GEOLOGICAL
SURVEY
OF
CANADA

DEPARTMENT OF ENERGY,
MINES AND RESOURCES

BULLETIN 179

GEOCHEMICAL EVOLUTIONARY TRENDS OF CONTINENTAL PLATES—A PRELIMINARY STUDY OF THE CANADIAN SHIELD

K. E. Eade and W. F. Fahrig

Price, $1.50

Ottawa
Canada
1971

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1450-1970-6056-2

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Text printed on Offset White
Set in Times Roman with
20th Century captions by
CANADIAN GOVERNMENT PRINTING BUREAU

Artwork by CARTOGRAPHIC UNIT, GSC

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CANADA

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Price: $1.50 Catalogue No. M42-179

Price subject to change without notice

Information Canada
Ottawa, 1971

PREFACE

The world demand for certain elements has in recent years been increased exponentially. To supply this demand the mineral industry will have to depend on vast low-grade deposits rather than relatively rare, small, rich deposits. The regional background abundances of the elements in normal rocks of the Canadian Shield will play a vital role in the search for these low-grade deposits. This study provides background data of this type and in doing so examines various fundamental questions relating to the character and development of the Canadian Shield.

Y.O. FORTIER,
Director, Geological Survey of Canada

OTTAWA, May 2, 1969

БЮЛЛЕТЕНЬ 179 — Геохимические эволюционные направления континентальных плит; предварительное изучение Канадского щита. К. Э. Ид и В. Ф. Фариг.

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Abstract

Thousands of samples of crystalline rocks collected during reconnaissance geological mapping by Geological Survey of Canada field parties have been used to examine some of the geochemical problems of the Canadian Shield. From these samples the average abundance of elements forming the surface crystalline rocks of the Shield has been estimated, and apparently significant regional variations in chemistry have been discovered. The value of these data in discussing the chemistry of continental crust at depth depends on whether surface values can be projected. As there are valid reasons for assuming that the proportion of high-grade metamorphic rocks increases with depth in the crust, the question becomes whether high-grade rocks are likely to be chemically different from lower grade equivalents. Very large areas of hornblende–granulite facies rock, along with consanguineous rocks of amphibolite facies in New Quebec, have been used to examine this question. Minor but consistent deficiencies in K_2O, U, Th, and H_2O have been found in the high-grade rocks relative to those rocks of lower grade. This fractionation has been ascribed to a process involving anatectic melting.

Archean surface crystalline rocks of the Canadian Shield differ chemically from those of Proterozoic age. The younger rocks are higher in K_2O, TiO_2, U, and Th, and lower in Na_2O, Cr, Ni, and possibly MgO and CaO. This may be a secondary result of vertical chemical zoning of the crust as a result of metamorphism accompanied by anatectic melting. The erosion of a zoned crust would result in the enrichment of elements such as K, Si, Na, U, and Th in younger sedimentary basins. The crystalline crust subsequently evolved from the sediments of these basins would be enriched in these elements relative to older rocks exposed as a result of erosion. The secular chemical evolution of the Shield may also reflect a progressive, though irregular, shift in the composition of new sial being added to the crust. Evidence for this progressive change is found in the increase in the abundance of potassium of successive dyke swarms that were feeders of new sial to the upper part of the crust.

Résumé

Des milliers d'échantillons de roches cristallines, recueillies par des équipes de la Commission géologique du Canada au cours de travaux de reconnaissance destinés à la cartographie géologique, ont été utilisés pour l'examen de certains des problèmes géochimiques du Bouclier canadien. A partir de ces échantillons, on a pu évaluer l'abondance moyenne des éléments qui constituent les roches cristallines de la surface du Bouclier et, selon toute apparence, on a découvert des variations

régionales importantes de la constitution chimique des roches. La valeur de ces données lorsqu'il s'agit de la composition chimique de la croûte continentale en profondeur est discutable; elle n'est valable que si les données concernant la surface peuvent être transposées. Comme il existe des raisons très valables de présumer que la proportion de roches fortement métamorphisées augmente avec la profondeur, la question revient à savoir si la composition chimique des roches très métamorphisées peut être différente de celle des roches équivalentes moins métamorphisées. Des zones étendues de roches à faciès à hornblende et à granulite, ainsi que des roches comagmatiques à faciès à amphibolite qui se trouvent au Nouveau-Québec, ont servi à étudier cette question. De faibles mais communes déficiences en K_2O, U, et H_2O ont été remarquées dans les roches fortement métamorphisées comparativement à celles qui le sont moins. Ce fractionnement a été attribué à un processus comportant une fusion anatectique.

Les roches cristallines archéennes de surface, du Bouclier canadien, diffèrent dans leur composition chimique des roches du Protérozoïque. Les roches les plus jeunes contiennent plus de K_2O, de TiO_2, d'U et de Th, et moins de Na_2O, de Cr, de Ni et peut-être même de MgO et de CaO. Ce peut être un résultat secondaire de la constitution dans la croûte de zones verticales de compositions chimiques différentes, provoquée par métamorphisme accompagné d'une fusion anatectique. L'érosion de cette croûte comportant des zones provoquerait l'enrichissement en K, Si, Na, U et Th dans des bassins sédimentaires plus jeunes. La croûte cristalline formée par la suite à partir des sédiments de ces bassins contiendrait donc une plus grande quantité de ces éléments par rapport aux roches plus anciennes exposées à l'érosion. L'évolution séculaire de la composition chimique du Bloucier peut également être le reflet d'une modification progressive, et irrégulière, de la composition du nouveau sial qui s'est ajouté à la croûte. La preuve de cette modification progressive est fournie par l'augmentation de la quantité de potassium contenue dans les innombrables essaims de dykes successifs qui ont permis au nouveau sial d'atteindre la partie supérieure de la croûte.

INTRODUCTION

Purpose of the Study

For many decades there has been an interest in knowing the abundance of elements forming the continental crust (Clarke, 1889; Harker, 1899; Knopf, 1916; Clarke and Washington, 1924; Sederholm, 1925; Goldschmidt, 1933; Grout, 1938; Poldervaart, 1955; Taylor, 1964). Parker (1967) has recently summarized the history and problems of determining the composition of the earth's crust. The reason for this interest is that a knowledge of the abundance of elements forming the continents is essential to the determination of the mechanisms by which the continental sialic plates have developed. Virtually all attempts to solve this problem depend upon the determination of the composition of rocks obtained at or near the surface, and the extrapolation of these data to depth with the use of certain premises.

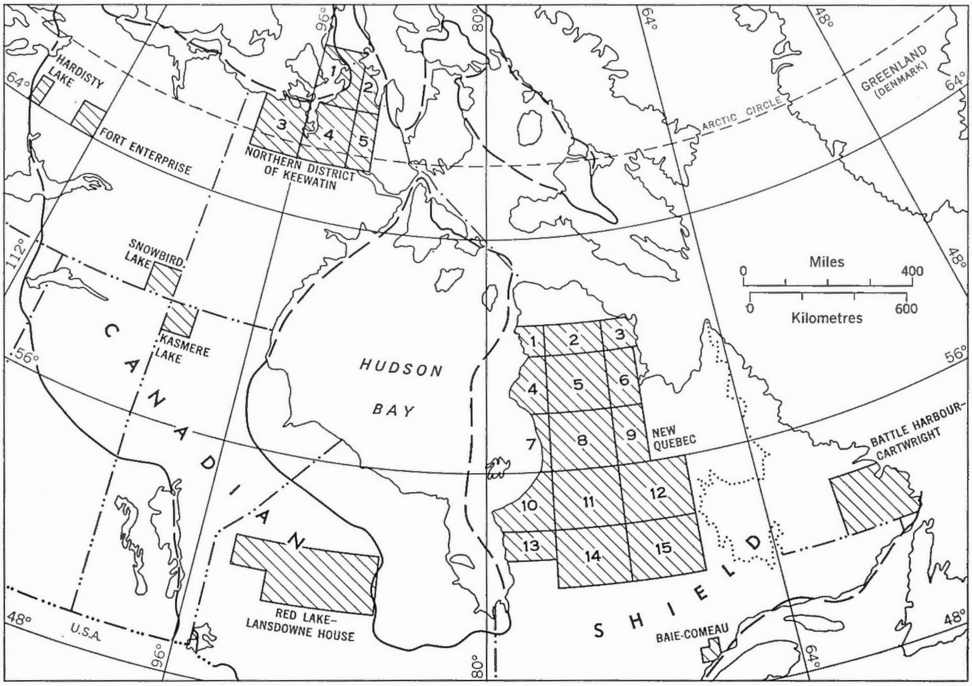

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FIGURE 1. Location map of areas sampled.

Original MS. received 26 March, 1969
MS. approved for publication 2 May, 1969

Direct observation indicates that the bulk of the continental crust consists of crystalline, that is, metamorphic and igneous rock. These rocks form a basement unit beneath quantitatively less significant cover rocks in much of the continents, and are widely exposed at the surface in Shield areas. Shields then, are windows that provide two-dimensional access to the crystalline basement unit, and therefore provide an important source of sample material of this unit.

The importance of the Canadian Shield as a geochemical window lies not only in its great extent but also in the wide range in age of the rocks of which it is composed. The rocks of this shield formed over a span of at least 2,000 m.y. and provide samples of crust as it has existed throughout a period of at least 2,500 m.y.

Reconnaissance geological mapping of the Canadian Shield by the Geological Survey of Canada in recent years has yielded collections of rock samples that have been used to study the surface rock compositions of certain map-areas (Fig. 1). If the chemical data from these separate areas are combined they provide adequate data for a reconnaissance examination of the over-all abundance of elements forming the surface rock of the Shield, and preliminary data on variations of surface chemistry within the boundaries of the Shield. These data allow us to correlate Shield chemistry with the structural subdivisions of the Shield, with the various ages of rocks forming the Shield, and with the metamorphic grade of Shield rocks (Fahrig and Eade, 1968).

Acknowledgments

Our colleagues of the Geological Survey of Canada, J.A. Fraser, W.W. Heywood, I.M. Stevenson, and F.C. Taylor, assisted materially not only by facilitating the use of specimen collections from their map-areas but with discussions of the analytical results in relation to the geology. D.M. Carmichael, A. Reid, and T.F. Frizzell assisted in preparation of the sample material. J.A. Maxwell, S. Courville, and W.H. Champ carried out or supervised the analytical work in the laboratories of the Geological Survey. H. Bielenstein assisted in the assembly of the data.

We are grateful to Prof. J.A.S. Adams, Rice University, for the determinations of U, Th, and K, and discussion of these results.

Prof. D.M. Shaw, McMaster University, assisted with discussions and comments during the course of the investigation.

PROCEDURE

Sample Collection

The samples were collected during routine geological mapping operations of two types; those on which traversing was carried out entirely by helicopter, and those on which traversing was by canoe, and on foot, in some cases with supporting traverses by fixed-wing float-equipped aircraft. The northern District of Keewatin and New Quebec projects were supported by helicopter and were designed to provide geological information suitable for final publication on maps at a scale of 1:1,000,000. All samples from these two projects were obtained along essentially rectilinear flight paths that provided semi-systematic arrays of collection points (Fig. 2). The Baie-Comeau work was helicopter-supported but a radial flight line pattern was used, and density of observations was suitable to provide a geological map for publication at a scale of 1:250,000.

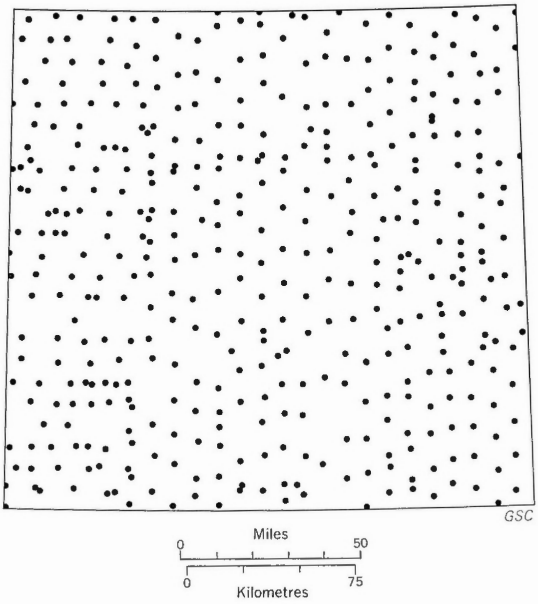

FIGURE 2
Typical semi-systematic array of sampling points, unit-area 5, New Quebec (see Fig. 1).

The remaining areas were mapped without helicopter support; Battle Harbour–Cartwright for publication at a scale of 1:500,000 and the remainder at 1:250,000. The areas mapped without helicopter support (hereafter referred to as 4-mile areas) provided a denser pattern of sampling sites, but traversing techniques resulted in less regular sampling patterns. In the Red Lake–Lansdowne House project, an attempt was made to collect typical samples at 1-mile intervals along the traverses. In the remaining 4-mile areas, the location of sampling sites was conditioned simply by the attempt of the geologist to provide a representative collection of rock samples from the various units encountered.

In some respects helicopter mapping provides an ideal medium for collecting material suitable for regional geochemical study. The grid-like pattern of collection sites has already been referred to but, in addition, the technique requires that a limited time be spent at each landing site so that the experienced geologist has time only to make relatively brief observations, and quickly collect samples of the most abundant rock types exposed at the site. This helps to eliminate the well-known tendency of geologists to collect samples of exotic, non-representative rock types.

Sample Preparation

The investigation involved the study of 27 unit-areas. New Quebec was divided into 15 unit-areas and northern Keewatin into 5. Each unit was numbered for ease of reference (Fig. 1). Each of the 7 remaining map-areas formed a unit-area in the investigation (Fig. 1). To prepare a sample for analysis (in all areas except Red Lake–Lansdowne House) the hand specimens of each rock type, as determined by the geological mapping, within each unit-area were grouped together. Approximately 20g from each hand specimen were combined to form a composite sample for each rock type in each unit-area.

It would have been preferable to crush and split all of each hand specimen in order to prepare the composite samples, however as further work was planned on the hand specimens they could not be treated in this manner.

All samples collected by Survey parties for systematic geochemical studies of the Red Lake–Lansdowne House area were crushed and ground, and small splits of the powdered samples were supplied to G.A. Reilly for use in preparing his master's thesis. Reilly subsequently prepared various composite samples from these powders (Reilly, 1965; Reilly and Shaw, 1967).

The 26 unit-areas (which excludes the Red Lake–Lansdowne House area) yielded 172 composite rock samples. The composites were crushed, ground, and mixed in preparation for analysis. In some instances duplicate 20g samples were split from each hand specimen to provide duplicate composite rock samples.

Special composite samples were prepared for all of Battle Harbour–Cartwright, all of northern District of Keewatin, and part of New Quebec (unit-areas 6,9,10,11,12,13, and 14, *see* Fig. 1) by mixing portions of the composite powdered rock samples in proportion to the areal extent of these rock-units, as measured on the geological maps.

There is no way of quantitatively evaluating, from the samples available, the extent to which they actually represent the rock types of the various map-areas. This might be done by a special sampling program, but it is doubtful whether such a program would yield significantly different regional chemical results. Such minor differences as might appear would be of questionable significance considering the large percentage of any area that is inaccessible to sampling procedures because of water and drift cover.

The number of specimens used in each composite to determine the chemistry of each unit is listed in Tables 2 to 9, as well as the number of square miles represented by each analysis. The number of samples per square mile gives the reader a qualitative idea of the relative reliability of the various rock type analyses. This can only be crude as some rock units are lithologically heterogeneous, whereas others are remarkably homogeneous.

Although it is desirable to study in detail the chemical variation within individual lithologic units in some areas, this has no bearing on the present study of the regional abundance and variation in abundance of elements forming the surface crystalline rocks of the Shield.

In summary, the sampling programs used in this study are considered adequate for a regional type of chemical study.

Analytical Methods and Accuracy

The 172 composite samples (representing those areas exclusive of Red Lake–Lansdowne House) were analyzed by rapid rock analysis techniques in the Analytical Chemistry Section of the Geological Survey of Canada. Silicon, aluminum, total iron, calcium, magnesium, potassium, titanium and manganese were determined by X-ray fluorescence using an Applied Research Laboratories X-ray spectrograph (model VXQ-25,000) and a fusion method based on that of Rose, *et al.* (1963). Sodium was determined by flame photometry, iron^{++} titrimetrically, phosphorus colorimetrically, and total water and carbon dioxide gravimetrically.

The following information, furnished by the Analytical Chemistry Section, on the accuracy of individual determinations is based on the methods used and assumes a *single* analysis only. Approximately 75 per cent of the composite samples were analyzed in triplicate and the remainder in duplicate, so that the results are more accurate than indicated.

Group A: ±1 sigma	Accuracy in the reported value (%)[1]
SiO_2 (30–75%)	±1.2
Al_2O_3 (up to 20%)	±0.7
Total Fe as Fe_2O_3 (up to 15%)	±0.5
CaO (up to 40%)	±0.3
MgO (up to 40%)	±1.0
K_2O (up to 5%)	±0.1
TiO_2 (up to 2%)	±0.05
MnO (up to 1%)	±0.02
Group B: ±2 sigma	
FeO (up to 15%)	±0.2
Na_2O (up to 10%)	±0.15
P_2O_5 (up to 1%)	±0.04
CO_2	±0.1
H_2O (total)	±0.1

[1] e.g. For $SiO_2 = 60\%$, the result for a single determination will be between 58.8 and 61.2%.

Barium, strontium, nickel, chromium, and in some samples vanadium and cobalt, were determined in the Spectrographic Laboratory of the Geological Survey of Canada by a quantitative emission spectrographic method for trace elements in common rocks. Excitation was by means of air-jet controlled D.C. arc. Samples, in powder form (approximately 150-200 mesh), were mixed with a buffer of Li_2CO_3 and carbon powder, and internal standard elements Pd and Eu. Fixed time exposures were made under closely controlled conditions. Transmittances of selected line pairs were read and intensity ratios of lines of elements versus the internal standards were calculated. The analytical values were obtained from working curves prepared in the same way from standard samples of similar rock types. Determinations are expected to be accurate within 15 per cent of the value reported.

Reilly (1965) has described the analytical techniques that were used, and their probable accuracy, in studying samples from the Red Lake–Lansdowne House area.

In this report, the average composition of the rocks of the northern District of Keewatin and the averages in part derived from it, differ slightly from figures published in a preliminary paper (Fahrig and Eade, 1968). Certain major rock units in two unit-areas were re-analyzed and checked, so that the figures in this report are more accurate.

The three *special* composites referred to under Sample Preparation were analyzed using classical chemical techniques by J.A. Maxwell, Analytical Chemistry Section, Geological Survey of Canada. These provide an indication of the accuracy of the values calculated from the rapid rock analyses for the three areas (Battle Harbour–Cartwright, northern District of Keewatin, and unit-areas 6, 9, 10, 11, 12, 13 and 14 of New Quebec). The comparison of values in Table 1 suggests that the averages calculated from groups of rapid rock analyses in this report are of satisfactory accuracy.

TABLE 1 *Comparison of analyses by rapid rock analysis and classical chemical techniques*

	New Quebec unit-areas (6,9,10,11,12,13,14)		Northern District Keewatin		Battle Harbour–Cartwright	
Oxides	Classical	Rapid	Classical	Rapid	Classical	Rapid
SiO_2	65.56	65.4	66.09	65.8	63.47	63.2
Al_2O_3	15.74	15.8	15.21	15.5	17.16	17.2
Fe_2O_3	1.45	1.5	1.41	0.9	1.82	2.0
FeO	2.83	2.9	3.58	3.7	3.03	3.1
MgO	2.56	2.5	2.07	2.0	2.10	2.3
CaO	3.53	3.2	3.31	3.2	3.58	3.4
Na_2O	3.85	4.0	3.09	3.6	3.55	3.2
K_2O	2.94	2.88	3.35	3.46	3.70	3.63
H_2O	0.82	0.9	0.76	0.8	0.64	0.7
TiO_2	0.46	0.46	0.56	0.56	0.74	0.72
P_2O_5	0.02	0.18	0.20	0.19	0.14	0.20
MnO	0.07	0.07	0.11	0.08	0.07	0.10
CO_2	0.16	0.2	0	0.10	0	0.2

Uranium and thorium content of the composite samples from all but the Red Lake–Lansdowne House area were determined by J.A.S. Adams using a gamma-ray spectrometric method which he has described (Adams, 1964). The weight of individual composites analyzed in this way was 300 to 400 grams. Fifteen duplicate runs on a random feed-back basis were made from the group of composites. In general terms, the laboratory estimated their errors as follows:

Th= ±0.3 ppm or 5% of amount present (whichever is larger);

U= ±0.3 ppm or 5% of amount present (whichever is larger);

K (Table 16)= ±0.1% as metal for amounts greater than 1.0%.

The error is also a function of the relative amounts of the three elements and the counting times (Adams, pers. comm.). Of the fifteen duplicates, one was rejected because of too short a counting time. In the remainder, all but two of the Th values, all but two of the U values, and all but two of the K values fall within the above error estimates.

Because this technique requires relatively large samples it could not be employed to determine the Th and U content of some of the smaller composites. However, the composites that were analyzed represented more than 90 per cent of the unit-areas, and the results would not be changed significantly by the inclusion of data on the remaining samples. Th and U analyses from the New Quebec area are discussed in a preliminary note (Fahrig, *et al.*, 1967).

Uranium and thorium content of composite samples from the Red Lake–Lansdowne House area were determined by chemical methods at the Geological Survey of Canada (Shaw, 1967).

Measurements and Calculations

The original chemical analyses as supplied by the laboratory were recalculated to 100 per cent, and all subsequent calculations are based on these values. All of the published values however have been rounded off to the same number of significant figures as given in the original analyses. The original total for each analysis supplied by the laboratory is also given (Tables 2 to 9).

The area occupied by each standard rock type in each unit-area was determined by measuring planimetrically the extent of each rock type on the standardized rock distribution maps, preparation of which is described in the following section. The average composition of each unit-area (Tables 2 to 9) was then calculated by weighting the analyses of the rock types of the unit-areas according to the areas represented by each rock type. Generally the average for the unit-area equals the average for the map-area, however the average for northern Keewatin and New Quebec map-areas,which consist of several unit-areas (Fig. 1), were calculated by weighting the average compositions of the unit-areas in the map-areas according to their size. All averages exclude cover rocks and large drift- or water-covered areas.

In the calculation of averages, when a value such as<30 ppm is reported in a spectrographic analysis, half of this value, in the example 15 ppm, is used in the calculations involving the analysis.

The composition of the Red Lake–Lansdowne House area was taken from Reilly and Shaw (1967).

Three averages (Tables 11 and 12) for the abundances of elements forming the surface crystalline rocks of the Canadian Shield were obtained from the above data. In one computation, the average composition of each of the nine map-areas (Fig. 1) was given a unit value; in the second, the average composition of each map-area was weighted according to the size of the map-area; and in the third, the average compositions of the map-areas were used to calculate an average for the structural province within which they lie and an over-all average was then calculated from the structural province averages by weighting according to the size of the structural province. In determining the average composition of structural provinces (Table 12), in those where only one area was studied (for example Fort Enterprise in the Slave Province) the average consists of the average composition calculated for that one map-area (Table 5 for Fort Enterprise). For those structural provinces in which two or more areas were studied, an average for the province was calculated by weighting the chemical averages of each area according to its size.

For the New Quebec area, a weighted average was obtained for all amphibolite facies rocks in each unit-area, i.e., the averages that do not include unit 8, Table 2. These averages are consolidated in Table 13. From these averages a weighted average for all amphibolite facies rocks of New Quebec is derived (Table 14). The composition of granulite facies rocks (unit 8) for each unit-area in which they occur in New Quebec are listed in Table 13, and the derived weighted average for granulite facies rocks in all New Quebec are listed in Table 14.

A weighted average was obtained for all Archean rocks, and a weighted average for all Proterozoic rocks (Table 15). Although some of the so-called Proterozoic areas contain Archean rocks reworked enough during subsequent orogenesis to give Proterozoic radiogenic ages, it is not possible to break these areas down into different age components.

STANDARDIZED ROCK DISTRIBUTION MAPS

Standardized rock distribution maps have been prepared for the sample areas, except for Red Lake–Lansdowne House (Fig. 3), and a simplified legend has been prepared as follows:

Unit 12	Gabbro, diorite, anorthositic gabbro
12a	Ultrabasic rocks, pyroxenite, peridotite, dunite
12b	Gabbro dykes
12c	Gabbro sills
12d	Meta-gabbro
11	Anorthosite
10	Granite, quartz monzonite to monzonite—higher level
9	Granite to granodiorite, foliated to massive, may be porphyritic—deeper level
8	Pyroxene-bearing granite to granodiorite gneisses and granulite
7	Banded gneisses, migmatite, granitic gneisses; minor amphibolitic inclusions
7a	Undivided granite and granitic gneiss
7b	Mixed gneisses
6	Undifferentiated gneisses and schists derived from sedimentary and volcanic rocks
5	Paragneiss, paraschist; minor amphibolite
5a	Garnetiferous gneiss
4	Amphibolite, amphibolite gneiss, greenschists; minor sedimentary schists and gneisses
3	Intercalated volcanic and sedimentary rocks
2	Sedimentary and metasedimentary rocks
2a	Conglomerate
2b	Arkose, quartzite, sandstone
2c	Argillite, siltstone, greywacke
2d	Carbonates
1	Volcanic and metavolcanic rocks; minor sedimentary and metasedimentary rocks
1a	Dacite, andesite, basalt, quartz latite
1b	Quartz-feldspar porphyry

The legend was prepared by assigning the same number to those units of different map-areas that appear from their original descriptions to be lithologically similar, but to which somewhat different terminology may originally have been applied. The rock distribution maps with standardized legends are thought to provide adequate lithologic background data, considering the scale of mapping, for the evaluation of the geochemical data. If, however, the reader wishes to refer to the original published maps and reports, the pertinent references are indicated on the individual, standardized rock distribution maps. On the rock distribution maps those areas of significant size for which the sampling density is inadequate, or which are overlain by either Phanerozoic cover rocks or glacial drift, have been left blank.

In a general way the sequence of units 1 to 7 of the legend exhibits a gradual increase in features indicative of anatexis. As a result some of the units are gradational, and distinctions between them somewhat arbitrary. Unit 8 is based entirely on metamorphic grade; most of the rocks of the unit are of hornblende-granulite facies. It was thought important to form a separate unit for rocks of higher grade metamorphism, as fractionation of elements in the crust appears to become significant as granulite facies conditions are approached and anatexis generally becomes widespread. The comparison of the chemistry of these rocks with that of adjacent rocks of lower metamorphic grade but of similar provenance, has proved to be an interesting aspect of the study.

NOTES ON SOME ASPECTS OF THE GEOLOGY OF THE SAMPLE AREAS

New Quebec

Micas extracted from the crystalline basement rocks of the sample areas of New Quebec (Fig. 1) generally yield K-Ar ages in the 2,500 m.y. range (Stockwell, 1964). These rocks then are classified as Archean. Rocks in the southeast corner of this area (units 5a, 7b, 12d of the standardized legend) contain micas that yield K-Ar ages in the 1,000 m.y. range. As these rocks include iron-formation, crystalline limestone, quartzite, and other metamorphosed rock types which are almost continuous with rocks of the Kaniapiskau Supergroup, they have been classified in part as Aphebian (early Proterozoic) in age (Eade, 1966). Some of the gneisses in this corner are undoubtedly Archean but yield 1,000 m.y. ages because their micas have been affected by the Grenville Orogeny.

In the New Quebec area there are, in addition to these Archean and Aphebian rocks, cover rocks whose chemistry is not the prime subject of this report but for which composite samples were prepared and chemical analyses obtained. These are units 2 and 2b shown on the standardized rock distribution maps. Eade (1966) has suggested that the rocks of unit 2 be correlated with those of the Belcher Islands, which are Aphebian. The rocks of unit 2b may be either Aphebian or Helikian (Eade, 1966).

For a detailed description of the various lithologies of the rocks in New Quebec map-area the reader is referred to Eade (1966) and Stevenson (1969), however unit 8 of the rock distribution map requires brief comment. It will be noted that the distribution of this unit, which consists of rocks of hornblende–granulite facies is not identical in unit-areas 5, 6, 8, 9 with that shown on Geological Survey of Canada Map 1229A because the composite samples were prepared by grouping hand specimens according to geological boundaries indicated by Stevenson (1969) in his initial field compilation. Microscope work resulted in a revision of some of these boundaries. The small changes in chemistry that would result from regrouping the samples according to the new boundaries would not invalidate, and indeed would likely strengthen, the conclusions reached in regard to the chemistry of the surface crystalline rocks of New Quebec.

Battle Harbour–Cartwright

On the basis of K-Ar dates, Stockwell (1964) indicated the rocks of Battle Harbour–Cartwright area were involved in the Grenville Orogeny and are Helikian or older. The rocks fall into two natural groups: the anorthosite suite, units 10, 11, 12, consisting of anorthosite and genetically related types; and the remaining rocks which consist chiefly of gneisses, units 5 and 7, and granite to granodiorite, unit 9 (Eade, 1962).

The anorthosite suite was intruded about 1,400 m.y. ago if they are correlatives of the anorthosites north of the Grenville Front (Emslie, 1964), and are classified as Paleohelikian. The remaining rocks of the map-area are thought to be chiefly older than the anorthosites, that is, Paleohelikian or older, although Stockwell (1965) suggested parts of unit 9 may have been emplaced during the Grenville Orogeny.

The anorthosites throughout the eastern Shield constitute a special problem to anyone attempting to use the composition of the surface rocks of the Shield to speculate regarding the composition of the crust at depth. For such purposes it is clearly desirable to eliminate from surface averages, cover rocks such as undeformed Precambrian sediments, flood basalts, and even high-level diabase sheets, as chemically these layers do not represent a significant thickness of the crustal prism of which they form a part. Anorthosites are in a somewhat similar category as, even in the Grenville Province where they may have been infolded during the Grenville Orogeny, they probably do not extend significantly below a depth of 5 miles. The chemical effect of these rocks in a crust 20- to 30-miles thick would be minor. For this reason two averages have been calculated for Battle Harbour–Cartwright area, only one of which includes the rocks of the anorthosite suite.

Red Lake–Lansdowne House

All the major units of this area are Archean, and younger rocks, for example, diabase dykes, constitute much less than one per cent of the surface rocks. Descriptions of the various lithologies are contained in Bostock (1962), Carruthers (1961), Donaldson (1961), Emslie (1961, 1962), and Jackson (1961, 1962). For some details of the copper and zinc geochemistry of the area the reader is referred to Holman (1963, 1964), and Emslie and Holman (1966).

Northern District of Keewatin

This area comprises 61,000 square miles in the Churchill (Structural) Province where K-Ar age determinations indicate that the rocks were last significantly metamorphosed during the Hudsonian Orogeny 1,700 m.y. ago. Although the K-Ar ages in the area all lie in a narrow range about 1,700 m.y. (Heywood, 1961), there are narrow belts of crystalline limestone, quartzite, and conglomerate in the area that are strikingly different from the surrounding, more abundant granitic country rocks. It is probable that the platform-type sedimentary rocks (map-units 2, 3, and possibly parts of 4) are of Aphebian age and were deposited on a crystalline Archean basement. Most rocks of the area are believed to consist of these Archean basement rocks which formed at least 2,500 m.y. ago and which were overprinted 1,700 m.y. ago by Hudsonian metamorphism. Heywood mapped the area and, agreed with this interpretation (pers. comm., 1967).

Fort Enterprise

This area lies entirely within the Slave (Structural) Province for which Stockwell (1965), on the basis of K-Ar work, indicated an Archean age with possibly some alteration during the Hudsonian Orogeny. Fraser (1958) suggested some of the major rock-units might be Proterozoic but it now appears that the only younger rocks are Proterozoic basic dykes that constitute a negligible proportion of the surface rocks.

Snowbird Lake

The age relationships of rocks in Snowbird Lake map-area bear a strong resemblance to those in northern Keewatin. As in northern Keewatin, a unit (2b) consisting of quartzite, conglomerate, limestone, argillite, and greywacke (Taylor, 1963) appears to be distinct from, and younger than the predominant rock types that consist of granitic and amphibolitic gneisses with metavolcanic and metasedimentary rocks (units 1, 2, 5, 7). The more massive granite and granodiorite (unit 9) also probably belong to the older group of rocks. It is suggested that unit 2b is Aphebian, and that most of the remaining rocks are Archean. Possibly some granites and granitic gneisses of the units thought to be Archean developed during the Hudsonian Orogeny.

Kasmere Lake

This area lies in the Churchill (Structural) Province in which K-Ar ages on micas in general are Aphebian. The ages of the predominant units in this area are thought, however, to be different from those of Snowbird Lake and northern Keewatin areas. In Kasmere Lake area, Fraser (1962) mapped a series of largely platform-type sediments (2b, 2c, 2d) which, as in northern Keewatin and Snowbird Lake areas, are considered to be of Aphebian age. The surrounding gneisses and gneissic granites are thought to be chiefly crystalline Archean basement (units 5, 7, 9). All these units have been intruded by Aphebian porphyritic, fluorite-bearing granites (unit 10). Aphebian rocks make up more than half of the exposed parts of Kasmere Lake area, mainly because of the widespread presence of the younger granites. This is in contrast with Snowbird Lake and northern Keewatin areas where Aphebian rocks are believed to constitute only minor parts of the areas.

Hardisty Lake

This area lies in the Bear (Structural) Province and all major Precambrian map-units of the area were probably formed during the Aphebian and were subsequently involved in the Hudsonian Orogeny (Stockwell, *et al.*, 1965). Map-unit 10 of the rock distribution map is the youngest of these major units (Fraser, 1967). The diabase dykes, which constitute a negligible part of the surface rocks, are of post-Aphebian age (Fahrig and Wanless, 1963).

Baie-Comeau

Micas from rocks of Baie-Comeau area yield K-Ar ages indicative of the Grenville Orogeny. Units 9 and 10 of the rock distribution map are thought to have been intruded during the Grenville Orogeny (Stockwell, *et al.*, 1965), although contact relations in the field are indefinite (Heywood, 1963). Stockwell (1964) suggested that anorthosite and gabbro, units 11 and 12 respectively on the rock distribution map, were emplaced during the Elsonian Orogeny and subsequently reworked during the Grenville Orogeny. The remaining rocks are thought to be of Aphebian age (Stockwell, 1964), but subsequently involved in the Hudsonian, modified during the Elsonian and reworked during the Grenville Orogeny. It is possible that some of the rocks classified as Aphebian may be still older, i.e., Archean.

THE AVERAGE COMPOSITION OF THE SURFACE CRYSTALLINE ROCKS OF THE CANADIAN SHIELD

Over-all Average Composition

One general objective of the present project was to obtain a reliable estimate of the abundance of elements forming the entire area of surface crystalline rock of the Canadian Shield. As crustal material apparently has varied systematically with geological age and tectonic history, attainment of this objective has been made more difficult. As a first step it was necessary to obtain an average composition for each of the major structural subdivisions of the Shield. For example, the average composition of New Quebec and Red Lake–Lansdowne House were weighted according to size to provide an average for the Superior Province. A Shield average was later obtained by weighting these province averages according to the sizes of the various provinces.

The final average can only be reliable if the unit sample areas provide adequate samples of the provinces which they represent. In this regard, the Superior and western Churchill Provinces are probably well represented by their sample areas. However, the part of Churchill Province forming Baffin Island, and the area east of New Quebec are defects in the over-all sampling of the Churchill Province. Similarly, the sample areas in the Grenville may not adequately represent that area. Even considering these defects however, it is likely that the average given for the entire Shield (Table 12) is very close to the true average abundance.

The average of Table 12, calculated according to the size of the tectonic provinces, is considered to be more representative than are the two over-all averages given in Table 11, one giving each sample area unit weight and the other weighted according to the size of each sample area. Table 11 also gives a recent estimate of element abundances by Shaw, *et al.* (1967), and U and Th by Shaw (1967).

It is emphasized throughout this report that the data represent only a two-dimensional sampling of the crystalline sialic plate that underlies the Canadian Shield, and that there is good evidence that the continental crust is vertically zoned. Minor errors in determining the over-all abundance of elements in surface rocks are therefore not of over-riding importance in considering the average composition of the total continental crust. One value of an over-all surface average is that it provides a base to which regional values may be compared. These regional variations may contribute to our understanding of the tectonic histories of the various regions, and possibly tell us something about the age of the rocks of which the various regions are composed.

Composition of Some Major Rock Types

The average composition of the major rock units in the areas studied (*see* Legend, Fig. 3) and the weighted over-all averages of these units are presented in Tables 18 to 24. Published analyses of similar rock types are included for comparison.

Unit 1: Volcanic and metavolcanic rocks, minor sedimentary and metasedimentary rocks

This unit has restricted distribution, Fort Enterprise, Snowbird Lake, and New Quebec; in New Quebec it is present in only 5 (10, 12, 13, 14, 15) of the 15 unit-areas. In these 5 areas there is much variation in the composition of the unit (*see* Table 3), reflecting variability in the amount of metasedimentary rocks included in the predominantly metavolcanic unit. The weighted average of this unit in New Quebec, Table 18, is somewhat different from the composition of the unit in Snowbird Lake and Fort Enterprise areas where it is almost entirely a metavolcanic unit. The over-all average for all of unit 1 is close to the average of the unit for New Quebec, reflecting the much greater area of the unit in that region.

The average composition of unit 1 is similar to the average composition of metavolcanic rocks in the Red Lake–Lansdowne House area (Reilly and Shaw, 1967), and is not dissimilar to the average composition of amphibolite facies greenstones from the Yellowknife volcanic belt (Boyle, 1961). The SiO_2 content in the average of unit 1 is notably higher however than in the Yellowknife rocks, probably reflecting the metasedimentary rocks included in unit 1. The average andesite of Nockolds (1954) bears little resemblance to the average of unit 1, but as the latter includes a wide variety of rock types, including andesite, this is to be expected. The great variation in chemical composition of the rocks in volcanic piles is illustrated in detailed analyses of volcanic rocks in the Michipicoten area of Ontario (Goodwin, 1962), at Yellowknife, and in the Noranda volcanic belt (Baragar, 1966, 1968).

Unit 5: Paragneiss, paraschist, and minor amphibolite

The composition of this unit in the different areas is highly variable, reflecting the variety of sedimentary rocks and the different metamorphic processes they have undergone to derive the paragneiss, paraschist, and minor amphibolite that constitute the unit. The unit is most abundant in New Quebec; so the over-all average of the unit is close to the average for New Quebec. The over-all average of the unit shows some differences from the averages of the metasedimentary unit in the Red Lake–Landsowne House area (Table 19). The latter is chiefly slate, argillite, quartzite, greywacke, conglomerate, their metamorphic equivalents, and minor iron-formation (Reilly and Shaw, 1967). Comparison of the averages suggests the presence of more carbonate-rich sedimentary rocks in Red Lake–Lansdowne House area and more siliceous sedimentary rocks in New Quebec. The inclusion of some iron-formation in the Red Lake average is reflected in the analyses.

Unit 6: Undifferentiated gneisses and schists derived from sedimentary and volcanic rocks

The 'basket' nature of this unit is reflected in the variation in composition from area to area. It is distinguished from unit 5 by the inclusion of significant amounts of rocks derived from the metamorphism of volcanic material. This accounts for the lower SiO_2, and the higher total Fe, MgO, and Al_2O_3 in the average of unit 6 as compared with the average of unit 5, features particularly apparent in the averages of the two units in the New Quebec area.

Unit 7: Banded gneisses, migmatites, granitic gneisses, and minor amphibolite inclusions

This unit encompasses most of the crystalline rocks of the Canadian Shield. Table 21 indicates that the average chemical composition of this unit varies from area to area and from unit-area to unit-area within New Quebec and the northern District of Keewatin (Tables 2 and 4 respectively). The variation reflects differences in the original rocks from which the gneisses were derived and differences in their metamorphic histories. The composition of an equivalent unit in the Red Lake–Lansdowne House area (Reilly and Shaw, 1967) is similar in many respects to the average of unit 7 (Table 21) and to the average granodiorite of Nockolds (1954), but Red Lake rocks are much lower in K_2O.

Unit 9: Massive to slightly foliated deeper level granitic rocks

In many areas the average composition of this unit is similar to the average of unit 7 and the average granodiorite (Nockolds, 1954). In some areas the rocks of this unit are chemically anomalous, for example, unit 9 in Kasmere Lake area is extremely siliceous compared with this unit in other areas. Average compositions of two units in the Red Lake–Lansdowne House area approximately comparable to unit 9, are listed in Table 22, one foliated granodiorite and the other massive to slightly foliated granite including undivided granitic rocks. The most conspicuous difference between these two units and the average of unit 9 is the lower quantity of K_2O present in the rocks of the Red Lake–Lansdowne House area. The unit 9 average is remarkably similar to the average granodiorite of Nockolds (1954) (*see* Table 21).

Unit 10: Higher level granite, quartz-monzonite to monzonite

In this report, this unit is equivalent in setting and characteristics to the high-level plutons of Read (1957, p. 365).

It is likely that unit 10 in Fort Enterprise area includes rocks that should be grouped with unit 9, which is not represented in that area. Unit 10 in Battle Harbour–Cartwright area consists of acid rocks associated with the anorthosite suite, namely monzonite, granodiorite, some syenite and syenodiorite. These rocks have an average composition slightly different from that of unit 10 in other areas with which they have been grouped. For this reason, an over-all average has been calculated for unit 10 which omits the Battle Harbour–Cartwright area (Table 23). This modified average closely resembles the average adamellite of Nockolds (1954). The composition of unit 10 in the Battle Harbour–Cartwright area is closer to the average calc-alkali syenite of Nockolds than it is to any other standard rock-type. In New Quebec and Fort Enterprise areas the rocks of unit 10 are granodiorites, but in Kasmere Lake, Hardisty Lake and Baie-Comeau areas, rocks of this unit are granites. In Baie-Comeau the unit resembles Nockolds alkali-granite average, but in Kasmere and Hardisty Lake areas it is similar to his calc-alkali granite average. The two granite units in the Red Lake–Lansdowne House area: one leucocratic, pink and white massive granite and the other massive porphyritic granite, do not resemble the modified over-all average of unit 10, nor are they similar to unit 10 in any of the individual unit areas.

Unit 11: Anorthosite

This unit is represented by a large mass in Battle Harbour–Cartwright area, and a much smaller one in Baie-Comeau area. No weighted average for the unit is included in Table 23 as it would be virtually identical to the average of this unit in Battle Harbour–Cartwright area. For comparison, published analyses of the Morin pluton of Quebec (Papezik, 1965), anorthosites of the Michikamau Intrusion of Labrador (Emslie, 1965), the Marcy-type anorthosite of the Adirondacks (Buddington, 1939), and an average anorthosite as determined by Nockolds (1954) are listed in Table 24. The analysis quoted for the Morin pluton is for a composite of the various rock-types comprising the pluton, and consequently is more equivalent to the composite nature of unit 11 than are the other analyses listed in Table 24. The two Michikamau analyses represent individual anorthosite specimens, the Adirondack analysis is a composite of analyses of four anorthosites, and Nockold's average is a composite of nine analyses. Nockold's average is not strictly comparable to that of unit 11 which is a composite including anorthosite and related anorthositic gabbros.

In Baie-Comeau area, unit 11 is much higher in MgO and lower in Al_2O_3 than is this unit in the Battle Harbour–Cartwright area. Unit 11 in Battle Harbour–Cartwright area contains far more K_2O and less CaO than is usual for rocks of this type. If anorthosite masses are layered intrusions, the pluton in the Battle Harbour–Cartwright area may be more representative of the upper levels of such plutons in which K_2O may be concentrated and CaO correspondingly lower.

METAMORPHISM AND CHEMICAL FRACTIONATION

There is particular interest at present in the thermal history and chemical composition of the earth's crust. The metamorphism of crustal rocks may be used to estimate temperatures that existed in parts of the crust during early epochs, and the composition of rocks of various metamorphic facies may be used to calculate the redistribution of crustal heat and heat sources that resulted from regional metamorphic events. Roy and Blackwell (1968) suggested that heat flow observed at the surface has two components, a virtually constant component derived from the lower crust and upper mantle, and a variable component generated by upper crustal radioactivity. Thus, most local variation in heat flow is due to sources in the uppermost 7 to 11 km of the earth's crust. During regional metamorphism, heat is transported by the movement of the more volatile components as well as by conduction, and heat sources may be concentrated as a result of differential movement of heat-producing elements such as potassium, uranium, and thorium (Jessop, 1968).

Data suitable for an examination of the fractionating effects of regional metamorphism are available from the New Quebec area. The rocks in this area consist largely of weakly to strongly foliated Archean granodioritic gneisses that are probably of metasedimentary origin. Early geological work in a part of this area suggested that only rocks of amphibolite facies were present, but reconnaissance mapping of 200,000 square miles of the area has revealed the widespread occurrence of rocks of the granulite facies.

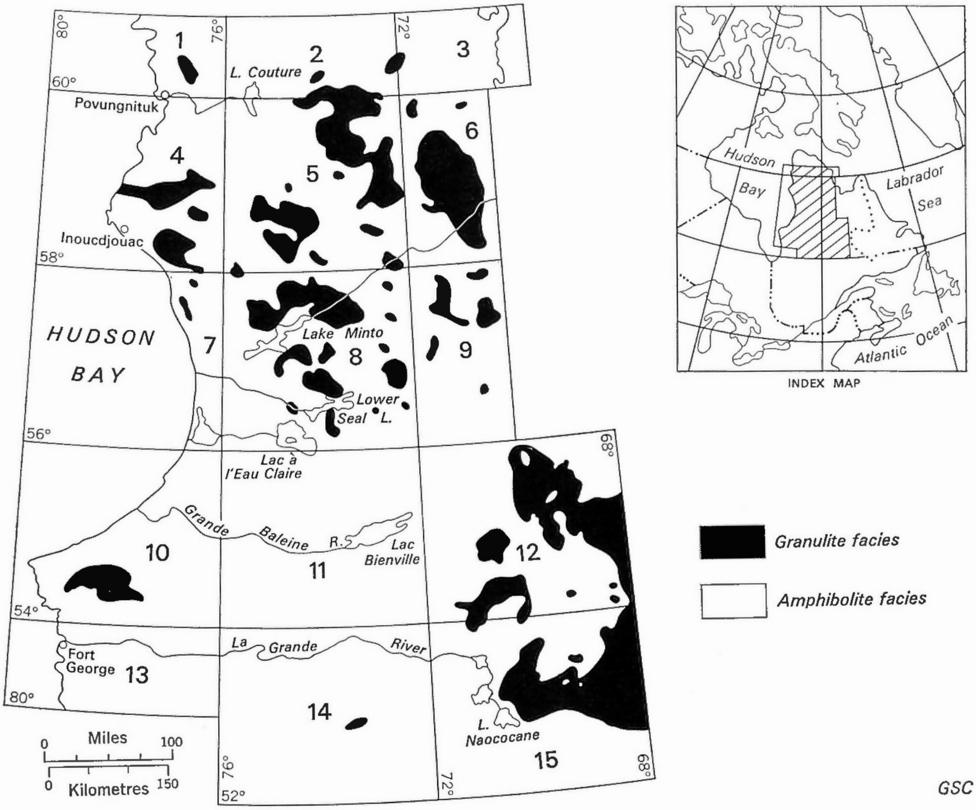

FIGURE 4. Distribution of granulite and amphibolite facies rocks in New Quebec sample areas.

The rocks of the granulite facies (shown in black in Fig. 4) are, at the one extreme, very coarse grained, rusty and white weathering, and exhibit a faint irregular gneissosity. This rock-type grades, as a result of an increase in finer grained, biotite-rich, metasedimentary material, into a strongly banded rusty and grey weathering paragneiss. Biotite is ubiquitous in all the rocks of this facies and is pleochroic from pale yellow to deep red. Plagioclase is the dominant feldspar, locally it has an antiperthitic texture, and its fresh surfaces are pale green or brownish green with a greasy lustre. Quartz is blue or dark grey. Hypersthene, hornblende and locally garnet and augite are common constituents.

These rocks are broadly similar in origin and composition to the common, lower grade, granitoid gneisses of the Canadian Shield. The banding of the gneiss and the inclusions of banded biotite-rich material suggest a derivation from predominantly sedimentary strata. The absence of notable quantities of crystalline limestone, lime-silicate or highly quartzose layers suggests a greywacke-type of primary sediment. Mineralogical peculiarities, notably the presence of hypersthene, calcic plagioclase and garnet, and textural features such as large grain size, are thought to result from metamorphism under conditions of high pressure and temperature. The presence of biotite and, less commonly, of dark hornblende in the association suggests the hornblende-granulite subfacies. These gneisses of New Quebec may constitute one of the world's largest areas of high-grade metamorphic rocks.

The rocks of the amphibolite facies are grossly similar in appearance to their neighbours of higher metamorphic grade, and the structures of one facies are continuous into rocks of the other facies. The granitoid varieties of the amphibolite facies are mainly pink or buff on a fresh surface, and rocks of this facies abound in minerals such as epidote, microcline and muscovite that are considered characteristic of lower temperature-pressure conditions. Locally, the preservation of structures in rocks of the amphibolite facies allows the identification of metasedimentary and metavolcanic rock types. For more detailed descriptions of rock varieties from both the hornblende-granulite and amphibolite facies of New Quebec see Eade (1966) and Stevenson (1969).

Major Elements

From the analyses representing the rocks of New Quebec, the average major element abundances of rocks of the amphibolite and granulite facies of each unit-area studied was obtained by measuring the areas underlain by rock units of the two facies, and using these measured areas to obtain a weighted average for each unit-area (Table 13). Some of the values in Table 13 are slightly different from previously published results dealing with the same samples (Eade, *et al.*, 1966). In deriving the present values, the chemical analyses were recalculated to 100 per cent, a procedure not followed in the earlier publication. In addition, minor arithmetical errors in the original calculations were corrected. The average composition of all amphibolite facies rocks and of all granulite facies rocks was obtained by weighting the data in proportion to the area occupied by each rock type (Table 14).

There are no major differences between the chemical composition of the two facies, probably because there were no primary differences in their proto-rocks. The values for Al_2O_3, total Fe (as FeO), P_2O_5 and, possibly, CaO and TiO_2, appear to be higher in the granulite facies, whereas K_2O, H_2O and, possibly, SiO_2 appear to be lower. The ferrous-ferric ratio also appears to be significantly higher in the granulite facies.

Of the 12 unit-areas in which both granulite and amphibolite facies rocks are represented (Table 13), 9 show lower SiO_2 values in the granulites, 11 lower K_2O values, and 11 lower H_2O values. In 9 of the 12 unit-areas FeO is higher in the granulites, and in 11 of the unit-areas Al_2O_3 is higher. As discussed later in this report, of 7 unit-areas that provided composites large enough for accurate determination of U and Th in both granulite and amphibolite facies, 7 show higher U in amphibolite facies and 5 show higher Th. The evidence that the constituents SiO_2, K_2O, H_2O, Th, and U as a group are depleted in rocks of granulite facies, relative to adjacent genetically related rocks of amphibolite facies, agrees with what is known of the crystal chemical response of these elements to conditions of increased temperature and pressure.

These results seem to corroborate the views of Ramberg (1951) and Heier and Adams (1965) that high-grade gneisses tend to be more basic than low-grade gneisses. This basification of granulites results from the loss by upward movement of a mixture of more volatile constituents (K_2O, H_2O, SiO_2) in response to regional metamorphism. The similarity of Ba and Sr values in amphibolite and granulite facies is readily explained by acceptance of these elements in mineral structures formed during high-grade metamorphism as postulated by Heier (1965).

Table 14 gives the mean composition of all amphibolite facies rocks and all granulite facies rocks of New Quebec area. It is emphasized that these mean compositions were calculated on the basis of the areal extent of the two facies. They do not therefore have any necessary or direct bearing on the question of the fractionation of elements as a result of high-grade regional metamorphism. It would be possible for example, depending on the relative sizes of areas of granulite and amphibolite facies in various unit-areas, for the mean value of K_2O in all of New Quebec to be higher in the granulite facies while at the same time in each unit-area the coexisting facies might indicate a consistent depletion of K_2O in the granulites.

With respect to the apparent metamorphic differentiation indicated above, it should be pointed out that due to the broad reconnaissance nature of the sampling, some specimens of hornblende-granulite gneiss have necessarily been included in the composites prepared to represent rocks of the amphibolite facies and vice versa. It is probable that if a more accurate separation of samples representing the two facies had been possible, the chemical contrast

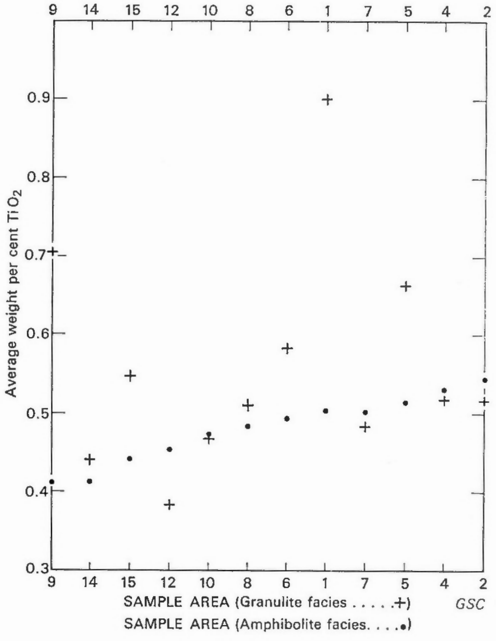

FIGURE 5
Average abundance of TiO_2 in rocks of amphibolite and granulite facies.

between rocks of the two facies would have been more striking. In the Mount Wright area (Roach and Duffell, 1968) immediately adjoining unit-area 15, New Quebec area, analyses of intermediate granulite (col. 3, Table 14) indicate significantly lower SiO_2 and K_2O, and higher TiO_2 and total Fe than the granulite facies rocks of unit-area 15 (Table 13).

The abundance of TiO_2 in the amphibolite facies and in the granulite rocks of each of the sample areas is shown in Figure 5 in which the values of TiO_2 in the two facies are plotted in a sequence such that the TiO_2 increases to the right. Titanium is generally higher in the granulite rocks and has a much greater range than in the amphibolite facies. As previously noted, biotite is ubiquitous in New Quebec rocks of the granulite facies, and the stability of high-temperature biotite may be the result of a concentration of titanium (Ramberg, 1948; Saxena, 1966). Titanium is so much higher in the granulite rocks of some of the unit-areas, for example, 1, 5, 9, relative to adjacent rocks of the amphibolite facies, that addition of titanium to the granulites is suggested. The source of the titanium may be a deeper, higher grade granulite in which biotite was unstable and from which titanium was expelled.

Radioactive Elements

The abundances of thorium, uranium and potassium listed in Table 2 have been used to calculate the averages given in Table 16. Some unit-areas, for example, 1 and 3, contain rocks of hornblende-granulite facies, but the composite samples prepared to represent these rocks were too small for accurate determinations of thorium and uranium by gamma-ray spectrometry. As a result, thorium and uranium determinations of both granulite and amphibolite facies rocks are available for only 7 of the 15 unit-areas.

A question in treating these chemical data was whether the thorium and uranium contents of these near surface samples have remained unchanged since the rocks were last regionally metamorphosed. Richardson and Adams (1963) found that uranium was lost from apparently fresh New Hampshire granite outcrop samples as a result of weathering. The samples from New Quebec, however, are all fresh-looking and lack any visible signs of weathering; the outcrop area was glaciated only recently and the surfaces of the outcrops are at present frozen for most of the year. On these grounds it seems unlikely that significant leaching has taken place since the retreat of Wisconsin ice from the area.

The data of Table 16 indicate a rough positive relationship among the abundances of the three radioactive elements in the surface crystalline rocks of New Quebec. Thorium, uranium, and possibly potassium have significantly lower average concentrations in rocks of hornblende-granulite subfacies than in surrounding rocks of amphibolite facies. Lambert and Heier (1967) recognized no such depletion in hornblende-granulite rocks of the Australian Shield but found that rocks of the pyroxene-granulite subfacies have distinctly lower abundances of U and Th (Table 17).

The ratio of thorium to uranium (Th/U) in the New Quebec rocks averages 8.1, a value more than double the commonly accepted one of 3 to 4 for average continental crustal rocks. This agrees with observations by Heier (1962) and by Heier and Adams (1965), who attributed higher local ratios in high-grade metamorphic rocks to large fluctuations in uranium concentrations, with high ratios being related to much lower than 'normal' uranium content. They suggested that because of the greater solubility of the oxidized uranyl complex ion, uranium is easier to remove in metamorphic processes. The use of composite samples in the present investigation undoubtedly smooths out the effect of large local fluctuations of this type. There still remains a higher than 'normal' over-all Th/U ratio for this part of the Shield.

The Th/U ratios in the rocks of New Quebec have a considerable spread but in general are lower in rocks of amphibolite facies than in rocks of granulite facies. Heier and Adams (1965), who analyzed a series of metamorphic rocks ranging from epidote amphibolite to pyroxine-granulite facies, found that if the lowest Th/U ratios from each metamorphic group were compared, the Th/U ratios decreased with increasing grade of metamorphism. They concluded that the Th/U ratio may decrease with increasing metamorphism. Lambert and Heier (1967) found a spread in Th/U ratios but concluded that amphibolite facies and hornblende-granulite facies rocks tend to have ratios above 4 whereas ratios less than 4 are most common in the pyroxene-granulite facies.

The abundance of thorium in the rocks of New Quebec is remarkably close to the estimate of 9.6 ppm which Taylor (1964) published for the abundance of this element in the crust (Table 17). His estimated crustal average of 2.7 ppm for uranium, however, is about twice the abundance in these rocks. Taylor's estimate is based on basalt and granite averages, but the granitic average undoubtedly contains a preponderance of analyses of high-level magmatic granitic material with a uranium content much greater than that of deep crustal gneisses. Gneisses such as those discussed may have been profoundly metamorphosed more than once during the Archean. The mineral transformations which occurred during each episode would allow fractionation of elements such as uranium. In addition, such predominantly high-grade gneisses contain few silicate species with the capacity of incorporating foreign ions into their structures, so that a higher percentage of these ions would be in adsorbed positions from which they could easily be mobilized.

The average U content of all New Quebec rocks, 1.2 ppm, is markedly lower than the 2.1 ppm average content for all areas reported here (weighted according to the size of each structural province). The 2.1 ppm value is close to the 2.0 ppm determined by Lambert and Heier (1967) for amphibolite facies rocks in southwest Australia. Estimates of U abundance in the continental crust (cols. 2, 3, and 4, Table 17) are all higher, ranging from 2.7 to 3.0 ± 0.6 ppm. It is suggested that earlier estimates of U content in continental crust were high because undue emphasis was given to late, high-level granite to granodiorite plutons that are higher in U and Th than are the more abundant granitic gneisses.

In generalizing about the significance of the chemical composition of the surface crystalline rocks of this area we are faced with one major question. Would most shield areas if eroded to moderate depths (say 5 miles) expose high-grade gneisses similar to these? If this is an acceptable assumption, then the bulk of the continental crust is likely to have radioactive element abundances similar to the surface rocks of New Quebec.

In the search for economic uranium mineralization, regional studies of U content in the crystalline rocks may be a valuable tool. Heier and Rhodes (1966) showed (col. 7, Table 17) that granites and gneisses of the Rum Jungle Complex in northern Australia contain much above normal U and Th and that this region is a uranium and thorium province. They suggested that separation of thorium and uranium from crystalline rocks, and concentration of uranium in structurally favourable zones took place during a period of low-grade metamorphism. In the Beaverlodge area of Saskatchewan, Tremblay (1968) reported average uranium contents in main rock types as follows: white quartzite, 3.0 ppm; layered gneiss, 3.7 ppm; granite, 5.4 ppm; and argillite-chlorite schist-impure quartzite, 4.5 ppm. All these values are above the estimates of the average continental crust uranium content. Tremblay suggested that the uranium of the deposits in the Beaverlodge area are derived from the country rocks with mobilization of uranium and its concentration during mylonitization, and further remobilization and concentration during late fracturing to produce workable deposits.

Roscoe (1966) stated that most of the world's past uranium production and almost all the reserves of low cost uranium have been derived from conglomeratic deposits and disseminated deposits in non-marine sedimentary rocks. In searching for similar uranium-bearing sedimentary sequences, the chances of success might be increased if the source area of the sedimentary rocks are crystalline rocks with above average U content. Conversely, if the source area consists of crystalline rocks in the granulite facies, with below average U content, there may be less possibility of economic uranium concentrations in the derived sedimentary rocks. In some instances however, the crustal zone removed to form the sedimentary deposits may have been much higher in radioactive elements than is the presently exposed area.

Vertical Chemical Zoning of the Earth's Crust

The present project has many objectives in common with a project reported by Shaw, *et al.* (1967). In their study it was pointed out that a reasonably accurate estimate of the composition of the Canadian Shield would be useful in considering questions such as: (1) Does the Canadian Precambrian Shield differ notably in composition from other shield areas, or from the crust of the earth as a whole? (2) Are there significant regional variations within the Canadian Shield itself? (3) Does the average Precambrian crust differ in composition from younger rocks? (4) Has the crust of the earth remained essentially a closed system throughout geological time?

A meaningful discussion of many of these questions is, however, dependent on the question posed by Shaw, *et al.* (1967), namely, can the composition of the surface crystalline rocks be used to measure the composition in depth, on the same basis that a modal analysis can be reliably estimated by a Rosiwal analysis? This was in part the assumption made when the present project was initiated. It was found in the early stages, however, that small but regular differences in composition existed between rocks of hornblende-granulite facies and those of amphibolite facies in the rocks of New Quebec. Other workers, e.g., Lambert and Heier (1967), found striking evidence of metamorphic differentiation with the appearance of pyroxene-granulite facies. It is likely that differentiation almost invariably takes place when continental sialic crustal material is exposed to conditions that produce mineral assemblages characteristic of the pyroxene-granulite facies. The question of whether the surface of the Shield represents the Shield at depth evolves into whether or not the various metamorphic facies are represented in almost the same proportion at depth as they are at the surface. In this regard, most workers assume (*see* Lambert and Heier, 1967) that the proportion of high-grade metamorphic rocks increases at depth, and there is some direct evidence, for example the rarity of pyroxene granulites at the surface and their frequent association with large faults, that this is the case. Some examples may be cited from the Canadian Shield. Skinner (1968) has stated that divergence of magnetic trends and the presence of basic to ultrabasic rocks within the belt of granulite facies rocks of the Moose River belt suggest the presence of a major structural feature in which deeper parts of the crust have been exposed either by faulting, sharp folding, or both. Similarly, Bell (1966) has described a belt of pyroxene-granulite rocks along the Churchill–Superior boundary in northern Manitoba, and Hall and Brisbin (1965) have described an upwarping of both the Conrad and Mohorovicic discontinuities along an extension of this belt. In both examples, the presence of high-grade rocks at the surface has been correlated with an upward movement of deep crustal material.

There are then strong empirical and theoretical (Taylor, 1967) grounds for believing that the continental crust is chemically zoned with a downward decrease in lithophile elements.

Care must be taken therefore in using the abundance of elements in the surface rocks of shield areas to deal with questions involving the chemical composition of the continental crust at depth.

CHEMICAL EVOLUTION OF THE CANADIAN SHIELD

It has not been clearly established whether continental crustal material has evolved chemically throughout geological time. The composition of the crystalline rocks of various ages that form the Canadian Shield should provide useful data in considering this question.

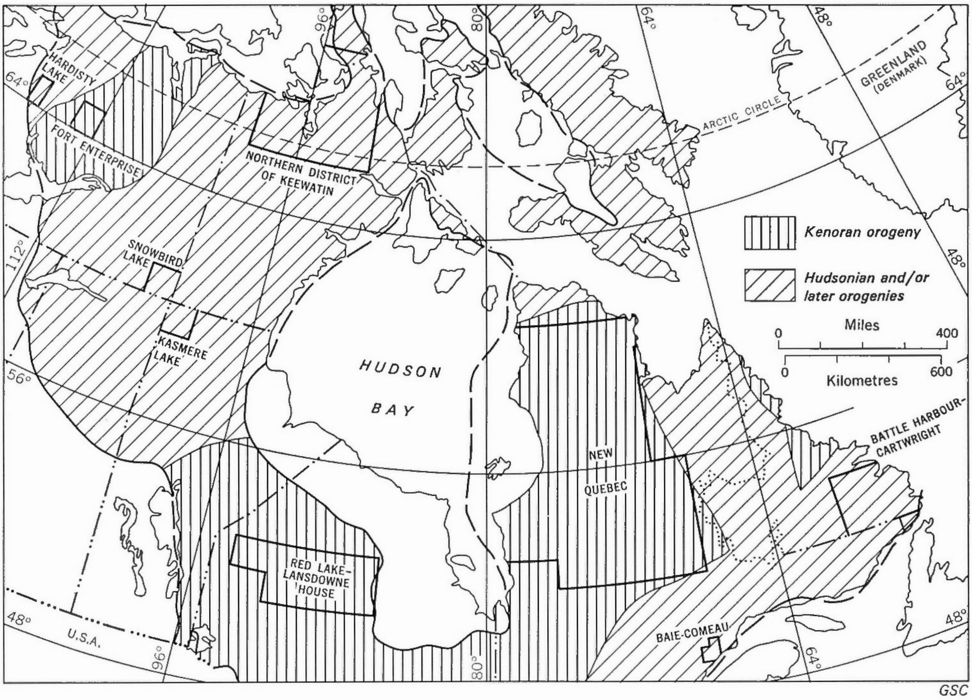

FIGURE 6. The Canadian Shield divided into areas whose rocks were last metamorphosed during the Kenoran orogeny and those last metamorphosed during Hudsonian and/or later orogenies.

In Figure 6 the Shield is divided into units whose tectonic histories are either one of two types. Within the lined areas, the rocks were last intensely affected by the Kenoran Orogeny about 2,500 m.y. ago, and all of the major units in these areas are of Archean age. In the dotted areas, K-Ar ages on micas indicate that the rocks were last intensely affected by the Hudsonian or the Grenville Orogenies, at 1,700 and 1,000 m.y. respectively. The rocks of the dotted areas yield Proterozoic K-Ar ages (i.e., younger than the Kenoran Orogeny and older than the Cambrian), however in many localities it can be shown that the rocks are of Archean age and yield Proterozoic radiometric K-Ar ages because of overprinting by metamorphism related to the younger orogenies.

Figure 7 shows the abundances of the elements in each of the areas studied; the regional variations are readily apparent. In this figure the elements are more or less grouped according to a combination of the important geochemical factors of size (ionic radius), valency (charge), and bond type (ionic–covalent–metallic). In each subgroup the arrangement is in order of decreasing ionic radius. This arrangement of presentation was developed by Taylor and White (1966).

All major units in New Quebec, Red Lake–Lansdowne House, and Fort Enterprise areas, are Archean, and all major units of Baie-Comeau and Hardisty Lake areas are thought to be Proterozoic. The remaining four areas appear from geological mapping to be mixed Archean and Proterozoic, the northern District of Keewatin and Snowbird Lake areas largely Archean, and the Kasmere Lake and Battle Harbour–Cartwright areas largely Proterozoic.

Data

It is instructive to compare the average chemistry of the various areas in terms of the age of the major rock units of which they are composed (Fig. 7). The surface crystalline rocks of Archean or largely Archean areas are significantly different in chemistry from areas that are mainly Proterozoic (Table 15). This difference is apparent even if only two averages are compared; the average of those areas composed entirely of Archean rocks, and the average of those areas that are entirely Proterozoic plus those that are mixed Proterozoic and Archean (Table 15, cols. 10 and 11). These two weighted averages indicate significantly lower K_2O, Ti_2O, U, and Th, and higher Na_2O, Ni, and Cr in the Archean rocks. This supports a recent examination of the problem (Engel, 1963) and in part contradicts data (Condie, 1967) suggesting that the composition of North America may not have changed during the last 3.5×10^9 years. The average composition of Archean Canadian Shield is similar to the average composition of Archean in Wyoming (Condie, 1967).

The chemical distinction between Archean and Proterozoic rocks is of considerable potential value in subdividing areas of Shield where neither geological nor radiometric data are unequivocal. Archean rocks reworked during the Hudsonian Orogeny, occurring in the Shield northwest of Hudson Bay (dotted area, Fig. 6) and Archean rocks within the Grenville (Structural) Province may possibly be distinguished by chemical data.

Discussion of Mechanism

There are two obvious possibilities for explaining the difference in composition between Archean and Proterozoic rocks: firstly, new sialic material supplied to the crust from the upper mantle may have varied in composition progressively with time; secondly, some major mechanism, presumably igneous-metamorphic, may have operated within the crust in such a way as to cause chemical fractionation resulting in zoning of pre-existing crustal material. This second possibility is discussed in the preceding section dealing with metamorphism and chemical fractionation. As pointed out, this mechanism should lead to chemical zoning of the crust with a gradual upward increase in mobile elements.

The argument can be used to explain a difference in chemistry between the surface crystalline rocks of Archean and Proterozoic ages. Archean rocks are older and have been subjected generally to greater erosion. The rocks exposed at these deeper erosion levels have been fractionated by generally higher grade, regional metamorphism and have lost mobile elements. Moreover, the sediments derived from the eroded upper parts of the Archean would be enriched in mobile elements, as could the crystalline crust derived subsequently from the sediments.

This explanation seems valid in New Quebec area as much of the present surface area represents a deep crustal level. The absence of high-level granites, the restriction of recognizable sedimentary and volcanic belts to the south part of the area, and the widespread occurrence of rocks of hornblende-granulite facies are arguments for this idea. However in the Red Lake–Lansdowne House and Fort Enterprise areas of Archean rocks, mildly metamorphosed sedimentary and volcanic rocks are widespread, along with high-level granitic intrusions with metamorphic aureoles. These areas do not therefore appear to represent deep crustal levels; yet both areas have chemical compositions closer to those of New Quebec than to those of younger Precambrian terrains. Although metamorphism accompanied by anatectic melting has likely resulted in chemical fractionation and in a vertically zoned crust (Taylor, 1967) this mechanism does not appear sufficient to explain the differences in chemistry between Archean and Proterozoic parts of the Canadian Shield. If metamorphic fractionation explains the observed differences, it requires that the Fort Enterprise and Red Lake–Lansdowne House rocks were derived from detritus from a still older landmass which had been fractionated by still older high-grade metamorphism.

The progressive chemical changes observed in the Shield may on the other hand be explained partly in terms of a progressive change in the chemistry of upper mantle derived material that has been added to the crust. An abundant source of new crustal material consists of flood basalts and their shallow intrusive equivalents, sheet-like masses of diabase, all of which were fed through swarms of diabase dykes.

Clear evidence of the former presence of widespread flood basalts, or near surface equivalents, is normally lacking because these bodies by virtue of their proximity to surface tend to be quickly eroded unless preserved by some special tectonic event. The best records of these surface and near surface magmatic events are commonly the swarms of diabase feeder dykes. The extent of these dyke swarms and the probable extent of sialic material which they have fed to, or near to, the surface has only been recognized in recent years (Fahrig and Wanless, 1963). These rocks must have been important contributors to the sedimentary accumulations upon, and bordering, the cratonic elements throughout Precambrian time. A record of the progressive changes in the chemical composition of this type of new sialic material during part of the Precambrian has been determined by examining the chemistry of successive dyke swarms.

In early studies of dyke swarms in the District of Mackenzie, Northwest Territories (Burwash, *et al.*, 1963), and in work on dyke swarms elsewhere in the Shield (Fahrig, *et al.*, 1965; Campbell and Imrie, 1965; Leech, 1966) it was pointed out that K_2O is more abundant in younger dykes. Unfortunately it is difficult to study the original composition of diabase dykes older than about 2,300 m.y., as all of these were metamorphosed and disrupted during the Kenoran Orogeny. However, data on the average composition of 32 swarms of unaltered dykes (some of which may be duplicates) ranging in age from 2,200 to 200 m.y. are now available. Figure 8 presents a frequency distribution diagram of K_2O contents in 17 swarms that give K-Ar ages greater than 1,300 m.y. and of K_2O contents in the 15 swarms that give K-Ar ages less than 1,300 m.y. The younger swarms have a notably higher K_2O content; none has an average K_2O content of less than 0.5 per cent. A striking increase in TiO_2 accompanies the increase in K_2O in younger dyke swarms (Fig. 8). A similar plot of Na_2O (Fig. 8) indicates a slight increase in abundance of Na_2O with decreasing age. This would not then explain the greater abundance of sodium in Archean rocks compared with Proterozoic rocks, but an explanation of this discrepancy may be found in other factors of the geochemical cycle of sodium.

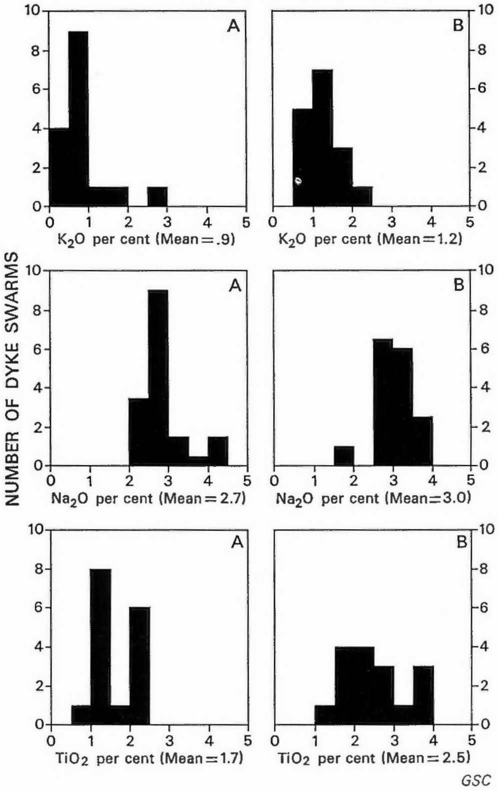

FIGURE 8

Abundances of K_2O, Na_2O and TiO_2 in 32 diabase dyke swarms. Histograms labelled A show K-Ar ages greater than 1,300 m.y. Histograms labelled B show K-Ar ages less than 1,300 m.y.

From these observations it is suggested that there has been a progressive change in the composition of new non-orogenic material, and that this progressive change was probably a feature of Archean as well as of post-Archean time. A recent paper (Danchin, 1967) reported high Ni and Cr abundances in very ancient shales in South Africa and these are interpreted as indicating either an ultrabasic or, less likely, a basic source rock. Both these elements are more abundant in Archean than in Proterozoic rocks of the Canadian Shield. It seems likely that new sialic material was irregularly, but progressively less basic with decreasing geologic age. A secular variation in the composition of continental volcanic rocks was suggested by Engel, *et al.* (1965) and independently by D. M. Shaw (pers. comm.). Goodwin (1966) suggested that Archean continental masses grew outward, and that the corresponding volcanic composition trend accompanying this growth changed from an early largely basic suite with minor felsic components to a complex suite with a large felsic component.

SUMMARY AND CONCLUSIONS

Three averages for the composition of the surface crystalline rocks of the Canadian Shield were calculated from chemical analyses involving 14,000 hand specimens collected from nine areas across the Shield. The preferred average, calculated according to the sizes of the tectonic provinces, takes into account the fact that crustal material as represented by surface crystalline rocks has apparently evolved with geologic time and tectonic history. The preferred Shield average is as follows: SiO_2 65.2%, Al_2O_3 15.8%, Fe_2O_3 1.2%, FeO 3.4%, MgO 2.2%, CaO 3.3%, Na_2O 3.7%, K_2O 3.23%, H_2O (total) 0.8%, TiO_2 0.57%, P_2O_5 0.17%, MnO 0.2%, CO_2 0.2%, Ba .073%, Sr .032%, Ni 18 ppm, Cr 59 ppm, U 2.1 ppm, and Th 13.0 ppm.

Gneissic rocks (unit 7) and massive granitoid rocks (unit 9), which together represent the major part of the surface rocks of the sample areas, are both similar to the average granodiorite of Nockolds (1954).

A study of the abundance of elements in rocks of hornblende-granulite facies versus related rocks of amphibolite facies indicates that rocks are chemically fractionated during high-grade regional metamorphism. In rocks of New Quebec the granulites are depleted in K_2O, H_2O, Th, and U, relative to rocks of amphibolite facies. The ferrous-ferric ratio appears to be higher in rocks of granulite facies. This basification of granulites apparently results from the loss of a mixture of more volatile elements due to their movement in response to regional metamorphism involving anatexis. As the proportion of high-grade metamorphic rocks undoubtedly increases downward in the crust there are strong grounds for believing that the continental crust is chemically zoned with a downward decrease in lithophile elements, so probably the surface rocks of the Shield do not truly represent the composition of the Shield at great depths.

The average composition of rocks in those study areas which are underlain by Archean material are significantly different from those underlain by rocks that are chiefly Proterozoic in age. The rocks of Archean age are higher in Ni, Cr, and Na_2O, and lower in K_2O, TiO_2, U, and Th than rocks that are Proterozoic. The process of chemical fractionation, resulting in zoning of pre-existing crustal material, is one possible explanation for these differences in composition. Secular variation in composition of new sialic material supplied to the crust from the upper mantle is another possible explanation. Flood basalts and near surface equivalents represent such new material but commonly only their feeders, diabase dyke swarms, are preserved. A study of the compositions of a number of such swarms, of different ages, suggests there has been a progressive change in the composition of new non-orogenic material, at least in post-Archean time. New sialic material was irregularly, but progressively, more alkalic with decreasing geologic age. Such a change was probably also a feature of Archean time. Thus two distinctly different processes may be involved in the chemical evolution of the crystalline rocks of continental sialic plates.

REFERENCES

Adams, J. A. S.
1964: Laboratory γ-ray spectrometer for geochemical studies, *in* The natural radiation environment; eds. J. A. S. Adams and W. Lowder, Chicago, Univ. Chicago Press, pp. 485–497.

Adams, J. A. S., Osmond, J. K., and Rogers, J. J. W.
1959: The geochemistry of thorium and uranium; *Phys. Chem. Earth*, 3, pp. 398–448.

Baragar, W. R. A.
1966: Geochemistry of the Yellowknife volcanic rocks; *Can. J. Earth Sci.*, 3, pp. 9–30.
1968: Major-element geochemistry of the Noranda volcanic belt, Quebec–Ontario; *Can. J. Earth Sci.*, 5, pp. 773–790.

Bell, C. K.
1966: Churchill-Superior province boundary in northern Manitoba; *Geol. Surv. Can.*, Paper 66-1, pp. 133–136.

Bostock, H. H.
1962: Lansdowne House, Ontario; *Geol. Surv. Can.*, Map 4–1962.

Boyle, R. W.
1961: The geology, geochemistry and origin of the gold deposits of the Yellowknife district; *Geol. Surv. Can.*, Mem. 310.

Buddington, A. F.
1939: Adirondack igneous rocks and their metamorphism; *Geol. Soc. Am.*, Mem. 7.

Burwash, R. A., Baadsgard, H., Campbell, C. L., Cumming, R. E., and Folinsbee, R. E.
1963: Potassium-argon dates of diabase dyke systems, District of Mackenzie, N.W.T.; *Bull. Can. Inst. Mining Met.*, vol. 56, pp. 706–710.

Campbell, F. A., and Imrie, A. S.
1965: Composition of diabase dykes at Quemont Mine; *Can. J. Earth Sci.*, 2, pp. 324–328.

Carruthers, C. A.
1961: North Caribou Lake, Ontario; *Geol. Surv. Can.*, Map 18–1961.

Clarke, F. W.
1889: The relative abundance of the chemical elements; *Bull. Phil. Soc.*, Washington, 11, p. 131.

Clarke, F. W., and Washington, H. S.
1924: The composition of the earth's crust; USGS Prof. Paper 127.

Condie, K. C.
1967: Composition of the ancient North American crust; *Science*, 155, pp. 1013–1015.

Danchin, R. V.
1967: Chromium and nickel in the Fig Tree shale from South Africa; *Science*, 158, pp. 261–262.

Donaldson, J. A.
1961: North Spirit Lake, Ontario; *Geol. Surv. Can.*, Map 50–1960.

Eade, K. E.
1962: Battle Harbour–Cartwright, Coast of Labrador, Newfoundland; *Geol. Surv. Can.*, Map 22–1962.
1966: Fort George River and Kaniapiskau River (west half) map-areas, New Quebec; *Geol. Surv. Can.*, Mem. 339.

Eade, K. E., Fahrig, W. F., and Maxwell, J. A.
1966: Composition of crystalline shield rocks and fractionating effects of regional metamorphism; *Nature*, 211, pp. 1245–1249.

Emslie, R. F.
1961: Lake St. Joseph, Ontario; *Geol. Surv. Can.*, Map 51–1960.
1962: Wunnummin Lake, Ontario; *Geol. Surv. Can.*, Map 1–1962.
1964: Potassium-argon age of the Michikamau anorthosite intrusion, Labrador; *Nature*, 202, pp. 172–173.
1965: The Michikamau anorthositic intrusion, Labrador; *Can. J. Earth Sci.*, 2, pp. 385–399.

Emslie, R. F., and Holman, R. H. C.
1966: The copper content of Canadian Shield rocks, Red Lake–Lansdowne House area, northwestern Ontario; *Geol. Surv. Can.*, Bull. 130.

Engel, A. E. J.
1963: Geologic evolution of North America; *Science*, 140, pp. 143–152.

Engel, A. E. J., Engel, C. G., and Havens, R. G.
1965: Chemical characteristics of oceanic basalts and the upper mantle; *Bull. Geol. Soc. Am.*, vol. 76, pp. 719–734.

Fahrig, W. F., and Eade, K. E.
1968: The chemical evolution of the Canadian Shield; *Can. J. Earth Sci.*, 5, pp. 1247–1252.

Fahrig, W. F., and Wanless, R. K.
1963: Age and significance of diabase dyke swarms in the Canadian Shield; *Nature*, 200, pp. 934–937.

Fahrig, W. F., Eade, K. E., and Adams, J. A. S.
1967: Abundance of radioactive elements in crystalline shield rocks; *Nature*, 214, pp. 1002–1003.

Fahrig, W. F., Gaucher, E. H., and Larochelle, A.
1965: Paleomagnetism of diabase dykes of the Canadian Shield; *Can. J. Earth Sci.*, 2, pp. 278–298.

Fraser, J. A.
1958: Fort Enterprise, Northwest Territories; *Geol. Surv. Can.*, Map 16–1958.
1962: Kasmere Lake, Manitoba; *Geol. Surv. Can.*, Map 31–1962.
1967: Hardisty Lake (west half), District of Mackenzie; *Geol. Surv. Can.*, Map 1224A.

Goldschmidt, V. M.
1933: Grundlagen der Quantitativen geochemie; *Fortschr. Mineral. Krist. Petrog.*, 17, pp. 112–156.

Goodwin, A. M.
1962: Structure, stratigraphy and origin of iron formations, Michipicoten area, Algoma District, Ontario, Canada; *Bull. Geol. Soc. Am.*, vol. 73, pp. 561–598.
1966: Archean protocontinental growth and mineralization; *Can. Mining J.*, 87, No. 5, pp. 57–60.

Grout, F. F.
1938: Petrographic and chemical data on the Canadian Shield; *J. Geol.*, 46, pp. 486–504.

Hall, D. H., and Brisbin, W. C.
1965: Crustal structure from converted head waves in central western Manitoba; *Geophysics*, 30, pp. 1053–1067.

Harker, A.
1899: On the average composition of British igneous rocks; *Geol. Mag.*, 4, p. 220.

Heier, K. S.
1962: Spectrometric uranium and thorium determination on some high-grade metamorphic rocks on Langoy, northern Norway; *Norsk. Geol. Tidsskr.*, 42, pp. 143–156.
1965: Metamorphism and the chemical differentiation of the crust; *Geol. Foren. Stockholm Forh.*, 87, pp. 249–256.

Heier, K. S., and Adams, J. A. S.
1965: Concentration of radioactive elements in deep crustal material; *Geochem. Cosmochim. Acta.*, 29, pp. 53–61.

Heier, K. S., and Rhodes, J. M.
1966: Thorium, uranium, and potassium concentrations in granites and gneisses of the Rum Jungle Complex, Northern Territory, Australia; *Econ. Geol.*, 61, pp. 563–571.

Heier, K. S., and Rogers, J. J. W.
1963: Radiometric determination of thorium, uranium, and potassium in basalts and in two magmatic differentiation series; *Geochim. Cosmochim. Acta*, 27, pp. 137–154.

Heywood, W. W.
1961: Geological notes, northern District of Keewatin; *Geol. Surv. Can.*, Paper 61-18 (with Map 28–1961).
1963: Baie-Comeau area, Quebec; *Geol. Surv. Can.*, Paper 62-20 (with Map 35–1962).

Holman, R. H. C.
1963: A regional geochemical reconnaissance of bedrock in the Red Lake–Lansdowne House area of Ontario, Canada, *in* Eight papers on regional geochemistry in Canada; *Geol. Surv. Can.*, Paper 63-23, pp. 28–39.
1964: Geochemistry (copper in bedrock), Lake St. Joseph, North Caribou Lake, North Spirit Lake, Wunnummin Lake, Miminiska, Lansdowne House, and Fort Hope, Ontario; *Geol. Surv. Can.*, Maps 50 to 56, 1963.

Jackson, G. D.
1961: Miminiska, Ontario; *Geol. Surv. Can.*, Map 8–1961.
1962: Fort Hope, Ontario; *Geol. Surv. Can.*, Map 6–1962.

Jessop, A. M.
1968: Three measurements of heat flow in eastern Canada; *Can. J. Earth Sci.*, 5, pp. 61–68.

Knopf, A.
1916: The composition of the average igneous rock; *J. Geol.*, 24, pp. 620–622.

Lambert, I. B., and Heier, K. S.
1967: The vertical distribution of uranium, thorium, and potassium in the continental crust; *Geochim. Cosmochim. Acta*, 31, pp. 377–390.

Leech, A. P.
1966: Potassium-argon dates of basic intrusive rocks of the District of Mackenzie, N.W.T.; *Can. J. Earth Sci.*, 3, pp. 389–412.

Nockolds, S. R.
1954: Average chemical compositions of some igenous rocks; *Bull. Geol. Soc. Am.*, 65, pp. 1007–1032.

Papezik, V. S.
1965: Geochemistry of some Canadian anorthosites; *Geochim. Cosmochim. Acta*, 29, pp. 673–709.

Parker, R. L.
1967: Composition of the earth's crust, *in* Data of Geochemistry; sixth ed., Chap. D, USGS Prof. Paper 440–D.

Poldervaart, A.
1955: Chemistry of the earth's crust; *Geol. Soc. Am.*, Spec. Paper 62, pp. 119–144.

Ramberg, H.
1948: Titanic iron ore formed by dissociation of silicates in granulite facies; *Econ. Geol.*, 43, pp. 553–570.
1951: Remarks on the average chemical composition of granulite and amphibolite-to-epidote amphibolite facies gneisses in west Greenland; *Medd. Dansk. Geol. Foren.*, 12, pp. 27–34.

Read, H. H.
1957: The granite controversy; London, Thomas Murby & Co.

Reilly, G. A.
1965: An estimate of the composition of part of the Canadian Shield in northwestern Ontario; Unpub. M.Sc. thesis, McMaster Univ., Hamilton, Ontario.

Reilly, G. A., and Shaw, D. M.
1967: An estimate of the composition of part of the Canadian Shield in northwestern Ontario; *Can. J. Earth Sci.*, 4, pp. 725–739.

Richardson, K. A., and Adams, J. A. S.
1963: Effect of weathering on radioactive elements in the Conway granite of New Hampshire; *Geol. Soc. Am.*, annual meeting (abstract), p. 137A.

Roach, R. A., and Duffell, S.
1968: The pyroxene granulites of the Mount Wright map-area, Quebec–Newfoundland; *Geol. Surv. Can.*, Bull. 162.

Roscoe, S. M.
1966: Unexplored uranium and thorium resources of Canada; *Geol. Surv. Can.*, Paper 66-12.

Rose, H. J., Adler, I., and Flanagan, F. J.
1963: X-ray fluorescence analysis of the light elements in rocks and minerals; *App. Spectros.*, 17, pp. 81–85.

Roy, R. F., and Blackwell, D. D.
1968: Heat generation of plutonic rocks and continental heat flow provinces; *Earth Planetary Sci. Letters*, 5, pp. 1–12.

Saxena, S. K.
1966: Distribution of elements between co-existing muscovite and biotite and crystal chemical role of titanium in the micas; *N. Jahrb. Mineral Abh.*, 105, pp. 1–17.

Sederholm, J. J.
1925: The average composition of the earth's crust in Finland; *Bull. Comm. Geol. Finlande*, 70.

Shaw, D. M.
1967: U, Th, and K in the Canadian Precambrian Shield and possible mantle compositions; *Geochim. Cosmochim. Acta*, 31, pp. 1111–1113.

Shaw, D. M., Reilly, G. A., Muysson, J. R., Pattenden, G. E., and Campbell, F. E.
1967: An estimate of the chemical composition of the Canadian Precambrian Shield; *Can. J. Earth Sci.*, 4, pp. 829–853.

Skinner, R.
1968: A preliminary study of the Moose River belt, northern Ontario (regional geology); *Geol. Surv. Can.*, Paper 67-38, pp. 3–6.

Stevenson, I. M.
1969: A geological reconnaissance of Leaf River map-area, New Quebec and Northwest Territories; *Geol. Surv. Can.*, Mem. 356.

Stockwell, C. H.

1964: Fourth report on structural provinces, orogenies and time-classification of rocks of the Canadian Precambrian Shield, *in* Age determinations and geological studies; *Geol. Surv. Can.*, Paper 64-17, Pt. II, pp. 1–21.

Stockwell, C. H., *et al.*

1965: Tectonic map of the Canadian Shield; *Geol. Surv. Can.*, Map 4–1965.

Taylor, F. C.

1963: Snowbird Lake map-area, District of Mackenzie; *Geol. Surv. Can.*, Mem. 333.

Taylor, S. R.

1964: Abundance of chemical elements in the continental crust, a new table; *Geochim. Cosmochim. Acta*, 28, pp. 1273–1285.

1967: The origin and growth of continents; *Tectonophysics*, 4, pp. 17–34.

Taylor, S. R., and White, A. J. R.

1966: Trace element abundances in andesites; *Bull. Vulcanol.*, 29, pp. 177–194.

Tremblay, L. P.

1968: Geology of the Beaverlodge mining area, Saskatchewan; *Geol. Surv. Can.*, Mem. 367 (advance ed.).

TABLE 2 Analyses of rock units and average composition by unit-areas, *New Quebec*

Unit-Area 1, New Quebec (NTS 35SW Part)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
7	2947	73	99.7	64.4	16.8	1.4	2.9	2.5	3.3	4.2	2.78	.8	.50	.13	.06	.20	.064	.029	0.9	10.1	48	86
7A	369	9	99.6	63.9	16.5	.7	3.7	1.5	4.2	4.4	2.55	1.4	.53	.11	.09	.40	.056	.026	N.M.	N.M.	120	140
8	256	6	99.8	57.4	17.9	1.4	5.0	3.5	5.9	4.2	2.33	.8	.90	.29	.11	.20	.068	.035	N.M.	N.M.	N.D.	100
Av. A(All Units)	3572	88		63.8	16.9	1.3	3.1	2.5	3.6	4.2	2.72	.9	.53	.14	.06	.20	.064	.029	0.9	10.1	52	92
Av. B(7, 7A)				64.3	16.8	1.3	3.0	2.4	3.4	4.2	2.75	.9	.50	.13	.06	.20	.063	.029	0.9	10.1	56	92

Unit-Area 2, New Quebec (NTS 35SE)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
6	100	11	99.4	56.5	17.7	1.1	5.1	4.4	6.9	3.8	1.65	1.4	.67	.14	.15	.30	.047	.033	N.M.	N.M.	82	86
7	5852	133	99.3	64.6	16.7	1.3	3.4	2.1	4.0	4.2	2.11	.7	.55	.13	.09	0	.055	.032	1.0	8.2	33	52
7A	1713	32	100.2	63.9	17.5	1.5	2.7	2.5	3.6	4.3	2.74	.6	.50	.12	.06	.10	.065	.043	0.5	7.4	N.D.	77
8	673	21	98.4	65.2	18.2	.6	3.1	1.0	3.7	4.5	2.17	.6	.52	.21	.08	.20	.065	.050	0.4	9.8	<40	43
9	1062	21	100.6	65.4	16.3	1.2	2.4	3.0	3.5	4.3	2.53	.6	.57	.11	.06	.10	.070	.044	0.0	5.8	N.D.	N.D.
Av. A (All Units)	9400	218		64.4	16.9	1.3	3.2	2.2	3.9	4.2	2.27	.7	.56	.13	.08	.10	.059	.037	0.8	7.9	24	51
Av. B (6, 7, 7A, 9)				64.4	16.9	1.3	3.2	2.3	3.9	4.2	2.28	.7	.54	.13	.08	.10	.059	.036	0.8	7.7	23	51

Unit-Area 3, New Quebec (NTS 25SW Part)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
7	3430	85	98.6	64.1	16.1	1.2	3.3	2.2	4.5	4.7	1.87	.8	.48	.09	.09	.41	.057	.027	0.4	6.2	90	960
7A	934	8	100.6	64.6	16.9	1.5	2.4	2.9	3.6	4.7	1.96	.8	.46	.08	.05	.10	.060	.045	N.M.	N.M.	N.D.	84
Av. A (7, 7A)	4364	93		64.3	16.3	1.3	3.0	2.3	4.3	4.7	1.89	.8	.48	.09	.08	.30	.058	.031	0.4	6.2	71	772

Unit-Area 4, New Quebec (NTS 34NW)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
6	41	1	100.5	54.5	12.9	4.1	14.3	3.4	2.8	2.4	3.32	1.7	.23	.06	.16	.10	.200	.023	N.M.	N.M.	73	130
7	6723	154	100.2	61.7	16.6	1.7	3.7	3.3	4.8	4.0	2.34	.8	.54	.10	.11	.40	.095	.031	0.9	7.4	87	75
7A	591	15	100.4	66.2	16.0	1.7	2.4	2.0	3.6	4.3	2.63	.5	.40	.10	.06	.10	.072	.037	0.6	7.9	94	140
8	2033	43	100.4	63.0	17.3	1.8	3.6	2.5	4.2	3.8	2.33	.7	.52	.08	.09	.10	.064	.033	0.6	5.7	N.D.	88
9	151	6	101.1	60.1	16.0	2.8	4.0	3.4	4.7	3.8	2.91	1.2	.86	.18	.10	.20	.061	.031	N.M.	N.M.	150	63
Av. A (All Units)	9539	219		62.2	16.7	1.7	3.6	3.1	4.6	4.0	2.37	.8	.53	.10	.10	.30	.087	.032	0.8	7.1	69	82
Av. B (6, 7, 7A, 9)				62.0	16.5	1.7	3.7	3.2	4.7	4.0	2.37	.8	.53	.10	.11	.40	.093	.031	0.9	7.4	88	80

Unit-Area 5, New Quebec (NTS 34NE)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
7	10693	237	101.3	65.3	16.8	2.2	2.8	1.3	3.2	4.4	2.68	.7	.45	.11	.08	.10	.067	.035	1.0	7.7	31	58
7A	701	16	100.3	67.4	16.3	1.0	2.7	.9	2.4	4.5	3.31	.7	.57	.17	.07	.10	.078	.028	1.0	10.8	N.D.	<20
8	4634	103	101.1	61.8	17.5	2.4	3.6	2.5	4.3	4.5	1.97	.6	.67	.19	.09	.10	.077	.047	0.5	4.2	34	71
9	3205	61	99.4	63.0	16.7	1.4	3.2	2.9	4.1	4.4	2.64	.6	.65	.16	.08	.10	.066	.032	0.8	7.6	27	72
12	15	4	101.6	52.8	16.5	2.2	7.6	8.1	6.7	2.9	.93	1.4	.76	.12	.16	0	.015	.027	N.M.	N.M.	160	250
Av. A (All Units)	19248	421		64.1	17.0	2.0	3.1	1.9	3.6	4.4	2.52	.7	.55	.14	.08	.10	.069	.034	0.8	7.0	30	63
Av. B (7, 7A, 9, 12)				64.8	16.8	1.9	2.9	1.7	3.4	4.4	2.70	.7	.51	.12	.08	.10	.067	.034	1.0	7.8	29	60

Unit-Area 6, New Quebec (NTS 24NW Part)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr	ppm V	ppm Co
7	4964	70	98.2	67.6	14.6	1.2	2.9	2.2	3.7	4.2	2.33	.7	.47	.10	.06	0	.058	.029	0.9	12.8	<30	45	80	<20
8	3320	59	97.6	65.9	14.8	1.4	3.7	2.1	4.4	4.3	1.88	.5	.58	.20	.09	.20	.110	.027	0.5	4.1	<30	60	92	<20
9	763	11	98.6	61.3	14.9	3.5	4.2	2.5	4.5	3.7	3.34	.8	.72	.30	.11	.10	.071	.027	N.M.	N.M.	<30	80	110	<20
12	64	5	95.8	58.9	15.7	2.6	5.3	4.2	7.1	3.7	.98	.6	.62	.10	.14	.10	.040	.019	N.M.	N.M.	<30	120	160	<20
Av. A (7, 8, 9, 12)	9111	145		66.5	14.6	1.5	3.3	2.3	4.0	4.2	2.25	.6	.53	.14	.08	.10	.078	.028	0.6	8.0	<30	52	90	<20
Av. B (7, 9, 12)				66.7	14.5	1.5	3.1	2.3	3.8	4.2	2.45	.7	.50	.10	.07	.10	.060	.029	0.9	12.8	<30	49	80	<20
12B		8	97.9	49.2	15.2	1.7	11.3	6.0	10.7	2.5	.27	1.4	1.22	.10	.18	0	.008	.017	N.M.	N.M.	96	80	300	65

TABLE 2 *Analyses of rock units and average composition by unit-areas, New Quebec (cont.)*

Unit-Area 7, New Quebec (NTS 34SW)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	M_nO	CaO	Na_2O	K_2O	$H_2O(T)$	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
7	1485	38	99.9	61.6	16.8	1.4	3.1	2.2	4.8	4.1	2.84	.8	.52	.20	.11	1.50	.082	.044	1.8	14.6	<40	23
7A	691	17	98.1	65.3	15.3	1.4	2.1	2.3	5.0	4.4	2.59	.6	.44	.13	.10	.20	.070	.032	0.7	5.8	40	200
8	49	5	100.1	61.7	17.1	1.0	4.4	3.7	4.6	4.7	1.34	.6	.48	.13	.11	.20	.046	.040	N.M.	N.M.	50	57
9	532	12	99.0	68.0	15.1	1.7	2.2	1.3	1.9	3.7	3.84	1.0	.57	.26	.06	.20	.071	.022	N.M.	N.M.	N.D.	N.D.
Av. A (All Units)	2757	72		63.7	16.1	1.5	2.7	2.0	4.3	4.1	2.94	.8	.50	.19	.10	.91	.076	.037	1.5	11.8	<40	64
Av. B (7, 7A, 9)				63.7	16.1	1.5	2.7	2.0	4.3	4.1	2.97	.8	.50	.19	.10	.91	.077	.037	1.5	11.8	<40	64

Unit-Area 8, New Quebec (NTS 34SE)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	M_nO	CaO	Na_2O	K_2O	$H_2O(T)$	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
7	7977	344	101.6	66.5	16.5	1.4	2.7	1.4	2.9	4.2	2.85	.7	.44	.12	.07	.10	.063	.036	1.4	13.6	<20	39
7A	1492	45	102.5	66.2	15.7	1.9	2.9	1.8	2.8	4.0	3.16	.7	.52	.16	.08	.10	.100	.026	1.2	14.8	<40	<20
8	3791	197	99.7	62.6	17.5	1.2	3.2	2.3	4.4	4.3	2.44	.7	.51	.17	.08	.60	.058	.040	0.7	5.8	<10	88
9	6876	179	99.4	65.3	17.4	1.1	2.4	1.5	2.8	4.4	3.21	.9	.49	.18	.07	.20	.078	.032	0.8	13.5	N.D.	27
12	33	27	101.0	52.5	11.8	4.5	9.8	8.5	7.8	2.0	1.13	1.0	.67	.06	.18	.10	.019	.015	N.M.	N.M.	110	350
Av. A (All Units)	20169	792		65.2	16.9	1.3	2.8	1.7	3.2	4.3	2.92	.8	.49	.15	.07	.20	.070	.035	1.0	12.2	<20	44
Av. B (7, 7A, 9, 12)				66.0	16.8	1.3	2.7	1.5	2.9	4.3	3.04	.8	.48	.15	.07	.10	.072	.033	1.1	13.7	<20	33

Unit-Area 9, New Quebec (NTS 24SW Part)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	$H_2O(T)$	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr	ppm V	ppm Co
7	5094	84	97.5	66.7	15.1	1.9	2.8	1.7	3.0	4.5	2.87	.8	.48	.21	.06	0	.070	.040	0.8	14.5	N.D.	34	<70	N.D.
7A	922	15	97.9	66.9	15.0	2.0	2.8	1.0	2.8	4.1	3.56	.8	.49	.20	.06	.31	.090	.039	0.7	8.2	N.D.	<30	<70	N.D.
8	998	20	96.9	63.7	16.0	2.6	3.3	1.8	4.0	4.5	2.30	.6	.71	.31	.06	.10	.075	.044	N.M.	N.M.	N.D.	38	<70	N.D.
9	3023	53	100.0	71.6	14.4	.7	1.7	.6	1.9	4.1	3.53	.8	.30	.10	.05	.20	.077	.036	2.0	13.2	N.D.	<30	<70	N.D.
12A	26	1	97.6	50.0	10.2	.4	7.3	15.5	7.5	2.4	.33	5.9	.35	0	.15	0	.027	.021	N.M.	N.M.	490	1200	130	72
Av. A(7,8,9,12A)	10063	173		67.8	15.0	1.6	2.5	1.3	2.8	4.4	3.06	.8	.45	.17	.06	.10	.074	.039	1.2	13.4	—	36	<70	—
Av. B(7,9,12A)				68.2	14.8	1.5	2.4	1.3	2.6	4.4	3.15	.8	.42	.16	.06	.10	.074	.038	1.2	13.4	—	30	<70	—
Leg Unit 12B		2	96.6	50.6	11.8	2.7	6.7	12.9	8.2	2.1	1.01	1.9	.37	0	.16	1.55	.016	.018	N.M.	N.M.	370	840	150	60

Unit-Area 10, New Quebec (NTS 33NW)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
1	13	12	98.1	65.6	14.0	1.1	6.1	3.9	2.1	1.4	2.68	2.3	.56	.07	.09	0	.028	.008	N.M.	N.M.	63	110
7	7955	44	99.3	63.9	16.3	2.2	3.7	2.3	3.4	3.5	2.79	1.0	.47	.16	.08	.10	.062	.040	1.1	9.3	N.D.	48
8	1229	13	98.5	63.2	14.1	.2	5.1	5.6	4.4	3.3	2.35	1.1	.47	.15	.10	0	.068	.051	N.M.	N.M.	100	31
9	4764	36	97.8	66.1	16.2	1.2	2.3	3.4	2.5	2.9	3.76	1.0	.48	.20	.05	.10	.088	.043	1.1	11.4	N.D.	<30
Av. A(1,7,8,9)	13961	105		64.6	16.0	1.7	3.3	3.0	3.1	3.2	3.08	1.0	.48	.17	.07	.10	.071	.042	1.1	10.1	<10	40
Av. B(1,7,9)				64.8	16.2	1.8	3.1	2.7	3.1	3.3	3.16	1.0	.48	.17	.07	.10	.072	.041	1.1	10.1	—	41
1A		4	99.7	47.1	15.8	1.1	10.2	8.6	8.3	1.9	2.03	3.4	1.23	.17	.15	0	.067	.018	N.M.	N.M.	69	69
2B		6	98.1	78.1	6.7	2.0	1.5	3.0	2.7	1.0	2.91	1.4	.30	.05	.08	.20	.060	.011	N.M.	N.M.	N.D.	N.D.
2		9	89.8	66.2	2.7	.3	.9	5.8	10.4	.1	3.34	.5	.19	.04	.06	9.58	.071	.005	N.M.	N.M.	N.D.	N.D.
12A		1	100.7	46.7	7.1	2.3	6.5	30.9	3.5	.3	.10	2.0	.19	.06	.19	.10	<.002	.003	N.M.	N.M.	1800	2600
12B		2	97.9	61.3	14.3	4.0	6.0	.8	4.2	3.4	2.71	1.4	1.38	.37	.16	0	.082	.037	N.M.	N.M.	<30	65

Unit-Area 11, New Quebec (NTS 33NE)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
6	32	6	98.7	51.8	17.7	3.3	6.2	5.6	7.9	3.5	1.02	1.3	1.22	.27	.14	0	.029	.067	N.M.	N.M.	<30	67
7	7980	103	99.2	65.1	15.6	1.7	3.0	2.8	3.5	3.9	2.38	.9	.46	.20	.08	.20	.064	.043	1.5	12.0	N.D.	80
9	13475	128	98.5	63.4	15.9	2.2	2.6	3.3	3.3	3.8	3.60	.9	.55	.21	.08	.20	.094	.051	1.0	13.4	N.D.	48
Av. A(6,7,9)	21487	237		64.0	15.8	2.0	2.8	3.1	3.3	3.9	3.14	.9	.52	.21	.08	.20	.083	.048	1.2	12.9	—	60
2B		4	98.8	66.5	11.6	3.6	.1	5.5	2.9	2.8	3.41	1.3	.42	.10	.10	1.52	.048	.011	N.M.	N.M.	N.D.	N.D.
12B		7	99.7	50.8	13.7	1.8	8.3	8.9	9.0	2.3	1.05	2.5	1.05	.19	.19	.10	.030	.027	N.M.	N.M.	160	330

Unit-Area 12, New Quebec (NTS 23NW)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
1	47	21	98.1	49.6	10.4	3.4	7.0	15.3	6.6	1.5	.82	4.0	.61	.13	.18	.41	.018	.020	0.5	1.9	760	920
6	931	14	98.7	62.5	15.7	.9	4.9	3.2	3.5	4.4	2.83	1.1	.66	.16	.09	0	.056	.037	N.M.	N.M.	100	240
7	8452	72	100.4	65.0	16.3	1.3	3.2	3.0	3.5	3.8	2.32	.8	.46	.19	.09	.10	.056	.041	1.2	7.0	<30	180
8	5674	60	99.3	65.8	17.5	1.4	2.8	1.3	2.5	3.8	3.50	.7	.38	.21	.03	0	.076	.041	0.8	8.5	N.D.	160
9	5997	63	97.6	67.5	15.4	1.2	2.3	2.1	2.4	3.8	4.04	.8	.41	.16	.06	0	.079	.038	0.8	11.7	N.D.	130
Av. A(1,6,7,8,9)	21101	230		65.6	16.3	1.3	2.9	2.3	2.9	3.8	3.14	.8	.43	.19	.07	.10	.068	.040	1.0	8.8	—	165
Av. B(1,6,7,9)				65.7	15.9	1.2	2.9	2.7	3.0	3.8	3.01	.8	.45	.18	.08	.10	.065	.040	1.0	8.9	—	167
2B		7	100.3	96.7	1.7	0	.1	0	.2	.1	.60	.4	.05	.02	.02	.10	.011	.003	N.M.	N.M.	N.D.	N.D.
12B		8	98.9	50.7	13.3	3.1	9.0	8.0	9.1	2.5	.71	1.7	1.25	.20	.19	.10	.018	.020	N.M.	N.M.	150	260

TABLE 2 *Analyses of rock units and average composition by unit-areas, New Quebec (conc.)*

Unit-Area 13, New Quebec (NTS 33SW)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
1	527	17	98.9	60.3	13.9	1.4	5.8	4.5	6.0	2.7	.95	2.0	.76	.13	.13	1.41	.018	.019	0.5	2.4	100	190
5	1267	8	100.3	68.9	17.1	.6	2.2	1.3	2.0	3.4	3.10	.8	.32	.10	.05	.20	.045	.027	N.M.	N.M.	N.D.	60
6	38	6	97.8	63.5	14.7	1.0	2.8	5.9	5.2	3.8	1.17	1.3	.38	.08	.07	0	.027	.037	N.M.	N.M.	150	380
7	6136	40	99.6	64.3	17.3	1.7	2.6	1.9	3.8	4.4	2.37	.9	.46	.19	.08	0	.084	.060	1.0	5.1	<30	44
9	967	11	97.8	64.1	16.1	1.8	2.8	1.7	4.5	4.4	3.14	.7	.45	.22	.09	0	.090	.077	N.M.	N.M.	N.D.	130
10	13	2	99.7	74.3	14.4	0	.3	.8	1.3	4.7	3.61	.3	.09	.05	0	.10	.014	.030	N.M.	N.M.	N.D.	N.D.
Av. A(1,5,6,7,9,10)	8948	84		64.8	16.9	1.5	2.7	2.0	3.7	4.1	2.48	.9	.45	.18	.08	.10	.075	.055	1.0	4.9	<30	65
2B		8	97.8	92.1	3.8	.3	.1	1.2	.3	.1	.84	.9	.12	.06	0	.10	.005	.005	N.M.	N.M.	N.D.	N.D.
12B		5	98.1	49.7	15.1	2.9	8.1	6.8	9.3	3.2	.84	2.5	1.33	.19	.14	.10	.030	.030	N.M.	N.M.	<30	130

Unit-Area 14, New Quebec (NTS 33SE)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
1	688	44	99.6	52.5	14.5	2.4	7.5	7.8	8.6	2.4	.78	2.0	.76	.15	.19	.30	.027	.020	1.1	2.7	190	380
5	12522	118	98.8	66.3	16.1	1.0	2.9	2.2	2.7	3.9	2.75	1.0	.39	.16	.07	.40	.069	.041	2.1	11.1	N.D.	170
6	545	24	99.0	55.8	15.8	2.5	6.4	5.4	6.6	3.3	1.32	1.7	.75	.16	.16	.20	.036	.028	0.7	2.6	110	240
7	5955	70	98.7	64.4	15.2	1.1	2.6	3.2	3.4	5.8	2.23	1.0	.47	.18	.08	.20	.052	.042	1.3	6.8	<30	120
8	58	1	100.6	64.6	16.1	.7	4.1	4.0	3.2	4.2	1.45	.8	.44	.27	.12	.10	.028	.034	N.M.	N.M.	66	160
9	1988	21	98.9	72.2	15.0	.7	.9	.6	1.5	3.9	4.00	.7	.22	.08	.04	.10	.056	.025	2.8	12.5	N.D.	N.D.
10	792	10	98.3	70.2	15.8	.7	1.2	.6	2.2	4.5	3.25	.7	.28	.15	.08	.31	.064	.042	N.M.	N.M.	N.D.	N.D.
Av. A(1,5,6,7,8,9,10)	22548	288		65.8	15.7	1.1	2.8	2.5	3.0	4.3	2.65	1.0	.42	.16	.08	.30	.061	.039	1.9	9.9	18	140
Av. B(1,5,6,7,9,10)				65.8	15.7	1.1	2.8	2.5	3.0	4.3	2.65	1.0	.42	.16	.08	.30	.061	.039	1.9	9.9	17	140
2B		10	97.7	92.3	3.9	.5	.1	.5	.3	.4	1.18	.6	.10	.02	.02	0	.012	.005	N.M.	N.M.	N.D.	N.D.
12A		2	99.1	42.0	6.2	2.4	8.2	34.1	2.4	.1	0	3.7	.40	.18	.19	.10	.003	.025	N.M.	N.M.	1500	1700
12B		8	98.6	49.2	14.8	3.9	9.0	5.0	8.2	3.5	1.26	2.3	1.73	.36	.19	.51	.045	.030	N.M.	N.M.	<30	130

Unit-Area 15, New Quebec (NTS 23SW)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	$H_2O(T)$	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
1	136	21	98.6	48.3	12.8	2.0	10.1	11.2	9.4	1.6	.28	2.8	.97	.15	.28	0	.006	.011	0.3	0.8	410	670
5	1168	13	99.4	63.3	16.0	.9	3.7	1.7	3.7	2.9	2.55	3.9	.59	.19	.08	.40	.064	.037	N.M.	N.M.	89	190
6	417	11	99.1	63.9	14.6	1.1	4.4	4.2	4.6	2.9	2.25	1.2	.43	.11	.09	0	.052	.028	N.M.	N.M.	150	280
7	6998	96	98.5	66.7	16.4	.5	2.9	2.0	2.7	4.1	2.92	.9	.41	.15	.09	.10	.064	.040	2.9	9.6	N.D.	100
8	5380	101	98.0	64.8	16.8	1.1	3.6	2.2	2.9	3.9	3.07	.7	.55	.18	.08	.10	.079	.045	1.3	10.7	<30	98
9	4180	35	101.1	68.4	16.1	1.0	1.7	1.6	2.3	3.8	3.74	.7	.44	.19	.06	.10	.100	.043	1.4	9.4	N.D.	N.D.
Av. A(1,5,6,7,8,9)	18279	277		66.2	16.4	.8	2.9	2.1	2.8	3.8	3.10	1.0	.47	.17	.08	.10	.076	.042	2.0	9.8	21	90
Av. B(1,5,6,7,9)				66.7	16.2	.7	2.7	2.0	2.8	3.8	3.11	1.1	.44	.17	.08	.12	.075	.040	2.3	9.3	17	87
2B		25	98.7	91.2	5.4	0	.1	0	.3	.5	1.57	.7	.10	.05	.02	.10	.022	.005	N.M.	N.M.	N.D.	N.D.
2D		6	98.2	33.1	0	.7	2.9	13.4	21.5	.1	.05	.5	.02	.05	.20	27.39	.006	.008	N.M.	N.M.	N.D.	N.D.
5A	349	10	99.2	62.0	17.5	.8	4.6	3.0	2.5	2.8	4.04	1.2	.87	.31	.08	.20	.120	.031	N.M.	N.M.	N.D.	47
7B	1528	38	98.4	59.7	17.2	1.5	4.1	3.7	4.9	3.8	2.94	.9	.73	.24	.11	.31	.120	.048	1.3	6.6	<30	44
12A		9	98.9	49.0	13.3	1.6	6.6	15.1	9.6	1.7	.23	1.7	.75	.10	.14	.10	.011	.019	N.M.	N.M.	600	810
12B		7	98.7	49.1	16.9	.5	9.1	8.2	10.1	2.4	.43	1.7	1.01	.10	.17	.10	.012	.026	N.M.	N.M.	180	140
12C		21	98.1	47.8	15.7	2.9	8.5	7.7	8.2	3.2	.60	3.2	1.79	.18	.16	.20	.018	.024	N.M.	N.M.	89	150
12D	134	7	97.8	58.6	17.5	.7	6.3	2.3	4.9	3.9	3.33	.4	1.33	.44	.14	.10	.150	.041	N.M.	N.M.	N.D.	120
Av. 15′ Grenville only (7b,5a,12)	2011	55		60.0	17.2	1.4	4.3	3.5	4.5	3.6	3.16	.9	.79	.27	.11	.03	.122	.045	1.3	6.6	<20	49

Average Composition, all of New Quebec

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	$H_2O(T)$	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
Average, all rocks (excluding cratonic cover rocks and dyke rocks)	64.9	16.2	1.5	3.0	2.3	3.3	4.1	2.80	.8	.49	.16	.08	.20	.073	.039	1.2	9.7	22	94

TABLE 3 | *Analyses of rock units and average compositions, Battle Harbour–Cartwright (NTS 13SE)*

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr	ppm V	ppm Co
4	70	18	98.2	56.3	19.3	1.6	4.1	2.9	5.9	3.8	3.32	1.4	.82	.21	.14	.10	.110	.038	N.M.	N.M.	76	<30	N.M.	N.M.
5	1148	108	99.2	63.3	15.9	2.8	4.2	1.7	3.6	3.0	3.24	.8	.91	.19	.12	.10	.072	.027	1.4	8.6	N.D.	57	N.M.	N.M.
7	9004	204	100.1	66.2	16.4	1.8	2.8	2.3	2.8	2.1	3.70	.8	.66	.19	.10	.20	.079	.030	1.4	9.6	N.D.	47	N.M.	N.M.
9	6506	76	101.2	65.9	16.1	2.4	2.1	1.8	1.8	3.9	4.35	.6	.70	.20	.09	.10	.150	.038	1.4	15.0	N.D.	N.D.	<70	N.D.
10	1194	69	98.3	57.9	18.7	1.9	4.5	1.9	4.1	4.9	4.02	.5	.99	.41	.13	.10	.170	.017	0.7	3.7	N.D.	<30	<70	<20
11	2444	52	97.7	53.6	23.1	1.3	4.1	1.4	6.5	4.9	2.84	.6	.77	.31	.10	.41	.130	.063	0.3	1.2	N.D.	N.D.	<70	<20
12	1389	79	97.6	49.7	18.2	2.1	6.8	8.1	9.4	2.9	.89	.9	.79	.10	.14	.01	.036	.038	0.3	1.0	170	220	130	50
Av. A(All Units)	21755	606		63.2	17.2	2.0	3.1	2.3	3.4	3.2	3.63	.7	.72	.20	.10	.20	.108	.037	1.2	8.9	11	38	—	—
Av. B(4,5,7,9)				65.8	16.2	2.1	2.6	2.1	2.5	2.9	3.92	.7	.70	.20	.10	.20	.106	.033	1.4	11.6	—	<30	—	—
Av. C(10,11,12)				53.6	20.7	1.6	4.9	3.4	6.6	4.4	2.60	.7	.83	.28	.12	.20	.114	.052	0.4	1.7	46	67	86	29

TABLE 4 Analyses of rock units and average composition, by unit-areas, northern District of Keewatin

Unit-Area 1, Northern District of Keewatin (NTS 57SW)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr	ppm V	ppm Co
4	425	18	98.6	58.8	17.0	1.4	6.7	3.5	4.4	3.3	2.68	1.1	.74	.10	.12	0	.062	.037	N.M.	N.M.	<30	92	170	<20
5	187	4	97.9	59.6	17.9	1.0	5.4	3.8	4.8	3.7	2.25	.6	.67	.10	.12	.10	.057	.035	N.M.	N.M.	<30	100	89	<20
6	205	6	98.5	61.7	17.5	1.3	3.9	2.3	4.8	4.8	2.28	.7	.54	.20	.09	0	.083	.048	N.M.	N.M.	N.D.	83	<70	N.D.
7	2452	48	98.3	66.1	16.0	.9	3.4	1.5	2.9	3.5	4.13	.8	.55	.20	.08	0	.073	.036	2.7	18.8	N.D.	<30	<70	<20
9	909	11	100.0	66.9	16.4	1.2	2.8	1.0	2.8	4.3	3.45	.4	.49	.20	.10	0	.094	.045	N.M.	N.M.	N.D.	N.D.	<70	<20
12		2	98.3	39.5	7.6	10.3	15.1	11.2	11.3	1.2	.50	1.0	2.03	.10	.24	0	.007	.009	N.M.	N.M.	120	120	1000	110
12B		1	98.3	42.9	14.1	1.8	14.5	5.8	6.5	1.6	.72	5.1	3.29	.61	.47	2.54	.010	.014	N.M.	N.M.	<30	<30	260	66
Av. A(4,5,6,7,9)	4178	87		65.1	16.3	1.0	3.7	1.7	3.1	3.7	3.66	.7	.56	.20	.09	.01	.076	.039	2.7	18.8	—	35	80	<20

Unit-Area 2, Northern District of Keewatin (NTS 57SE, W½)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr	ppm V	ppm Co
2B	8	5	98.1	60.4	3.6	0	1.7	8.8	12.6	.7	.98	2.3	.21	0	.05	8.56	.014	.012	N.M.	N.M.	N.D.	<30	N.D.	N.D
4	384	4	99.2	57.4	15.7	1.7	5.1	5.5	7.4	3.4	1.57	.9	.77	.40	.14	0	.049	.051	N.M.	N.M.	68	90	130	<20
5	691	12	100.1	61.7	12.6	2.6	6.0	5.1	5.3	2.9	1.79	.8	.80	.20	.16	.10	.028	.013	N.M.	N.M.	100	160	110	<20
6	745	21	99.3	61.1	15.7	1.1	6.3	4.2	3.2	3.6	2.85	.9	.62	.10	.12	.10	.071	.039	N.M.	N.M.	90	150	120	<20
7	3456	29	99.8	65.3	16.1	1.7	2.9	1.8	2.8	3.8	3.81	.8	.64	.20	.08	0	.075	.031	2.5	14.8	N.D.	<30	<70	<20
9	230	2	99.6	63.5	16.6	1.1	5.1	2.4	1.8	3.6	4.27	.9	.61	0	.07	0	.030	.015	N.M.	N.M.	<30	120	<70	<20
12		1	101.4	45.7	11.3	6.3	11.3	8.0	10.7	3.5	.64	1.0	1.16	.10	.23	0	.005	.008	N.M.	N.M.	80	170	640	59
12B		2	101.4	51.5	14.2	2.8	10.4	3.9	6.7	2.6	2.38	1.5	2.83	.99	.19	.10	.140	.039	N.M.	N.M.	<30	<30	200	48
Av. A(2B,4,5,6,7,9)	5514	73		63.7	15.7	1.7	4.0	2.8	3.4	3.6	3.29	.8	.66	.20	.10	.03	.065	.031	2.5	14.8	31	70	80	<20

Unit-Area 3, Northern District of Keewatin (NTS 66NE)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr	ppm V	ppm Co
2	148	8	98.4	70.2	4.9	.2	1.1	1.5	10.9	1.8	1.69	.8	.15	0	.07	6.61	.021	.012	N.M.	N.M.	N.D.	<30	N.D.	N.D.
4	307	6	98.6	62.5	18.3	.2	4.6	1.5	2.6	3.7	5.02	.7	.58	.20	.06	.10	.017	.030	N.M.	N.M.	N.D.	<30	<70	N.D.
6	3098	70	99.9	64.2	16.2	.6	4.3	2.7	3.8	3.2	3.38	.6	.64	.20	.08	.10	.084	.030	1.3	11.5	N.D.	<30	110	N.D.
7	5752	106	99.1	66.3	15.5	1.0	3.5	1.3	3.2	3.6	3.64	.9	.54	.20	.07	.10	.085	.035	2.3	15.0	N.D.	<30	<70	N.D.
9	2189	38	98.9	66.1	16.4	.7	3.2	1.6	2.9	3.4	3.95	.8	.60	.20	.07	0	.100	.036	2.9	14.8	N.D.	N.D.	<70	N.D.
12	26	7	98.5	49.9	16.0	2.9	9.3	5.9	8.1	2.9	1.42	1.7	1.34	.20	.16	0	.033	.046	N.M.	N.M.	<30	34	330	380
Av. A(2,4,6,7,9)	11494	228		65.6	15.8	.8	3.7	1.8	3.4	3.4	3.64	.8	.57	.20	.07	.10	.085	.034	2.1	14.0	—	<30	80	—

TABLE 4 | *Analyses of rock units and average composition, by unit-areas, northern District of Keewatin (conc.)*

Unit-Area 4, Northern District of Keewatin (NTS 56NW)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	$H_2O(T)$	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr	ppm V	ppm Co
2	1	1	100.8	98.7	.5	0	0	0	.2	.1	.20	.2	.09	0	0	0	.005	N.D.	N.M.	N.M.	N.D.	N.D.	N.D.	N.D.
2B	8	6	98.6	83.3	7.2	.4	3.0	.7	1.1	2.0	1.30	.5	.27	0	.14	0	.034	.012	N.M.	N.M.	N.D.	N.D.	N.D.	N.D.
3	371	58	96.9	63.4	11.6	.6	3.0	4.4	5.6	1.5	3.23	1.5	.46	.10	.09	4.65	.055	.013	N.M.	N.M.	<30	<30	85	<20
4	2094	83	99.8	62.0	14.4	2.1	6.6	3.6	3.3	3.2	2.16	1.3	.54	.10	.17	.40	.042	.020	2.1	7.7	110	190	120	<20
7	9876	172	98.0	67.5	15.1	.6	3.6	1.6	2.7	3.5	3.73	.9	.56	.20	.07	0	.067	.024	3.5	17.7	N.D.	<30	<70	N.D.
9	1633	35	97.7	65.3	17.0	.6	2.3	1.9	2.8	4.7	3.83	.8	.41	.20	.06	.10	.068	.032	2.8	10.1	N.D.	64	<70	N.D.
12A		22	101.5	45.2	6.6	5.8	12.5	18.2	3.6	.9	.24	4.8	.34	.10	.64	.98	.005	.011	N.M.	N.M.	1100	800	<70	66
12B		2	98.9	51.7	14.1	2.3	10.3	4.3	7.4	3.4	1.70	2.2	2.06	.30	.19	.10	.031	.030	N.M.	N.M.	56	37	250	61
Av. A(2,2B,3,4,7,9)	13983	355		66.3	15.1	.8	3.9	2.0	2.9	3.5	3.49	1.0	.54	.16	.08	.19	.063	.024	3.2	15.2	17	57	77	—

Unit-Area 5, Northern District of Keewatin (NTS 56NE, W½)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	$H_2O(T)$	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr	ppm V	ppm Co
2B	16	6	98.5	95.6	2.4	0	.1	0	.2	.1	.81	.6	.13	0	0	0	.023	<.002	N.M.	N.M.	N.D.	<30	N.D.	N.D.
4	2104	93	98.2	64.6	14.1	1.0	4.6	3.3	4.1	4.1	2.27	1.0	.62	.20	.10	0	.055	.028	1.4	8.2	65	<180	<70	<20
7	4291	75	98.3	68.2	15.5	.8	2.6	1.1	2.9	4.1	3.46	.6	.48	.20	.06	0	.073	.025	2.4	16.7	N.D.	<30	N.D.	N.D.
9	525	16	97.9	71.8	13.4	1.2	2.0	.7	1.8	3.8	3.70	.6	.58	.20	.05	.10	.086	.020	6.5	37.1	N.D.	N.D.	N.D.	N.D.
12A		18	97.9	45.5	7.1	2.5	7.5	22.4	7.5	1.1	.51	5.1	.56	0	.20	.10	.008	.007	N.M.	N.M.	1100	1100	150	90
12B		6	100.4	49.8	12.9	2.5	8.7	9.9	8.3	2.3	1.05	2.7	1.48	.20	.18	.10	.020	.021	N.M.	N.M.	400	500	260	71
Av. A(2B,4,7,9)	6936	190		67.4	14.9	.9	3.2	1.7	3.2	4.1	3.11	.7	.53	.20	.07	.01	.069	.025	2.4	15.7	20	73	—	—

Average Compositions, all of Northern District of Keewatin

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	$H_2O(T)$	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr	ppm V	ppm Co
Average all rocks	65.8	15.5	.9	3.7	2.0	3.2	3.6	3.46	.8	.56	.19	.08	.10	.071	.029	2.6	15.1	13	52	<70	—

TABLE 5

Analyses of rock units and average composition, Fort Enterprise (NTS 86A)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
1	104	12	99.9	53.1	11.5	.8	7.3	4.1	13.6	2.3	1.12	.9	.66	.07	.41	4.11	.020	.017	N.M.	N.M.	190	340
2A	21	1	100.6	60.2	13.4	1.6	8.9	3.0	7.9	1.2	.64	1.3	.87	.09	.40	.40	.012	.010	N.M.	N.M.	110	100
5	209	12	101.8	61.1	16.3	2.5	6.3	3.6	3.7	2.3	1.91	1.1	.83	.07	.13	.10	.037	.017	N.M.	N.M.	60	88
7	1926	57	99.7	59.2	15.1	2.6	5.8	3.9	5.5	3.5	2.15	.9	.97	.13	.14	.10	.036	.020	N.M.	N.M.	84	90
10	1750	34	101.6	66.0	14.9	1.0	4.7	2.1	3.3	3.6	2.89	.6	.63	.19	.10	.10	.074	.022	1.7	8.4	66	97
Av. A (All Units)	4010	116		62.2	14.9	1.8	5.4	3.1	4.7	3.5	2.43	.8	.81	.15	.13	.20	.052	.021	1.7	8.4	78	100

TABLE 6

Analyses of rock units and average composition, Snowbird Lake (NTS 65D)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	pp Cr
1	256	19	99.7	52.1	15.7	1.7	9.1	6.1	8.8	2.3	.53	1.8	1.07	.08	.21	.40	.009	.013	0.1	0.8	96	98
1A	3	2	100.5	75.7	14.5	.1	1.1	0	2.7	3.2	1.28	.6	.41	.08	.08	.20	.028	.016	N.M.	N.M.	N.D.	N.D.
2	424	14	102.3	62.2	16.1	1.8	6.0	4.6	3.7	2.1	1.70	.9	.61	.10	.14	.10	.043	.021	1.4	8.1	52	78
2A	4	1	101.0	30.2	4.9	1.6	.5	11.1	20.8	1.5	2.33	.7	.12	1.29	.10	24.96	.058	.100	N.M.	N.M.	41	N.D.
2B	106	23	100.5	53.7	12.4	1.2	4.2	5.7	8.6	3.5	1.43	1.2	.50	.10	.12	7.37	.028	.015	N.M.	N.M.	N.D.	87
3	139	7	99.6	54.4	16.0	3.4	8.2	3.7	8.2	3.0	.84	.6	1.10	.15	.21	.10	.024	.021	N.M.	N.M.	94	74
4	29	22	100.4	51.7	15.5	1.9	8.4	8.0	9.5	1.8	.69	1.2	1.00	.11	.19	.10	.026	.020	0.2	1.4	210	26
5	1026	27	100.5	63.4	16.1	.9	4.8	2.5	3.7	3.7	3.15	.6	.82	.22	.09	.10	.082	.031	1.2	12.4	N.D.	52
7	1074	27	101.5	65.5	15.6	1.8	3.8	1.4	3.5	4.1	2.90	.4	.67	.15	.09	.10	.086	.030	0.8	11.1	N.D.	N.D.
9	734	18	100.1	69.9	15.8	1.0	1.4	1.0	1.8	4.4	3.99	.3	.32	.09	.03	0	.008	.024	3.5	17.9	N.D.	N.D.
12	47	13	99.1	56.0	20.9	1.1	5.3	3.0	7.9	2.9	1.05	.8	.48	.11	.11	.30	.041	.035	0.4	4.2	57	59
Av. A (All Units)	3842	173		63.6	15.8	1.4	4.5	2.6	4.0	3.7	2.73	.6	.67	.14	.10	.30	.055	.026	1.5	11.6	18	38
Av. B(1,2,3,4,5,7,9,12)	3729	147		63.9	15.9	1.4	4.5	2.5	3.9	3.7	2.77	.6	.67	.15	.10	.10	.056	.027	1.5	11.6	20	36

TABLE 7 Analyses of rock units and average composition, Kasmere Lake (NTS 64N)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
2B	234	35	99.5	71.1	13.7	1.7	1.7	1.3	2.1	4.2	3.38	.1	.47	.10	.08	.10	.050	.010	3.4	30.3	N.D.	40
2C	195	29	99.4	66.8	15.3	1.4	2.7	2.1	2.7	3.9	3.06	.6	.50	.13	.07	.70	.034	.009	2.3	15.0	60	67
2D	16	10	97.7	53.9	10.0	.5	1.5	7.6	10.6	3.8	.95	.7	.48	.08	.03	9.62	.009	.003	N.M.	N.M.	N.D.	59
5	114	83	101.3	65.3	15.2	1.0	3.9	3.0	3.4	2.9	3.30	.8	.53	.13	.12	.59	.043	.009	3.8	17.3	N.D.	59
7	809	193	101.8	68.1	15.9	1.3	2.3	1.8	3.3	2.9	3.38	.2	.44	.11	.10	.29	.046	.015	2.9	15.8	N.D.	52
9	933	114	97.5	71.8	15.3	.7	1.9	.7	1.6	3.1	4.04	.2	.38	.10	.06	.01	.051	.015	2.8	16.2	N.D.	N.D.
10	912	78	102.3	73.0	14.3	1.0	1.3	1.6	1.2	2.3	4.63	.3	.28	.06	.04	.10	.055	.010	4.9	42.2	<20	28
Av. A(All Units)	3213	542		70.6	15.1	1.1	1.9	1.5	2.1	2.9	3.90	.3	.39	.09	.07	.10	.049	.012	3.5	24.5	—	30

TABLE 8 Analyses of rock units and average composition, Hardisty Lake (NTS 86C, W½)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr
1B	157	14	102.0	69.8	14.0	1.7	2.2	1.2	1.8	3.1	4.55	.9	.60	.09	.08	.10	.049	.020	N.M.	N.M.	N.D.	65
6	2	2	98.9	54.7	18.2	1.1	4.9	7.5	3.5	1.7	4.65	2.9	.40	.10	.13	.20	.073	.018	N.M.	N.M.	79	53
9	1111	72	100.8	68.1	14.8	1.0	2.8	1.0	2.2	3.4	4.80	1.1	.60	.08	.08	.20	.068	.018	6.5	29.9	N.D.	43
10	344	20	100.6	71.4	14.3	1.3	2.0	1.0	1.3	2.9	4.61	.6	.40	.08	.07	.10	.042	.010	13.1	54.3	N.D.	N.D.
Av. A (1B, 6, 9, 10)	1614	108		68.9	14.6	1.1	2.6	1.0	2.0	3.3	4.74	1.0	.56	.08	.08	.20	.061	.016	8.1	35.7	—	36

TABLE 9 Analyses of rock units and average composition, Baie-Comeau (NTS 22F, part)

Unit	Sq. Miles	No. Specs.	Original Total	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm U	ppm Th	ppm Ni	ppm Cr	ppm V	ppm Co
5	273	19	99.0	64.2	16.4	1.2	3.3	1.3	3.4	4.5	3.07	.4	1.00	.40	.71	0	.076	.037	1.3	7.2	N.D.	<30	<70	<20
7	966	67	99.9	66.1	14.9	2.1	3.0	1.6	2.7	3.9	3.70	.7	.85	.30	.11	0	.055	.027	1.3	10.9	N.D.	<30	<70	<20
8	48	1	100.1	46.0	14.7	4.7	9.8	4.7	8.3	3.8	1.22	.8	3.75	1.90	.19	.20	.076	.078	N.M.	N.M.	N.D.	N.D.	180	49
9	199	9	97.7	65.4	16.2	1.3	3.5	.6	2.9	4.2	4.41	.4	.82	.20	.07	0	.110	.027	N.M.	N.M.	N.D.	<30	<70	<20
10	35	1	100.5	71.9	13.8	1.1	1.7	0	.9	2.9	6.91	.4	.21	0	.04	.10	.048	.007	N.M.	N.M.	N.D.	N.D.	N.D.	N.D.
11	65	4	98.1	53.1	19.7	1.1	5.9	5.3	7.7	3.8	1.17	.7	1.11	.20	.10	.10	.018	.019	N.M.	N.M.	130	100	120	40
12	15	2	97.9	47.2	12.0	.6	10.1	17.6	6.0	1.7	.41	3.4	.61	0	.16	.20	.013	.011	N.M.	N.M.	240	180	140	70
Av. A. (All Units)	1601	103		64.6	15.5	1.8	3.5	1.8	3.2	4.0	3.55	.6	.96	.30	.10	.01	.064	.029	1.3	10.1	—	<30	74	<20
Av. B (5, 7, 9, 10)				65.9	15.3	1.8	3.1	1.4	2.8	4.0	3.76	.6	.86	.30	.10	.01	.066	.029	1.3	10.1	—	<30	68	<20
Av. C (11, 12)				51.8	18.2	1.3	6.7	7.5	7.4	3.3	1.03	1.2	1.02	.20	.11	.10	.017	.017	N.M.	N.M.	150	115	124	46

TABLE 10 *Summary of average compositions, Tables 2 to 9 and Red Lake–Lansdowne House Area*

Sample Area	Unit-Area	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	$H_2O(T)$	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	Ni	Cr
New Quebec	1	63.8	16.9	1.3	3.1	2.5	3.6	4.2	2.72	.9	.53	.14	.06	.20	.064	.029	.0052	.0092
	2	64.4	16.9	1.3	3.2	2.2	3.9	4.2	2.27	.7	.56	.13	.08	.10	.059	.037	.0024	.0051
	3	64.3	16.3	1.3	3.0	2.3	4.3	4.7	1.89	.8	.48	.09	.08	.30	.058	.031	.0071	.0772
	4	62.2	16.7	1.7	3.6	3.1	4.6	4.0	2.37	.8	.53	.10	.10	.30	.087	.032	.0069	.0082
	5	64.1	17.0	2.0	3.1	1.9	3.6	4.4	2.52	.7	.55	.14	.08	.10	.069	.034	.0030	.0063
	6	66.5	14.6	1.5	3.3	2.3	4.0	4.2	2.25	.6	.53	.14	.08	.10	.078	.028	<.0030	.0052
	7	63.7	16.1	1.5	2.7	2.0	4.3	4.1	2.94	.8	.50	.19	.10	.90	.076	.037	<.0040	.0064
	8	65.2	16.9	1.3	2.8	1.7	3.2	4.3	2.92	.8	.49	.15	.07	.20	.070	.035	<.0020	.0044
	9	67.8	15.0	1.6	2.5	1.3	2.8	4.4	3.06	.8	.45	.17	.06	.10	.074	.039	—	.0036
	10	64.6	16.0	1.7	3.3	3.0	3.1	3.2	3.08	1.0	.48	.17	.07	.10	.071	.042	<.0010	.0040
	11	64.0	15.8	2.0	2.8	3.1	3.3	3.9	3.14	.9	.52	.21	.08	.20	.083	.048	—	.0060
	12	65.6	16.3	1.3	2.9	2.3	2.9	3.8	3.14	.8	.43	.19	.07	.10	.068	.040	—	.0165
	13	64.8	16.9	1.5	2.7	2.0	3.7	4.1	2.48	.9	.45	.18	.08	.10	.075	.055	<.0030	.0065
	14	65.8	15.7	1.1	2.8	2.5	3.0	4.3	2.65	1.0	.42	.16	.08	.30	.061	.039	<.0018	.0140
	15	66.2	16.4	.8	2.9	2.1	2.8	3.8	3.10	1.0	.47	.17	.08	.10	.076	.042	.0021	.0090
New Quebec Average excluding Grenville		65.0	16.2	1.5	3.0	2.3	3.3	4.1	2.80	.8	.49	.16	.08	.20	.072	.039	.0022	.0095
Grenville 15′		60.0	17.2	1.4	4.3	3.5	4.5	3.6	3.16	.9	.79	.27	.11	.30	.122	.045	<.0020	.0049
New Quebec Average including Grenville		64.9	16.2	1.5	3.0	2.3	3.3	4.1	2.80	.8	.49	.16	.08	.20	.073	.039	.0022	.0094
Northern District of Keewatin	1	65.1	16.3	1.0	3.7	1.7	3.1	3.7	3.66	.7	.56	.20	.09	0	.076	.039	—	.0035
	2	63.7	15.7	1.7	4.0	2.8	3.4	3.6	3.29	.8	.66	.20	.10	0	.065	.031	.0031	.0070
	3	65.6	15.8	.8	3.7	1.8	3.4	3.4	3.64	.8	.57	.20	.07	.10	.085	.034	—	<.0030
	4	66.3	15.1	.8	3.9	2.0	2.9	3.5	3.49	1.0	.54	.16	.08	.20	.063	.024	.0017	.0057
	5	67.4	14.9	.9	3.2	1.7	3.2	4.1	3.11	.7	.53	.20	.07	0	.069	.025	.0020	<.0073
Northern District of Keewatin Average		68.5	15.5	.9	3.7	2.0	3.2	3.6	3.46	.8	.56	.19	.08	.10	.071	.029	.0013	.0052
Hardisty Lake		68.9	14.6	1.1	2.6	1.0	2.0	3.3	4.74	1.0	.56	.08	.08	.20	.061	.016	—	.0036
Fort Enterprise		62.2	14.9	1.8	5.4	3.1	4.7	3.5	2.43	.8	.81	.15	.13	.20	.052	.021	.0078	.010
Snowbird Lake		63.6	15.8	1.4	4.5	2.6	4.0	3.7	2.73	.6	.67	.14	.10	.30	.055	.026	—	.0038
Kasmere Lake		70.6	15.1	1.1	1.9	1.5	2.1	2.9	3.90	.3	.39	.09	.07	.10	.049	.012	—	.003
Baie-Comeau		64.6	15.5	1.8	3.5	1.8	3.2	4.0	3.55	.6	.96	.30	.10	.01	.064	.029	—	<.0030
Battle Harbour-Cartwright		63.2	17.2	2.0	3.1	2.3	3.4	3.2	3.63	.7	.72	.20	.10	.20	.108	.037	.0011	.0038
Red Lake—Lansdowne House		66.30	15.37	1.26	2.85	2.05	3.97	3.87	2.25	.87	.47	.13	.07	.15	.0649	.0515	.0022	.0054

TABLE 11

Average abundance of elements in crystalline rocks of the Canadian Shield

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm Ni	ppm Cr	ppm Th	ppm U	Th/U
Av. weighted as to size of nine samples areas	65.1	16.0	1.4	3.1	2.2	3.4	3.9	2.89	.8	.52	.16	.08	.20	.073	.038	20	77	10.8	1.5	7.2
Av. all nine areas weighted equally	65.9	15.6	1.4	3.4	2.1	3.3	3.6	3.28	.7	.63	.16	.08	.10	.066	.029	20	52	15.5	2.6	6.0
Average (Shaw *et al.* 1967)	64.93	14.63	1.36	2.75	2.24	4.12	3.46	3.10	.92	.52	.15	.068	1.28	.107	.034	23	99	10.3	2.45	4.2

TABLE 12

Average abundance of elements in crystalline rocks of the Canadian Shield, by structural provinces, and over-all average abundance, weighted according to size of structural province

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm Ni	ppm Cr	ppm Th	ppm U	Th/U
Bear Province (Hardisty Lake)	69.5	14.7	1.1	2.6	1.0	2.0	3.3	4.78	1.0	.56	.08	.08	.20	.061	.016	—	36	35.7	8.1	4.4
Slave Province (Fort Enterprise)	62.2	14.9	1.8	5.4	3.1	4.7	3.5	2.43	.8	.81	.15	.13	.20	.052	.021	78	100	8.4	1.7	4.9
Churchill Province (Snowbird Lake, Kasmere Lake, Northern Keewatin)	65.9	15.5	.9	3.6	2.0	3.2	3.6	3.43	.7	.56	.18	.08	.10	.068	.028	13	49	15.5	2.6	6.0
Superior Province (Red Lake-Lansdowne House, New Quebec-part)	65.2	16.0	1.5	3.0	2.3	3.4	4.1	2.70	.7	.49	.15	.08	.20	.071	.041	22	88	9.7*	1.2*	8.1*
Grenville Province (Battle Harbour-Cartwright, Baie-Comeau, New Quebec-part)	63.0	17.1	1.9	3.2	2.4	3.5	3.3	3.59	.7	.74	.21	.10	.20	.106	.037	12	39	8.8	1.2	7.3
Average Canadian Shield, weighted according to size of structural provinces	65.2	15.8	1.2	3.4	2.2	3.3	3.7	3.23	.8	.57	.17	.08	.20	.073	.032	18	59	13.0	2.1	6.2

*Does not include Red Lake–Lansdowne House.

TABLE 13 *Composition of amphibolite facies (a) and granulite facies (g) rocks, by unit-areas (1 to 15), New Quebec*

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	a	64.3	64.4	64.3	62.0	64.8	66.7	63.7	66.0	68.2	64.8	64.0	65.7	64.8	65.8	66.7
	g	57.4	65.2		63.0	61.8	65.9	61.7	62.6	63.7	63.2		65.8		64.6	64.8
Al_2O_3	a	16.8	16.9	16.3	16.5	16.8	14.5	16.1	16.8	14.8	16.2	15.8	15.9	16.9	15.7	16.2
	g	17.9	18.2		17.3	17.5	14.8	17.1	17.5	16.0	14.1		17.5		16.1	16.8
Fe_2O_3	a	1.3	1.3	1.3	1.7	1.9	1.5	1.5	1.3	1.5	1.8	2.0	1.2	1.5	1.1	.7
	g	1.4	.6		1.8	2.4	1.4	1.0	1.2	2.6	.2		1.4		.7	1.1
FeO	a	3.0	3.2	3.0	3.7	2.9	3.1	2.7	2.7	2.4	3.1	2.8	2.9	2.7	2.8	2.7
	g	5.0	3.1		3.6	3.6	3.7	4.4	3.2	3.3	5.1		2.8		4.1	3.6
MgO	a	2.4	2.3	2.3	3.2	1.7	2.3	2.0	1.5	1.3	2.7	3.1	2.7	2.0	2.5	2.0
	g	3.5	1.0		2.5	2.5	2.1	3.7	2.3	1.7	5.6		1.3		4.0	2.2
CaO	a	3.4	3.9	4.3	4.7	3.4	3.8	4.3	2.9	2.6	3.1	3.3	3.0	3.7	3.0	2.8
	g	5.9	3.7		4.2	4.3	4.4	4.6	4.4	4.0	4.4		2.5		3.2	2.9
Na_2O	a	4.2	4.2	4.7	4.0	4.4	4.2	4.1	4.3	4.4	3.3	3.9	3.8	4.1	4.3	3.8
	g	4.2	4.5		3.8	4.5	4.3	4.7	4.3	4.5	3.3		3.8		4.2	3.9
K_2O	a	2.75	2.28	1.89	2.37	2.70	2.45	2.97	3.04	3.15	3.16	3.14	3.01	2.48	2.65	3.11
	g	2.33	2.17		2.33	1.97	1.88	1.34	2.44	2.30	2.35		3.50		1.45	3.07
H_2O(total)	a	.9	.7	.8	.8	.7	.7	.8	.8	.8	1.0	.9	.8	.9	1.0	1.1
	g	.8	.6		.7	.6	.5	.6	.7	.6	1.1		.7		.8	.7
TiO_2	a	.50	.54	.48	.53	.51	.50	.50	.48	.42	.48	.52	.45	.45	.42	.44
	g	.90	.52		.52	.67	.58	.48	.51	.71	.47		.38		.44	.55
P_2O_5	a	.13	.13	.09	.10	.12	.10	.19	.15	.16	.17	.21	.18	.18	.16	.17
	g	.29	.21		.08	.19	.20	.13	.17	.31	.15		.21		.27	.18
MnO	a	.06	.08	.08	.11	.08	.07	.10	.07	.06	.07	.08	.08	.08	.08	.08
	g	.11	.08		.09	.09	.09	.11	.08	.06	.10		.03		.12	.08
CO_2	a	.20	.10	.30	.40	.10	.10	.91	.10	.10	.10	.20	.10	.10	.30	.12
	g	.20	.20		.10	.10	.20	.20	.60	.10	0		0		.10	.10
Ba	a	.063	.059	.058	.093	.067	.060	.077	.072	.074	.072	.083	.065	0.75	.061	.075
	g	.068	.065		.064	.077	.110	.046	.058	.075	.068		.076		.028	.079
Sr	a	.029	.036	.031	.031	.034	.029	.037	.033	.038	.041	.048	.040	.055	.039	.040
	g	.035	.050		.033	.047	.027	.040	.040	.044	.051		.041		.034	.045
Ni ppm	a	56	23	71	88	29	<30	<40	<20	—	—	—	—	<30	17	17
	g	—	<40		—	34	<30	40	<10	—	100		—		66	<30
Cr ppm	a	92	51	772	80	60	49	64	33	30	41	60	167	65	140	87
	g	100	43		88	71	60	200	88	38	31		160		160	98
Total Fe as FeO	a	4.2	4.4	4.2	5.2	4.6	4.4	4.0	3.9	3.7	4.7	4.6	4.0	4.0	3.8	3.3
	g	6.3	3.6		5.2	5.8	5.0	5.4	4.3	5.6	5.3		4.1		4.7	4.5
FeO/Fe_2O_3	a	2.3	2.5	2.3	2.2	1.5	2.1	1.8	2.1	1.6	1.7	1.4	2.4	1.8	2.5	3.9
	g	3.6	5.2		2.0	1.5	2.6	4.4	2.7	1.3	25.5		2.0		5.9	3.3

TABLE 14 *Average composition of amphibolite facies and granulite facies rocks, New Quebec*

	1	2	3		1	2	3
SiO_2	65.2	64.0	62.8	TiO_2	.47	.54	.6
Al_2O_3	16.1	16.8	16.1	P_2O_5	.16	.19	.1
Fe_2O_3	1.5	1.5	1.0	MnO	.08	.07	.1
FeO	2.9	3.5	5.22	CO_2	.20	.20	
MgO	2.3	2.2	3.5	Ba	.071	.077	
CaO	3.3	3.7	3.7	Sr	.039	.041	
Na_2O	4.1	4.1	3.5	Ni ppm	21	22	
K_2O	2.83	2.60	1.9	Cr ppm	97	88	
H_2O (total)	.9	.7	.76				

1. Average composition of all amphibolite facies rocks of the sample area, calculated from values in Table 3.
2. Average composition of all granulite facies rocks of the sample area, calculated from values in Table 3.
3. Intermediate granulite Seahorse Lake area, Mount Wright map-area, Quebec-Newfoundland (Roach and Duffell, 1968).

TABLE 15 *Average composition of Archean and Proterozoic rocks*

	PROTEROZOIC		MIXED PROTEROZOIC AND ARCHEAN				ARCHEAN			(10)	(11)
	(1)	(2)	(3)	(4)[1]	(5)	(6)	(7)	(8)	(9)	Proterozoic Average (Weighted average of 1,2,3,4,5,6)	Archean Average (Weighted average of 7,8,9)
	Hardisty Lake	Baie-Comeau	Kasmere Lake	Battle Harbour–Cartwright	Northern District Keewatin	Snowbird Lake	Fort Enterprise	Red Lake–Lansdowne House	New Quebec		
SiO_2	68.9	64.6	70.6	65.8	65.8	63.6	62.2	66.3	64.9	65.0	65.1
Al_2O_3	14.6	15.5	15.1	16.2	15.5	15.8	14.9	15.4	16.2	16.0	16.0
Fe_2O_3	1.1	1.8	1.1	2.1	.9	1.4	1.8	1.3	1.5	1.2	1.5
FeO	2.6	3.5	1.9	2.6	3.7	4.5	5.4	2.9	3.0	3.4	3.0
MgO	1.0	1.8	1.5	2.1	2.0	2.6	3.1	2.1	2.3	2.1	2.3
CaO	2.0	3.2	2.1	2.5	3.2	4.0	4.7	4.0	3.3[3]	3.3	3.4
Na_2O	3.3	4.0	2.9	2.9	3.6	3.7	3.5	3.9	4.1	3.5	4.1
K_2O	4.74	3.55	3.90	3.92	3.46	2.73	2.43	2.25	2.80	3.51	2.70
H_2O (total)	1.0	.6	.3	.7	.8	.6	.8	.9	.8	.7	.7
TiO_2	.56	.96	.39	.70	.56	.67	.81	.47	.49	.62	.50
P_2O_5	.08	.30	.09	.20	.19	.14	.15	.13	.16	.19	.15
MnO	.08	.10	.07	.10	.08	.10	.13	.07	.08	.09	.08
CO_2	.20	.0	.10	.20	.10	.30	.20	.10	.20	.10	.20
Ba	.061	.064	.049	.106	.071	.055	.052	.065	.073	.081	.079
Sr	.016	.029	.012	.033	.029	.026	.021	.052	.039	.031	.041
U ppm	8.1	1.3	3.5	1.4	2.6	1.5	1.7	N.A.	1.2	2.2	1.2[2]
Th ppm	35.7	10.1	24.5	11.6	15.1	11.6	8.4	N.A.	9.7	13.6	9.7[2]
Ni ppm	—	—	—	—	13	18	78	22	22	12	23
Cr ppm	36	<30	30	<30	52	38	100	54	94	45	88

[1] Average does not include anorthosite and related rocks.
[2] Does not include data from Red Lake–Lansdowne House area.
[3] Probably low; classical analysis of a composite representing a large part of this area gave 3.53 compared to 3.24 calculated from X.R.F. analyses.

TABLE 16 *Thorium, uranium and potassium concentrations in crystalline rocks of New Quebec*

	Unit Area	Th (ppm)	U (ppm)	K (per cent)	Th/U
Hornblende granulite facies	2	9.8	0.4	2.1	24.5
	4	5.7	0.6	1.8	9.5
	5	4.2	0.5	1.4	8.4
	6	4.1	0.6	1.6	6.8
	8	5.8	0.7	2.1	8.3
	12	8.5	0.8	2.9	10.6
	15	10.7	1.3	2.2	8.2
Average Th, U and K content of hornblende granulite facies of New Quebec		7.1	0.8	2.1	8.9
Amphibolite facies	1	10.1	0.9	2.3	11.2
	2	6.6	0.8	2.0	8.2
	3	6.2	0.4	1.6	15.5
	4	7.4	0.9	2.0	8.2
	5	7.8	0.9	2.3	8.8
	6	12.8	0.9	2.1	14.2
	7	11.8	1.5	2.7	7.9
	8	12.3	1.1	2.4	11.2
	9	13.4	1.2	2.9	10.8
	10	10.1	1.1	2.9	9.2
	11	12.9	1.2	2.0	10.8
	12	9.0	1.0	2.7	9.0
	13	4.9	1.0	2.2	4.9
	14	9.9	1.9	2.3	5.2
	15	9.2	2.3	2.8	4.0
Average Th, U and K content of amphibolite facies of New Quebec		9.9	1.3	2.4	7.4
Average Th, U and K content of all the rocks of the sample area		9.7	1.2	2.3	8.1

TABLE 17 | *Summary of Th, U, K concentrations from various sources*

	1	2	3	4	5	6	7
Th ppm	13.0	11.4±2	10.0	9.6	17.5	2.0	45.7
U ppm	2.1	3.0±0.6	2.8	2.7	2.0	0.4	10.3
K %	3.14	—	2.6	2.09	3.3	2.5	—

1. Average of all areas in this report, weighted according to area of structural provinces.
2. Average for continental crust, Adams *et al.* (1959).
3. Average for continental crust, Heir and Rogers (1963).
4. Average for continental crust, Taylor (1964).
5. Amphibolite facies rocks, southwest Australia, Lambert and Heier (1967).
6. Granulite facies rocks, southwest Australia, Lambert and Heier (1967).
7. Arithmetic mean of Rum Jungle Complex granites and gneisses, northern Australia, Heier and Rhodes (1966).

TABLE 18 Average composition of rocks of Unit 1

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm Ni	ppm Cr
Average, Unit 1, New Quebec	55.0	14.0	2.0	7.1	7.1	7.6	2.4	.81	2.2	.79	.14	.18	.70	.021	.019	195	352
Unit 1, Fort Enterprise	53.1	11.5	.8	7.3	4.1	13.6	2.3	1.12	.9	.66	.07	.41	4.11	.020	.017	190	340
Unit 1, Snowbird Lake	52.1	15.7	1.7	9.1	6.1	8.8	2.3	.53	1.8	1.07	.08	.21	.40	.009	.013	96	98
Average, all Unit 1	54.5	14.1	1.9	7.4	6.8	8.1	2.4	.79	2.1	.82	.13	.20	.90	.019	.018	180	314
Amphibolite facies greenstone, Yellowknife Belt (Boyle, 1961)	50.03	14.52	1.57	11.46	6.51	8.99	2.36	.66	1.84	1.12	.13	.21	.09				
Epidote amphibolite facies greenstone, Yellowknife Belt (Boyle, 1961)	50.45	13.96	2.00	9.61	6.53	10.23	1.85	.39	2.47	1.02	.13	.21	.68				
Average andesite (Nockolds, 1954)	54.20	17.17	3.48	5.49	4.36	7.92	3.67	1.11	.86	1.31	.28	.15					
Metavolcanic rocks, Red Lake—Lansdowne House (Reilly and Shaw, 1962)	52.63	14.33	2.30	8.04	6.41	9.14	2.44	.68	1.90	.88	.12	.18	.58	.0272	.0234	91	239

T=Total

TABLE 19 Average composition of rocks of Unit 5

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm Ni	ppm Cr
Average, Unit 5, New Quebec	66.3	16.2	1.0	2.9	2.1	2.7	3.8	2.76	1.2	.40	.16	.07	.40	.066	.039	—	161
Unit 5, Battle Harbour-Cartwright	63.3	15.9	2.8	4.2	1.7	3.6	3.0	3.24	.8	.91	.19	.12	.10	.072	.027	—	57
Average, Unit 5, Keewatin	61.2	13.7	2.3	5.9	4.8	5.2	3.1	1.89	.8	.77	.18	.15	.10	.034	.018	85	147
Unit 5, Fort Enterprise	61.1	16.3	2.5	6.3	3.6	3.7	2.3	1.91	1.1	.83	.07	.13	.10	.037	.017	60	88
Unit 5, Snowbird Lake	63.4	16.1	.9	4.8	2.5	3.7	3.7	3.15	.6	.82	.22	.09	.10	.082	.031	—	52
Unit 5, Kasmere Lake	65.3	15.2	1.0	3.9	3.0	3.4	2.9	3.30	.8	.53	.13	.12	.60	.043	.009	—	59
Unit 5, Baie-Comeau	64.2	16.4	1.2	3.3	1.3	3.4	4.5	3.07	.4	1.00	.40	.71	0	.076	.037	—	<30
Average, all Unit 5	65.6	16.1	1.2	3.3	2.2	2.9	3.7	2.77	1.1	.49	.17	.09	.30	.065	.036	—	143
Average, metasedimentary rocks, Red Lake— Lansdowne House, (Reilly and Shaw, 1967)	63.07	14.52	2.10	4.95	2.82	4.62	2.92	1.65	1.44	.54	.14	.11	.27	.039	.034	38	122

T=Total

TABLE 20 *Average composition of rocks of Unit 6*

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm Ni	ppm Cr
Average, Unit 6, New Quebec	60.5	15.6	1.5	5.4	4.1	4.8	3.7	2.22	1.3	.63	.15	.11	.10	.051	.033	111	238
Average, Unit 6, Northern Keewatin	63.5	16.2	.7	4.6	2.9	3.7	3.3	3.23	.7	.63	.18	.09	.10	.082	.033	17	55
Unit 6, Hardisty Lake	54.7	18.2	1.1	4.9	7.5	3.5	1.7	4.65	2.9	.40	.10	.13	.20	.073	.018	79	53
Average, all Unit 6	62.5	16.0	1.0	4.9	3.3	4.1	3.4	2.88	.9	.63	.17	.10	.10	.071	.033	49	117

TABLE 21 *Average composition of rocks of Unit 7*

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm Ni	ppm Cr
Average, Unit 7, New Quebec	65.0	16.2	1.5	3.2	2.2	3.5	4.2	2.52	.8	.47	.14	.08	.10	.066	.038	27	75
Unit 7, Battle Harbour-Cartwright	66.2	16.4	1.8	2.8	2.3	2.8	2.1	3.70	.8	.66	.19	.10	.20	.079	.030	N.D.	47
Average, Unit 7, Keewatin	66.9	15.5	.9	3.3	1.5	2.9	3.7	3.71	.8	.55	.20	.07	0	.073	.029	—	<30
Unit 7, Fort Enterprise	59.2	15.1	2.6	5.8	3.9	5.5	3.5	2.15	.9	.97	.13	.14	.10	.036	.020	84	90
Unit 7, Snowbird Lake	65.5	15.6	1.8	3.8	1.4	3.5	4.1	2.90	.4	.67	.15	.09	.10	.086	.030	N.D.	N.D.
Unit 7, Kasmere Lake	68.1	15.9	1.3	2.3	1.8	3.3	2.9	3.38	.2	.44	.11	.10	.30	.046	.015	N.D.	52
Unit 7, Baie-Comeau	66.1	14.9	2.1	3.0	1.6	2.7	3.9	3.70	.7	.85	.30	.11	0	.055	.027	N.D.	<30
Average, all Unit 7	65.4	16.0	1.4	3.2	2.1	3.4	3.9	2.84	.6	.51	.16	.08	.10	.068	.035	20	63
Paragneiss, *lit-par-lit* gneiss, migmatite, mixed rocks, hybrid granitic rocks with amphibolite inclusions, Red Lake—Lansdowne House (Reilly and Shaw, 1967)	66.73	15.83	1.25	2.97	1.86	3.63	3.84	1.75	.86	.52	.16	.07	.06	.051	.046	14	36
Average granodiorite (Nockolds, 1954)	66.88	15.66	1.33	2.59	1.57	3.56	3.84	3.07	.65	.57	.21	.07					

TABLE 22 Average composition of rocks of Unit 9

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm Ni	ppm Cr
Average, Unit 9, New Quebec	65.9	16.0	1.5	2.4	2.4	2.9	3.9	3.54	.8	.49	.18	.07	.10	.084	.041	<10	56
Unit 9, Battle Harbour-Cartwright	65.9	16.1	2.4	2.1	1.8	1.8	3.9	4.35	.6	.70	.20	.09	.10	.150	.038	N.D.	N.D.
Average, Unit 9, Keewatin	66.4	16.3	.8	2.8	1.5	2.7	4.0	3.82	.7	.52	.19	.07	—	.085	.034	—	24
Unit 9, Snowbird Lake	69.9	15.8	1.0	1.4	1.0	1.8	4.4	3.99	.3	.32	.09	.03	0	.008	.024	N.D.	N.D.
Unit 9, Kasmere Lake	71.8	15.3	.7	1.9	.7	1.6	3.1	4.04	.2	.38	.10	.06	0	.051	.015	N.D.	N.D.
Unit 9, Hardisty Lake	68.1	14.8	1.0	2.8	1.0	2.2	3.4	4.80	1.1	.60	.08	.08	.20	.068	.018	N.D.	43
Unit 9, Baie-Comeau	65.4	16.2	1.3	3.5	.6	2.9	4.2	4.41	.4	.82	.20	.07	0	.110	.027	N.D.	<30
Average, all Unit 9	66.1	16.0	1.5	2.4	2.2	2.7	3.9	3.69	.8	.51	.18	.07	.10	.089	.039	—	45
Foliated granodiorite, Red Lake—Lansdowne House area (Reilly and Shaw, 1967)	68.41	15.75	1.06	1.99	1.41	3.44	4.38	1.96	.70	.37	.11	.05	.07	.0606	.0645	8.7	16
Massive to slightly foliated granite, includes undivided granite rocks Red Lake—Lansdowne House (Reilly and Shaw, 1967)	69.85	15.67	.90	1.42	.95	2.67	4.28	2.78	.57	.29	.12	.03	.06	.0771	.0539	3.5	6.0

TABLE 23 Average composition of rocks of Unit 10

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O(T)	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm Ni	ppm Cr
Average, Unit 10, New Quebec	70.2	15.7	.7	1.2	.6	2.2	4.5	3.26	.7	.28	.15	.08	.30	.063	.042	—	—
Unit 10, Battle Harbour-Cartwright	57.9	18.7	1.9	4.5	1.9	4.1	4.9	4.02	.5	.99	.41	.13	.10	.170	.047	N.D.	<30
Unit 10, Fort Enterprise	66.0	14.9	1.0	4.7	2.1	3.3	3.6	2.89	.6	.63	.19	.10	.10	.074	.022	66	97
Unit 10, Kasmere Lake	73.0	14.3	1.0	1.3	1.6	1.2	2.3	4.63	.3	.28	.06	.04	.10	.055	.010	<20	28
Unit 10, Hardisty Lake	71.4	14.3	1.3	2.0	1.0	1.3	2.9	4.61	.6	.40	.08	.07	.10	.042	.010	N.D.	N.D.
Unit 10, Baie-Comeau	71.9	13.8	1.1	1.7	0	.9	2.9	6.91	.4	.21	0	.04	.10	.048	.007	N.D.	N.D.
Average, all Unit 10	66.4	15.8	1.2	3.3	1.6	2.8	3.8	3.68	.5	.58	.20	.09	.10	.089	.028	27	46
Average, modified Unit 10, omitting Battle Harbour-Cartwright	69.1	14.9	1.0	2.9	1.5	2.4	3.4	3.57	.5	.45	.14	.08	.10	.064	.022	35	51
Leucocratic, pink and white massive granite, Red Lake—Lansdowne House (Reilly and Shaw, 1967)	72.12	14.78	.76	.99	.55	1.84	3.89	3.79	.59	.21	.08	.03	.04	.0850	.0459	3.3	<4
Massive porphyritic granite (phenocrysts of potash feldspar) Red Lake—Lansdowne House (op. cit.)	67.97	15.57	1.14	1.63	1.07	2.95	4.09	3.65	.49	.44	.24	.05	.07	.1200	.0788	5.0	6.0
Average adamellite (Nockolds, 1954)	69.15	14.63	1.22	2.27	.99	2.45	3.35	4.58	.54	.56	.20	.06					
Average calc-alkali granite (op. cit.)	72.08	13.86	.86	1.67	.52	1.33	3.08	5.46	.53	.37	.18	.06					
Average alkali granite (op. cit.)	73.86	13.75	.78	1.13	.26	.72	3.51	5.13	.47	.20	.14	.05					
Average calc-alkali syenite (op. cit.)	59.41	17.12	2.19	2.83	2.02	4.06	3.92	6.53	.63	.83	.38	.08					

TABLE 24 | *Average composition of rocks of Unit 11*

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	$H_2O(T)$	TiO_2	P_2O_5	MnO	CO_2	Ba	Sr	ppm Ni	ppm Cr
Unit 11, Battle Harbour-Cartwright	53.6	23.1	1.3	4.1	1.4	6.5	4.9	2.84	.6	.77	.31	.10	.40	.130	.063	N.D.	N.D.
Unit 11, Baie-Comeau	53.1	19.7	1.1	5.9	5.3	7.7	3.8	1.17	.7	1.11	.20	.10	.10	.018	.019	130	100
Morin pluton, Quebec, anorthosite, gabbroic anorthosite, anorthositic gabbro; bulk composition (Papezik, 1965, p. 695)	53.21	23.31	1.73	2.88	2.59	9.75	4.20	.7	.61	.85	.08	.06	.75	.020	.070	9	54
Anorthosites, Michikamau Intrusion (Emslie, 1965, p. 394)	51.9	25.6	.6	.9	.7	9.2	5.5	.7	.9	.1	.03	<.01					
	53.6	24.5	1.4	2.0	<.5	9.0	5.4	.5	.4	1.2	.03	.04					
Marcy type anorthosite, core of Adirondack massif, average of 4 analyses (Buddington, 1939, p. 30)	54.54	25.61	1.00	1.26	1.03	9.92	4.58	1.01	.55	.67							
Anorthosite(in massifs) (Nockolds, 1954, p. 1020)	54.54	25.72	.83	1.46	.83	9.62	4.66	1.06	.63	.52	.11	.02					

NOTE: In the above tables N.M. = not measured; N.D. = not detected in spectrographic analyses; O indicates that none of the constituent was reported in major element analyses; values such as <30 indicate the presence of the element in amounts too small for precise determination by the spectrographic method used; the short dashed lines indicate that in averages calculated from two or more analyses of a constituent the constituent was present in measurable quantity in one or more of the contributing analyses but in the calculated average the value was below a significant level.