largest and most important of their kind that have ever been operated in the world. They have furnished the major part of the kuown production for the past fifteen years, and in 1907 contributed 84 per cent of the world's supply. The growth of the industry is well shown by the following statistics of production, which are taken from the Mineral Statistics of Canada.[1]

[1] Prepared by J. McLeish, chief of the Division of Mineral Resources and Statistics, Mines Branch, Department of Mines, Ottawa.

—	Production.	Value.
	Tons	$
1878	50	
1879	300	19,500
1880	380	24,700
1881	540	35,100
1882	810	52,650
1883	955	68,750
1884	1,141	75,097
1885	2,440	142,441
1886	3,458	206,251
1887	4,619	226,976
1888	4,404	255,007
1889	6,113	426,554
1890	9,860	1,260,240
1891	9,279	999,878
1892	6,082	390,462
1893	6,331	310,156
1894	7,630	420,825
1895	8,756	368,175
1896	10,892	423,066
1897	13,202	399,528
1898	16,124	475,131
1899	17,790	468,635
1900	21,621	729,886
1901	32,892	1,248,645
1902	30,219	1,126,688
1903	31,129	915,888
1904	35,611	1,213,502
1905	50,669	1,486,359
1906	60,761	2,036,428
1907	62,241	2,484,768
1908	66,548	2,555,361
1909	87,300	2,201,775
1910	100,385	2,476,558
1911	102,224	3,026,306

The following tabulated statement by Mr. McLeish shows the production and shipments during 1910, and the stock on hand at the end of the year: —

—	Production.	Shipments.			Stock on hand Dec. 31.	
	Tons.	Tons.	Value.	Per ton.	Tons.	Value.
			$	$		$
Crude No. 1	1,971	1,688	445,130	263 70	1,605	426,782
" 2	2,844	1,732	171,684	99 12	2,842	405,419
Mill Stock No. 1	16,026	12,830	701,681	54 69	69,933	718,765
" 2	56,321	42,612	997,967	23 42	24,541	591,752
" 3	19,006	16,816	142,447	8 47	3,389	29,988
Total asbestos	96,168	75,678	2,458,929	32 49	39,310	2,172,706
Asbestic	....	24,707	17,629	0 71		

In the absence of a uniform classification of asbestos of different grades, the above subdivisions have been adopted purely on a valuation basis. Crude No. 1, comprising material valued at $200 and upwards, and Crude No. 2 under $200. Mill Stock No. 1 includes stock valued at from $45 to $100; No. 2 from $20 to $40; No. 3 under $20.

The shipments of asbestos in 1909 were in detail as follows:—
Crude No. 1, 912 tons, value $246,655, or $270.37 per ton;
Crude No. 2, 2,162 tons, value $328,855, or $152.11 per ton;
Mill stock No. 1, 14,776 tons, value $785,731, or $53.18 per ton;
Mill stock No. 2, 32,417 tons, value $800,728, or $24.70 per ton;
Mill stock No. 3, 13,082 tons, value $122,618, or $9.37 per ton;
Total, 63,349 tons, value $2,284,587, averaging $36.06 per ton;
asbestic 23,951 tons, value $17,188.

The exports of asbestos during the twelve months ending December, 1910, are reported by the Customs Department as 71,485 tons, valued at $2,108,632, comprising: 57,939 tons valued at $1,505,477 to the United States; 6,700 tons, value $280,452, to Great Britain; 440 tons, value $15,952, to Germany; 2,187 tons, value $94,619, to France, and 1,242 tons, value $43,948, to other countries.

The imports of manufactures of asbestos during the same period are reported as valued at $230,489.

HISTORY.

Asbestos was known in the Eastern Townships of Quebec as early as 1847, when it was mentioned by Sir William Logan in a report of the Geological Survey, but it was not until thirty years later that it came into commercial importance. The deposits of Thetford and Coleraine were found about 1877, and, facilitated by the building of the Quebec Central railway then in course of construction, work was begun upon them almost immediately, and has continued to the present time. The mines at Danville, the next largest centre of asbestos production, were opened in 1879, and the East Broughton deposits were located shortly after.

For the first fifteen years the only product of importance that was obtained from the mines was the 'crude' asbestos, or that which was long enough in its fibre to be recovered by hand cobbing and sorting. This, although it is a most valuable part of the production, is relatively of small amount as can be seen by the table of classified production quoted above.

After considerable experimenting a method of mechanical concentration was at length devised by some of the pioneer mine managers of the district, which with many modifications has been successfully used ever since. Its beneficial effect on the industry is shown by the increased output since 1893 and 1894. Great credit is due to the operators who developed this process, which has given to the industry its present large importance and its growing possibilities.

The deposits are so large that the principal mines seem to have almost inexhaustible reserves, and consequently the plants installed are of the most durable character possible. Around the principal mines substantially built towns have grown up, and the whole industry shows a stability that is unusual for mining operations.

RELATIONS OF THE DEPOSITS TO THE COUNTRY ROCK.

While all the asbestos occurs in serpentine its relations to the country rock are of two different types. These may be distinguished as the Thetford type of deposit, and the Broughton type. The former consists principally of cross fibre, which occurs in veins; the latter generally of slip fibre, which is not in veins. It is, therefore, advisable to consider the character and discuss the origin of these two classes of deposits separately.

DEPOSITS OF THE THETFORD TYPE.

Evidence.—The country rock of the deposits of the Thetford type is a peridotite, in places so rich in olivine as to become dunite, which contains narrow bands of serpentine along joints and any other crevices. The asbestos forms gash-veins within these bands or zones of serpentine, the asbestos vein being parallel to the serpentine bands in which it occurs.

The veins usually develop along the joint planes of the rock, and in any fissures or cracks due to dynamic or other deformation. The largest veins are often arranged with something approaching rectangular intersection; a parallel series of minor veins may develop normal to the direction of some pressure which has been exerted upon the rock; yet smaller veins fill the crevices formed in the pro-

Plate VI

Peridotite containing bands of serpentine each of which contains a vein of asbestos.

11159—p. 58

cess of rock disintegration, when shells are cast off rectangular blocks, thus tending to reduce them to rounded and spheroidal masses. In Fig. 2, these features may be seen. The two vertical and the main horizontal veins are evidently former joint planes of the rock. The parallel oblique lines are incipient veins forming in pressure cracks due to regional dynamic metamorphism; and rounding the corners of the blocks separated by the main veins, are small crescentic fractures in which asbestos fibre is beginning to appear. These latter are the veins of the third class mentioned above. Another feature which this diagram is intended to show is that the asbestos veins are invariably accompanied by a band of pure serpentine on either side. Thus, in the diagram (Plate IV) specimen 2048, which represents

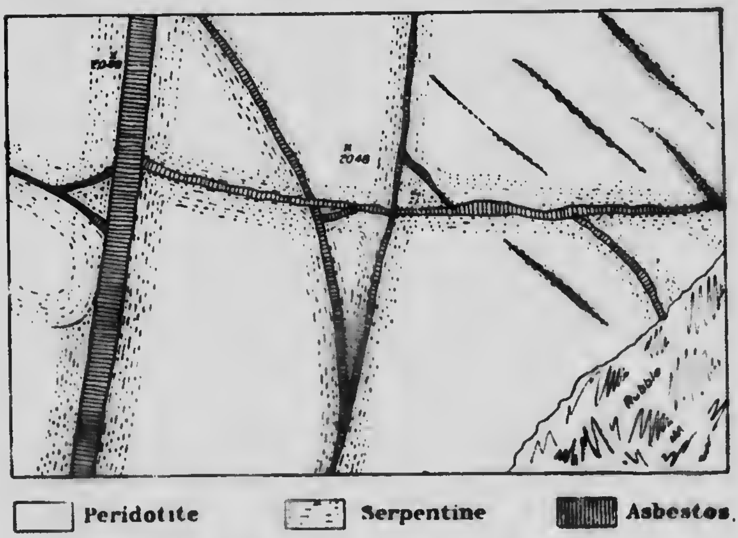


FIG. 7.—Diagram showing relations of asbestos, serpentine, and peridotite at Black Lake.

the average rock of this locality, is a peridotite consisting of 80 per cent to 90 per cent olivine. The remainder of the rock consists of orthorhombic pyroxene, and a few grains of feldspar (Plate IV).

Specimen 2049 is serpentine, which has resulted from the alteration of the adjacent rock (Plate V). The serpentine band is proportionate in width to the asbestos vein. In forty-nine measurements of veins selected at random in the principal pits, the width of the asbestos vein was a little more than one-sixth of the serpentine. To be exact, the ratio of the asbestos vein to the entire band of serpentine and asbestos was found to be 1:6·6; and seventeen of the forty-nine measurements gave practically unanimity with that ratio. These measurements included veins varying in width from one-fourth to 2 inches. Hence the proportion between the asbestos and serpentine in such rocks seems to be a fairly constant one. According to these measurements, the serpentine should yield about 15 per cent of asbestos. This is in excess of the actual production from run-of-mill rock; but the latter usually contains considerable peridotite as well as serpentine.

Chemical analyses were made by Mr. M. F. Connor of the Mines Branch, Department of Mines, of specimens of peridotite No. 2048, serpentine No. 2049, and of asbestos from the large vein shown in the diagram near No. 2049. The results of Mr. Connor's analyses are given below. The Fe_2O_3 found in asbestos by analysis E is probably due to impurities in the specimen, as grains of magnetite are not infrequently found amongst asbestos fibres.

CHEMICAL ANALYSES OF SPECIMENS.

(See Plates IV and V.)

—	2048. Peridotite.	2049. Serpentine.	E. Asbestos in 2049.
SiO_2	38·16	40·08	39·62
TiO_2	none.	none.	—
Al_2O_3	0·63	2·11	0·81
Fe_2O_3	3·32	1·13	4·52
FeO	4·76	1·70	1·90
MgO	41·84	*37·90	39·73
CaO	0·68	0·20	trace.
K_2O, Na_2O	0·20	0·10	not determ'd
$H_2O - 110°$	0·47	1·35	0·43
$H_2O + 110°$	9·63	13·89	13·32
	99·69	98·46	100·33

*Probably low.

Plate VII

Microphotograph of asbestos vein. Polarized light X 20. Serpentine can he seen at left and right. Central parting and other interstices are filled by iron ore.

In a discussion of the chemical composition of asbestos, Dr. J. T. Donald has expressed the opinion that, the flexibility of the fibre depends on the amount of combined water it contains. Dr. Donald writes[1] as follows:—

'When harsh fibre is analysed we find it to contain less water than the soft fibre. In fibre of very fine quality from Black Lake, analysis showed 14·38 per cent of water, whilst a harsh fibre sample gave only 11·70 per cent. It is well known that if soft fibre be heated to a temperature that will drive off a portion of the combined water there results a substance so brittle that it may be crumbled between thumb and finger. These is evidently some connexion between the consistency of the fibre and the amount of water in its composition.'

Summary of Evidence.—The principal facts bearing on the origin of the asbestos of the Thetford type may be briefly recapitulated. In parts of the large rock masses, whether sills or stocks, where the heaviest material and that which is first to crystallize would naturally collect, the rock is an olivine rich peridotite, or dunite. Small bands or zones of serpentine occur along joints and any other crevices in the dunite and carry veins of asbestos which run parallel in direction with the joint or other crevices. The veins of asbestos occupy the central part of the serpentine bands, and are roughly proportional to them in breadth. In the asbestos veins the fibres lie crosswise, and the vein is usually divided into two parts at least by a film of iron ore, generally magnetite.

Microscopic sections show the outer sides of the veins of asbestos to be somewhat irregular fibres of asbestos penetrating to various distances into the serpentine beyond the average edge of the vein. The boundary between the serpentine and peridotite is nearly if not quite as sharply defined as that between the asbestos and serpentine (Plate VII).

Granite is very frequently found in the vicinity of good asbestos deposits, suggesting that the asbestos is due in considerable part at least to the action of magmatic waters accompanying the granite intrusion.

Theoretical.—All considerations of the origin of asbestos resolve themselves into two classes:—

[1] Journal General Mining Association, Quebec, 1891, p. 28.

(*a*) Those that regard the veins as originally open fissures which have been filled by material brought from without. According to this view the veins have been filled from the walls inward, or are endogenous veins.

(*b*) Those that regard the asbestos veins as crystallized parts of the serpentine, the fibres being considered to have grown outward as crystals from a central fracture or crevice. These are distinguished as exogenous veins.

Review of Previous Opinions.—The mode of occurrence of asbestos, and the origin of the veins, have been discussed by various writers on the subject. In a bulletin of the United States Geological Survey, 1904, J. Hyde Pratt says: 'It can be conclusively shown in nearly all cases that the serpentine in which chrysotile asbestos is found is of igneous origin. The original rock in cooling would solidify first along its contact with any included masses of the country rock that had been broken off during the intrusion of the molten magma. The outer portions of the molten rock would thus cool much more suddenly than the interior portions, and there would be a tendency for them to develop cracks and parting planes. In the alteration of these primary rocks to serpentine, through the agency of aqueous solutions, vapours, etc., there would be, perhaps, to some extent at least, a widening of these cracks, but in the end they would be filled with serpentine deposited from aqueous solutions from their walls, and the resulting fibrous structure of the serpentine filling these seams represents the nearest approach to a true crystallization that the mineral serpentine assumes, except when it is found as a pseudomorph after another mineral. It is probable that this chrysotile asbestos may have been formed some time before the complete alteration of the primary rock into serpentine. This is emphasized by the fact that in the southern part of the United States, where the rock has been but partly altered to serpentine, seams of chrysotile asbestos are occasionally found, and that in other cases, seams of asbestos are found almost entirely enclosed by a peridotite rock which is altered but little into serpentine. Then again, it may be that in the first alteration of the basic magnesian rock the seams and crevices are filled with serpentine which has been derived from the main mass of the basic magnesian rock, and that later, during the process of complete alteration of the rock into serpentine, these seams have become asbestiform, due to the action of aqueous solutions.'

Dr. G. P. Merrill[1] considers the crevices which are now occupied by asbestos veins to be due to partial dehydration of the serpentine, and compares them to the cracks in septarian nodules in clay-iron stone.

Mr. F. Cirkel[2] agrees with Dr. Merrill's views in part, but believes that the forces which produced the intrusion of the granite dykes have greatly aided in the formation of fissures.

Dr. R. W. Ells[3] says: 'In whatever way the fissures were caused, and it is very probable that they have been formed by the great processes of metamorphism to which the rocks were exposed in the change from diorite matter to serpentine, the vein asbestos appears more naturally to have been produced by a process of segregation of serpentinous matter from the sides of the fissure, very much as ordinary quartz in many mineral veins is known to have been produced, the segregated, or infiltrated matter gradually filling the original fissure, and meeting at or near the centre: in proof of which the presence of a comb of particles of iron is very often found occupying the centre of the vein, and quite frequently these iron grains assume sufficient size to form a regular parting of iron ore in the fibre.'

Dr. A. P. Low, in a recent report[4] thus referred to the origin of the asbestos deposits of Thetford Mines and Black Lake: 'As is well known, the asbestos of these places is a fibrous variety of asbestos called chrysotile, and occurs as the filling material of small cracks in the rocks. These cracks were probably formed by shrinkage of the mass, and perhaps in part by the crushing action of the same pressure which lengthened and flattened the serpentine areas, and at the same time made the associated rocks schistose. The asbestos appears to the writer to have been deposited in the rocks under great pressure from superheated waters, which, penetrating the rock, absorbed the material of the serpentine until the solution became a saturated one. With cooling, the mineral would be deposited in the cracks. The finely divided state of the mineral, and

[1] Bulletin Geological Society of America, 1904.
[2] Asbestos, Its Occurrences, Exploitation, and Uses, Mines Branch, Department of Mines, Ottawa.
[3] Bulletin of the Geological Survey, Canada, 1903.
[4] The Chibougamau mining region, Geological Survey, Canada, 1906.

the direction of the fibres across the vein, point to its deposition under pressure. Where the veins are less than an inch in width, the crystallization has begun upon one side of the crack and has extended across to the other; in wider veins the mineral appears to have commenced formation on both sides of the crack, so that there is a break in the continuation of the fibre near the centre of the vein, where grains of iron and other impurities are often found between two sets of fibre. Masses and dykes of granite have been intruded into the serpentine, and these probably account for the necessary pressure and heated waters to form the asbestos.'

Dr. A. E. Barlow[1] emphasizes the evidence that asbestos veins have been developed in situ, growing from a central crevice, and considers the serpentinization to have been due to the action of heated magmatic waters accompanying the intrusives, especially the intrusion of the granite, and that they grow in direct proportion to the amount of magmatic water supplied.

Dr. C. H. Richardson[2] attributes the formation of asbestos veins to the crystallization of serpentine derived from peridotite by the action of both magmatic and meteoric waters. He recognizes the outward method of growth of the fibre from crevices within the veins.

Mr. W. J. Woolsey[3] pointed out the 'exogenous' or outward growing character of asbestos veins. This vein had been worked out independently by Mr. Woolsey sometime previously, but his material was not published until 1910.

Mr. J. S. Diller[4] in describing the asbestos deposits of Caspar mountains, Wyoming, points out that some of the veins cut others and draws the conclusion that all were not formed at one time. He also draws attention to the proximity of granite to the asbestos deposits of this area. Concerning the asbestos of the Grand canon, Arizona, Mr. Diller concludes that 'The veins of asbestos were not deposited in open fissures but by replacement of serpentine in the plane of

---

[1] 'Some Notes on the Occurrence of Asbestos.'—Journal Canadian Mining Institute, Montreal, 1910.

'Economic Resources of the Chibougamau Mining District.'—Journal Canadian Mining Institute, Montreal, 1911.

[2] Report, Geological Survey of Vermont, 1909-10; also Journal Canadian Mining Institute, 1911.

[3] 'Notes on Recent Developments in Asbestos Mining,' Journal Canadian Mining Institute, 1910.

[4] 'Types and Modes of Occurrence of Asbestos in the United States,' Journal Canadian Mining Institute, 1910.

least strength somewhat later than the development of the serpentine itself.'

'Here, too,' he adds, 'we have convincing evidence of the development of asbestos by igneous intrusion. We may, therefore, the more readily accord to the granite dykes in Canada and elsewhere a decided influence in the formation of the asbestos near their contacts.'

Conclusions.

The opinion has already been expressed by the writer that asbestos veins are portions of the serpentinized bands which have crystallized *in situ,* the crystals or fibres growing outward from fractures of the rock which are indicated by partings or films of iron ore in the veins; that these fractures have been the channels through which water has been brought which has been the principal agent in changing the dunite to serpentine; also that the segregation of the dunite or olivine rich peridotite from the other rocks of the serpentine belt is due to gravitational adjustment.

The position, size, and number of asbestos veins in rich ground make it inconceivable that the spaces they now occupy were once open fissures, and especially that many of them were open at the same time. Open fissures up to 2 inches in width, running in all directions from vertical to horizontal, extending 100 feet or more in length, and occupying in places as much as 10 per cent of the entire rock, would be a mechanical impossibility. The possibility remains of crevices having been enlarged and filled by replacement.

But the asbestos of the veins is practically identical in chemical composition with the serpentine of the walls, which is strong evidence against the material composing the veins having been brought in either from above or below. Segregation from the walls also would imply a difference in chemical composition, which does not exist. In other words, the material removed would have been replaced by material of exactly the same chemical composition, which is altogether improbable if not impossible.

---

[1] Jonrnal Can. Min. Institute, Montreal, 1909.
Economic Geology, New Haven, Conn., Vol. IV, No. 5, 1909.
[4] Summary Report on the Serpentine Belt of Sonthern Qnebec,' Geological Survey, Ottawa, Canada, 1909.
Journal of the Canadian Mining Institnte, Montreal, 1910.

It is, therefore, concluded that the veins are crystallized portions of the serpentine walls, and that the crystals (fibres) have grown outwards from the original crevices which are now represented by partings of iron ore found near the centre of the veins. In cases where there is no such parting the growth of the crystals has taken place on one side of the fracture only. In most cases, however, there has been crystallization on both sides of the fracture, thus leaving a parting in the vein.

The fractures are believed to be of three different modes of origin:—

(*a*) Joints, due to contraction of the peridotite during the process of cooling.

(*b*) Strain fractures caused by regional compression.

(*c*) Fractures caused by exfoliation, or the casting off of concentric shells from angular blocks which have been previously separated from one another by fractures of the preceding classes. The increase in the volume of the rock when it is altered from peridotite to serpentine probably aids in forming fractures of this class.

The essential changes in composition that take place when the rock is altered from peridotite to serpentine are an addition of water and a loss of iron. The principal agent required to bring about these changes is water, of which there are two possible sources, viz., magmatic waters accompanying the intrusions of peridotite and granite, and surface or ground waters of meteoric origin.

Meteoric waters would have access to all three of the classes of fractures mentioned above. Magmatic waters accompanying the peridotite would probably have access to the joints which were among the first fractures to be formed, but not to the later fractures which were formed after the peridotite magma had completely cooled. If the granite intrusions took place as late as the regional disturbances which produced the strain fractures, the magmatic waters of the granite would have access both to the joints and the strain fractures. This was probably the case, as the granite is rarely found to be fractured. It does not seem likely that any but meteoric waters have entered the third class of fractures mentioned.

Much the greater proportion of asbestos is found along joints and strain fractures, but it also occurs beside the fractures due to exfoliation as well. It is, therefore, concluded that serpentine and asbestos have been formed from peridotite by both magmatic and meteoric waters; but that the greater part is probably due to magmatic waters, especially those that were derived from the granite magma.

In their distribution the asbestos deposits of the Thetford type follow segregations of peridotite that are rich in olivine. These occur near the base of sills and in the central parts of stocks. Erosion has uncovered stocks to a greater depth on the north than on the south side of stocks, and so has exposed more asbestos deposits on the north side of the hills which the stocks usually form. The presence of granite is an important factor in locating deposits of the Thetford type.

Two practical deductions arise from these theoretical conclusions:—

(1) The structure and mode of origin of the deposits indicate that they may extend to a depth that is even greater than the limits of profitable mining. But on the other hand a detailed examination of the enclosing igneous rock may show a deposit to be of limited extent.

(2) The position which the asbestos-bearing rock occupies in the series, especially in sills, and its readier erosion and removal tend to give it a lower surface than most of the rocks with which it is associated. Good areas are, therefore, frequently found on comparatively low ground, and are more often covered by soil than the harder, barren rock. Consequently, drift-covered areas in the vicinity of the mines should be carefully prospected. The value of such areas as some in the neighbourhood of the Danville mines, and lands between Thetford Mines and the Poudrier road—where not occupied by granite—probably depends on the possibility of prospecting and working through the drift.

DEPOSITS OF THE BROUGHTON TYPE.

Evidence.—The asbestos deposits of this type consist almost entirely of slip fibre, and are wholly in serpentine rock. The rock is finely fractured, and being almost entirely reduced to serpentine there is little evidence of the character of the original rock. In a few sections, however, remnants of pyroxene and traces of rectangular cleavage can be distinguished under the microscope.

The asbestos is generally in thin layers of overlapping fibres which lie parallel to, and along the faces of the numerous fractures.

In places, almost the entire rock seems to be fibrous, and the only distinction between the asbestos recovered in the concentrating mills and the waste on the dump is in the length of the fibre in each. Veins of asbestos of average width and of excellent quality are occasionally found.

Talc is found in veins, and soapstone in masses, in the serpentine of this type. A good example is at the Fraser mine, where considerable talc was mined at one time.

The deposits of the Broughton type are all found in comparatively thin sills, usually from 100 feet to 600 feet in thickness. The lower portion of these sheets consists of a compact serpentine in places evidently derived from pyroxene, and which yields so little asbestos that it is not usually worked. Above the asbestos-bearing portion of the serpentine there is, in several cases, a band of greenstone schist which is of igneous origin, and forms a part of the sill. In some places where the greenstones are absent from the sill which carries the asbestos, they have been found in separate sills from 100 feet to several hundred feet above those which contain asbestos.

In chemical composition, asbestos of the Broughton type is identical in all essential respects with that from Thetford, as the following analyses show:—

Chemical Analyses.

—	Broughton, range VII, lot 14. Analysis by J. T. Donald.*	Black Lake Analysis by M. F. Connor.
SiO_2	40·87	39·62
Al_2O_3	0·90	0·81
Fe_2O_3	....	4·52
FeO	2·81	1·90
MgO	41·50	39·73
H_2O	13·55	13·75
	99·63	100·33

* Journal, General Mining Association of Quebec, 1891, p. 27.

Granite, which is of very frequent occurrence in the Thetford deposits, has not been found at Broughton.

Summary of Evidence.—The asbestos of the Broughton type is similar in chemical composition to the Thetford type, and like that type it is found only in serpentine. It occurs, however, chiefly as slip fibre, and in places makes up a large proportion of the rock. The serpentine occurs only in sills, and shows microscopic evidence that it has been derived from pyroxene. The asbestos-bearing portions are not at the base of the sills in which they occur, but in the upper part of them, and are associated with talc and soapstone. There is no granite with the asbestos deposits.

Theoretical.—No discussion of the causes of the peculiar features of the Broughton type of asbestos has been found in reviewing the literature of asbestos. The features to be accounted for are serpentine at the bottom of sills without asbestos; serpentine containing asbestos in the upper portions of sills; soapstone and talc with or more frequently above the asbestos-bearing part of a sill; and occasionally sheared greenstone, probably diabase, at the top of the sill.

The order in which the rocks are arranged indicates separation according to gravity, as in sills of the Thetford phase. The complete or nearly complete serpentinization of the greater part of the sill, however, obscures the original character of much of the rock.

Serpentine, it is well known, may originate from the alteration of olivine, pyroxene, or hornblende. Also, it is well established that pyroxene may alter either to serpentine or to talc and soapstone. Microscopic evidence shows that a considerable part of the serpentine at Broughton has been derived from pyroxene, while the origin of much of the remainder cannot be certainly determined. Except at one mine—the Robertson—no traces of olivine have been found.

If the serpentine is largely or wholly derived from pyroxene, the original rock at Broughton was pyroxenite, instead of peridotite as at Thetford. The position of the asbestos-bearing portion, near the top of sills, as well as its association with talc and soapstone, support this view.

Since the asbestos occurs in all parts of the sills that have been much sheared and shattered, and is not found outside of these shear zones, it seems probable that there is some casual connexion between the excessive fracturing and the forming of asbestos. This may be that the mechanical action of the shearing has developed a fibrous structure in the serpentine, or that the shear zone has afforded channels for the circulation of water, or that both causes have contributed to the asbestos. The fact that the asbestos fibres generally run parallel to the nearest fracture seems to indicate that the asbestos has been formed since or at the same time that the shear zone was developed. Since the parts of the serpentine outside of the shear zone that do not carry asbestos seem to be as completely serpentinized as those within the asbestos-bearing band, or shear zone, there seems to be no means of finding out whether the serpentinization took place before or after the shear zone was formed.

The zones of shearing and fracturing are best developed towards the top of the serpentine in each exposure. But as these are not always in alignment with the cleavage of the enclosing sediments they are not properly speaking parts of a single great zone, and it would thus appear that the shearing has been localized by some condition of the rock which existed previous to the development of the shear zone. As a step towards the analysis of these complex conditions, it is tentatively suggested that the sills first solidified as pyroxenite, or a peridotite high in pyroxene; that the pyroxenite was altered to serpentine or, in places, to soapstone; that the upper portions may have had a development of asbestos in the form of 'mass fibre' or asbestos irregularly distributed through the rock, possibly due to a greater action of magmatic waters near the top of the sills; and that this fibrous structure weakened the resisting power of the rock and the shear zone was thus localized. The shearing would thus bring the mass fibre into its parallel position with regard to the shearing planes, and give it the character of slip fibre.

In any event the asbestos-bearing portion seems to be an established feature of the sills, and the shear zone doubtless extends to great depths. Consequently the asbestos may also be expected to continue at depth.

MINING AND MILLING.

Mining.—All the mines are worked by open-cut methods. The ground at the bottom of the pit is usually cut into a series of benches, generally about 8 to 15 feet high, which afford a number of faces from which the rock can be quarried at the same time. At the Bell mine, Thetford, quite extensive underground work has been carried on in winter with apparent success. Generally, the mines are operated only by day. At the King mine, Thetford, work is carried on in the pit at night by the aid of search lights. At the Danville mine, some underground work has been carried on. Several of the pits have reached a depth of about 200 feet, with two or three times greater horizontal extension.

Plate VII

Amalgamated Asbestos Corporation, Limited. Kings' pit, from the south: about 200 feet deep.

11159—p. 70

Plate IX

Part of Ling asbestos mine, East Broughton, Que., The rock is loose and friable and may be removed with very little blasting.

Plate X

Concentrating mill and electric tramway, Frontenac asbestos mine, East Broughton, Que.

Handling and Dressing.—In some of the mines the asbestos-bearing portion is separated from the barren rock in the pit, and in part the crude from the mill-stuff, and each is loaded into separate boxes and hoisted to the surface. A certain amount of hand cobbing is also done in some pits. In most, however, all hand separation is done at the surface. Then, the separate products are emptied into tramcars, which are usually drawn by small locomotive engines; the dead rock is then taken to the waste dump, and the rock which will afford crude asbestos, to the cobbing sheds, where it is separated by hand work and put in bags. The remainder, usually 35 per cent to 70 per cent of all the rock handled, goes to the ore bins, or, in some cases, directly to the mill for mechanical concentration.

This concentration is an ingenious process which has been developed by some of the pioneer mine managers of the district. The essential features are successive crushings and screenings of the rock, and the removal of the asbestos thus liberated by means of suction fans. The crushing is effected by jaw and rotary crushers of the standard types, and a finer crushing is frequently effected by means of rolls. After the first crushing much or all of the material is dried in rotary driers, with direct heat.

The rock is finely pulverized by a specially designed machine known as the cyclone. This consists of two heavy screw-propeller-like fans of chilled iron, which revolve at a speed of 2,000 revolutions per minute, or more, in a closed chamber. The small rock fragments are thus driven together with such force as to reduce them to powder, and the smallest particles of asbestos are released and collected as before.[1]

The fibre drawn off at the various stages of the milling process is collected in settling chambers and conveyed to a rotary classifier, by which the product is separated into various grades according to the length of the fibre.

Suction fans for the removal of dust from the cyclone, the classifier, and sometimes from the mill are important accessories to the equipment. Magnets are usually employed over the shaking screens to eliminate particles of iron ore, scrap, etc.

---

[1] An interesting discussion of the "Breaking of Asbestos-bearing Rocks," by Edward Torrey, has lately appeared in the Bulletin of the Canadian Mining Institute, Montreal, 1911.

The various mills differ from one another in details, some of which are regarded as more or less secret features, but the general practice is essentially uniform. The milled fibre is classified into three or more grades, and the crude asbestos usually in two. The question of adopting a standard classification is under consideration.

USES.

A small proportion of the asbestos produced, all of the highest grades, is used in making asbestos cloth and various fireproof textiles; while much the greater part is used for covering, and insulation purposes. Boards, shingles, and roofing felts for fireproof construction, materials for electric insulation and protection from acids, boiler and pipe coverings are among the products in common use.

The manufacture of asbestos goods has hitherto been carried on practically only in Europe and the United States. Recently, however, a plant for the manufacture of asbestos shingles, mill-boards, and covering material has been established at Lachine, Quebec, by The Asbestos Manufacturing Company, a company allied to the long-established manufacturing firm of Keasbey and Mattison, of South Ambler, Pennsylvania. A plant for the manufacture of textiles has just been added, and all forms of asbestos manufacture will now be made.

STATUS AND POSSIBILITIES OF THE INDUSTRY.

The assurance of large reserves which all of the principal mines have, has led to most of them being well equipped. The machinery is generally the best known, and the buildings are usually suitable and substantial.

As long as the mining can be done by open-cuts or quarrying, the costs will probably vary only with the nature of the ground, the management, the price of labour, and the conditions of equipment. But in the methods of concentrating, changes are more likely to take place. The present mill practice is the result of the experience of the past fifteen or twenty years, and varies considerably in different mills in details, and probably also in economy. The varying statements of the power required to operate different mills seems to indicate a wide diversity in the efficiency of the concentrating plants.

The enlargement of the market for asbestos products depends mainly on the skill of the manufacturers and the supply of substitutes for asbestos. The steadily increasing price of lumber is continually widening the field for asbestos boards and shingles, while the ingenious applications of asbestos for heat resisting and insulating materials seem likely to give it a great advantage over any known substitutes.

It is rather remarkable that no rival fields in the production of asbestos have yet appeared. The only field that has so far shown a sustained and growing production is that of the Ural district in Russia. The increase in output there for the last ten years has been about the same as that of Canada during the first ten years of the development of the Eastern Townships district. As far as can be learned, the Russian product is not adapted to many of the uses to which Canadian asbestos may be put. This fact, together with difficulties of work and transport, will doubtless keep that field for a long time at least in a subordinate position to Canada in the world's market.

OCCURRENCES OF ASBESTOS.

1.	Wolfestown,	range IV,	lots 24 and 25, Asbestos Mining & Manufacturing Co.
2.	Coleraine,	block B,	Black Lake Chrome & Asbestos Co.
3.	Wolfestown,	range II,	lot 24, Asbestos Mining & Manufacturing Co.
4.	Coleraine,	block A,	Black Lake Chrome & Asbestos Co.
5.	Ireland,	range III,	lot 26, King Bros.
6.	Coleraine,	block A,	Black Lake Chrome & Asbestos Co.
7.	"	"	Standard Asbestos Co.
8.	"	"	American Asbestos Co.
9.	"	range B,	lots 30 and 31, American Asbestos Co.
10.	"	block A,	American Asbestos Co.
11.	"	range B,	lots 29 and 30, Johnson's Asbestos Co.
12.	"	block A,	American Asbestos Co.
13.	"	"	" "
14.	"	range B,	lots 27 and 28, W. half, Union Asbestos Co.
15.	"	"	lot 28, E. half, Bell's Asbestos Co.
16.	"	range A,	lot 29, Dr. James Reed.
17.	"	"	lot 28, Dr. James Reed.
18.	"	" B,	lot 27, E. half, Bell's Asbestos Co.
19.	"	" A,	lot 27, Dr. James Reed.
20.	Thetford,	" VI,	lot 28, Johnson's Asbestos Co.
21.	Ireland,	" X,	lot 26, Johnson's Asbestos Co.
22.	Thetford,	" V,	lot 28, King Bros.
23.	"	" V,	lot 27, The Bell mine.
24.	"	" V,	lot 27, The Bell mine.
25.	"	" V,	lot 26, King Bros.
26.	"	" VI,	lot 26, King Bros.
27.	"	" VI,	lot 27, Johnson's Asbestos Co.
28.	Wolfestown,	" IV,	lot 26, McDonald Bros.
29.	"	" III,	lot 25.
30.	Garthby,	" II,	S.E. lot 16.
31.	Thetford,	" V,	lot 27, west ½ Ward—Ross.

Chromite.

Chromite, or chromic iron, is an oxide of chromium and iron, which is valuable, not as an ore of iron, but chiefly for its content of chromium, an element that is used in certain important chemical and metallurgical processes. It is found in this district in irregular or lense-shaped bodies of workable size and also in nodules and grains which are widely disseminated through the serpentine and pyroxenite.

The output, hitherto, has been obtained from the district between Thetford Mines and D'Israeli: Chrome siding, near Black Lake, being the principal shipping station. Smaller shipments have also been made at Thetford Mines, and D'Israeli.

Promising deposits have, however, been long known to exist at many places in the serpentine belt of southern Quebec. Many of these, doubtless, only await transportation facilities and other market conditions to bring them into use. Important occurrences have been reported from the townships of Bolton, Orford, Melbourne, Ham, Ireland, Leeds, Wolfestown, Coleraine, and Thetford, and as far north as Mount Albert, in Gaspé.[1]

PRODUCTION.

The following are the annual returns[2] of production from 1894 to 1909, inclusive:—

—	Tons.	Value.
		$
1894	1,000	20,000
1895	3,177	41,300
1896	2,342	27,004
1897	2,637	32,174
1898	2,021	24,252
1899	2,010	21,842
1900	2,335	27,000
1901	1,247	16,744
1902	900	13,000
1903	3,509	51,121
1904	6,074	67,146
1905	8,575	93,301
1906	9,035	91,859
1907	7,196	72,901
1908	7,225	82,008
1909	2,470	26,604

[1] Geology of Canada, 1863, p. 749, *et al.*

[2] Mineral Production of Canada, by J. McLeish, Chief of the Division of Mineral Resources and Statistics, Mines Branch, Department of Mines, Ottawa, Canada.

A part of these ores is used by the Electric Reduction Company of Buckingham, Quebec, in the manufacture of ferro-chrome. Except for occasional small shipments to Europe, the remainder—more than three-fourths of the total production—is shipped to the United States. It is there used in the manufacture of bichromates for use in dyeing textiles, tanning leather, for pigments used in printing and painting, in making chrome steel, and lower grades for lining furnaces.

HISTORY.

The element chromium was discovered in 1797, by Vauquelin, a chemist at L'Ecole Politechnique, Paris, in specimens of crocoisite or chromate of lead from the Ural mountains. In the following year, 1798, the corresponding compound of chromium with iron—chromite—was first discovered by Meder. The first ores are said by W. Glenn[1] to have been found nearly simultaneously in the northern Urals by Soymonof, and in the southern Urals by Metschinskow, at about this time. Twenty years later, the use of chromium for dyeing was learned; and in 1827 chromite was discovered near Baltimore in America by P. Tyson, one of the founders of the well known chemical company of that name. The chrome industry has been an important one ever since.

From 1830 to 1860 the United States was the leading producer of chromic iron, the principal output being from Maryland, with lesser amounts from Pennsylvania and California. At present there is only a small production from the United States, although most of the Canadian, and large quantities of foreign ores, are consumed in that country. The mines of Norway and of Scotland were also important producers in the latter part of the last century.

The deposits of Turkey took the lead in the production of chromium between 1860 and 1870, and held that position until the opening of the New Caledonia mines within very recent years. Siberia, New South Wales, and New Zealand have also produced varying amounts of chromite at different times.

DEVELOPMENT IN CANADA.

As early as 1861 samples of some tons weight from the township of Ham, in Wolfe county, were sent to London and Glasgow by Major R. G. Leckie. These samples showed an average content of

[1] Trans. Amer. Inst. Min. Eng., 1895, U. S. G. S., Vol. XVII.

43·9 per cent chromic oxide. Although they were then valued at £10 to £12 per ton of ore—a price about four times that of the present time—no mining was carried on, owing, in part at least, to the lack of railway facilities, which have since been provided in the course of the general settlement of the district.

The next serious attempt to exploit the chromite ores of Quebec seems to have been made in 1886, or 1887, when upwards of 100 tons of ore from Wolfestown, Leeds, and Thetford were mined and shipped to Philadelphia, principally by the late Dr. James Reed. No further work is on record until 1894, when operations were begun at several points by Messrs. Nadeau, Leonard, and others. One thousand tons are reported to have been shipped that year, and there has been a constant output ever since.

CHARACTERS OF THE ORE.

Chromite occurs in the rock in varying proportions, from masses of pure ore to disseminations in the country rock too poor to be used as ores. The value depends on the amount of oxide of chromium, Cr_2O_3, which the ore contains. Ores carrying 45 per cent or more of chromic oxide are put into the market as crude ore. Ore falling below 50 per cent, however, is penalized, and that running above 50 per cent is at a premium of 50 cents to $1 per unit per ton. Ore carrying less than 40 per cent and as much as 10 per cent is concentrated to 50 per cent or more. It is, therefore, important to secure as high a grade of product as possible, the grade depending on the completeness of the separation of the ore from country rock, and of the proportion of chromic oxide originally contained in the ore.

Theoretically, chromite consists of one molecule of ferrous iron and one of chromic oxide. But it is known that the iron may be replaced by a certain proportion of magnesium, and the chromium to some extent by aluminium. Accordingly Pratt (Op. cit.) has suggested that chromite is probably an isomorphous mixture of FeO, Cr_2O_3; MgO, Cr_2O_3; and MgO, Al_2O_3.

On examining microscopic sections of chromite from Black lake, it has been found to consist of two parts: a reddish brown, translucent substance, and a black, opaque material (Plate XI). In specimens selected from the high grade ores, the reddish material was found to make up as much as 90 per cent of the whole; while in specimens of poor ores the black portion was greatly in excess.

Plate XI

Microphotograph of chromite. The opaque portion which is richer in iron fills irregular spaces and sends off arms into the translucent magnesia-rich part of the ore.

Specimens of medium grades of ore show the two portions in the thin section to be definitely distinct from each other, though often intricately intergrown. In a few cases they had the appearance of interlocking octahedral crystals, but in general, crystal outlines cannot be well distinguished in either. In reflected light the two kinds of material are absolutely indistinguishable.

An attempt was made to etch a specimen in thin section, but unsuccessfully. The cover glass being removed, the section was treated with hydrochloric acid at boiling temperature for twenty minutes, but no perceptible effect was produced on either of the substances.

A quantity of rock was crushed, and sized, and a magnetic separation attempted. With an electric current of 2·5 amperes on a Wetherell separator, no part of the mineral proved magnetic; at 6 amperes, all was taken up. After repeated trials, a fairly good separation was effected with an amperage of 3·8—the belt moving at 20 feet per minute, the first magnet standing $\frac{7}{32}$ inches from the belt, and the second $\frac{9}{32}$, and with a slow feed. Microscopic examination showed that the heads consisted of the black opaque portion of the ore, and that the red translucent part formed the tails. Separate treatment of each of the products, made several times, yielded very clean heads, but the separation of the tails was not quite so satisfactory.

One-fourth of the crushed material which passed through the 150 mesh screen and remained on the 200 mesh, was treated in an experimental hydraulic separator, using an ascending current. By this means a tolerably good separation was also effected. The difference in the density of the two products was not determined. but the red portion proved the lighter.

Another feature, that evidently has a bearing of some importance on the concentration of chromite, is the fact that the reddish brown portion is the more friable. On screening the products of a single crushing it was found that the proportion of red to black grains increased directly with the fineness of the material. Practically all that passed through the 200 mesh screen was red, and the greater part that lay on 80 mesh, black; while that remaining on the 150 mesh screen was intermediate in composition. In the mill concentration, chromite, after passing through jaw crushers, is stamped to about $\frac{1}{20}$ inch, and separated from the gangue by means of Wilfley tables. There is a notable loss of fine particles, or float, which it is evident from this investigation consists of a valuable portion of the ore, and not a waste product.

In view of the correspondence in formula between chromite and pitchblende, a specimen of chromite was tested for radium, by Dr A. S. Eve, of the Department of Physics of McGill University. It proved to be so feebly radio-active that no examination of the separate products for this purpose was thought necessary.

The two kinds of ore obtained by magnetic separation described above was submitted for chemical analysis. The following are the results:—

(A) is the reddish brown, less magnetic, lighter, and more friable portion;

(B) is the black, opaque, magnetic part.

—	A.		B.	
	—	Molecular ratio.	—	Molecular ratio.
SiO_2	6·51	0·109	4·10	0·068
Al_2O_3	10·34	0·101	11·34	0·110
Cr_2O_3	45·30	0·300	48·20	0·320
FeO	13·94	0·193	15·66	0·217
MnO	0·32	0·004	0·36	0·005
CaO	2·50	0·045	1·50	0·027
MgO	16·70	0·417	15·66	0·341
CO_2	2·46	0·056	1·45	0·033
TiO_2	0·12	0·001	0·12	0·001
H_2O	0·12	....	0·08	
	2·03	....	1·97	
	100·37	....	100·44	

Assigning to CO_2 in the above analyses all the CaO, and an additional amount of MgO to satisfy it; and to SiO_2 enough MgO to make bronzite, the results may be regarded as impurities. Combining the remaining constituents in the three molecules, FeO, CrO (MnO being added to FeO), MgO, Cr_2O_3, and MgO, Al_2O_3, there is only left an excess of MgO in A, of 85 molecules; and in B, of 49. In other words, the ratios of the protoxide to the sesquioxide bases (exclusive of amounts entering into the impurities, calcite and bronzite) are as follows: in A, 494:401, and in B, 489:430.

The difference in composition of these two specimens, which seems to account for their difference in optical and physical character, is that magnesia is higher in A than in B; while ferrous iron is higher in B. Dr. Wadsworth, who made a microscopic study of chromite and picotite in peridotite,[1] has suggested that chromite may be an altered form of picotite, a variety of spinel in which chromium occurs to as much as seven per cent. To this Pratt (Op. cit.) takes exception, and considers it probable that chromite consists of three isomorphous molecules, FeO, Cr_2O_3; MgO, Cr_2O_3; and MgO, Al_2O_3. He says: 'With the increase of the ratio of the molecule MgO, Al_2O_3, and a corresponding decrease in the molecule FeO, Cr_2O_3, the more translucent the mineral will become.'

It is a well known fact that pure chromite, answering the formula FeO, Cr_2O_3, has not yet been found in nature, except in meteorites. But the FeO is replaced in part by MgO, and the Cr_2O_3 by Al_2O_3. This it is that has suggested an isomorphic relation of these molecules. The following are analyses of chromite from (I) Bolton, and (II) near Lake Memphremagog, Que., given by Hunt.[2]

—	I.	II.
Cr_2O_3	45·90	49·75
Al_2O_3	3·20	11·30
FeO	35·68	21·28
MgO	15·03	18·13
	99·81	100·46

The analysis of specimen A clearly shows that the translucent portion of the sample in question cannot be picotite, even in somewhat altered form, since it has more than six times as much chromic oxide as that mineral contains. In some sections (see Fig. 7) the relative positions of the translucent and opaque portions are such as to suggest that the opaque might be an altered form of the other, but in others both appear to be primary. It, therefore, seems mere probable that they are intergrowths, and, as Pratt has suggested, that Cr_2O_3 may have for its protoxide base either FeO or MgO, and

[1] Lithological Studies, Cambridge, Mass., 1884, p. 184.
[2] Geology of Canada, 1863, p. 504.

that the two molecules are commonly both present in an isomorphic relation. Accordingly, when the magnesia molecules are in excess the mineral has the properties of specimen A, and when the iron-bearing molecules increase to an amount nearly equal to the other the mineral takes the properties of specimen B.

It has not yet been found possible to ascertain whether or not any difference in commercial values is to be looked for in the two classes of ores, namely, those whose bases are either iron, or magnesia. For the manufacture of bichromates it is not apparent that there could be any, but for steel alloys there might be a difference in the value of such bases. The microscopic study of chromite specimens from this district indicates that the greater portion of them are of the magnesian, or A class. The sample chosen for analysis was selected because the microscopic section showed somewhat equal proportions of the two classes of mineral.

MINERALS ASSOCIATED WITH CHROMITE.

The principal gangue in the chromite deposit is the country rock which consists essentially of olivine, pyroxene, and serpentine as already described. A few other minerals are also found with the ores and although in small amounts are perhaps worthy of notice.

Magnetite.—Magnetite occurs in the country rock as primary crystals and also in grains and small irregular masses and veins in serpentine. It is also found in grains in larger masses which appear to be primary, and intergrown with the chromite ore.

Vesuvianite.—At the Dominion and Caribou pits of the Black Lake Consolidated Company's chrome properties and also at the mine of the American Chrome Company there are shoots, veins, and irregular vuggs of vesuvianite. Small well formed crystals are found in places lining the interior walls of drusy cavities. Specimens were handed to Mr. R. P. D. Graham, Lecturer in Mineralogy at McGill University, who has kindly furnished the following analysis and description:—

Lilac-coloured Vesuvianite from Lot 26, Range II, Township of Coleraine, Megantic County, Que.

Montreal Pit, Dominion Chrome Mine.

The percentage composition given below is the mean of closely agreeing duplicate analyses of the mineral except in the case of the alkalis, which were not determined in duplicate.

—	%	Molecular ratio.	
SiO_2	36·77	612	 3
Al_2O_3	20·05	196	 1
CaO	37·47	669	796. 4
FeO	0·65	9	
MnO	0·20	3	
MgO	2·69	67	
Na_2O	2·88	46	
K_2O	0·21	2	
	100·92		

Regarding the mineral as a lime alumina silicate, in which a part of the lime has been isomorphously replaced by equivalent amounts of the several other monoxides present, the molecular ratio $CaO:Al_2O_3:SiO_2$ is approximately 4:1:3. If no replacement had taken place, there would be 44·58 per cent lime (0·796 × 56), and the percentage composition of the mineral recalculated from the above analysis on this basis is given in column I below. Column II gives the theoretical figures for $4CaO$, Al_2O_3, $3SiO_2$.

—	I.	II.
SiO_2	36·26	35·57
Al_2O_3	19·77	20·16
CaO	43·97	44·27
	100·00	100·00

The mineral occurs in small transparent crystals up to 1 mm. in length, and having a high lustre. There is practically no loss in weight (0·05%) after heating at 105°C. for an hour, and the colour also remains unchanged; at a higher temperature, fusion with intermescence takes place, and if the mineral has been powdered, it cakes and turns a bath-brick colour. It is not acted upon by acids. The melt obtained after fusion with sodium carbonate is deep green, indicating the presence of manganese, and the violet or lilac colour of the mineral is probably due to its small content (0·20%) of the oxide of this element. A qualitative test for chlorine gave negative results.

The crystals were not measured completely, but a sufficient number of angles were determined on three of them to identify the mineral as vesuvianite. The forms observed on these were ***a*** (100), ***m*** (110), *p* (111), *s* (311), and *v* (511); the angles measured in the zone (*a p*) were as follows, the corresponding values for vesuvianite being given in brackets for comparison:—

av.	22° 5′ to 23° 16′	(22° 55′)
vs.	11° 47′ to 12° 15′	(12° 15′)
sp.	29° 33′	(29° 30′)

Owing to the small size of the faces, some of the angles could only be obtained approximately, which accounts for the somewhat large limiting values.

The specific gravity (3·32) and the optical character (uniaxial, negative) also agree with vesuvianite.

Analyses of vesuvianite do not as a rule lead to any simple formula for the mineral, and specimens from different localities may vary considerably in composition. It is, roughly speaking, a lime-alumina silicate, in which varying proportions of the lime may be replaced by other monoxides, while ferric oxide may at the same time take the place of some of the alumina. It was shown by Rammelsberg that the ratio R″:R‴ in vesuvianite is always 2:1; and he proposed, as a general formula for the mineral, the type $4R''_4$, SiO_4, R'_6 SiO_5. In the case of the specimen described above, the ratio Ca″:Al‴ = 2:1, as required for vesuvianite, but the composition is most nearly represented by the general formula $2R'_4$ SiO_4. R_6SiO_5, or $2CA_2$, SiO_4. Al_2, SiO_5.

Diamonds.—In view of the recent discovery of diamonds by Mr. R. A. A. Johnston, Mineralogist of the Geological Survey, in rocks containing chromite which were found by Mr. Chas. Camsell in the Tulameen district, British Columbia, specimens from Black Lake were handed Mr. Johnston for examination. Four specimens were taken. One was of chromite ore from the Montreal pit of the Dominion Chrome Company, now the property of the Black Lake Consolidated Mining Company; one of serpentine from the vicinity of the ore body, and one of vesuvianite from the same pit. The fourth specimen was a piece of peridotite taken near Black Lake station. The last three specimens contained no diamonds, but the specimen of chro ite ore was found to contain about 0·06 per cent of diamonds, which are small but otherwise of good quality. The diamonds found are too small to be of commercial value as gems. Nevertheless their occurrence is important as the examination of a single specimen is by no means a complete test of the whole deposit or of the chromite of the entire district. Forty-five localities in which chromite is found are shown on the accompanying map of the Thetford-Black Lake district, and many others are known farther to the southward. The examination of these as well as further testing of the deposit at the Montreal pit, and an examination of the gravels in the vicinity of any of the deposits where this is practicable, is necessary before it can be safely told whether or not the diamonds are of commercial importance in the district.

The following is Mr. Johnston's description of the process he employed in extracting the diamonds and of the results attained:—

'Examination of specimens from the vicinity of Black Lake, Quebec, with a view to ascertaining the presence or absence in them of any form of diamond, by R. A. A. Johnston:—

'No. 1.—This specimen consisted of a massive, shiny black, somewhat granular chromite, more or less intimately mixed with some greyish serpentinous material.'

'A fragment was broken from this specimen and crushed to a powder passing a sieve of sixty meshes to the linear inch; this powder was then treated in a separatory tube with Thoulet solution of a specific gravity of about 3·0; the heavier separate which settled at the bottom of the tube weighed after washing and drying approximately 11 grammes; this was mixed with 50 grammes of chemically pure dry carbonate of soda and the mixture fused in a large platinum crucible at a cherry red heat for four hours; after cooling the melt was digested in distilled water to complete disintegration, the supernatant liquid filtered off and the residue treated with hydrochloric acid to remove oxides of iron, magnesium, etc. About half of the chromite was removed in these operations. This course of procedure was repeated several times. It soon became evident that this method was of little effect upon the coarser particles of chromite that were being left after each set of operations; fusion with bisulphate of potassium was then resorted to, and the residue from this treatment which showed a number of minute diamonds along with some undecomposed chromite was freed from the latter by a final fusion with sodium carbonate.'

'The residue of diamonds obtained in the manner indicated above was found to weigh nearly seven milligrammes or 0·06 per cent of the heavy separate operated upon, which constituted nearly the whole of the specimen.'

'These diamonds appear to the naked eye as nothing more than dust particles; under the microscope, however, with a moderate power they are seen to be perfectly transparent and beautifully crystallized; the most common form is that of the simple octahedron; many of them though, are apparently combinations of the cube and octahedron. The hardness could not be determined with accuracy owing to the very small amount of material available for experiment, but in the course of their removal from a beaker with the aid of a camel's hair brush, it was noted that even such light pressure as was occasioned in this way was sufficient to cause abundant fine scratches upon the glass.'

'When exposed to radium emanations they can be seen to fluoresce distinctly, a test which is regarded as conclusive evidence of the character of the mineral.'

'From the Montreal Pit, Black Lake Consolidated Company, Black Lake, Quebec.'

'No. 2.—From the same locality as the preceding specimen. A dull greenish grey serpentine. Treated in the same manner as No. 1, it gave negative results.'

'No. 3.—From the same locality as No. 1. A bright pink vesuvianite. It likewise gave negative results.'

'No. 4.—From near Black Lake Station. A dull grey peridotite. It also gave negative results.'

Molybdenite.—Enclosed in vesuvianite at the Caribou pit a metallic mineral was found in veinlets. On examination by means of the blow pipe, Mr. MacLean found it to have the properties of molybdenite. The quantity obtainable was too small to admit of a chemical analysis.

RELATIONS TO THE COUNTRY ROCK.

It is a striking feature of the occurrence of chromite, that it is found in greater or less amount throughout the entire peridotite and serpentine belt. In parts of the rock not occupied by ore bodies nodules of chromite are occasionally found, and grains of the mineral are more or less freely scattered through the entire rock. This general dissemination of the chromite, together with the highly altered condition of the rocks at first, seemed to suggest that the ore bodies had been formed by a concentration of the mineral from the surrounding rock, but further examination does not support this view.

The ore bodies do not commonly have well defined walls, aud grains of chromite are quite as plentifully disseminated through the rock adjacent to the ore bodies as elsewhere. In fact, except where there has been faulting or slipping, the ore bodies generally pass by gradation into lean ore, and thence into chromite-bearing rock too poor to be worked.

The ore bodies are generally irregular in shape, though they commonly have an approach to ellipsoidal outlines in the surface section, indicating that they are more or less lense-shaped. In such cases the longer axes lie parallel to the general foliation of the country rock, that is N.E.-S.W., and so the form may be the result of regional pressure which has taken place after the ore bodies were formed.

One of the largest bodies of ore yet proven is at the No. 1 pit of the Black Lake Chrome and Asbestos Company. This ore body is some 80 feet in length, from 5 to 50 feet wide, and has been worked to a depth of 340 feet. It dips to the west at an angle of about 60°. In its general form this ore body appears to be quite similar to the famous Wood mine, of Lancaster, Pennsylvania, which was one of the first chromite mines to be worked in America. This was first described by Prof. Frazer[1] as follows: 'The country rock

[1] Second Geological Survey of Pennsylvania, 1880.

is serpentine. The ore body as proven is almost 50 fathoms long at its greatest extension. Depth proved to 120 fathoms. Pitch of the mine from 40° to 60° under the horizon. The width of the ore bearing rocks is from 10 to 35 feet, or may be taken generally at 20 feet.'

The Montreal pit of the Dominion Chrome Company (map 23 A, Fig. 6), is another of the larger deposits. Here the work has been done chiefly by an open-cut of 100 × 40 feet, with a maximum depth of 60 feet. The original ore body, which dips towards the northwest at a low angle, has been followed all the way. It was 15 feet thick at the surface, and maintained that thickness at different places. Where this has been removed several bore-holes have been sunk to test the underlying rock. The logs of two of those holes are given below. The hole A is a vertical one, that at B dips northwest at 60°. This is the direction of the dip of the ore body, but at a considerably higher angle. The holes begin at practically the same place.

A.		B.	
0-43 feet	serpentine.	0-47 feet	serpentine.
43-46 "	ore.	47-50 "	ore.
46-55 "	serpentine.	50-51 "	serpentine.
55-58 "	ore.	51-59 "	ore.
58-74 "	serpentine.	59-63 "	serpentine.
74-80 "	ore.	62-63 "	ore.
80-82 "	serpentine.	63-65 "	serpentine.
82-83 "	ore.	65-73 "	ore.
	serpentine.	73-83 "	serpentine.
		83-84 "	ore.
		84-88 "	serpentine.
		88-98 "	ore.
			serpentine.
Total ore, 13 feet.		Total ore, 31 feet.	

Some portions of the rock, classed as serpentine in the above logs, are granite; but their measurements are not distinguished. Boring B being nearly parallel to the dip of the lenses, shows the dimensions along the axes nearest to the vertical, which appear to be approximately two and a half times the thickness of the ore bodies.

The Caribou pit (locality 37 on the accompanying map of Black Lake mining district), of the Black Lake Chrome and Asbestos Company, shows some features of interest, although the removal of the rock between the ore bodies, as well as the ore, leaves little to show the relations of the original deposit. At present it is a pit 90 feet deep, showing small lenses of rich ore on either side. There is a wall of granite on the southeast and northwest sides. On the southwest side the granite is a dyke 8 feet thick, on the opposite side about 2 feet thick, and less regular. The ore at present seen is near but not touching the granite walls. Isolated bodies of ore are said to have been found between the dykes, and the amount of rock removed would certainly indicate that some values must have been obtained in various parts of it. The history of the working before the property fell into the hands of the present owners could not be ascertained, but the best ore seems to have been near the sides of the present pit. Molybdenite occurs in small quantities with the chromite at one place in this pit.

The Canadian Chrome Company's mine (locality 32 on accompanying map 23A) is an open pit, of somewhat similar extent to the last. In the central part of the northeast wall a body of granite, some 10 feet in width at the surface, extends downward vertically for 30 feet, and is then replaced by serpentine. It is one of those places in which the granite has the appearance of being contemporaneous with the peridotite from which the serpentine has been formed. The best ore seems to have been obtained near the western side of this pit. The ore body of this property appears to be less well defined than usual, but practically all the serpentine near, and for a considerable distance to the northeast of the main pit, is impregnated by chromite, furnishing a very large amount of low grade concentrating material.

The mine of the American Chrome Company (localities 14, 15, etc., on accompanying map 23 A) is essentially similar to the above in its development, and the ore occurs as disseminations in the rock for a very considerable distance about the mine.

The property of H. Leonard (localities 3, 4, 5 on accompanying map 23 A), near Breeches lake, appears to be similar to those mentioned in the relations of the deposit to the country rock, but the deposit is not well developed. It shows a considerable amount of good ore, exposed in three cuttings, one of which is 100 feet in length. The others are respectively 100, and 500 feet distant. The ore appears to be 5 or 6 feet in width at each of these places, and the covering of drift and talus on the surface makes it impossible to say how closely these different exposures of ore can be traced together. They lie in succession in a southwesterly direction from the larger pit.

The numerous other mines and prospects of the district are worked by open-cut, and this fact, with the smaller development, makes it difficult to obtain definite evidence of the shape, or relation of the ore bodies, except in sections exposed on the surface. There appears to be no definite order of succession in these ore bodies, but they are separated by masses of the country rock, in some cases a few inches, in others many feet in thickness. While their distribution is irregular, they seem to occur most frequently in a zone of the country rock parallel to and not far distant from its contact with the adjacent sediments.

GENESIS.

Evidence.—The features that are essential in considering the origin of the chromite ores are the shape, the relations to wall rock, and the distribution of the deposits. The relation of chromite to other minerals in the microstructure of the rock should also be taken into account.

In shape the ore bodies are roughly lenticular. Several lenses varying in size from mere pockets up to masses containing thousands of tons commonly occur near enough together to form a sort of ore bearing zone in the rock. The walls are not usually well defined, but the ore passes into country rock by rather gradual transition. The principal deposits occur in rock that is intermediate in composition between peridotite and pyroxenite. This seems to be equally general whether the country is in the form of a stock or of a sill.

In microscopic sections of rock containing ore, the chromite shows the relations of a primary mineral.

Theoretical.—Three hypotheses have been advanced by different investigators to account for the origin of chromite ore. Briefly stated these are:—

(*a*) That chromite is a secondary mineral formed during the serpentinization of peridotite;

(*b*) that chromite is a primary mineral that was formed by pneumatolitic action during the cooling magma of the country rock;

(*c*) that chromite is a primary mineral, and the deposits products of magmatic differentiation.

The last mentioned is the view now generally accepted.

Review of Previous Opinions.—

(*a*) Von Groddeck[1] and Glen[2] are amongst the writers on the subject who have held this opinion. The origin of chromite seems to have been connected with that of serpentine in the belief that chromite occurs only in serpentine. Since chromite occurs in unaltered peridotite and pyroxenite as well as in serpentine, this view is plainly untenable.

(*b*) Meunier[3] arrived at the opinion that chromite was formed by pneumatolitic action from chemical experiments in which he produced chromite synthetically. By introducing hydrogen into a porcelain tube at red heat containing equal parts of protochloride of iron and sesquichlorite of chromium, Meunier obtained chromite and other products. The chromite contained 63·06 per cent Cr_2O_3; a higher percentage than is found in any chromites in nature, except from meteorites.

The occurrence of molybdenite and manganiferous vesuvianite in the chromite deposits at Black Lake lends some support to this view; but their bearing could not be safely applied to the deposits as a whole without further evidence.

(*c*) The origin of chromite ores by magmatic differentiation from the country rock has been advocated by several writers whose conclusions are in practical agreement.

Dr. F. D. Adams[4] was the first to advance this view for the ores of Quebec. Messrs. Pratt and Lewis[5] have since showed the deposits of the southern Appalachians to have a similar origin; while Professor J. H. L. Vogt[6] had previously established the primary origin of the chromite deposits of Hestmandø, Norway. There, in fresh or little altered peridotites, bodies of chromite were found by Professor Vogt, corresponding in shape and position to those previously known to occur only in serpentine. F. D. Power[7] from a study of the chromite ores of New Caledonia considers chromite to be an

[1] 'Lehre von den Lagerstatten den Erze,' 1879.
[2] XVII Annual Report, U.S. Geological Survey.
[3] Contribution à la histoire de fer Chrome, St. Meunier Comptes Rendus, vol. CX, 1890.
[4] Transactions of the Province of Quebec Mining Association, 1894.
[5] Pratt, J. H., Trans. Am. Inst. Min. Eng., 1899. U.S.G.S., 1900.
Pratt, J. H., and Lewis, J. V., North Carolina Geol. Survey, 1905.
[6] Zeitschrift für Praktische Geologie, October, 1894.
[7] Transactions of the Institution of Mining and Metallurgy, Vol. VIII, 1899-1900.

original constituent of the eruptive rock. But he finds the deposits arranged along joints and natural channels in the rock, and hence believes the deposits have been formed by solution and redeposition; although recognizing the difficulty of finding a natural solvent of chromite. E. C. Harder[1] considers the chromite deposits of western and central California, except certain placers, to have been formed by magmatic segregation. Mr. Harder adds that in some places later decomposition and alteration has undoubtedly modified the nature of the deposit. F. Cirkel[2] expresses the belief that the chromite was formed during the cooling of the magma. A. L. Hall and W. A. Humphrey[3] find in the chromites of the Transvaal that the mineral is a primary constituent of the rock. They also note evidences that chromite crystallized at about the same time as the rhombic pyroxenes, a fact which is noticeable in the Quebec ores.

Conclusions.—The microscopic evidence that chromite occurs in isolated grains as a primary mineral, its general occurrence in traces at least in all the rocks of the series, the shape of the deposits, their relation to the wall rock, and the fact that they occur principally in a particular phase of the intrusive complex, viz., in transition rock between peridotite and pyroxenite, all go to support the opinion that the deposits were segregated from the magma of the original rock before it was completely solidified. The occurrence of vesuvianite in two of the chromite deposits indicates that there has been pneumatolitic action. But granite intrusions which are found near each of these deposits were formed somewhat later than the rock which contains the chromite. It is, therefore, certainly possible, and seems more probable, that the vesuvianite was formed by pneumatolitic action due to the intrusion of the granite, rather than to the intrusion of the basic rocks.

On the whole the conclusion seems unavoidable that, the ore bodies are results of differentiation from the magma of the original rock; that they have been modified in shape by mechanical deformation which they, as well as the enclosing rock, have undergone; and that this deformation may have taken place in part while the country rock was still in a partially plastic condition. Subsequent solution and redeposition may have taken place to some small extent; but of

[1] Bulletin No. 430, U.S. Geol. Survey, 1910.
[2] Report on Chrome Iron Ore Deposits in Eastern Townships, Province of Quebec, Dept. of Mines, Canada, Mines Branch, 1909.
[3] Trans. Geol. Soc. South Africa, Vol. XI, 1908.

this there seems, as yet, to be no certain proof, since the small vein-like bodies of chromite which are occasionally found, show no internal structure to distinguish them from ultra basic off-shoots of chromite bearing portions of the intrusive rock.

MINING.

Mining is carried on in open-cuts, except at the Black Lake pit No. 1, where a shaft has been sunk. As the ore bodies are often small and discontinuous, the least expensive methods of working have usually been adopted. Power drills and derrick hoists are the principal equipment used. The diamond drill has been used successfully for prospecting.

Concentration.—The ore is bought and sold on a basis of 50 per cent chromic oxide. If higher than this, a premium is paid, if lower the ore is penalized. Consequently ore carrying approximately 45 per cent is shipped as crude; all from that quality to about 10 per cent is concentrated to 50 per cent or a little higher. The highest percentage reached in either crude or concentrated ore is rarely above 55 per cent Cr_2O_3.

The method of concentration that has been followed recently, consists, successively, of crushing, stamping, and concentrating by means of Wilfley tables. The middlings from the first Wilfley are usually treated on a second table, and a product rarely exceeding 51 per cent is obtained. No data is at present at hand as to the percentage of recovery. There is, however, an apparent loss in 'float,' or very finely crushed ore, which is carried from the tables with the lighter rock particles.

USES.

A limited quantity of these ores was used for a time by the Electric Reduction Company of Buckingham, Quebec, in the manufacture of ferro-chrome. Except for this, and occasional small shipments to Europe, the Canadian product is shipped to the United States. It is there used in the manufacture of bichromates for use in dyeing textiles, tanning leather, for pigments used in printing and paint, and in making chrome steel, and the lower grades for lining furnaces.

OCCURRENCES OF CHROME IRON ORE.

1.	Garthby,	range V, lot 36.	O. Brousseau.
2.	"	" V, " 37.	O. Brousseau.
3.	"	" I, " B.	Gosselin.
4.	"	" I, " C.	H. Leonard & Co.
5.	"	" II, " 5, 6, 7, 8,	H. Leonard & Co.
6.	"	Breeches lake,	H. Leonard & Co.
7.	"	range II, N. lot 4.	M. J. Hawley.
8.	Ireland	" II, lot 28,	King Bros.
9.	Coleraine,	block A,	Black Lake Chrome & Asbestos Co.
10.	"	" A,	" "
11.	"	" A.	" "
12.	"	" A.	" "
13.	"	range IV, lot 7,	American Chrome Co.
14.	"	" IV, " 8,	" "
15.	"	" IV, " 9,	" "
16.	"	" IV, " 10,	" "
17.	"	block A,	Black Lake Chrome & Asbestos Co.
18.	"	" A,	" "
19.	"	" A.	" "
20.	"	range X, lot 19 N. W.,	James Reed.
21.	"	block A,	Black Lake Chrome & Asbestos Co.
22.	"	" A,	" "
23.	"	range X, lot 9,	James Reed.
24.	"	block A,	Black Lake Chrome & Asbestos Co.
25.	"	" A,	" "
26.	"	" A,	Standard Asbestos Co.
27.	"	" A,	Black Lake Chrome & Asbestos Co
28.	"	" A,	Standard Asbestos Co.
29.	"	" A,	Black Lake Chrome & Asbestos Co.
30.	"	" B, lot 28,	Union mine.
31.	"	range B, " 26,	Ward and Ross.
32.	"	" A, " 16,	Canadian Chrome Co.
33.	"	" A, " 17,	J. Lemelin.
34.	"	Ind. Res. range XIII, L. 8,	Star Chrome Mining Co.
35.	"	range IV, lot 25,	F. E. Narges.
36.	"	" XIII, " 5, Ind. Res.,	Star Chrome Mining Co.
37.	"	" III, " 25,	A. Boudreau.
38.	"	" II, " 25,	Dominion Chrome Co., Montreal.
39.	Wolfestown,	ranges II and III, lot 24,	Bell Asbestos Co.
40.	Coleraine,	block A,	Black Lake Chrome and Asbestos Co.
41.	Garthby,	ranges I and K.	
42.	Coleraine	" IV, lot 4,	Adam and St. Onge.
43.	"	" A, " 15.	
44.	"	" B, " 13,	American Chrome Co.
45.	"	" XIII, " 2,	R. H. Gardiner.

STATUS AND POSSIBILITIES OF THE INDUSTRY.

The position of Canada amongst other countries of the world in regard to the production of chromite, from 1903 to 1907, is shown by the following table of statistics also prepared by Mr. McLeish.[1] It is also stated by Mr. McLeish that, "Turkey is one of the most important producers of chromite, the ore being found in many parts of both European and Asiatic Turkey. Unfortunately no complete records of production are available."

---

[1] Op. cit.

World's Production of Chromite in Metric Tons (2,204·6 lbs.).

—	1903.	1904.	1905.	1906.	1907.
Australia	1,982	403	53	15	30
Bosnia and Herzegovina	147	278	186	320	310
Canada	3,183	5,510	7,779	8,196	6,528
Greece	8,478	6,530	8,900	11,530	11,730
India	...	...	2,751	4,445	7,391
New Caledonia	...	47,247	76,933	84,241	3,800
Rhodesia	...	...	...	3,308	7,273
Russia	16,421	26,575	27,047	16,976	
Norway	...	154			
United States	152	125	22	109	205
Turkey	No complete statistics available.				

For the period between 1903 to 1907, Canada held either the third or fourth place amongst countries producing chromite. This is with the exclusion of Turkey whose production, though doubtless sometimes large, is variable, evidently owing to the cost of transportation being nearly equal to recent current prices. Concerning the Turkish industry, United States Consul Ernest L. Harris, Smyrna, recently gave the following notes on the outlook for chrome ore in Asia Minor[1]: 'Chrome ore has declined so much in price that there is not much profit in mining it, and certainly not in districts far distant from the sea. As much as $100 per ton was paid for chrome ore 20 years ago, but the same quantity and quality cannot be sold delivered to-day, f.o.b. Smyrna, for more than $17 per ton; often it brings only $15.'

'The most important mines formerly worked were those of Daghardi, in Broussa. The district which has produced and exported the greatest quantity of chrome ore in Asia Minor is that termed the basin of Macri, of which the port of that name was the chief point of shipment. This port is in the vilayet of Smyrna, on the southern coast of the peninsula. Considerable chrome is also shipped through the port of Smyrna. The mines are situated in the mountains near Sarakoui, on the Aidin railway line. There are also many other chrome pits which have been left unworked on account of the difficulties connected with transportation.'

'Chrome ore in Asia Minor is usually found on mountains from 4,000 to 5,000 ft. high. It is removed from the pit to the railroad

[1] Engineering and Mining Journal, New York, May 30, 1908.

station, or market, on the backs of donkeys and camels, the surer-footed donkeys being used in the higher altitudes and the camels for the plains. This method usually involved two or three transfers between the point of origin and the port of Smyrna. It usually takes one donkey a week to carry 400 lbs. of chrome ore from the pits on the mountain-tops to the canal station below; it then takes five camels one day to transport a ton of chrome ore over a distance of 15 miles. The last shipments of chrome ore made from Smyrna were 1,500 tons in 1906. None of the mines has ever been worked with up-to-date machinery. As the chrome ore of other countries comes on the world's market in increasing quantities, that of Turkey must necessarily decline in the face of keen competition, not on account of the quality of the ore, but from the difficulties of internal transportation, if for no other reason. The largest firm which ever handled chrome at Smyrna has returned all its mines to the Turkish government, as the annual tax upon the ownership of these mines amounted to more than they could be worked for at profit.'

The controlling producers of the world are evidently New Caledonia, where a natural concentration of chromite owing to the disintegration of the serpentine country rock gives more continuity to the ore bodies, and Russia, where chromite was first discovered.

The principal chromite properties in Quebec have recently changed ownership having been acquired by the newly formed Black Lake Consolidated Mining Company. In the interval of reorganization, work has been practically suspended, but it is to be hoped that the suspension is only temporary.

In geographical position and means of transportation, the Quebec district has great advantages over chromite bearing districts yet known in other parts of the world. The Quebec Central railway passes through the centre of the district and gives communication to the sea-board. The distance from Black Lake station to Quebec is 80 miles; to Boston, 314 miles; and to New York, 447 miles.

The obstacles of most importance in the operation of the chromite mines are the comparatively small size of individual ore bodies, and the necessity of concentrating much of the ore. These difficulties are general, and apparently apply to chromite mining in most other countries. While the mining of a single lens of ore may be highly profitable, the amount of dead rock to be passed through before reaching another is a very uncertain factor. In some places one ore body is separated from another by only a few inches of rock, in others, by many feet. Consequently, it is difficult to obtain a regular production from a single pit except in the larger bodies, and in all cases ample exploratory work is necessary.

Much of the district seems to have been only superficially prospected and thorough detailed work is likely to extend the discoveries of the mineral, especially to the south of the area embraced in the accompanying map. In view of the natural advantages of location and means of transportation, it is safe to conclude that, many of the deposits already known will shortly be further worked, and that new developments will be made from time to time. Moreover, should the utilization of slightly lower grades become feasible, immense quantities of ore could be put in the market from this field.

Antimony.

The only occurrence of this mineral that is yet known in the district is in range I of South Ham, lot 28 of the old, or 56 of the later numbering—on the property of the late Dr. James Reed, of Reedsdale, Province of Quebec.

The ores are native antimony, with less amounts of stibnite, kermesite, and valentinite. The deposit is said to have been found in 1863, and to have been soon after developed and equipped with a mining and concentrating plant. After a time the works closed, and the property passed into the hands of the late owner, to whose estate it still belongs.

The development, as far as could be made out in the present state of disrepair, consisted of four shafts. An adit, which could not be entered at the time of our visit, starts at a lower level some 300 feet from the main shaft, and is said to reach it at a depth of 100 feet. Considerable drifting is reported to have been done along the length of the ore body.

Character of Deposit.—This is a contact deposit, in which the ores occur in schists along their contact, with an intrusion of diabase and serpentine. The schists strike N. 50° magnetic, and have a vertical dip. A serpentine ridge runs east and west. The serpentine just north of the main shaft is exposed for about 150 feet in length, east and west, and has a breadth of 75 feet. It is bordered by diabase on the west and northwest sides; but on the southwest comes directly in contact with the slates, of which it contains fragments. The principal workings are at the south contact of the serpentine with the schists, with one small shaft on the northwest side of a similar hill, about 1,000 feet east of the mouth of the adit. As these two intrusions of serpentine are doubtless connected at no great distance beneath the slates, it is not improbable that antimony may be found in the intervening distance. On the other hand, this structure lessens the probability of the deposit continuing to a great depth.

No distinct veins of any considerable width could be found in the present state of the workings, but the principal amount of ore seems to be in flakes, along the cleavage planes of the schists. The proportion of ore becomes greater as the contact is approached.

Two specimens of antimony ore from this property which have been assayed for gold by Mr. H. A. Leverin, of the Mines Branch, yield only a trace.

Talc.

Steatite or soapstone—as well as purer forms of talc—occurs in numerous places in the townships of East Broughton and Ireland. It generally bears the same relation to the older serpentine that pyroxenite has to peridotite. It is an altered form of pyroxenite and, in some places shows distinct pseudomorphs of steatite after pyroxene.

Soapstone has been quarried to a small extent at the old Fraser mine, East Broughton, lot 14, range VII, and on lot 5, range V, of Thetford. A considerable quantity is easily available on lot 2, range XI, of Broughton, and Ham, lots 42, 43, and 50, range I.

A better quality of talc is found on the farm of W. I. Porter, lot 2, Craigs Road range of Ireland, where it probably occurs in workable quantity.

Platinum.

A small amount of platinum was reported to have been found in the gravels near the Chaudière river, in the county of Beauce, by

T. Sterry Hunt, in 1852. The natural habitat of platinum is in chrome bearing peridotites. These gravels are 30 miles southeast of the serpentine belt and it is altogether probable that they have been in part derived from it. A nugget of platinum has also been found at Plattsburg, N.Y., some 50 miles south of the serpentine belt in Brome. In the Tulameen district of British Columbia, Mr. Camsell finds the platinum to occur with the chromite. Two specimens of chromite from Black lake, which have been assayed by Mr. H. A. Leverin, Mines Branch, Department of Mines, have yielded no platinum.

Copper.

Chalcopyrite is found in small quantities, apparently as primary segregations, near the outer edges of the diabase in many places in this district. Most of them, however, are mere mineral occurrences, and not of commercial importance.

On lot 22, range I, of Garthby, is the property known as the Coulombre mine, on which a shaft was sunk over forty years ago. The ore is a compact pyrite carrying a small copper content. It is extremely free from silica, and might be useful in conjunction with some of the siliceous copper ores of the Capelton district.

While there is little facility for finding the limits of the ore body, the extent over which isolated exposures are found, indicates the possibility of an important body, perhaps like one of those found under similar conditions to the southwest of this district, at the Huntingdon and Lake Memphremagog mines.

Smaller amounts of a better grade copper ore occur near the north shore of Clapham lake, on lot 15, range VIII, of Thetford. This is also in diabase near the contact with slate.

In lots 8 and 9, range I, of Wotton, diabase carries a little disseminated pyrite over an area of some 20 acres. It is possible that by stripping the soil from the rocks the ore might be found to be concentrated in places, into workable deposits.

INDEX

A

	Page
Adams, Dr. F. D., characteristics of granite of serpentine belt......	31
" " origin of Quebec chromite ores....................	89
" " serpentines shown to be altered igneous, not sedimentary	3
Agriculture, conditions of	14
Altitudes	12
American Chrome Co., vesuvianite at properties of............	80
" " Co's mine	87
Analysis, asbestos, Broughton type	68
" Danville slate	22
" diabase	33
" chromite	79
" peridotite	27
" " serpentine, and asbestos	60
" pyroxene	30
" pyroxenite	31
" serpentine	29
" Sillery slate	21
" soapstone	36
" sundry	49
" vesuvianite	81
Antimony	9
" mineral of serpentine belt	54
" only occurrence known in district	95
Aplite, occurrence and characteristics	35
Asbestos, Broughton phase	35, 67
" chemical composition of	61
" classification of	57
" cross fibre and slip fibre	54
" endogenous and exogenous veins	62
" exports and imports of	57
" history	57
" industry, status and possibilities	72
" large production of in district	1
" Manufacturing Co............	72
" mines of district largest in world............	55
" mining and milling	70
" occurrences of	73
" origin of, conclusions of author	65
" " two theories	61
" percentage of in serpentine	60
" probable continuance of at depth............	70
" present production	7
" production of	56
" relation to country rock	58
" " of granite to	8, 61

PAGE

Asbestos, Thetford type, origin of 61
" two varieties in serpentine 6
" uses of 72
Assay antimony ore for gold 96
" chromite for platinum 97

B

Barlow, Dr. A. E., origin of asbestos 64
Bibliography 4
Black Lake Chrome and Asbestos Co., Caribou pit, features of interest 86
" " " large body of chrome ore 85
Black Lake Consolidated Co., chrome properties, vesuvianite at 80
" " chromite examined for diamonds 83
" " chromite properties acquired by 94
Broughton phase, igneous rocks 35
" type, deposits of 67

C

Canadian Chrome Co's mine 87
Chalcopyrite 9, 97
Chrome iron ore, occurrences of 92
Chromite, analysis of from Bolton 79
" annual production 7
" district distinguished for production of 1
" found pure only in meteorites 79
" gangue of chromite deposit 80
" important mineral of district 54
" method of occurrence 9
" mines, obstacles in operation of 94
" nature, production, history, and development 74
" ores, origin of 88
" suggestion that may be a form of picotite 79
" test of for radium 78
" Turkey one of principal producers 92, 93
" world's production of 93
Cirkel, F., origin of asbestos 63
Climate 13
Concentration, method of for chromite 91
Connor, M. F., analysis of Black Lake asbestos 68
" " " diabase 33
" " " peridotite, serpentine and asbestos 60
" " " pyroxene 30
Copper, mineral of serpentine belt 54, 97
Coulombre mine 97

D

Danville Asbestos and Asbestic Co 14
Dawson, Sir J. W., reference to Palaeozoic fossils 50
Diabase, characteristics of 32
Diamonds 82
" occurrence of in chromite 9

PAGE

Diller, J. S., origin of asbestos 64
D'Israeli Mining Co 7
Dominion Chrome Co., chromite examined for diamonds 83
" " large body of ore 86
" chrome mine 81
Donald, Dr. J. T., analysis Broughton type asbestos 68
" " chemical composition of asbestos 61
Drainage—rivers of district 12

E

Electric Reduction Co., manufacture of ferro-chrome 75, 91
Ells, Dr. R. W., areal geology revised by 4
" " origin of asbestos 63
Eve, Dr. A. S., test of chromite for radium 78

F

Farnham formation, characteristics of 21
Fossils, age of Ordovician rocks determined by 25, 50
Fraser mine, talc mined at 68, 96

G

Gabbro, characteristics of 31
Geological history 53
Geology, economic 6, 54
" general 6, 15, 52
Glaciation, evidences of 23
Gold, trace found in antimony ore 96
Graham, R. P. D., analysis and description of vesuvianite 80
[illegible]e, bearing upon presence of asbestos 8, 64, 67
frequently found with asbestos 61
of serpentine belt, characteristics 33
Graphite in Farnham formation 21
Greenstone schists 36

H

History 2
Hunt, T. Sterry, analysis of chromite 79
" " " soapstone 36
" " examinations by 3
" " origin of serpentine 29

I

Igneous rocks, distribution, etc 25
Iron ore partings in asbestos veins 66

J

Johnston, R. A. A., discovery of diamonds by 82

K

PAGE

Keasbey and Mattison, manufacturers of asbestos goods ... 72
Kermesite ... 9
" associated with antimony ... 95

L

Leckie, R. G., experimental shipment of chromite by ... 75
Leonard, H., chrome property ... 87
Leverin, H., assay of antimony ore for gold ... 96
" " chromite ore for platinum ... 9, 97
L'Islet formation, characteristics of ... 20
Logan, Sir Wm., work in district ... 3
Low, Dr. A. P., origin of asbestos ... 63

M

MacLean, Alex., field assistant ... 1
Magnetite associated with chromite ... 80
Merrill, Dr. G. P., origin of asbestos ... 63
Mining, methods of for chromite ... 91
Molybdenite ... 84, 87

P

Peridotite ... 27
Platinum ... 9
" associated with chromite ... 97
" found in serpentine belt ... 54, 97
Porphyrite ... 33
Porter, W. I., talc on farm of ... 96
Pratt, J. Hyde, opinion respecting chromite ... 79
" " origin of asbestos ... 62
Pyrite ... 9, 97
Pyroxenite ... 30

Q

Quaternary deposits ... 22

R

Reed, Dr. James, antimony property ... 95
" " shipment of chromite by ... 76
Richardson, Dr. C. H., origin of asbestos ... 64
Rose, R. R., field assistant ... 1
Russia, asbestos production in Ural district ... 73

S

Selwyn, Dr. A. R. C., sedimentary origin of rocks questioned ... 3
Serpentine ... 28
" belt, origin of rocks of ... 42
" " principal mineral deposits in ... 18
" of Broughton phase ... 35
" origin of ... 69
Sillery formation, characteristics of ... 20

PAGE.

Soapstone. *See* Talc.
" Broughton phase 36, 45, 68
" quarries 96
Steatite. *See* Soapstone.
Stibnite 9
" associated with antimony 95

T

Table of formations 19
Talc, associated with asbestos 6, 68
" " " Broughton serpentine 7
" mineral of serpentine belt 54
" numerous deposits of 96
Thetford phase, igneous rocks 25
Topography 9
Transportation and communication 14

U

Uses of asbestos 72
" chromite 75, 91

V

Valentinite 9
" associated with antimony 95
Vesuvianite associated with chromite 80, 81

W

Wadsworth, Dr., suggestion as to nature of chromite 79
Waterpowers 13
Williams, Dr. George, relation between hornblende and quartz 34
Woolsey, W. J., origin of asbestos 64
Wyoming, asbestos deposits of Caspar mountains 64

CANADA
DEPARTMENT OF MINES

HON. LOUIS CODERRE, MINISTER; A. P. LOW, DEPUTY MINISTER;

GEOLOGICAL SURVEY

R. W. BROCK, DIRECTOR.

CLASSIFIED LIST OF RECENT REPORTS OF GEOLOGICAL SURVEY.

Since 1910, reports issued by the Geological Survey have been called memoirs and have been numbered Memoir 1, Memoir 2, etc. Owing to delays incidental to the publishing of reports and their accompanying maps, not all of the reports have been called memoirs, and the memoirs have not been issued in the order of their assigned numbers, and, therefore, the following list has been prepared to prevent any misconceptions arising on this account.

11159—8

Memoirs and Reports Published During 1910.

REPORTS.

Report on a geological reconnaissance of the region traversed by the National Transcontinental railway between Lake Nipigon and Clay lake, Ont. By W. H. Collins. No. 1059.

Report on the geological position and characteristics of the oil-shale deposits of Canada. By R. W. Ells. No. 1107.

A reconnaissance across the Mackenzie mountains on the Pelly, Ross, and Gravel rivers, Yukon and North West Territories. By Joseph Keele. No. 1097.

MEMOIRS—GEOLOGICAL SERIES.

Memoir 1. *No. 1, Geological Series.* Geology of the Nipigon basin, Ontario. By Alfred W. G. Wilson.

Memoir 2. *No. 2, Geological Series.* Geology and ore deposits of Hedley mining district, British Columbia. By Charles Camsell.

Memoir 3. *No. 3, Geological Series.* Palæoniscid fishes from the Albert shales of New Brunswick. By Lawrence M. Lambe.

Memoir 5. *No. 4. Geological Series.* Preliminary memoir on the Lewes and Nordenskiöld Rivers coal district, Yukon Territory. By D. D. Cairnes.

Memoir 6. *No. 5. Geological Series.* Geology of the Haliburton and Bancroft areas, Province of Ontario. By Frank D. Adams and Alfred E. Barlow.

Memoir 7. *No. 6, Geological Series.* Geology of St. Bruno mountain, Province of Quebec. By John A. Dresser.

MEMOIRS—TOPOGRAPHICAL SERIES.

Memoir 11. *No. 1, Topographical Series.* Triangulation and spirit levelling of Vancouver island, B.C., 1909. By R. H. Chapman.

Memoirs and Reports Published During 1911.

REPORTS.

Report on a traverse through the southern part of the North West Territories, from Lac Seul to Cat lake, in 1902. By Alfred W. G. Wilson. No. 1006.

Report on a part of the North West Territories drained by the Winisk and Upper Attawapiskat rivers. By W. McInnes. No. 1080.

Report on the geology of an area adjoining the east side of Lake Timiskaming. By Morley E. Wilson. No. 1064.

MEMOIRS—GEOLOGICAL SERIES.

Memoir 4. *No. 7, Geological Series.* Geological reconnaissance along the line of the National Transcontinental railway in western Quebec. By W. J. Wilson.

Memoir 8. *No. 8, Geological Series.* The Edmonton coal field, Alberta. By D. B. Dowling.

Memoir 9. *No. 9, Geological Series.* Bighorn coal basin, Alberta. By G. S. Malloch.

Memoir 10. *No. 10, Geological Series.* An instrumental survey of the shorelines of the extinct lakes Algonquin and Nipissing in southwestern Ontario. By J. W. Goldthwait.

Memoir 12. *No. 11, Geological Series.* Insects from the Tertiary lake deposits of the southern interior of British Columbia, collected by Mr. Lawrence M. Lambe, in 1906. By Anton Handlirsch.

Memoir 15. *No. 12, Geological Series.* On a Trenton Echinoderm Fauna at Kirkfield, Ontario. By Frank Springer.

Memoir 16. *No. 13, Geological Series.* The clay and shale deposits of Nova Scotia and portions of New Brunswick. By Heinrich Ries assisted by Joseph Keele.

MEMOIRS—BIOLOGICAL SERIES.

Memoir 14. *No. 1, Biological Series.* New species of shells collected by Mr. John Macoun at Barkley sound, Vancouver island, British Columbia. By William H. Dall and Paul Bartsch.

Memoirs Published During 1912.

MEMOIRS—GEOLOGICAL SERIES.

Memoir 13. *No. 14, Geological Series.* Southern Vancouver island. By Charles H. Clapp.

Memoir 21. *No. 15, Geological Series.* The geology and ore deposits of Phoenix, Boundary district, British Columbia. By O. E. LeRoy.

Memoir 24. *No. 16, Geological Series.* Preliminary report on the clay and shale deposits of the western provinces. By Heinrich Ries and Joseph Keele.

Memoir 27. *No. 17, Geological Series.* Report of the Commission appointed to investigate Turtle mountain, Frank, Alberta, 1911.

Memoir 28. *No. 18, Geological Series.* The geology of Steeprock lake, Ontario. By Andrew C. Lawson. Notes on fossils from limestone of Steeprock lake, Ontario. By Charles D. Walcott.

Memoirs Published to Date During 1913.

MEMOIRS—GEOLOGICAL SERIES.

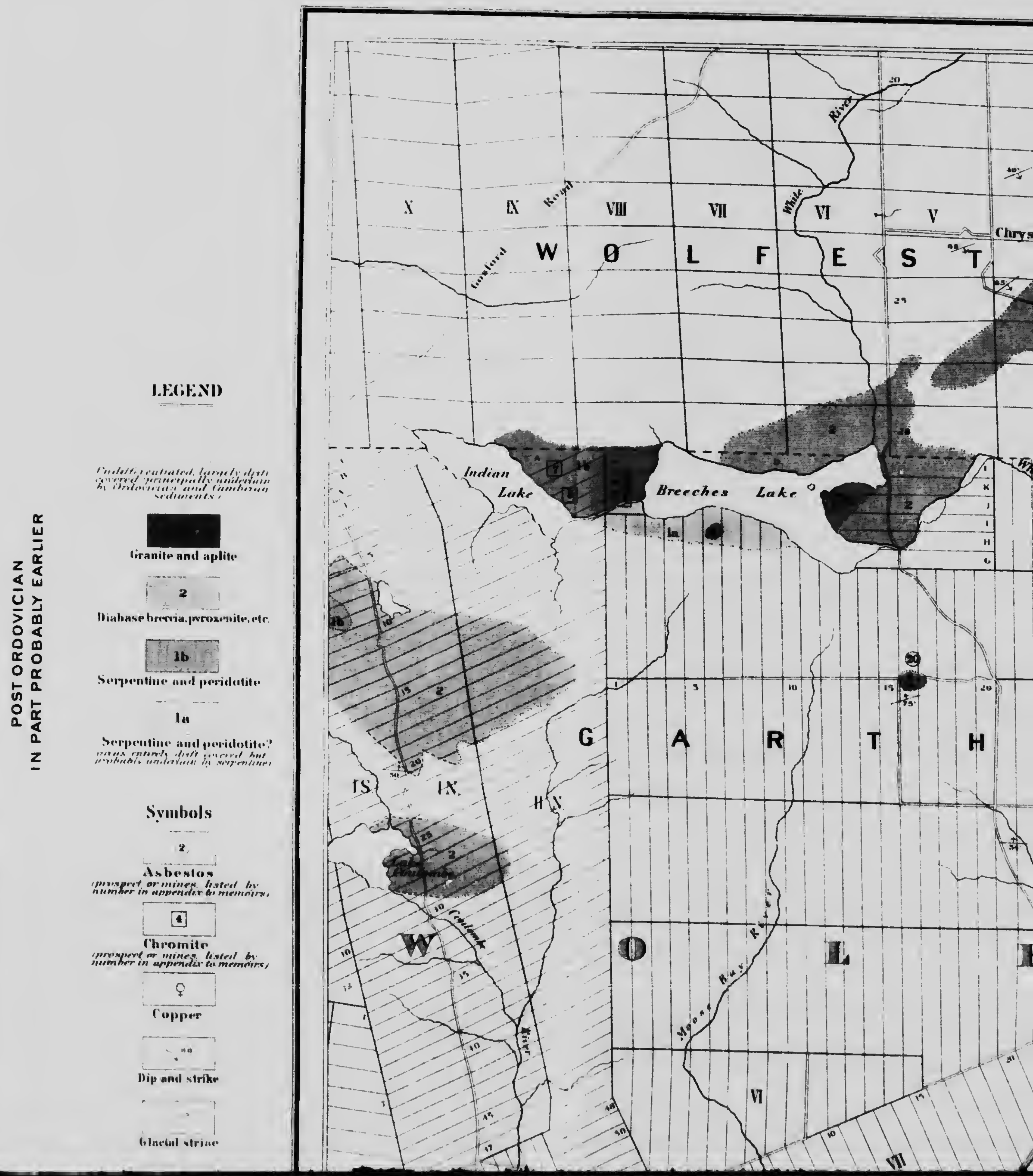
Memoir 18. *No. 19, Geological Series.* Bathurst district, New Brunswick. By G. A. Young.

Memolir 13. *No. 20, Geological Series.* Wheaton district, Yukon Territory. By D. D. Cairnes.

Memoir 25. *No. 21, Geological Series.* Clay and shale deposits of the western provinces (Part II). By Heinrich Ries and Joseph Keele.

Memoir 37. *No. 22, Geological Series.* Portions of Atlin district, B.C. By D. D. Cairnes.

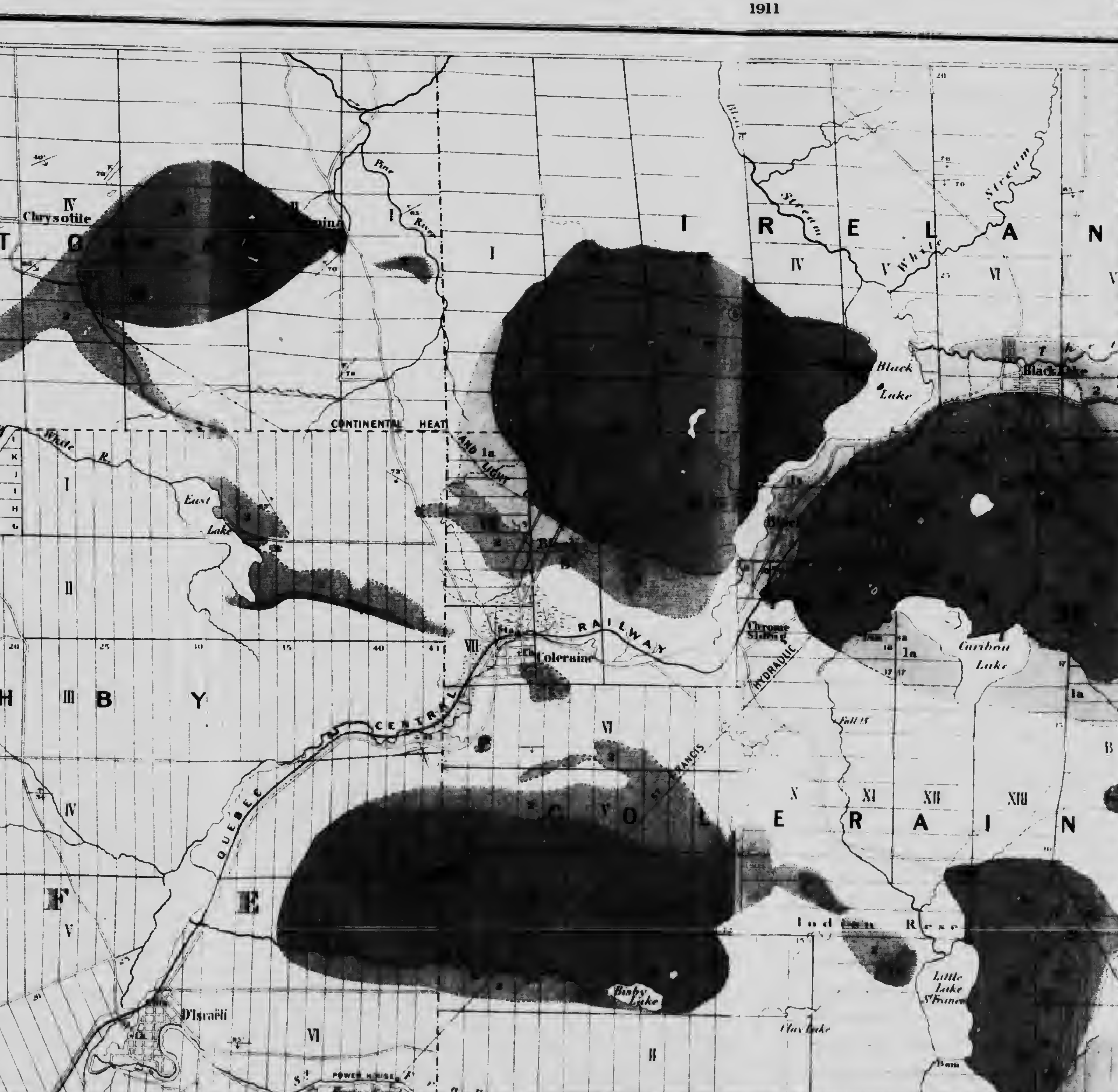
ECONOMIC GEOLOGY



Canada
Department of Mines
GEOLOGICAL SURVEY

Hon W Templeman Minister. A P Low, Deputy Minister
R W Brock, Director

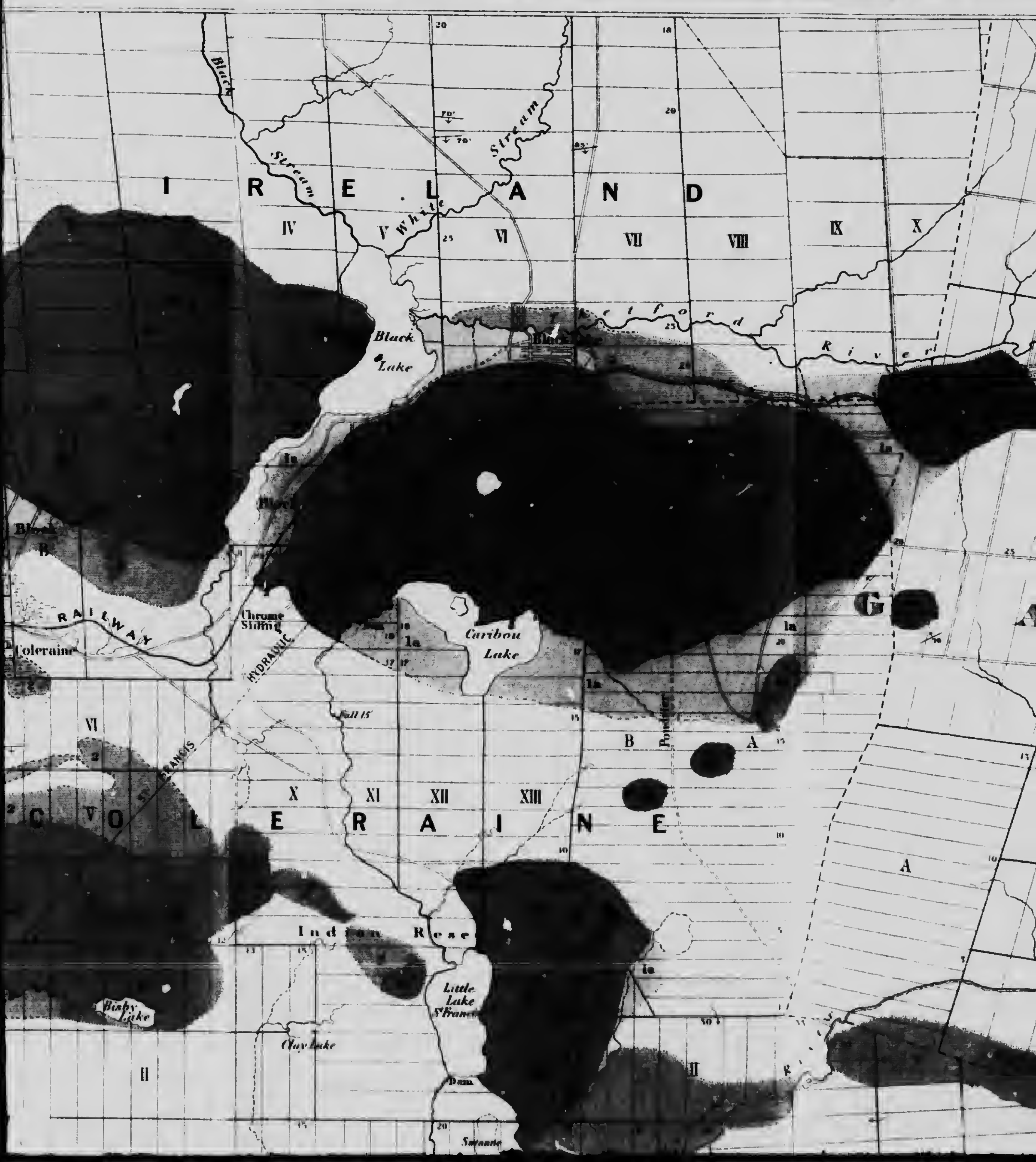
1911



Canada
Department of Mines
GEOLOGICAL SURVEY

HON W TEMPLEMAN, MINISTER A P. LOW, DEPUTY MINISTER;
R W BROCK, DIRECTOR

1911



QUEBEC

Magnetic North
True North
Mag. Decl. about 16°30' West
St Antoine-de Pontbriand
Ch.
Kingsville
Robertson
Sta.
THETFORD
ANTIC
Sacré-Cœur-de-Marie
Bécancour Lake
Clapham Lake
Trout Lake
I
II
III
IV
V
VI
VII
VIII
IX
X
XI

number in appendix to memoirs

Copper

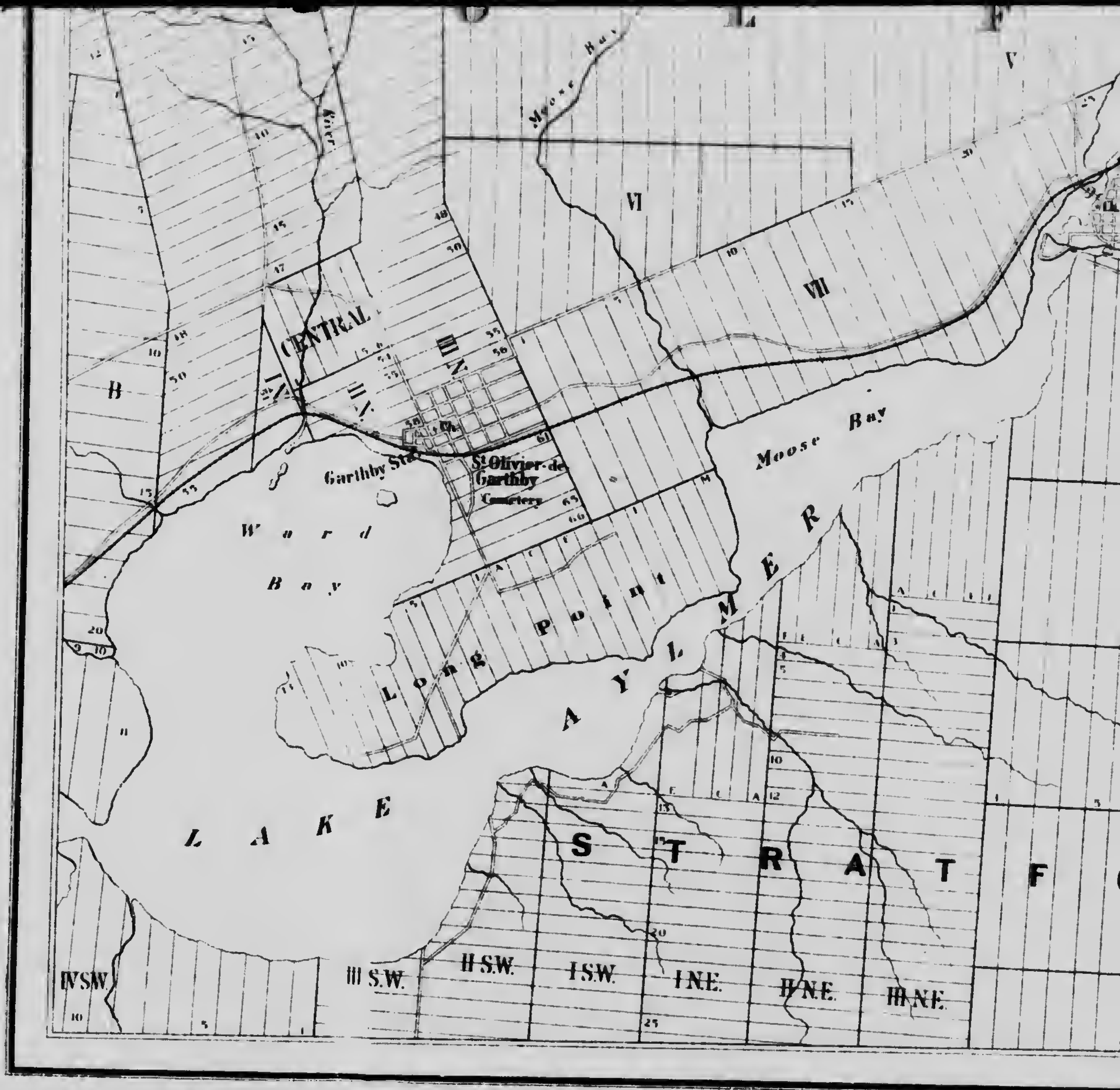
Dip and strike

Glacial striae

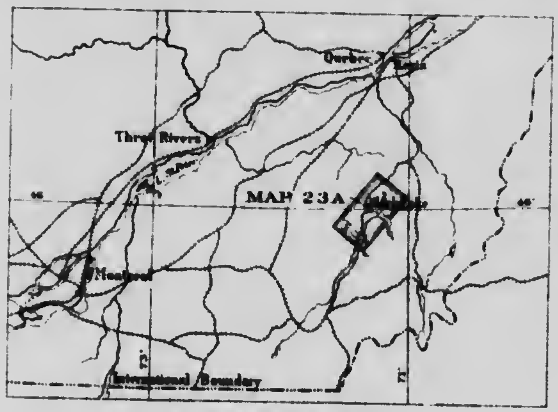
Geological boundary
(defined)

Geological boundary
(approximate)

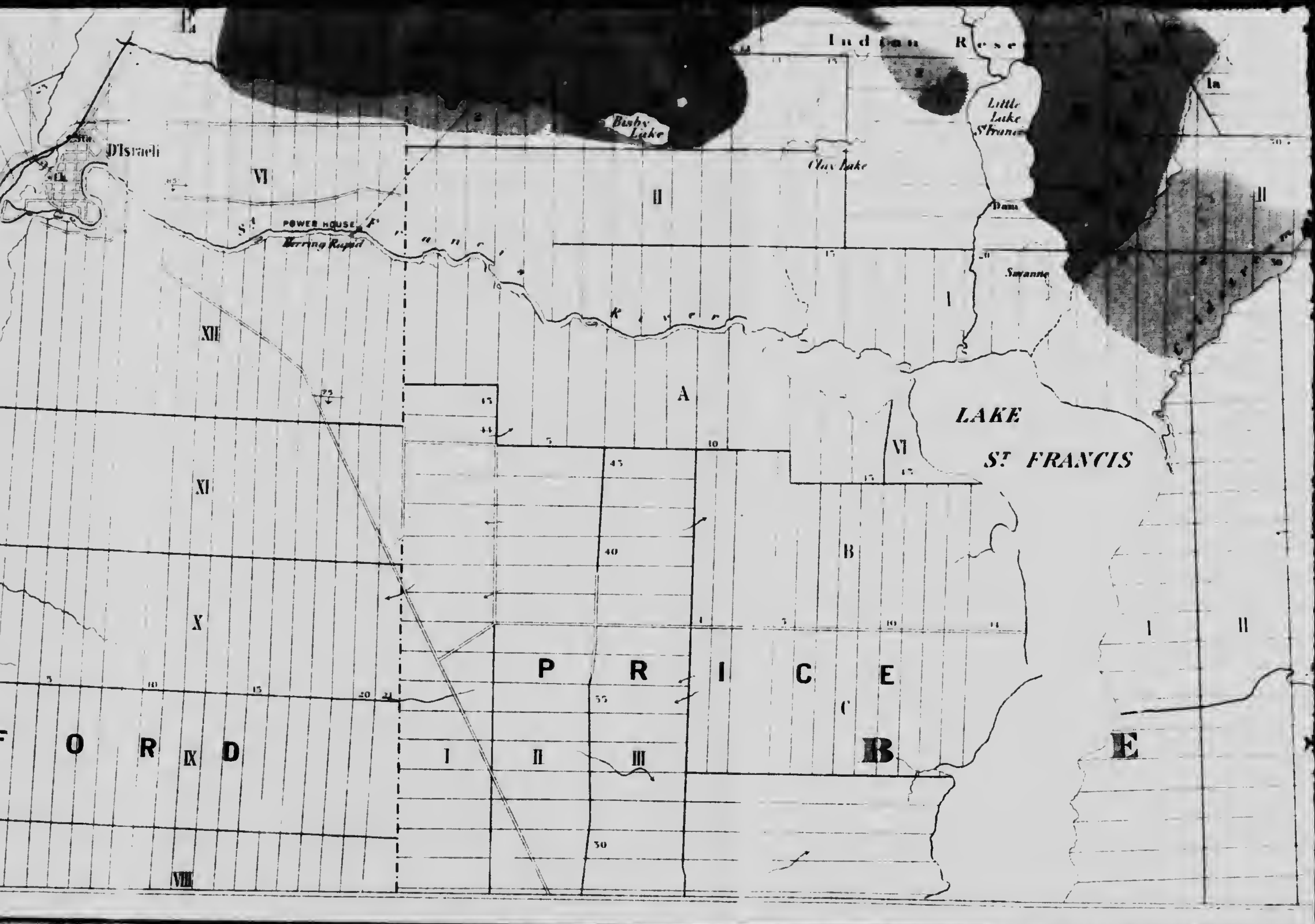
Geological boundary
(assumed)



C.O. Senécal, *Geographer & Chief Draughtsman*
G.G. Aitken, A. Dickison *and* O.E. Prud'homme, *Draughtsmen*



Scale: 70 Miles to 1 Inch



MAP 23 A

THETFORD-BLACK LAKE MINING DISTRICT

Counties of

BEAUCE, MEGANTIC and WOLFE

QUEBEC

Scale: $\frac{1}{63,360}$

Miles

Kilometres

I MILE TO I INCH

MAP 23 A

ORD-BLACK LAKE MINING DISTRICT

Counties of

BEAUCE, MEGANTIC and WOLFE

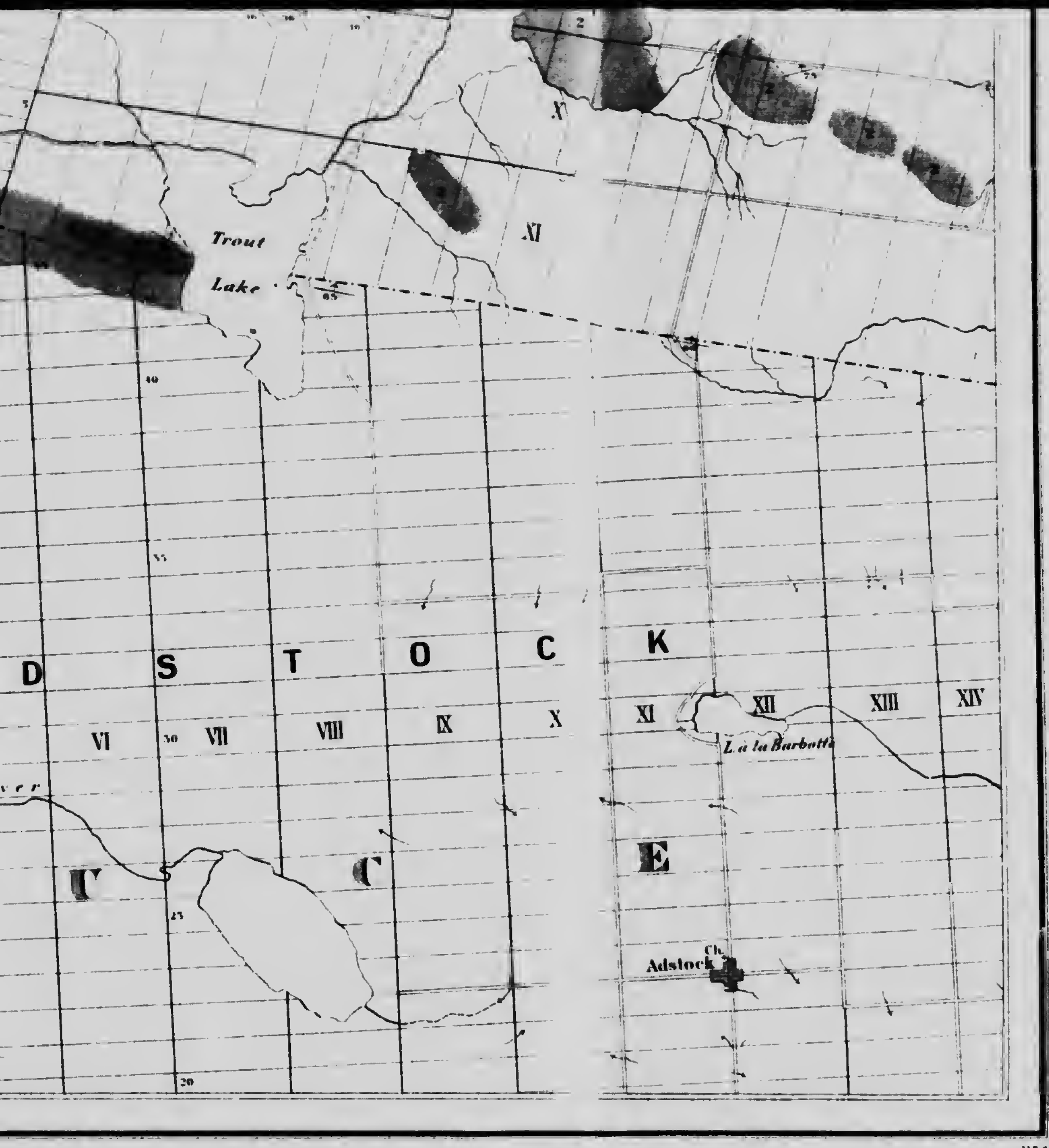
QUEBEC

Scale: $\frac{1}{63,360}$

Miles

Kilometres

1 MILE TO 1 INCH

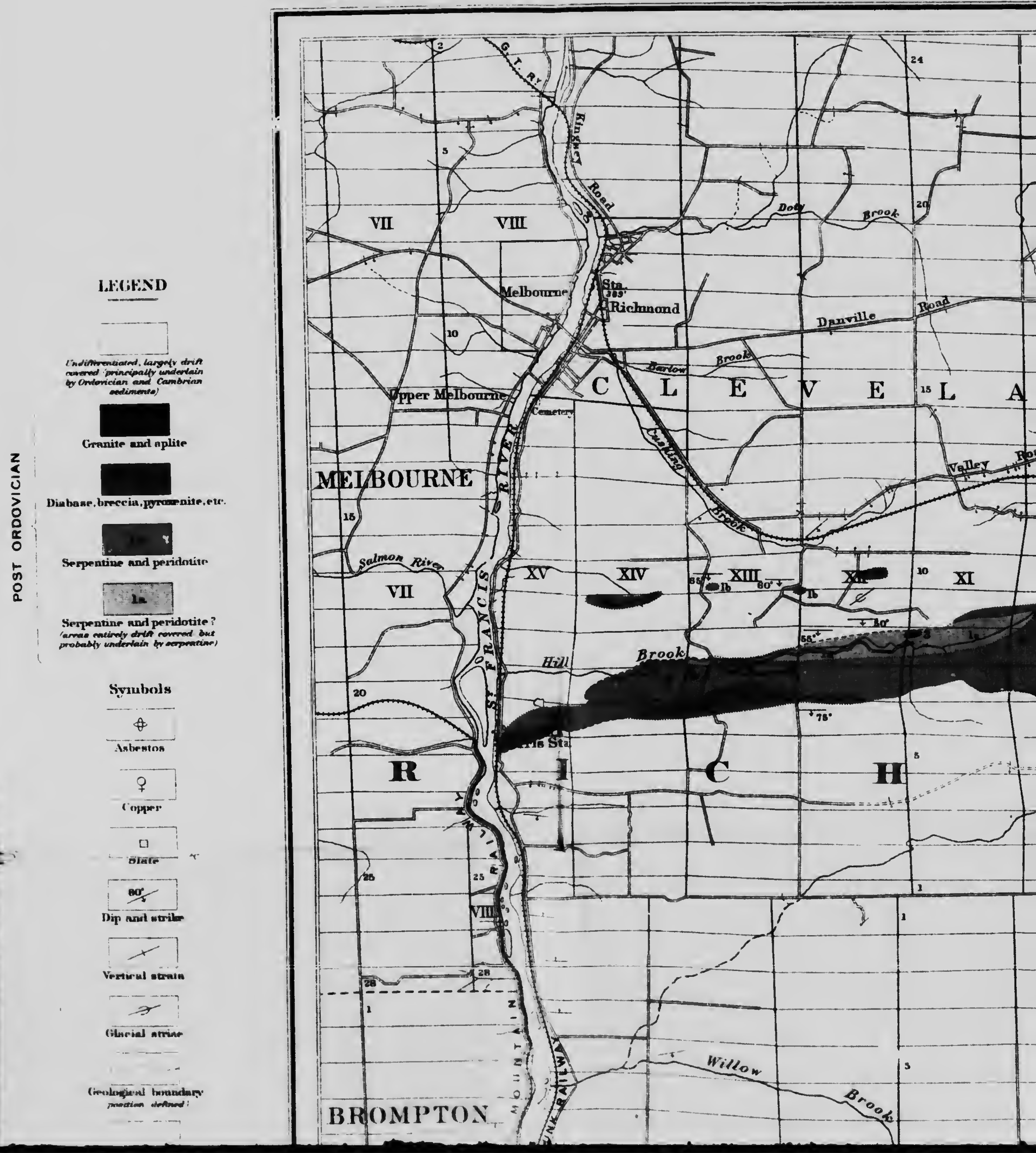


GEOLOGY

JOHN A. DRESSER (IN CHARGE)	*1907-1909*
A. McLEAN	*1907-1909*
R. R. ROSE	*1907*

G.G. AITKEN	*MAP COMPILER*

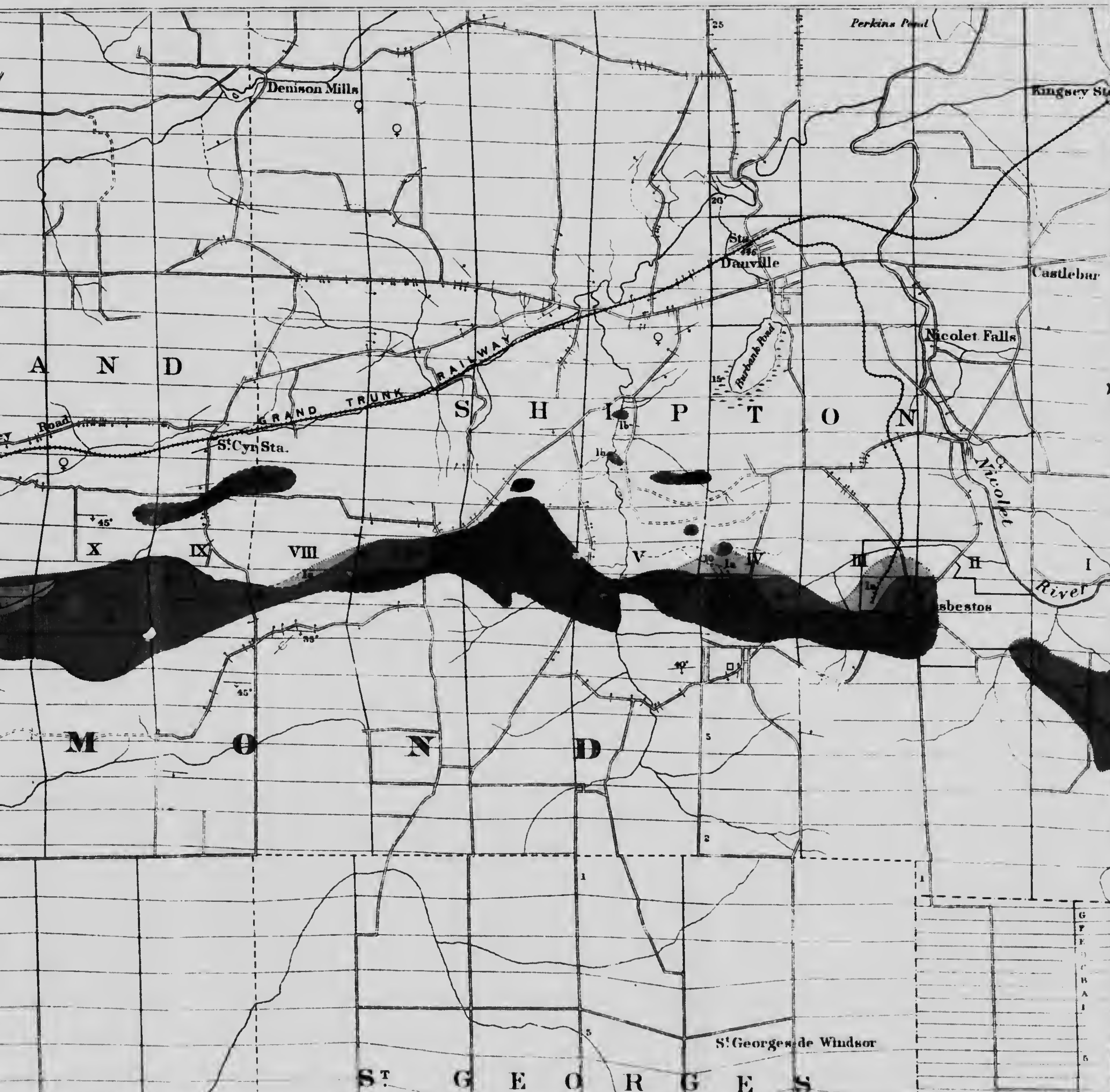
ECONOMIC GEOLOGY



Canada
Department of Mines
GEOLOGICAL SURVEY

HON. W. TEMPLEMAN, MINISTER; A. P. LOW, DEPUTY MINISTER;
R. W. BROCK, DIRECTOR.

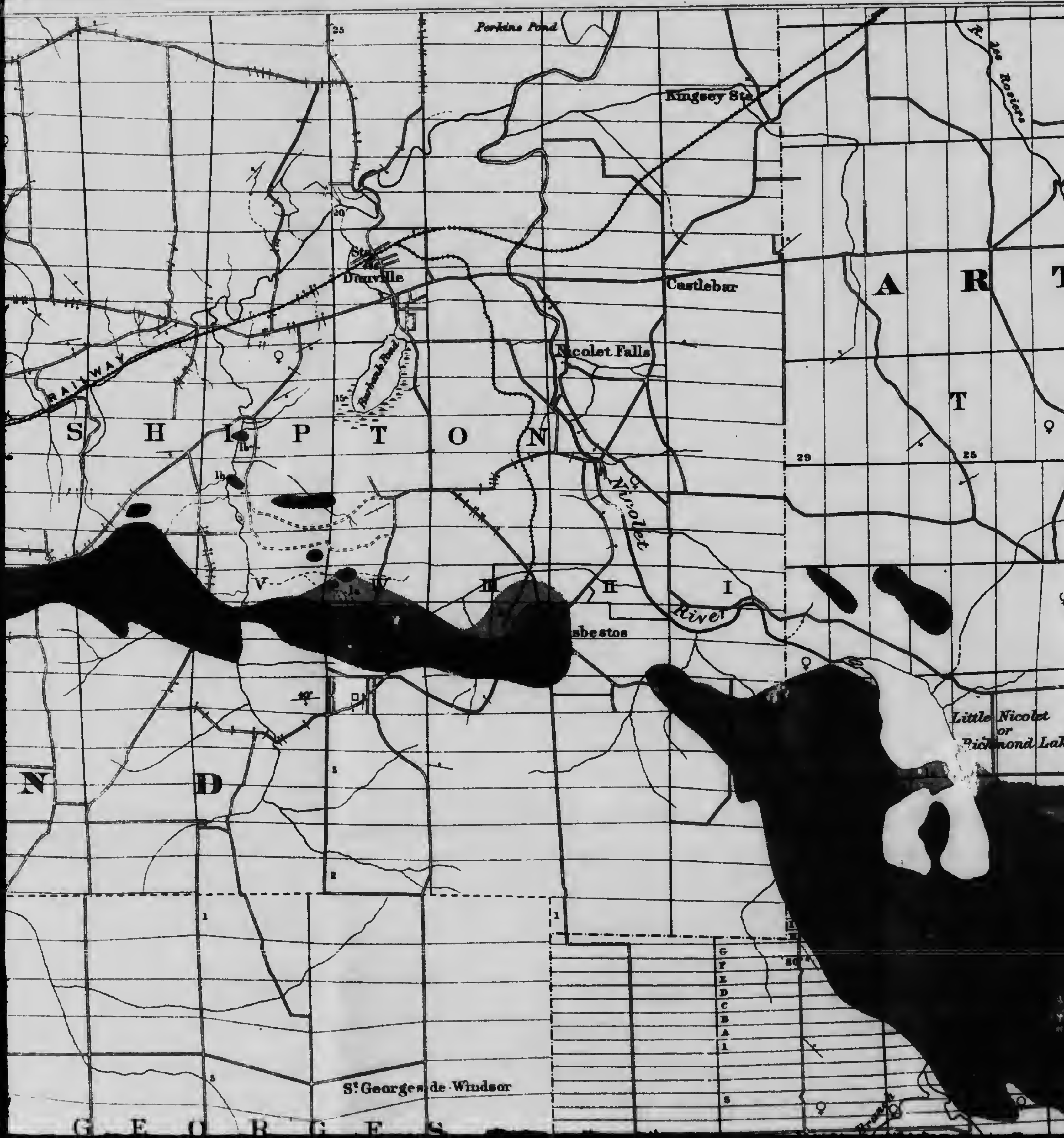
1911



Canada
Department of Mines
GEOLOGICAL SURVEY

HON. W. TEMPLEMAN, MINISTER; A. P. LOW, DEPUTY MINISTER;
R. W. BROCK, DIRECTOR.

1911



QUEBEC

IV
Craig Road
S.t Patrice
V
THABASCA
VI
INGWICK
VII
10
5
2
1
20
15
VIII
IX
Mag. North
True North
X
S.t Remi
XI
I
II
III

Dip and strike

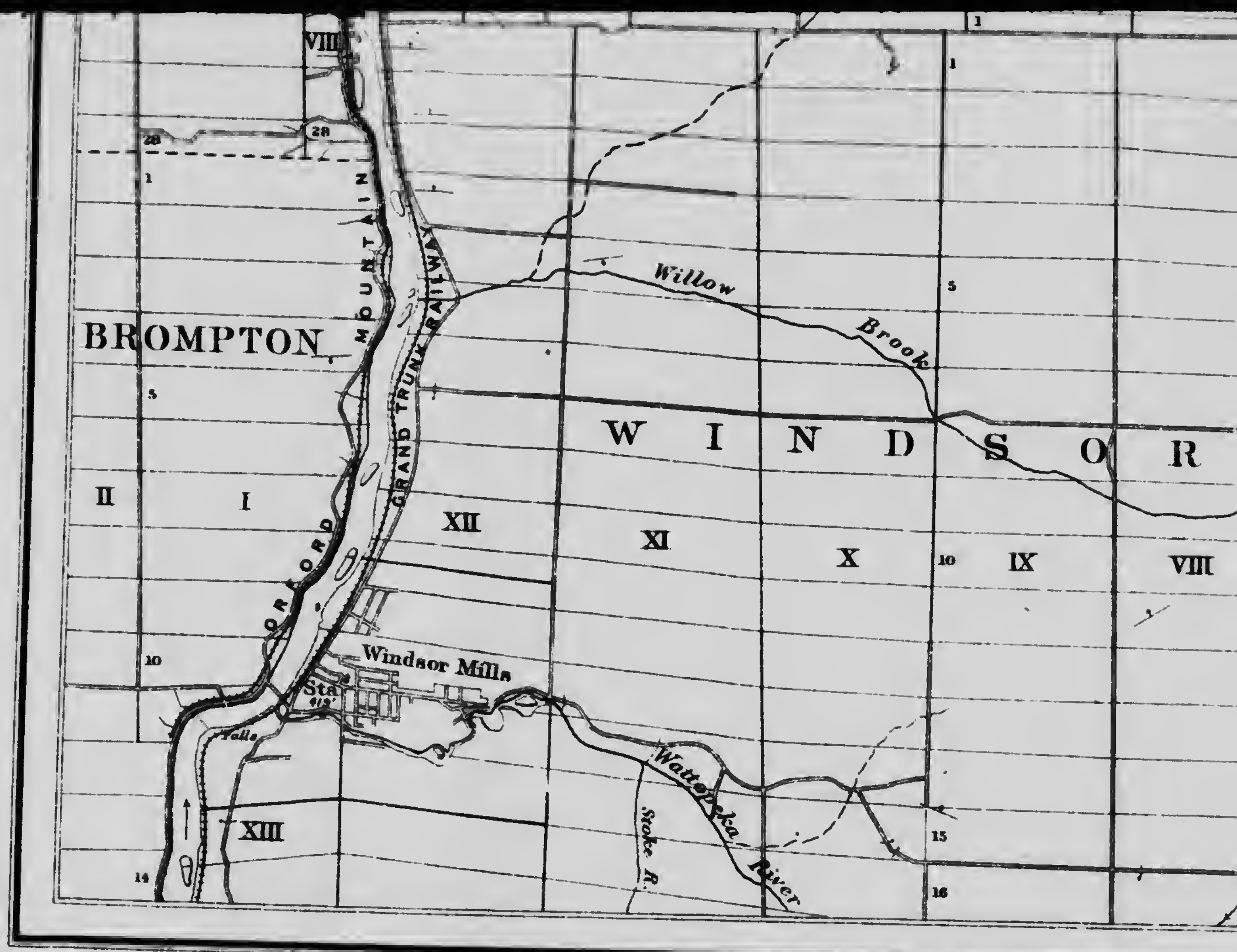
Vertical strata

Glacial striae

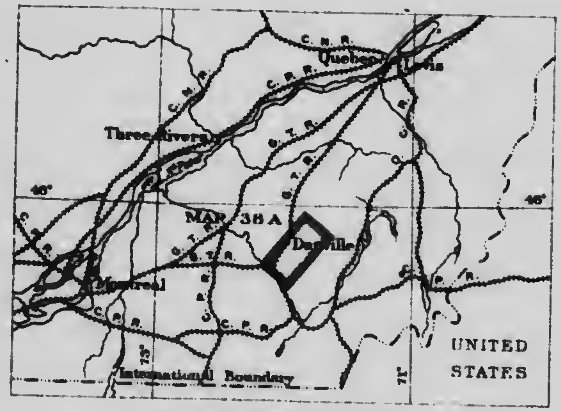
Geological boundary
position defined

Geological boundary
position approximate

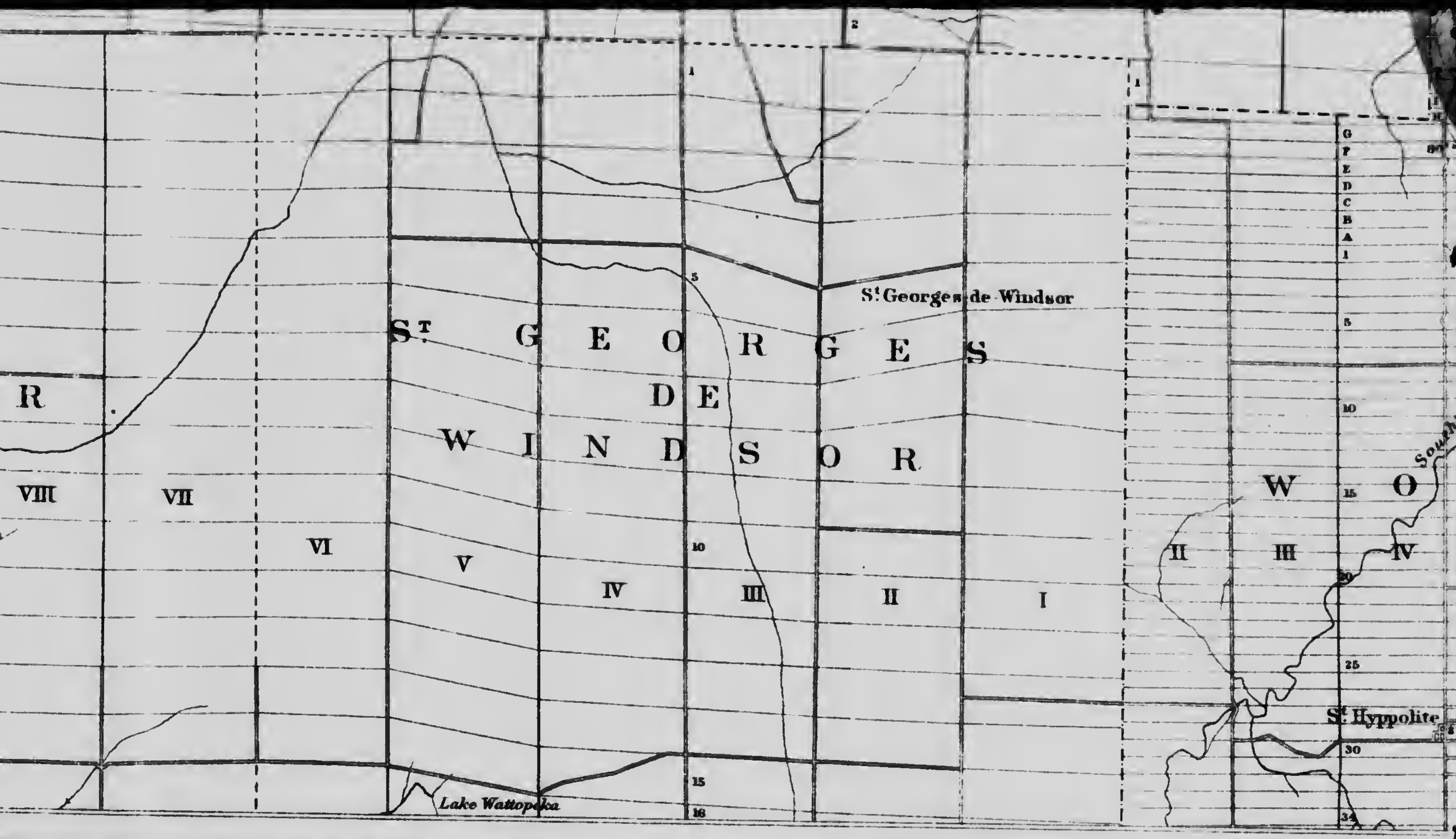
Geological boundary
position assumed)



C. O. Senécal, *Geographer and Chief Draughtsman.*
O. E. Prudhomme *and* A. M^c Gregor, *Draughtsmen.*



Scale, 70 Miles to 1 Inch



MAP 38A

DANVILLE MINING DISTRICT

Counties of

ARTHABASCA, RICHMOND and WOLFE

QUEBEC

Scale, $\frac{1}{63,360}$

Miles

Kilometres

I MILE TO I INCH

MAP 38A

DANVILLE MINING DISTRICT

Counties of

ARTHABASCA, RICHMOND and WOLFE

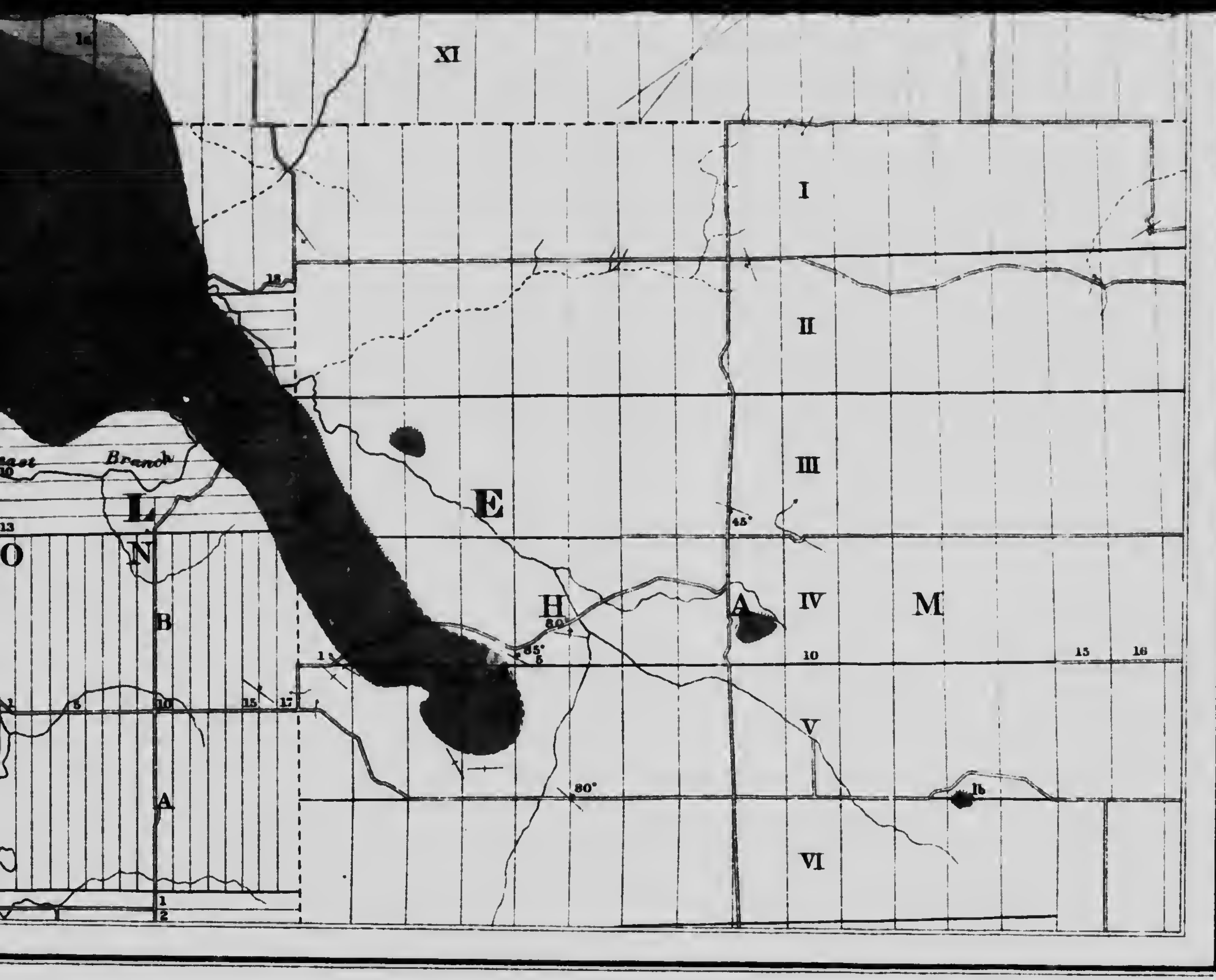
QUEBEC

Scale, $\frac{1}{63,360}$

Miles

Kilometres

1 MILE TO 1 INCH



1184

GEOLOGY

JOHN A. DRESSER, (IN CHARGE) 1907, 1909.
A. McLEAN 1909

G. G. AITKEN, MAP COMPILER.

To accompany Memoir Nº 2[illegible]

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)

1.0 2.8 2.5 4.5 5.0 3.2 2.2 5.6 3.6 6.3 7.1 4.0 2.0 8.0 9.0 1.1 1.8 1.25 1.4 1.6

HON. W. TEMPLE

ECONOMIC GEOLOGY

LEGEND

Undifferentiated, largely drift covered (principally underlain by Ordovician and Cambrian sediments)

POST-ORDOVICIAN IN PART PROBABLY EARLIER

Granite and aplite

Diabase breccia, pyroxenite etc.

Serpentine and peridotite

Ia — Serpentine and peridotite? *(areas entirely drift covered but probably underlain by serpentine)*

Symbols

Asbestos

Chromite

Talc

Antimony

Copper

Dip and strike (80°)

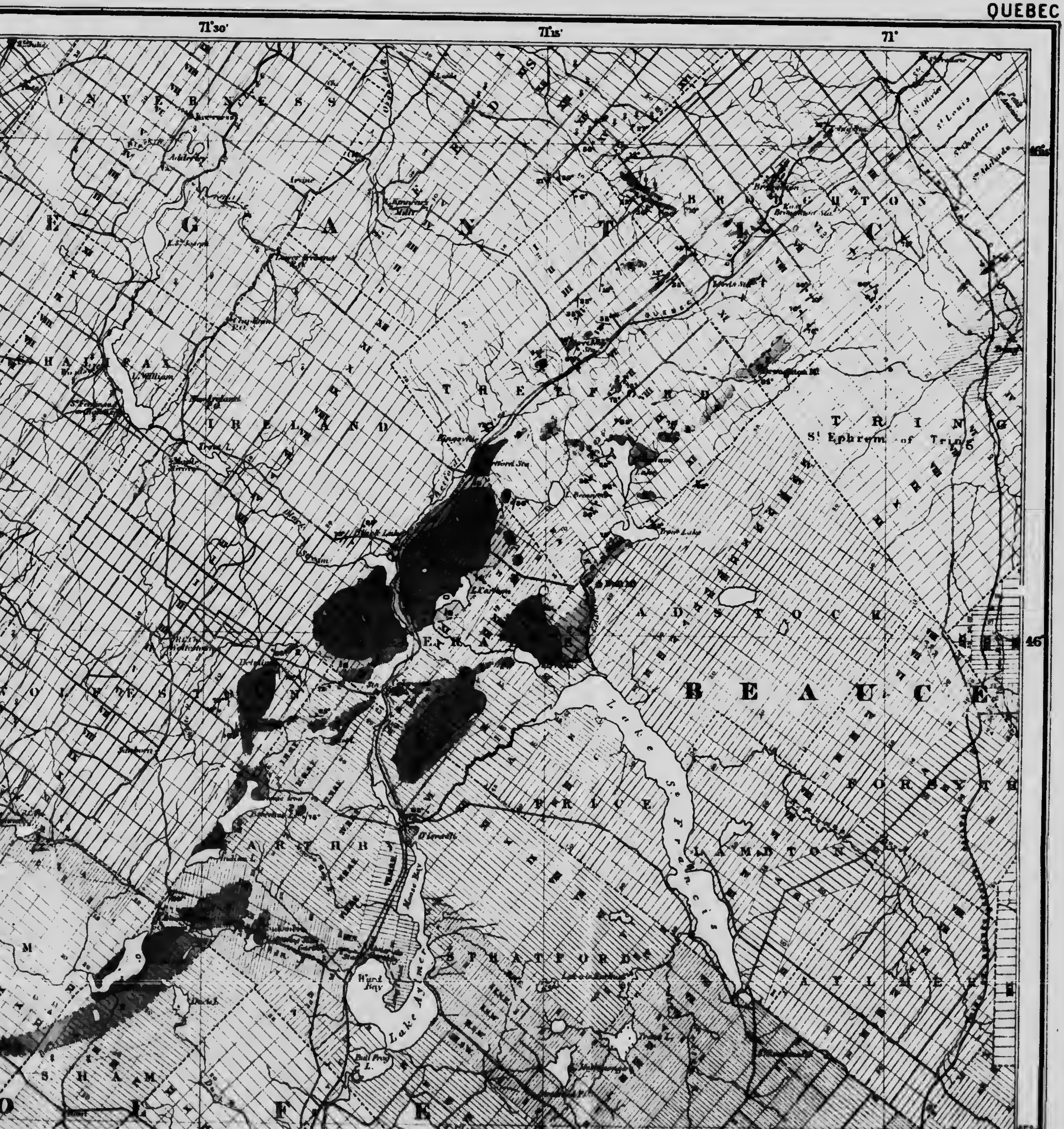
Vertical strata

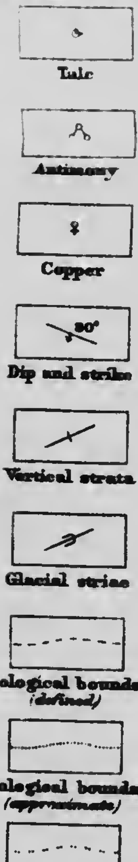
Glacial striae

Canada
Department of Mines
GEOLOGICAL SURVEY

W. TEMPLEMAN, MINISTER; A.P. LOW, DEPUTY MINISTER;
R.W. BROCK, DIRECTOR.

1911





Talc

Antimony

Copper

Dip and strike

Vertical strata

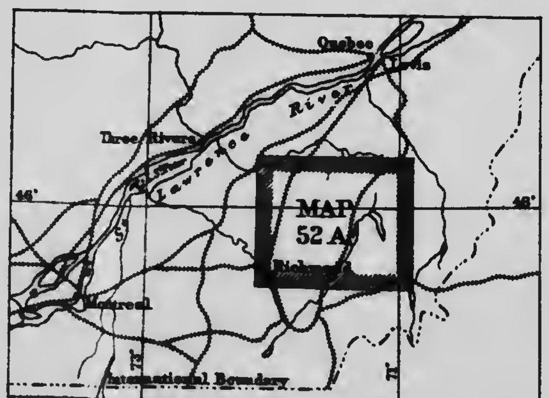
Glacial striae

Geological boundary *(defined)*

Geological boundary *(approximate)*

Geological boundary *(assumed)*

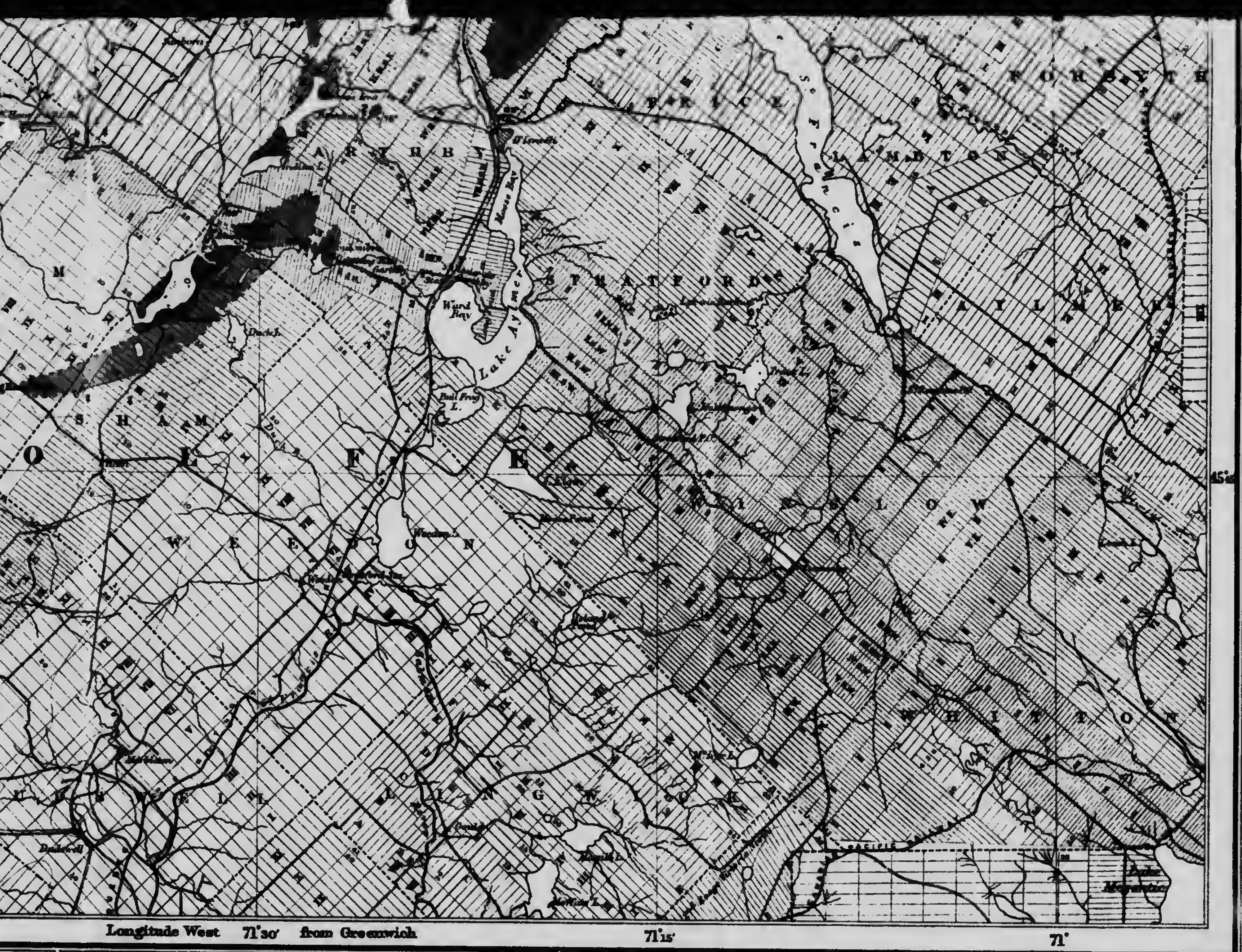
C.O.Senécal, *Geographer and Chief Draughtsman.*
A.McGregor, *Draughtsman.*



Scale of 70 miles to 1 inch

SERI

E



MAP 52 A

Northeast Part of the SERPENTINE BELT

EASTERN TOWNSHIPS

QUEBEC

Scale, $\frac{1}{253,440}$

Miles

Kilometres

4 MILES TO 1 INCH

GEOLOGY

JOHN A. DRESSER (IN CHARGE)	1907-1909
A. McLEAN	1907-1909
R. R. ROSE	1907

To accompany Memoir No 22