GEOLOGICAL
SURVEY
OF
CANADA

DEPARTMENT OF ENERGY,
MINES AND RESOURCES

BULLETIN 239

THE ALKALINE ROCKS OF CANADA

K. L. Currie

Ottawa
Canada
1976

rice, $8.00

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1,300-1975-6530-2

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Text printed on Georgian Offset, smooth (brilliant white)
Set in Times Roman with New Gothic Roman captions.

Artwork by CARTOGRAPHIC UNIT, GSC

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By
K. L. Currie

DEPARTMENT OF
ENERGY, MINES AND RESOURCES
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Price: $8.00 Catalogue No. M42-239

Price subject to change without notice

INFORMATION CANADA
OTTAWA, 1976

PREFACE

Although alkaline rocks have become somewhat ignored in the search for mineral deposits, a surprising variety of metals and industrial minerals are produced from them. Molybdenum, zirconium, copper, and apatite are currently being recovered from alkaline rocks, and they are also the major source of niobium, rare-earths, nepheline, barite, vermiculite, corundum, and diamond.

This report reviews alkaline rocks known in Canada and provides a description of the principal types, their geological setting, origin, and mineral potential. It is by means of such data that the Geological Survey meets one of its principal objectives, the preparation of estimates of the potential abundance and probable distribution of the mineral and fuel resources available to Canada.

D. J. McLaren,
Director, Geological Survey of Canada

Ottawa, September 13, 1973

CONTENTS

PAGE

Part I: INTRODUCTION TO THE ALKALINE ROCKS

CHAPTER I

CHAPTER II

Part II: DESCRIPTIONS OF THE ALKALINE ROCKS OF CANADA

CHAPTER III

CHAPTER IV

CHAPTER V

CHAPTER VI

CHAPTER VII

CHAPTER VIII

Illustrations

THE ALKALINE ROCKS OF CANADA

Abstract

In the introductory chapters the author discusses the classification and terminology of alkaline rocks, their occurrence and distribution in Canada, and their origin and economic significance.

The main part of the report is devoted to descriptions of the alkaline rocks of Canada as follows: alkaline basalt family, nephelinite-carbonatite family, carbonatite complexes lacking nephelinitic rocks, miaskitic syenite complexes, nepheline syenite gneiss complexes, and agpaitic syenite complexes.

Résumé

Dans les chapitres préliminaires, l'auteur traite de la classification et de la terminologie des roches alcalines, de leur présence et de leur répartition au Canada, de leur origine et de leur signification économique.

La partie principale du rapport est consacré à la description des roches alcalines du Canada sous les titres suivants: groupe du basalte alcalin, groupe des carbonatites néphélinitique, complexes de carbonatite syénitiques sans roches néphélinitiques, complexes de syénite miaskitique, complexes de gneiss à néphéline et complexes de syénite agpaitique.

PART I: INTRODUCTION TO THE ALKALINE ROCKS

Alkaline rocks have long held a peculiar fascination, out of all proportion to their volumetric importance, for both professional and amateur geologists. Explanation of their unique suite of rare minerals, often crystallized in spectacularly large and beautiful forms, and of their amazing diversity of chemical compositions strains or exceeds the bounds of present petrogenetic theories. Economically, these rocks are the major source of niobium, diamonds, and nepheline, and a significant source of iron, copper, molybdenum, rare-earths, zirconium, uranium, mica (vermiculite), barite, and apatite. They also represent a major potential source of aluminum, so far untapped except in the U.S.S.R.

Although the unusual appearance and mineralogy of alkaline rocks assure their recognition (excepting nepheline gneisses), and although many Canadian occurrences have been studied in some detail, basically, little is known about them. For example, how is the distribution of alkaline rocks related to other rock-types or to major geologic structures? How are the various types of alkaline rocks genetically related to one another? How do the trace element contents (and economic potential) of alkaline rocks vary with mineralogy and structure? Because much detail is known about small areas and relatively little about more general problems, a compilation of data should help to clarify some of the larger problems, if only to define them more precisely. The present work aims to supply such a compilation. Hopefully, it will also supply part of the data needed to relate the origin of alkaline rocks to larger concepts of geologic theory such as plate tectonics, and the origin of igneous rocks in general.

The data have been compiled mainly from published literature, written and oral communications from other geologists, and from the results of the author's own field and laboratory investigations. Mr. John Stirling conducted much of the literature search and made the drawings. Professor J. Gittins provided a number of references from his file on Canadian alkaline rocks. The interpretation of the data, however, is the responsibility of the author. In a study of this kind gaps and errors in the data are almost unavoidable. The author would be grateful if readers would call his attention to any errors or omissions that they may notice.

Chapter I

Classification and Terminology of Alkaline Rocks

Despite the impressive number of studies of alkaline rocks, almost all aspects of their origin and development remain debatable. The very definition of an alkaline rock is fraught with difficulty and controversy. A standard petrology text (Turner and Verhoogen, 1960, p. 194) suggests vaguely that ". . . rocks are usually considered alkaline when the content of (K_2O + Na_2O) is sufficiently high as compared to SiO_2 or Al_2O_3 for specifically alkaline (usually sodic) minerals such as feldspathoids and aegirine to appear. Feldspathoids are correlated with a high proportion of alkali with respect to silica; aegirine, aegirine-augite, and nonaluminous sodic amphiboles (riebeckite, arfvedsonite) express a high ratio of alkali to alumina." This 'definition' not only begs the question of when (K_2O + Na_2O)/SiO_2 is "high," and leaves unclear the position of glassy volcanic rocks that contain potential feldspathoids, but it lumps together at least three different suites of rocks of vastly different mineralogy, tectonic position, and differentiation trend. I propose the following definition:

> An alkaline rock is one that contains a feldspathoidal mineral either in the rock itself or in the chemical analysis recalculated into the C.I.P.W. norm.

"Feldspathoidal mineral" is to be understood in the extended sense as including nepheline, leucite, kaliophilite, kalsilite, melilite, analcite, and the cancrinite group, as well as feldspathoids in the mineralogical sense, namely sodalite, nosean, and hauyne. Corundum, although not a feldspathoidal mineral in the above sense, is very commonly associated with nepheline-bearing gneisses, for example in the Bancroft region of Ontario.

One of the three groups of rocks considered as alkaline by Turner and Verhoogen (1960) is not included in the present definition, namely those of normal alkali/silica ratio and high alkali/alumina ratio. Such rocks as riebeckite and arfvedsonite granite are fairly common on the Canadian Shield, but appear to have little relation to the silica-undersaturated alkaline rocks. I propose to term such rocks 'alkali,' for example *alkali granite*. A small group of alkali granites, of which only one Canadian example is known, at Blatchford Lake north of the East Arm of Great Slave Lake, contains typically alkaline minerals of high Na/Al ratio such as astrophyllite and enigmatite. Such granites may have some relation to undersaturated agpaitic alkaline rocks.

Alkaline rocks may not contain a modal feldspathoidal mineral even though one appears in the norm. Biotite, for example, in silica-undersaturated rocks produces nepheline or leucite in the norm, whereas titanaugite in basalt usually produces normative nepheline. According to a strict construction of the Turner–Verhoogen definition, such rocks are not alkaline, but the proposed definition clearly shows their alkaline character. The inverse problem of nonappearance of normative feldspathoid in modally alkaline rocks occurs

Original manuscript submitted: September 14, 1972.
Final version approved for publication: September 7, 1973.

occasionally. Some leucite-rich rocks show no normative feldspathoid, and may even show normative quartz (Irvine and Baragar, 1971, p. 530). If the normative analyses are projected onto some subsystem such as nepheline-olivine-quartz (Poldervaart, 1964; Irvine and Baragar, 1971), the proportion of quartz-normative analyses becomes even higher. This problem is of little practical significance, however, because such rocks are invariably associated with feldspathoid-bearing or feldspathoid-normative rocks. Hence if a number of analyses are available, either modal or chemical, an occurrence of alkaline rocks will be correctly identified even though some individual analyses may be misidentified.

Although alkaline rocks comprise less than 1 per cent of igneous rocks, almost one third of all rock names are of alkaline rocks—a total of more than 250. I propose to use a drastically simplified nomenclature; otherwise alkaline rocks cannot be discussed at all without the aid of a glossary. According to the principles first worked out in detail by Johannsen (1937) and most recently modified by Streckeisen (1967), an igneous rock can be named by its position in the double triangle quartz-alkali feldspar-plagioclase-feldspathoids, together with its content of mafic minerals. This scheme can also be applied to alkaline rocks despite difficulties caused by the appearance of different mineral assemblages in rocks of almost identical chemical composition crystallized under different physical conditions—a characteristic alkaline rocks share with metamorphic rocks. The scheme adopted in Table 1 is based on the feldspathoid index, or ratio of feldspathoids to feldspar plus feldspathoids, the potassium index, or ratio of potassic aluminosilicates to total aluminosilicates, and the colour index, or per cent of dark minerals. Alkaline rocks fall naturally into three groups: those in which feldspars are a major or dominant constituent; those that are deficient or lacking in feldspar but rich in feldspathoids; and the ultramafic alkaline rocks poor in both feldspar and feldspathoids. As shown in Table 1, the rocks in the first and third groups can generally be described by familiar names modified to show their alkaline character. Less familiar names are needed to describe the second group, but only 6 names are proposed. With a judicious choice of adjectives, 33 names can be made to cover almost all significant varieties of alkaline rocks. From a purely practical viewpoint, nepheline-rich gabbro, for example, will be recognized by many more persons than the alternative 'rouvillite.' The system of nomenclature outlined in Table 1 is therefore adopted in the hope that it simplifies and clarifies the nomenclature of alkaline rocks. The

TABLE 1 | *The nomenclature of the alkaline rocks*

I. *Feldspathoid index 0–50, colour index less than 90*

<table>
<tr><th rowspan="2">% An in plagioclase</th><th colspan="4">POTASH ALUMINOSILICATE/TOTAL ALUMINOSILICATE (%)</th></tr>
<tr><th>0–10</th><th>10–40</th><th>40–70</th><th>70–100</th></tr>
<tr><td rowspan="2">0–10</td><td>MARIUPOLITE</td><td>LITCHFIELDITE</td><td rowspan="3">MONZONITE
latite</td><td rowspan="3">SYENITE
trachyte</td></tr>
<tr><td colspan="2">phonolite</td></tr>
<tr><td>10–50</td><td>DIORITE
andesite</td><td>SYENODIORITE
trachyandesite</td></tr>
<tr><td rowspan="2">50–100</td><td rowspan="2">GABBRO (1)
basalt (2)</td><td rowspan="2">SYENOGABBRO
trachybasalt</td><td colspan="2">(VERY RARE)</td></tr>
<tr><td>vicoite</td><td>vulsinite</td></tr>
</table>

(1) Gabbro with colour index less than 90 may be called *anorthosite*
(2) Basalt with feldspathoid index over 10 may be called *basanite*

II. *Feldspathoid index 50–100, colour index less than 90*

POTASH ALUMINOSILICATE/TOTAL ALUMINOSILICATE (%)

Colour Index	0–50	50–100
0–30	URTITE leuconephelinite	ITALITE leucitite
30–60	IJOLITE nephelinite	FERGUSITE wyomingite
60–90	MELTEIGITE ankaratrite	MISSOURITE madupite

III. *Colour index greater than 90*

MAFIC MINERALS PRESENT IN AMOUNTS GREATER THAN 25%

	olivine	pyroxene	amphibole	mica	carbonate	melilite
olivine	dunite					
pyroxene	peridotite	pyroxenite				
amphibole		perknite	hornblendite			
mica				glimmerite		
carbonate	silico-carbonatite				carbonatite	
melilite				alnoite		melilitite

Rules of Nomenclature

(1) If the colour index is not used in selecting the name, add an appropriate prefix to specify C.I., namely leuco- if C.I. is less than 10, or mela- if C.I. is greater than 50, otherwise no prefix.

(2) Specify mafic minerals if unusual or genetically important, using the suffix -bearing if the amount is less than 25% of the volume of mafic minerals.

(3a) For rocks in Groups I and III, name major feldspathoid and establish amount. If feldspathoid occult, use 'alkaline,' if F.I. less than 10 use name of feldspathoid plus suffix -bearing, if F.I. is 10–35 use name of feldspathoid, if F.I. is 35–49 use name plus suffix -rich.

(3b) For rocks in Group II, name major feldspathoid only if it is *not* nepheline in sodic rocks, or leucite in potassic rocks.

(3c) In Groups I and II name the second feldspathoid, if any, and establish its amount (0–25% of feldspathoid use name plus suffix -bearing; 25–49%, use name plus suffix -rich).

(4) If only chemical data are available compute the CIPW norm (molecular), correct it according to the following rules, and use the norm to name the rock.

APPENDIX TO TABLE 1

Deriving a Modal Name from the CIPW Molecular Norm

In order to convert the CIPW molecular norm into a reasonable representation of an alkaline rock, one must (1) convert the nepheline to the Burger–Morozewicz composition, (2) remove LARNITE from the norm, (3) remove ILMENITE from the norm, and (4) redistribute the resulting 'excess' iron and alkalis. These objectives may be achieved as follows:

1. Convert normative LC to $\frac{1}{2}$(OR + KS). Adjust the NE/KS ratio to 3 by converting nepheline group minerals to feldspar according to OR + NE = KS + AB. (If 'excess' NE or KS appears, it may be handled in the following steps.)

2. Normative LA is due to modal titanaugite, or to melilite. If LA is less than IL, make titaniferous pyroxene (TP by LA + IL = TP + FeO). This will eliminate LA from basaltic rocks, but for others it is necessary to make normative melilite (as was done in the earliest CIPW norms) from a mixture of AKERMANITE (AK), GEHLENITE (GE), and NA-MELILITE (NM). This may be done in the following order: (a) LA + IL + $\frac{1}{2}$OL = AK + PE + FeO, (b) 7LA + 2AN + 3OL = 6AK + 2GE, (c) 2LA + AN = GE + 3WO, (d) LA + 2WO + OL = 2AK. Finally an amount of (NE +

$\frac{1}{3}$KS) = (AK + GE)/3 is combined with an equal amount of normative pyroxene and reported as NM.
3. (a) If NS is present in the norm, any remaining IL is reacted to make 2NS + IL + 2OR = 2AC + RA + 2KS where RA is an acronym for the agpaitic mineral ramsayite $Na_2Ti_2Si_2O_9$. Note that either AB or OR, or a mixture, may be used, depending on the requirements of step 1. (b) If NS is not present in the norm, IL is reacted with any WO in excess of DI by WO + IL = SP + FeO, and the remainder reacted by IL + NE + $1\frac{1}{2}$DI = TP + AC + CT where CT is an acronym for the calcium Tschermak's molecule $Ca_2Al_2SiO_6$. Note that this process will cause NE to disappear from some basaltic analyses, producing instead a sodic titanaugite. This is in accordance with observation.
4. It remains to distribute the FeO generated by conversion of IL. (a) NS is present: NS + 2FeO = AC (note that the oxygen balance is defective both here and in 3(a)). Divide any excess FeO/3, and report as MT. (b) Melilite is present; feldspar must be removed. Pool all unsilicated iron (includes FeO + MT + HM), and assume it to be ferrous, then go through the following reactions (i) AN + FeO = CT + FS, (ii) OR + 3FeO = BIOTITE, (iii) AB + $\frac{1}{2}$WO + FeO = CT + AC. Any remaining iron may be divided by 3 and reported as MT. (c) Neither NS nor melilite is present: if AC is less than TP, convert 2AB + WO + 2FeO = CT + 2AC until AC = TP. Now compute (KS + NE)/(AB + OR + AN). If this ratio is greater than 2, follow the same procedure as outlined in 3(b). If it is less than 2, the 'excess' FeO from IL is converted to BIOTITE by OR + 3FeO = BI, and any excess converted to AC by 2AB + WO + 2FeO = CT + 2AC.
5. Recalculated to 100 per cent, the modified norm may be used to name the rock from Table 1 by adding together NE + KS and setting them equal to nepheline, adding DI + CT + TP + AC and setting it equal to pyroxene, and by adding AK + GE + NM and setting it equal to melilite.

only name adopted that appears to conflict with established practice is *alkaline* basalt, in place of *alkali* basalt. There is an unfortunate conflict in the literature in the use of the terms 'alkali' and 'alkaline.' For acid rocks, alkali is consistently used for rocks with high alkali/alumina ratios that are saturated with silica. Alkaline seems to be generally accepted for all compositions as the appropriate descriptor for undersaturated rocks, as for example in the term 'alkaline rocks.' However, 'alkali basalt' is an entrenched term for basaltic rocks commonly showing normative nepheline, but no modal feldspathoid. To be consistent, such rocks should be called 'alkaline basalts,' the term 'alkali basalt' being reserved for (hypothetical) basaltic rocks containing sodic mafic minerals, but no normative nepheline. This usage is adopted here.

Among the names discarded for this report, the largest group is that of the lamprophyres. The terminology of these rocks is in a state of confusion, but the literature appears to agree that 'lamprophyre' is a textural term referring to a rock of porphyritic texture with mafic phenocrysts, and either lacking feldspar or containing it only in a finely granular matrix. Since texture is not considered in the nomenclature of Table 1, none of the names for lamprophyres is necessary. A considerable group of names attached to agpaitic rocks has been discarded as either redundant or attached to textural meanings. Finally, names referring to minerals present in accessory or even trace amounts have been discarded, since such minerals can be recognized by adding prefixes to the rock name. To relate the system of nomenclature adopted to other descriptions, a glossary of alkaline rock names and related terms is given in Appendix I.

The system of nomenclature adopted is based entirely on the modal composition of the rocks. Such a classification breaks down for glassy or severely altered rocks, which must be classified on chemical criteria. The norm classification, although useful to specify whether or not a rock is alkaline, is unsatisfactory for alkaline rocks because the normative compositions have no relation to modal compositions. Fortunately, relatively few alkaline rocks contain substantial amounts of glass. For those that do, a modification of the norm, which enables the rocks to be classified from Table 1, is suggested in an appendix to Table 1. Normative calculations are basically inapplicable to alkaline rocks because they take no account of CO_2 and H_2O, which are essential ingredients of many alkaline rocks.

Chemical data may be presented in several ways however, some of which are of great assistance in dividing the alkaline rocks into families. Such a division is shown in Figures 1 and 2.

Figure 1, the alkali versus silica plot, has been recognized for some time as an effective discriminator between alkaline and subalkaline rocks (Irvine and Baragar, 1971). On this plot the average analyses of various types of alkaline rocks, as plotted by Nockolds (1954), are shown. Although the boundaries are arbitrarily drawn, the different mineralogical types clearly fall into different fields. The characteristics of these families are discussed in more detail below, but on this diagram a definite gap may be immediately noted between the alkali basalt family and the agpaitic syenite family, whereas the other families grade into one another. Such gradation is a feature of the chemical analyses of some suites of rocks and should not be construed as a "failure" of the diagram. The area of 'melilite facies' conversion (Tilley and Yoder, 1967) shows clearly in the silica-poor part of the nephelinite field. Although it does not show here, melilite-bearing rocks nearly always have lime/alkali ratios greater than 3, and monticellite is commonly present in melilite-bearing rocks if this ratio is greater than 5. The plot of silica-agpaitic index ($Na_2O + K_2O/Al_2O_3$) displays a gradation between the alkali basalts and the agpaitic syenites, but a gap between nephelinite and agpaitic syenites, and between nephelinite and miaskitic rocks. The genetic significance of these gaps is discussed. On Figures 1 and 2, five major families are distinguished, which seem to correspond to some fundamental division of alkaline rocks. Their characteristics are discussed.

Alkaline Basalt Family

The alkaline basalt family contains abundant plagioclase and pyroxene, commonly titanaugite in the typical varieties, whereas olivine, kaersutite, biotite, and nepheline may be present in lesser or accessory amounts. The cumulative ultrabasic members of this family are peridotite, occasionally amphibole-bearing, whereas the salic members are rich in alkali feldspar (mainly potassic), sometimes rich in nepheline, and may contain hastingsite and/or fayalite, but commonly lack acmitic pyroxene. Chemically, strong differentiation is evident in alkaline basalt suites, with SiO_2 rising from about 45 per cent in primitive varieties to 61–62 per cent in some trachytes, and $Na_2 + K_2O$ varying from 5 per cent to 11–13 per cent in the same range. Chemically and mineralogically, some nepheline-rich alkaline basalts (basanites) show transitions to nephelinite. Alkaline basalt lavas occasionally show strong temporal and geographic connection with agpaitic complexes of plutonic character, but plutonic complexes of alkaline basalt composition are rare, although subvolcanic complexes such as the Monteregian Hills are common.

Nephelinite-Carbonatite Family

The nephelinite-carbonatite family is characterized by the lack of feldspar, particularly plagioclase. Plutonic varieties are composed mainly of nepheline and aegirinic pyroxene, although titanaugite occurs in some ultramafic cumulate varieties. Olivine is rare. Differentiation in such complexes leads to enrichment in nepheline, and commonly to the appearance of melanite, and eventually to wollastonite. The volcanic and subvolcanic equivalents of these rocks have a mineralogy so different from that of the plutonic complexes that, in the absence of chemical analyses, it would be hard to believe in their equivalence. Olivine is a major constituent, together with augitic pyroxene, some nepheline, minor phlogopite and, commonly, small amounts of calcic plagioclase. Melilite appears in silica-poor varieties (in place of plagioclase) and monticellite in lime-rich rocks. Pyrochlore and perovskite are characteristic accessory minerals. Most rocks of this family contain

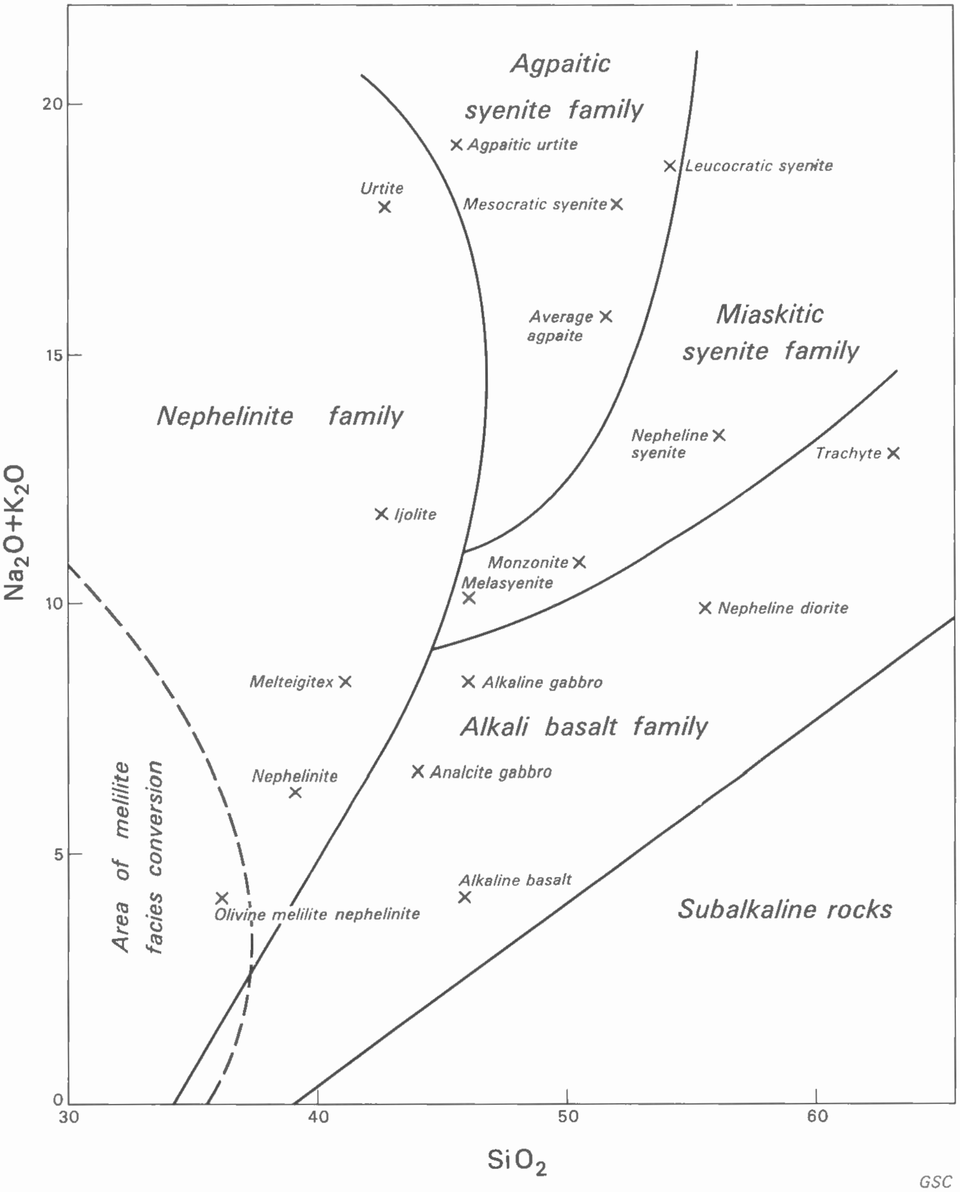

FIGURE 1. Alkali-silica diagram for alkaline rocks. The labelled points show the average composition for various types of alkaline rocks, as compiled by Nockolds (1954).

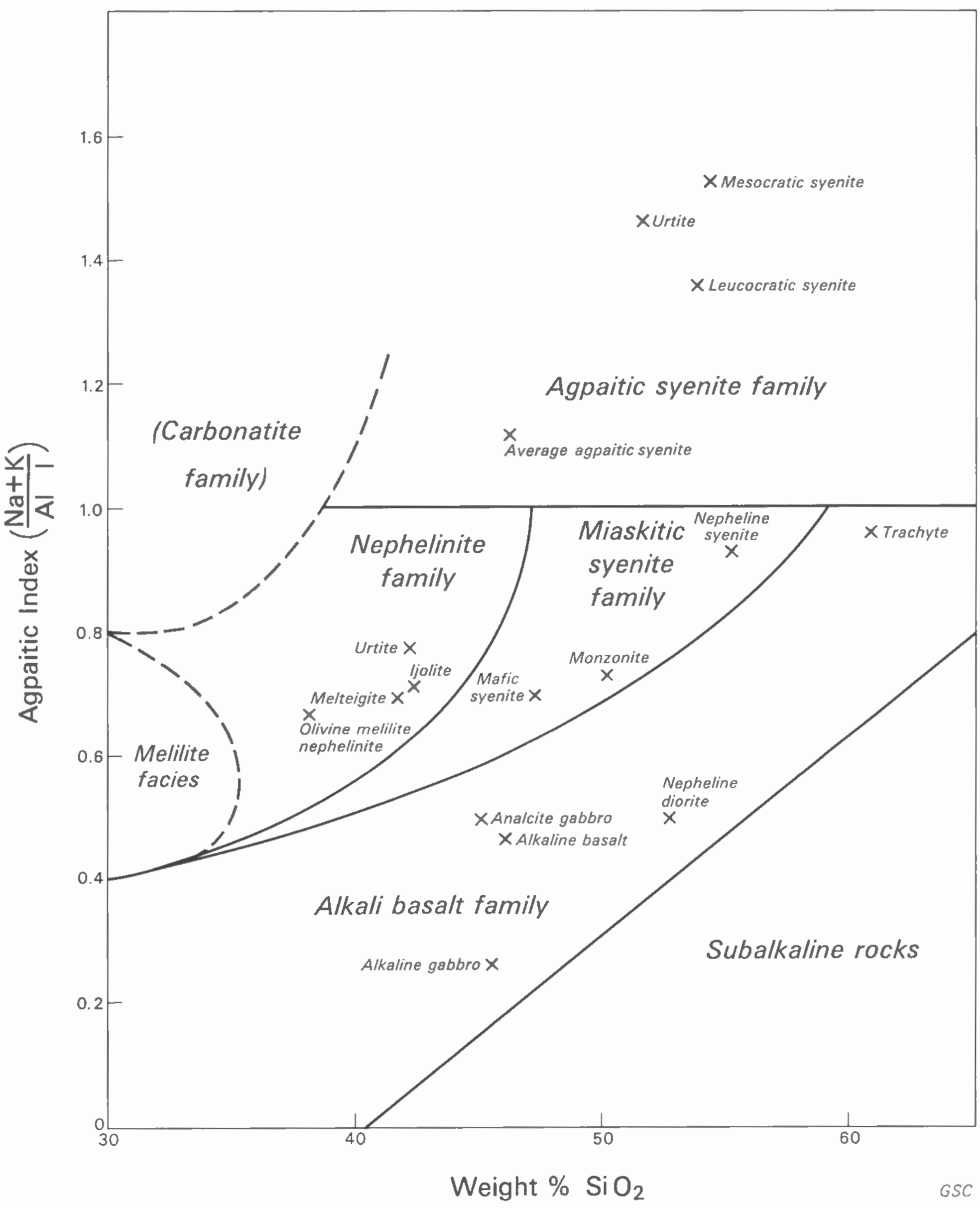

FIGURE 2. Agpaitic index-silica diagram for alkaline rocks. The labelled points show the average composition for various types of alkaline rocks, as compiled by Nockolds (1954).

greater or lesser amounts of primary carbonate and there is continuous gradation to carbonate-rich varieties, even within the same complex. For this reason, the chemistry of nephelinitic rocks is difficult to summarize, since the initial silica content may vary from 15 to 40 per cent depending on carbonate content. Commonly, however, the SiO_2 content varies very slowly with differentiation, and may even decrease, whereas the alkali content increases rapidly from $Na_2O + K_2O$ of 5 per cent or less, to more than 20 per cent.

Plutonic and hypabyssal nephelinitic rocks commonly show evidence of liquid immiscibility (Currie and Ferguson, 1971), which produces miaskitic nepheline syenite. Hence, even though nephelinitic rocks do not themselves contain significant feldspar, nephelinitic complexes commonly contain a nepheline syenite fraction. Syenitic rocks may also be developed as the result of metasomatism (fenitization), a process which is particularly characteristic of this family of rocks. In some cases the two processes may operate together, producing immiscible syenite magma by rheomorphically melting metasomatized rocks.

Canada has a considerable number of magnificent examples of different types of central nephelinitic-carbonatitic complexes, among them Oka, Quebec, Callander Bay, Ontario, and Ice River, British Columbia, as well as several nephelinitic dyke swarms.

Carbonatite Family

The carbonatite family is here restricted to alkaline igneous rocks containing major primary carbonate that are not associated with nephelinitic rocks. Two types of association are seen in Canada. First, carbonatite (a rock-unit composed of more than 50 per cent carbonate) may be associated with mildly alkaline ultrabasic rocks, particularly mica peridotites, commonly with diopsidic pyroxene, as in the northwestern Ontario occurrences at Schryburt Lake and Big Beaver House. Such complexes show some affinity to nephelinitic complexes, since they typically contain pyrochlore, and may weakly metasomatize the wall-rocks. Autometasomatic formation of phlogopite or vermiculite is characteristic of these rocks. A second type of carbonatite occurs as lens-like or vein-like masses in larger masses of mildly alkaline syenite. Carbonatites of this character commonly contain alkali feldspar, and may have high agpaitic indices; they are only weakly alkaline, and may contain traces of quartz in late veins. Both types tend to display elongate or dyke-like form, as opposed to the subcircular outline of nephelinitic complexes.

The term 'carbonatite complex' has been very loosely used for complexes containing *any* more or less igneous-looking carbonate rocks, even when the carbonate is present only as small plugs or dykes in a vastly larger body of alkaline rocks. This usage simply obscures the significance of carbonate minerals in alkaline rock genesis, since it is clear that almost all nephelinitic rocks of plutonic habit, as well as many miaskitic syenites, contain primary carbonate. The carbonatites, as defined here, have little or nothing in common with these rocks, except the abundant carbonate, which because of the difference in chemistry and paragenesis of the surrounding alkaline rocks, has no decisive bearing on their origin. The use of the term 'carbonatite complex' in this sense should be abandoned, and carbonate treated in the same way as any other primary mineral or group of minerals. The terminology for this purpose has been discussed at length by von Eckermann (1948) and others.

Miaskitic Syenite Family

Miaskitic syenites are alkali feldspar-rich alkaline rocks that contain sufficient alumina to accommodate all the alkalis in aluminum silicates with 1: 1 Na + K:Al ratio (mainly nepheline and feldspar). Such rocks may arise by differentiation from more basic types, whether by immiscibility or by fractional crystallization, but large masses of miaskitic syenite are apparently generated independently of more basic rocks. The more mafic members of such complexes not uncommonly contain olivine and/or titanaugite, but the major mafic mineral is typically biotite, which may be accompanied or replaced by aegirine, kaersutite, hastingsite, or other sodic amphiboles. Alkali feldspar, commonly coarsely perthitic, is the major constituent of all the rocks, accompanied by interstitial nepheline. Among volcanic rocks, phonolites have a chemistry and mineralogy similar in every way to miaskitic syenites, but such rocks are rare in Canada, except in the form of dykes. Chemically, miaskitic syenites have a limited range of composition, the SiO_2 content ranging from 50 to 58 per cent and the corresponding alkali content ranging from 10 to 16 per cent, although the associated mafic rocks may have silica content as low as 45 per cent.

Most miaskitic syenites occur as subcircular plutonic complexes, more or less concentrically zoned, which may be up to 15 miles in diameter. However, miaskitic syenites are also found as strongly gneissic bands intercalated in a sequence of metamorphic rocks that commonly contains marbles. Such nepheline-bearing gneisses may display the extraordinary mineral pair sodalite-corundum, i.e., a peralkaline and peraluminous mineral in the same rock, although it is not clear that these two minerals are in equilibrium.

Agpaitic Syenite Family

Agpaitic syenites are rare rocks in which the alkali content is so high relative to aluminum that all alkalis cannot enter into aluminum silicates of 1:1 Na + K:Al ratio, but must form peralkaline minerals such as sodalite, acmite, and 'agpaitic' minerals (ramsayite, eudialyte, rinkolite, and other rare sodium silicates with zirconium, titanium, and rare-earths). Alkaline amphiboles are the most typical mafic minerals, although acmite is not uncommon. Biotite is absent. Agpaitic rocks tend to be relatively low in nepheline, and consist mainly of alkali feldspar, usually perthitic, alkaline amphiboles, and varying but usually subordinate amounts of sodalite, natrolite, analcite, nepheline, and agpaitic minerals. The last are especially concentrated in pegmatitic veins, schlieren, and patches, which constitute virtual treasure troves of rare minerals, some agpaitic complexes containing more than 100 mineral species. Agpaitic rocks are commonly found as relatively large, subcircular complexes of plutonic habit displaying igneous layering, as at Khibini, U.S.S.R., and Ilimaussaq, Greenland. Known Canadian examples are moderately to strongly metamorphosed, except Mount St-Hilaire. Alkaline volcanic rocks of agpaitic character are unknown in Canada.

Occurrence and Distribution of Alkaline Rocks in Canada

Genetic links between alkaline magmatism and other geological events have been recognized for more than 50 years, but their exact nature is still a hotly disputed question. Four major and five minor belts of alkaline rocks may be discerned in Canada, each probably linked to tectonic events (Fig. 3), although these links are not obvious. The four major belts comprise the Cordilleran alkaline province (1 on Fig. 3), the Grenville alkaline province (6), (both of which appear to be related, in part at least, to orogenic activity), the Kapuskasing "High" (4), presumably related to horst-like uplift of large dimensions, and the Ottawa–St. Lawrence system (7), related to long-lived rifting on a continental scale, of which an earlier manifestation was the Nipissing alkaline province (5). The relations of the minor belts are less clear. The northwest Ontario carbonatite belt (2) appears to be related to faulting, as does the Coldwell province (3), but the nature of the links is unclear. The Nagagami River belt (9) is entirely covered by drift or younger rocks.

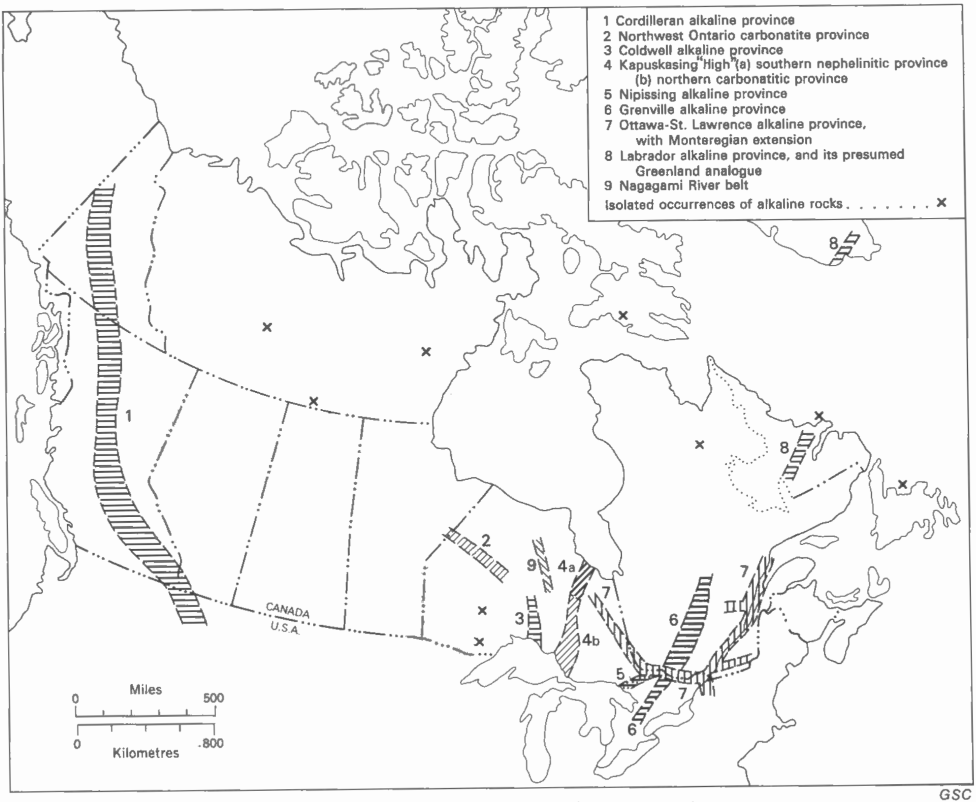

FIGURE 3. Belts of alkaline rocks in Canada.

The Labrador province (8) is probably part of the Gardar province of Greenland which is controlled by normal faulting. Bodies not belonging to a known group of alkaline rocks form about 5 per cent of the approximately 120 occurrences in Canada. The characteristics of the most important alkaline rock provinces are discussed here.

Ottawa – St. Lawrence Graben System

The Ottawa–St. Lawrence graben system (Kumarapeli and Saull, 1966; Fig. 3, belt 7) was characterized by alkaline igneous activity of great temporal and spatial persistence. About 560 million years ago alkaline igneous activity extended from Lake Nipissing, down the Ottawa River, along the St. Lawrence to the Strait of Belle Isle, and possibly across the (then closed) Atlantic Ocean to Norway and Sweden (Doig, 1970). In a general way the magmatic activity was of nephelinite-carbonatite type at the ends, and miaskite-syenite toward the middle (Chatham, Rigaud areas), with various small cross-fractures (Saguenay Valley, Labrador front) exhibiting carbonatite or nephelinite-carbonatite activity. The system was active intermittently for the next 350 million years, producing isolated nephelinitic and syenitic dyke swarms. About 200 million years ago the system began another phase of intensive activity along its entire length, at the same time opening extensions through Lake Temiskaming toward James Bay, and along Lake Champlain toward the central United States. The climax of this episode occurred along a line crossing the rift at a low angle, producing the Monteregian Hills. This magmatic activity was nephelinitic and/or carbonatitic at the ends, grading to alkaline basaltic toward the middle. As with the Kapuskasing "High", the area marked out by the alkaline rocks is somewhat larger than that delineated by the fault structures, although clearly closely linked with them.

Kapuskasing "High"

The Kapuskasing "High" is a roughly linear gravity and magnetic high, accompanied by outcrop of granulite facies metamorphic rocks, extending from Kapuskasing toward James Bay. It has been interpreted as a horst. Along this feature and its southwestern extension, an extraordinary number of complexes containing carbonate rock occur. Some are true carbonatites; others are nephelinite-carbonatites. Most are poorly known. Despite striking structural and petrographic similarities they are of vastly disparate ages, ranging from 1,700 to 1,000 m.y. (Gittins *et al.*, 1967). Although the Kapuskasing "High" is a feature of limited extent, the alkaline rocks strongly suggest that it has an extension southwestward to the northeast part of Lake Superior (where syenites occur in the Port Coldwell complex), which in turn is known to connect to the block-faulted area of the 'Mid-Continent' high in the United States. Such an extension suggests a belt of block faulting of continental dimensions and extraordinary persistence, comparable in every way to the Ottawa–St. Lawrence rift system. Another smaller offshoot, perhaps comparable to the Saguenay River branch of the St. Lawrence system, runs north along Nagagami River to Albany Forks. A remarkably high concentration of alkaline complexes occurs along this narrow linear belt.

Eastern Flank of the Cordillera

The eastern flank of the Cordillera, which extends in an irregular band from Mexico to Alaska, has been recognized for many years as a locus of alkaline igneous activity (Eardley, 1960). In Canada the belt appears to be roughly 200 miles wide, and includes an unusual variety of rock-types, ages, and compositions ranging from nephelinite-carbonatite (Ice River), to alkaline basaltic, to syenitic. Ages range from Devonian (?) to sub-recent. The more recent rocks, and those east of the Rocky Mountain Trench, are essentially undeformed, but some others (Mount Copeland) are intensely deformed and metamorphosed. The Cordilleran belt of alkaline rocks should possibly be divided into two, since recent studies suggest that two separate but related belts are present (Lipman *et al.*, 1971).

Northern Flank of the Grenville Province

The northern flank of the Grenville province (Fig. 3, belt 6) forms an older analogue of the Cordilleran belt of alkaline rocks. This belt stretches some 500 miles from Blue Mountain in Ontario to Lac Albanel in Quebec. In Ontario the alkaline rocks are strongly metamorphosed and deformed, and many contain corundum, apparently as the result of metamorphic and/or metasomatic reactions. Some of the rocks have been termed ijolites and theralites, but virtually all approach syenitic composition. The alkaline rocks of southwestern Quebec are somewhat more massive, but gneissic textures are also prominent in parts of this region. An age of 1,290 m.y. has been suggested for Blue Mountain (Krogh and Hurley, 1968) from Rb-Sr isochron data, but the rest of the belt gives both K-Ar and Pb isotope ages of 900–1,000 m.y., identical with the age of metamorphism.

The two large agpaitic complexes in central Labrador are almost certainly related to the mineralogically similar, and roughly contemporaneous agpaitic rocks of the Gardar igneous province of Greenland (Bridgewater and Walton, 1964), which appears to strike into central Labrador. They may be taken as another indication that Greenland is a part of North America that was split off during late Mesozoic time.

Wilson (1971) has recently described a large group of intrusions in northwestern Ontario, possibly including Sturgeon Lake. These intrusions are described as alkalic or alkaline, but the examples for which information is available to the writer are all alkalic, i.e., saturated with silica.

The Origin of Alkaline Rocks

The origin of alkaline rocks has been a favourite topic of debate among petrologists for many years. To understand the distribution and significance of Canadian alkaline rocks, certain features of these arguments must be understood. Since alkaline rocks are rare and of relatively small volume, many petrologists have constructed schemes to derive them from more common magmas by the intervention of some rare or inefficient process. For example, Bowen (1928) supposed that early-formed biotite could sink into the residual magma and be resorbed, giving alkaline undersaturated rocks. The source of sufficiently large amounts of early-formed biotite was never clarified, but the scheme has an appealing plausibility because it explains some very peculiar rocks in terms of well-known and reasonably well understood processes. Such theories are, in general, only successful for rocks whose compositions are not too far removed from more common subalkaline rocks. More exotic rocks need more exotic theories.

Petrogenetic Considerations

The rocks most commonly mentioned as parents of alkaline rocks are the alkaline basalts. Alkaline basalts on a world-wide scale show close links with tholeiitic basalts, forming the cappings of many oceanic volcanoes composed mainly of tholeiitic basalts for example, or occurring in belts with well-defined relations to neighbouring belts of tholeiitic basalts. Recent experimentally supported theories of basalt genesis explain these relations rather satisfactorily (Green, 1971), and the origin of alkaline basalts seems to be reasonably well understood. The upper mantle, supposed to be composed of some variety of peridotite of which the exact mineralogical composition is disputed, is assumed to be partly melted, probably in the presence of traces (0.1 weight per cent) of water, yielding a basaltic liquid. The composition of this liquid varies, becoming gradually more alkaline with depth due to the enhanced stability of orthopyroxene at high pressures. The stabilization of this relatively siliceous mineral throughout most of the melting interval makes the resulting liquid poor in silica, hence alkaline. It should be pointed out that alkaline rocks are not so much rich in alkalis as poor in silica; on the alkali-silica diagram (Fig. 1) subalkaline rocks are joined to their alkaline equivalents by lines parallel to the SiO_2 axis, not by lines parallel to the alkalis axis. This point can be clearly seen by comparing some of the average analyses of Nockolds (1954). Desilicating the average granodiorite produces a composition very close to the average nepheline syenite, and desilicating the average tholeiitic basalt produces a close match to the average alkaline basalt (Currie, 1970).

According to the theory just outlined, the amount of normative nepheline in basaltic rocks may be expected to increase with depth of generation, and conversely with decreasing depth of generation the amount of normative nepheline will decrease and eventually disappear. Continental plateau basalts, such as those found in the Coppermine River area of the Northwest Territories (Baragar, 1969), seem to occupy a special position in this sequence. Although such basalts are predominantly tholeiitic, chemical and modal analyses show that nearly all such fields contain a small but significant proportion of alkaline basalts. This suggests that such basalts must come from a relatively constant depth in the crust corresponding to the pressure at which the partial melt in equilibrium with the upper mantle becomes nepheline normative. According to the experimental data of Green (1971), this pressure would correspond to a depth of roughly 50 to 75 km.

For more strongly alkaline rocks of basaltic affinities, correlations between depth of generation of melt, and degree of silica undersaturation can also be suggested. In the Monteregian Hills of southeastern Quebec the compositions become steadily more undersaturated from east to west. This can be interpreted to mean that the magma was drawn from steadily increasing depths. The present day heat flow decreases from east to west. Hence, one would have to go to deeper and deeper depths to reach the melting temperature, and according to the model the magmas should become progressively more undersaturated with depth of generation. In some cases the change in composition can be explained in terms of current concepts of plate tectonics; for example, the well-known progression from tholeiitic to alkaline basalts as one passes west from Japan to Manchuria (Kuno, 1959) can be explained by assuming that the magma is generated along the margin of the Pacific plate that dips westward under Manchuria.

Nephelinites

The limits to which desilication can proceed with increasing pressure are not clearly defined experimentally. Observationally, small amounts of very alkaline, feldspar-free *nephelinites* are occasionally found as very late differentiates of theoliitic or alkaline basaltic volcanoes, for example in Salt Lake crater, Hawaii. Such nephelinites are virtually always explosively erupted, suggesting high volatile contents in the magma, and commonly contain inclusions thought to come from considerable depths in the upper mantle. There may also be a substantial time lapse between the eruption of the preceding alkaline basalts and the nephelinites. Somewhat similar relations are observed in the Monteregian Hills, where the nephelinitic rocks west of Montreal appear to have been very rich in volatiles, and hence explosively emplaced. Several attempts have been made to explain the origin of nephelinites by deriving them from alkaline basalts, either as late differentiates erupted from great depth, or as primary melts derived from the primitive upper mantle material by melting under high volatile pressures. The most complete scheme of generation of nephelinitic rocks in this way has been set out by Bultitude and Green (1968), who presented supporting experimental data. However, continued studies by Kushiro (1969) very strongly suggest that under the conditions used by Bultitude and Green probable upper mantle compositions would melt to give silica-saturated calc-alkaline rocks. Kushiro suggested that the results of Bultitude and Green could be explained by leakage of water from their charges, with resulting leaching of silica. The data of Holloway (1971) showed that this mechanism could remove large amounts of silica from the samples, a result which would produce nephelinitic compositions in the residues. These data were made the basis of a speculative hypothesis on the origin of nephelinites by Currie (1970), who assumed that a free vapour phase was locally present in the upper mantle, and was able to leach sufficient silica from basalt to locally convert it to nephelinite.

If nephelinites cannot be generated by a variation of the processes that produce alkaline basalts, their genesis presents a considerable problem. The highly explosive nature of nephelinite eruptions, the ubiquitous occurrence of fenite zones around plutonic complexes of nephelinitic chemistry, the extreme concentrations of carbonates and phosphates, all show that rocks of nephelinitic chemistry crystallized from magmas extremely rich in volatiles. The proof of their deep-seated origin seems more tenuous. Although ultrabasic nodules with high pressure mineralogy are present in some nephelinites, they are absent in some 'continental' nephelinites, but abundant in those associated with the east African rifts (Holmes and Harwood, 1932), and are most common in nephelinites associated with alkaline basalts, as at Hawaii. Furthermore, the mineral assemblage nepheline-wollastonite, common in plutonic rocks of nephelinitic chemistry, is unstable at pressures above about 3.5 kilobars, transforming to soda-melilite (Yoder, 1964), whereas the assemblage nepheline-diopsidic pyroxene, found in virtually all nephelinitic complexes, is unstable at temperatures of more than about 950°C, breaking down to melilite-bearing assemblages. As shown by Currie and Gelinas (1972), these data require most nephelinitic complexes to equilibrate in a narrow field of pressure and temperature to avoid the appearance of melilite. Since no relicts of melilite are found in plutonic nephelinitic complexes, it seems unlikely that they have been directly derived from great depths.

Bailey and Schairer (1966) offered a hypothesis on the origin of ijolitic rocks which could explain this dilemma. According to their (dry) melting experiments, ijolitic melts are the low melting fraction of a considerable range of alkaline rocks rich in feldspar and ferric iron. Thus ijolitic rocks could arise by remelting of pre-existing alkaline rocks, possibly at temperatures near 900 degrees which may rarely be reached in some parts of the crust. According to a diagrammatic sketch by Bailey and Schairer (1966, p.166), materials originally melted in the mantle could ascend into the crust, and there be remelted yielding ijolitic (nephelinitic) magma.

A serious objection to this hypothesis is the highly oxidized state of the iron in the relevant experimental systems. Analyses of alkaline rocks suggest that rocks with most of the iron in the ferric state are rare, and that parental material for generating ijolite by the Bailey–Schairer mechanism would thus also be rare. In their original paper they attempted to avoid this objection by supposing that the refusion is accompanied by a flux of volatiles from the mantle. An influx of water and carbon dioxide might be expected to oxidize the pre-existing rocks and also to provide the abundance of volatiles characteristically associated with ijolites and nephelinites. In this form the theory approaches the position of some Russian petrologists, who hold that ijolites are entirely metasomatic rocks derived from conversion of gabbro by alkaline aqueous solutions ascending from depth (Sheinmann, 1971). Currie and Ferguson (1972) outlined observational evidence from fenite aureoles around nephelinitic complexes that alkaline metasomatism, possibly combined with partial melting, can produce ijolitic rocks.

In summary, the origin of nephelinitic magmas is poorly understood. The evidence seems to indicate that three different varieties may occur: (i) Deep-seated nephelinitic magma rising from the mantle, and typically associated with basaltic rocks. Inclusions suggestive of upper mantle mineralogy are always present in this type, which includes the rare peridotite variety kimberlite. (ii) Nephelinitic magmas resulting from the remelting of pre-existing alkaline rocks. Little work has been done on the criteria for recognition of such rocks, but they might be expected to have a distinctive trace element content, very low in elements such as Cr and Ni, which are concentrated in early magmatic phases, and high in elements that are concentrated in late magmatic phases, such as rare-earths. (iii) Rocks of nephelinitic chemistry resulting from metasomatism of country rocks, with or without partial melting. Such rocks can frequently be identified by textural criteria and field relations. The Portage complex of northern Ontario is a well-known example. The second and possibly the third type of nephelinitic complex might be expected to occur in areas of previous alkaline igneous activity.

The differentiation of nephelinitic magmas also presents difficult problems. Many nephelinitic dyke rocks are characterized by the occurrence of ocelli–small, generally ellipsoidal blebs of composition radically different from the matrix. Such ocelli show clear evidence that they were originally liquid, for example flattening or moulding in the flow direction, flow structure, partial amalgamation, and intrusion. Mafic minerals in ocelli are of composition similar to those in the matrix, and may cross the boundary of the ocellus existing in apparent equilibrium in both ocellus and matrix. Such evidence strongly suggests that many ocelli represent droplets of an immiscible liquid developed during differentiation of nephelinitic magma. Experiments on some ocellar rocks show that under appropriate conditions they melt to form immiscible liquids (Ferguson and Currie, 1971; Ferguson and Currie, 1972; Roedder and Weiblen, 1970; Roedder and Coombs, 1967; Philpotts and Hodgson, 1968). The liquids involved appear to be of four general types: nephelinitic, carbonatitic, hydrous and alkaline, or syenitic. The experiments on natural rocks agree in general with the synthetic experimental work of Koster van Groos and Wyllie (1966) on the immiscibility of carbonates and mafic silicates, and the work of Watkinson and Wyllie (1971) on the separation of alkaline, hydrous liquids. Separation of hydrous alkaline liquids is probably a common occurrence at a late stage of magmatic evolution (Burnham, 1967), and in water-rich magmas, such as most nephelinites appear to be, it may occur at a much earlier stage. Such hydrous liquids are assumed to be the source of the fenitizing solutions characteristic of nephelinitic plutonic complexes. The role of immiscibility in silicate liquids is much less well defined, but a recent study by Currie (1972) suggests that it is most important at low pressures in basic to ultrabasic liquids. The common patterns ijolite-nepheline syenite, or ijolite-carbonatite-nepheline syenite seen in many complexes can be explained by immiscibility, which appears to be a controlling factor in the evolution of many nephelinitic rocks.

Heteromorphism is unusually prominent in nephelinitic magmas. Although such a situation is fundamental to metamorphic petrology, it is relatively uncommon in igneous petrology. The appearance of melilite and its incompatibility relations with feldspar are the principal causes of heteromorphism in nephelinites, although heteromorphism between the pairs amphibole-potash feldspar, and biotite-plagioclase is also known. Heteromorphic pairs define limiting conditions for their formation analogous to the facies concept of metamorphic petrology. Such ideas have not been widely applied to igneous petrology as yet, although they are appearing in the study of the genesis of basalts, but they promise a much closer definition of the conditions of formation of igneous rocks.

Carbonatites

I propose to separate a class of carbonatites defined as ultramafic rocks containing olivine and titanium-poor diopsidic pyroxene. Neither of these minerals is rare in nephelinitic rocks, but olivine is associated with titanium-rich pyroxenes, and commonly appears in volcanic or near-surface environments, whereas diopsidic pyroxenes are typical of deeper seated complexes and generally coexist with nepheline. When comparing the Canadian examples on the Kapuskasing "High" with such very mafic nephelinitic complexes as Oka and Castignon Lake, Quebec, it appears that there is a gradation between nephelinitic and ultramafic types. Franz and Wyllie (1966) have shown that ultramafic carbonatites must have a high CO_2/H_2O ratio to crystallize olivine. This corresponds well with the limited fenitization aureoles around ultramafic carbonatites, which suggests low water content. The relatively lower water content presumably lowers the eruptive energy, so that instead of the circular complexes cleanly punched through their surroundings that are so typical of nephelinitic complexes, ultramafic carbonatites tend to appear in the form of tabular masses following well-defined planes of weakness.

The origin of ultramafic carbonatites has been the subject of considerable debate in the Russian literature (Sheinmann, 1971). Some authors suggest that the ijolite-urtite series is a derivative of such rocks, whereas others derive carbonatites from weakly or nonalkaline ultramafic rocks such as dunite and peridotite, and still others relate carbonatites to kimberlitic parent rocks. The ultimate source, in any event, appears to be in the mantle. The manner in which CO_2 is distributed in the mantle, and its concentration relative to water are unknown. Experimental data suggest that CO_2 is sparingly soluble in magmas relative to H_2O, but that the solubility increases with both pressure and alkalinity. By appropriate adjustment of these factors it may be possible to explain how in some areas, such as the Kapuskasing "High", ultramafic carbonatites with high CO_2/H_2O ratios are erupted before water-rich nephelinitic carbonatites, whereas in other provinces, such as the Monteregian Hills, the latest differentiates (the Oka complex and related rocks) are very rich in CO_2. In the absence of sufficient experimental data, however, these are merely speculations.

Miaskitic Syenites

Alkaline syenitic rock compositions tend to fall close to the undersaturated part of "petrogeny's residua system," i.e., they commonly approach the lowest melting composition in the system alkali feldspar-nepheline-kalsilite (Hamilton and MacKenzie, 1965). Such compositions can be produced either as the final product of fractional crystallization of a more mafic rock, or as the low melting fraction of an alkaline parent rock. The residuum of differentiation is clearly seen in the trachytic or, more rarely, phonolitic flows associated with alkali basaltic volcanoes. Differentiation, however, fails to account for the relative proportions of alkaline rocks. Many, perhaps most, alkaline provinces show a predominance of syenitic rocks, in some cases almost to the exclusion of basic rocks, whereas the fractional crystallization mechanism produces salic rocks totalling only a few per cent of the mafic rocks. This difficulty is precisely analogous to that attending the derivation of granite from basaltic parent magma. The process is possible, but it is so inefficient that it cannot explain the observed abundance of the salic rocks. Hence it seems probable that appeal must be made to the second mechanism, namely anatexis of crustal rocks. For alkaline rocks, however, the possible range of parents is drastically restricted, since they must also be, at least mildly, alkaline. The possible parents are thus themselves alkaline rocks, and miaskitic syenite complexes should on this reasoning be restricted to areas of previous alkaline igneous activity. This prediction is not notably successful. Around Lake Superior for example there are a considerable number of large syenitic complexes (Port Coldwell province, Poohbah Lake, Sturgeon Lake) but few older alkaline rocks. Thus one of two additional qualifications becomes necessary. First, one may suppose that a process akin to fenitization occurs from time to time in the deep crust, due to escape of volatiles from the mantle. Perhaps areas such as the Nemag Lake, Ontario, alkaline breccia may be due to this sort of process. Such areas could later be melted, assisted by the upward flux of heat with the volatiles, yielding syenites. The other possibility is analogous to some current views on the genesis of andesites—namely, that they result by two-stage anatexis from the mantle, the first stage incorporating basalt into the oceanic plate, where it is carried under the continental edge, and remelted on its downward path to yield andesite. Since alkaline basalts are also known to occur in the oceans, although in small amount, it is reasonable to suppose that they also will be remelted during descent of the continental plate. Depending on the original composition, particularly the iron content and its oxidation state, such rocks could yield either syenitic or nephelinitic melts (Bailey and Schairer, 1966). Such a mechanism could presumably explain the syenitic rocks in the Cordillera, where syenites are ubiquitous, although volumetrically insignificant compared to the enormous granodioritic batholiths.

Agpaitic Syenites

Although such mechanisms seem to explain the normal miaskitic syenites reasonably well, they do not explain the existence of strongly peralkaline rocks. The alkali/alumina ratio of alkali feldspars and feldspathiods is 1, whereas the mafic minerals common in alkaline rocks have ratios of less than 1, with the exception of aegirine and arfvedsonitic amphiboles. If a melt crystallizes mafic minerals at an early stage, the agpaitic ratio will therefore increase (assuming it was initially less than 1) until the appearance of aegirine and alkali feldspar. If these minerals are crystallized in any quantity before the agpaitic ratio reaches 1, the agpaitic ratio of the residual liquids cannot increase any further. In order to obtain agpaitic residual liquids the parent liquid would have to be one sufficiently basic that alkali feldspar did not form, and one in which the formation of aegirine or arfvedsonite was prevented, possibly by very reducing conditions. Some alkaline basalts, for example those of the Monteregian Hills, seem to fulfil the required conditions, and the agpaitic rocks of Mount St-Hilaire may have formed in this way. The enigmatite in agpaitic rocks and the local presence of fayalite strongly suggest very reducing conditions. The rarity of potassic peralkaline rocks may be related to the formation of biotite under the postulated conditions, thus reducing the potassium content. According to this mechanism, a melt would have to become agpaitic before alkali feldspar crystallized, by crystallization of mafic minerals under tightly controlled oxygen fugacity. The restrictiveness of these conditions may explain the rarity of agpaitic rocks.

Another possible factor may be immiscibility. Preliminary calculations (Currie, 1972) suggest that the agpaitic syenite of Mount St-Hilaire is immiscible with the derivatives of alkali basalt in the same complex. The immiscibility field, however, is very limited, suggesting that agpaitic rocks generated by such a mechanism would be rare.

The crystallization of agpaitic melts is not well understood. Since the crystallization of undersaturated mafic minerals (titanaugite, kaersutite, biotite, etc.) is assumed to drive the residual liquid into agpaitic compositions, the residual agpaitic melts need not be strongly undersaturated with silica, and may even be oversaturated, as in the agpaitic granites. Since large quantities of mafics have been removed, abundant crystallization of mafic minerals is not to be expected. Observed agpaitic rocks tend to crystallize leucocratic minerals first, and dark minerals last. Since feldspar and nepheline have agpaitic ratios less than that of the melt, their crystallization tends to increase the agpaitic ratio of the resulting liquid, a commonly observed trend in agpaitic rocks resulting in spectacular mineralogy in late pegmatites. The mafic minerals–acmite, enigmatite, and sodic amphiboles–are strongly agpaitic, and their crystallization reduces the agpaitic index of the melt. The appearance of ultramafic bodies, occasionally seen in the complexes of the Red Wine province, must be expected to substantially reduce the agpaitic character of the residual melt.

Nepheline Gneisses

Alkaline rocks tend to be looked on as strange objects, with little history and no future. Most geologists are content simply to record their presence and their (often exotic) mineralogy. Hence there is very little information on the dynamic history of alkaline rock bodies. This lacuna is of particular importance in the study of nepheline gneiss belts. We are simply unable to say what an alkaline complex metamorphosed to amphibolite grade might look like. The necessary mineral stability data do not exist. Sufficient observations on mildly regionally metamorphosed bodies such as Ice River have not been made. There is no way of disproving from observation that the Perry River occurrence, for example, is a metamorphosed and tectonically rearranged ijolite-carbonatite complex. Possibly, to a great extent, it is. The 800-mile stretch of the southeastern Ontario nepheline belt, with its nephelinitization in York River and Wolfe belts, the anhydrite around Bancroft, and replacement of plagioclase by nepheline and scapolite cast great doubt on this belt as a chain of primary alkaline igneous complexes. In terms of explaining belts of alkaline rocks, we simply do not have enough data to explain nepheline gneiss belts. In terms of individual occurrences, however, some of the alkaline rocks are clearly the result of metasomatism. These occurrences extend sufficiently far from rocks of undoubted igneous parentage that one must say, at the very least, that metamorphism expands the action of alkaline metasomatism in an unprecedented manner. To the author it seems more likely that metamorphism redistributes the alkali elements in the same way as any others, and in the process of devolatilization, so typical of progressive metamorphism, converts alkali-rich, nonsilicate rocks into alkaline silicate rocks. The chains of such nepheline gneisses therefore represent former levels in the stratigraphic pile, or positions in the tectonic framework, at which alkali-rich rocks are abundant, whether these rocks were igneous or sedimentary.

Tectonic Significance of Alkaline Rocks

We have deduced that among the igneous alkaline rocks the alkaline basalts represent initial melt from deep in the mantle (the nephelinitic rocks may in part represent such a melt but more probably are secondary after basaltic precursors), and that syenitic rocks are almost certainly secondary after more mafic precursors. We may therefore enquire where the parental alkaline mafic melts are likely to appear. In recent years much work has been done in relation to the concepts of "plate tectonics" (cf. Wyllie, 1971). According to these ideas, the crust of the earth is composed of a limited number of rigid plates, perhaps 100 km thick, which are in constant motion, new plates being generated at the mid-ocean ridges and old ones being consumed at subduction zones. Magma is generated at the ocean ridges at relatively shallow depths (hence mainly tholeiitic basalt) and at varying depths near the edges of the plates along the subduction zones. Although most of the magma generated along the mid-ocean ridges is tholeiitic, some is alkaline (Cann, 1971), and alkaline basalts are relatively common in the oceanic islands where they often form cappings on mainly tholeiitic edifices. Such alkaline rocks may be the result of some process of differentiation of tholeiite, but it seems more probable that the alkaline basalts, which commonly appear after a considerable period of quiescence, come from greater depths than the tholeiites, whereas the nephelinites come from great depths, as suggested by the mineralogy of their included ultramafic nodules. In any event, a descending oceanic plate must commonly contain small amounts of alkaline rocks, ranging in composition from mildly alkaline basalts to extremely alkaline and undersaturated nephelinitic varieties.

Along the subduction zones, such rocks are presumably melted, just as are their tholeiitic counterparts. Wyllie (1971, p. 371–374) has briefly summarized some of the currently fashionable theories on the derivation of the typical orogenic andesites and granodiorites by melting of the tholeiitic rocks along subduction zones. Without attempting to unravel the extremely complex and controversial aspects of the generation and emplacement of these rocks, it may be pointed out that whatever process is selected, it can be applied with equal merit to the generation of alkaline rocks by using the alkaline rocks of the subducting oceanic plate as parental materials. Furthermore, the temperatures, in the down-going slab at least, tend to be lower than normal for a given depth, so that melting would take place at greater depths, and the melts would therefore be more alkaline. Presumably, correlations between depth of generation and composition, such as those shown by Dickinson (1968) and Lipman *et al.* (1971), should also be valid for alkaline rocks, but the lack of sufficient analytical data and the compositional variability of single complexes of alkaline rocks do not at present permit the construction of such correlations.

Assuming that the observed "orogenic belts" are the result of plate interactions, the distribution of alkaline rocks in the Canadian Cordillera (Fig. 1) and elsewhere in the North American Cordillera (Eardley, 1960) makes it clear that alkaline rocks are as abundant in this orogenic belt as in the parts of the Canadian Shield presumably remote from plate edges. The mere physical presence of alkaline rocks in these belts does not prove a genetic connection. The Devonian or Mississippian Ice River complex was emplaced in an unfolded continental rise prism of shales and limestones, and the metamorphosed Mount Copeland, Perry River, and Lonnie complexes may also have been emplaced before the major deformation. Conversely, the widely spread alkaline basalts, mainly of Miocene and more recent age, postdate the main deformation of the Cordillera but are related to a late tensional regime.

Even granted these exceptions however, there remains a considerable number of syenite bodies that give K-Ar radiometric ages and locations, suggesting association with the more abundant granitoid rocks. The ages tend to cluster near 200 and 50 m.y., but the bodies form a single relatively narrow eastward convex belt extending from Kruger Mountain in the south to the Stikine River district in the north. So far as is known, alkaline rocks are not associated with the batholithic masses of the Coast Range intrusions. Recent work in the region of the alkaline syenites suggests that the nearby granitoid rocks may have been emplaced in an island arc environment (J. O. Wheeler, pers. com.), with the alkaline rocks emplaced to the continental side of the arc, which, according to the ideas of Karig (1971), could be characterized by crustal tension. Even assuming that all the alkaline rocks in the Cordillera were emplaced under conditions of crustal tension, the widespread occurrence of alkaline rocks in an orogenic belt, emplaced roughly contemporaneously with orogenic deformation, contradicts the generally accepted opinions on the genesis of alkaline rocks, as expressed, for example, by Turner and Verhoogen (1960): "Rocks of the nepheline syenite family are widely distributed in sectors of continents characterized tectonically by crustal stability, or simple fracturing."

Many Canadian alkaline complexes do occur in such regions, particularly in association with long-lived normal fault systems of large dimensions. The St. Lawrence valley rift system, for example (Fig. 3, belts 7 and 5), can be traced, according to Kumarapeli and Saull (1966), from the Strait of Belle Isle, up the St. Lawrence River, with probable side branches running along the Saguenay and Richilieu rivers, up the Ottawa River as far as Mattawa, and thence in two branches, a younger extending through Lake Temiskaming to the region of Kirkland Lake, and an older extending westward to Lake Nipissing, and probably across to Georgian Bay. The correct extension of this older branch is rather conjectural and poorly defined, but according to Kumarapeli and Saull, the branch is thought to continue in a rather ill-defined manner westward into Lake Superior, joining the system of normal faulting that comprises the Lake Superior basin, the mid-Continent gravity high to the southwest, and the Kapuskasing "High" to the north. Hence the system, in total, would extend from Newfoundland to Texas. Various parts of this vast and intricate network were active at different times, but the oldest parts are of Precambrian age. Despite the long continued activity of the fault network however, little lateral movement on the faults seems to have occurred, i.e., the faults have not spread significantly from their original position. This observation accords well enough with similar observations on the rift valleys of eastern Africa, the Rhinegraben and associated features of Europe, and the Lake Baikal feature of the U.S.S.R. It does not accord very well, however, with the ideas of plate tectonics, according to which such features should be either sites of active spreading, as for example the mid-ocean ridges and their landward extensions in the western U.S.A., or relatively shallow and ephemeral features. It seems clear, on the contrary, that such deep-seated fault systems are semipermanent features of the earth's crust, able to tap at intervals primary alkaline to subalkaline magma. The concentration of carbonatites, both nephelinitic and ultramafic along such features, raises serious problems about the nature and evolution of volatile content in the earth's upper mantle or lower crust. How is the CO_2 held before eruption? What is the mechanism of concentration? The geographic and temporal distribution of carbonatites on such features makes it clear that the conventional "answers" to such questions simply ignore the observational facts. No trace of vast volumes of CO_2-poor magma is present to suggest that concentration could have been by crystal settling of CO_2-poor phases. The variability in composition militates strongly against the idea of a primary carbonatite magma. If the primary magma is carbonated nephelinite for example, why is the mechanism of concentration of CO_2 so erratic, and where is the site of the gas before concentration? The concept that the CO_2 can come from the atmosphere, either directly or by assimilation of carbonate rocks, has been discredited by others. Whatever the answer to these problems, and none is in sight at present, field observation makes it clear that CO_2 in varying concentration is an important or essential component of all alkaline magmas except alkaline basalts, and magmas possibly derived directly from alkaline basalts such as agpaitic rocks.

Alkaline rocks are also associated with smaller areas of normal faulting. In most cases, as along the Nagagami River belt, the Bay of Fundy, and in the Seal Lake district, alkaline basalts are present. Presumably, the orientation of these belts is related to tectonic forces within the earth, but their exact nature is not known. The Seal Lake and Nagagami River belts lie roughly perpendicular to major structural boundaries – namely, the continental edge and the Kapuskasing "High," respectively. Whatever the tectonic cause, the resulting fractures go very deep, probably 50 km or more, to tap alkaline basalt magma.

We have concluded that alkaline rocks should appear as a normal constituent of many orogenic belts, and that they appear over long periods associated with semipermanent systems of deep fractures. Under these conditions it seems inevitable that alkaline rock provinces will be metamorphosed in some instances. Judging from Canadian examples, the net result of such a process will be an enhancement of the continuity of the chain of alkaline rocks, and a degradation of the differences between types of alkaline rocks. In other words, the alkaline rock province will tend to turn into a smeared-out jumble of more or less alkaline syenite. This process is accompanied by more or less intense metasomatism, and any rocks that have favourable compositions will be turned into alkaline rocks. Thus local sources of alkalis, such as evaporite deposits, may be utilized during metasomatism, giving a semicontinuous chain of alkaline rocks. The exact conditions under which this process takes place, and the reactions involved are unknown, but field observations suggest that most of the process takes place under conditions of upper amphibolite-grade metamorphism. In terms of structure, this process tends to print a fabric on the rocks, and to establish a more linear chain of alkaline rock occurrences than previously existed. The intersection of the metamorphism with older belts of alkaline rocks is particularly interesting. One such example may occur in the Cordillera where alkaline gneisses occur west of the Rocky Mountain Trench, and little metamorphosed alkaline rocks to the east. The Perry River belt (McMillan, 1973) could, for example, be a metamorphosed equivalent of the Ice River complex.

A limited number of alkaline complexes fall into none of the tectonic classes noted. Many of these occur in remote, poorly explored areas, and other alkaline rocks may occur in their vicinity, defining other alkaline provinces. Other occurrences may be linked to known provinces of alkaline rocks in a manner as yet unelucidated. However, when all allowances have been made for these possibilities, a residue of occurrences remains which must be explained by assuming that alkaline magma is occasionally generated and erupted apart from defined tectonic events.

In summary, alkaline rocks may be expected in the following tectonic settings: (1) In orogenic belts, (a) as a discontinuous chain of small, generally syenitic plutons, showing similarities in age and location to larger granitoid plutons, (b) as post-tectonic plateau basalts, (c) as metamorphosed alkaline rocks, originally emplaced before orogenesis. (2) In the region of long-lived, deep-seated normal faulting of continental dimensions, the alkaline rocks may be differentiated: alkaline basalt complexes, either intrusive or extrusive; nephelinitic complexes with abundant carbonate, either intrusive or extrusive; or rarely, alkaline rocks whose source is at great depth, such as kimberlites. Alkaline rocks in such a setting tend to occur not only in the faulted blocks themselves, but in a broader zone up to several tens of miles across, which may then cross the trend of the fault system at a low angle.

Finally, alkaline rocks may tend to occur associated with normal faulting of limited dimensions, where abundant basaltic magma has been erupted. In addition to feebly alkaline basalts, the alkaline rocks in such districts may include agpaitic syenites or ultramafic carbonatites, but miaskitic syenites are rare.

Chapter II

The Economic Significance of Alkaline Rocks

Many varieties of metals and industrial minerals either are produced from alkaline rocks or are known to occur in economically significant amounts. Prospecting of these rocks has been somewhat neglected in the search for mineral deposits, probably due to the difficulty in locating them and the extreme variability within and between alkaline complexes, but they are now the major source of niobium and rare-earths among metals, and of nepheline, barite, vermiculite, corundum, and diamond among nonmetals. Molybdenum, zirconium, copper, and apatite are being recovered from alkaline rocks, which appear to be potential sources of substantial amounts of these metals. Iron is recovered as a by-product. Syenites represent a major repository of alumina, which may be of economic importance under some conditions. Uranium and thorium are concentrated in syenites and carbonatites, but few of the concentrations are of economic interest. Other minerals are concentrated in alkaline rocks, but little is known about the economic significance of such concentrations. Although many geochemical studies have shown exceedingly high concentrations of certain elements in some complexes, or in some phases of some complexes, the average, or characteristic concentrations associated with particular types are poorly known because of the extreme variability within and between complexes. The associations of elements in alkaline rocks are commonly different from those in the better known subalkaline rocks; this can raise difficult problems of technology. Often the use of the mineral deposit appears to depend as much on advances in mining technology and metallurgical techniques, as well as on market conditions, as it does on discovery of adequate reserves.

In the following summary, the salient features of the commercially significant materials most often sought, or exploited, in alkaline rocks are outlined. These summaries are intended only to suggest the possible scope, not to give a review for each material.

Niobium

Carbonatites and nephelinite-carbonatites contain the bulk of the world's reserves of niobium, a metal whose use in the fabrication of high-temperature steel alloys is steadily increasing. The ore mineral in carbonatites is pyrochlore, although many other niobium-bearing minerals are present. Pyrochlore is commonly concentrated along lenticular zones, often concentric with the outlines of the alkaline complex, many of which are also rich in magnetite and markedly radioactive due the to presence of betafite, or uranian pyrochlore. The mineral paragenesis of pyrochlore deposits is commonly exceedingly complicated and imperfectly understood. Among the most puzzling problems are the high Nb/Ta ratios, which in alkaline rocks almost always exceed 100, and commonly exceed 400, whereas in granitic rocks they average 4.8 (Rankama and Sahama, 1950). Significant amounts of Nb also occur in syenitic rocks, but no economically exploitable deposits are known in Canada.

Nb is mined in Canada at the St. Lawrence Columbium and Metals Corporation, Oka, Quebec. Production in 1969 was 3.1 million pounds Nb_2O_5 from estimated ore reserves of 3.1 million tons grading 0.49 per cent Nb_2O_5. Other Canadian deposits have been extensively developed, but none brought into production. The major reason for this is an enormous deposit at Araxa, Brazil, where pyrochlore has been concentrated by residual weathering. For the past several years, production from this deposit has averaged 6.3 million pounds Nb_2O_5 a year.

Rare-earths

Rare-earths are concentrated in all alkaline rocks, and their presence is commonly used as a diagnostic test for the magmatic nature of carbonate rocks (Deans and Powell, 1968). Rare-earths are particularly concentrated in the nephelinite-carbonatite complexes and in agpaitic syenites. In carbonatites they are mainly in the form of the cerium group. A considerable amount is disguised in calcite, dolomite, pyrochlore, perovskite, apatite, sphene, and zircon, but rare-earth carbonates and, less commonly, phosphates may be present, either disseminated or concentrated, with bastnasite, parisite, monazite, and ancylite the most common carriers. Lanthanum plus cerium commonly comprises over 80 per cent of the rare-earths, with neodymium and praseodymium making up much of the rest. In agpaitic rocks, they are found in apatite (up to 8 per cent total rare-earths), in complex sodium-zirconium silicates, such as eudialyte and lamprophyllite, and as rare-earth silicates, notably rinkolite. Cerium group earths are predominant, but less so than in carbonatites, and the minerals contain significant amounts of europium, gadolinium, terbium, and dysprosium. Rare-earth phosphates may be present in late-stage pegmatites.

Rare-earths are commercially recovered from carbonatite dykes at Mountain Pass, California (ore grade 6.39 per cent rare-earths). An experimental operation has attempted to recover rare-earths and zirconium from eudialyte-rich agpaitic syenites at Narsaq, Greenland. Similar deposits have been evaluated in central Labrador. Some African carbonatites have been suggested as potential sources, if the market improves. They could probably be recovered as a byproduct from some niobium mining operations.

Molybdenum

Molybdenum is typically thought of as an element associated with granitic, rather than syenitic rocks. However, it appears to be concentrated to a notable extent in miaskitic syenites, and in the fenite aureoles of nephelinite carbonatites with a syenitic component. The development of nepheline gneisses appears to concentrate this material, and the successful exploitation of the deposit of Mount Copeland, British Columbia, shows that these concentrations are potentially of economic interest. Molybdenite occurs throughout the British Columbia nepheline gneiss belt, and is found consistently along, though not in, the southeastern Ontario and southwestern Quebec nepheline gneiss belts. Disseminated molybdenite is common in fenite aureoles, as at Callander Bay, Ontario. In the past these aureoles seem to have been little prospected, more attention being paid to the intrusive rocks. According to the deduced composition of fenitizing fluids (Currie and Ferguson, 1971), fenite zones have been intensively soaked by potentially ore-forming fluids and should be thoroughly examined. Since the outcrop of the fenitized aureole is commonly better than that of the magmatic core in Canadian occurrences, prospecting should not be unduly difficult, or expensive.

Copper

Copper is recovered from the Palabora carbonatite, South Africa, together with apatite, magnetite, and vermiculite, and a minor byproduct baddeleyite (ZrO_2). Palabora is essentially a mica-pyroxenite complex, with a small carbonatite core, and a thin rim of syenite, probably in part of fenitic origin. The ore, mainly chalcopyrite-bornite-chalcocite-cubanite, is found in the carbonatite and to some extent in a surrounding apatite-rich pyroxenite. Although no other concentrations of copper even remotely similar in scale to Palabora have yet been discovered in carbonatite, minor copper concentrations have been discovered in several similar biotite pyroxenites associated with carbonatite. Such bodies occur in Canada (e.g., Big Beaver House, Schryburt Lake), and appear to offer possible targets for copper prospecting. Copper concentration is also known in nephelinitic rocks, both in volcanic rocks, as at the volcano Nyiragongo near Lake Kivu in Zaïre, and in the fenite aureoles surrounding deeper seated nephelinitic complexes, where copper sulphides are common in fractured areas.

The most productive recent prospecting in Canadian alkaline rocks has been for copper in the miaskitic syenites of the Cordillera. Alkaline syenites form a rather well defined arcuate belt extending from the Stikine River district on the Alaska boundary, south to Kruger Mountain on the Washington state boundary. Although the syenites form a single belt, and show many petrographic similarities, they fall into two distinct age groups, one giving K-Ar ages of about 200 m.y., and the other giving ages of about 50 m.y. The older syenites have been known for many years to be mineralized (e.g., Copper Mountain), but very similar mineralization has more recently been found in the younger syenites in the Goosly Lake area. The mineralogy of the deposits varies, but mineralization is commonly found both in the alkaline rocks and in the surrounding formations, and many of the deposits are, in the broad sense, "porphyry coppers." Chalcopyrite and bornite are the main copper carriers, often accompanied by significant amounts of sphalerite and galena, and in a few cases by gold and silver values. The discovery of copper in this chain of syenites suggests the possibility of its presence in the rather similar chain of syenites in the Grenville province of Ontario and Quebec. A similar syenite chain has not been discovered in the analogous position in the Appalachian orogenic belt.

Zirconium

Zirconium is strongly concentrated in agpaitic alkaline rocks, reaching 2 per cent weight in some pegmatite phases, mainly in the form of complex Na-Zr silicates, notably eudialyte. Such rocks offer a potential source of zirconium, but since this metal is mainly used in refractories as an oxide or silicate, considerable metallurgical problems are involved. Eudialyte commonly contains a variety of other elements, notably rare-earths, and seems to be a logical ore for a variety of elements concentrated in alkaline rocks. An experimental operation to recover zirconium and rare-earths from eudialyte was undertaken at Narsaq, West Greenland, and considerable prospecting of the Seal Lake district, Labrador, has been undertaken with the same objective. The complexities of the metallurgy, the erratic grades, and the unusual mineralogy make such deposits uneconomic compared to alluvial zircon deposits.

Baddeleyite (ZrO_2) is recovered as a byproduct from mining operations at Palabora, South Africa, and at Araxa and Poço de Caldas, Brazil. Alkaline rocks are the only known source of substantial amounts of baddeleyite, and if the use of zirconium as a metal increases, this material would be particularly favourable due to its high zirconium content.

Small amounts of gem-quality zircon (cyrtolite) have occasionally been recovered from nepheline pegmatites in the Bancroft region of Ontario, but this operation has never been of significant proportions.

Zr/Hf ratios are notably high in alkaline rocks, and these rocks are not prospective sources of Hf.

Titanium

Titanium is concentrated in much the same way as zirconium, but is also present in more basic alkaline rocks in the form of sphene and titaniferous magnetite. Commonly, such sphene contains large amounts of rare-earths. Some basic alkaline rocks grade as high as 14 per cent TiO_2 over substantial volumes, mainly in sphene and titaniferous magnetite, but the metallurgical problems, and the competition of other sources of titanium do not suggest that these are of economic interest at present. Titanium might, however, be produced as a byproduct of iron, as is now being attempted at Palabora.

Iron

Iron in the form of magnetite is present in significant amounts in almost all rocks of the carbonatite, nephelinite-carbonatite, and alkaline basalt families. Because of the relatively small size of most alkaline complexes, and the lens-like, erratic distribution of the magnetite, few magnetite bodies are likely to be of interest solely as a source of iron. However, production of iron ore as a byproduct has proved feasible at Palabora, South Africa, and at Khibini, U.S.S.R., and has been suggested for several Canadian complexes. Some magnetite concentrations were formerly mined as sources of iron, as at Fen, Norway, and Jacupirange, Brazil.

Thorium and Uranium

Almost all bodies of nephelinitic and carbonatitic affinity, and many of syenitic affinity are markedly radioactive. However, detailed prospecting of alkalic radioactive occurrences has generally proved disappointing because of erratic distribution, generally low grade, and high thorium to uranium ratios. The radioactive elements are most commonly disguised in titanium, niobium, and zirconium minerals, particularly zircon, sphene, and pyrochlore. A possible exception to this pessimistic assessment is the Bancroft area. Some of the carbonate associated with uranium mineralization in this area has been classified as possibly carbonatitic (Heinrich, 1966). This classification, however, seems rather dubious to the author.

Aluminum

Aluminum has been produced from nepheline concentrates in the U.S.S.R. for about 20 years, and a large new plant was recently completed at Krasnoyarsk, Siberia, apparently using nepheline concentrates as mill feed. The nepheline is calcined to produce a mixture of $CaSiO_3$ and $Na_2O.Al_2O_3$. The latter mixture is leached by caustic soda and the solution treated by CO_2 to produce alumina and alkali carbonates (Allen and Charsley, 1968). The costs involved in treating the nepheline are said to be met from the byproducts, which include portland cement and soda. The mining operation at Khibini also produces apatite, magnetite, and a low-grade nepheline concentrate used in the bottle glass industry.

Nepheline gneisses in the southeastern Ontario nepheline belt were extensively examined during the Second World War as a possible emergency source of aluminum, but outside the U.S.S.R. the economics of such recovery do not appear to be attractive. Nonetheless, nepheline-rich rocks, particularly ijolites and urtites, as well as miaskitic syenites, remain enormous potential sources of aluminum.

Nepheline and Nepheline Syenite

In addition to their potential uses as ores of aluminum, nepheline and nepheline syenite have acquired a major position in the glass and ceramic industry. This use is based on their high content of alumina, and the presence of abundant sodium which acts as a flux. Small amounts have also been used in paints and as fillers in plastics. Canada is the largest free-world producer of nepheline syenite, the entire production coming from the Blue Mountain region of Ontario.

For nepheline syenite occurrences to be of economic interest it is necessary that a concentrate consisting entirely of nepheline and alkali feldspar can be made cheaply, efficiently, and uniformly. For glass material the iron content must be less than 0.1 per cent, and even trace amounts of refractory minerals such as corundum or zircon are objectionable. Since the material is high bulk, low value, it is also necessary for a deposit to be located near good transportation, and within a reasonable distance of markets. These considerations seem to militate strongly against most eastern Canadian occurrences. Appropriate occurrences in western Canada, such as Mount Copeland, would seem to be more promising, however.

Vermiculite

Vermiculite is a characteristic accompaniment of ultrabasic rocks associated with carbonatites. The world's largest producer is the Palabora complex of South Africa, but vermiculite could be produced in small quantity from several Canadian complexes. Although transportation difficulties would possibly be fatal to vermiculite mining as a single operation, production from alkaline complexes might be a viable operation if combined with production of iron and phosphate.

Phosphates

Carbonatites, some nephelinite-carbonatites and agpaitic syenites all contain high concentrations of phosphates, almost entirely contained in the mineral apatite. These concentrations are mined at Palabora and Khibini. Numerous potential ores have been outlined in eastern Africa, but most are not economically attractive except in combination with some other product. The situation in North America appears even less attractive in the face of competition from sedimentary phosphate rock, but byproduct recovery of apatite may be feasible.

Corundum

Corundum was formerly widely used as an abrasive. This market has now mainly been taken over by artificial abrasives, except for a few special purposes, for which the properties of natural corundum surpass those of artificial materials, mainly optical grinding flours. Although the southeastern Ontario nepheline gneiss belt formerly produced large amounts of corundum, and many occurrences are known, none of these properties appears to be of any economic significance due to limited markets and the competition of foreign sources of corundum.

Barite

Barite deposits of nephelinitic-carbonatitic derivation are common. Those of commercial interest form veins and replacement bodies outside the complex, commonly in unaltered wall-rocks, as at Malvern, Arkansas, which lies close to the Magnet Cove complex. A possible Canadian example is the barite deposits south of Golden, B.C., which all lie relatively close to the Ice River complex. Barite is also present as late-stage segregations and replacements in carbonatites, as at Mountain Pass, California, and is sometimes concentrated by residual weathering.

Diamond

Diamond is found as a primary mineral only in the rare alkaline ultramafic rock kimberlite, and possibly in the related ultramafic potassic rock cedricite. Kimberlite may be defined as carbonated mica-peridotite characterized by the assemblage olivine, enstatite, chrome diopside, phlogopite, although some authors also insist on the presence of pyrope garnet and/or picroilmenite, a magnesian ilmenite. Such rocks are found most commonly as intensely brecciated and serpentinized polymictic pipes of material, but also exist as massive porphyritic varieties, and as tuffs and tuff breccias. Diamond may or may not be present, but if present it occurs in extremely minute quantities.

Only three occurrences of kimberlite have been definitely identified in Canada, one at Ile Bizard near Montreal in the form of a pipe, with nodules of deep-seated origin, another as a dyke from the Upper Canada Mine, Kirkland Lake, and the third on Somerset Island in the Arctic. Another possible example occurs in Michaud Township, a few miles north of Kirkland Lake. Some rocks which have generally been termed kimberlites do not qualify because their mineral assemblage is incorrect, and such rocks cannot be expected to contain diamonds. About 100 diamonds have been found in alluvial drift around the Great Lakes, presumably weathered from kimberlitic rocks somewhere to the north or northeast. Other occurrences of 'diamond' in the literature, most from British Columbia, have been shown to be periclase.

Two of the three kimberlite occurrences in Canada are connected with the St. Lawrence rift system, and are contemporaneous with alkaline basaltic volcanism. Russian workers suggest that these are general rules, kimberlites being found in an exterior zone around basaltic and alkaline volcanism, particularly where ultrabasic, melilite-bearing rocks are found.

Summary of Economic Considerations

Alkaline rocks occur in three different tectonic settings. The mineral deposits associated with alkaline rocks vary according to the tectonic setting, as well as to the composition of the rocks. Miaskitic syenites of two markedly different ages in the central part of the Canadian Cordillera appear to be consistently mineralized with copper in the form of chalcopyrite–bornite deposits similar to some porphyry coppers. An arcuate belt of such deposits, stretching from Copper Mountain on the south to Galore Creek in the north, curves across the Intermontane Zone of the southern Canadian Cordillera (Wheeler, 1970), bending to the west at its northern end and intersecting the Coast Crystalline complex.

Economic molybdenum mineralization has not been found in unmetamorphosed syenites of this type, but metamorphosed syenites in orogenic belts, such as Mount Copeland, seem to be good potential sources of molybdenum. Such older syenitic rocks might be found by working out the disposition of earlier orogenic episodes in the Cordillera and examining the zones favourable for emplacement of alkaline rocks. Metamorphosed syenites are also a possible source of nepheline and nepheline syenite, which are used in the ceramics industry.

The discovery of metal deposits in the Cordillera suggests that the syenite belt in the Grenville province of Ontario and Quebec is also worth re-examining. The unmetamorphosed bodies such as those at Obedjiwan, Quebec, should be examined for copper mineralization, and the more metamorphosed examples, such as those around Bancroft, should be considered as possible molybdenum prospects, particularly since many occurrences of molybdenite are known from this region.

A belt of alkaline rocks that is similar to one in the northeastern United States may exist in the Appalachian geologic province, but if so, it must be covered by later rocks or largely destroyed by younger intrusions. The most probable location of such a belt would be in northwestern New Brunswick, between the granite belt and the ultramafic belt.

Prospecting applied to alkaline rocks from zones of normal faulting should be aimed at different targets. The syenitic rocks in such settings appear to be relatively barren, although weak copper mineralization has been found in the Port Coldwell complex, and some gold deposits may be associated with the Otto stock. The rocks of major interest, however, are the nephelinitic and ultramafic carbonatites. Such complexes can commonly be found by airborne magnetic survey, although there are well-authenticated examples that have little or no magnetic signature. There is a strong tendency for such complexes to group, and if one is found it is probable that there are others nearby. Such groups of complexes commonly have similar chemistry and mineralogy, although minerals of economic interest are often very erratically distributed. Mineralization of potential economic interest is found mainly in the carbonatitic phases and in the fenite aureoles. The paragenesis of deposits in alkaline complexes is commonly very complex, and careful mapping using diagnostic minerals is necessary to trace mineralized zones. Pyrochlore and perovskite are concentrated in carbonatite, but may occur in ijolite, and even in the country rocks. Copper mineralization is most prominent in the fenite aureole, and molybdenite is virtually confined to it.

Continental fracture systems and associated alkaline rocks may be used as a guide to terrane suitable for diamond prospecting. Suitable techniques of soil sampling can suggest the location of kimberlite bodies, but their exact location in glaciated terrane is an incompletely solved problem. The St. Lawrence rift system and its possible extensions seem the only promising region for diamond prospecting in Canada, although the favourable region may extend outward some tens of miles from the actual faults.

No deposits of commercial importance have been exploited in agpaitic syenites except in the Kola peninsula of Russia. However, the extreme concentration of certain elements in these rocks suggests that they are important potential sources of a number of rare elements, given improved metallurgy and favourable market conditions.

Native copper has been found in the plateau basalts of the Coppermine River, Northwest Territories, Michipicoten Island and surroundings, Ontario, and the Seal Lake district of Labrador. None of these occurrences has yet been shown to be of commercial importance, although these occurrences, and associated sulphide mineralization, have attracted much prospecting interest.

Alkaline rocks contain high concentrations of many elements of commercial importance. In many instances, however, the deposits are sufficiently complex, geologically and metallurgically, that their value cannot be appreciated and evaluated without much additional study.

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PART II: DESCRIPTIONS OF THE ALKALINE ROCKS OF CANADA

Brief descriptions of the occurrences of Canadian alkaline rocks known to the author are given in the following six chapters. The organization of large numbers of such descriptions presents difficulties. First, what constitutes a separate occurrence? Dykes and satellitic intrusions are very common, and in some alkaline rock provinces are not clearly related to any central complex. This problem has been met by a dual solution: (1) by describing the province in general terms before beginning the descriptions of individual bodies, and (2) by collecting the unrelated minor intrusions into a single group. A further step is grouping the various complexes into related clusters, so that similarities and differences may be more easily perceived. The general division used is that outlined in Part I, namely alkaline basalt, nephelinites, ultramafic carbonatites, miaskitic syenites, agpaitic syenites, and nepheline gneisses. Within these divisions it has been found helpful to subdivide; the subdivisions are explained at the beginning of each chapter. Finally, a relatively rigid format has been adopted for describing each individual occurrence. Although this format forms a somewhat Procrustean bed, the data are presented as concisely, clearly, and consistently as possible.

Chapter III

The Alkaline Basalt Family

Among alkaline rocks, alkaline basaltic rocks are distinguished by their high content of calcic plagioclase, commonly labradorite, and a characteristic purplish titanaugite. Olivine is commonly present, although in subordinate amounts, but feldspathoids are rare, and seldom form a substantial percentage of the volume, although rare transitions to nephelinite occur among lavas. Primary feldspathoids are virtually restricted to nepheline and analcite in plutonic varieties, and to nepheline, hauyne, and leucite in volcanic rocks. Other rocks, sometimes termed basalts, such as 'melilite-basalt,' and others, are members of the nephelinite family.

There is a continuum of basaltic compositions between tholeiitic basalts, with a little normative quartz, through olivine basalts, with hypersthene and olivine in the norm, to alkaline basalts with nepheline in the norm. This continuum can be explained by modern theories of basalt genesis. Suites of basaltic rocks do not show a sharp differentiation into alkaline and subalkaline varieties, but rather a variety of transitions. Within the alkaline part of this spectrum, three different suites of alkaline rocks are defined. First, basaltic rocks of transitional chemistry, i.e., suites of rocks in which some analyses are alkaline, and others, subalkaline. This situation is most common among the 'plateau basalts' or 'flood basalts.' Second, there are suites of rocks which remain moderately alkaline throughout, but which show little differentiation. Finally, some alkaline basalt complexes display strong differentiation, with the development of salic residuals. Just as alkaline basalts are transitional between alkaline and subalkaline mafic rocks, so the salic differentiates tend to be transitional. Even in the same complex both silica-undersaturated and silica-saturated salic rocks may be found.

Plateau basalts, i.e., large outpourings of little-differentiated basaltic rocks from fissures or ill-defined vents associated with large-scale rifting, are commonly described as tholeiites in petrology textbooks. Recent work, however, has shown that this generalization is not correct (Baragar, 1969; Kuno, 1969), and that almost all continental flood basalts contain a significant number of nepheline normative flows. Plateau basalts are essentially surface features, thus subject to destruction by erosion, although their feeder dykes should persist. Identification of such dykes is difficult without chemical analyses and detailed petrographic work. The sheer volume of feebly alkaline rocks in plateau basalts makes them a potentially very significant source of secondary alkaline rocks by rheomorphism and anatexis. Plutonic equivalents of such rocks appear to be rare. Most gabbroic complexes contain substantial amounts of either hypersthene or feldspathoids in the norm.

Selected references

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Plateau Basalts

Name	Coppermine River (B-11; Fig. 4)
Location and access	The basalts of the Coppermine River Group cover an area of about 5,000 square miles extending from Great Bear Lake to Coronation Gulf, centred near 68°N, 116°W. The region is almost inaccessible except by aircraft, although there is ship service from Tuktoyaktuk to Coppermine.
Form and structure	A 10,000-foot-thick pile of little-differentiated basalt flows, most less than 50 feet thick. Presumably related dykes are found cutting the older rocks to the south, and the tholeiitic Muskox layered complex is thought to be a plutonic equivalent.
Petrography	The crystallized parts of the flows consist principally of labradorite and pyroxene, which in the alkaline flows is titanaugite. Rare modal nepheline also occurs. Each flow tends to become more alkaline toward its top, and the volcanic pile in general becomes more alkaline toward the top. Representative analyses are shown in Table 2.
Age	Whole rock K-Ar ages tend to cluster in the 1,100–1,200 m.y. bracket. A whole rock Rb-Sr isochron gave 1,210 m.y.
Economic aspects	Occurrences of native copper in the Coppermine River lavas have been known for centuries. They have recently excited renewed prospecting interest.
Selected reference	Baragar, W.R.A. (1969); The geochemistry of the Coppermine River basalts; Geol. Surv. Can., Paper 69-44.

TABLE 2 *Chemical analyses of the Coppermine River basalts and related rocks*

	1	2	3	4	5	6	7	8
SiO_2	51.2	48.0	49.6	46.3	47.2	46.7	49.79	51.56
Al_2O_3	13.1	12.4	13.4	13.4	13.4	13.9	14.71	13.57
Fe_2O_3	4.6	5.8	5.8	5.1	5.6	4.4	9.52	2.00
FeO	6.8	7.0	7.2	10.1	9.1	8.2	4.20	7.80
MgO	7.3	7.5	6.8	7.0	6.2	9.0	3.70	8.26
CaO	7.0	7.0	7.8	7.4	8.1	5.7	3.50	10.80
Na_2O	2.7	3.6	2.8	3.7	3.1	4.3	4.85	2.28
K_2O	2.0	2.1	1.5	0.9	1.2	1.1	3.53	0.69
TiO_2	1.84	1.64	2.21	2.01	2.54	1.35	1.33	.79
P_2O_5	0.18	0.18	0.22	0.17	0.26	0.10	0.14	—
MnO	.17	.24	.21	.26	.23	.28	.22	0.12
H_2O	3.0	3.0	2.8	3.0	2.7	3.9	2.71	—
CO_2	0.5	0.1	0.3	0.2	0.2	0.1	2.03	0.09
Total	100.39	98.56	100.00	99.54	100.00	99.03	100.23	98.56
				Molecular norm				
q	3.54	—	2.30	—	—	—	—	—
or	11.20	11.96	8.65	5.68	7.04	6.71	15.76	2.97
ab	23.48	31.00	24.32	33.54	27.10	37.45	27.31	16.47
ne	—	0.27	—	0.28	—	0.56	5.46	—
an	16.81	11.42	18.91	17.34	18.43	7.68	14.29	33.33
di	15.74	21.75	18.10	14.50	19.24	26.00	2.52	4.96
hy	22.01	—	18.78	—	16.26	—	—	20.04
ol	—	15.70	—	20.25	2.30	21.03	5.67	15.28
ap	0.27	0.27	0.27	0.28	0.54	0.28	0.42	—
il	3.07	2.71	3.78	3.55	4.34	2.34	3.57	1.98
mt	3.87	4.89	4.86	4.55	4.74	3.91	24.99	4.96

1. Average Coppermine basalt (lower member).
2. Typical nepheline normative basalt (lower member).
3. Average Coppermine basalt (middle member).
4. Nepheline normative basalt (middle member).
5. Average Coppermine basalt (upper member).
6. Nepheline normative basalt (upper member).

(The above analyses from Baragar, 1969).

7. Average Seward lava, (from Dimroth *et al.*, Geol. Surv. Can., Paper 70-40, p. 45–143).
8. Average Bay of Fundy lava (from Powers and Lane, Bull. Amer. Inst. Mining Engr. for 1916, p. 535–548).

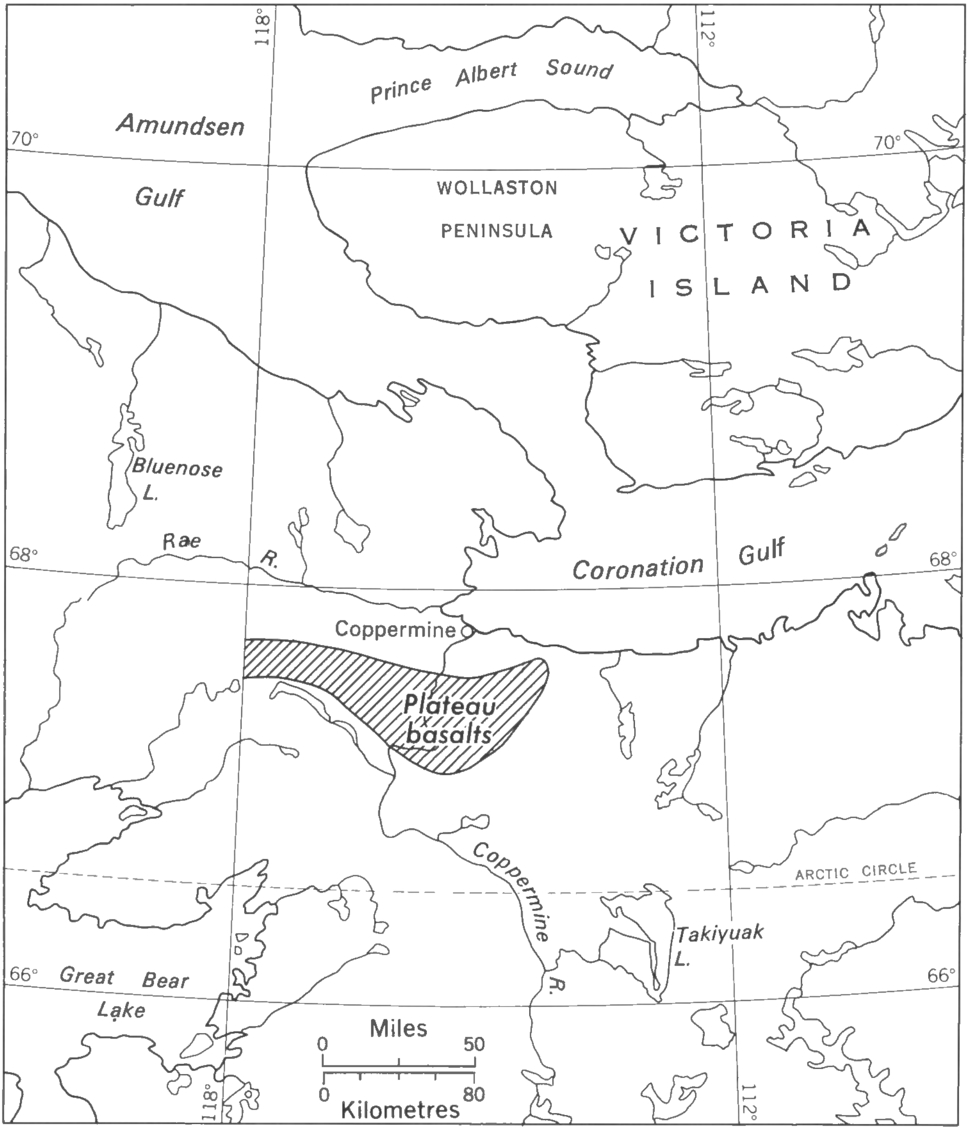

FIGURE 4. Plateau basalts in the Coppermine River area (modified from GSC Map 1250A).

Name	Michipicoten Island (B-13; Fig. 5)
Location and access	Michipicoten Island, about 17 miles long by 6 miles wide, lies in the eastern part of Lake Superior, 100 miles northwest of Sault Ste. Marie, Ontario. The island may be reached by scheduled ferry. Similar rocks are found at Cape Gargantua and Mamainse Point on the mainland, which are readily accessible via Ontario Highway 17 from Sault Ste. Marie.
Form and structure	Repetitive sequence of thin flows, totalling some 14,300 feet of section, now dipping at moderate angles to the south and southwest.

Petrography	The rocks consist of moderately to highly altered dark olivine basalts of medium to coarse grain size, including some distinctive rocks with glomerophyric feldspar. About 15 to 20 per cent of the chemical analyses is either nepheline normative, or has positive Poldervaart numbers.
Age	The age is not definitely known, but may be about 1,400 m.y., based on radiometric ages of other Keweenawan rocks believed to be of similar age.
Economic aspects	Showings of native copper, and of chalcocite-bornite mineralization have been known on Mamainse Point for many years, and have more recently been reported from Michipicoten Island.
Remark	The plateau basalts of the Seal Lake district, central Labrador, are sufficiently similar to the Michipicoten sequence that speculative suggestions have been made that the 'Grenville front' represents a much altered rift-type structure along which the two regions were once joined (W.R.A. Baragar, pers. com., 1972).
Selected reference	Annells, R. N. (1973): Proterozoic flood basalts of eastern Lake Superior; The Keweenawan volcanic rocks of the Mamainse Point area, Ontario; Geol. Surv. Can., Paper 72-10.

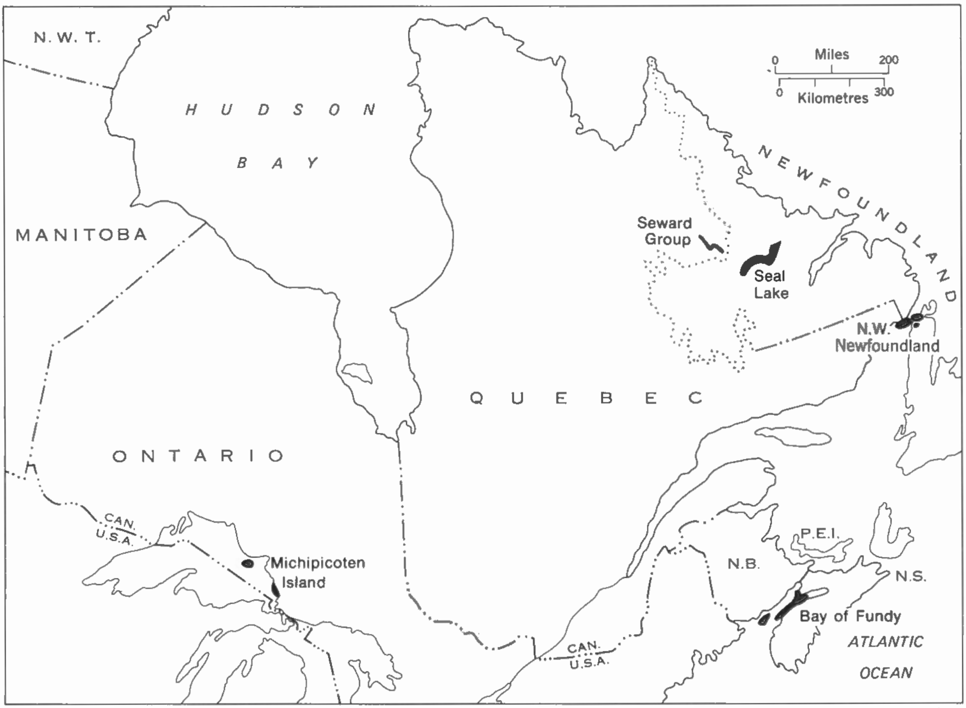

FIGURE 5. Plateau basalts in eastern Canada.

GSC

Name	Bay of Fundy (B-117)
Location and access	Southeastern shore of the Bay of Fundy, and various islands within the bay, extending southward into the United States. The Nova Scotia localities, including the celebrated zeolite locality at Cape Blomidon, can be reached by road with short walks, but the islands, including Grand Manan, can be reached only by boat. Many of the exposures are precipitous.
Form and structure	Approximately 1,000 feet of generally tholeiitic flows, contained within a thicker sequence of polymictic conglomerate, sandstone, and minor shale. The trough in which these rocks are found may, in part, be fault controlled.
Petrography	The basalts are made up of roughly equal amounts of labradorite and diopsidic augite, with accessory magnetite. Olivine is present locally, and glass forms up to 40 per cent of the rocks. About one fifth of the analyses (Table 2, column 8) is nepheline normative, even though quartz is known to occur in vugs in some of the basalts. Substantial amounts of agglomerate and tuff are locally present.
Age	An average of five K-Ar dates (whole rock) gives 198 m.y., that is, latest Triassic.
Economic aspects	Unknown. Native copper has been reported.
Remark	The Tertiary plateau basalts of Cape Dyer, eastern Baffin Island, show many similarities to the Bay of Fundy basalts, but as yet no analyses with normative nepheline have been reported from this district.
Selected reference	Powers, S. and Lane, A. C. (1916): Magmatic differentiation in effusive rocks; Bull. Amer. Inst. Mining Engr., v. 110, p. 535–548.

Name	Central British Columbia plateau basalts (B-14; Fig. 6)
Location and access	Plateau basalts occur in a north-northwest-trending belt about 100 miles wide by 300 miles long, extending northward from Kamloops. Numerous outliers of this belt occur, stretching into northern British Columbia and possibly into the Yukon, and southward to the possibly related Columbia River plateau basalts in the United States. Parts of this vast area are readily reached by highway, but others are inaccessible.
Form and structure	The plateau basalts consist of an intricately layered assemblage of huge, flat volcanic shields, and interlayered flows of fissure-type. The proportion of eruptions from central vents increases with time, so that the youngest parts of the sequence are confined to the region of central volcanoes along linear features controlled by deep-seated zones which can be identified with plate tectonics. Large parts of the basalt assemblage are preserved by downfaulting along normal faults roughly parallel to the trend of the belt.
Petrography	The rocks are mainly composed of primitive olivine basalt, with a rather high proportion of glass. Chemical analyses (Table 3) are more consistently alkaline than are those from most other plateau basalt provinces, but this may be a result of sample selection, rather than a true reflection of over all composition.
Age	The oldest K-Ar ages range from 10 to 13 m.y., or Miocene, with ages ranging downward to a radiocarbon date of 220 years for the Aiyansh flow, possibly the most recent volcanic event in Canada.
Economic aspects	Unknown.
Selected references	Souther, J. G. (1970): Volcanism and its relationship to recent crustal movements in the Canadian Cordillera; Can. J. Earth Sci., v. 7, p. 533-568. Sutherland-Brown, A. (1969): Aiyansh lava-flow of British Columbia; Can. J. Earth Sci., v. 6, p. 1460–1468.

TABLE 3 *Chemical analyses of alkali olivine basalts from central British Columbia*

	1	2	3
SiO_2	45.80	46.24	44.00
Al_2O_3	14.75	15.79	15.11
Fe_2O_3	2.12	2.86	3.63
FeO	13.64	11.81	7.90
P_2O_5	0.87	1.00	0.58
CaO	9.81	7.94	9.86
MgO	2.30	4.43	8.62
TiO_2	3.79	3.00	3.01
MnO	0.22	0.15	0.18
SO_3	.15	.09	—
Na_2O	3.83	2.40	4.48
K_2O	2.60	3.90	1.73
CO_2	0.01	—	0.01
H_2O-	.06	—	.44
H_2O+	.11	0.10	.26
TOTAL	100.06	99.71	99.81
Plagioclase	40.7	49.0	28
Olivine	14.9	10.1	9
Pyroxene	?	30.0	—
Opaque	11.3	10.9	—
Glassy matrix	33.6	—	63

1, 2. Aiyansh lava-flow (Recent, after Sutherland-Brown, 1969).
3. Poplar buttes (Pliocene, after Church, 1970, p. 124).

Name	Northwestern Newfoundland (B-118)
Location and access	Plateau basalts occur at Cloud Mountain on the east side of the Great Northern Peninsula, at Belle Isle between Newfoundland and Labrador, and in the Table Head–Henley Harbour area of southern Labrador. These localities are best reached by boat.
Form and structure	The basalts form the Lighthouse Cove Formation, from 50 to 400 feet thick, which overlies Precambrian gneisses or Lower Cambrian sedimentary rocks. Both dykes and flows occur, and dykes spread considerably beyond the present limits of exposure, suggesting an originally wider extent.
Petrography	The rocks are now extensively altered to chlorite and epidote but originally consisted of plagioclase zoned from labradorite to oligoclase, augite, opaque oxides, often skeletal, and local olivine. Considerable amounts of chloritized material, probably representing devitrified glass, are locally present. Four of twenty-five analyses are nepheline normative (Table 1), which is about average for this type of basalt. Twelve analyses are quartz normative, but this may be due, in part, to secondary alteration.
Age	The stratigraphic age is firmly fixed as Lower Cambrian by exposures on Belle Isle, but radiometric dates on supposedly related dykes vary from 344 to 805 m.y.
Economic aspects	None known.
Remarks	Similar basic lavas are present in eastern Quebec (Tibbit Hill Formation), but their chemistry is poorly known. Potassic alkaline basalts (shoshonites) have been reported from the Bathurst area of New Brunswick (D. Jones, pers. com., 1971). All these lavas could presumably be part of a sequence along the western edge of the Appalachian province.

Selected reference Strong, D. F. and Williams, H. (1972): Early Paleozoic flood basalts of northwestern Newfoundland; their petrology and tectonic significance; Geol. Assoc. Can. Proc., v. 24, p. 43–54.

FIGURE 6. Tertiary and Quaternary plateau basalts in British Columbia (after Souther, 1970).

Strongly Alkaline Basalts

Name Horsefly Creek 'leucite' basalt (B-119)

Location and access Boulders of basalt-bearing, large, trapezohedral, white phenocrysts up to an inch across occur near the mouth of Horsefly Creek where it empties into Quesnel Lake (52°27′N, 121°26′W) near the site of an old placer gold mine. This material was reported to be leucite by Hoffman (1894), but recent re-examination shows the material to be analcite (A. M. Soregaroli, written com., 1973). Leucite-bearing volcanics have also been reported from the headwaters of Horsefly Creek on Big Timothy (Big Takomkane) Mountain (Peach, 1963), but this occurrence is also unconfirmed.

Form and structure Unknown. Big Timothy Mountain consists of a recent basaltic volcano situated on the older Takomkane batholith of granodiorite composition. Fresh cinder cones occur a few miles to the east on the boundary of Wells–Grey Provincial Park.

Petrography	Analcite occurs in the boulders in the form of dodecahedral phenocrysts up to 2 inches across in a dark grey, medium- to fine-grained basaltic matrix. The mineral, which may be leucite in Big Timothy Mountain, is very fine grained and interstitial.
Age	Unknown, but probably younger than Miocene.
Economic aspects	None known.
Remark	These are the only reported occurrences of leucite (as opposed to pseudoleucite) from Canadian rocks, although there is an apocryphal reference in Dana's Textbook of Mineralogy, 4th ed., p. 551, to an occurrence in boulders on the shores of Vancouver Island, and a recent unconfirmed report from southern British Columbia (Monger, J. H. (1968): Geol. Surv. Can., Paper 67-42.
Selected references	Hoffman, G. C. (1894): Geol. Surv. Can., Ann. Rept. VII, pt. R, p. 13–14. Peach, P. (1963): International Upper Mantle Project–Canadian Progress Report.

Name	Seward Group lavas (B-12; Fig. 5)
Location and access	Lavas outcrop in an elongate, discontinuous belt from Seward Lake to Hematite Lake (54°N, 66°W to 56°26′N, 68°54′W) along with gabbroic sills.
Form and structure	The Seward lavas are a group of lava flows of indeterminate thickness occurring along the eastern edge of the miogeosynclinal part of the Labrador Trough. Farther to the north probably similar rocks (Nimish volcanics) lie higher in the sequence than the Seward Group, which directly overlies the Archean basement. The sill at Hematite Lake appears to have a stratigraphic level approximately equivalent to the level of the Nimish volcanics.
Petrography	The lavas are composed of a fine-grained assemblage of feldspar and chlorite clouded with finely divided iron oxide. The feldspar is probably alkalic. Chemical analyses (Table 2) show that they are distinctly alkaline.
Age	Early Proterozoic, according to stratigraphic position.
Economic aspects	None known.
Remarks	Numerous large slabby boulders of nepheline syenite occur in the same general area as the alkaline gabbro sill at Hematite Lake (J. Gittins, pers. com., 1972). A differentiated central complex may exist in this area.
Selected reference	Dimroth, E., Baragar, W. R. A., Bergeron, R., and Jackson, G. D. (1970): The filling of the circum-Ungava geosyncline; *in* Symposium on basins and geosynclines of the Canadian Shield, A. J. Baer, ed., Geol. Surv. Can., Paper 70-40, p. 45–143.

Name	Currie Mountain (B-12)
Location and access	Six miles west of Fredericton, N.B., on the north bank of Saint John River. The knoll is located in a bend of Highway 21.
Form and structure	Currie Mountain itself forms a prominent knoll some quarter mile in diameter and 150 feet high. A thin horizon of basaltic rocks occurs in the surrounding Pennsylvanian red beds and conglomerates, and is assumed to be cogenetic with Currie Mountain.
Petrography	The rocks are fine-grained alkali basalts showing strong flow textures. Phenocrysts of labradorite, clinopyroxene, and olivine are abundant in a groundmass mainly composed of andesine with minor titanaugite. Talc and carbonate alteration is abundant. Analyses are mildly but persistently alkaline (G. Pajari, pers. com., 1972).

Age	The stratigraphic age of these rocks was formerly thought to be well defined as Carboniferous, but the conformable nature of the flows does not seem to be well established, and the rocks might be as young as Triassic.
Economic aspects	None known.
Selected reference	Poole, W. H. and Anderson, F. D. (1959): Woodstock–Fredericton; Geol. Surv. Can., Map 37–1959.

Name	Notre Dame Bay (BM-10)
Location and access	Lamprophyre dykes outcrop on the shore of the Notre Dame Bay region, Newfoundland, particularly in the vicinity of older granite batholiths. Most of the localities can be reached only by boat.
Form and structure	The dykes vary in width from 1 inch to 5 feet, and are, in detail, sinuous, anastomosing, and irregular, although most have a well-defined northeasterly trend. Internal zoning with multiple fine-grained or chilled selvages are common. The dykes consistently cut granites thought to be of Devonian age.
Petrography	The mafic phenocrysts are zoned titanaugite and biotite, with local olivine, commonly altered. The groundmass contains augite, kaersutite, biotite, and labradoritic plagioclase, and sporadic primary carbonate. Some dykes contain glass. Chemical analyses (Table 4) are very similar to those of the Monteregian Hills.
Age	Amphibole and biotite give K-Ar ages ranging from 115 to 144 m.y.
Economic aspects	None known.
Remark	The age, petrography, and chemistry of these rocks strongly suggest links to the Monteregian province.
Reference	Heyl, G. R. (1936): Geology and mineral resources of the Bay of Exploits area; Nfld. Dept. Nat. Resources, Bull. 3.

TABLE 4 *Chemical analyses of dykes from Notre Dame Bay, Newfoundland (after Heyl, 1936)*

Chemical analyses of lamprophyre dyke					
	Chemical analyses (%)			Norms (%)	
	1*	2*		1	2
SiO_2	36.11	37.07	Or	15.01	10.01
Al_2O_3	12.00	11.83	Ab	13.05	10.27
Fe_2O_3	7.87	7.59	An	17.79	15.29
FeO	8.00	6.90	Ne	0.60	6.65
MgO	7.87	9.42	Di	8.68	18.45
CaO	10.13	10.20	Fo	10.99	10.57
Na_2O	1.67	2.68	Mag	10.67	6.50
K_2O	2.48	1.74	Il	10.34	10.79
H_2O+	2.74	2.61	Hem	0.48	3.20
H_2O-	1.51	0.99	Ap	2.69	2.02
CO_2	2.27	0.95	Cal	5.10	2.20
TiO_2	5.44	5.66	Plag	$Ab_{44}An_{56}$	$Ab_{42}An_{58}$
P_2O_5	1.10	0.93			
MnO	0.22	0.18			
TOTAL	99.41	98.75			

*Analyses by A. Willman
1. Chilled facies of lamprophyre dyke, Lobster Cove, Exploits Island.
2. Central zone of lamprophyre dyke, Lobster Cove, Exploits Island.

Differentiated Complexes

Name	The Monteregian Hills[1] (BM-1 to BM-9, NM-42, NM-43; Fig. 7)
Location and access	The alkaline rock province of the Monteregian Hills (named by F. D. Adams from the type pluton Mount Royal = Mons Regius) stretches 120 miles from Oka, some 20 miles west of Montreal, eastward to Mount Megantic on the Maine–Quebec border. The exact boundaries are not clear, and it is possible that minor intrusions of the same group are found at even greater distances. All the known intrusions are found within easy access from highways.
Form and structure	The Monteregian province is composed of 10 principal plutons, ranging from 0.5 mile to more than 3 miles in largest dimension. All tend to be subrounded, zoned plutons. Minor intrusions in the form of dykes and sills are very numerous, in some places clearly satellitic to the major bodies. The Monteregian plutons are found along a belt colinear with the Ottawa valley graben, a trend parallel to a broad positive gravity anomaly seated some 10,000 to 15,000 feet below the surface, but cutting across a variety of tectonic provinces.
Petrography	The Monteregian province shows a marked change in composition from east to west, becoming progressively poorer in silica and richer in calcium, iron, and magnesium. East of Montreal the rocks are generally of gabbroic affinities, typified by the presence of kaersutitic amphibole, titanaugite and, commonly, of olivine. Feldspars are abundant, with plagioclase in the gabbroic rocks, and perthites in the more differentiated varieties. There is a distinct tendency toward agpaitic composition in the late differentiates, some of which are silica-saturated. West of Montreal the rocks do not contain feldspar, and hence fall into the nephelinite family. Such rocks tend to be emplaced in the form of breccia pipes rather than dykes, and the major plutons end with the nephelinitic Oka complex.
Age	Radiometric age determinations range from 95 to 115 m.y. for K-Ar ages on biotite, with Rb-Sr ages tending to be slightly less (85–114 m.y.). The Monteregian Hills also show a tight cluster of paleomagnetic poles consistent with a Lower Cretaceous age.
Economic aspects	No significant metallic deposits are known to be related to the basaltic rocks of the Monteregian Hills. Such rocks have been quarried in a number of places as a source of cement material, and as road aggregate.
Remarks	The Monteregian Hills are probably the best studied alkaline province in Canada. Many of these studies have concentrated on very fine points however, and some of the general relations of the Monteregian Hills are still not clear.
Selected references	Adams, F. D. (1903): The Monteregian Hills; a Canadian petrographic province; J. Geol., v. 11, p. 239–282. Larochelle, A. (1968): Paleomagnetism of the Monteregian Hills, new results; J. Geophys. Res., v. 73, p. 3239–3246. Pouliot, G. (ed.) (1969): Guidebook for the geology of Monteregian Hills; Geol. Assoc. Can.–Mineral Assoc. Can., Montreal, 169 p. Zartman, R. E., Brock, M. R., Heyl, A. V., and Thomas, H. H. (1967): K-Ar and Rb-Sr ages of some alkalic intrusive rocks from central and eastern United States; Amer. J. Sci., v. 265, p. 848–870.

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[1] For the purpose of this report it is accepted that the geological features were named originally in English and, therefore, plutons will be referred to as "Mount Royal," "Mount Johnson," etc. In recent years some of the geographic features comprising the Monteregian Hills have been renamed and different generics have been applied in different reports. Toponymic designations as approved in November 1974 are used on the figures illustrating this report, with the result that there is a difference between the illustrations and the text. However, consistency in geological nomenclature is maintained.

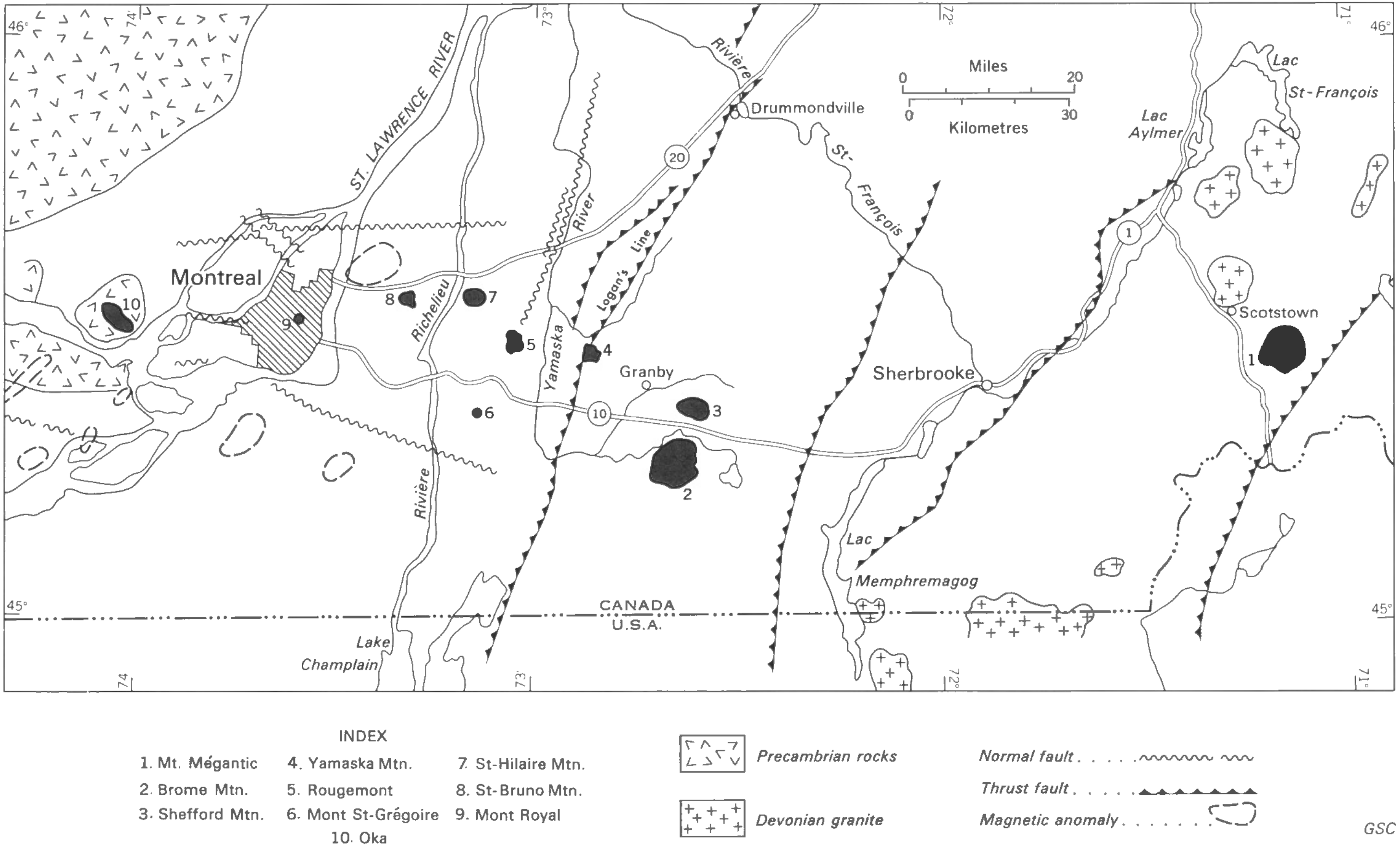

FIGURE 7. The Monteregian Hills (after Pouliot, 1969).

Name	Mount Royal (BM-1; Figs. 7, 8)
Location and access	Mount Royal lies in the heart of downtown Montreal. Virtually all of the igneous rocks of the main pluton are within Mount Royal Park, and the cemetery adjoining it to the north. However, numerous smaller dykes and satellitic masses are found, particularly to the north and east, along Côte des Neiges Road and Boulevard Édouard-Montpetit.
Form and structure	Mount Royal, with an area of 1.25 square miles, is a crudely elliptical pluton, elongated along a northeast-trending axis, which shows poorly defined concentric zoning, and local layering. The pluton cuts flat-lying Utica shales and Trenton limestones of Ordovician age, which are warped and twisted near the contact, with generally inward dips. Within a metamorphic aureole less than 400 feet wide, shales have been raised to hornblende hornfels facies.
Petrography	The pluton is composed principally of melanocratic gabbros and associated ultramafic rocks, with subordinate, generally marginal screens of nepheline diorite and nepheline monzonite. An abundant dyke suite includes lamprophyres and feldspathoidal- and quartz-bearing monzonites. The mafic rocks occur in lenticular masses grading into one another. Pegmatitic and fine-grained varieties occur but are subordinate to the monotonous medium-grained and coarse-grained varieties characteristic of this stock. The diversity of rock-types results from varying amounts of augite ($2V=+44\text{–}51^\circ$) commonly zoned, and occasionally titaniferous, olivine (Fo_{80}–Fo_{64}), plagioclase (An_{80}–An_{65}), and kaersutite ($2V=-70-80^\circ$). The minerals are generally subhedral, and the texture ophitic, with accessory biotite, sphene, magnetite, and ilmenite. Nepheline diorite forms a strongly layered screen within this mass, composed of roughly 50 per cent andesine, 11 per cent kaersutite, 6 per cent titanaugite, 7 per cent alkali feldspar, 10 per cent nepheline, and accessory sodalite, sphene, opaques, and apatite. Nepheline monzonite occurs as dykes a few inches to a few feet wide, locally so numerous that the rock is best described as an intrusive breccia. The northern flank of the intrusion contains 50 to 100 per cent monzonite, comprised mainly of normally zoned plagioclase (An_{45}–An_{15}), and alkali feldspar (Or_{60}–Or_{70}), commonly in roughly equal amounts, together with variable but subordinate amounts of kaersutite with green hastingsite rims, aegirine-rimmed augitic pyroxene, nepheline, and accessory garnet, sodalite, sphene, apatite, zircon, and opaques. Some rare, small dykes have pegmatitic, miarolitic textures, and contain quartz. Fine-grained lamprophyric dyke rocks were emplaced simultaneously with the monzonites. They correspond in most cases to the composition of mafic units in the pluton, the most common being composed mainly of kaersutite and calcic plagioclase. Chemical analyses of the Mount Royal pluton display a sharp division into basic and acid types (Table 5).
Age	A whole rock Rb-Sr age gives 110 m.y. for the Mount Royal pluton in agreement with the paleomagnetic age.
Economic aspects	None known, although some satellites of the Mount Royal pluton have been quarried.
Remarks	Mount Royal shows in subdued form the sharp division between mafic and salic phases characteristic of Mount St-Hilaire, and also the tendency for the salic rocks to be agpaitic. These observations suggest that such behaviour is typical of the basaltic magma in this part of the Monteregian province.
Selected reference	Gelinas, L. (1972): Geology of Mount Royal; 24th Intern. Geol. Cong. Guidebook for Excursion B-12.

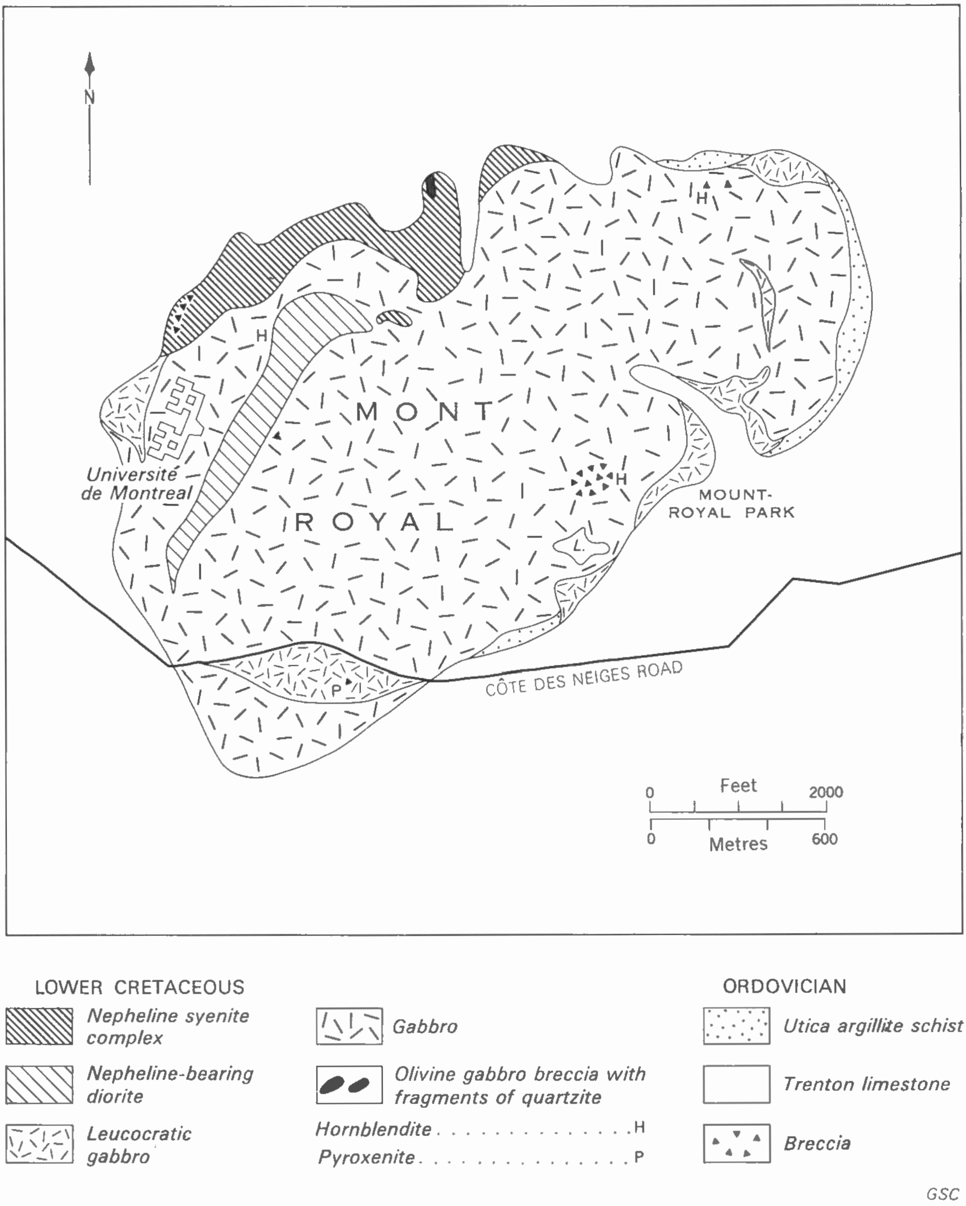

FIGURE 8. Geology of the Mount Royal pluton (after Gelinas, 1972).

TABLE 5 *Chemical analyses of rocks from the Mount Royal pluton (after Gelinas, 1972)*

	1118	1102	1117	1100	1105	1104	1108	1112	1130	1129	1124	1114
SiO_2	33.62	36.32	39.80	43.20	44.82	46.19	47.64	52.92	53.87	55.19	60.64	63.91
Al_2O_3	10.90	13.94	15.30	8.41	16.45	16.42	17.08	20.22	19.45	20.52	18.21	20.21
TiO_2	6.31	5.48	4.92	2.81	4.13	3.69	3.50	1.70	1.58	0.88	0.88	0.13
FeO	9.73	8.36	6.23	7.04	4.76	4.95	5.42	2.72	3.05	2.48	.56	.36
Fe_2O_3	10.78	7.21	7.26	5.39	5.50	3.03	2.99	1.61	3.03	1.56	3.74	1.10
MnO	0.23	0.20	0.20	0.19	0.22	0.27	0.23	0.28	0.24	0.18	0.11	0.06
MgO	8.09	10.02	6.11	15.98	5.51	4.88	4.20	1.54	1.26	.85	.54	.02
CaO	14.69	13.58	13.98	15.63	11.61	12.12	10.54	7.47	6.47	3.76	2.87	.91
Na_2O	2.34	2.30	3.11	0.92	4.07	5.40	5.29	7.30	6.64	8.89	7.51	7.40
K_2O	0.77	0.75	1,05	.34	1.80	1.94	2.49	3.96	4.11	5.52	4.77	5.88
P_2O_5	2.54	1.84	2.04	.09	1.13	1.11	0.62	0.29	0.30	0.17	0.17	0.02

(Totals adjusted to 100 per cent by the analyst, B. M. Gunn)

Location of analyses:
1118. Alkaline peridotite, Université de Montreal entrance on Blvd. Édouard Montpetit.
1102. Titanaugite gabbro, Blvd. Camilien Houde.
1117. Titanaugite gabbro, same location as 1118.
1100. Alkaline peridotite, east of Lac Castor.
1105. Foliated leucocratic kersantite, U. de M. escalator tunnel.
1104. Nepheline diorite, 200 yards east of Ecole Polytechnique.
1108. Tephrite dyke, Ecole Polytechnique parking lot.
1112. Nepheline monzonite, Ecole Polytechnique parking lot.
1130. Nepheline monzonite, Blvd. Édouard Montpetit at Centre Social.
1129. Nepheline monzonite, footpath, rear of Ecole Polytechnique.
1124. Quartz monzonite, end of Ridgewood Ave.
1114. Nepheline monzonite, same location as 1118.

Name	Mount Bruno (BM-2; Figs. 7, 8, 9) (also called Mt. St. Bruno)
Location and access	About 10 miles east of Mount Royal, forming a low wooded hill less than a mile north of Highway 9 (45°30′N, 73°20′W).
Form and structure	The Mount Bruno pluton underlies a low wooded hill from which a prominent fillet of glacial material trails away to the south. The pluton is irregularly elliptical in shape, with a northwest-southeast axis, but the exposure is poor. Steeply dipping foliation is concentric about a point in the northwestern part of the intrusion. The pluton intrudes poorly exposed Ordovician shales that have been hornfelsed into a prominent topographic high, within which three central lakes cover much of the pluton.
Petrography	The pluton is principally composed of feldspathic peridotite. Cumulus olivine (Fo_{84-78}) and titanaugite ($z \Lambda c = 42-52°$, $2V = 45-50°$) comprise most of the rock, but plagioclase (An_{60-69}) is always present, increasing in abundance toward the centre of the intrusion, where it becomes a cumulus phase, making the rock a well-layered gabbro. Along the southern margin, the peridotite contains kaersutite, and locally nepheline. A narrow breccia zone, up to 30 feet wide, surrounds the intrusion. It is composed of distorted and partly assimilated hornfelsed sedimentary rocks in a fine-grained biotite-plagioclase-quartz matrix, presumably resulting from melting of the country rocks by the intrusion. Peridotite in contact with this breccia displays hypersthene rims around the olivine, and partial replacement of augite by biotite. Hypersthene and quartz-bearing gabbro of related character form a large body in the northwestern part of the pluton, and a series of east-west-trending dykes east of the main lake. The youngest rocks are quartz-bearing alkali syenites forming a north-trending, dyke-like mass in the southern part of the intrusion, and abundant lamprophyre dykes in the hornfels collar. The latter are commonly so charged with olivine and pyroxene phenocrysts that they approximate the same composition as the rest of the mass.
Age	No radiometric age is available for Mount Bruno, but the paleomagnetic pole is concordant with other Monteregian intrusions.

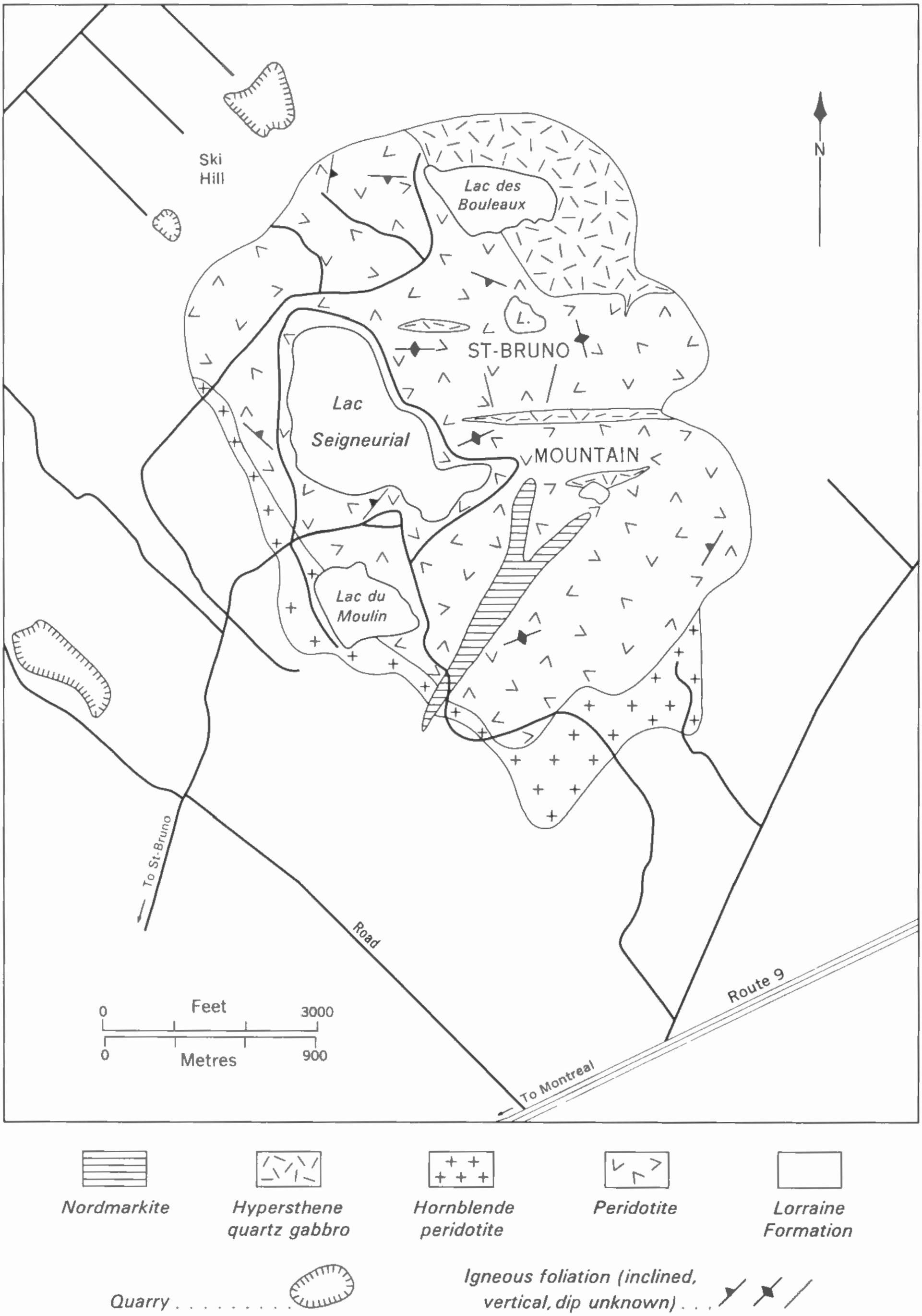

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FIGURE 9. Geology of the Mount Bruno pluton (after Philpotts, 1969).

Remark	The incidence of nonalkaline rocks in the Mount Bruno pluton presumably reflects the results of rheomorphism of the wall-rocks.
Selected references	Dresser, J. A. (1910): Geology of St. Bruno Mountain, Quebec; Geol. Surv. Can., Mem. 7. Philpotts, A. R. (1969): Notes on the geology of Mt. Bruno; Guidebook for the geology of Monteregian Hills, G. Pouliot, ed., Geol. Assoc. Can.–Mineral. Assoc. Can., Montreal, p. 75–76.

Name	Mount St-Hilaire (BM-3; Figs. 7, 10) (also called Beloeil or Rouville Mountain in older literature)
Location and access	Just east of the town of St-Hilaire, about 2 miles south of Autoroute 20 between Montreal and Quebec City. Most of the mountain is owned by McGill University, and the west half is open to the public as a park.
Form and structure	Mount St-Hilaire forms a prominent wooded hill about 2½ miles in diameter, rising 1,100 feet above the surroundings. The north side exposes precipitous rock faces, whereas the southern side is covered by gently sloping drift. The pluton is shaped like a crude figure-of-eight, with the long axis east-west. The western, gabbroic part of the intrusion, about 1½ by 2 miles, is composed of concentric rings of steeply dipping, layered gabbro and diorite. The eastern half of the pluton consists of a zoned phonolitic mass, locally showing prominent flow texture, characterized by an enormous number of inclusions, some of them large enough to be mappable. The median zone between the two halves of the intrusion is complex and poorly understood. Gabbros and phonolites interfinger complexly, but in general the salic rocks intrude the mafic ones. Large amounts of hornfelsed, brecciated sedimentary rocks are present. The contacts of the pluton with the surrounding, flat-lying limy Ordovician sedimentary rocks of the Lorraine stage are poorly exposed, but the sedimentary layering appears to be slightly, if at all, distorted. Contact metamorphism to hornblende hornfels grade occurs around the basic rocks, and to some extent around the salic rocks also, but soda metasomatism is the most prominent feature around the latter. Dykes are not common in the hornfels zone, but a numerous and complex dyke assemblage is present in the pluton itself; some dykes apparently radiate from a centre within the basic mass, and others are associated with its edges.
Petrography	Only the mafic rocks are described in this section, the description of the agpaitic salic rocks being reserved for Chapter VIII. The mafic part of the Mount St-Hilaire pluton grades from melanocratic varieties at the centre to less melanocratic types at the margin. Much of the centre is composed of melanocratic gabbro with intercalations of feldspathic pyroxenite and perknite. The principal minerals are medium- to coarse-grained plagioclase (An_{68-78}), and faintly pleochroic titanaugite. Biotite and kaersutite are commonly present, but in erratic amounts, and olivine may be present even in the most leucocratic rocks, although it is absent from many specimens. Large amounts of apatite and magnetite are consistently present. In the more leucocratic rocks, the calcicity of the plagioclase decreases to An_{15-40}, and the plagioclase is commonly rimmed by thick sanidine mantles, which may partly replace the plagioclase. Nepheline is present interstitially, and in some rocks may reach 25 per cent by volume. Traces of sodalite are found in a few of the nepheline diorites. Apparently the youngest gabbroic rocks at Mount St-Hilaire are feebly alkaline gabbroic dykes and screens, found in the median valley between the two parts of the intrusion, and consisting of labradorite, augite, and a little biotite.
Age	An Rb-Sr age determination on biotite from Mount St-Hilaire yielded 99 m.y. The pluton also gives Monteregian paleomagnetic poles.
Economic aspects	A quarry was operated for some years in the gabbroic part of the pluton but is now abandoned.

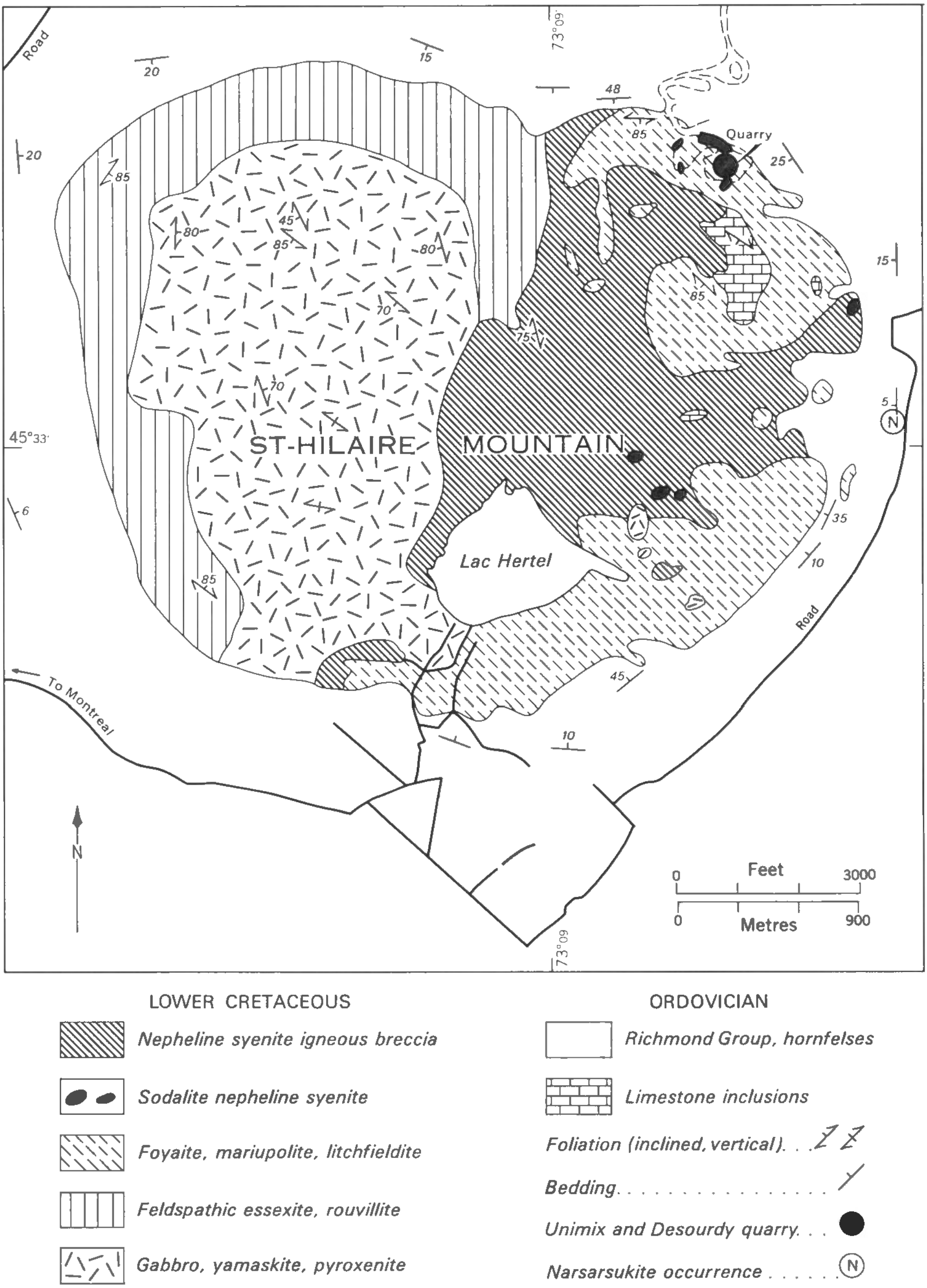

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FIGURE 10. Geology of the Mount St-Hilaire pluton (after Pouliot, 1969).

Remarks

Mount St-Hilaire is generally considered one of the keys to understanding the petrology of the Monteregian Hills because it displays the typical mafic suite, as well as syenitic rocks in close contact. Unfortunately, the development of Mount St-Hilaire is poorly understood. Several complex schemes have been proposed, including two periods of intrusion with tectonic movements between, or a long interval of erosion. None of these schemes have gained widespread acceptance.

Selected references

Gold, D. P. (1963): The relationship between the limestones and the alkaline igneous rocks of Oka and St. Hilaire, Quebec; McGill Univ., Montreal, unpubl. Ph.D. thesis.

O'Neill, J. J. (1914): St. Hilaire (Beloeil) and Rougemont Mountains, Quebec; Geol. Surv. Can., Mem. 43.

Pouliot, G. (1969): Notes on the geology of Mont St. Hilaire; *in* Geology of Monteregian Hills, G. Pouliot, ed., Geol. Assoc. Can.–Mineral. Assoc. Can., p. 93–102.

TABLE 6 *Chemical analyses of basaltic rocks from the Mount St-Hiliare pluton (after Pouliot, 1969)*

	1	2	3	4	5	6
SiO_2	34.32	37.11	49.96	51.26	51.79	51.88
Al_2O_3	12.19	10.64	18.83	23.78	23.29	19.00
TiO_2	9.69	6.75	2.40	1.66	1.26	1.53
FeO	9.27	10.92	6.64	2.20	1.94	3.59
Fe_2O_3	8.41	5.39	2.52	1.81	1.60	3.04
MnO	0.23	0.30	0.20	0.10	0.14	0.19
MgO	8.56	8.83	3.52	1.96	1.47	1.25
CaO	15.85	13.15	7.42	8.00	6.63	4.63
Na_2O	0.78	2.15	5.26	6.72	7.57	9.04
K_2O	.24	0.73	2.85	2.16	2.75	3.78
P_2O_5	.19	2.87	0.25	—	0.46	0.67
CO_2	.29	0.79	—	—	.30	.20
H_2O+	.36	.29	0.07	0.55	.70	1.28
H_2O-	.01	.03	.53	.10	.14	0.02
TOTAL	100.39	99.95	100.45	100.30	100.04	100.10

1. Perknite; analyst: H. Ulk (1962).
2. Porphyritic gabbro; analyst: H. Ulk (1962).
3. Feldspathic essexite; analyst: M. F. Connor (1914).
4. Rouvillite; analyst: M. F. Connor (1914).
5. Rouvillite; analyst: H. Ulk (1962).
6. Rouvillite; analyst: H. Soutar (1965).

Name

Rougemont (BM-4; Figs. 7,11)

Location and access

Rougemont forms a prominent hill lying some 5 miles southeast of Mount St-Hilaire, about 6 miles north of Autoroute 9, the Eastern Townships Autoroute, from which it can be reached by secondary roads. Development of a ski hill on the northern slopes of the mountain has resulted in various trails from which much of the mountain can be examined.

Form and structure

Rougemont forms an imperfect ellipse, roughly 2½ by 1½ miles, elongated north-south. Topographically the complex is expressed by a horseshoe-shaped ridge with steep slopes to the northwest and east reaching about 1,150 feet above the plain. The pluton is moderately strongly layered, the layering dipping inward at angles increasing toward the centre. Dykes are abundant in the hornfels collar and within the intrusion, commonly striking either east-west or north-northeast. The pluton intrudes Ordovician Lorraine shales, metamorphosed to hornblende or pyroxene hornfels facies, brecciated, and variously rheomorphosed. The sedimentary rocks dip inward toward the contact for a distance of 30 to 300 feet. A major north-trending fault cuts the hornfels on the east side of the hill, separating flat-lying or gently dipping beds to the west from tightly folded beds to the east. This fault is probably a branch of Logan's Line, marking the western boundary of the Appalachian province.

Petrography

Rougemont consists principally of feldspathic peridotite, with a thin marginal zone of gabbro and hybrid gabbro. Olivine shows little variation in composition, ranging from Fo_{74-78}, whereas pyroxene, in general more abundant than olivine, is the titanaugite characteristic of the Monteregian province. Plagioclase compositions range from An_{36-98}, but for most of the intrusion fall between An_{80-95}. Brown hornblende locally poikilitically encloses the cumulus minerals, and becomes a major phase in the gabbros. Minor amounts of ilmenite, magnetite, and deep green spinel occur in most samples. Chemical analyses are presented in Table 7. The marginal rocks contain large amounts of very strongly zoned, euhedral plagioclase, commonly micrographically intergrown with quartz. The major mafic minerals are hypersthene and biotite, which locally clearly replace olivine and augite. The hybrid gabbro grades into rheomorphic breccia containing fragments of hornfelsed shales. Dykes consist either of porphyritic olivine-pyroxene-rich rocks similar to the intrusion, or of finer grained gabbro. Fragments of these dykes are found in the breccia which they cut, suggesting that intrusion of dykes continued throughout emplacement of the pluton.

Age

K-Ar and Rb-Sr ages on biotite give 110 and 111 m.y., respectively, for the age of the Rougemont pluton.

Economic aspects

Because of its topographic prominence, Rougemont has occasionally been used as a ski hill.

Selected references

O'Neill, J. J. (1914): St. Hilaire (Beloeil) and Rougemont Mountains, Quebec; Geol. Surv. Can., Mem. 43.

Philpotts, A.R. (1969): Geology of Mont Rougemont; Guidebook for geology of Monteregian Hills; G. Pouliot, ed., Geol. Assoc. Can.–Mineral. Assoc. Can., Montreal, p. 77–83.

TABLE 7 *Chemical analyses of the Rougemont pluton (after O'Neill, 1914)*

	450	451	452	453
SiO_2	44.62	44.39	40.68	45.44
Al_2O_3	7.90	8.36	19.83	5.85
Fe_2O_3	4.22	2.18	4.68	2.84
FeO	5.67	8.25	6.49	6.49
MgO	14.00	16.70	7.67	16.24
CaO	19.44	12.90	17.64	18.16
Na_2O	1.20	1.28	1.10	1.03
K_2O	0.31	1.28	0.27	0.38
H_2O+	.75	2.08	.27	1.15
H_2O-	.07	0.02	.08	0.10
CO_2	.60	—	—	—
TiO_2	1.87	1.98	2.04	1.50
MnO	0.10	0.15	0.10	0.24
TOTAL	100.75	99.57	100.85	99.42

	Modes	
	452	453
Anorthite	52.25	6.06
Ti-Augite	32.51	70.75
Olivine	8.35	13.38
Hornblende	0.43	8.82
Biotite	—	0.50
Opaque	6.52	.50

Analyst: M. F. Connor.
450. Olivine melagabbro.
451. Porphyritic olivine melagabbro.
452. Alkaline olivine gabbro.
453. Olivine-hornblende jacupirangite.

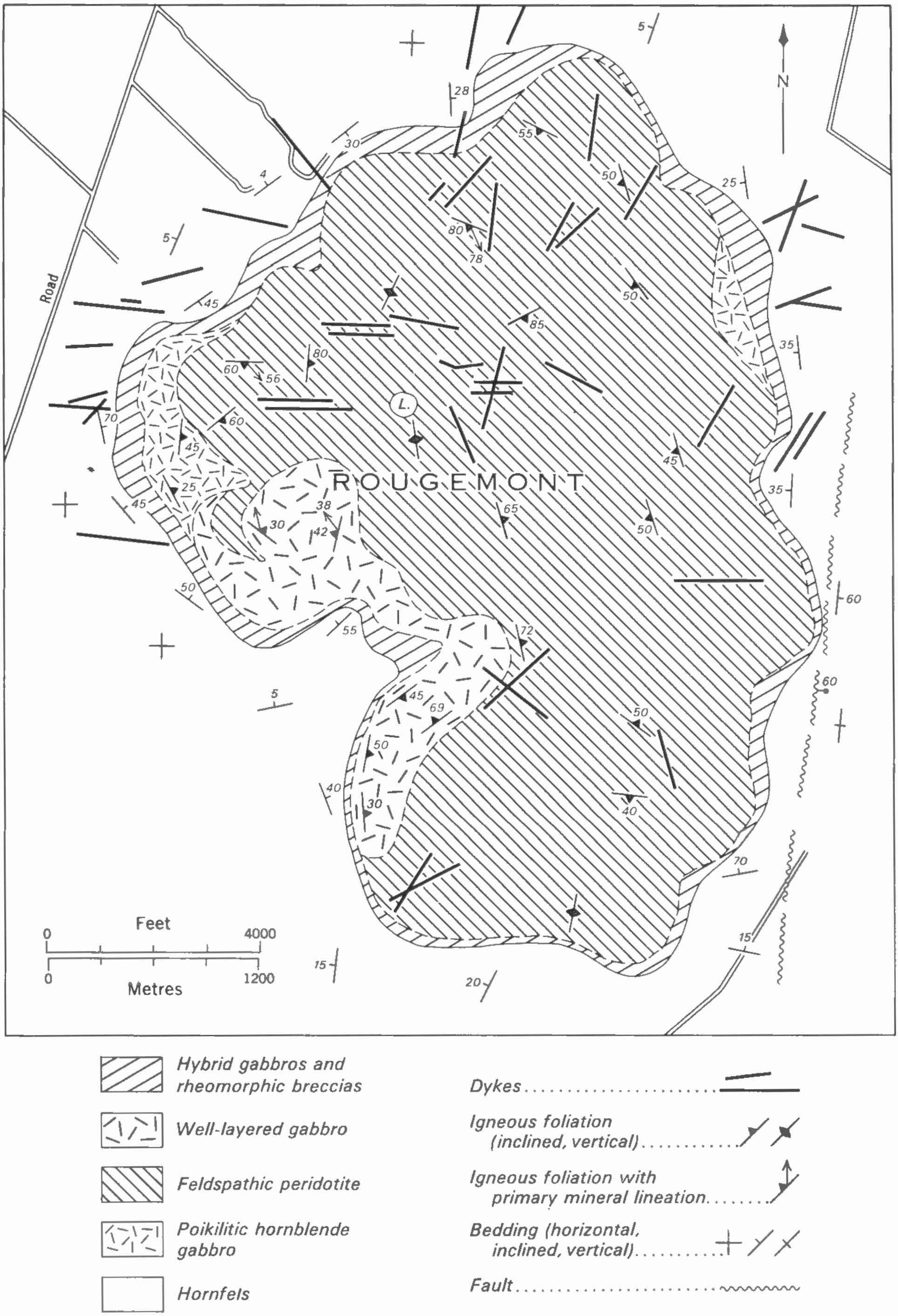


FIGURE 11. Geology of the Rougemont pluton (after Philpotts, 1969). GSC

Name	Mount Johnson (Mont St-Grégoire) (BM-5; Figs. 7,12) (also called Monnoir)
Location and access	Mount Johnson lies south of the Eastern Townships Autoroute between the hamlets of Marieville and Mont-St-Grégoire. The pluton is readily reached by the autoroute and local roads which pass around the foot of the mountain. Haulage roads from the large quarries give ready access to most parts of the pluton.
Form and structure	The pluton consists of an almost circular hill some 3,000 feet in diameter and 500 feet high, with precipitous southern slopes, and rather more gentle northern ones. The pluton consists of an outer series of relatively coarse sialic rocks grading into a finer grained, younger core of more plagioclase-rich rocks. All rocks show strong rhythmic layering and vertical alignment of feldspars. The foliation dips vertically, indicating that the pluton is composed of a series of concentric vertical cylinders. Crossbedding, channel scours, and other "sedimentary" structures indicate that the outer part of the intrusion is the older. Ordovician Lorraine siltstone exposed around the intrusion is raised to hornblende hornfels grade in a narrow collar which tends to dip toward the intrusion at the contact. No brecciation is observed, and the only dyke is a large ring dyke on the northwest side of the intrusion.
Petrography	The central rocks consist of oligoclase, minor potash feldspar, augite, and a few per cent of olivine, biotite, kaersutite, and nepheline. Toward the margin the olivine gradually disappears, the feldspar becomes less calcic, and the rock is coarser grained.

TABLE 8 *Chemical composition of the Mount Johnson pluton (after Philpotts and Pajari, 1969)*

	Average composition of Mount Johnson	Average of core series	Average of peripheral series
SiO_2	50.74	49.59	51.55
TiO_2	2.30	2.51	2.16
Al_2O_3	18.86	18.64	19.01
Fe_2O_3	3.11	2.80	3.33
FeO	4.84	5.72	4.23
MnO	.25	.24	.24
MgO	2.52	2.90	2.26
CaO	6.43	6.81	6.16
Na_2O	6.36	6.54	6.23
K_2O	2.90	2.92	2.89
P_2O_5	.86	.92	.81
H_2O	.89	.54	1.14
TOTAL	100.06	100.13	100.01
		trace elements (ppm)	
La	157	144	166
Co	9	9	8
Zr	366	408	337
Ni	3	3	3
Y	40	38	41
Cu	6	5	6
V	75	94	62
Nb	172	154	184
Ba	1300	1060	1460
Sr	1500	1400	1500
Li	11	13	10
Rb	74	76	73
Ga	14	16	12

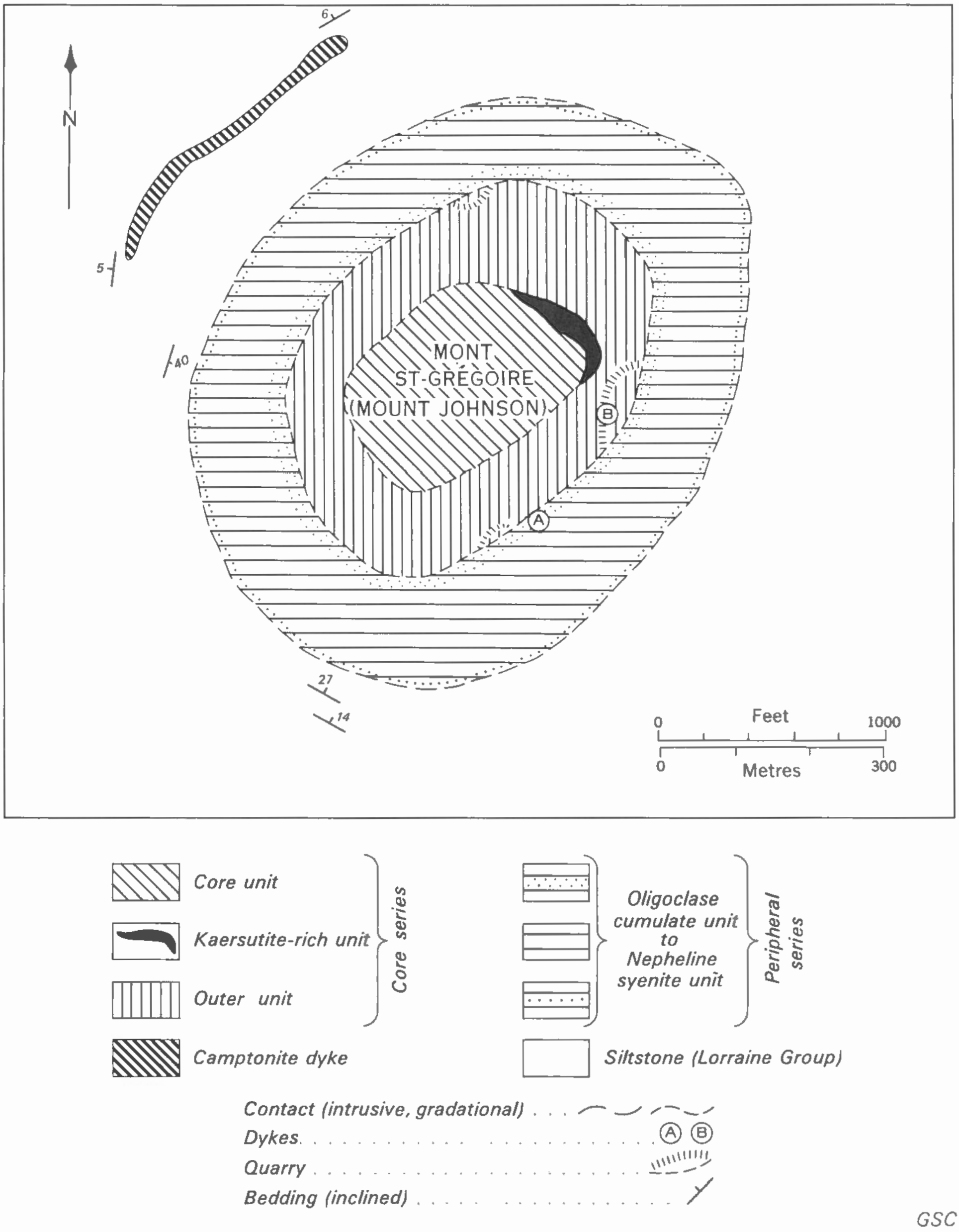


FIGURE 12. Geology of the Mount Johnson pluton (after Philpotts and Pajari, 1969).

	About 1,200 feet from the centre, augite is replaced by kaersutite, and the rock contains inclusions of oligoclase syenodiorite. From here to the contact the amount of alkali feldspar increases at the expense of kaersutite, and nepheline increases slowly in amount. Chemical compositions are shown in Table 8.
Age	Paleomagnetic pole determinations are consistent with a lower Cretaceous age.
Economic aspects	The rocks of Mount Johnson are exploited as building stone in several large quarries.
Remarks	The mechanism of intrusion of the pluton has been studied by several people dating back to F. D. Adams. The most probable mechanism appears to be that the magma rose in the centre and descended along the walls. It has been suggested that two interpenetrating cells were present, separated by immiscibility.
Selected reference	Philpotts, A. R. and Pajari, G. E. (1969): The geology of Mt. Johnson; Guidebook to geology of Monteregian Hills; G. Pouliot, ed., Geol. Assoc. Can.–Mineral. Assoc. Can., Montreal, p. 85–92.

Name	Mount Yamaska (BM-6; Fig. 13)
Location and access	Mount Yamaska lies just north of the Eastern Townships Autoroute, near the town of St-Paul-d'Abbotsford, about 35 miles east of Montreal. The intrusion can be reached on foot from nearby local roads.
Form and structure	The pluton forms a lobate but nearly circular mass roughly $1\frac{1}{4}$ miles in diameter. The northern slopes are steep, the southern ones more gentle and drift covered. The pluton consists of two differentiated interpenetrating bodies. The older and larger central mass displays moderately well developed layering dipping inward at angles of 35–50° near the centre. The younger mass on the southwest side of the pluton appears to be a nearly vertical, pipe-like mass. The pluton intrudes shales and sandstones of the Ordovician Sillery Formation forming a hornfels zone 200 to 500 feet wide, within which complex breccias cemented by igneous material are common. A complex and compositionally diverse suite of dykes is found within the hornfels collar and within the pluton itself.
Petrography	The older part of the pluton consists of an irregular central mass of feldspathic peridotite, grading outward through gabbro and syenodiorite into a discontinuous rim of biotite syenite or monzonite on the northwestern side of the intrusion. The peridotites consist of titanaugite, kaersutite, and iron-titanium oxides, with lesser amounts of very calcic plagioclase, and accessory apatite, sphene, hercynite, olivine, biotite, and pyrite. These rocks pass by gradation, or abrupt transition into gabbros displaying strong cryptic zoning in the plagioclase, which passes from An_{90} near the peridotite, to An_{10} near the boundary of the intrusion. Strong layering and lineation of plagioclase are common. The change in composition of plagioclase is accompanied by increase in kaersutite at the expense of pyroxene, and finally by the appearance of hastingsite. The marginal monzonite locally contains traces of quartz. The younger part of the intrusion grades from central feldspathic peridotite, to nepheline-bearing gabbro, to nepheline syenite, locally sodalite-bearing. The chemical composition of typical phases and minerals is shown in Table 9. Minor intrusions include augite porphyry and nepheline syenite plugs and dykes.
Age	K-Ar ages on biotite gave 107 m.y. compared to an Rb-Sr age of 85 m.y. obtained on the same mineral. The paleomagnetic data suggest an early Cretaceous age.
Economic aspects	None known.

Selected references

Gandhi, S. S. (1966): Igneous petrology of Mt. Yamaska; McGill Univ., Montreal, unpubl. Ph.D. thesis.

Gandhi, S. S. (1969): Notes on the geology of Mount Yamaska; *in* Geology of Monteregian Hills, G. Pouliot, ed., Geol. Assoc. Can.–Mineral. Assoc. Can. Guidebook.

Young, G. A. (1906): The geology and petrography of Mt. Yamaska; Geol. Surv. Can., Ann. Rept. 16 (n.s.), pt. H.

TABLE 9 *Chemical analyses of the Mount Yamaska pluton (after Gandhi, 1969)*

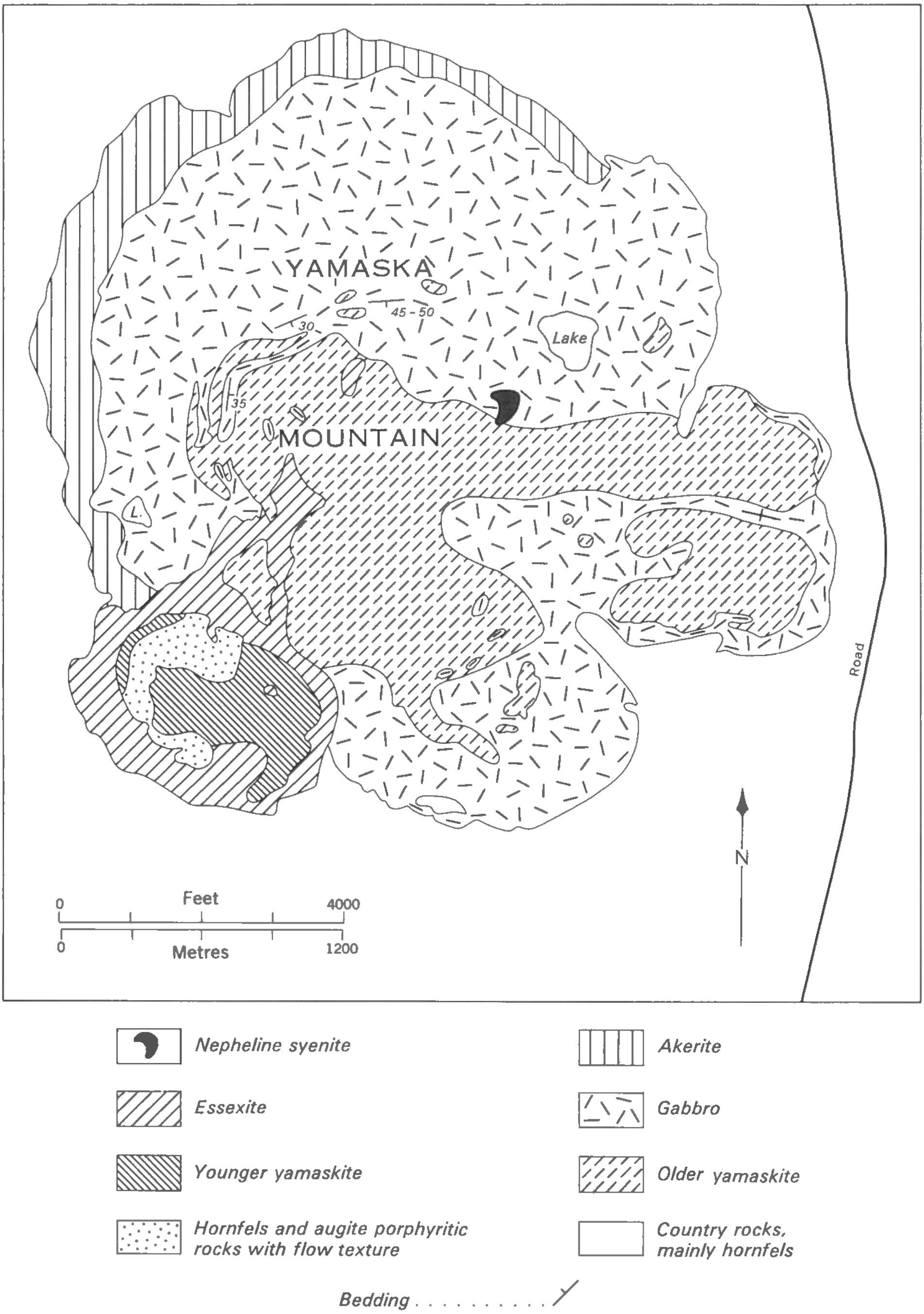
	5264	5176	5260	5280	Y-3	5212	Y-2	DG-8	5143	5274	5227	5272	Y-1	5249
SiO_2	31.72	32.67	35.59	37.80	39.97	39.25	43.91	40.59	42.61	43.71	45.44	50.36	57.75	58.13
Al_2O_3	8.77	8.45	9.84	11.84	8.68	13.59	19.63	15.30	18.00	16.79	16.73	15.99	17.50	17.65
TiO_2	6.88	8.92	6.44	5.00	4.05	5.51	3.80	5.66	4.25	5.41	3.26	3.17	1.53	1.59
Fe_2O_3	10.44	8.99	10.70	7.28	8.63	5.63	4.16	5,15	4,30	4.31	4.91	1,93	2.92	1.69
FeO	7.60	9.05	10.45	7.85	7.99	8.11	5.55	8.20	6.22	7.50	5.87	7.89	2.94	4.00
MnO	0.31	0.87	0.19	0.17	0.19	0.80	0.07	0.53	0.16	0.19	0.77	0.26	0.19	0.33
MgO	8.01	8.55	8.66	9.25	10.32	6.05	5.20	7.12	6.05	5.11	4.84	3.34	1.70	1.86
CaO	18.33	15.70	13.66	13.83	15.18	12.30	9.49	11.71	13.53	10.23	8.90	7.51	3.86	3.74
Na_2O	1.24	1.60	0.99	2.06	1.19	3.94	4.49	2.51	2.09	2.99	4.46	4.58	5.08	6.27
K_2O	0.31	0.60	.41	0.86	0.74	1.06	1.51	0.98	0.58	0.67	1.24	2.29	3.51	3.99
P_2O_5	5.50	2.23	.19	.35	.10	1.94	0.32	.34	.28	.21	1.47	0.82	1.05	0.43
H_2O	1.01	0.61	1.10	.51	.57	0.47	.53	.54	.87	.71	0.82	—	0.37	—
CO_2	—	.11	0.15	.71	1.15	—	.51	—	.23	—	.15	0.41	.55	0.66
FeS_2	—	—	—	—	1.01	—	0.64	—	—	—	—	—	.21	—
TOTAL	100.12	98.35	98.37	97.51	99.77	98.65	99.81	98.63	99.17	97.83	98.86	98.55	99.16	100.34

5264, 5176, 5260, 5280, Y-3. Feldspathic kaersutite perknite (titanaugite + kaersutite + anorthite, with accessory magnetite, biotite, olivine, sphene, and pyrite).
5212, Y-2. Kaersutite melaessexite (kaersutite + andesine, and lesser amounts of titanaugite, nepheline, alkali feldspar).
DG-8, 5143, 5274, 5227, 5272. Kaersutite and/or titanaugite gabbro.
Y-1, 5249. Alkaline biotite monzonite (± kaersutite).

TABLE 10 *Chemical composition of typical Monteregian minerals (after Gandhi, 1969)*

	Pyroxenite, perknite, and related ultramafic rocks				Alkaline gabbro					Essexite		
	Titan-augite	Titan-augite	Kaers-utite	Kaers-utite	Titan-augite	Titan-augite	Kaers-utite	Kaers-utite	Titan-biotite	Titan-augite	Kaers-utite	Kaers-utite
SiO_2	44.00	45.52	39.86	39.24	47.84	47.38	41.48	40.96	37.38	45.12	39.88	40.35
Al_2O_3	8.62	8.32	12.11	12.71	5.39	4.11	12.18	12.13	13.67	6.66	12.08	12.05
TiO_2	4.52	4.10	6.49	6.03	2.16	2.06	5.25	5.06	4.86	3.82	5.86	5.06
Fe_2O_3	4.51	4.47	5.00	4.05	3.03	2.72	2.29	3.01	1.43	3.82	4.09	4.11
FeO	3.07	3.80	6.62	9.05	4.67	6.04	8.41	7.71	17.63	5.00	10.67	10.69
MnO	0.17	0.23	0.21	0.32	0.23	0.23	0.17	0.25	0.17	0.26	0.42	0.38
MgO	12.44	11.34	11.14	10.59	14.36	13.46	12.69	12.76	11.19	11.26	9.98	8.63
CaO	21.80	21.42	12.08	11.95	21.51	21.75	11.14	11.31	1.47	21.57	12.08	12.03
Na_2O	1.16	1.12	2.80	2.94	0.69	0.82	2.32	2.93	0.42	1.36	2.87	2.97
K_2O	0.11	n.d.	1.37	1.34	n.d.	.05	1.44	1.10	9.46	n.d.	1.99	2.02
P_2O_5	.16	0.22	0.22	0.27	0.07	.06	0.10	0.20	0.04	0.22	0.18	0.27
H_2O	—	—	.99	.62	—	—	1.02	.53	1.53	—	.61	.59
TOTAL	100.56	100.54	98.89	99.11	99.95	98.68	98.49	97.95	99.25	99.09	100.71	99.15

n.d.: not determined.
These values are for Mt. Yamaska, but they probably represent compositions in other similar Monteregian Hills.



GSC

FIGURE 13. Geology of the Mount Yamaska pluton (after Gandhi, 1969).

Name	Brome (BM-7; Figs. 7, 14)
Location and access	The Brome complex lies on the south side of the Eastern Townships Autoroute some 45 miles east of Montreal. The complex is crossed by a number of secondary roads, including those linking the new town of Bromont and the well-known ski resort.
Form and structure	With an area of 22.4 square miles, Brome is the largest of the Monteregian complexes. It outcrops on four major peaks, Brome, Gale, Spruce, and Pine mountains, which together form a south-facing horseshoe rising some 1,100 feet above the surrounding rolling country. The complex forms an irregularly elliptical mass some 4 miles in north-south dimension by 3 miles east-west. Strong layering, dipping moderately inward, is present in the outer part of the complex, but both layering and regular zonation tend to disappear in the central part of the complex. In general, the rocks pass from marginal gabbro through nepheline diorite to a central mass of leucocratic syenite. Quartz-bearing syenites occur as crescentic marginal masses around the complex, and rarely as small bodies within the central syenite. The relationships of the various units are complex, as they locally crosscut and include older rocks, and in other places seem to grade into one another. Plagioclase-biotite dykes cut all units of the complex, and the hornfels collar. The complex cuts Cambrian and Ordovician argillites and siliceous dolomites, which have been hornfelsed to sanidinite facies in a zone locally more than 1,000 feet wide, with development of cordierite in the argillites, and of melilite and kalsilite in rare localities in the limy rocks. Rheomorphic breccia and hybridization is locally displayed.

TABLE 11 *Chemical analyses of the Brome complex (after Valiquette and Pouliot, 1969)*

Analysis number	15V8	8V13	8V30	23V18	36P24	1V2	21V19	3F1	44V9	36P27	6V3	37P12
SiO_2	34.32	41.12	49.03	46.82	39.74	58.10	65.12	64.62	63.30	60.20	53.80	55.05
Al_2O_3	14.63	20.22	20.48	18.73	13.86	17.70	16.43	17.58	18.07	19.64	20.64	20.55
TiO_2	6.58	4.15	2.64	3.45	4.19	1.48	0.48	0.27	0.58	0.49	0.36	0.25
CaO	14.44	12.80	7.45	7.24	13.40	3.42	.94	1.07	.82	1.50	1.52	1.26
MgO	7.68	5.34	2.24	3.40	6.07	1.77	.36	0.33	.43	.28	0.43	0.22
FeO	10.45	7.20	5.47	8.51	8.49	3.40	1.92	.86	.99	.84	.29	.61
Fe_2O_3	7.13	3.54	2.49	2.30	4.84	2.14	0.96	.50	1.12	1.55	2.86	2.68
Na_2O	1.40	3.20	5.04	3.39	3.50	7.04	6.43	6.40	7.58	8.03	10.96	11.80
K_2O	0.08	0.28	2.05	1.94	1.55	3.22	5.46	6.32	5.84	5.98	5.44	5.28
MnO	.20	.17	0.22	0.20	0.27	0.23	0.28	0.09	0.13	0.14	0.35	0.39
P_2O_5	2.57	1.81	.93	1.46	1.34	.43	.14	.14	.10	.05	.07	.03
BaO	—	—	.05	0.09	0.05	.30	.08	.05	.02	.06	.01	.01
SrO	—	—	.31	.27	.24	.23	.01	.01	.01	.03	.02	.01
V_2O_3	—	—	.01	.02	.04	.01	.01	.01	.01	.01	.01	.01
H_2O+	0.55	0.65	.79	1.40	1.51	.41	.40	.20	.46	.78	2.12	1.08
H_2O-	.05	.04	.01	0.05	0.01	.03	.02	.02	.02	.02	0.12	0.01
TOTAL	100.08	100.52	99.21	99.27	99.10	99.91	99.04	98.47	99.48	99.60	99.00	99.24

15V8. Foliated alkaline olivine gabbro.
8V13. Alkaline gabbro with large poikilocrysts of kaersutite.
8V30. Alkaline gabbro, Gale Mountain.
23V18. Porphyritic alkaline gabbro, north of Pine Mountain.
36P24. Nepheline diorite, summit of Brome Mountain.
1V2. Biotite trachydiorite, Gale Mountain.
21V19. Porphyritic alkaline microsyenite, Pine Mountain.
3F1. Leucocratic alkali syenite, roadside on east slope of Gale Mountain.
44V9. Pulaskite, west slope of Brome Mountain.
36P27. Nepheline syenite, Brome Mountain.
6V3. Nepheline syenite, roadside northwest of Brome Mountain.
37P12. Phonolite, border zone of nepheline syenite.

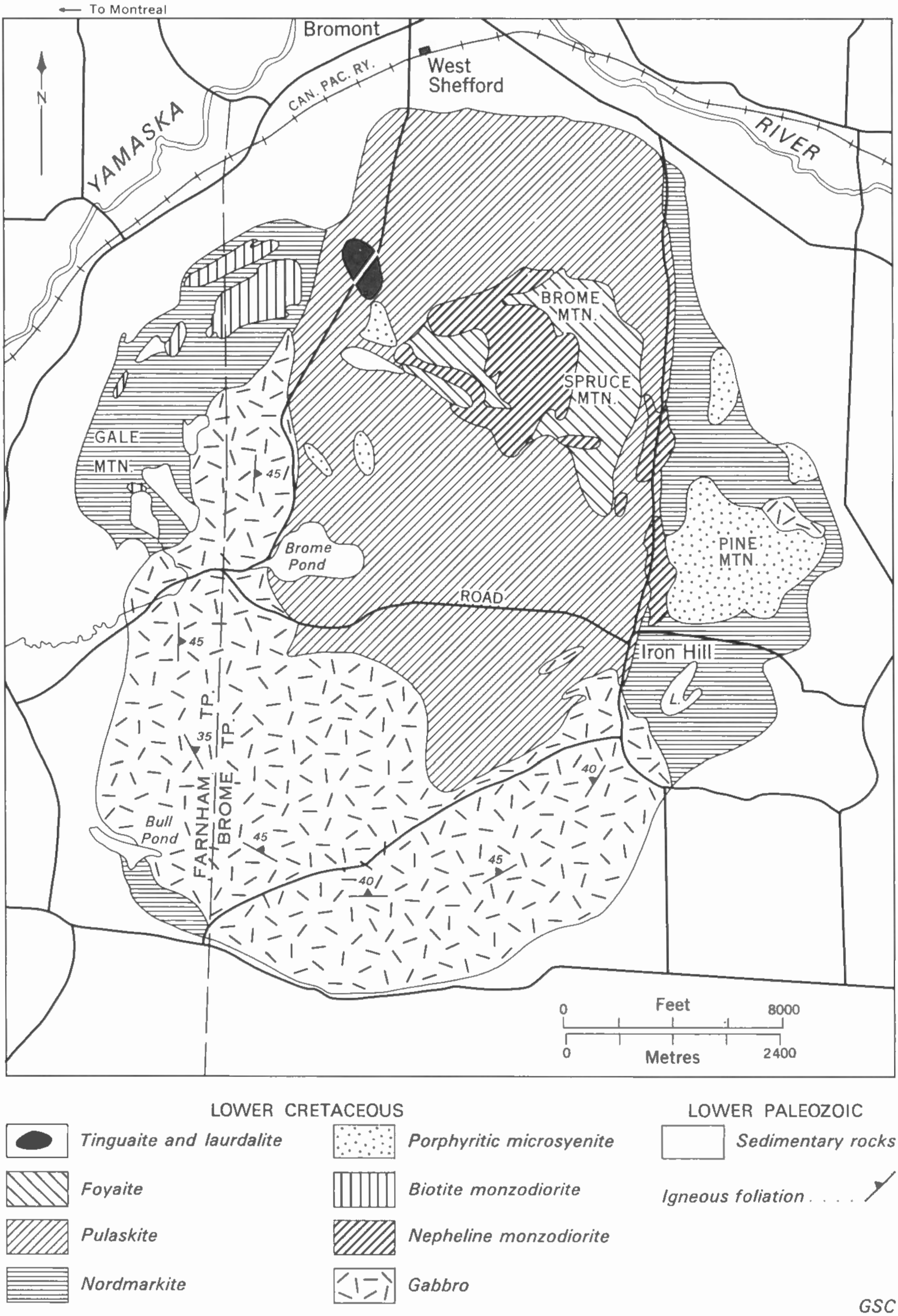


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FIGURE 14. Geology of the Brome complex (after Valiquette and Archambault, 1968).

Petrography The gabbro is composed of zoned plagioclase (An_{80-55}), feebly pleochroic augite with kaersutite rims, a little olivine (Fo_{77-72}), and various amounts of ilmenite and titaniferous magnetite. Local peridotitic layers are present in which the pyroxene is more titaniferous. In the dioritic rocks the plagioclase is oligoclase, whereas the mafic mineral is kaersutite in the cores, zoned to marginal hastingsite. Minor amounts of alkali feldspar, and accessory amounts of nepheline, sodalite, melanite, cancrinite, and titanaugite are commonly present. The monzonitic and syenitic phases contain major amounts of xenomorphic alkali microperthitic feldspar (Ab_{60-40}), not uncommonly overgrown on zoned plagioclase, as well as aegirine and biotite. Nepheline-rich phases are locally present. Numerous variants of the dioritic and syenitic rocks occur depending on the type of phenocrysts, but there appears to be no systematic distribution.

The quartz-bearing syenites range from porphyries to coarse-grained varieties. The alkali feldspar may be microperthitic or antiperthitic; augite with aegirinic rims is the principal mafic mineral, but kaersutite and fayalite are commonly present. Enigmatite and pyrochlore have been identified locally. Quartz is present interstitially, and in miarolitic cavities between the feldspars.

Age Paleomagnetic pole determinations suggest an early Cretaceous age for the Brome complex.

Economic aspects None known.

Remarks The quartz-bearing syenites on Brome Mountain are particularly intriguing. Their mineralogy and texture suggest that they are not due to assimilation or contamination. Presumably they result from some process of igneous differentiation. The presence of enigmatite suggests that this process may involve the appearance of agpaitic rocks. A similar situation on a smaller scale is seen on Mount Royal.

Selected references

Dresser, J. A. (1906): The geology and petrography of Brome Mountain; Geol. Surv. Can., Ann. Rept. 16 (n.s.), pt. G.

Valiquette, G. and Archambault, G. (1968): Géologie de la Montagne de Brome; Natur. Can., 95, p. 1257-1276.

Valiquette, G. and Pouliot, G. (1969): Geology of Brome and Shefford Mountains; *in* Geology of Monteregian Hills, G. Pouliot, ed., Geol. Assoc. Can.–Mineral. Assoc. Can., Montreal, p. 125–137.

Name Shefford Mountain (BM-8; Figs. 7, 15)

Location and access Shefford Mountain is 3 miles north of the Brome complex, on the opposite side of the Eastern Townships Autoroute. All parts of the complex may be reached on foot from local secondary roads.

Form and structure The mountain is an east-west oriented ellipse about 3 by $1\frac{1}{2}$ miles in maximum dimensions, steep on the north side, and gently sloping on the south. The pluton consists of a gabbroic core in the eastern part, surrounded by imperfect crescentic screens of more sialic rocks, with an area of breccia and porphyry at the western end of the complex. The more massive rocks display foliation and, rarely, banding, dipping steeply toward a central point. The western end of the complex seems to display another centre towards which older syenitic and dioritic rocks dipped. The contacts of the pluton with the surrounding Paleozoic sedimentary rocks are poorly exposed but a hornfels aureole clearly exists, and the sedimentary rocks appear to dip into the pluton. A varied suite of dyke rocks, including phonolitic and alkali basaltic types, is present.

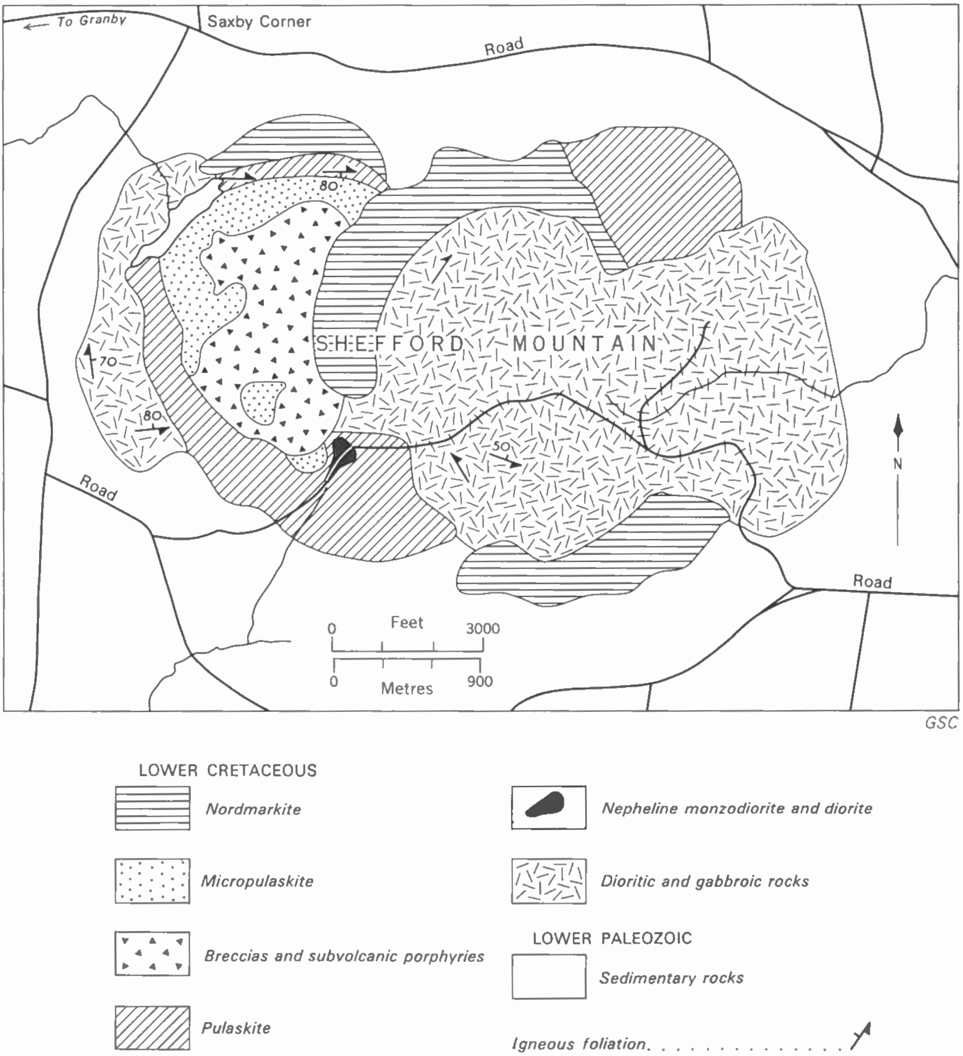

FIGURE 15. Geology of the Shefford Mountain pluton (after Valiquette, 1969).

Petrography The oldest rocks of the Shefford Mountain complex occur on the west end of the mountain in the form of complex and heterogeneous porphyries, igneous breccias, and explosion breccias, possibly of subvolcanic origin. The oldest component is brecciated trachyte and latite enclosed in dark plagioclase porphyry. These rocks are surrounded and brecciated by nepheline-bearing monzonite and syenite consisting of microperthitic alkali feldspar (Ab_{60} Or_{40}) with interstitial nepheline and minor hastingsite aegirine and biotite. Zircon, apatite, and sphene may be present, as well as secondary zeolites. The outermost parts of the western complex are imperfect crescents of quartz syenite and diorite. The eastern complex consists of a central core of gabbro and diorite composed of andesine or labradorite, kaersutite, and minor amounts of augite and olivine. Some varieties contain significant amounts of alkali feldspar and biotite and grade to monzonite, which locally contains interstitial quartz.

	This central mass is surrounded by an incomplete rim of quartz syenite which intrudes the older rocks. This pale green, medium-grained rock consists principally of microperthitic alkali feldspar (Ab_{60} Or_{40}), with minor interstitial quartz, aegirine, and fayalite. This unit contains an enclave of nepheline-bearing diorite, and grades at its northeastern corner into undersaturated syenite.
Age	Paleomagnetic data suggest an early Cretaceous age.
Economic significance	None known.
Selected references	Dresser, J. A. (1903): The geology and petrography of Shefford Mountain; Geol. Surv. Can., Ann. Rept. 13 (n.s.), pt. L. Valiquette, G. (1969): Geology of Shefford Mountain; *in* Geology of Monteregian Hills; G. Pouliot, ed., Geol. Assoc. Can.–Mineral. Assoc. Can., Montreal, p. 142–149.

TABLE 12 *Chemical analyses of the Shefford Mountain pluton (after Valiquette, 1969)*

	17C11†	11P1†	4C19†	4C38†	4P2†	10P5*	8C37*	12P10†	8C11†	41C25†	14C24*	25C19*
SiO_2	68.11	60.25	60.77	63.04	55.44	59.90	60.83	51.97	56.20	52.59	50.99	49.90
Al_2O_3	14.97	17.19	17.13	16.53	16.80	17.21	17.30	17.89	19.40	19.70	17.98	19.63
TiO_2	0.16	1.28	0.88	0.65	1.78	0.75	0.81	1.92	1.61	2.18	2.21	2.06
Fe_2O_3	.76	2.07	1.43	1.88	3.69	2.08	1.57	3.19	2.09	4.06	3.58	3.46
FeO	2.40	2.83	2.41	1.43	3.42	2.44	1.87	4.87	2.79	4.60	4.99	5.11
MnO	0.24	0.18	0.25	0.22	0.25	0.27	0.18	0.17	0.18	0.23	0.19	0.14
MgO	.08	1.10	.49	1.76	1.19	.87	1.86	2.47	1.22	1.91	3.32	2.18
CaO	.67	2.86	2.49	1.35	5.57	1.81	2.28	6.89	5.42	5.44	9.09	11.62
Na_2O	7.18	6.67	7.97	7.45	6.54	8.21	7.79	6.36	5.96	4.68	4.81	3.72
K_2O	5.26	4.88	5.48	5.26	4.17	5.85	4.66	2.66	4.04	2.61	1.29	0.59
P_2O_5	0.01	0.26	0.14	0.13	0.50	0.11	0.21	0.87	0.54	0.88	0.95	.99
H_2O+	.16	.43	.56	.30	.65	.50	.74	.74	.55	1.12	.60	.60

Analysts:
†Paul Hebert
*B. M. Gunn
(Totals adjusted by analysts to 100 per cent)

17C11.	Alkali quartz syenite, contains minor aegirine and riebeckite.
11P1.	Alkaline biotite syenite.
4C19.	Porphyritic fine-grained pulaskite.
4C38.	Porphyritic syenite, with feldspar phenocrysts.
4P2	Alkaline trachydiorite, oligoclase and anorthoclase phenocrysts.
10P5.	Foliated nepheline syenite with alkali amphibole and biotite.
8C37.	Pulaskite, contains augite plus zoned alkali amphibole.
12P10.	Nepheline trachydiorite.
8C11.	Alkaline porphyritic trachydiorite, plagioclase phenocrysts.
41C25.	Fine-grained, porphyritic alkaline trachydiorite.
14C24.	Foliated diorite.
25C19.	Poikilitic dioritic anorthosite.

Name	Mount Megantic (BM-9; Figs. 7, 16)
Location and access	Mount Megantic lies almost on the Quebec-Maine boundary, about 7 miles southeast of Scotstown (45°27′N, 71°07′W). The area is encircled by secondary roads from Scotstown, but the mountain itself is accessible only by trails.
Form and structure	The mountain is almost circular, about 6 miles in diameter, rising 2,000 feet above the surroundings to a height of 3,625 feet. It consists of a central, rounded core, and an outer collar separated from the main mass by a deep valley. The alkaline rocks are exposed in the median valley and outer collar, where they intrude folded and metamorphosed rocks of the Lower Devonian Compton Formation. The alkaline rocks either intrude, or are intruded by, a central granite.
Petrography	The collar of alkaline rocks consists of an internal ring of dioritic rocks, and an external ring of quartz-bearing syenite. The dioritic rocks are composed of poikilitic

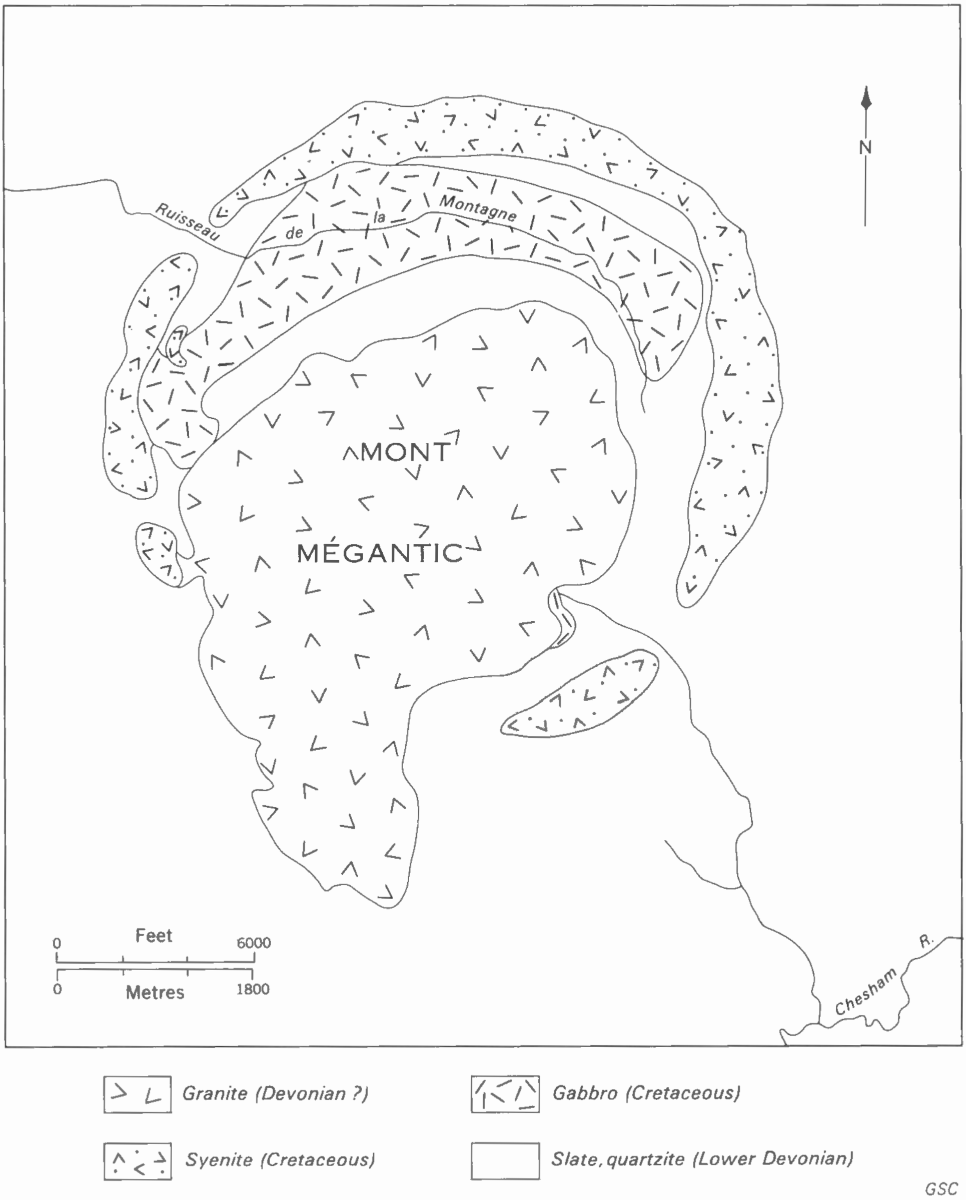

FIGURE 16. Geology of the Mount Megantic complex (after Reid, 1961).

	kaersutite surrounding oligoclase or labradorite, and varying amounts of titanaugite, biotite, and magnetite. The outer syenitic rocks are greenish, medium-grained aggregates of perthitic alkali feldspar with lesser amounts of aegirine, fayalite, and augite, the last two commonly rimmed by a greenish amphibole. Interstitial quartz is present in amounts up to 10 per cent, as well as accessory amounts of apatite, allanite, zircon, and sphene. Dykes around the complex are commonly plagioclase-biotite lamprophyres, but feldspar-free analcite melteigites also occur.
Age	K-Ar ages on biotite from Mount Megantic are 107 m.y. compared to 85 m.y. Sr-Rb ages from biotite. The central granite has also given Monteregian ages, but on somewhat chloritized biotite.
Economic aspects	The region of Mount Megantic was at one time the source of gold derived from placer mining. The ultimate source of the placer gold has not been traced, but may have been Mount Megantic.
Remarks	The relation of the central granite of Mount Megantic to the fringing rocks is a problem. Petrographically it is identical to nearby Devonian granites, for example the Scotstown granite. However, it gives Cretaceous ages and according to Reid (1961) intrudes the alkaline rocks. McGerrigle (1935), however, claimed that the alkaline rocks intruded the granite. It seems highly implausible on theoretical grounds that large amounts of granite could develop from a magma capable of crystallizing Monteregian-type alkaline diorite. The most plausible hypothesis seems to be that the granite was originally Devonian, and has acted as a locus for Monteregian magmatism, possibly becoming partly remobilized in the process.
Selected references	McGerrigle, H. W. (1935): The Mt. Megantic area and its gold placers; Que. Bur. Mines, Ann. Rept., 1935, pt. D. Reid, A. M. (1961): The petrology of the Mt. Megantic igneous complex; London, Univ. of Western Ontario, unpubl. M.Sc. thesis.

Name	St-Jean (Fig. 17)
Location and access	Alkaline rocks are found north of St-Jean, Quebec, along the shores of Richelieu River as far as Chambly. The main occurrences are on the west bank of the river about 2 miles north of St-Jean in various quarries and woods, at Fryers Rapids, 6 miles north of St-Jean, and at Chambly just below the dam. Another outcrop has been found near Grandbois, about 3 miles east of the quarries noted above. All these localities are readily accessible by local roads.
Form and structure	These occurrences probably represent disjointed fragments of the same sill. At Fryers Rapids the sill is about 5 feet thick. The feeder for this sill may be in the Grandbois region, where geophysical anomalies suggest a more equant intrusion.
Petrography	The outcrops west of Richelieu River are all of nepheline syenite, whereas the outcrop to the east is of nepheline kaersutite diorite.
Age	Not definitely known, but assumed to be Early Cretaceous like the rest of the Monteregian province.
Economic significance	None known.
Selected reference	Clark, T. H. (1955): St. Jean-Beloiel area; Que. Dept. Mines, Geol. Rept. 66.

Name	St-Amable (Fig. 17)
Location and access	Two miles west of the village of St-Amable (45°39′N, 73°17′W). The sill outcrops on a series of low buttes up to 25 feet high.

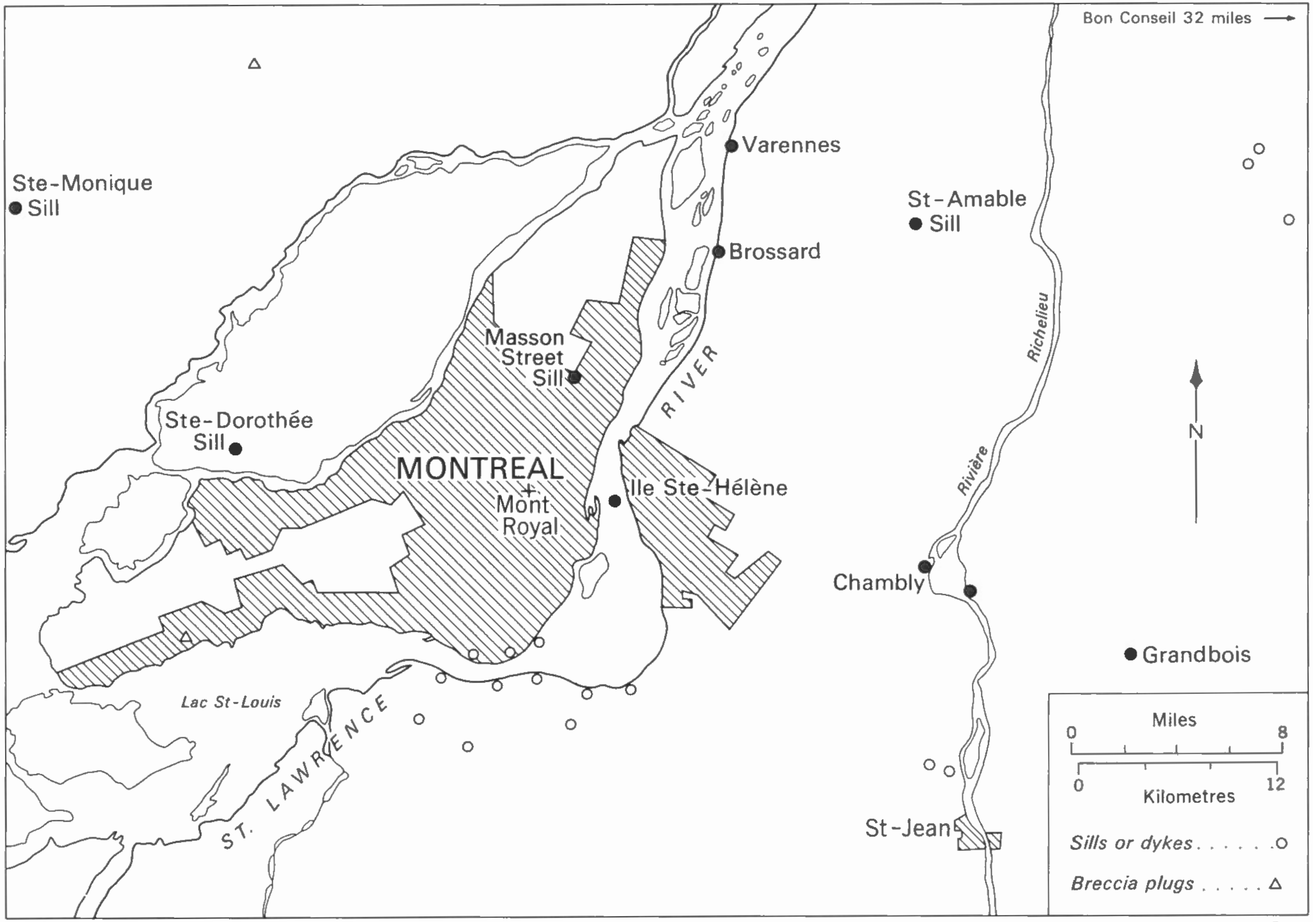

FIGURE 17. Minor occurrences of alkaline rocks in the Monteregian province (after Gold, 1967).

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Form and structure	Multiple sill some 25 feet thick with numerous internal contacts, variously chilled, and unusual internal contortion.
Petrography	Fine-grained nepheline syenite.
Age	Not definitely known, but assumed to be Early Cretaceous.
Economic aspects	None known.
Selected reference	Clark, T. H. (1964): St. Hyacinthe area; Que. Dept. Nat. Resourc., Geol. Rept. 101.

Name	Bon Conseil (Fig. 17)
Location and access	Two miles northeast of the village of Notre-Dame-du-Bon-Conseil, on Highway 13.
Form and structure	Unknown.
Petrography	Only two outcrops are present. One is composed of titaniferous augite with interstitial biotite, the other of kaersutite gabbro veined by biotite syenite.
Age	A K-Ar age on biotite gave 430 m.y. This seems to conflict with the Monteregian character of the rocks, and is possibly in error.
Economic significance	None known.
Selected reference	Clark, T. H. (1964): Yamaska-Aston area; Que. Dept. Nat. Resourc., Geol. Rept. 102.

Name	Masson Street (Fig. 17)
Location and access	This sill extended from the corner of St. Joseph Blvd. and Papineau Ave., some 2 miles westward to Pie IX and Rosemount Blvds. in eastern Montreal. It was formerly exposed in quarries, now filled in, and the author was unable to find any remaining exposures.
Form and structure	Sill about 25 feet thick.
Petrography	Phenocrysts of aegirine, nepheline, hauyne, and orthoclase in a fine-grained syenitic matrix.
Age	Presumed to be Early Cretaceous.
Economic aspects	Formerly quarried for road metal.
Selected reference	Clark, T. H. (1952): Montreal area; Que. Dept. Mines, Geol. Rept. 46.

Name	Ste-Monique (Fig. 17)
Location and access	Twenty-three miles northwest of Mount Royal, just northwest of the village of Ste-Monique. The alkaline rocks are exposed on the crest of numerous small hillocks within an area of about a half square mile.
Form and structure	Sill about 20 feet thick.
Petrography	The rock is mainly composed of augite and analcite with varying amounts of olivine and phlogopitic mica. Traces of labradoritic plagioclase are locally present. Felsic segregations (ocelli) are present in some places, as well as fine-grained variants.
Economic aspects	None known.

Remark	These rocks are clearly more closely related to nephelinites than to basalts.
Selected reference	Gold, D. P. (1967): Alkaline ultrabasic rocks in the Montreal area, Quebec; *in* Ultramafic and related rocks; P. J. Wyllie, ed., New York, John Wiley and Sons, p. 288–302.

Name	Ste-Dorothée (Fig. 17)
Location and access	On Highway 8, about a quarter mile east of the village of Ste-Dorothée, and 11 miles north of Mount Royal. The rocks are exposed in a road-cut, and in a small quarry to the north of the highway.
Form and structure	Sill about 20 feet thick.
Petrography	The matrix is mainly composed of augite and kaersutite with a little analcite and biotite, and minor plagioclase. Nodules, veinlets, and lenses (ocelli) of syenitic material are present and spectacular.
Age	Assumed to be Early Cretaceous.
Economic aspects	None known.
Remark	This sill has been used as a test case for the importance of immiscibility in generating alkaline magmas of contrasting composition.
Selected reference	Philpotts, A. R. and Hodgson, C. J. (1968): The role of liquid immiscibility in alkaline rock genesis; 23rd Intern. Geol. Congr. Proc., v. 2, p. 175–188.

Name	Brossard (Fig. 17)
Location and access	Brossard lies on the east bank of St. Lawrence River, about 5 miles east of Mount Royal. Alkaline rocks were uncovered during excavation for the St. Lawrence Seaway, but now no longer outcrop.
Form and structure	The form and structure are indeterminate, but appear to be that of a small pluton, possibly a few hundred feet across.
Petrography	The rocks consist of kaersutite gabbro, with rather little variation. Extensive chemical analyses are given by Gunn (1972).
Age	The pluton is assumed to be of Early Cretaceous age.
Economic aspects	None known.
Remarks	Similar rocks have been penetrated in drill core at Varennes, 5 miles to the north, where they appear to be sill-like. A probable Monteregian pluton has been detected by geophysical means below Montreal harbour, some 6 miles to the west.
Selected reference	Gunn, B. M. (1972): The fractionation effect of kaersutite on basaltic magmas; Can. Mineral., v. 11, pt. 4, p. 840–850.

Name	Ile Ste-Hélène (Fig. 17)
Location and access	Ile Ste-Hélène is in the St. Lawrence River off the city of Montreal. The islands were the site of Expo 67, and its successor, Terre des Hommes. In the course of preparation of these spectacles, much rock was excavated from Ile Ste-Hélène and the neighbouring Ile Ronde, and the topography of the islands changed, so that relatively little outcrop remains. The two islands have been joined, and now form a park.
Form and structure	The alkaline rocks occur in a poly-phase breccia pipe of uncertain, but not large, dimensions, cutting flat-lying Ordovician sedimentary rocks.

Petrography	The older phase of the breccia consists of diatreme breccia, without igneous material, in which the fragments have been downdropped. This is intruded by a younger stage in which fragments have been uplifted, and are enclosed in a matrix of olivine basalt or gabbro, consisting of olivine and zoned green pyroxene phenocrysts in a matrix of 55 per cent labradorite, 35 per cent titanaugite, 5 per cent kaersutite, commonly as overgrowths on pyroxene, and 5 per cent opaques and accessories. The pyroxene phenocrysts grade from green cores to colourless rims.
Age	Assumed to be Early Cretaceous.
Economic aspects	None known.
Selected reference	Clark, T. H., Kranck, E. H., Philpotts, A. R. (1967): Ile Ronde breccia, Montreal; Can. J. Earth Sci., v. 3, p. 507–513.

Chapter IV

The Nephelinite-Carbonatite Family

A large group of alkaline rocks lack, or are very poor in, feldspar. The mineralogy of these rocks is dominated by nepheline and pyroxene in plutonic examples, and by olivine, melilite, and various feldspathoids in hypabyssal and volcanic examples. Primary carbonate is commonly present, and may be sufficiently abundant to constitute an essential mineral. The presence of carbonate suggests a volatile-enriched magma, a suggestion further enhanced by the common association of alkali metasomatic aureoles (fenites) with rocks of this kindred. Although nephelinites themselves contain little feldspar, they are capable under some circumstances of separating an immiscible syenitic fraction, hence many nephelinitic complexes contain a nepheline syenite component, generated either by metasomatism and anatexis of the country rocks, or by immiscible liquid separation from the parent magma.

In Canada, occurrences of the nephelinite-carbonatite group are the most numerous and the best exposed examples of alkaline rocks. Gradations from alkali basalt to nephelinitic character occur in the Monteregian province west of Montreal, culminating in the Oka complex. The Nipissing alkaline province around Lake Nipissing, Ontario, is entirely nephelinitic. Another major alkaline province, mainly of nephelinite-carbonatite character, occurs along the Kapuskasing "High" of Ontario. As outlying examples, we may mention Big Spruce Lake and Kaminak Lake in the Northwest Territories.

Although all these provinces contain nephelinitic rocks, i.e., rocks lacking feldspar and rich in modal or normative nepheline, the character of the complexes varies considerably. Three types of nephelinitic complexes may be distinguished: (1) nephelinitic-nepheline syenite complexes; (2) nephelinitic-peralkaline syenite complexes; and (3) nephelinitic ultrabasic complexes. The nephelinitic-nepheline syenite complexes contain nepheline syenite as a major component of the complex, but this syenite contains no peralkaline minerals, and differentiation within the syenite is commonly weak. This is the most common type of complex in Canada, and is typified by the Callander Bay complex, Ontario. Substantial amounts of carbonatite are commonly present in such complexes, but the carbonatite may be dispersed throughout the body, as lenses or streaks, instead of forming a central plug. Nephelinitic-peralkaline syenite complexes contain a major syenitic fraction, commonly displaying strong differentiation culminating in peralkaline pegmatites, which may show typically agpaitic mineral assemblages, and minor or negligible carbonatite fraction. The type Canadian example is the Ice River complex of British Columbia. Ultrabasic nephelinitic complexes display no syenitic fraction, usually contain carbonatite as a major component, and commonly contain large amounts of olivine (a mineral uncommon in the other varieties). The type Canadian example is the Oka complex. Whether these variations, which are continuous, reflect variations in the initial magma, the conditions of emplacement, or other factors, is unknown. In the following descriptions we divide the complexes into these three categories to show the similarities between various examples.

Nephelinite-Miaskitic Syenite Complexes

Name	Nipissing alkaline province (Fig. 18)
Location and access	The Nipissing alkaline province occurs within the depressed area occupied by Lake Nipissing, Ontario, and its eastward continuation in the valleys of French and Mattawa rivers, possibly continuing down the upper Ottawa River valley. The central complexes within Lake Nipissing are accessible only by boat, but the rest of the province is traversed by provincial Highways 17 and 11, and various secondary roads. The best exposures are commonly in road-cuts.
Form and structure	The province contains four, or possibly five, nearly circular central complexes about 2 miles in diameter spaced at intervals of 5 to 10 miles. Extensive fenitization and dyke aureoles surround each complex, and nephelinitic lamprophyre dykes occur sporadically along the floor of the valley. Fenitization is found erratically along the edges of the valley, which represents a Paleozoic graben. The central complexes intrude Precambrian granitoid rocks, probably originally of Archean or Aphebian age, but strongly metamorphosed during the Grenville orogeny. The complexes are overlain in two places by Lower to Middle Ordovician sediments of the Chazy stage, which filled craters of possible volcanic origin.
Petrography	Four principal types of alkaline rocks are found in the Nipissing province, namely pyroxene-biotite-olivine (or kaersutite)-analcite rocks, mainly as lamprophyric dykes; carbonatite, mainly as zones or dykes in other rock-types; nepheline syenite, as screens and dykes or as small blebs (ocelli) in the nephelinitic rocks; and fenitic syenites, i.e., metasomatic rocks, commonly found associated with other alkaline rocks, but occasionally found as isolated patches.
Age	K-Ar ages on whole rock samples and on biotite show a fairly close clustering of ages around 560 m.y., although whole rock ages on potash-rich rocks range downward to about 300 m.y. The age seems surprisingly old in view of the Ordovician crater filling in some of the complexes.
Economic aspects	Significant pyrochlore mineralization occurs in two complexes. Two others have been drilled to test their magnetite content, and base metal prospecting, mainly for Cu and Ni, has been carried out around three of the central complexes.
Selected references	Currie, K. L. and Ferguson, J. (1971): A study of fenitization around the alkaline complex of Callander Bay, Ontario; Can. J. Earth Sci., v. 8, p. 498–517. Lumbers, S. B. (1971): Geology of the North Bay area; Ont. Dept. Mines Northern Affairs, Geol. Rept. 94.

Name	Callander Bay (NN-15; Fig. 18)
Location and access	The Callander Bay complex lies mainly under Callander Bay at the east end of Lake Nipissing (46°15′N, 79°20′W). The town of Callander Bay lies on the complex, and large road-cuts on Highway 11 expose the fenite aureole with unusual completeness. Some small islands in the bay are accessible only by boat, but the rest of the complex is easily accessible from highways and secondary roads.
Form and structure	The complex is almost perfectly circular, and about 2 miles in diameter. The outer parts show a strongly concentric structure, mainly due to the presence of many cone sheets, with which the immediate surroundings of the complex are riddled. It seems probable that the central depression is the expression of an original crater. The complex is intruded into north-northwest-trending Precambrian gneisses, mainly of granitoid character, which have been variously fenitized. This aureole and the edges of the complex are cut by a varied suite of dykes.

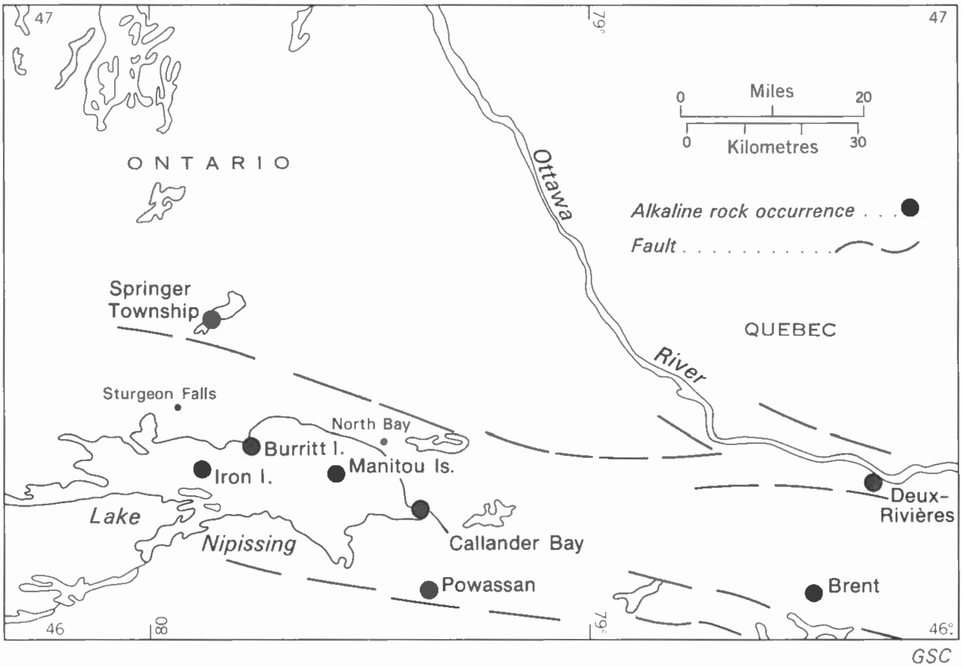

FIGURE 18. The Nipissing alkaline province.

The presence of any sizable central core of alkaline rocks in the Callander Bay complex is rather uncertain. Drilling suggests that the central, water-covered part may consist of complexly layered fenitic syenite and carbonatite, possibly with cone-sheet structure, surrounded by crescentic shells of nepheline syenite on the east side.

Petrography

The country rocks around the complex consist mainly of orthoclase cryptoperthite, oligoclase with warped twin lamellae, and interpenetrating biotite and hornblende, together with lesser amounts of strained quartz. Garnet is commonly present in accessory amounts, and garnet-amphibole-rich lenses up to a foot wide are common. Fenitization, occurring at distances of up to 2,000 feet from the complex, especially around lamprophyre dykes, is first noticeable in an outer zone characterized by narrow breccia veinlets, hematite along cracks, and rare soda pyroxene. The middle, or main zone of fenitization displays abundant development of soda pyroxene on fractures, commonly with accentuation of gneissosity, and an intricate network of pyroxene veinlets. Inner zone fenites, characterized by loss of gneissosity, miarolitic cavities, and generally igneous texture, occur as lenses within the middle zone, and appear locally to grade into nepheline syenite. Fenitization results in a complex series of chemical changes (Table 13; Figs. 19, 20) resulting in production of syenitic rocks.

Fine-grained to aphanitic brownish trachyte, commonly containing sanidine phenocrysts up to a half inch long, and charged with inclusions of country rocks, forms pods or dykes in the fenite zone, sometimes appearing to grade into the fenite. The trachytes are characterized by extreme potassium content. Trachyte both cuts and is cut by carbonatite, lamprophyre, and nepheline syenite dykes. Lamprophyre dykes are concentrated within the fenite aureole, but also occur throughout the region. The most common type contains altered olivine phenocrysts, plus clinopyroxene and biotite in a fine-grained, greenish black matrix of clinopyroxene, biotite, and analcite.

Many of these rocks contain ellipsoidal masses of calcite (ocelli) up to $\frac{1}{4}$ inch in diameter. A rarer type of lamprophyre contains kaersutite instead of olivine, and ocelli rich in alkali feldspar and/or analcite instead of calcite. Zoned phenocrysts of mafic minerals cross ocelli boundaries, the zones having apparently grown in both matrix and ocellus. Nepheline syenite is found as a crescentic mass about 6,000 feet long on the east side of the bay, and as rare dykes. The rocks consist of varying proportions of orthoclase or microcline string perthite, altered nepheline, biotite, aegirine, and minor sphene. A mafic type containing clots of biotite and aegirine and a leucocratic amphibole-bearing variety can be distinguished. One dyke appears to contain pseudoleucite. Dykes and sheets of carbonatite are ubiquitous but not volumetrically important, the longest intersection in drill core being 300 feet. Carbonatite selvages are common on lamprophyre dykes, and gradations from lamprophyre to carbonatite have been found. The carbonatites consist of varying and complex mixtures of biotite, aegirine, potash feldspar, apatite, barite, and opaques in a matrix of intergrown calcite and dolomite. Significant amounts of pyrrhotite, chalcopyrite, and molybdenite occur.

Age

Two K-Ar age determinations on biotite from lamprophyre and nepheline syenite returned ages of 568 and 575 m.y., respectively.

Economic aspects

Callander Bay has been drilled to test the magnetite content of the carbonatite prospected for radioactive minerals (probably uranian pyrochlore), and tested as a source of nepheline syenite. None of these ventures yielded encouraging results.

Remarks

The petrology of the Callander Bay complex has been studied in detail, both as to the origin of the magmatic rocks and the process of fenitization. Ferguson and Currie (1971) showed that the magmatic evolution involved two stages of immiscibility, one separating carbonatite from a primitive nephelinitic magma, and the other separating syenite from a kaersutite lamprophyre. Currie and Ferguson (1971, 1972) show that fenitization was caused by highly concentrated alkali brines, mildly acid and strongly oxidizing, which probably stemmed from the syenitic part of the magma, or possibly from the carbonatitic part.

Selected references

Currie, K. L. and Ferguson, J. (1971): A study of fenitization around the alkaline carbonatite complex at Callander Bay, Ontario; Can. J. Earth Sci., v. 8, p. 498–517.

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Ferguson, J. and Currie, K. L. (1971): Evidence of liquid immiscibility in alkaline ultrabasic dykes at Callander Bay, Ontario; J. Petrol., v. 12, p. 561–585.

Ferguson, J. and Currie, K. L. (1972): The geology and petrology of the Callander Bay alkaline complex; Geol. Surv. Can., Bull. 207.

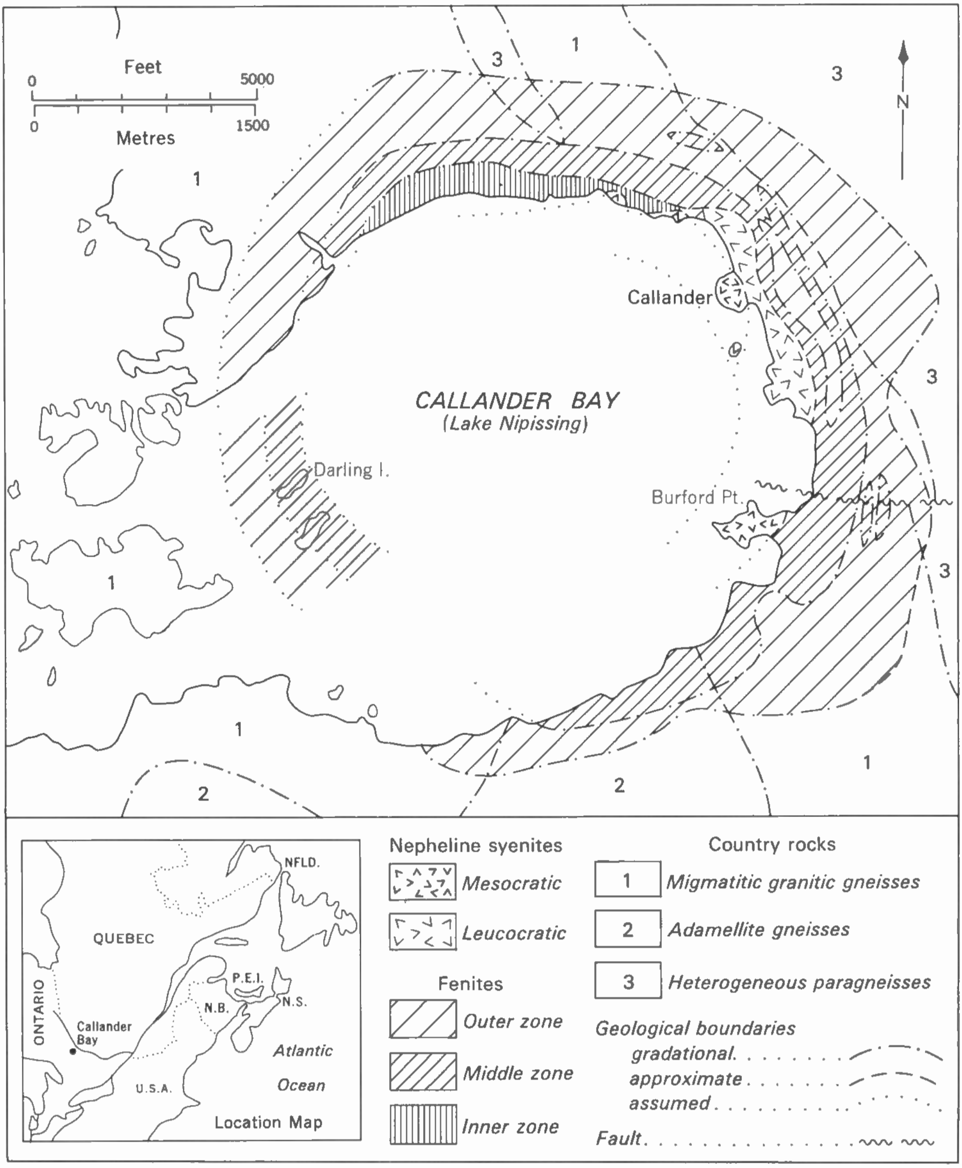

FIGURE 19. Geology of the Callander Bay complex (after Ferguson and Currie, 1972).

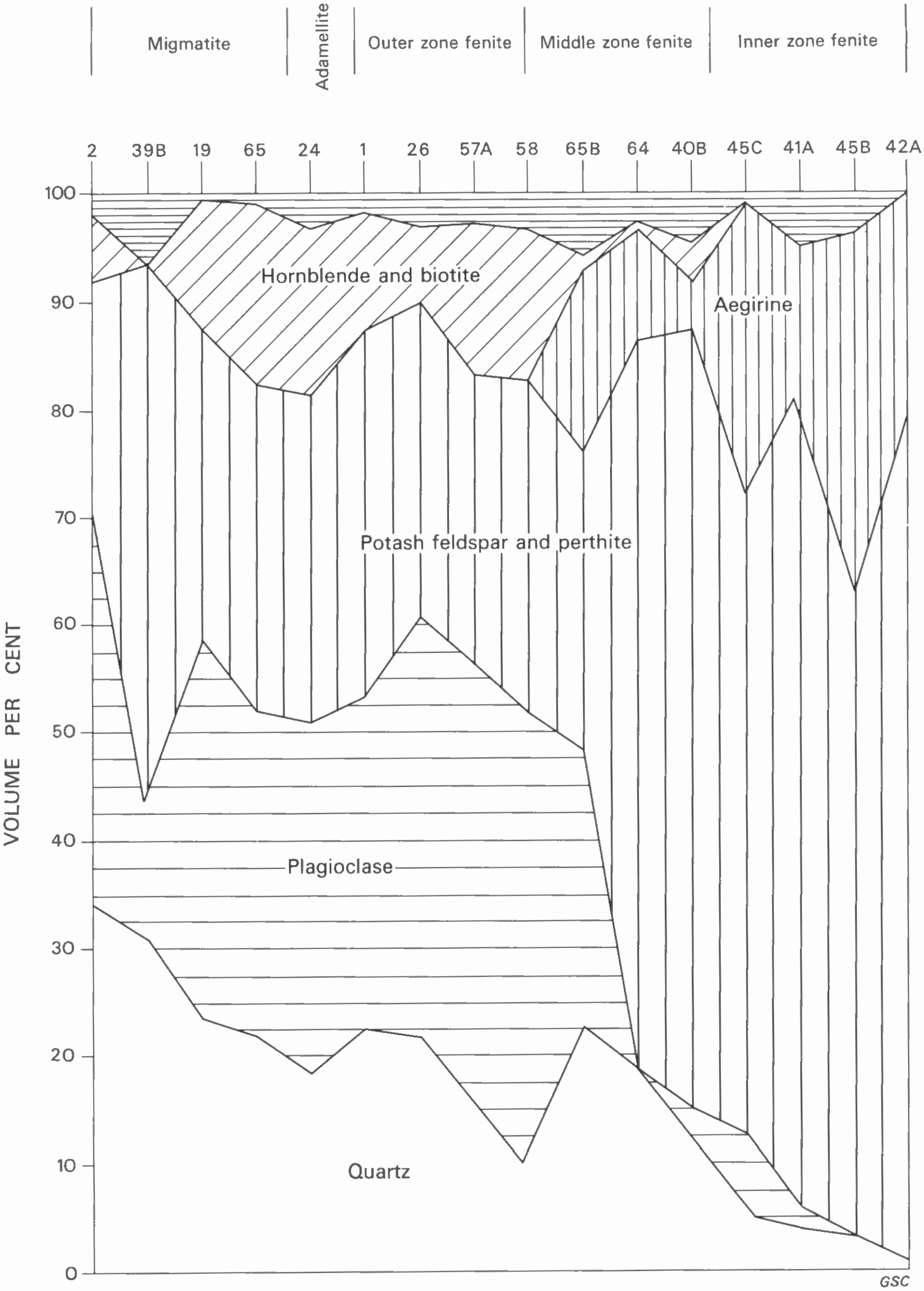

FIGURE 20. Modal trends of fenitization in the Callander Bay complex (after Currie and Ferguson, 1971).

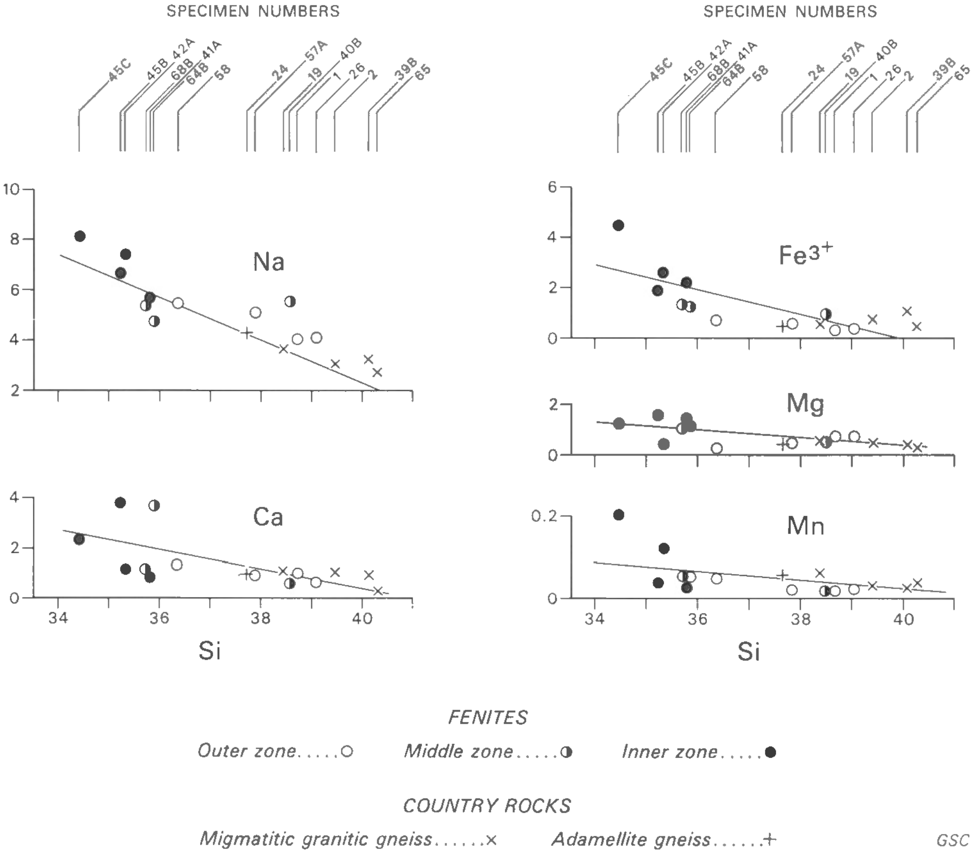

FIGURE 21. Chemical trends of fenitization in the Callander Bay complex, showing the decrease in the number of Si ions per 100 oxygen ions with increasing fenitization, and the concomitant increase in other cations (after Currie and Ferguson, 1971).

TABLE 13 | *Composition of the Callander Bay complex**

	Chemical Composition of Fenites*															
	Country rocks					Outer zone fenites				Middle zone fenites				Inner zone fenites		
Specimen number	2	19	39B	65	24	1	26	57A	58	68B	40B	64B	41A	42A	45B	45C
SiO_2	72.10	68.36	72.22	73.13	67.17	69.53	70.69	67.71	64.91	62.99	69.60	60.27	61.70	58.70	59.37	57.30
TiO_2	0.51	0.86	0.24	0.31	0.50	0.56	0.46	0.39	0.40	0.51	0.37	0.35	0.25	0.47	0.36	0.62
Al_2O_3	13.08	12.31	12.26	12.83	15.25	13.90	13.91	15.25	16.43	14.85	14.90	12.64	15.20	15.00	12.27	11.70
Fe_2O_3	1.52	1.21	2.53	1.06	1.43	0.82	0.88	1.32	1.69	3.20	2.30	2.81	5.00	5.80	4.29	9.80
FeO	1.40	5.60	0.20	1.80	3.00	1.70	1.50	2.20	1.90	2.30	1.00	1.70	0.60	1.90	2.90	1.80
MnO	0.06	0.12	.05	0.03	0.11	0.04	0.04	0.06	0.09	0.09	0.04	0.10	.05	0.23	0.08	0.38
MgO	.62	.71	.46	.43	.47	.91	.93	.48	.41	1.29	.50	1.32	1.80	.50	1.77	1.40
CaO	1.76	1.88	1.54	.46	1.69	1.64	1.10	1.62	2.25	1.87	1.00	5.76	1.30	1.70	5.92	3.80
Na_2O	2.98	3.40	3.10	2.71	4.01	3.76	3.80	4.62	5.24	4.97	5.19	4.13	5.00	6.33	5.78	7.08
K_2O	5.03	4.62	5.86	6.19	5.31	5.31	5.30	5.10	4.94	4.61	5.26	4.65	6.62	6.99	4.59	3.87
P_2O_5	0.21	0.18	0.08	0.05	0.12	0.24	0.16	0.10	0.12	0.25	0.08	0.14	0.11	—	0.51	0.10
H_2O	.80	.60	.40	.60	.70	.70	.60	.60	1.20	1.70	.20	1.50	.70	0.20	.40	.40
CO_2	.10	.10	.80	.10	.10	.30	.10	.30	0.50	1.10	.10	4.40	1.40	.10	.90	1.20
Sr	.027	.019	.018	.013	.015	.027	.020	.033	.034	0.033	.028	0.028	0.018	.064	.190	0.044
Ba	.130	.120	.110	.096	.110	.150	.110	.130	.170	.095	.110	.074	.028	.140	.130	.190
Zr	.025	.088	.045	.030	.051	.035	.041	.073	.058	.031	.060	.027	.030	.030	.044	.110
Rb (ppm)	160	100	190	260	140	170	220	110	120	120	195	120	190	160	190	90
Nb (ppm)	70	100	110	30	110	70	80	50	40	30	50	—	50	275	30	50
TOTAL	100.25	100.07	99.91	99.75	99.94	99.62	99.64	99.99	100.34	99.89	100.74	99.90	99.80	98.15	99.50	99.79

*Chemical analyses by Analytical Chemistry Section, Geol. Surv. Can., using "rapid methods."

Modal Composition of Country Rocks and Fenites*

	Migmatitic gneiss				Adamel-lite	Outer zone fenites				Middle zone fenites				Inner zone fenites		
Specimen number	2	19	39B	65	24	1	26	57A	58	68B	40B	64B	41A	42A	45B	45C
Quartz	33.8	23.6	30.8	22.0	18.4	22.4	21.5	15.7	9.9	22.4	12.2	18.8	3.9	—	2.9	5.5
Plagioclase	36.1	35.1	13.6	29.4	31.9	30.6	39.0	26.6	41.5	25.8	2.3	—	2.2	—	—	7.3
K-feldspar+perthite	22.1	29.1	49.1	30.4	30.9	34.5	26.5	47.7	30.6	28.1	72.7	67.8	73.2	78.3	54.4	59.6
Biotite	4.8	3.7	—	8.4	5.1	6.9	6.1	1.5	1.7	0.9	0.3	0.3	—	—	—	—
Hornblende (+alteration)	1.8	7.9	—	9.2	10.8	3.8	3.8	7.4	11.3	2.6	3.9	—	—	—	—	—
Garnet (+alteration)	—	—	—	—	2.1	—	—	0.5	2.2	—	—	—	—	—	—	—
Aegirine	—	—	—	—	—	—	—	—	—	14.6	4.6	10.1	16.4	21.6	39.0	16.3
Na-amphibole	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9.4
Calcite	—	—	1.9	—	—	0.3	—	—	—	2.6	—	0.3	—	—	0.5	0.3
Apatite	0.5	0.1	—	0.1	—	.7	0.2	0.4	—	0.3	0.3	—	—	—	2.4	.3
Sphene	.5	.5	—	.1	0.4	.8	1.2	1.7	—	—	—	—	—	—	0.5	—
Opaque	.4	—	4.6	.4	.4	—	1.7	0.2	1.1	2.7	3.7	2.7	4.3	0.1	—	—

*Modes based on count of 2,000 points at 0.3 mm interval.
Data after Currie and Ferguson (1971).

TABLE 14 *Chemical analyses of lamprophyres and coexisting ocelli from the Callander Bay complex*

	1(a)	1(b)	1(c)	2(a)	(2b)	2(c)	3(a)	3(b)	3(c)	
SiO_2	37.71	39.40	17.43	34.86	36.34	25.00	40.26	53.5	38.96	SiO_2
TiO_2	4.10	4.35	1.12	4.62	5.11	0.11	3.95	0.7	4.27	TiO_2
Al_2O_3	7.69	8.91	nil	7.61	7.62	7.60	15.48	21.6	14.0	Al_2O_3
Fe_2O_3	4.83	5.84	9.49	1.84	2.71	1.61	6.23	4.1	13.46	Fe_2O_3
FeO	7.67	8.05		9.76	10.06		6.56			FeO
MgO	8.63	8.81	6.12	8.13	8.92	0.92	5.29	2.2	5.60	MgO
CaO	14.20	12.72	31.20	14.41	14.08	20.62	10.28	1.3	11.66	CaO
MnO	0.13	0.15	nil	0.17	0.17	0.17	0.23	n.d.	—	MnO
Na_2O	.81	.93	nil	.42	.52	nil	2.52	2.1	2.58	Na_2O
K_2O	2.86	3.08	0.62	3.51	3.13	8.15	3.69	10.2	3.05	K_2O
H_2O	4.63	4.61	4.60	2.73	2.71	2.70	3.68	4.1	* 5.66	H_2O
CO_2	4.86	2.88	27.81	10.61	8.10	32.20	1.20			CO_2
P_2O_5	1.61	1.61	1.61	1.09	1.12	0.92	0.63			P_2O_5
TOTAL	99.73	101.34	100.00	99.76	100.59	100.00	100.00	99.8	99.24	TOTAL

Analyses by rapid methods, analyst S. Courville.
n.d.: not determined.
*loss of ignition.
1(a) Olivine lamprophyre, 76 A.
1(b) Olivine lamprophyre 76 A, less ocelli constituting 7.9% of volume.
1(c) Computed composition of ocelli in specimen 76 A (total iron computed as FeO).
2(a) Olivine lamprophyre 34 C.
2(b) Olivine lamprophyre 34 C less ocelli constituting 9.8% of volume.
2(c) Computed composition of ocelli in specimen 34 C.
3(a) Kaersutite lamprophyre 125 A.
3(b) Ocelli from specimen 125 A (electron microprobe analysis by G. R. Lachance).
3(c) Matrix of specimen 125 A (rock analysis less 8.9% of ocelli).

Name	Manitou Islands (NN-16; Fig. 22)
Location and access	The Manitou Islands lie about 6 miles offshore from North Bay in Lake Nipissing, and are accessible only by boat (46°15′N, 79°35′W).
Form and structure	The Manitou Islands form an irregularly circular group of five islands, the group being about 2 miles from north to south by 1.7 miles. The central part of the complex, under water between the islands, appears to be composed of alternating screens of carbonatite, syenite, and fenite up to 100 feet thick, whereas the surrounding fenite zone is exposed on the islands. The magnetic signature suggests that the complex is about 2 miles in diameter and almost perfectly circular.
Petrography	The country rocks, very poorly exposed on the islands, comprise generally granitoid gneisses, commonly garnetiferous, similar to those at Callander Bay. The outer parts of the islands display such rocks moderately fenitized with development of pyroxene veinlets, whereas the inner side is composed of coarse-grained to pegmatitic potash feldspar-aegirine rock, containing many veinlets of coxcomb pyroxene. Soda amphibole is found sparsely distributed through the rocks, commonly replacing aegirine. Minor fine-grained pyrite and magnetite is present, and the rock is cut by feldspar-calcite veinlets. Carbonatite occurs as crescentic thin dykes, and drilling shows that carbonatite screens up to 100 feet thick are present under the central bay. A suite of lamprophyric and syenite dykes similar to those at Callander Bay cuts the rocks of the islands. All five islands expose small outliers of Ordovician rocks unconformably overlying the complex, grading upward from coarse conglomerate through shale to dolostone. These rocks were apparently deposited in a crater formed as a result of alkaline igneous activity.
Age	A K-Ar age on biotite from the fenite zone gave 568 m.y.

Economic aspects

The complex contains five deposits of uranian pyrochlore, the largest just east of Newman Island. Nova Beaucage Mines drilled the deposits and sank a shaft on Newman Island to 442 feet, with 2,500 feet of drifting. In 1958 a pilot plant was constructed on the north shore of Lake Nipissing, but in 1960 all operations were closed. Nova Beaucage Mines reported in 1958 that 1,893,000 tons of ore grading 0.86 per cent Nb_2O_5, and 2,962,000 tons grading 0.041 per cent U_3O_8 and 0.69 per cent Nb_2O_5 were present in the Newman deposit.

Selected references

Lumbers, S. B. (1971): Geology of the North Bay area; Ont. Dept. Mines Northern Affairs, Geol. Rept. 94, p. 51–52, 81–82.

Rowe, R. B. (1958): Niobium (Columbium) deposits of Canada; Geol. Surv. Can., Econ. Geol. Ser. 18, p. 45–62.

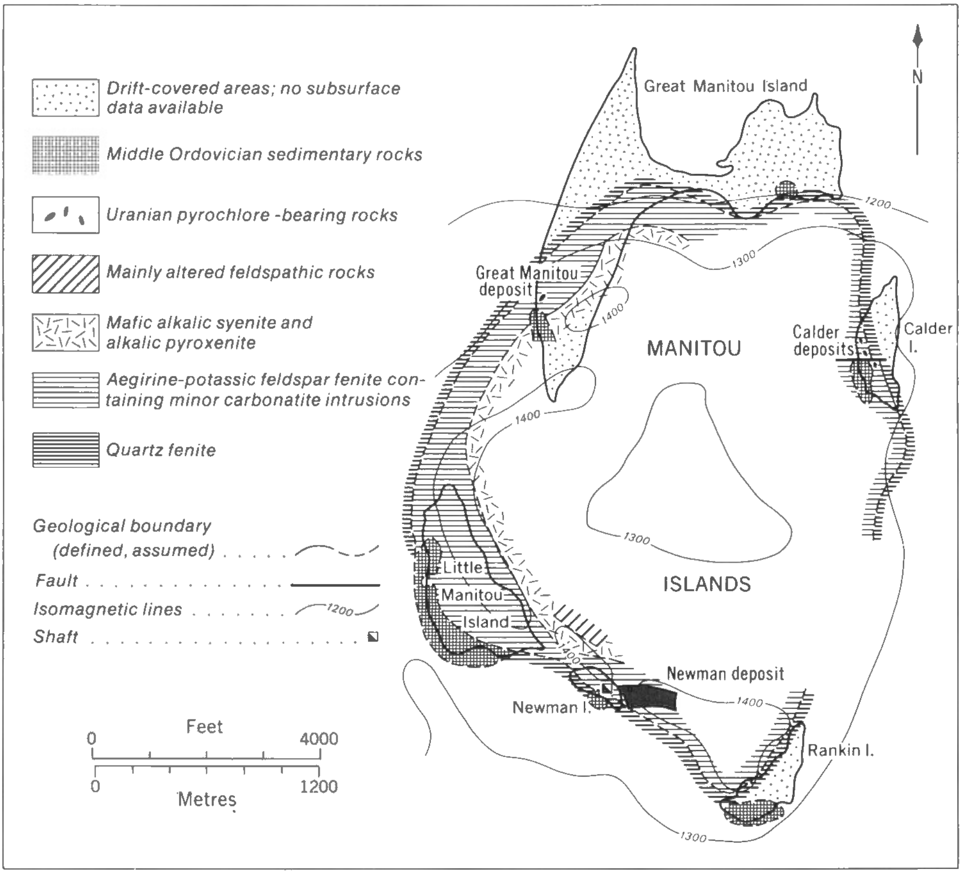

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FIGURE 22. Geology of the Manitou Islands complex (after Lumbers, 1971).

Name	Burritt Island (NN-17; Fig. 18)
Location and access	Exposed on Burritt Island in Lake Nipissing, due south of the Sturgeon River. The locality can be reached only by boat (46°15′N, 79°45′W).
Form and structure	Unknown. Possibly the outcrops on Burritt Island may be the northern fringe of a central complex of the Manitou Islands type, the rest of which is hidden by the lake.
Petrography	"Most of the island is underlain by shattered, slightly fenitized granitic rocks, but toward the southern end, these rocks grade through quartz fenite into aegirine-potassic feldspar fenite which dominates the southern 400 feet of the island. On the eastern side of the island the aegirine-potassic feldspar fenite contains dykes rich in aegirine with some carbonate and altered nepheline, and a carbonatite intrusion that can be traced for about 200 feet along the shore and up to 50 feet inland. The carbonatite contains abundant fine- to coarse-grained aegirine crystals and crystal aggregates concentrated in crude layers, minor amounts of hematite, magnetite, apatite and sodic amphibole, and traces of pyrite and pyrochlore crystals. Lamprophyre dykes are present in the fenites on the northern part of the island." (Lumbers, 1971).
Age	Unknown, but assumed to be the same as the rest of the Nipissing province.
Economic aspects	None known.
Selected reference	Lumbers, S. B. (1971): Geology of the North Bay area; Ont. Dept. Mines Northern Affairs, Geol. Rept. 94, p. 51.

Name	Iron Island (NN-18; Fig. 23)
Location and access	Iron Island lies in the southwestern part of Lake Nipissing, about 21 miles west-southwest of North Bay (46°15′N, 79°55′W), a locality accessible only by boat. Alkaline rocks are exposed on the southwestern point of the island.
Form and structure	Drilling suggests that the complex is a roughly elliptical body 1.5 miles long by 1 mile wide, elongated in a north-south direction. The complex appears to consist of a central core of carbonatite surrounded by an irregular shell of magnetite-rich alkaline pyroxenite. The complex intrudes Precambrian granitoid gneisses, variously fenitized, and is overlain by Ordovician sandstone.
Petrography	The fenite zone varies from a few hundred feet wide south of the complex to more than 1,000 feet on the north. The progression of fenite zones is similar to that at Callander Bay, and a similar suite of trachyte and lamprophyre dykes is present. The outer parts of the complex are ultramafic rocks rich in titanaugite and magnetite, locally containing amphibole, garnet, and melilite, as well as varying amounts of nepheline. Most of these rocks are rich in carbonate, both primary and secondary, and a core of dolomitic carbonatite is present in the northwestern part of the complex.
Age	The age is not definitely known, but is assumed to be the same as that of the rest of Nipissing province.
Economic aspects	Large amounts of iron oxides and apatite are present in the pyroxenite, together with traces of nickel, copper, and uranian pyrochlore associated with the carbonatite. Significant amounts of barite and fluorite are also present locally. Between 1951 and 1953, Nipiron Mines drilled 26 holes totalling 16,318 feet on this complex, but activity has been dormant for many years.
Selected reference	Lumbers, S. B. (1971): Geology of the North Bay area; Ont. Dept. Mines Northern Affairs, Geol. Rept. 94, p. 50–51.

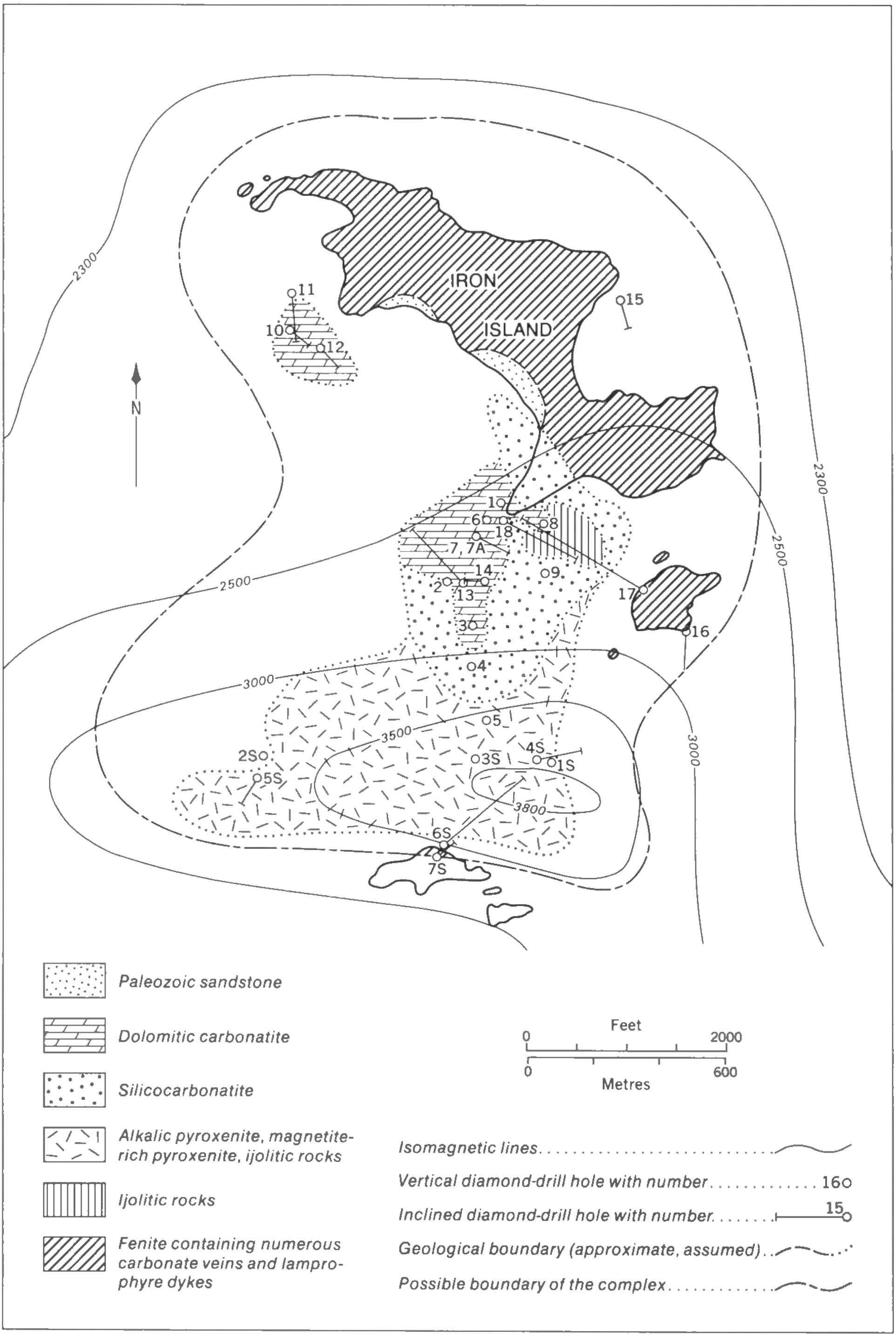

FIGURE 23. Geology of the Iron Island complex (after Lumbers, 1971).

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Name	Brent (NN-19; Fig. 24)
Location and access	The Brent crater lies some 50 miles southeast of North Bay, Ontario (46°04′N, 78°29′W), about 23 miles by bush road from Deux Rivières, and 3 miles north of the railway hamlet of Brent. The crater can be reached by a poor road from Highway 17, leaving the highway just west of Deux Rivières.
Form and structure	The crater forms an almost circular depression, about 2 miles in diameter, in the north-trending granitoid gneisses of the Grenville province. Most of the crater is obscured by a blanket of Ordovician sedimentary rocks, but a low-grade fenite aureole, cut by lamprophyre dykes, is exposed. Drilling shows that trachyte similar to that in other complexes is present at depth. Ultramafic, carbonatitic breccias occur on the west side of the crater.
Petrography	Chemical and mineralogical trends within the fenite aureole are similar to those at Callander Bay. The lamprophyre dykes contain porphyritic olivine and clinopyroxene, with minor biotite, in a matrix of clinopyroxene, biotite, and analcite with abundant carbonate. There are many gradations to carbonatite, and some of the carbonatite-rich parts are mineralized with chalcopyrite. The trachytes are fine-grained to aphanitic aggregates of sanidine, altered aegirine, and opaque dust, charged with partly digested fragments of country rocks.
Age	A whole rock K-Ar age on a lamprophyre dyke yielded 576 ± 40 m.y., whereas whole rock K-Ar ages on the trachytes yielded irregularly younger ages down to 310 m.y.
Economic aspects	None known.
Selected reference	Currie, K. L. (1971): A study of potash fenitization around the Brent crater—a Paleozoic alkaline complex; Can. J. Earth Sci., v. 8, p. 481–498.

Name	Springer Township (Lavergne) (NN-20; Fig. 18)
Location and access	Thirty-five miles northwest of North Bay in Springer Township, about a half mile west of Highway 64 where it crosses Brulé Creek. The occurrence may be reached by foot from this point.
Form and structure	The occurrence is a poorly defined area with a strong east-west elongation, probably several hundred yards long and a few tens of yards wide, consisting of shattered and metasomatized granite in the midst of sound granite and granite gneiss. No alkaline igneous rocks are visible.
Petrography	The rocks are brecciated and shattered on several scales. Large blocks up to several feet on a side are separated by veinlets of purplish, fine-grained, crushed rock, mineralized with aegirine. Aegirine veinlets less than a millimetre thick wander across the rocks suggesting much finer scale brecciation, and with a hand lens it can be seen that crystals in apparently sound rock are also broken. The whole area has a variable reddish, or purplish cast, the colour being more intense in the crush zones. Quartz does not occur in the more fenitized parts, and aegirine is abundant. The occurrence is traversed by numerous relatively small, erratic carbonate veins, commonly rich in fluorite, and by trachytic veinlets. A peculiar, dark coloured, flinty crush-rock resembling pseudotachylite is locally present.
Age	Not definitely known but assumed to be that of the Nipissing province generally.
Economic aspects	A low-grade, rare-earth mineralization is present, and a little pyrochlore.
Remarks	An area of fenitization that is similar exists on the south side of the Nipissing graben and is exposed in a road-cut on Highway 11, 4 miles south of Powassan. Similar areas occur just east of Lake Nosbonsing, and about 1 mile east of Deux Rivières on Highway 17.
Selected reference	Lumbers, S. B. (1971): The geology of the North Bay area; Ont. Dept. Mines Northern Affairs, Geol. Rept. 94.

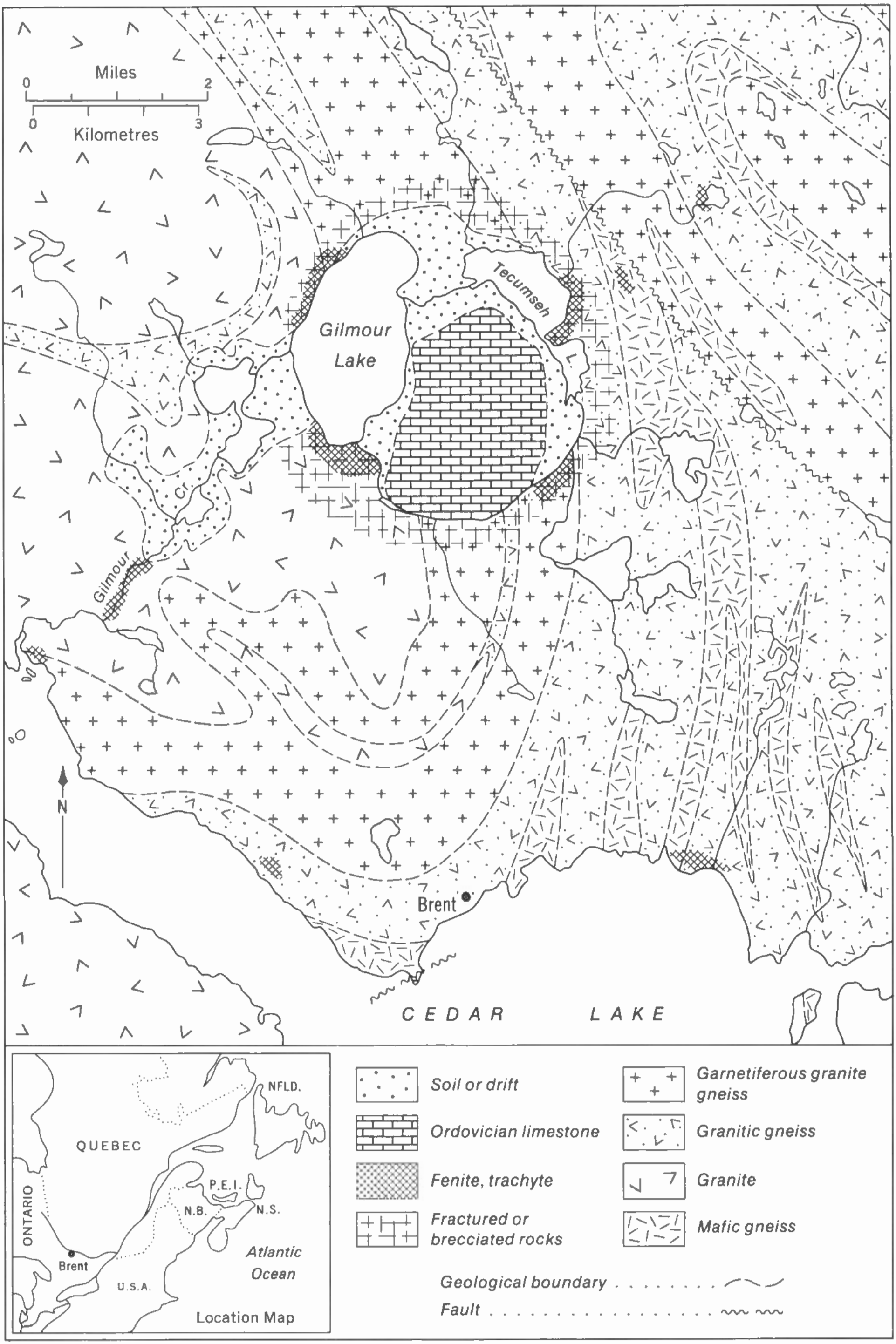


FIGURE 24. Geology of the Brent Crater (after Currie, 1971). GSC

Name	Kapuskasing "High" alkaline province (Fig. 25)
Location and access	The Kapuskasing "High" forms a complex north-northeast-trending belt roughly 60 miles wide extending from Chapleau, Ontario, to James Bay. Although approached in part by the Ontario Northland Railway line, most parts of the belt are accessible only by aircraft. An extension may possibly pass southwest toward Lake Superior.
Form and structure	The Kapuskasing "High" contains separate, but related, chains of gravity and magnetic highs. Metamorphic rocks of granulite grade appear in a narrow slice 6 to 12 miles wide in the northeastern part of the belt but most is underlain by granitoid gneisses of Aphebian age. Although the exact character of the belt is not yet understood, it appears to be a section of the crust upthrown along deep-seated faults expressed at the surface as a complex series of interrelated north-northeast-trending normal faults. The disposition of the belt south of Chapleau is unclear, but the southern margin of the belt may bend westward and reach Lake Superior in the vicinity of Montreal River.
Petrography	An unusual concentration of carbonatite-bearing complexes occurs on the Kapuskasing "High." In the northern part these complexes are mainly lenticular, whereas farther south they are roughly circular, and consistently contain nephelinitic and syenitic rocks. The complexes are not randomly distributed, but tend to form clusters.
Age	Age determinations on alkaline rocks from the Kapuskasing "High" tend to fall in the range 1,550–1,700 m.y. or 1,000–1,100 m.y. (Gittins *et al.*, 1967). If it is assumed that both groups are controlled by the same structure, then it was active for at least 700 million years. This is roughly the same time scale as that observed on the St. Lawrence graben system.
Economic aspects	The carbonatites of the Kapuskasing "High" are the site of several important pyrochlore deposits. Others have been prospected for rare-earths, apatite, and iron.
Selected references	Bennett, G., Brown, D. D., George, P. T., and Leahy, E. J. (1967): Operation Kapuskasing; Ont. Dept. Mines, Misc. Paper 10. Gittins, J., Macintyre, R. M., and York, D. (1967): The ages of carbonatite complexes in eastern Canada; Can. J. Earth Sci., v. 4, p. 651–655.

Name	Lackner Lake (Nemegos) (NK-22; Fig. 26)
Location and access	The Lackner Lake complex lies about 7 miles northeast of the station of Nemegos on the Canadian Pacific Railway line (47°50′N, 83°15′W). It may be reached by auto via the Chapleau Highway, and an access road about 13 miles long.
Form and structure	The complex is almost perfectly circular and about 3 miles in diameter. It forms a distinctive topographic ring rising several hundred feet around the surrounding Precambrian gneisses, but the outcrop is poor. The complex appears to be a ring complex in which older, central rings of ijolitic rocks have been intruded and replaced by a central core of nepheline syenite, and marginal screens of nepheline syenite. The surrounding rocks are fenitized, the acid varieties to syenitic rocks and the gabbroic ones to ijolitic rocks.
Petrography	The northeast-trending gneisses of the country rocks are composed of hornblende-biotite quartzofeldspathic gneisses, commonly garnetiferous and quartz-poor, intruded by slightly metamorphosed gabbro. The gneisses have been metasomatized with development of aegirine and riebeckite, forming brecciated mesocratic sphene-rich syenites, in which the fractures are filled with magnetite. Gabbroic rocks have been intensely brecciated, with conversion of the pyroxene to aegirine, and replacement of plagioclase by nepheline. The fractures are filled with magnetite or nepheline or both. A variant of this type of rock, $\frac{3}{8}$ mile in diameter, forms the *Portage Complex* on the northeastern side of the main mass. The complex is a very heterogeneous mass

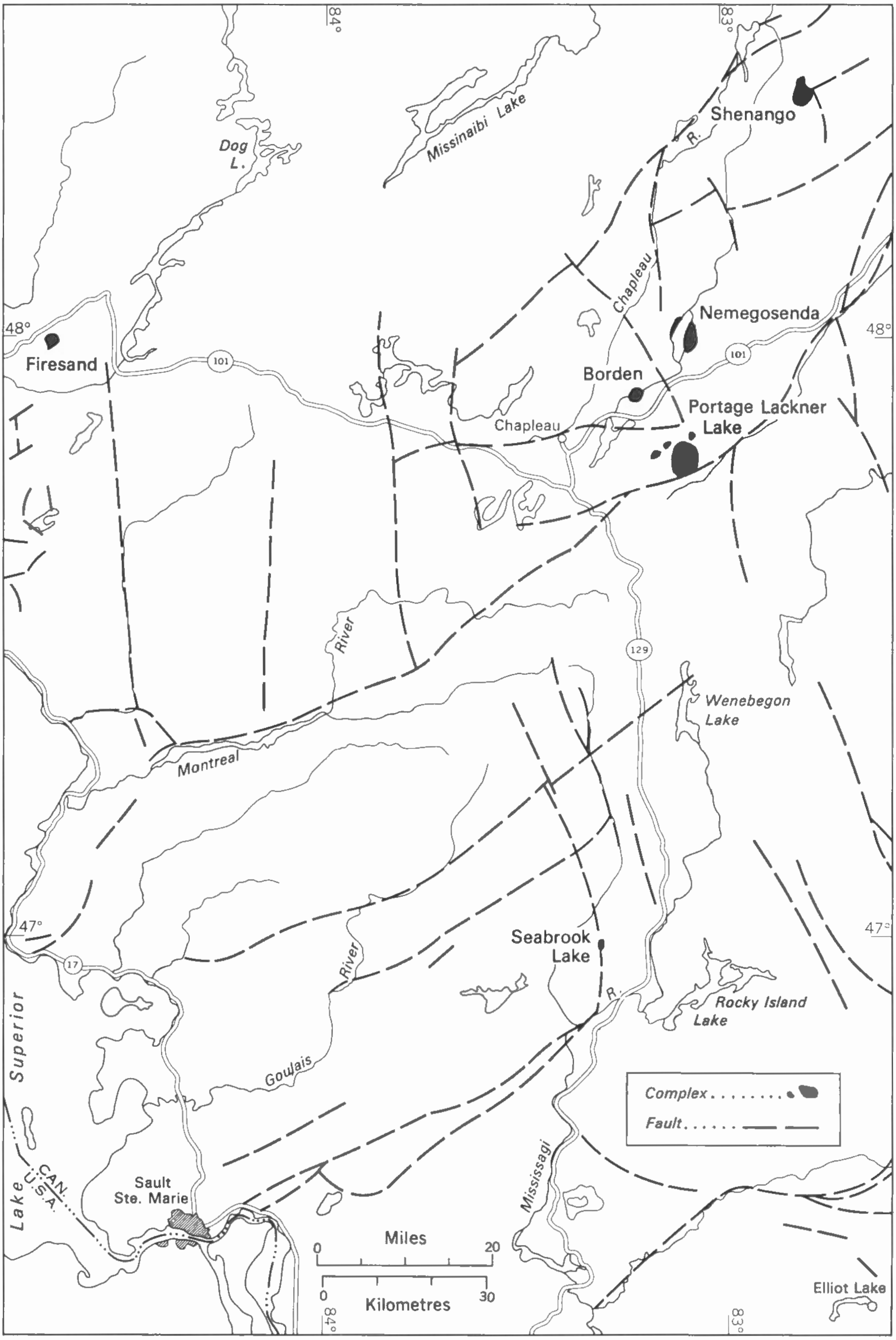


FIGURE 25. Relation of nephelinite-carbonate complexes in east-central Ontario to faults related to the Kapuskasing "High" (in part after Ont. Dept. Mines Map 2198a).

TABLE 15 *Chemical analyses of the Lackner Lake complex (after Hodder, 1961)*

	Chemical composition							
	1	2	3	4	5	6	7	8
SiO_2	50.12	50.32	50.65	50.73	52.42	42.02	51.32	51.22
TiO_2	0.34	0.32	0.32	0.22	0.22	0.96	0.28	0.22
Al_2O_3	21.79	21.82	22.49	22.74	17.91	16.59	19.36	23.55
FeO	2.51	1.96	2.17	1.19	5.46	7.72	4.74	0.42
MnO	4.76	5.61	4.62	5.06	5.78	5.06	5.78	3.89
MgO	0.28	0.28	0.21	0.18	0.36	0.46	0.32	0.14
CaO	1.12	.83	.65	1.08	1.81	3.98	1.23	0.79
NaO	3.86	3.58	3.33	3.19	3.28	10.72	4.23	3.36
K_2O	8.19	7.97	7.49	7.61	3.68	7.07	6.34	7.86
H_2O	6.22	6.36	7.24	7.11	7.55	4.15	6.08	7.02
H_2O+	0.43	0.37	0.24	0.38	1.21	0.03	0.22	1.02
H_2O-	.21	.21	.17	.09	0.19	.19	.05	0.11
P_2O_5	.23	.17	.17	.18	.09	1.08	.21	.15
CO_2	nil	.19	.19	.12	nil	0.19	.04	.18
TOTAL	100.06	99.99	99.94	99.88	99.96	100.22	100.20	99.93

Analyst: W. H. Herdsman

	Modes							
Alkali feldspar	37.9	40.4	46.9	42.8	55.2	49.1	48.4	37.0
Nepheline	43.2	44.3	40.2	41.6	26.1	15.9	27.8	48.3
Biotite (hornblende in 8)	5.3	1.0	3.4	1.4	—	—	—	4.2
Aegirine-augite	11.2	11.1	7.6	11.3	14.2	31.5	17.7	3.0
Accessories	2.4	3.0	1.9	2.9	4.5	3.5	8.2	7.5
TOTAL	100.0	99.8	100.0	100.0	100.0	100.0	102.1	100.0

1, 2, 3, 4. Chemical composition and modes of equigranular nepheline syenites.
5, 6, 7. Chemical composition and modes of malignites.
8. Composition and mode of inequigranular nepheline syenite.

of ijolitic rocks varying from breccia to pegmatite, and variously replaced by biotite, calcite, and magnetite. The igneous rocks of the Lackner Lake complex comprise a central core of fine-grained trachytoid syenite, surrounded by crescentic masses of strongly foliated ijolitic rocks, locally containing wollastonite, melanite, magnetite, and apatite in major amounts. Numerous ghost-like remnants of syenitic rocks are found in this zone, which gradually becomes feldspathic toward the outer margin, passing into melanocratic nepheline syenite, and then into a coarse trachytoid nepheline syenite with microcline microperthite laths, 1 to 2 inches long, set in euhedral nepheline cubes. Aegirine was the principal mafic, but has been replaced by hornblende and biotite. Sodalite, sphene, calcite, pyrochlore, and perovskite are present in accessory amounts. Drilling has revealed the presence of numerous, although small, screens of foliated carbonatite, mainly calcite with accessory yellow garnet, biotite, sphene, and pyrochlore. Lamprophyre dykes and cone sheets, mainly of biotite-kaersutite-aegirine-rich composition, cut both the complexes and the surrounding metasomatic rocks.

Age

A K-Ar age on biotite yielded 1,090 m.y. (Gittins *et al.*, 1967).

Economic aspects

The Lackner Lake complex has been intensively prospected for magnetite, apatite, and niobium, mainly in basic metasomatized rocks around and within the intrusion. In 1955, Multi-Minerals Ltd. reported outlining a body of 10 million tons grading 15.5 per cent magnetite, 19.5 per cent apatite, and 0.23 per cent Nb_2O_5. Various smaller bodies, some of them strongly radioactive, contain much higher percentages of iron and/or phosphate.

Selected references	Hodder, R. W. (1961): Alkaline rocks and niobium deposits near Nemegos, Ontario; Geol. Surv. Can., Bull. 70. Parsons, G. E. (1961): Niobium-bearing complexes east of Lake Superior; Ont. Dept. Mines, Geol. Rept. 3, p. 51–69.

Name	Borden (NK-24)
Location and access	Eight miles northeast of Chapleau in the valley of the Borden River. The complex can be reached on foot from Highway 101, a mile to the south, but outcrop is virtually nonexistent.
Form and structure	Unknown, but a strong magnetic anomaly suggests a near-circular complex about 1 mile in diameter.
Petrography	Alkali syenite with carbonatite, possibly in the form of dykes and cone sheets, has been recovered from drill core, but the bulk of the complex is ijolitic (Watkinson *et al.*, 1972).
Age	Unknown.
Economic aspects	None known.
Remarks	Borden forms a triplet with Lackner Lake and Nemegosenda Lake. The complex may be satellitic to these two larger complexes, and other satellites are undoubtedly present in this region. Ijolitic boulders have been recovered from an area about 18 miles southwest of Lackner Lake, in Township 12E, District of Sudbury, where there is another prominent magnetic anomaly.
Selected reference	Watkinson, D. H., Thurston, P., Shafiqullah, M. (1972): The Shawmere anorthosite of Archean age in the Kapuskasing belt, Ontario; J. Geol., v. 80, p. 736–739.

Name	Nemegosenda Lake (NK-25; Fig. 27)
Location and access	Sixteen miles northeast of the town of Chapleau, about 3 miles north of the Folyet–Chapleau Highway (48°00′N, 83°05′W). An access road exists but is in poor condition, and access is by aircraft.
Form and structure	The Nemegosenda Lake complex is an elliptical mass 3½ by 1½ miles, whose long axis trends north-northwest. Much of the complex is hidden by the lake, but arcuate ridges are present on the western shore. The complex consists of a broad aureole of mafic and salic fenites surrounding a relatively narrow fringe of mafic alkaline rocks, and a central core of nepheline syenite. Lamprophyre and carbonatite dykes cut the complex and the surroundings, and may form cone sheets.
Petrography	The migmatitic, northeast-trending country rocks comprise quartz-oligoclase-biotite-garnet gneiss alternating with hornblende oligoclase gneiss, both cut by relatively fresh gabbroic intrusions. These rocks are variously fenitized with nepheline replacing plagioclase, producing ijolitic rocks from gabbro. The outer ring of alkaline igneous rocks consists of crescentic screens of ijolite and jacupirangite, locally wollastonite- and melanite-bearing. These rocks have been variously brecciated and metasomatized by younger nepheline syenites that occupy the central 80 per cent of the intrusive. All the alkaline rocks locally show strong foliation, suggesting cone-sheet structure. As at Lackner Lake, the nepheline syenites become progressively finer grained toward the centre, displaying several recognizable phases. Carbonatites, calcitic and almost monomineralic, occur as cone sheets in the fenites, whereas biotite-orthoclase lamprophyres occur throughout the complex.
Age	A K-Ar age on biotite from the nepheline syenite gave an age of 1,010 m.y. for the Nemegosenda Lake complex (Gittins *et al.*, 1967).
Economic aspects	In 1961, Dominion Gulf Ltd., as a result of extensive drilling, estimated that in excess of 20 million tons of material grading 0.47 per cent Nb_2O_5 was present in

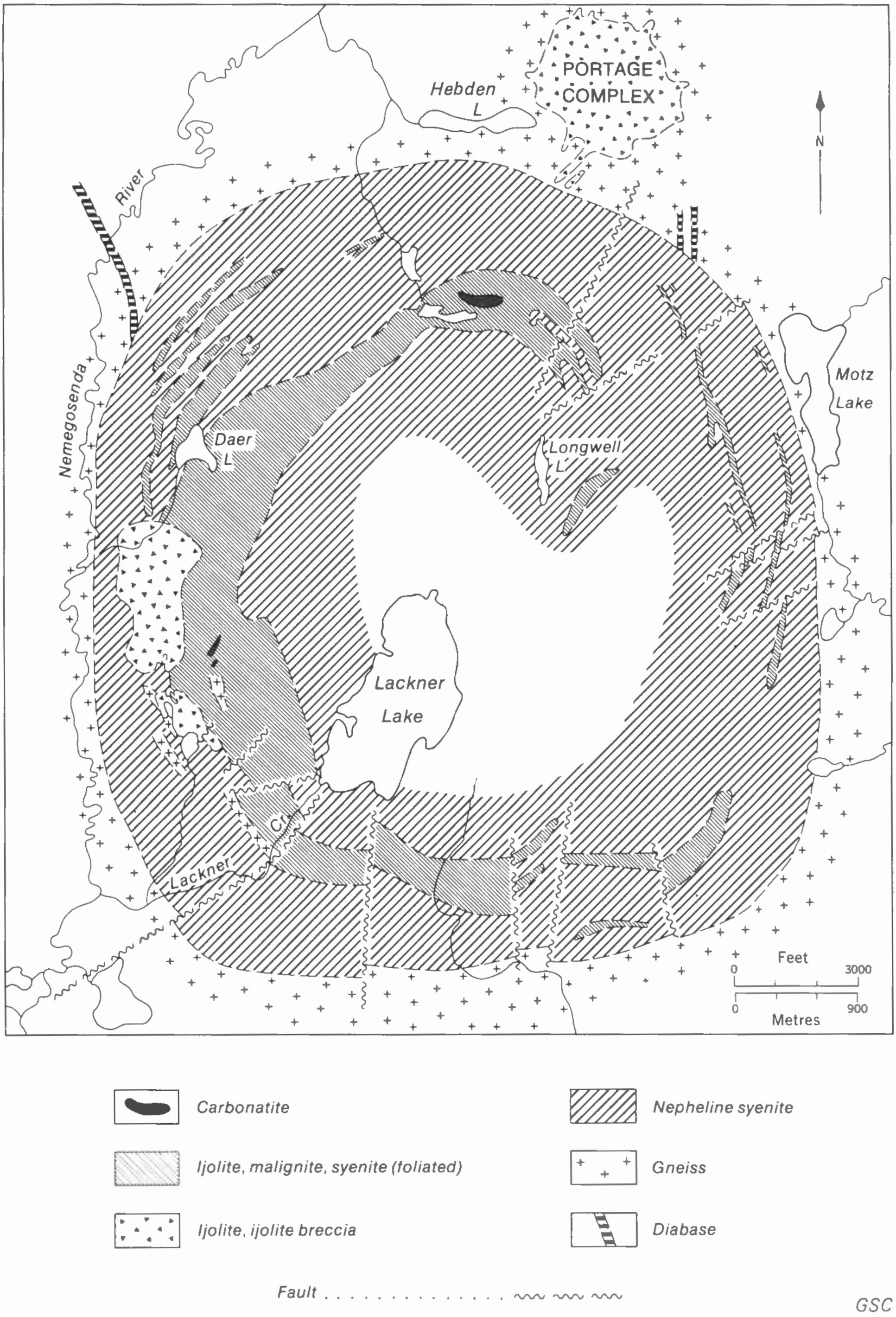


FIGURE 26. Geology of the Lackner Lake complex (after Parsons, 1961).

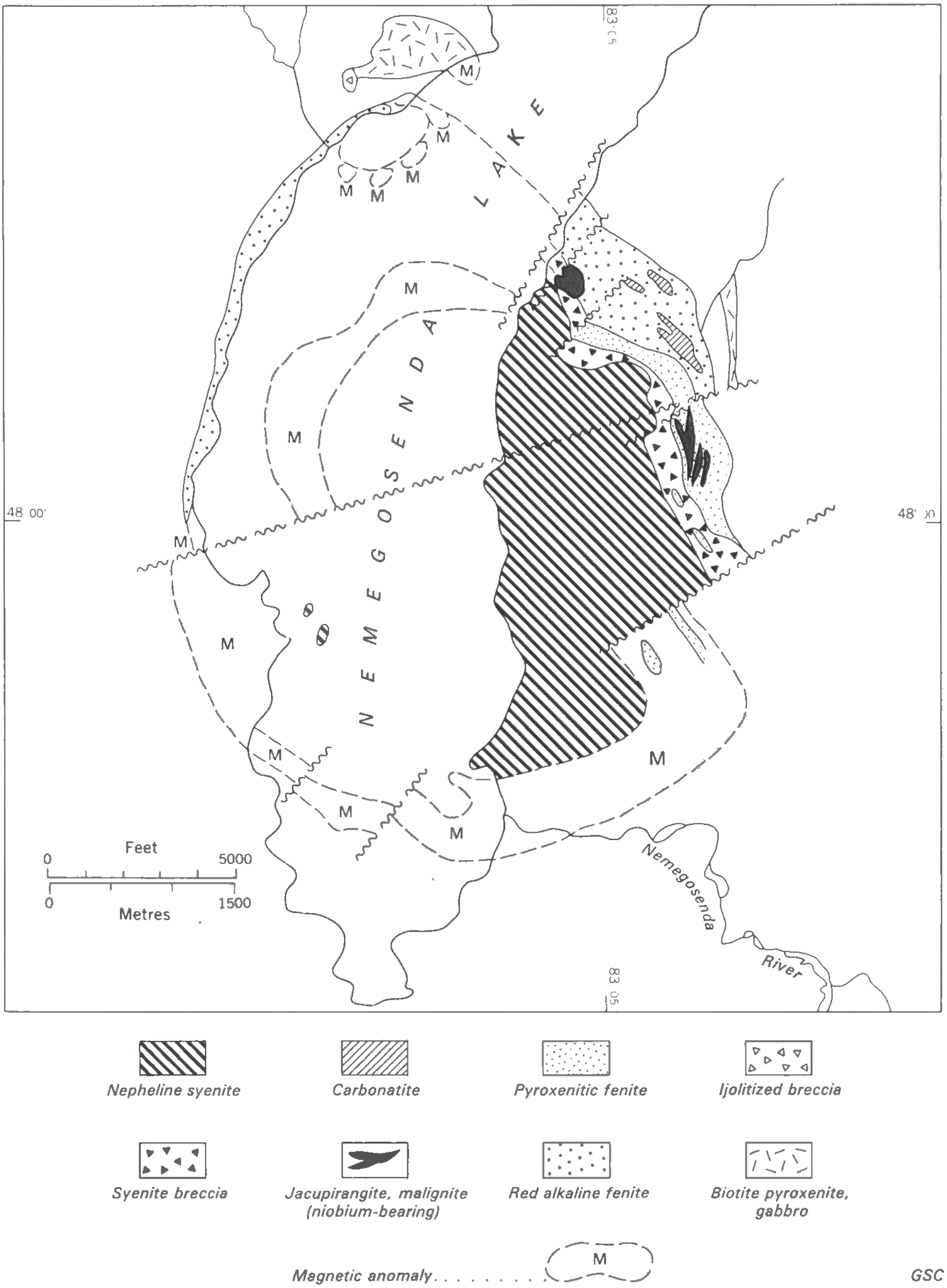


FIGURE 27. Geology of the Nemegosenda Lake complex (after Parsons, 1961).

	pyrochlore in the mafic and ultramafic rocks rich in wollastonite and garnet. Superficial examination of this complex has also been made to assess the possibilities of concentrating nepheline, but the rocks are too heterogeneous and rich in mafic minerals to be attractive.
Selected reference	Parsons, G. E. (1961): Niobium-bearing complexes east of Lake Superior; Ont. Dept. Mines, Geol. Rept. 3, p. 33–50.

Name	Shenango (NK-26)
Location and access	Thirteen miles west of Folyet, and 1 mile south of the Canadian National Railways line (82°48′W, 48°26′N). Access is by railway.
Form and structure	A teardrop-shaped mass roughly $2\frac{1}{2}$ miles long and $1\frac{1}{2}$ miles in maximum width, with its long axis north-south, and the widest part to the south. The northern end of the body appears to be controlled by faults.
Petrography	No published petrographic descriptions are available, but the complex is said to consist mainly of syenite and alkaline diorite (Watkinson *et al.*, 1972).
Age	K-Ar determination on biotite gave 1,075 m.y. (Watkinson *et al.*, 1972).
Economic significance	Unknown.
Selected references	Carlson, H. D. (1963): Preliminary geological map of the Folyet area; Ont. Dept. Mines, Map P. 283. Watkinson, D. H., Thurston, P., and Shafiqullah, M. (1972): The Shawmere anorthosite of Archean age in the Kapuskasing belt, Ontario; J. Geol., v. 80, p. 736–739.

Name	Seabrook Lake (NK-27; Fig. 28)
Location and access	Forty-eight miles northwest of Elliot Lake, Ontario, and 6 miles west of Highway 129, in Township 5E, District of Algoma. The body is accessible via an old lumber road branching off from Highway 129 at Aubrey Falls on the Mississagi River.
Form and structure	The Seabrook Lake complex is a teardrop-shaped body roughly $1\frac{1}{2}$ miles in north-south length, and half of that across. The complex occurs along a major north-south fault, and is itself strongly brecciated in some parts. It intrudes massive granite, cut by diabase dykes, both of which are fenitized.
Petrography	The complex contains a circular core of foliated dolomitic carbonatite with accessory pyroxene and amphibole, a few hundred feet in diameter and offset by the fault. This is surrounded by a heterogeneous collar of brecciated silico-carbonatite and then by an elongate mass of ijolite and alkaline pyroxenite, highly inhomogeneous, brecciated in part, and possibly partly metasomatic. Carbonatite dykes are found in these rocks, as well as lamprophyre dykes and rare feldspathoidal alkaline dykes. The country rocks have been brecciated and pyroxene and carbonate introduced along fractures in a zone a few hundred feet wide.
Age	A K-Ar age determination on biotite from the silico-carbonatite gave 1,103 m.y. (Gittins *et al.*, 1967).
Economic aspects	Tarbutt Mines Ltd. has prospected Seabrook Lake for iron, niobium, and radioactive minerals, but despite strong magnetic and radioactive anomalies the results are not encouraging, although visible pyrochlore is present.
Remark	Seabrook Lake is connected by a complex system of faults to the Lackner Lake area, and it is conceivable that Seabrook Lake lies on some kind of southerly extension of the Kapuskasing "High."
Selected reference	Parsons, G. E. (1961): Niobium-bearing complexes east of Lake Superior; Ont. Dept. Mines, Geol. Rept. 3, p. 11–22.

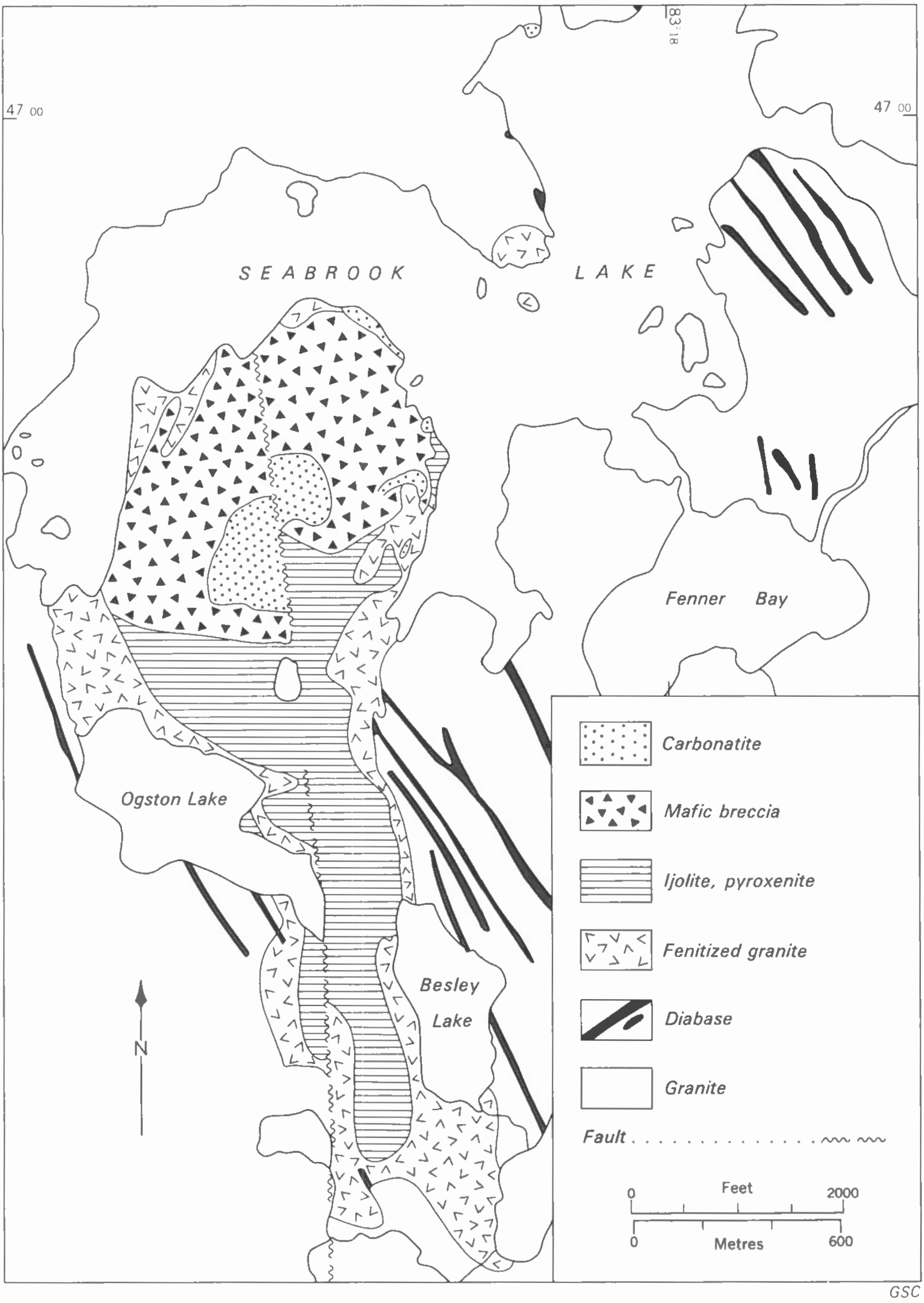


FIGURE 28. Geology of the Seabrook Lake complex (after Parsons, 1961).

Name	Firesand River (NK-28; Fig. 29)
Location and access	Four and one-half miles east of the town of Wawa, Ontario, and readily accessible via a branch road from the highway joining Wawa to Hawk Junction (48°00′N, 84°40′W).
Form and structure	The complex underlies a nearly circular area about a mile in diameter, part of which is underlain by a hill rising about 150 feet above the surrounding sand plains. Although outcrop is not good, abundant rubble is present. Drilling defines a foliated ring complex with inward dips of about 70 degrees, intruding mildly metasomatized, northwest-trending Archean greenstones which are cut by syenite bodies, and one diabase dyke.
Petrography	The central core of the complex consists of high-standing, near massive, ankeritic dolomite with late barite-quartz schlieren, surrounded by an outer ring, about 1,000 feet wide, of coarse calcite carbonatite containing biotite, aegirine, apatite, magnetite, and various sulphides. Strong foliation consistently dips inward at about 70 degrees. Between the two rings irregular crescentic screens of mafic silicate rocks are present, consisting of nepheline, aegirine, biotite, melanite, apatite, and calcite in varying amounts. Similar rocks occur as lenses within the calcite carbonatite, and as dykes in the country rocks. Olivine-biotite-augite lamprophyres (monchiquites) are found in the region of the Firesand River complex. The amount of fenitization in the country rocks is uncertain, but development of aegirine, biotite, and minor calcite in the greenstone has been noted.
Age	A K-Ar age on biotite from the Firesand River complex yielded 1,048 m.y. (Gittins *et al.*, 1967).
Economic aspects	The Firesand River complex was examined first as an iron prospect due to the unusual ring-shaped magnetic anomaly, but more recent work has been done on its Nb content. Fairly substantial drill-core footages, grading about 0.25 per cent Nb_2O_5, were obtained.
Selected reference	Parsons, G. E. (1961): Niobium-bearing complexes east of Lake Superior; Ont. Dept. Mines, Geol. Rept. 3, p. 23–33.

Name	Nagagami River Belt (NR-29, 30, 31, 35; Fig. 30)
Location and access	Along the Nagagami River, Ontario, from roughly latitude 50°15′N some 80 miles north-northwest to Albany Forks, approximately at 84°20′W. All this area is difficult of access because of swamp, and can be reached only by aircraft, or by boat along the Nagagami River.
Form and structure	Little is known about the form of the individual complexes in this belt, except that they produce strong, closed, subcircular magnetic anomalies. Outcrop is nonexistent, and all the bodies are probably covered by a substantial thickness of Paleozoic rocks. Eight distinct anomalies are present on aeromagnetic maps, of which five have been shown by drilling to result from alkaline complexes. At least some of these complexes are strongly foliated. The country rocks appear to be migmatitic, predominantly granitoid gneisses.
Petrography	A drillhole on the anomaly at Albany Forks passed down the dip of 473 feet of foliated dolomitic carbonatite containing bands of magnetite and pyrochlore. Drilling on the Little Current River anomaly, which is 15 miles in diameter, indicates the presence of alkaline diorite and syenite, whereas two smaller anomalies near Mammamattawa seem to be caused mainly by ijolitic rocks. The southernmost anomaly, penetrated by four drillholes, is composed mainly of alkaline syenite and diorite.
Economic aspects	Pyrochlore and magnetite are known to be present in considerable amounts, but the possible economic significance is unknown.
Age	Not definitely known, but certainly Precambrian.

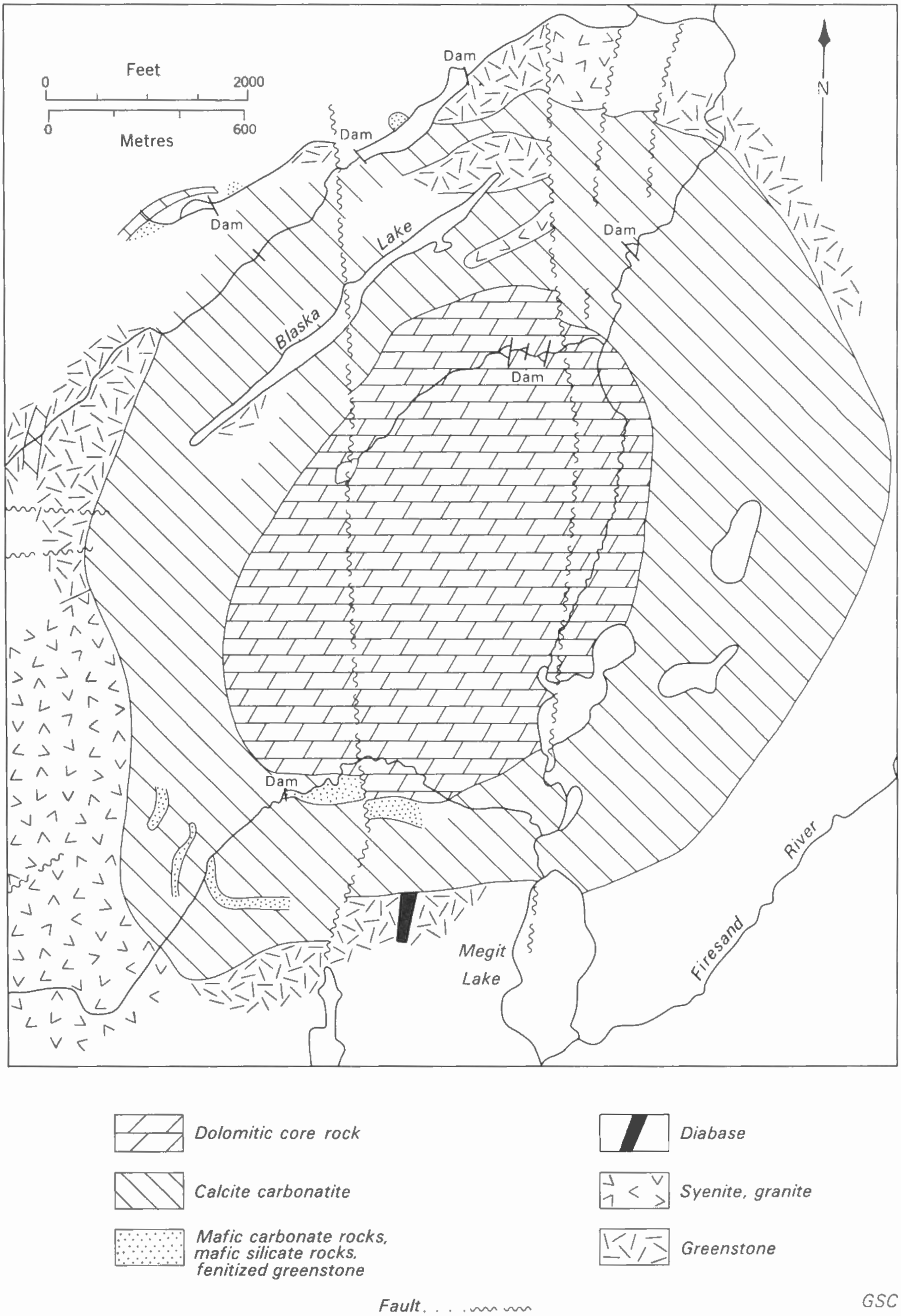
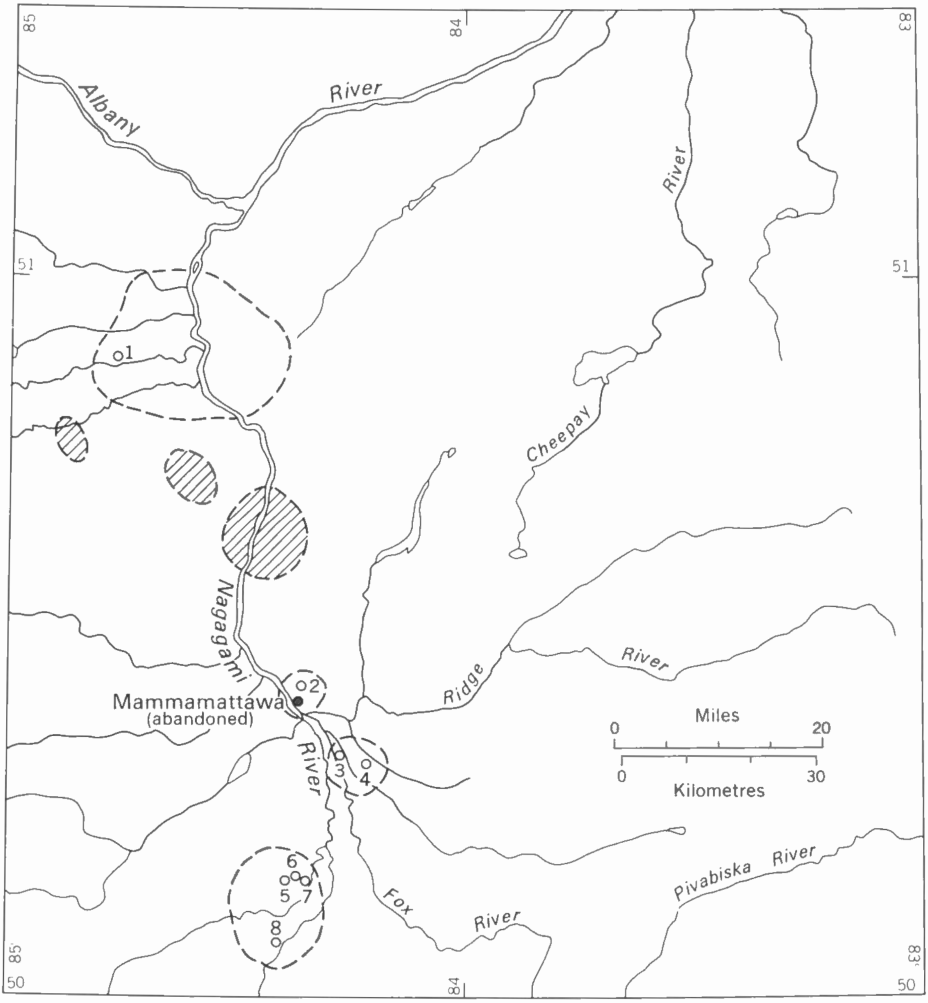


FIGURE 29. Geology of the Firesand River complex (after Parsons, 1961).



DRILL LOGS

1. 0'-75' Pleistocene
   75'-790' Lower Paleozoic
   790'-1120' Alkalic diorite and syenite

2. 0'-920' Pleistocene and lower Paleozoic
   920'-940' Alkalic olivine diorite

3. 0'-820' Pleistocene and lower Paleozoic
   820'-1220' Alkalic olivine diorite

4. 0'-870' Pleistocene and lower Paleozoic
   870'-1030' Alkalic olivine diorite

5. 0'-520' Pleistocene and lower Paleozoic
   520'-543' Alkalic syenite
   543'-590' Granite

6. 0'-480' Pleistocene and Paleozoic
   480'-740' Alkalic syenite and diorite

7. 0'-480' Pleistocene and lower Paleozoic
   480'-806' Alkalic syenite

8. 0'-280' Pleistocene and lower Paleozoic
   280'-577' Alkalic syenite

Geophysical data (alkalic syenite and granite, alkalic gabbro and diorite). ▨

GSC

FIGURE 30. The Nagagami River alkaline province, and presumed complexes within it (after Innes and Ayres, 1971).

Remarks	The strong alignment and close association of the anomalies, and the proven presence of alkaline rocks suggest that this belt represents a major alkaline rock province. It may be an offshoot of the Kapuskasing "High." The very limited drilling results suggest a range of alkaline rock-types comparable to that of the Monteregian petrographic province.
Selected references	Innes, D. G. and Ayres, L. D. (1971): Caramat-Pagwa River sheet; Ont. Dept. Mines Northern Affairs, Geol. Comp. Ser., Map 2202. Satterly, J. (1970): Aeromagnetic maps of carbonatite-alkalic complexes in Ontario; Ont. Dept. Mines Northern Affairs, Map P. 452 (revised).

Name	Prairie Lake (NC-37; Fig. 31)
Location and access	Twenty-two miles northeast of Schreiber on the north shore of Prairie Lake (49°02′N, 86°46′W). The complex is readily accessible only by aircraft.
Form and structure	The complex is almost circular, and about 1 mile in diameter. The central core consists of brecciated and altered ijolite with minor nepheline syenite, surrounded by a thin shell of calcite carbonatite. The complex intrudes Archean, granitoid country rocks, moderately to intensely fenitized. Outcrop is poor.
Petrography	A variety of ijolitic rocks is present in the central core, including melanite, and wollastonite-rich units. The core may display mineral layering, but this has been disrupted by brecciation and intrusion of nepheline syenite. The carbonatite appears to be younger than the core, and forms a relatively massive and homogeneous unit of calcite-biotite-apatite rock.
Age	K-Ar dating of biotite gave 1,112 m.y.
Economic aspects	Radioactive pyrochlore mineralization associated with the complex has been drilled with indifferent results.
Remarks	The age and location of the Prairie Lake complex strongly suggest a genetic connection with the syenitic Port Coldwell and Killala Lake complexes. Rocks of chemistry similar to that of the Prairie Lake complex intrude the Port Coldwell complex (kaersutite-biotite-augite lamprophyres with analcite in the matrix, and commonly carbonate or felsic ocelli) and occur sporadically in the environs, particularly in the region of Heron Bay (NC-36, 48°40′N, 86°20′W).
Selected reference	Ferguson, S. A. (1971): Columbium (Niobium) deposits of Ontario; Ont. Dept. Mines Northern Affairs, Mineral. Resourc. Circ. 14, p. 53.

Nephelinite-Agpaitic Syenite Complexes

Name	Ice River (N-39; Fig. 32)
Location and access	In the Rocky Mountains, about 15 miles south of Field, British Columbia, in Yoho and Kootenay National parks (51°30′N, 116°30′W). The complex can readily be reached by helicopter from Golden, B.C., but such flights are not encouraged by park authorities. The part in the Ice River valley is fairly easily accessible by gravel road and pack trail from Leanchoil on the Trans-Canada Highway, whereas the eastern part is difficult to reach except by climbing from trails at the headwaters of Vermilion River.
Form and structure	The complex forms a U-shaped mass open to the north, with an outlying area to the east. The maximum length is about 8 miles, and the width between the arms about 6 miles. Structurally the complex consists of two distinct parts. The older, feldspar-free rocks form a sill, or laccolith-like mass, attached to a vertical pipe on Mount Sharp. This mass follows more or less faithfully a contact between the Cambrian Ottertail and Chancellor formations. It is cut by a pipe-like, younger syenitic complex

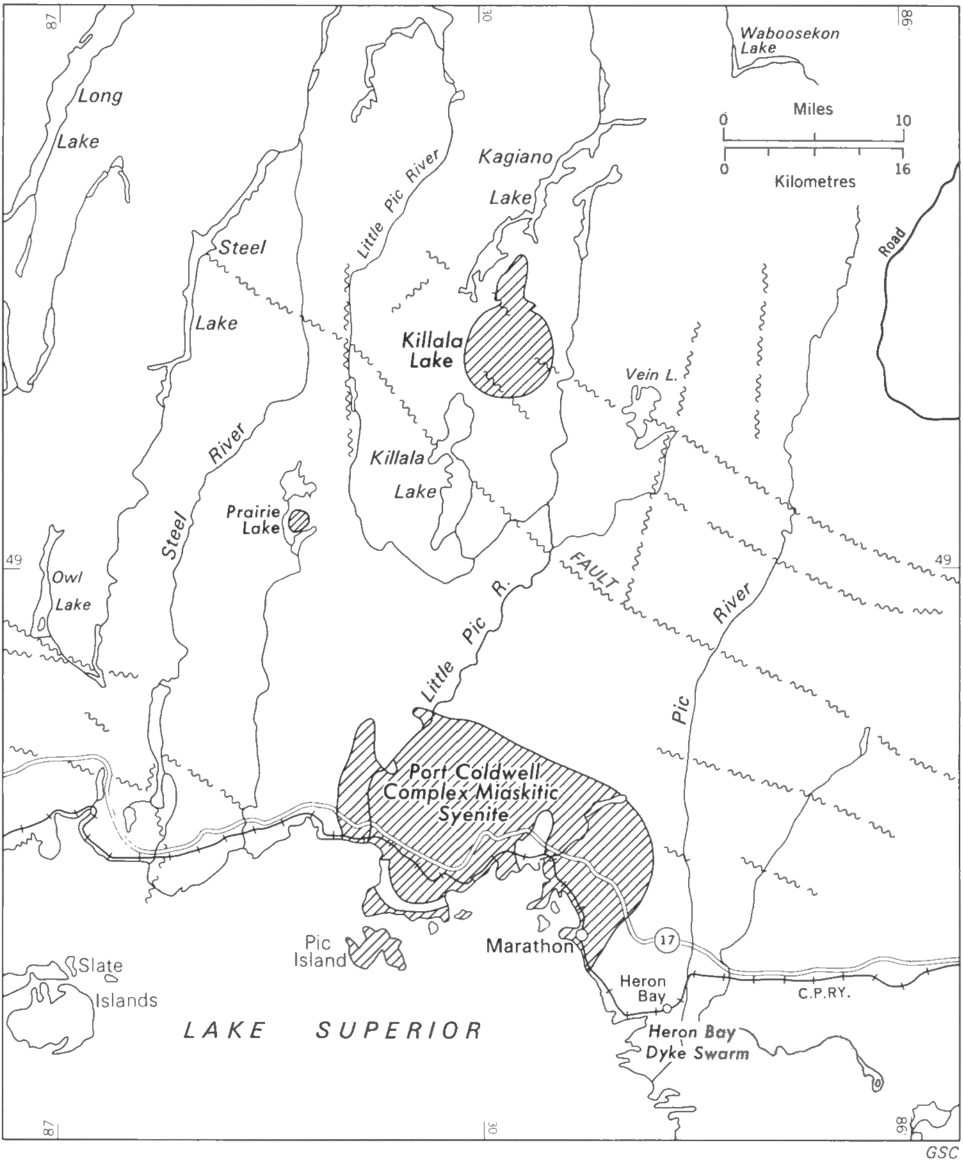


FIGURE 31. The Prairie Lake, Port Coldwell, and Killala Lake alkaline complexes.

which appears to pass almost vertically through the older alkaline and sedimentary rocks. The syenite is surrounded by a contact aureole of impressive dimensions, locally reaching a width of 1,200 feet.

Petrography

The older feldspar-free part of the complex consists of repeated sequences of layered rocks, attached to an ultramafic pipe, presumed to be the source of the magma. The ultramafic rocks are composed principally of titanaugite, with important amounts of magnetite, sphene, biotite, and minor, but persistent, nepheline. Similar material is found at the base of the layered sequence, which in upward sequence consists of alkaline pyroxenite, mela-ijolite, melanite ijolite, ijolite, urtite, wollastonite urtite, and carbonatite. Within this sequence cryptic and rhythmic layering is present, the pyroxenes varying continuously from titanaugite through hedenbergitic varieties to aegirine. 'Sedimentary features,' such as graded bedding and channel scours, are locally present. The amount of nepheline increases steadily with differentiation, except at the very end where carbonate becomes dominant. Chemically, the complete gradation from alkaline pyroxenite to urtite is displayed (Table 16). Carbonatite is locally an important part of the layered series, and an elongate plug of strongly foliated ankeritic carbonatite is present in the northwestern part of the intrusion. This plug is believed to be the result of mechanical concentration of carbonatite during later deformation of the Ice River complex.

The syenite complex is characterized by the presence of large amounts of kaersutite, a mineral rarely found in the layered complex, except in certain ijolitic pegmatites. The syenite series is strongly zoned, but not layered. The outer parts consist of rather melanocratic rocks, commonly brecciated, and showing a strong gneissosity, presumably secondary. This unit grades inward through mesocratic varieties to coarse-grained, massive, green syenites containing sodalite. Titanaugite and kaersutite, common in the mafic varieties, disappear and acmitic pyroxene is the principal mafic. Complex, large perthite crystals with interstitial nepheline comprise the bulk of the rock, and traces of sodalite are present in all but the most mafic.

The dyke suite is varied and complex, representing all the principal compositions. The feldspar-free dykes commonly contain felsic ocelli, whereas many of the syenitic dykes are strongly peralkaline, due to the presence of large amounts of sodalite, cancrinite and, in places, of agpaitic minerals, notably ramsayite, astrophyllite, rosenbuschite, and possibly eudialyte. In addition to dykes, a very complex assemblage of pegmatitic schlieren occurs within the complex.

The wall-rocks of the Ice River complex are variously affected, mainly by conversion into granular hornfels. Tremolite, diopside, wollastonite, garnet, and epidote are locally present, but specific alkaline minerals are rare, although swarms of aegirine needles occur in a few specimens.

Age

K-Ar age determinations on biotite vary from 220 to 392 m.y., and whole rock Rb-Sr ages, from 244 to 280 m.y.

Economic aspects

Several Ag-Pb-Zn prospects occur within the hornfels aureole of the Ice River complex, from which there was a small production early in the century. The mineralization was massive pyrite and pyrrhotite with disseminated argentiferous galena, chalcopyrite, sphalerite, and arsenopyrite. Veins and fissure fillings of similar type are common within about 15 miles of the Ice River complex. Native mercury panned out of the Kicking Horse River has also been suggested to stem from the Ice River complex, possibly due to breakdown of a feebly mercurous mineral such as tetrahedrite. All of the Ice River complex, save a small sliver in Moose Creek valley, is closed to prospecting because of its location in a national park.

Remarks

(1) The Ice River complex has been deformed and metamorphosed during the formation of the structures in the western Main Ranges. The effects of these events have not been fully worked out, but the complex appears to have acted principally as a rigid kernel around which the sedimentary rocks deformed in plastic fashion.

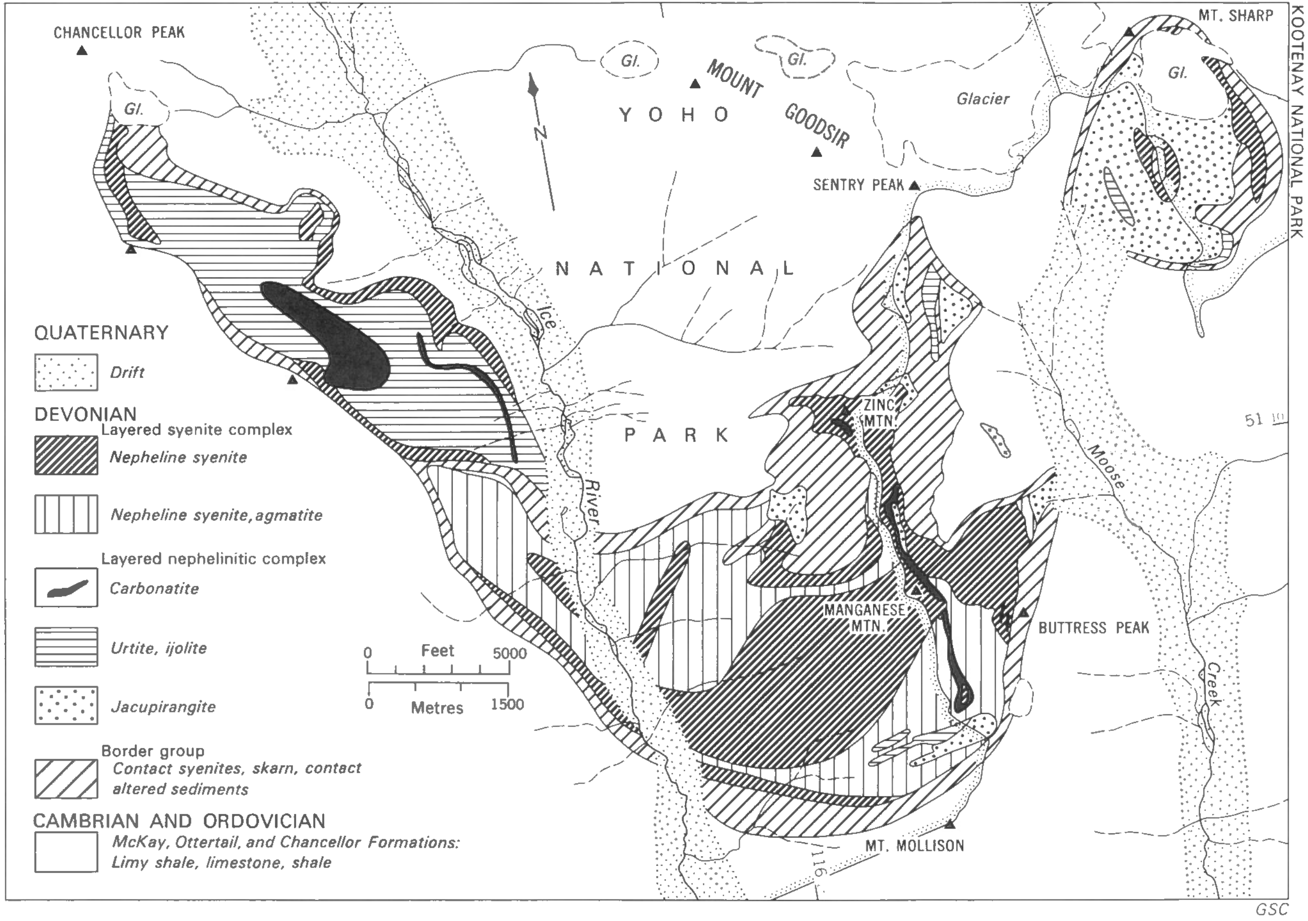


FIGURE 32. Geology of the Ice River alkaline complex (after Currie, 1975).

This leads to very intricate sheared contacts in some parts of the complex. Gneissosity in the mafic syenites presumably developed at this time also, and the characteristic U-shape of the complex may be due to deformation.

(2) The Ice River complex is an outstanding example of a complex whose evolution is probably controlled by immiscibility. The chemistry is almost identical to that at Callander Bay, and the field relations are compatible with this hypothesis. The syenitic fraction evolved toward agpaitic residual liquids, possibly due to the large amount of kaersutite precipitated.

(3) Other alkaline rocks possibly related to the Ice River complex are found at Mount Hunter, 18 miles to the northwest (trachyte), and at Mount Laussedat, 48 miles to the northwest (sodalite veins). Possibly the source of Ba in the well-known barite occurrences southeast of Golden may also be traced to this source, although in their present form some of these occurrences are known to be post-orogenic veins.

Selected references

Allan, J. A. (1914): Geology of the Field map-area, British Columbia and Alberta; Geol. Surv. Can., Mem. 55.

Currie, K. L. (1975): The geology and petrology of the Ice River alkaline complex; Geol. Surv. Can., Bull. 245.

TABLE 16 *Chemical analyses of the Ice River complex*

	1	2	3	4	5	6	7	8	9
SiO_2	33.6	42.0	40.7	44.5	0.4	46.7	51.9	54.4	58.0
TiO_2	5.1	3.22	2.04	0.19	.0	1.9	1.1	0.2	0.2
Al_2O_3	9.9	11.4	19.2	26.2	.2	21.8	23.0	23.9	24.1
Fe_2O_3	6.4	4.1	3.3	1.1	.0	2.0	1.2	2.0	2.0
FeO	8.2	7.4	8.2	2.1	10.4	6.8	4.8	0.9	0.0
MnO	0.18	0.20	0.28	0.5	1.7	0.18	0.19	.1	.1
MgO	9.8	11.6	4.7	.2	13.5	2.8	1.0	.8	1.6
CaO	21.4	13.3	9.5	9.7	32.1	6.1	3.6	1.2	0.5
Na_2O	0.5	3.5	7.7	10.4	0.1	7.6	7.1	9.7	6.0
K_2O	.1	2.6	3.7	4.9	.2	5.0	6.3	6.3	6.3
P_2O_5	1.9	0.6	0.5	0.0	.0	0.1	0.1	0.0	0.0
H_2O	0.8	.9	.7	.9	.2	$< .1$	$< .1$	.2	$< .1$
CO_2	2.1	$< .1$	.2	.3	42.0	.6	.7	.8	1.9
TOTAL	99.9	100.6	100.7	101.0	99.8	99.7	100.1	100.3	100.8

Analyses by Analytical Chemistry Section, Geol. Surv. Can., using "rapid methods."

1. Pyroxenite
2. Mela-ijolite
3. Ijolite
4. Urtite
5. Carbonatite
6. Mafic nepheline syenite
7. Nepheline syenite
8. Sodalite syenite
9. Contact syenite

Name Kaminak Lake (N-40; Fig. 33)

Location and access Eight hundred and fifty miles north of Winnipeg, about 60 miles west of Hudson Bay (62°35'N, 94°40'E) at the east end of Kaminak Lake. The locality is readily accessible only by aircraft.

Form and structure A northeast-trending elliptical body about $4\frac{1}{2}$ miles by $1\frac{1}{2}$ miles intruded along the contact of Archean greenstone and tonalite. Crude repetitive layering is present with gradual variation from melteigite to urtite. Syenite and nepheline syenite cut the ijolitic rocks as dykes, and as a lens-like mass in the northeastern corner of the complex.

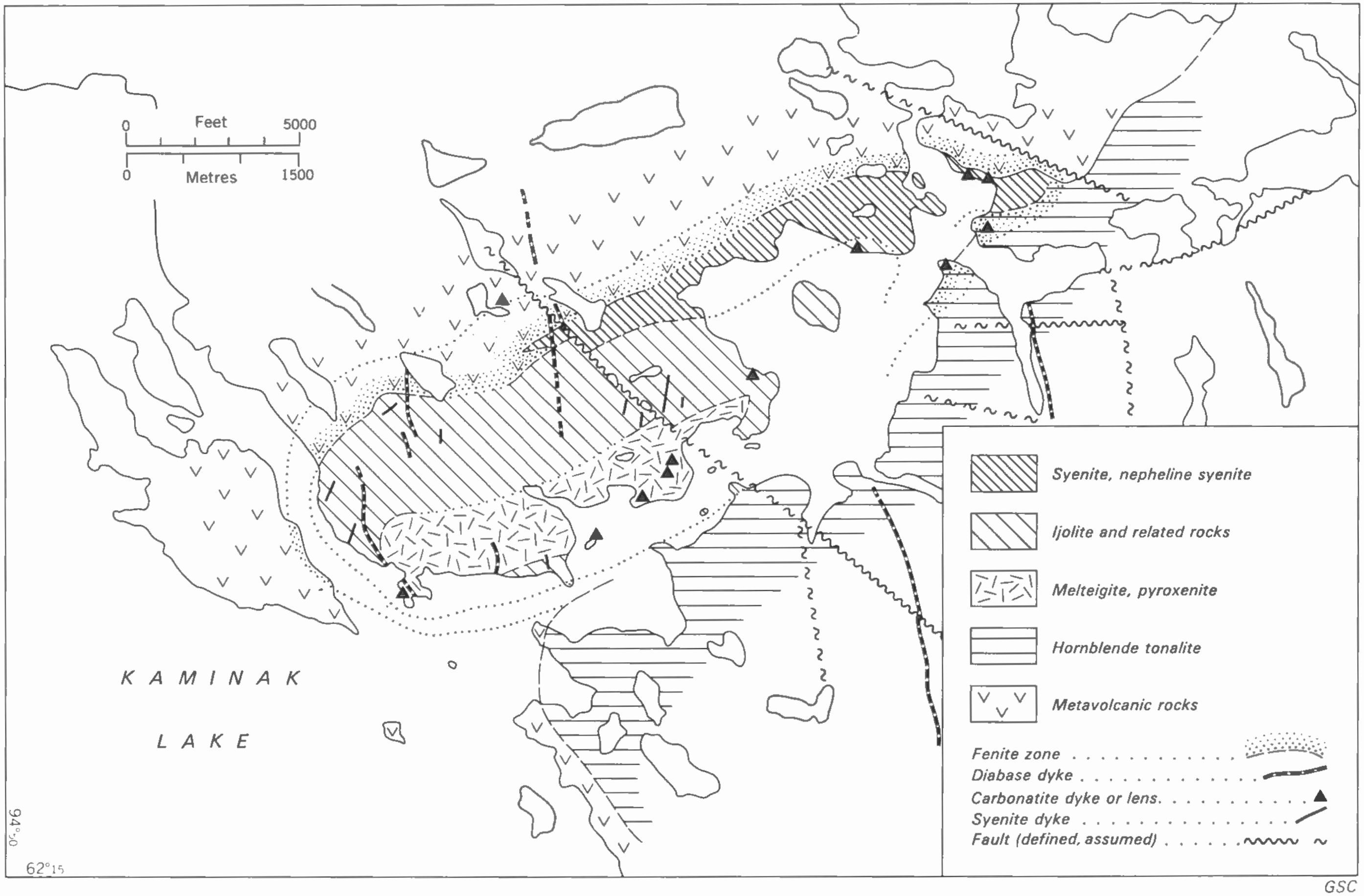


FIGURE 33. Geology of the Kaminak Lake complex (after Davidson, 1970).

Petrography	The ijolite series, in addition to varying amounts of pyroxene and nepheline, contains accessory amounts of calcite and, locally, melanite. Wollastonite is not present, except in altered rocks. The syenitic rocks are massive and coarse grained, but in thin section show an extraordinary variety of altered and recrystallized textures. Primary nepheline is not present, its place being taken by sulphatic cancrinite. Melanite and aegirine are present together in many specimens. The syenite has altered much of the ijolite, producing a peculiar vermicular intergrowth of nepheline and potash feldspar reminiscent of pseudoleucite, as well as large masses of sulphatic cancrinite. Syenitic and carbonatitic dykes are present in and around the pluton. The complex is surrounded by a broad zone of alkaline amphibole fenite up to 2,500 feet wide.
Age	A K-Ar determination on biotite yielded 1,820 m.y., but an Rb-Sr isochron (Wanless, pers. com., 1973) gave an age of 2,686 m.y., and according to R.H. Ridler (pers. com., 1973) stratigraphic relations clearly show the pluton to be Archean.
Economic aspects	None known.
Remarks	The Kaminak Lake complex is in many ways strikingly similar to the Ice River complex. Two other alkaline complexes have been discovered in this area by Ridler (*see* Geol. Surv. Can., Paper 73-1, pt. A, p. 166, 171). They appear to define a linear trend N71°E, extending for about 40 miles in both directions from Kaminak Lake, and are possibly controlled by normal faulting.
Selected references	Davidson, A. (1970): Kaminak Lake alkalic complex; *in* Report of Activities, April to October, 1969, Geol. Surv. Can., Paper 70-1, pt. A, p. 135–137. Davidson, A. (1970): Nepheline-K-feldspar intergrowth from Kaminak Lake, N.W.T.; Can. Mineral., v. 10, p. 191–206.

Name	Big Spruce Lake (N-41; Fig. 34)
Location and access	One hundred and twenty miles north-northwest of Yellowknife (63°35′N, 115°55′W). The locality is readily accessible only by aircraft.
Form and structure	The complex is a northeast-trending elliptical body some $5\frac{1}{2}$ by 2 miles, a large part of which is hidden by the lake. Foliation is present in some units, but the internal structure of the complex is unknown. It intrudes a generally granitoid terrane of Precambrian age.
Petrography	The northeastern part of the body is composed of alkaline pyroxenite, whereas much of the rest is ijolitic, commonly bearing minor amounts of plagioclase. Syenitic rocks form a trachytoid margin to the complex that contains nepheline in widely varying amounts, as well as small amounts of sodalite. Sodalite veinlets occur throughout the complex. A body of foliated, fluorite-bearing carbonatite on the northwest shore of Big Spruce Lake appears to form a lens in the alkaline complex. Fine-grained, saturated or quartz-bearing syenites are locally present around the complex, probably due to fenitization of the country rocks.
Age	Not definitely known, but almost certainly Precambrian.
Economic aspects	The carbonatite was drilled by COMINCO to test the radioactive and rare-earth content. Results were not encouraging.
Remark	The Big Spruce Lake complex is now almost entirely underwater, since the lake level has been raised, by dams, for power generation.
Selected reference	Lord, C. S. (1942): Snare River and Ingray Lake map-areas, N.W.T.; Geol. Surv. Can., Mem. 235, p. 34–35.

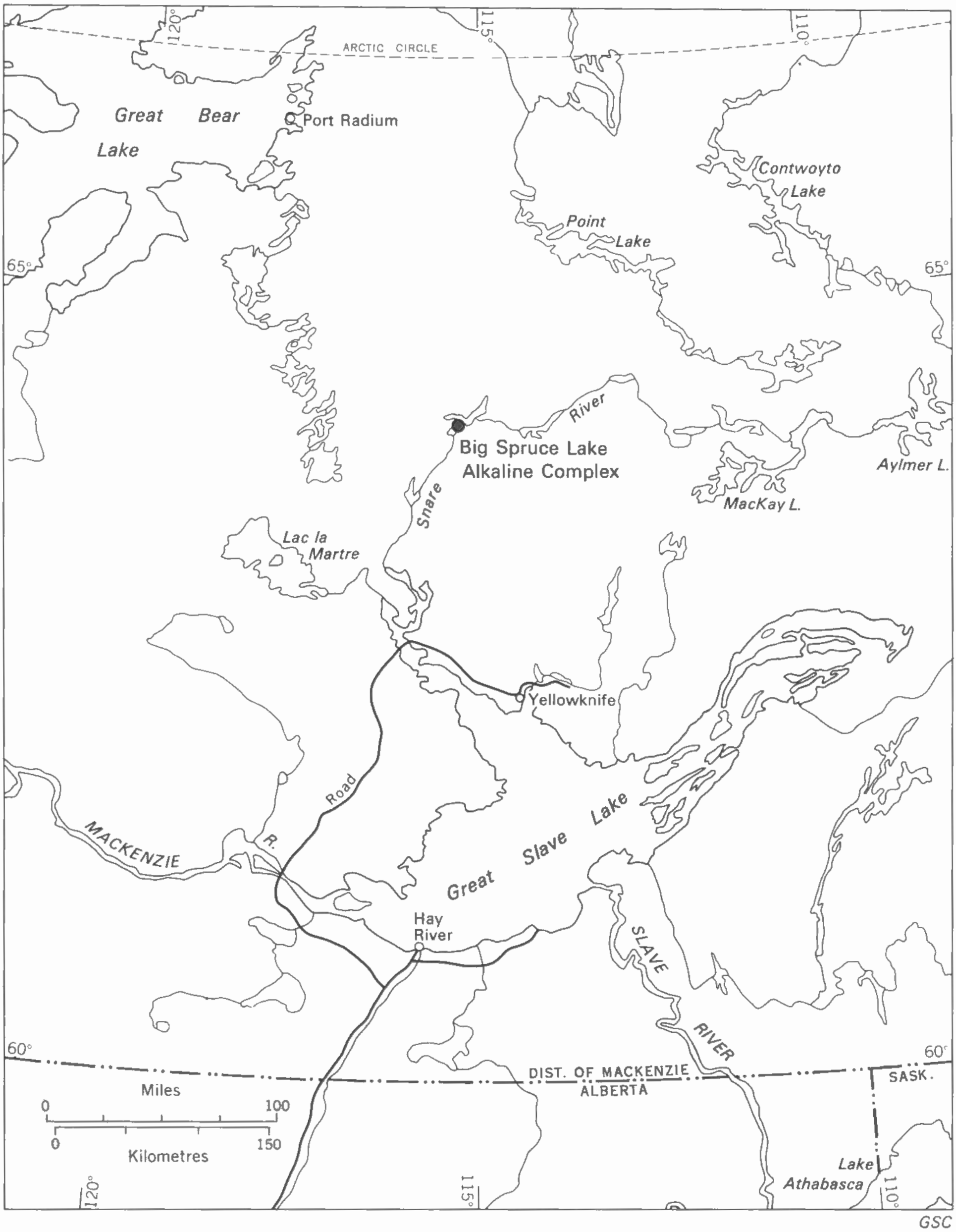


FIGURE 34. The Big Spruce Lake complex.

Ultramafic Nephelinite Complexes

Name	Oka (NM-42; Fig. 35)
Location and access	In the Oka Hills, just north of Lac des Deux Montagnes, and about 20 miles west of Montreal (45°30′N, 74°00′W). The region is readily accessible by automobile on Quebec Highways 8 and 29 and various local roads.
Form and structure	The Oka complex is shaped like a distorted northwest-trending figure-of-eight, some 2 miles long by 1 mile wide. The complex underlies a crater-like depression in Precambrian, generally metasedimentary, gneisses. Outcrop is poor, and most of the information comes from drill core, of which some 225,000 feet has been obtained. The rock-units are essentially concentric shells, defining steeply dipping dome-like structures, intersecting near the village of La Trappe. A poorly exposed fenite aureole surrounds the complex, penetrated by alnoitic dykes and breccia plugs.
Petrography	The main intrusion appears to have been emplaced from the outside inward. The oldest, ultramafic rocks, consisting of varying proportions of titanaugite, melilite, magnetite, nepheline, and accessory biotite and calcite, form a large crescentic mass in the northwest part of the intrusion, and a number of smaller dyke-like crescentic masses in the same general area. The melteigite-ijolite-urtite group commonly forms a series of concentric rings inside the ultramafic rocks, but in some areas of the intrusion contacts the surrounding fenite zone. The rocks consist mainly of nepheline and sodic pyroxene, with accessory biotite and calcite. Near the margins of the complex, significant amounts of potash feldspar occur. Varieties with melanite and wollastonite occur locally. The main carbonatite mass is largely composed of calcite, although an important mass of dolomite-apatite rock probably of the same age occurs at the western end of the intrusion. Several important varieties of carbonatite contain monticellite and melilite. The carbonate rocks are all strongly foliated, and may have been emplaced as a complex series of cone sheets. All of the older rocks are cut by radial and concentric fractures along which the intrusive rocks have been strongly altered to aggregates of biotite and calcite, with minor rare-earth carbonates and zeolites. The intrusion of lamprophyre dykes and breccias continued throughout the emplacement of the complex, and afterwards, the breccia pipes in many places forming "blowouts" along dyke-filled fractures. Fenitization is marked by extreme desilication, proceeding from feebly fenitized granitoid gneisses to rheomorphically mobilized material, containing abundant nepheline. Carbonatite dykes are particularly abundant in the fenite zone.
Age	A Rb-Sr date on biotite from the Oka complex yielded 114 m.y., whereas K-Ar dates on the same mineral show a considerable range from 99 m.y. to 120 m.y. Isochron ages for mica, whole rock, and nepheline are 120, 125, and 127 m.y., respectively, by the K-Ar method. Mafic minerals give anomalously old ages by K-Ar due to excess Ar-40.
Economic aspects	The Oka complex is the site of a major niobium mine, operated by St. Lawrence Columbium and Metals Corporation, a half mile north of La Trappe. Discovered in 1953, the mine began production in 1961 as an open-pit operation, but is now entirely underground. To date, about 3 million tons of ore has been mined at a mean grade of 0.45 per cent Nb_2O_5. The annual production is about 5 million pounds of pyrochlore concentrates, making the operation the second largest producer of niobium in the world. The ore is found as disseminated or streak-like concentrations of pyrochlore in mixed ijolite-carbonatite rocks. Although many other niobium minerals are present, including niocalite, latrappite, and perovskite, only pyrochlore appears to be potential ore. Six other niobium-rich zones have been outlined in and near the Oka complex, but none have as yet been brought into production, except the St. Lawrence Metals property.

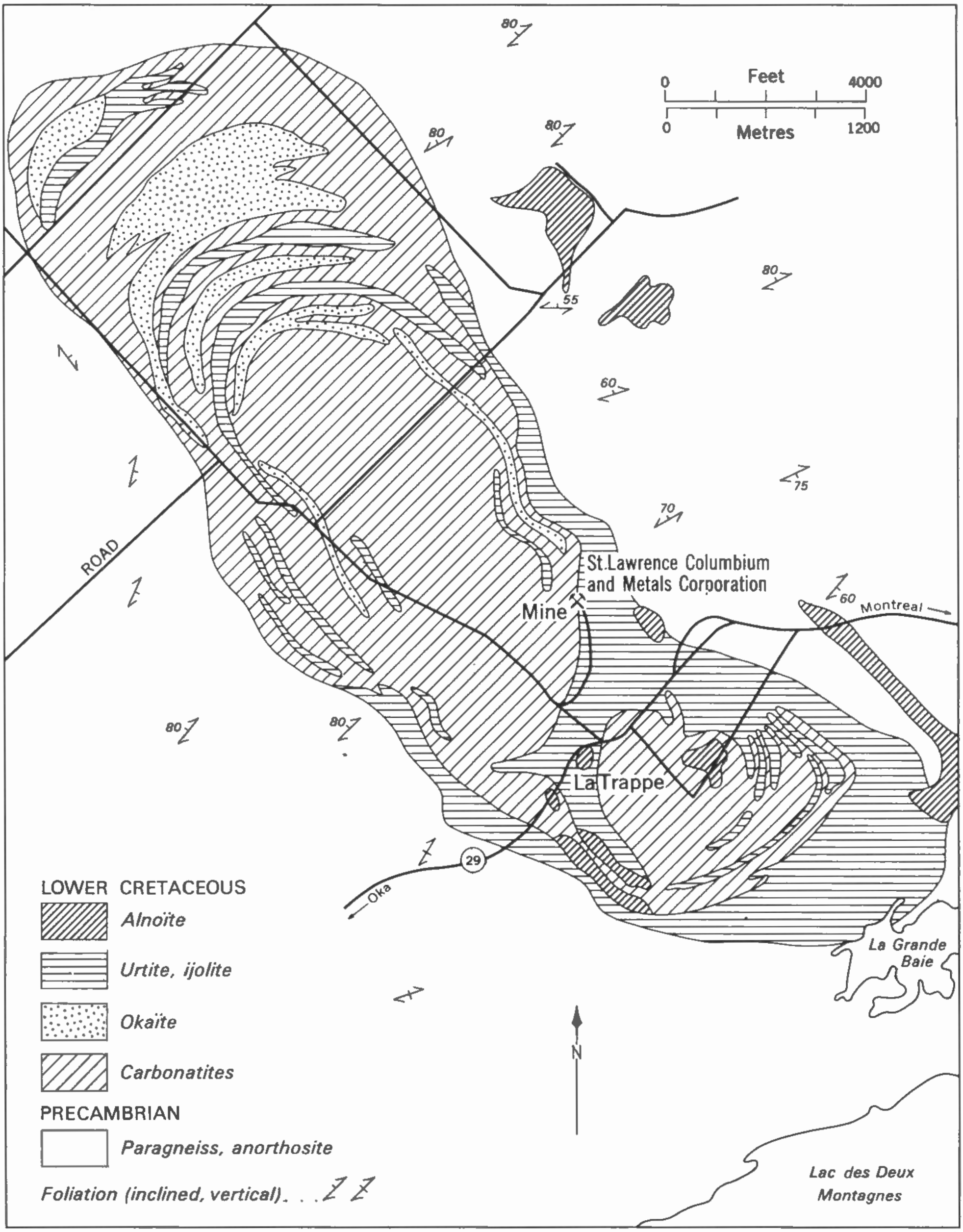


FIGURE 35. Geology of the Oka complex (after Gold, 1969).

Remarks The Oka complex is the centre of a considerable number of unusual ultramafic alkaline dykes, pipes, and sills. Perhaps the best known of these are at Ile Cadieux, on the opposite side of the St. Lawrence River, which were the subject of a classic paper by N. L. Bowen on melilite-bearing rocks. Similar dykes occur at Como, a few miles to the northwest, and in various breccia pipes around Oka, as described in the above-mentioned reference (Fig. 35), as well as at St-Lin (Ville des Laurentides) and St-André Avellin.

It has been recognized for many years that the presence of melilite indicates a very shallow origin for igneous rocks. The Oka complex is therefore subvolcanic.

Selected reference Gold, D. P. (1969): The Oka carbonatite and alkaline complex; *in* Geology of Monteregian Hills, G. Pouliot, ed., Geol. Assoc. Can.–Mineral. Assoc. Can., Guidebook, Montreal, p. 43–62.

TABLE 17 *Chemical analyses of the Oka complex (after Gold, 1969)*

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	4.26	0.67	1.73	14.68	17.35	30.58	33.53	41.91	39.39	48.21	30.37
TiO_2	0.43	.15	0.00	0.87	1.24	1.64	3.44	0.63	0.45	0.25	2.39
Al_2O_3	.49	.02	.89	2.37	2.87	9.52	13.20	20.59	15.95	26.55	9.20
Fe_2O_3	2.85	.65	4.35	4.03	15.33	9.17	7.27	2.75	4.05	0.59	5.55
FeO	1.50	.29	3.21	3.24	8.50	4.50	3.41	2.42	0.98	.57	6.02
MnO	1.23	.40	0.10	1.31	3.27	0.83	0.40	0.90	.71	.09	0.35
MgO	5.76	1.09	15.67	9.46	4.20	6.40	8.66	3.27	1.30	.13	10.70
CaO	45.98	51.22	29.68	37.48	27.19	26.86	19.14	8.93	19.77	9.18	15.31
SrO	2.24	1.95	1.06	0.43	—	0.71	0.25	0.12	0.12	0.17	0.26
BaO	0.19	0.12	0.10	—	0.58	.11	.35	.35	.89	.23	.33
Na_2O	.11	.14	.30	0.46	1.84	4.29	2.45	11.57	7.79	8.82	1.54
K_2O	.08	.49	.16	.37	0.58	0.71	2.16	2.69	2.57	2.18	3.79
P_2O_5	2.40	1.81	7.16	5.50	3.71	1.84	2.37	0.41	0.74	0.10	0.87
CO_2	32.16	40.44	34.68	18.53	13.18	2.13	2.34	1.16	3.38	1.32	9.88
H_2O+	0.11	0.33	0.15	0.52	0.51	0.78	1.64	1.55	1.69	1.48	1.96
H_2O-	.44	.05	.00	.03	.01	.02	0.09	0.22	0.00	0.05	0.36
Nb_2O_5	.56	.14	—	.19	—	—	—	—	—	—	—
SO_3	—	—	0.35	—	—	—	—	—	—	—	—
F	—	—	—	—	—	—	—	—	—	—	0.40
TOTAL	100.79	99.96	99.59	99.83	100.36	100.09	100.70	99.27	99.98	99.92	99.30
In parts per million											
Be	1.5	8	>0.5	>0.5	12	5.5	2.6	3.8	2.6	3.1	9.5
Sc	4	5	16	14	14	24	23	8	17	<7	13
V	230	56	30	90	300	185	400	91	325	50	790
Cr	<10	<10	<50	<50	<10	<20	<20	<20	<20	<20	210
Ni	<10	<10	<6	<6	<10	<4	<4	10	16	23	130
Cu	6	9	18	12	<5	9.5	76	20	14	12	7.9
Y	26	86	46	200	190	71	55	27	88	9	36
Zr	45	58	28	1200	60	56	320	9	315	8	225
Nb	4000	900	3000	—	—	—	—	—	—	—	—
La	640	600	180	1000	1500	780	480	80	300	39	110
Ce	920	1100	720	2400	3500	1500	780	600	740	<150	<150
Yb	2	5.4	4.2	14	13	4.2	4.7	2.5	7	<1	5.7

1. Coarse-grained calcite carbonatite
2. Pegmatitic calcite carbonatite
3. Fine-grained apatite-dolomite carbonatite
4. Monticellite-calcite carbonatite
5. Melilite-calcite carbonatite
6. Melilite-rich nephelinite ("okaite")
7. Jacupirangite
8. Ijolite
9. Wollastonite ijolite
10. Urtite
11. Lamprophyric ouachitite

Name	Ile Bizard (NM-46; Fig. 36)
Location and access	Ile Bizard is in the northwestern suburbs of Montreal, Quebec. The exposure is on the northwest shore of the island, readily reached by automobile.
Form and structure	The locality appears to be a breccia pipe of the type common in the vicinity of Oka. The best exposures are on a low hill 100 yards north of the road where very diverse lithologies occur in the breccia in a kimberlitic matrix. A little farther on in a bulldozed trench there is another exposure containing numerous ultramafic inclusions, including eclogite.
Petrography	The matrix is fine grained and serpentinized, containing zoned grossularite, phlogopite, calcite, melilite, perovskite, apatite, and magnetite. The inclusions are of chrome diopside, magnesian ilmenite, pyrope, enstatite, and serpentinized olivine in varying proportions. Numerous blocks of almost unchanged sedimentary rocks are found in the breccia also, derived from the Ordovician sedimentary rocks penetrated by the pipe. A chemical analysis is given in Table 18.
Age	Assumed to be Early Cretaceous, like the other Monteregian intrusions.
Economic aspects	A bulk sample of this material was taken by Anglo American Corporation and treated for diamond recovery. Six small diamonds are said to have been recovered. These are the only diamonds known to have been recovered from bedrock in Canada.
Remarks	Numerous occurrences of ultrabasic alkaline rocks are known west and northwest of Montreal, mainly in the form of breccia pipes. Some of the better known occurrences are shown on Figure 36, and chemical analyses are given in Table 18. With the exception of Ile Bizard, however, all these occurrences contain melilite and/or monticellite, and therefore crystallized at relatively shallow depths.
Selected reference	Gold, D. P. and Marchand, M. (1969): The diatreme breccia pipes and the related alnoite, kimberlite, and carbonatite intrusions occurring in the Montreal and Oka areas; *in* Geology of Monteregian Hills, G. Pouliot, ed., Geol. Assoc. Can.–Mineral Assoc. Can., Montreal, p. 5–42.

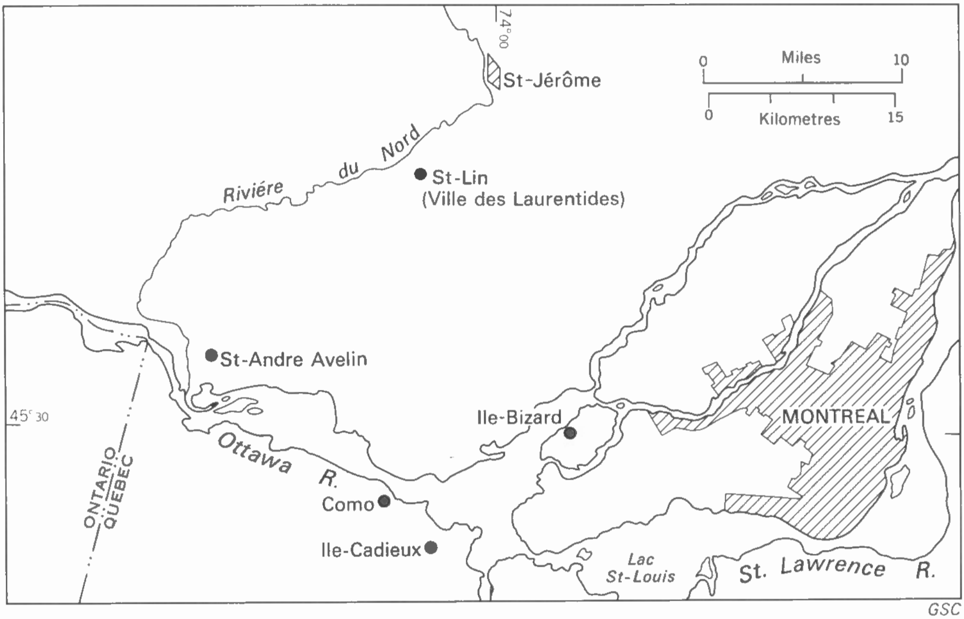


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FIGURE 36. Location of Ile Bizard kimberlite and other occurrences of ultramafic alkaline rocks in the Monteregian province.

TABLE 18 *Chemical analyses of kimberlite and ultramafic nephelinitic dyke rocks of the Monteregian province (after Gold and Marchand, 1969)*

	1	2	3	4	5	6	7	8	9
SiO_2	33.58	44.43	31.63	35.41	29.24	31.94	33.26	30.27	39.80
TiO_2	2.27	3.03	2.44	2.57	2.40	1.97	2.15	2.84	1.45
Al_2O_3	6.93	14.02	10.60	11.25	11.40	5.87	5.90	10.00	8.32
Fe_2O_3	13.20	4.86	4.56	6.27	5.84	5.87	5.30	4.88	0.14
FeO		6.09	6.42	5.07	4.74	5.77	6.54	6.95	8.19
MnO	n.d.	0.04	0.11	0.24	0.19	0.22	0.15	0.16	0.18
MgO	20.08	4.08	17.82	13.29	10.38	21.51	26.41	20.11	4.62
CaO	12.89	11.53	17.16	18.42	18.35	17.38	14.47	14.73	13.30
Na_2O	0.18	4.14	0.16	2.53	1.44	0.52	1.23	1.49	2.75
K_2O	.77	1.73	2.48	2.20	2.42	2.23	0.82	2.85	1.44
P_2O_5	1.16	0.83	1.09	1.05	2.10	0.75	.76	0.95	1.88
H_2O	8.76	1.96	0.93	1.21	6.09	2.81	2.00	2.17	0.45
CO_2	0.00	2.77	4.92	0.24	5.02	1.97	1.10	3.24	17.30
TOTAL	99.82	99.52	100.32	99.75	99.61	98.81	100.09	100.64	99.82

n.d.: not determined.

1. Kimberlite, Ile Bizard.
2. Lamprophyric melteigite ("ouachitite"), Ste-Dorothée.
3. Lamprophyric melteigite ("monchiquite"), Ste-Monique.
4. Alnoite, Oka, includes 0.12 SrO, 0.22 BaO.
5. Alnoite, Pt. St-Charles, includes 0.15 SrO, 0.24 BaO.
6. Monticellite alnoite, Brilund, includes 0.11 SrO, 0.23 BaO, 0.11 F.
7. Monticellite alnoite, Ile Cadieux, includes 0.08 BaO.
8. Monticellite alnoite, Como.
9. Matrix of Ile Ste-Hélène breccia.

Name	St-Honoré (NM-48; Fig. 37)
Location and access	About 8 miles north-northwest of Chicoutimi, Quebec, in the angle of the Saguenay and Shipshaw rivers. The complex is readily accessible via local roads.
Form and structure	The complex forms a mass 5 miles north to south by 4 miles east to west, consisting of a central core of carbonatite, adjoined to the east by nepheline syenite, and a partial rim of diorite. The complex intrudes Precambrian granitic, syenitic, and anorthositic gneisses, and is overlain by Ordovician limestone, preserved in this area by downfaulting. The limestone was deposited on an irregular erosion surface, suggesting that the alkaline complex is substantially older than Ordovician sedimentation. Outcrop is sparse.
Petrography	The central core of the mass is composed of buffish dolomitic carbonatite rich in hydrocarbons (5 per cent), monazite, bastnasite, pyrite, pyrrhotite, chalcopyrite, and molybdenite, with pronounced thorium mineralization. Fragments of altered alkaline silicate rocks are present. A brick-red Nb and apatite-rich dolomitic carbonatite surrounds this central core, strongly foliated and dipping inward at about 65 degrees. Monticellite-bearing layers are present, as well as local concentrations of magnetite, siderite, phlogopite, nepheline, and garnet (both schorlomite and andradite are present). The outer layers of the carbonatite may be layered with oligoclase-microcline syenite containing nepheline, cancrinite, aegirine, and melanite, as well as accessory sphene, biotite, carbonate, magnetite, and apatite. In more massive specimens the syenite contains much less oligoclase, and more microcline. The marginal diorite is mainly composed of plagioclase, with lesser and variable amounts of aegirine, biotite, carbonate, magnetite, and apatite. Magnetite is always sufficiently abundant to produce a strong magnetic anomaly.

Age	Six K-Ar measurements on biotite gave an average of 640 m.y., with one anomalously low measurement of 495 m.y. This age is significantly older than those obtained from the Nipissing alkaline province.
Economic aspects	St-Honoré has been extensively prospected and developed by SOQUEM as a Nb prospect, and also shows interesting concentrations of rare-earths, as well as potentially significant amounts of Zn and Mo.
Selected reference	Valée, M. and Dubuc, F. (1970): The St-Honoré carbonatite complex, Quebec; Can. Inst. Mining Met. Trans., v. 73, p. 346–356.

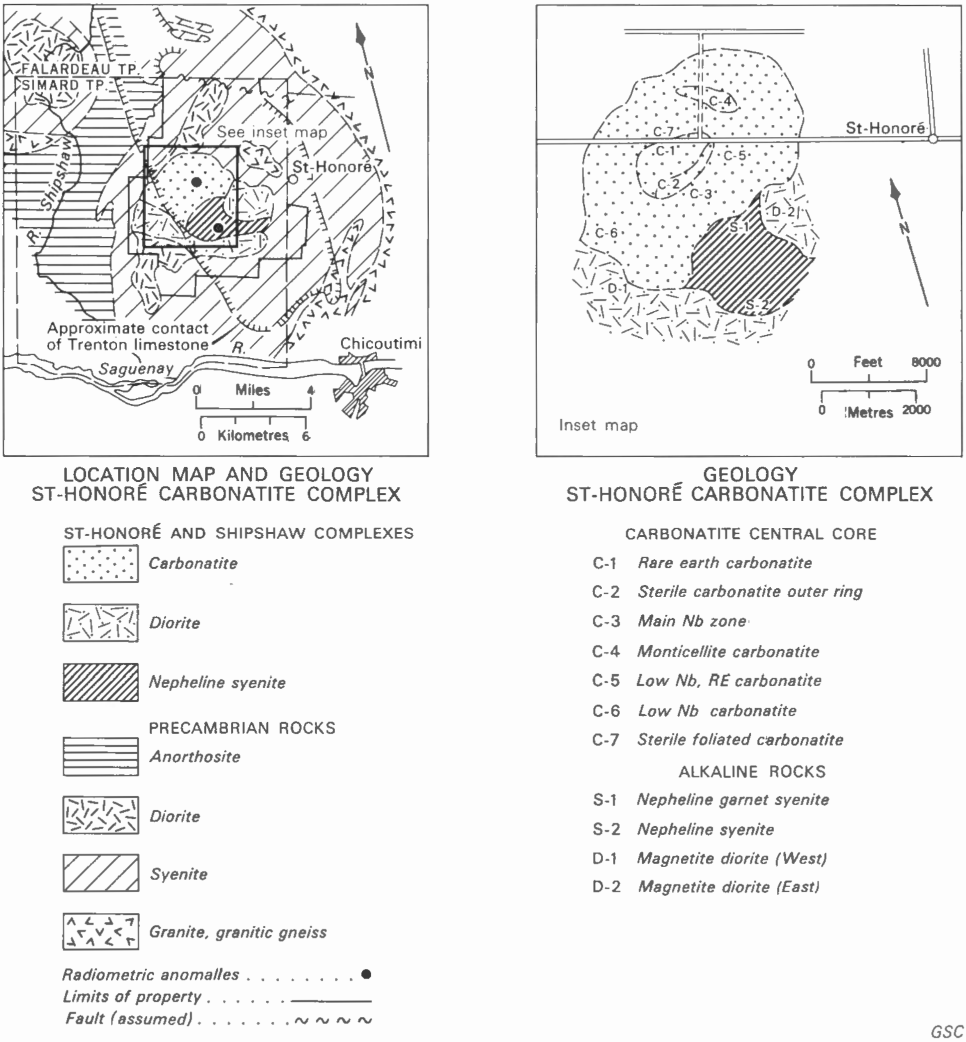


FIGURE 37. Geology of the St-Honoré complex (after Vallée and Dubuc, 1970).

Name	Castignon Lake (N-49; Figs. 38, 39, and 40)
Location and access	Alkaline ultramafic rocks are exposed in an area of about 300 square miles 650 miles north of Quebec City, to the west and south of Castignon Lake (56°25′N, 68°50′W). The area is accessible only by aircraft.
Form and structure	About a dozen pipes, up to a mile in diameter, and 30 to 40 dykes are exposed. Some of the pipes appear to have remnants of tuff rings attached to them, whereas many of the dykes have a brecciated structure and show evidence of strong circulation in the form of flow banding. Some of the tuff breccias contain fragments brought up from the Archean basement some thousands of feet below. The rocks intrude mildly deformed Proterozoic sedimentary rocks of the Labrador Trough.
Petrography	The lithologies exposed vary from massive ankeritic to dolomite carbonatite, through olivine and biotite carbonatites, to olivine-augite-phlogopite rocks. Melilite- and monticellite-bearing varieties are present but rare, occurring mainly as fragments in tuff breccia, together with some nodules of garnet peridotite. Ocelli of carbonate are commonly present in the silicate rocks. The chemistry of the rocks (Table 19) is unusual because of the high iron content as compared to rather low modal content of iron oxides.
Age	A whole rock K-Ar determination on a lamprophyric dyke gave 1,873 ± 53 m.y., an age similar to that of the latest metamorphism in this region.

TABLE 19 *Chemical analyses of the Castignon Lake and Aillik complexes (after Dimroth (1970), and Kranck (1953).*

	1 P30-4	2 W35-3	3 2B1	4 13B1	5 4B1	6 11B5-1	7 11B2	8 8B5-2	9 D23-27	10 P26-5	11 5B1	12
SiO_2	29.24	27.92	22.65	11.42	14.39	17.22	17.95	20.65	33.23	35.02	34.18	20.66
TiO_2	3.92	3.38	1.03	0.22	3.90	0.02	1.82	0.47	3.79	2.33	2.38	3.87
Al_2O_3	3.93	2.58	3.75	2.36	3.41	.20	4.57	4.32	3.40	2.11	2.20	5.35
Fe_2O_3	2.31	1.16	1.29	1.92	1.34	.91	1.46	1.91	10.71	9.15	8.79	7.51
FeO	14.55	14.48	7.07	13.87	7.58	7.46	10.54	8.92	7.87	7.51	7.43	6.44
MnO	0.23	0.28	0.43	0.74	0.61	1.33	0.42	1.30	0.50	0.29	0.29	0.31
MgO	16.38	18.93	6.48	9.05	4.06	12.03	11.09	9.47	23.55	23.61	21.39	16.96
CaO	10.22	5.75	24.30	21.95	32.35	23.19	18.31	20.33	4.36	6.62	8.99	20.15
Na_2O	0.03	0.03	0.11	0.67	0.04	0.02	0.41	0.24	0.07	0.09	0.10	0.67
K_2O	.03	.01	1.34	.68	.22	.55	1.60	2.08	.34	.36	.88	1.93
H_2O+	4.56	2.88	0.75	.67	2.43		1.54	1.26	6.08	6.96	5.45	2.80
H_2O-	0.10	0.08		.14		.30	0.09	0.08	0.20	0.14	0.14	0.45
CO_2	12.69	21.83	24.85	31.00	27.92	36.78	29.08	26.25	4.70	4.56	6.59	10.43
P_2O_5	0.99	0.20	5.42	3.28	0.77	0.03	0.85	1.97	0.68	0.59	0.61	2.92
S	.38	.12	0.21	0.85	.52	.15	.15	0.14	.23	.17	.18	—
F	n.d.	n.d.	n.d.	1.27	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0.24
SrO	0.07	0.02	0.11	0.20	0.08	0.07	0.20	0.04	0.0047	0.007	0.04	—
BaO	.02	.002	.06	—	.02	.02	.27	.29	.0067	.0044	.02	0.15
Cr_2O_3	.05	.07	.006	0.004	.13	.005	.12	.007	.087	.10	.11	—
NiO	.06	.06	.009	.004	.15	.007	.07	.003	.09	.10	.14	—
Nb_2O_3	.02	.02	.03	.04	.02	.007	.014	.014	.014	.014	.007	—
ZrO_2	—	—	.05	.03	.035	.00	.00	.03	—	.006	.035	—
La_2O_3	—	—	.05	.06	.04	.004	.01	.02	.012	.006	.01	—
TOTAL	99.78	99.80	99.99	100.43	100.01	100.30	100.56	99.79	99.85	99.59	99.93	100.84

n.d.: not determined.
1. Carbonated alkaline peridotite, Castignon Lake.
2. Olivine ankeritic-dolomitic carbonatite, Castignon Lake.
3, 5, 6. Biotite-olivine calcite carbonatite, Castignon Lake.
4. Apatite-fluorite carbonatite, Castignon Lake.
7, 8. Biotite, ankeritic-dolomitic carbonatite breccia, Castignon Lake.
9, 10, 11. Carbonated alnoite tuff, Castignon Lake.
12. Carbonated lamprophyric alnoite, Aillik, Labrador.

Economic aspects	None known.
Remark	The chemistry and mineralogy, as well as the physical form of the Castignon Lake rocks, are similar to those at Aillik, Labrador.
Selected reference	Dimroth, E. (1970): Meimechites and carbonatites of the Castignon Lake complex, New Quebec; N. Jb. Miner. Abh., v. 112, p. 239–278.

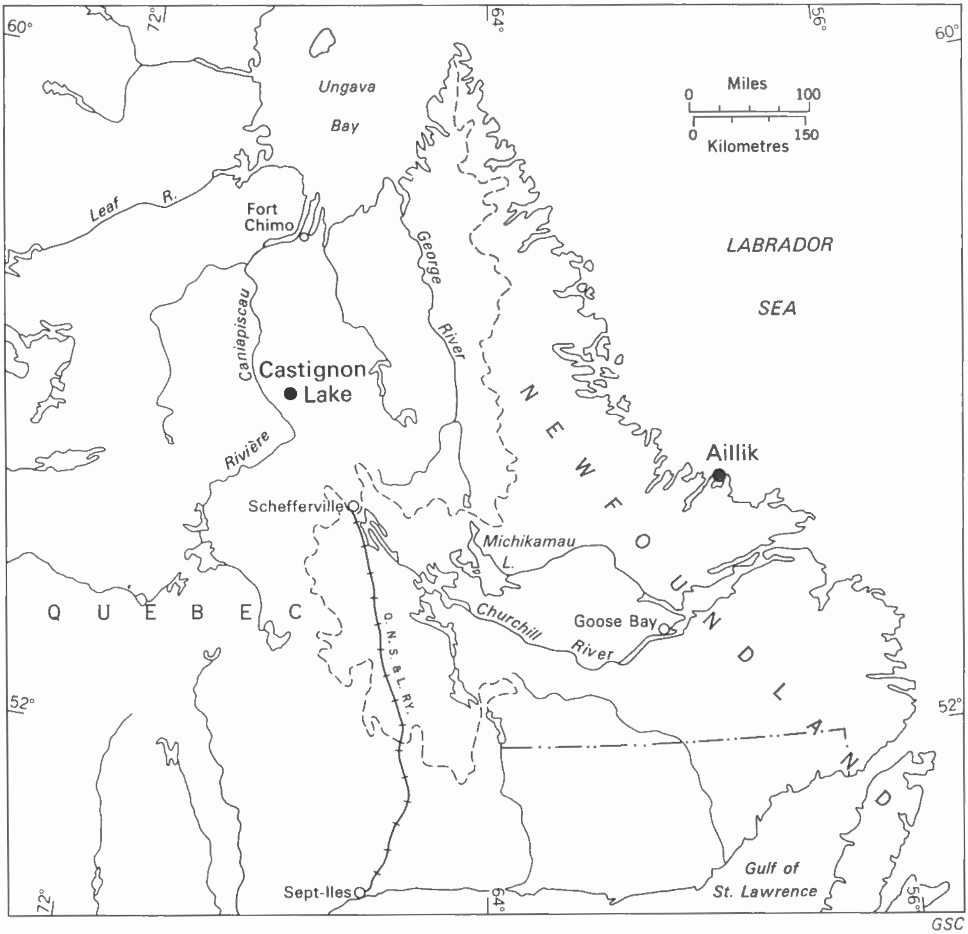


FIGURE 38. The Castignon Lake and Aillik alkaline rocks.

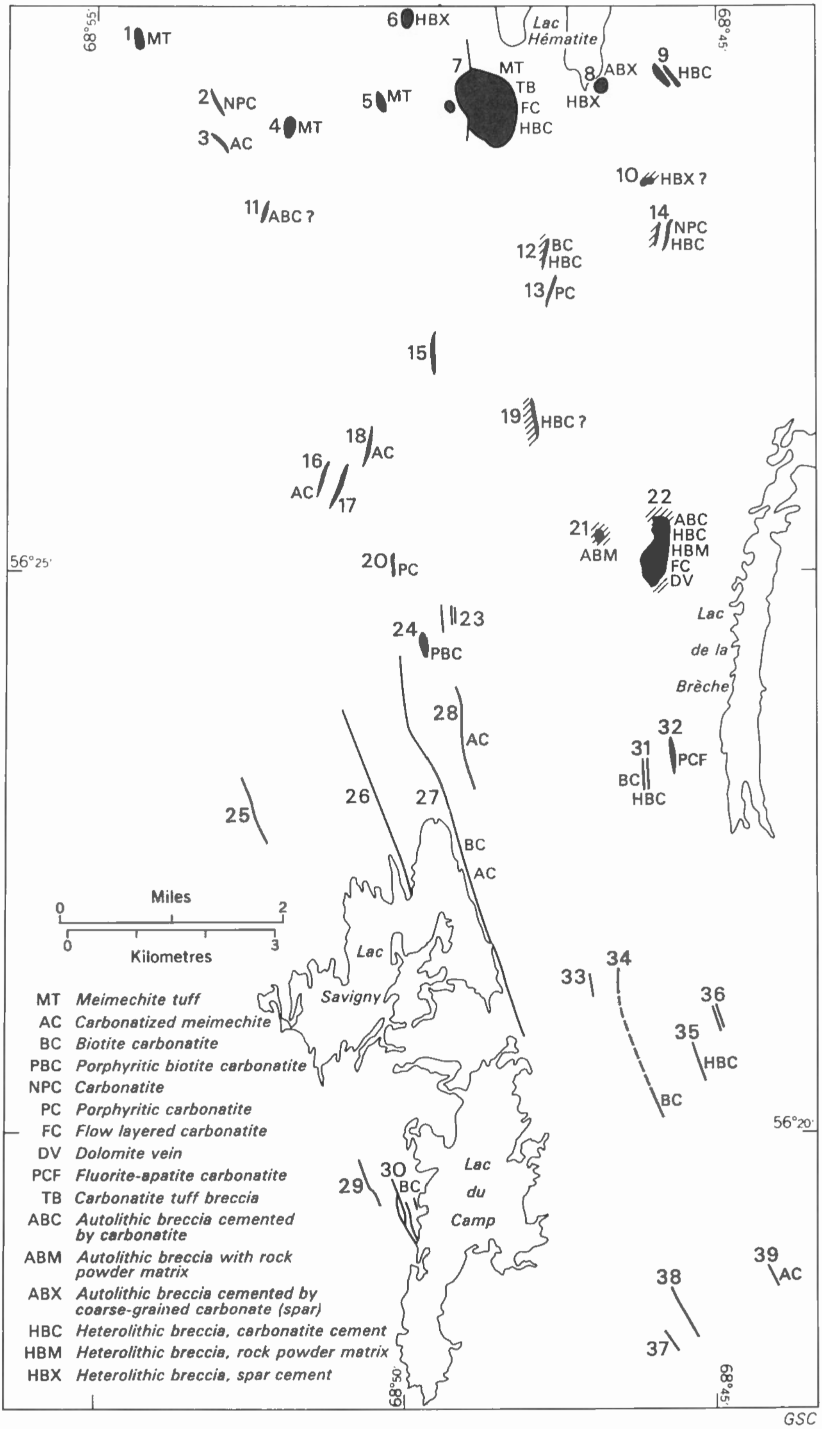
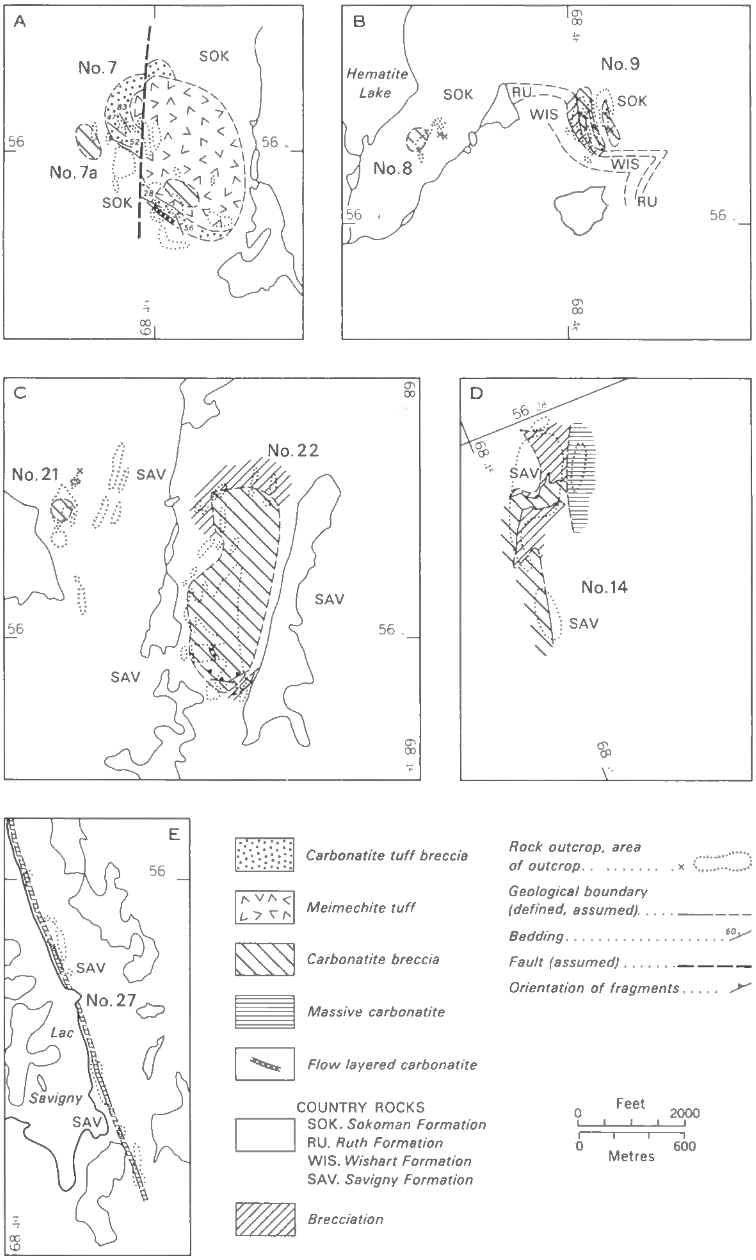


FIGURE 39. Geology of the Castignon Lake alkaline rock occurrences (after Dimroth, 1970).



A: *No. 7, exposes the lower part of the eruptive cone. Parts of the tuff cone are preserved in the southwest. The tuff cone is cut by an outer ring of meimechite tuff, and by an inner ring of carbonatite breccia.*

B: *Nos. 8, and 9. The diatreme No. 9 consists of three coalescing dykes.*

C: *Nos. 21, and 22, exposing deep levels of a diatreme.*

D: *No. 14. This is a poorly exposed diatreme, possibly similar to No. 9.*

E: *No. 27. A biotite carbonatite dyke, crosscutting the Savigny Slates.* *GSC*

FIGURE 40. Carbonatite localities in the Castignon Lake field (after Dimroth, 1970).

Name	Aillik (N-52; Fig. 38)
Location and access	Cape Aillik and Cape Makkovik, on the Atlantic coast of Labrador, about 120 miles north-northeast of Goose Bay (54°30′N, 58°30′W). Access is best by small boat, since many of the exposures are on islands.
Form and structure	The dykes occur as flatly dipping cone sheets with conspicuously sinuous margins. None of the dykes is more than 5 feet thick, but they appear to define a centre beneath Aillik Bay, which could be a central complex.
Petrography	Most of the dykes are ultramafic, consisting of phlogopite, augite, and rare olivine phenocrysts in a strongly carbonatized fine-grained matrix. However, lamprophyric dykes of syenitic affinity containing nepheline, albite, augite, and hornblende also occur. The chemical analyses (Table 19) show an unusual iron-rich composition for the ultramafic rocks.
Age	K-Ar determination on biotite gives 570 m.y.
Economic aspects	None known.
Remark	These young alkaline dykes should not be confused with the much older subalkaline lamprophyre dykes common on the coast of Labrador, which give K-Ar dates on biotite of 1,470 m.y.
Selected reference	Kranck, E. H. (1953): Bedrock geology of the seaboard of Labrador between Domino Run and Hopedale, Newfoundland; Geol. Surv. Can., Bull. 26, p. 29.

Name	Kirkland Lake (NM-45; Fig. 41)
Location and access	In the Upper Canada Mine at Kirkland Lake, Ontario. The dyke was penetrated only in mine drifts and is thus not accessible.
Form and structure	Three-foot dyke trending north-northwest with minor apophyses.
Petrography	A dark greenish porphyritic rock with olivine and phlogopite phenocrysts in a carbonate-rich matrix containing accessory pyrope, chromite, perovskite, and apatite.
Age	A K-Ar age on phlogopite yielded an age of 151 m.y.
Economic aspects	The presence of kimberlite in the Ottawa River–Lake Timiskaming graben, together with the presence of alluvial diamonds to the south, suggests that this region may be favourable ground for the occurrence of diamonds.
Remark	An almost identical dyke was noted by Satterly (Ont. Dept. Mines, Ann. Rept., 58, pt. 4, p. 13) in Michaud Township, 20 miles to the north.
Selected reference	Lee, H. and Lawrence, D. E. (1968): A new occurrence of kimberlite in Gauthier Township, Ontario; Geol. Surv. Can., Paper 68-22.

Name	Sextant Rapids (NM-47; Fig. 41)
Location and access	Sextant Rapids on the Abitibi River, and Coral Rapids, a few miles downstream (50°12′N, 81°38′W). Coral Rapids is a station stop on the Ontario Northland Railway line.
Form and structure	The largest occurrence is a 60-foot sill at Sextant Rapids, but several dykes 5 to 10 feet wide are exposed, cutting Devonian limestone at Coral Rapids.
Petrography	The dykes consist of serpentinized olivine and titanaugite phenocrysts, in a matrix of clinopyroxene, phlogopite, and calcite, possibly with some altered melilite.
Age	Not definitely known, but post-Devonian.
Economic aspects	None known.

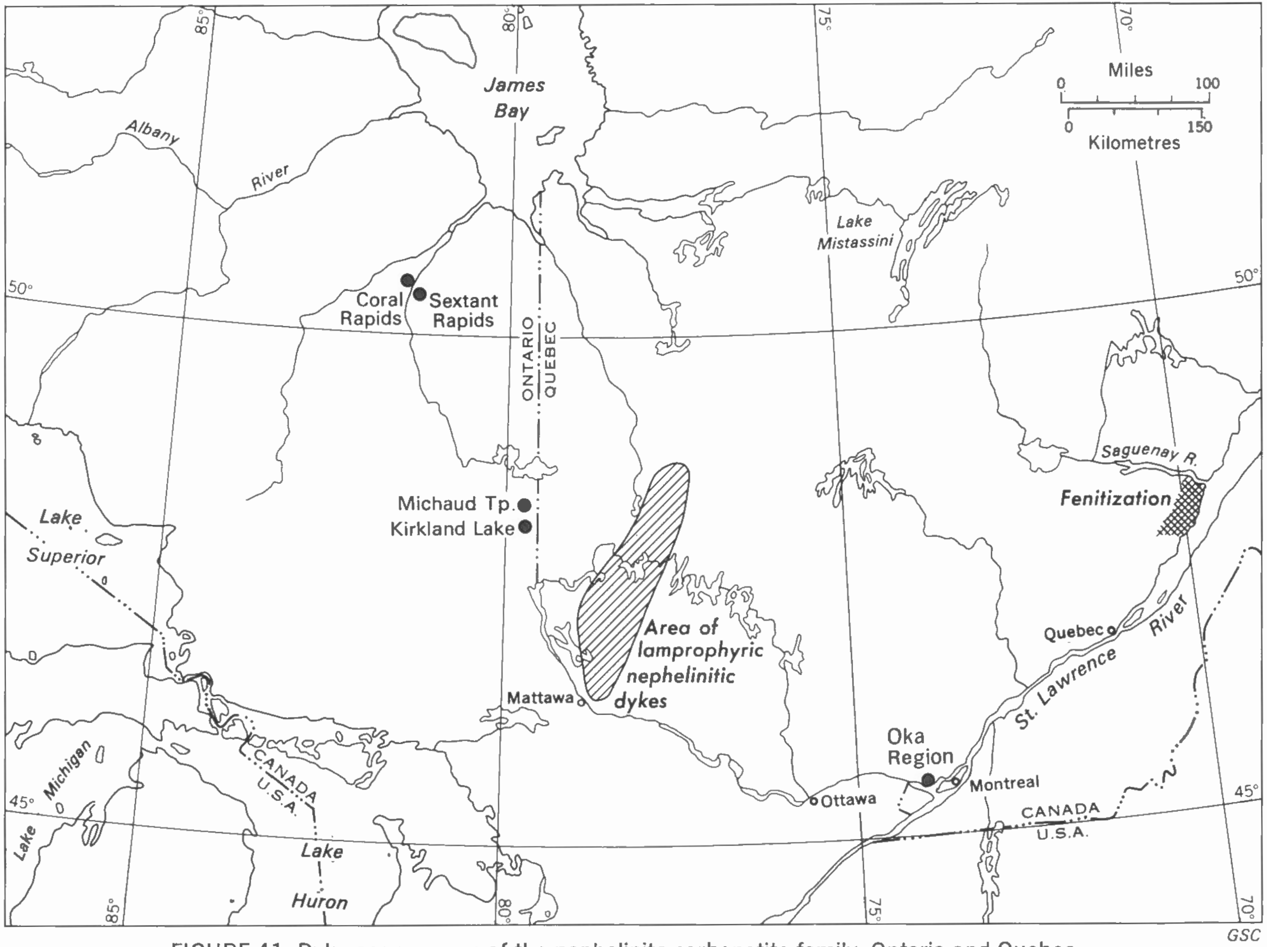


FIGURE 41. Dyke occurrences of the nephelinite-carbonatite family, Ontario and Quebec.

Remark	These rocks have occasionally been referred to as kimberlite, but they are clearly not kimberlite, nor related to it, since they contain neither pyrope nor orthopyroxene but the low-pressure assemblage titanaugite plus melilite.
Selected reference	Bennett, G., Brown, D. D., George, P. T., and Leahy, E. J. (1969): Operation Kapuskasing; Ont. Dept. Mines, Misc. Paper 10.

Name	Northwestern Quebec dykes (N-51; Fig. 41)
Location and access	Lamprophyric nephelinitic dykes occur over a large area of northwestern Quebec, extending north-northeast from Mattawa to Bachelor Lake (49°30′N, 76°05′W). Described examples are generally from drill cores, blasted cuts, or wave-washed exposures and no description of access is, in general, possible.
Form and structure	Dykes and sills up to a few feet thick.
Petrography	Massive dark, greenish grey rocks with small olivine and phlogopite phenocrysts in a panidiomorphic matrix of augite, calcite, phlogopite and, occasionally, of analcite. Perovskite, ilmenite, apatite, and magnetite are commonly present in accessory amounts.
Age	A K-Ar age on phlogopite from Bachelor Lake yielded 1,110 m.y. (Watson, 1955), but a similar dyke in the Noranda area gave an age of 1,520 m.y. by the same method (R. K. Wanless, pers. com., 1972).
Economic aspects	None known.
Remark	These dykes are *not* kimberlites but low-pressure dykes similar to those around nephelinitic central complexes. The lack of pyrope and orthopyroxene shows that none of the mineral assemblages crystallized at high pressure.
Selected reference	Watson, K. D. (1955): Kimberlite at Bachelor Lake, Quebec; Amer. Mineral., v. 40, p. 565–579.

Name	Semlin (N-50; 50°45′N, 121°03′W)
Location and access	Two miles east of Semlin, B.C., on the shore of Thompson River. The dyke can be reached by walking along the tracks of the Canadian National Railways line from Semlin station.
Form and structure	Four-foot-thick, north-trending dyke cutting sedimentary and volcanic rocks of the Triassic Nicola Group.
Petrography	Biotite plates to 1 inch diameter occur in a fine-grained groundmass of biotite, zoned augite, olivine, melilite, and accessory perovskite. Primary and secondary carbonate is locally abundant.
Age	Unknown.
Economic aspects	The locality was at one time used as a source of road metal, and alnoite blocks are common in some fills in the Ashcroft region.
Remark	This alkaline ultramafic rock may possibly be connected with the Miocene alkaline basaltic activity in this region.
Selected reference	Drysdale, C. W. (1914): Geology of the Thompson River valley below Kamloops Lake, B.C.; Geol. Surv. Can., Sum. Rept. 1912, p. 133–134.

Name	Rossland dyke (N-53; 49°07′N, 117°51′W).
Location and access	Col between Record Mountain and Granite Mountain, about 5 miles northwest of Rossland, B.C. The locality can be reached by a climb of moderate difficulty from roads in the area.
Form and structure	Five-foot dyke cutting Tertiary granite.
Petrography	The rock is dark greenish, and consists of small phenocrysts of pseudoleucite wrapped by biotite, which lie in a matrix of augite (37 per cent), biotite (20 per cent), pseudoleucite (33.8 per cent), magnetite (5.7 per cent), and apatite (3.0 per cent). The chemical analysis (Daly, 1912, p. 368) has a remarkably high K_2O:Na_2O ratio of more than 3:1.
Age	Unknown.
Economic aspects	None known.
Remarks	This is the only rock so far discovered in Canada that approaches missourite in composition. Daly (op. cit.) described a number of other melanocratic, feldspar-free, alkaline dykes along the 49th Parallel, particularly in the Selkirk Range. The origins and relations of such dykes are poorly understood at present.
Selected reference	Daly, R. A. (1912): The North American Cordillera at the 49th Parallel; Geol. Surv. Can., Mem. 38, p. 367–369.

Chapter V

Carbonatite Complexes Lacking Associated Nephelinitic Rocks

The term carbonatite signifies igneous, or at least intrusive rocks composed of more than 50 per cent carbonate minerals. Carbonatites are commonly found as component parts of nephelinitic complexes, whether as veins, plugs, or apparent differentiation products. However, carbonatites are also found in complexes which contain no nephelinitic rocks. These latter occurrences are discussed in this chapter.

Carbonatites are fairly commonly found in association with alkaline ultramafic rocks, often forming either dykes within the complex or the matrix of an ultramafic breccia. The alkaline character of the occurrence is expressed by the presence of either phlogopite or biotite, commonly altered to vermiculite, which in silica-undersaturated rocks gives rise to feldspathoids in the norm. Because of their mineral composition, such ultramafic bodies weather readily, and are poorly exposed, hence poorly known.

Carbonatites are also found associated with feebly alkaline, or subalkaline syenites. Carbonatite may be present in the form of veins, dykes, or elongate tabular masses. Alkaline character is indicated by the presence of biotite or alkaline amphiboles in the carbonatites.

Carbonatites in complexes lacking nephelinitic rocks may show some marginal fenitization of the country rocks, but such aureoles are commonly weak and small, and may be lacking entirely. However, there appear to be gradations among ultramafic rocks from carbonatite associated with nephelinitic rocks to those associated with subalkaline rocks.

Name	Lonnie (CR-68; Fig. 42)
Location and access	About 5 miles east of the hamlet of Manson Creek, central British Columbia (55° 40′N, 124°30′W). The complex can be reached by walking up the valley of Granite Creek from the road crossing on the highway to Vanderhoof.
Form and structure	A lenticular mass about 2,000 feet long by 300 feet wide, conformable to the surrounding mica schist and gneiss of the Wolverine Complex, which trend northwest, and dip steeply southwest.
Petrography	From northeast to southwest the sequence of rock-types is (a) fenite, (b) alkalic monzonite, (c) foliated biotite-calcite carbonatite, (d) massive biotite-calcite carbonatite, (e) alkalic monzonite, (f) aegirine-calcite carbonatite, and (g) fenite. The fenites are reddened and fractured with complex intergrowths of sodic pyroxenes and amphiboles, and the contacts with the complex are commonly sheared and boudined. The 'monzonite' is a granular rock very rich in albite, with minor calcite and biotite. Mortar structure and bent twin lamellae are characteristic. Some parts of the carbonatite contain sodic amphiboles, and pyrochlore is disseminated throughout much of the complex.
Age	Unknown. The most recent metamorphism was approximately 45 m.y. ago.

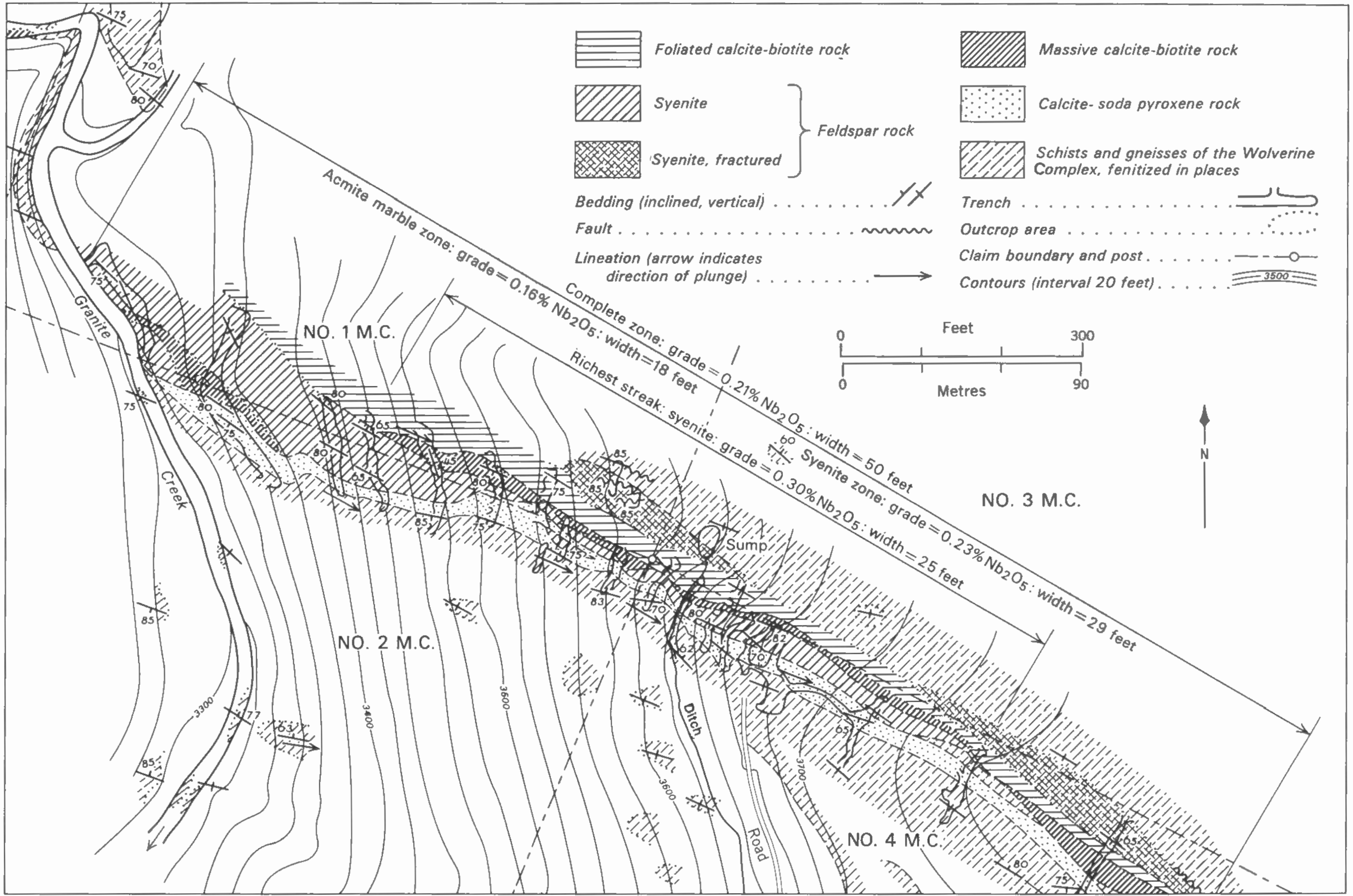


FIGURE 42. Geology of the Lonnie complex (after Rowe, 1958).

Economic aspects	The whole of the complex is mineralized with pyrochlore. Columbite and niobian rutile occur in the monzonite. The best grade is about 0.21 per cent Nb_2O_5 over 50 feet.
Remark	The Lonnie complex could conceivably be a mineralized band in the Wolverine Complex, which contains rare, thin marble horizons, but it seems more likely to be a carbonatite metamorphosed with its surroundings.
Selected reference	Rowe, R. B. (1958): Niobium (Columbium) deposits of Canada; Geol. Surv. Can. Econ. Geol. Ser. 18, p. 29–31.

Name	Verity (Lemprière, C-69; Fig. 43)
Location and access	Twenty-three miles north of Blue River, on the east side of the North Thompson River, about 4 miles south of Lemprière station on the Canadian National Railways line. The locality can be reached either by railway, or by crossing the river at Albreda from the Thompson highway.
Form and structure	Lenses up to 150 feet wide in a quartz-plagioclase-hornblende-biotite gneiss. The lenses appear to be folded along with their surroundings, and commonly show a strong foliation. The carbonatite is cut by feldspar-rich pegmatites. Outcrop is poor.
Petrography	The carbonatite consists mainly of granular dolomite with variable amounts of olivine, soda amphibole, biotite-vermiculite, magnetite, and ilmenite. The mafic minerals commonly define the foliation. Minor calcitic lenses are also present.
Age	Unknown.
Economic aspects	The carbonatites contain a low tenor of uranoan pyrochlore and columbite, as well as pyrite and pyrrhotite.
Remark	The mineralogy of the Verity carbonatites strongly suggests that they are not of metasedimentary origin. This locality is only some 35 miles from the Perry River nepheline gneiss occurrence, which also has carbonatite parts. Nepheline and sodalite syenite occur around the Verity deposit also, but their relation to the carbonatite is not understood because of poor outcrop and difficult terrain.
Selected reference	Rowe, R. B. (1958): Niobium (Columbium) deposits of Canada; Geol. Surv. Can., Econ. Geol. Ser. 18, p. 31–35.

Name	Creswell River (C-56; Fig. 44)
Location and access	Sixteen hundred miles north of Winnipeg on Somerset Island, between the Aston and West Creswell rivers (73°08′N, 94°07′W). This extremely remote location can be reached only by aircraft.
Form and structure	The complex intrudes monoclinally dipping Ordovician carbonates in a series of interlocking circular structures, covering an area of about 300 by 700 feet. About 12 individual units can be discerned, which appear to require multiple intrusion, presumably in a fluidized state, as indicated by the rounded xenoliths and phenocrysts and the lack of contact metamorphism. The character of the units varies from intrusive breccia to massive porphyry.
Petrography	The xenolith-free phases of the intrusion consist of dark green to black rocks with rounded olivine phenocrysts, and violet to reddish brown garnet, always surrounded by kelyphitic rims. The rock is mottled by irregular lobate patches of carbonate and pyrite. Phlogopite phenocrysts up to a centimetre long are present. Microprobe studies (Table 20) show the olivines to average near Fo_{90} in composition, both in phenocrysts and groundmass, whereas the garnets are of two types, one rich in pyrope and uvarovite molecules, and the other rich in almandine molecule, with substantial pyrope but very little uvarovite. The matrix of the rocks may be either dolomitic carbonate, or an indeterminate mixture of serpentine, clay minerals, and chlorite. Perovskite occurs in this matrix.

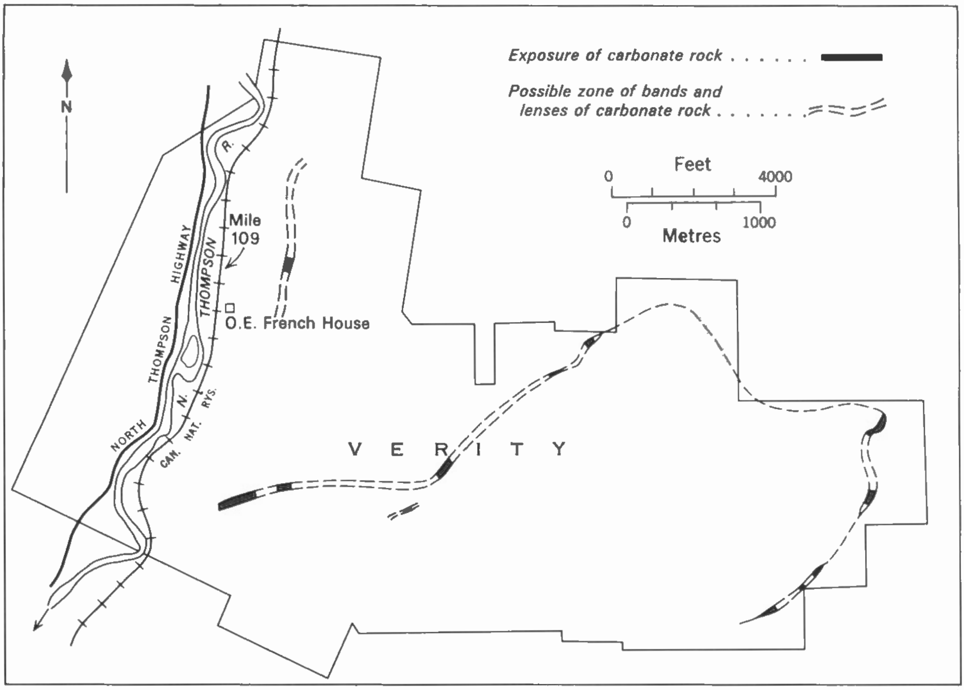


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FIGURE 43. Occurrences of carbonate rock on the Verity prospect (after Rowe, 1958).

TABLE 20 *Chemical analyses of the Creswell kimberlitic carbonatite*

SiO_2	21.43
TiO_2	0.44
Al_2O_3	1.89
Fe_2O_3	6.12
FeO	3.89
MgO	19.91
CaO	10.83
Na_2O	0.81
K_2O	1.19
P_2O_5	0.98
NiO	.23
MnO	.13
H_2O	2.18
CO_2	30.76
TOTAL	100.79

Olivine

Average phenocryst	(7)	91.1% Fo, core, 0.38% NiO 90.0% Fo, rim, 0.34% NiO
Average groundmass		89.6% Fo

Garnet

Average pyrope	(2)	75.44% pyrope, 10.32% uvarovite, 10.11% almandine
Average almandine	(9)	31.12% pyrope, 3.92% grossular 62.58% almandine

(Data *after* Mitchell and Fritz, 1973)

Analysis by Analytical Chemistry Section, Geol. Surv. Can., using "rapid methods". Sample donated by R. L. Christie.

Age	Not definitely known, but post-Ordovician and possibly Mesozoic.
Remark	The mineral assemblage and form of this intrusion are generally consistent with those of a kimberlite pipe. The amount of carbonate present is unusual, although not unknown in some African examples. Due to the high content of carbonate it is here classified tentatively as an ultramafic carbonatite, but possibly it should be included with the kimberlites.
Selected references	Blackadar, R. G. and Christie, R. L. (1963): Geological reconnaissance, Boothia Peninsula, and Somerset, King William, and Prince of Wales Islands, District of Franklin; Geol. Surv. Can., Paper 63-19. Mitchell, R. H. and Fritz, P. (1973): Kimberlite from Somerset Island, District of Franklin, N.W.T.; Can. J. Earth Sci., v. 10, p. 384–393.

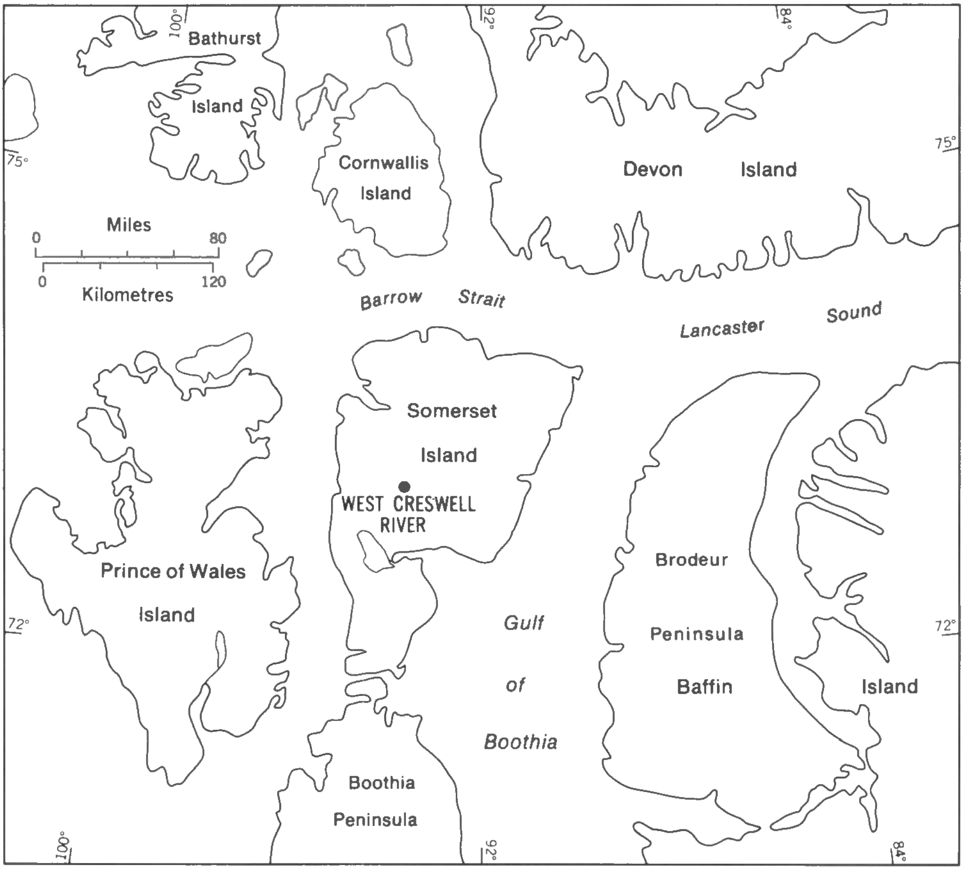

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FIGURE 44. The West Creswell River carbonatite.

Name	Carb Lake (C-59; Fig. 45)
Location and access	Four hundred and seventy miles north-northwest of Thunder Bay, 6 miles east of the Ontario–Manitoba boundary (54°48′N, 92°00′W). The locality is readily accessible only by air.
Form and structure	The complex does not outcrop, but boulders of carbonatite are found near Carb Lake. The magnetic anomaly shows a distinct northwest-southeast 'grain,' although it approaches circularity.
Petrography	Drilling shows that the complex consists mainly of carbonatite. Both calcite and dolomite are present in erratically varying proportions, together with about 20 per cent apatite, biotite, and mafic rock fragments consisting of sodic amphibole, vermiculite (or biotite), and accessory amounts of magnetite, apatite, and pyrite. Fluorite and rare-earth carbonates (ancylite and synchysite) are present in local concentrations, and disseminated pyrochlore was found throughout much of the drill core.
Age	Not known.
Economic aspects	The Carb Lake complex has been extensively investigated as a source of niobium and rare-earths. Some selected samples grade 2 per cent Ce and 1 per cent La.
Remark	Carb Lake, Big Beaver House, and Schryburt Lake form a linear group of complexes of strikingly similar character. The line joining them seems to parallel a strong structural trend, expressed in the internal structure of Carb Lake and Big Beaver House, and by the trend of faults and greenstone belts on Ontario Department of Mines compilation maps. It seems possible that a structure similar to the Kapuskasing "High" may exist in this region, extending on into Manitoba to the Cinder Lake complex.
Selected reference	Ferguson, S. A. (1971): Columbium (Niobium) deposits of Ontario; Ont. Dept. Mines Northern Affairs, Mineral Resourc. Circ. 14, p. 35–36.

Name	Big Beaver House (C-58; Fig. 45)
Location and access	Three hundred and forty miles north of Thunder Bay near 52°55′N, 89°55′W, about 24 miles northwest of Schryburt Lake. The locality is easily accessible only by air.
Form and structure	The complex is exposed on the shore of a lake as a northwest-trending carbonatite dyke with northeasterly dip. Drilling shows foliated calcite carbonatite with abundant zones of serpentinized pyroxenite. The granites intruded by the complex are fenitized, and fenitized fragments are found in the pyroxenite. The aeromagnetic anomaly is about 3.2 miles in diameter, and approximately circular.
Petrography	The matrix of the complex appears to be a serpentinized pyroxenite containing amphibole, and varying amounts of vermiculite and carbonate, with lesser amounts of magnetite and disseminated sulphides, including chalcopyrite. This rock has a matrix of carbonatite, which also forms crescentic screens within it. Sodic amphibole, magnetite, and barite form seams within the calcite carbonatite, and pyrochlore is commonly found in these seams. Massive apatite occurs in the calcite.
Age	A K-Ar age on biotitic mica gave 1,005 m.y.
Economic aspects	The Big Beaver House complex has been prospected and drilled by Many Lakes Exploration Co. as a possible niobium, copper, and apatite source.
Selected reference	Ferguson, S. A. (1971): Columbium (Niobium) deposits of Ontario; Ont. Dept. Mines Northern Affairs, Mineral Resourc. Circ. 14, p. 36–37.

Name	Schryburt Lake (C-57; Fig. 45)
Location and access	Three hundred and twenty-five miles north of Thunder Bay, Ontario, near 52°35′N, 89°35′W. The locality is accessible only by air.
Form and structure	Surface outcrop is sparse, but boulders of intensely serpentinized ultrabasic rocks are present. Drilling revealed a foliated carbonatite containing lens-like masses of silicate rocks. The Schryburt Lake complex appears on aeromagnetic maps as an intense, closed, near-circular anomaly about 2 miles in diameter, and thus may be a ring complex of this size.
Petrography	The complex appears to consist principally of coarse-grained calcite with varying amounts of mica, amphibole, magnetite, and apatite, and accessory perovskite, pyrochlore, fluorite, and sulphides. Bands of massive magnetite and apatite up to several feet thick are present. Green streaky lenses and schlieren of ultramafic rocks, now intensely serpentinized, occur sporadically. The surrounding granitoid gneisses are feebly fenitized.
Age	Unknown, possibly the same as that of Big Beaver House, 24 miles to the northwest (1,005 m.y.)
Economic aspects	The Schryburt Lake complex has been drilled as a niobium prospect by Many Lakes Exploration Co.
Selected reference	Heinrich, E. W. (1966): The Geology of carbonatites; Chicago, Rand McNally and Co., 555 p.; *see* p. 398.

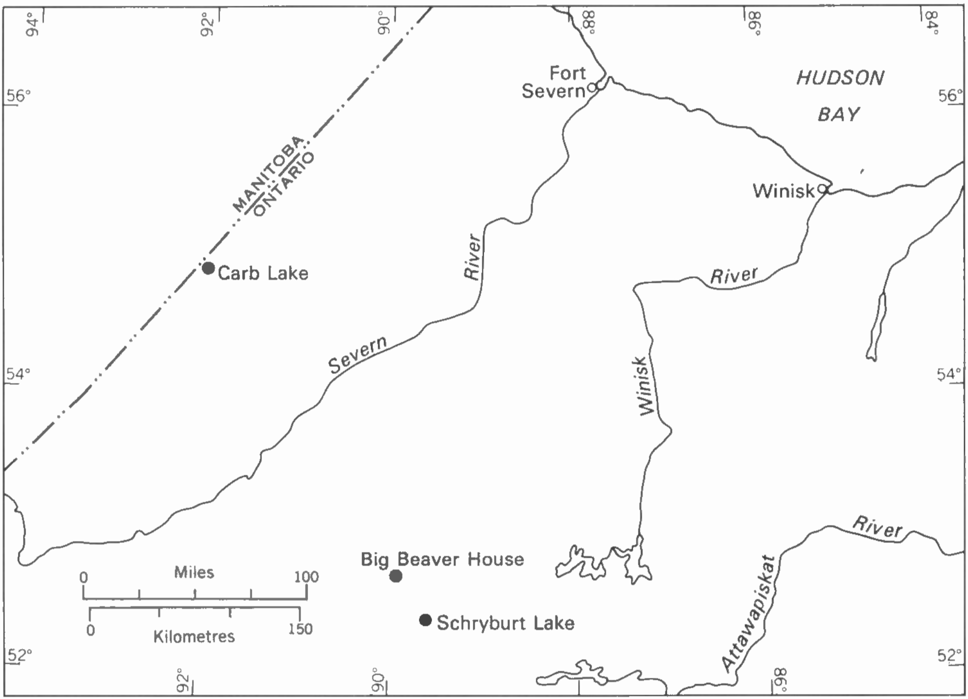

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FIGURE 45. Carbonatite complexes in northwestern Ontario.

Name	Cargill (CK-60; Fig. 46)
Location and access	Eleven miles southeast of Kapuskasing, Ontario, on the boundary between Cumming and Cargill townships (49°20′N, 82°51′W). The complex is readily accessible only by air.
Form and structure	The complex has the form of an elongate dumbbell, about 4 miles along its northeast trend, and a mile across. Outcrop is exposed only in the southern half, east of the Cargill fault which transects the complex. Four near-vertical layers are present. The hybrid granitoid country rocks are little affected by the intrusion, which is in turn cut by a later north-northeast-trending diabase dyke.
Petrography	The most easterly layer is pyroxenite, composed of titaniferous augite with up to 10 per cent olivine, and very rich in magnetite (up to 25 per cent). Traces of pyrite, pyrrhotite, and chalcopyrite are present, and the pyroxenite is cut by calcite-apatite veins. To the west the rock becomes richer in amphibole and biotite, and contains some carbonate. This rock appears to grade into a fine-grained, buff, dolomitic carbonatite. Gabbro, possibly belonging to the Cargill complex, is exposed northwest of the Cargill fault.
Age	A K-Ar age on biotite yielded 1,740 m.y., although coarse fractions low in K (vermiculite?) yielded substantially older ages up to 1,860 m.y., presumably due to K loss.
Economic aspects	The Cargill complex was examined and drilled in the 1950's as a copper and iron prospect, but evaluations were unfavourable.
Remark	The Cargill complex occurs on the Kapuskasing "High", along with several other ultramafic carbonatite complexes (Fig. 47). These complexes are distinguished from nephelinitic complexes occurring on the same structure by (a) generally greater age (with the exception of Clay-Howells), (b) elongate shape, (c) more northerly location. These characteristics appear to define two distinctly different subprovinces of carbonatites.
Selected reference	Bennett, G., Brown, D. D., George, P. T., and Leahy, E. J. (1967): Operation Kapuskasing; Ont. Dept. Mines, Misc. Paper. 10, p. 66–68.

Name	Clay-Howells (CK-61, Fig. 48)
Location and access	Thirty-two miles northeast of Kapuskasing, Ontario, and some 2 miles south of a highway from Smooth Rock Falls to Smoky Falls. The complex is crossed by the Mattagami River. Although the complex can be reached on foot or by boat, the most satisfactory access is by air.
Form and structure	The carbonatitic part of the Clay-Howells complex consists of a curving, northeast-trending, dyke-like mass, possibly about 3 miles long and a few hundred feet wide. Individual parts of this body form lenticular masses up to 3,500 feet long and 300 feet wide. The dykes occur within a near-circular mass of aegirine syenite about 8 miles in diameter.
Petrography	The dykes consist of calcite containing garnet, amphibole, and disseminated magnetite, with zones of magnetite-rich amphibolite along the contact of syenite and carbonatite.
Age	K-Ar determination on biotite yielded 1,010 m.y. This seems anomalously young because of the ages of the geologically similar Cargill, Goldray, and Argor complexes.
Economic aspects	Diamond drilling for the Steel Co. of Canada in 1955, plus milling tests, indicated the presence of large amounts of recoverable magnetite from this complex. Niobium was present both in the concentrate and in the tailings.
Selected reference	Bennett, G., Brown, D. D., George, P. T., and Leahy, E. J. (1967): Operation Kapuskasing; Ont. Dept. Mines, Misc. Paper 10, p. 68–70.

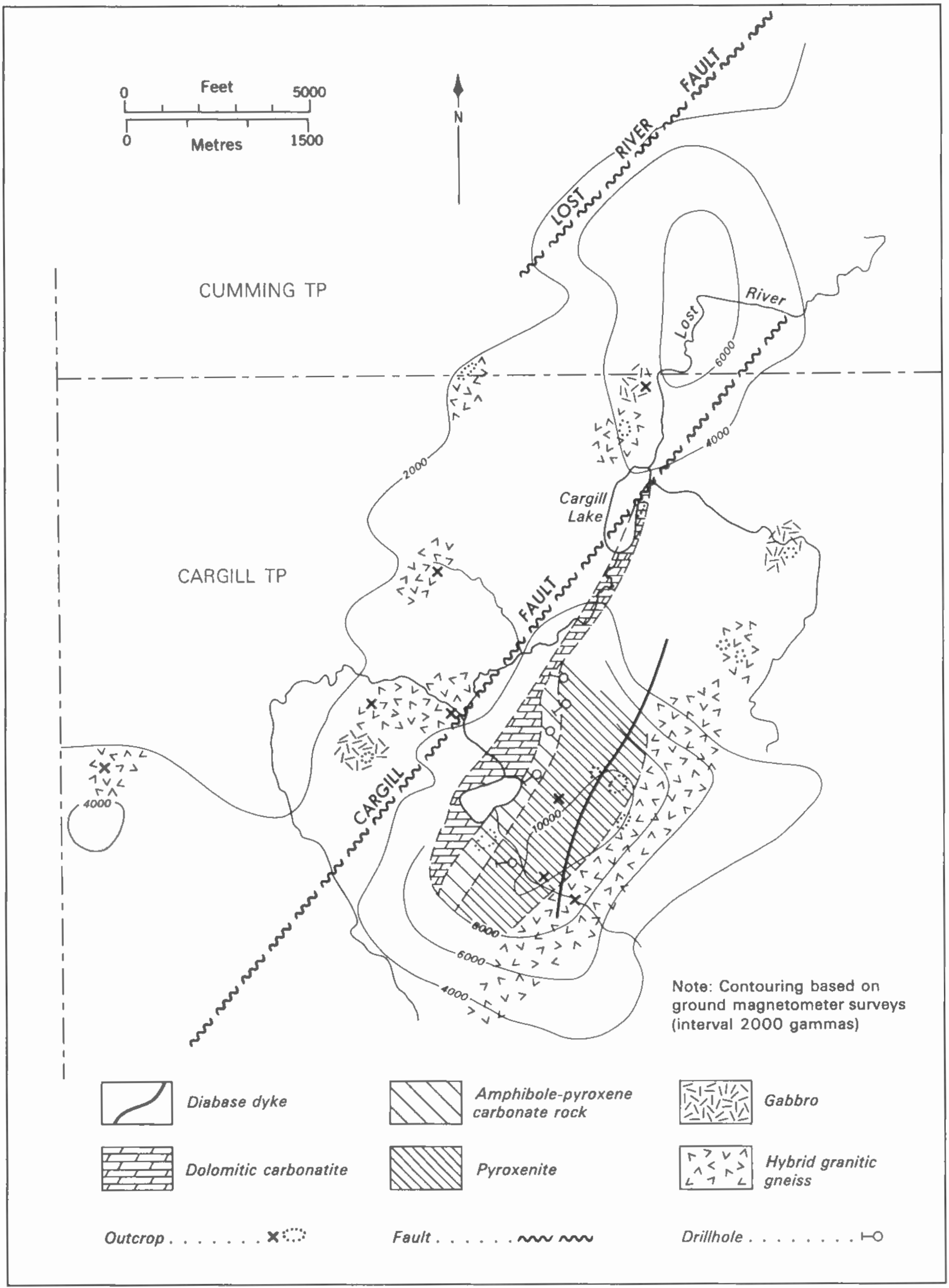

FIGURE 46. Geology of the Cargill complex (after Bennett *et al.*, 1967).

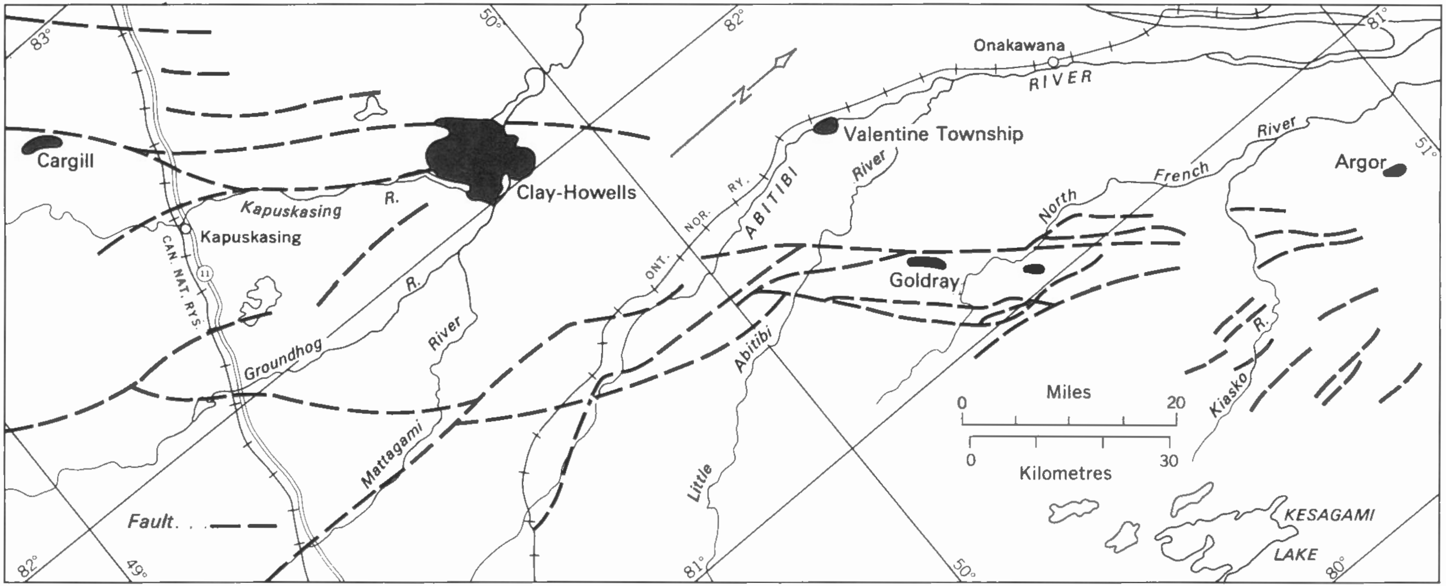

FIGURE 47. Carbonatite complexes in the northern part of the Kapuskasing "High."

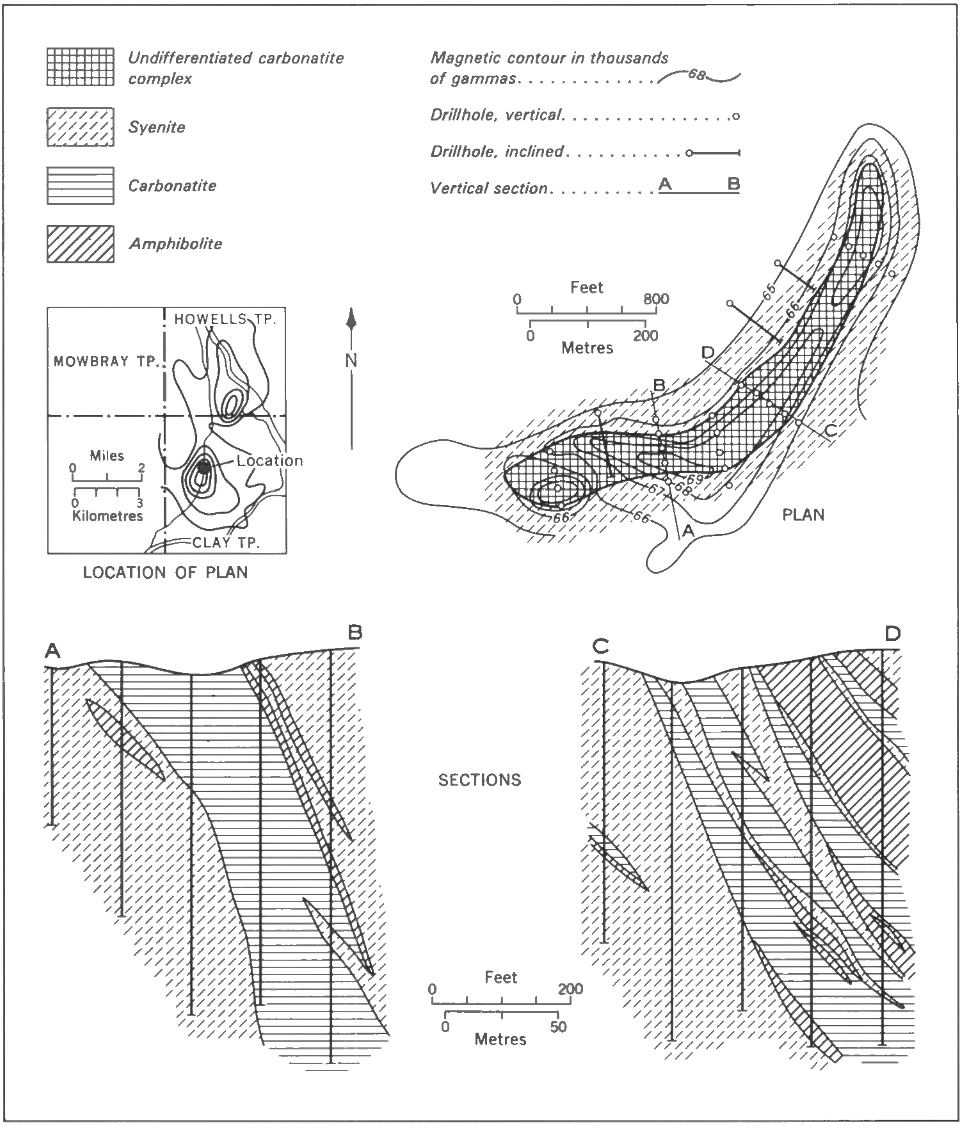

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FIGURE 48. Geology of the Clay-Howells complex (after Bennett *et al.*, 1967).

Name	Teetzel Township (CK-116)
Location and access	Ten miles north of Kapuskasing, Ontario, on the Kapuskasing River, about 1 mile east of the railway to Smoky Falls.
Form and structure	A dyke-like body some 30 feet wide, striking northeast along a fault.
Petrography	The rock is a granular calcitic carbonatite containing phlogopite and varying amounts of sodic amphibole and pyroxene.
Age	A K-Ar age determination on phlogopite gave 1,155 m.y.
Economic aspects	None known.
Selected reference	Bennett, G., Brown, D. D., George, P. T., and Leahy, E. J. (1967): Operation Kapuskasing; Ont. Dept. Mines, Misc. Paper 10, p. 68–70.

Name	Argor (CK-64; Fig. 47)
Location and access	Twenty-five miles south of Moosonee, Ontario, on South Bluff Creek (50°45′N, 81°01′W). The area is best reached by aircraft.
Form and structure	A dyke at least 8,400 feet long, varying from 350 to 800 feet wide, trends north-northeast, and dips 70 to 80 degrees east, cutting northeast-trending granulites.
Petrography	The matrix of the dyke is a dolomitic carbonatite containing 5 to 15 per cent apatite, 5 to 10 per cent riebeckite, 5 to 10 per cent phlogopite, and 2 to 15 per cent titaniferous magnetite, as well as disseminated pyrochlore. Lenses of calcite with minor apatite and fluorite occur within the body, and toward the western side ultramafic silicate rocks composed of augite, diopside, hornblende, and biotite are present, with minor carbonate and inclusions of country rocks. The country rocks appear to be unaffected by the intrusion of the dyke.
Age	A K-Ar age on biotite yielded an age of 1,655 m.y.
Economic aspects	Large amounts of pyrochlore are present. Exploration has outlined an orebody of 62.5 million tons grading 0.52 per cent Nb_2O_5.
Remark	Two other bodies almost identical to the Argor dyke occur about 20 and 30 miles to the south—the Goldray and Lewers Township occurrences. These three bodies seem to form a zone of carbonatite dykes, but only the Argor complex contains significant niobium. The Goldray body gave a K-Ar age of 1,695 m.y. on biotite.
Selected references	Ferguson, S. A. (1971): Columbium (Niobium) deposits of Ontario; Ont. Dept. Mines Northern Affairs, Mineral Resourc. Circ. 14, p. 33–34. Stockford, H. R. (1972): The James Bay pyrochlore deposit; Can. Mining Met. Bull., v. 65, p. 61–69.

Name	Township 107 (C-55; Fig. 49)
Location and access	Thirty-five miles northwest of Sudbury, Ontario, on the boundary between Townships 107 and 108, just south of the Big Bend of Spanish River. The body is accessible by automobile from Sudbury via Highway 544, and local lumber roads.
Form and structure	The length and width of the carbonatite are concealed by swamp, but it appears to form a dyke-like mass about a half mile wide, striking N35°E and dipping moderately southeast. The carbonatite is locally strongly foliated, but is considerably brecciated. The mass appears to intrude faintly fenitized granite gneiss, and is cut by altered mafic dykes.
Petrography	The main body consists of dolomitic carbonatite containing disseminated phlogopite. The rocks are coarse grained, and faintly homogeneous, but strongly foliated. The mafic dykes, probably originally lamprophyres, are converted to vermiculite,

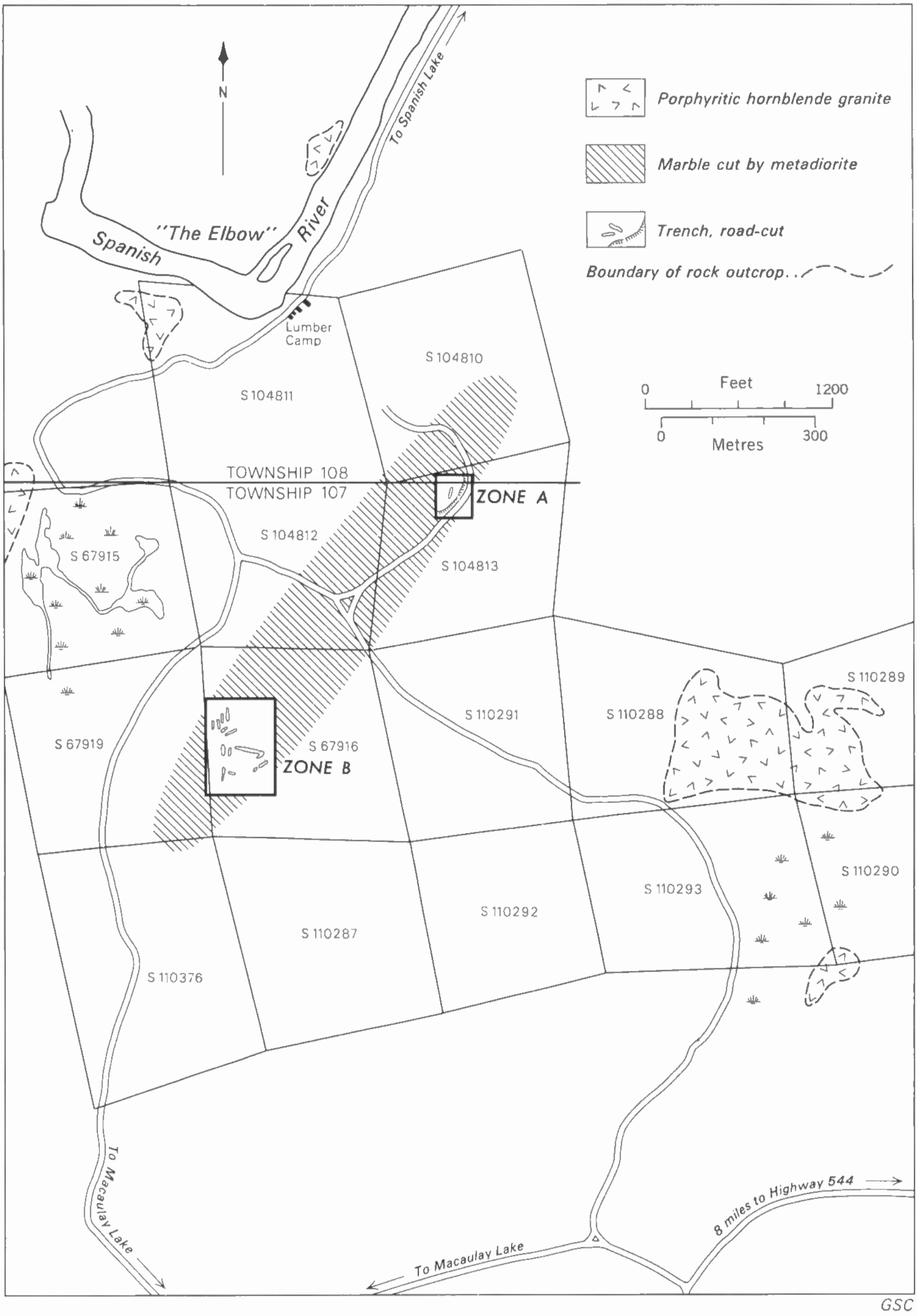

FIGURE 49. Geology of the Township 107 carbonatite occurrences (after Guillet, 1962).

	or are intensely serpentinized. Chemically, the carbonatite is characterized by a low Sr_{87}/Sr_{86} ratio of 0.702, and by substantial content of Ce, Y, La, and Nb.
Age	A K-Ar determination on a biotitic mica gave 1,560 m.y.
Economic aspects	Considerable development work, including trenching and bulk sampling, has been done on the body as a vermiculite prospect.
Remark	Recent work on diamond-drill cores from the Township 107 complex shows that extensive fenitization occurs at depth, as well as irregular zones of ijolitic rocks (P. Mainwaring, pers. com., 1973). These data suggest that the complex is either of nephelinitic character, or gradational toward nephelinitic character.
Selected reference	Guillet, G. R. (1962): Vermiculite in Ontario; Ont. Dept. Mines, Ind. Miner, Rept. 7, p. 18–20.

Name	Nemag Lake (C71)
Location and access	About 15 miles southwest of Sudbury, Ontario, in the Whitefish Indian Reservation, just southwest of Nemag Lake. The locality is accessible by local roads from Highway 17.
Form and structure	Two breccia plugs a few hundred yards in diameter occur near a major southwest-striking fault; other faults are present. The pipes penetrate Proterozoic sedimentary rocks.
Petrography	The fragments of the breccia appear to be strongly fenitized country rocks, now of aegirine syenite composition, in a matrix of dolomitic carbonatite containing large amounts of alkaline amphibole, pyroxene, and minor phlogopite.
Age	Unknown.
Economic aspects	None known.
Selected reference	Palonen, P. and Mills, D. H. (1969): Preliminary map of Whitefish Lake I.R.; Ont. Dept. Mines Northern Affairs, Map P. 597.

Name	Meach Lake (McGerrigles Field) (C-70; Fig. 50)
Location and access	About 15 miles north of Ottawa in Gatineau Park, Quebec. The occurrence can readily be reached by driving up the Gatineau Parkway to the Champlain Lookout, and walking along a trail about 1 mile farther north.
Form and structure	Carbonatite appears in the form of a large number of arcuate dykes up to a few feet wide penetrating a Precambrian aplite stock about 1 mile in diameter. In general, the dykes have an east-west trend. A large number of small breccia patches of carbonatitic character occur outside the aplite.
Petrography	Thicker dykes are distinctly zoned, with a central dolomitic core and calcitic margins, but the dolomitic core is absent in thin dykes. Apatite is ubiquitous, and amphibole, phlogopite, pyrite, and pyrrhotite are present in varying amounts. Barite-fluorite and quartz masses are locally present. The margins of the dykes are intensely metasomatized with development of phlogopite and richterite, and at greater distances are hematitized and albitized rocks containing alkaline amphibole. The breccia nests are commonly rich in phlogopite books, and contain a carbonate matrix.
Age	A K-Ar date on phlogopite yielded 920 m.y., which is approximately the age of the latest metamorphism in this region.
Economic aspects	None at present. Many years ago some prospecting was done for mica.
Selected reference	Hogarth, D. D. (1966): Intrusive carbonate rock near Ottawa, Canada; Mineral. Assoc. India., I.M.A. Volume, p. 45–53.

FIGURE 50. Geology of carbonatite dykes in the Meach Lake area (after Hogarth, 1966).

Name	Megiscane Lake (C-72; Fig. 51)
Location and access	Near Megiscane Lake, Quebec (48°34′N, 75° 36′W). Access is by aircraft only.
Form and structure	The carbonatite appears to occur as part of an elliptical complex about 3 miles long, elongated along the northeast trend of the Grenville Front. The outlines of the bodies are marked by a magnetic high.
Petrography	The complex consists of coarse-grained, faintly schistose, calcitic carbonatite containing varying amounts of aegirine, hornblende, and biotite, with accessory amounts of garnet, magnetite, sphene, and pyrite. The carbonatite contains up to 0.26 per cent

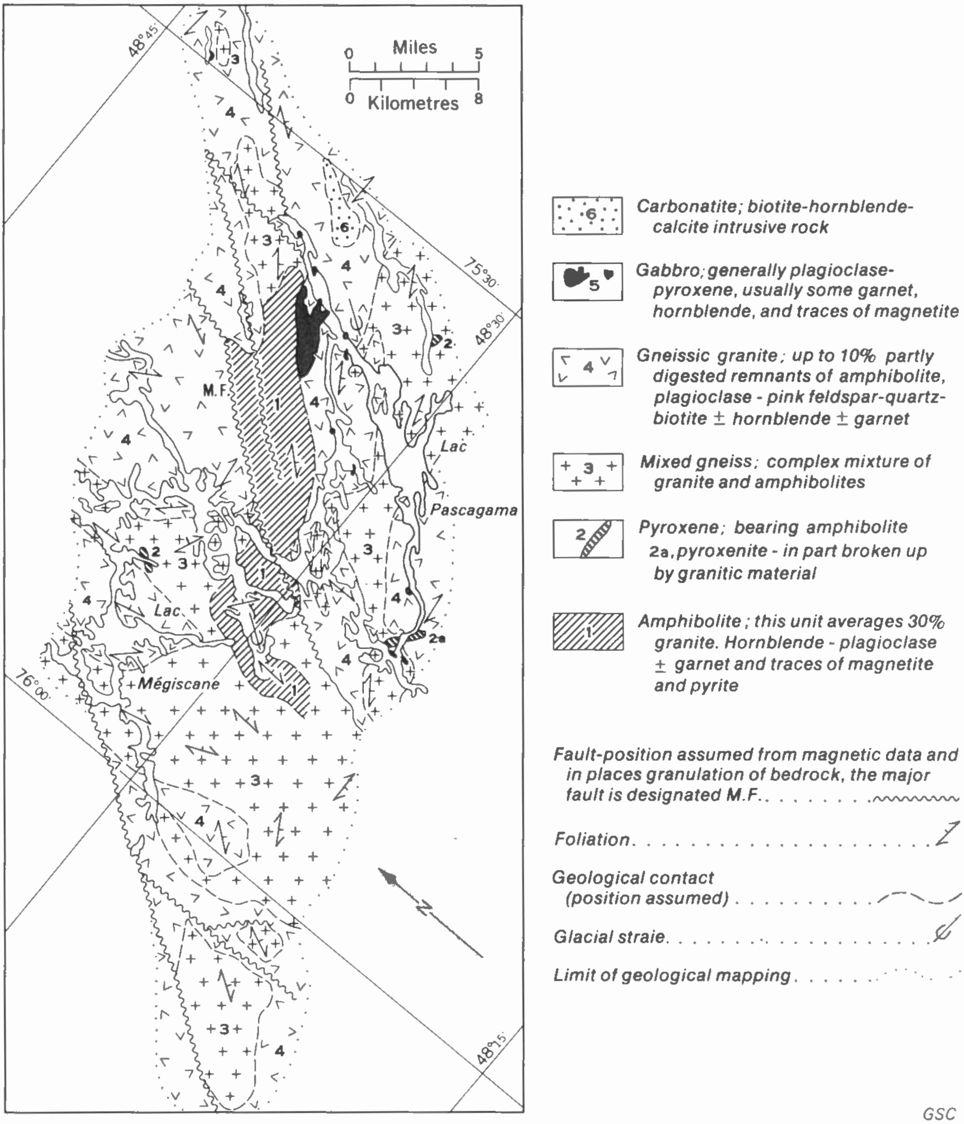

FIGURE 51. Geology of the Megiscane Lake carbonatite (after Charbonneau, 1969).

	total rare-earths. Breccia funnels of similar character intrude pyroxene-bearing amphibolite within 1 mile of the main mass.
Age	A K-Ar determination on biotite gives 975 m.y.
Economic aspects	None known.
Selected reference	Charbonneau, B. W. (1969): A Grenville Front magnetic anomaly, Megiscane Lake, Quebec; *in* Report of Activities, April to October, 1968, Geol. Surv. Can., Paper 69-1, pt. A, p. 70–77.

Name	Chicoutimi–Baie-Comeau (CN-65, CN-66; Fig. 52)
Location and access	Carbonatite dykes occur about 20 miles north-northwest of Chicoutimi near Shipsaw River, and in road-cuts on a highway west of Baie-Comeau. Although these localities lie 155 miles apart, other dykes probably occur along the north edge of the St. Lawrence graben system.
Form and structure	Dykes from 3 inches to 2 feet wide, generally of north to northeasterly trend. Zones of brecciation and fenitization may be found associated with the dykes.
Petrography	The rocks are fine grained, greyish green, and consist of aggregates of altered olivine, coarsely crystalline calcite, biotite, and apatite in a fine-grained carbonatitic matrix. The phenocrysts are commonly rounded, suggesting mechanical abrasion during intrusion. Fenitized country rocks show a characteristic purplish shade, and commonly contain large crystals of alkaline amphibole, and seams of coarse carbonates. The rocks invariably show brecciation.
Age	K-Ar ages on biotite from the dykes north of Chicoutimi give an age of 564 m.y.
Economic aspects	None known.
Selected references	Doig, R. and Barton, J. M. (1968): Ages of carbonatites and other alkaline igneous rocks in Quebec; Can. J. Earth Sci., v. 5, p. 1401–1407. Quebec Dept. of Natural Resources, Report of 1968 field work (1970): Que. Dept. Nat. Resourc., Paper S. 115, p. 10.

Name	Mutton Bay (CN-67; Fig. 52)
Location and access	North shore of the Gulf of St. Lawrence near the village of Tabatière (50°50′N, 58°55′W). The locality is best reached by coastal steamer and small boat.
Form and structure	A syenite complex some 15 miles in diameter is the host rock of small, northeast-trending carbonatite dykes. The dykes are less than 1 foot wide, and are most abundant on some islands off the coast.
Petrography	The syenite is composed mainly of perthite, with minor biotite, hornblende, and augite, and accessory apatite and sphene. The calcite carbonatite locally contains large amounts of biotite.
Age	K-Ar ages on biotite from the carbonatite give 566 m.y. compared to a Rb-Sr date on the same mineral of 630 m.y. The syenite gives K-Ar ages on biotite of 562 m.y. and 576 m.y.
Economic aspects	Unknown.
Remark	The identification of the veins as carbonatite is obviously weak. Possibly the whole syenite complex should be considered as alkaline, but the present information is inconclusive.
Selected reference	Davies, R. (1968): Geology of the Mutton Bay intrusion and surrounding rocks, North Shore, Gulf of St. Lawrence, Quebec; McGill Univ., Montreal, unpubl. Ph.D. thesis.

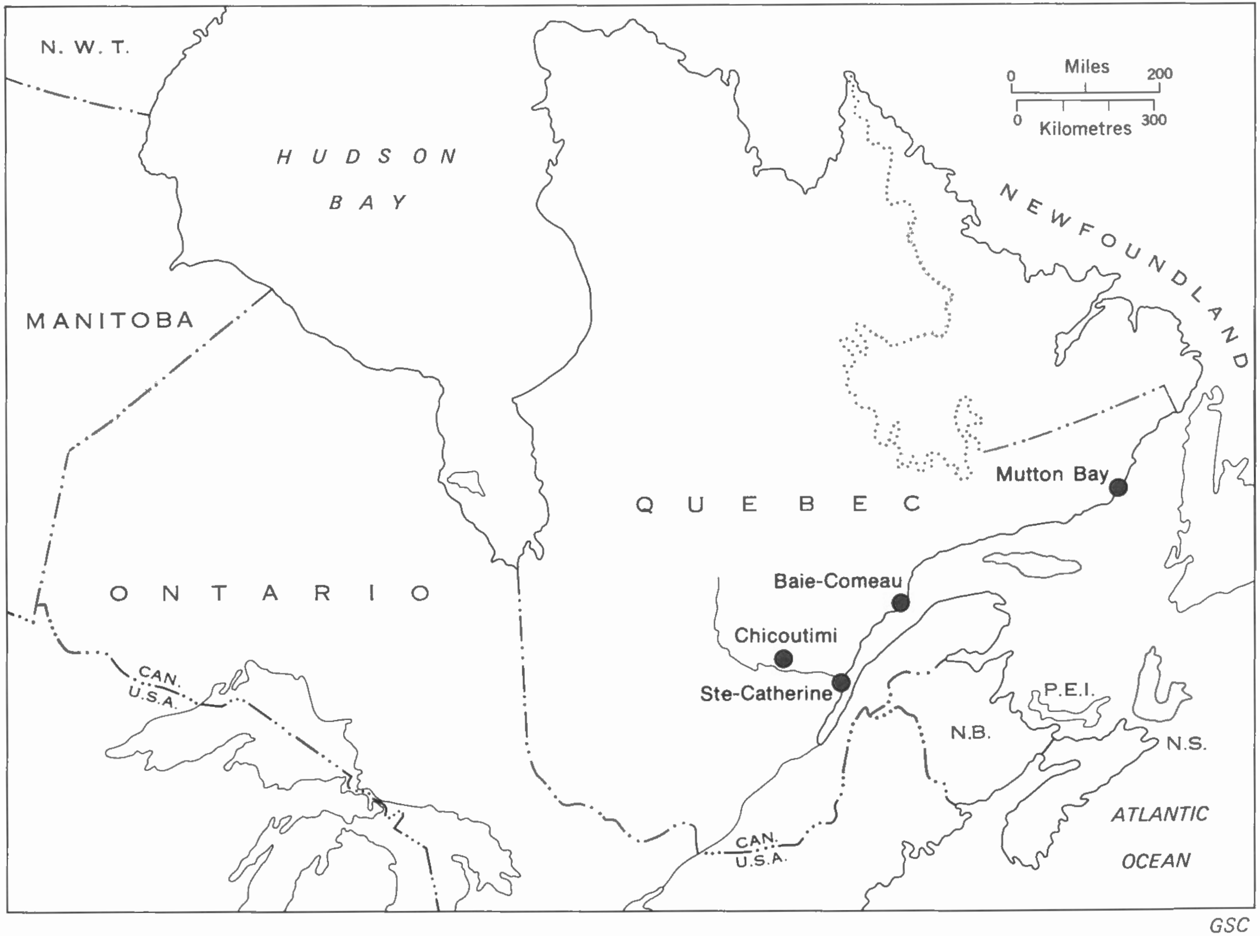

FIGURE 52. Carbonatitic rocks in the St. Lawrence valley.

Chapter VI

Miaskitic Syenite Complexes

Miaskitic syenites form what the average geologist considers to be 'normal' alkaline rocks, i.e., aggregates of alkali feldspar, with lesser amounts of plagioclase, variable amounts of nepheline, and mafic minerals ranging from biotite through various types of more or less alkaline amphibole, to alkalic pyroxenes. These rocks occur in two very different settings, either as sharply bounded, commonly subequant, intrusive complexes, which may have associated volcanic phases and commonly contain mafic to ultramafic rocks, or alternately as nebulous conformable bands in metamorphosed gneiss complexes. The latter rocks are sufficiently different in their setting, geological character, and mineral associations that they are described separately in the next chapter. This chapter deals only with the miaskitic syenite complexes that show clear-cut intrusive relations to their surroundings. Such complexes generally occur as somewhat elliptical, or irregularly shaped masses, with a pronounced zonal structure, grading from mafic on the outside to salic in the interior. This gradation commonly corresponds to a decrease in feldspathoid content, and saturated, or quartz-bearing rocks are rather common as late phases of such complexes. Gabbroic or even pyroxenitic phases may be present, but they are always of negligible volume compared to the syenite, and are invariably intruded by the later syenitic rocks. Volcanic rocks of similar composition are associated with several Canadian miaskitic syenite complexes, implying that they were intruded at shallow depths. However, the syenitic rocks in such complexes, i.e., the phases of plutonic appearance, tend to be coarse grained, and rarely resemble porphyries, although large phenocrysts of alkali feldspar are commonly present.

The mineralogy of miaskitic syenite rocks is generally simple, consisting of coarse perthitic potash feldspar, plus or minus independent, finer grained, sodic plagioclase, porphyritic or interstitial nepheline, and one or two of the following: biotite, hornblende, hastingsite, aegirine, titanaugite, and fayalite. Although alkaline amphiboles such as arfvedsonite and richterite have been reported, they appear to be rare in Canadian examples. Sodalite may be present, but only as an alteration product, or in late veins. Opaque minerals are not commonly abundant, but Cu and Mo mineralization is locally present, and some gold and silver mineralization appears to be associated with certain rocks of this type.

Miaskitic syenite complexes commonly contain minor marginal or late phases bearing a low tenor of quartz, as well as large volumes of rock containing neither quartz nor feldspathoids. The mechanism by which such complexes can pass from undersaturated to oversaturated compositions is unknown.

Name	Kruger Mountain (SR-73; Fig. 53)
Location and access	Ten miles west of Osoyoos, B.C. (49°00′N, 119°35′W). The body is readily accessible from the Richter Pass highway, which passes across it.

Form and structure The Kruger syenites form, in their main outcrop, a near-rectangular mass, 7 miles long by 2 miles wide, trending northwest along the edge of the Similkameen batholith, with smaller lenticles to the south and northwest. The syenites intrude greenstones and metasedimentary rocks of the Carboniferous(?) Kobau Group, and are in turn intruded by the Similkameen batholith. No pronounced contact effects are evident in the Kobau Group, although hornfelsed blocks are occasionally found in the syenites, and veins of syenite occur in the wall-rocks. Agmatite of syenite in an aplitic matrix is found at one place on the Kruger–Similkameen contact, but elsewhere this contact appears to be gradational.

Petrography The pluton shows a moderately developed zonal structure, with melanocratic syenite or diorite most common in the southwest part adjacent to the Similkameen batholith, and more leucocratic and nepheline-rich varieties occurring mainly near the Kobau Group to the northeast. This zonation is rather imperfect however, and the melanocratic, nepheline-poor syenites seem to form a matrix for the other rocks. All the rocks show a moderately strong trachytoid foliation parallel to the contacts. The melanocratic rocks contain large amounts of pale green, nonpleochroic augite, locally amounting to pyroxenite, which is characteristically armoured with hastingsitic amphibole. The more leucocratic rocks contain hastingsite and biotite as the mafic minerals. Microcline, occasionally perthitic, is the only feldspar found in abundance, although a little fine-grained sodic andesine is present in the mafic syenites. Nepheline originally occurred as euhedral phenocrysts and interstitial granules, but much of it is now altered to natrolite and sericite. Garnet is present in all the rocks, varying from resinous brownish varieties in the melanocratic rocks to greenish yellow granules in the more leucocratic rocks. Chemical analyses are presented in Table 21.

Age The age of the Kruger syenites is not definitely known but is presumably similar to or slightly older than that of the Similkameen batholith, which has yielded a K-Ar age on muscovite of 139 m.y.

TABLE 21 *Chemical analyses of the Kruger Mountain complex and related rocks*

	1	2	3	4	5	6	7	8	9
SiO_2	50.49	52.53	55.11	48.5	57.32	58.39	54.70	52.95	52.38
TiO_2	0.92	0.07	0.48	0.81	0.88	1.22	0.82	0.70	1.10
Al_2O_3	15.83	19.05	21.28	25.3	17.27	17.79	21.69	14.00	15.29
Fe_2O_3	6.11	4.77	2.64	1.9	1.62	4.32	5.40	2.57	2.99
FeO	3.04	2.10	1.29	2.5	3.94	1.33		5.55	5.53
MnO	0.11	0.13	0.08	0.08	0.09	0.08	0.12	0.13	0.10
MgO	3.38	1.99	.59	1.7	2.68	2.26	2.43	7.29	5.84
CaO	7.99	5.75	2.82	3.5	4.24	3.88	4.97	6.93	7.30
Na_2O	3.12	4.03	6.24	5.8	4.52	3.73	4.87	2.73	3.68
K_2O	6.86	7.30	8.36	4.83	5.96	7.00	5.00	5.09	3.84
P_2O_5	0.42	0.28	0.27	0.49	0.57	nil	nil	0.47	0.75
H_2O	1.49	1.62	.72	4.1	.55	2.37	2.7	.66	.84
CO_2	0.07	0.27	.08	0.8	—	0.01	0.4	nil	nil
TOTAL	99.83	99.89	99.96	100.3	99.64	102.38	103.10	100.07	99.64

1. Malignite, Kruger Mtn. (perthite 36.3, augite 36.5, biotite 11.0, melanite 9.5, nepheline 5.4).
2. Melanocratic nepheline syenite (perthite 63.9, biotite 11.1, melanite 8.8, nepheline 15.1).
3. Nepheline syenite, Kruger Mtn. (analysis 1, 2, 3 after Daly, 1912).
4. Nepheline porphyry, Marron Formation (after Monger, 1968, p. 25).
5. "Pulaskite" Dyke, after LeRoy, Geol. Surv. Can., Mem. 21, p. 46.
6. Trachyte, Marron Formation (Church, 1970, p. 401).
7. Mafic phonolite, Marron Formation (Church, 1970, p. 401).
8. Fayalite syenite phase of the Coryell Intrusions (orthoclase 45, labradorite 10.6, augite 24.5, olivine 10.7, biotite 5.2) (Daly, 1912, p. 357).
9. Mafic contact phase of the Coryell syenite batholith (Daly, 1912, p. 361).

Economic aspects

The Horn Silver Mine, a major producer of gold, silver, lead, and zinc, lies within the Kruger Mountain pluton, but the mineralized zone is a stockwork of quartz veins probably related to the younger Similkameen batholith.

Selected references

Campbell, C. D. (1939): The Kruger alkaline syenites of British Columbia; Amer. J. Sci., v. 237, p. 527–549.

Daly, R. A. (1912): North American Cordillera, Forty-Ninth Parallel; Geol. Surv. Can., Mem. 31, pt. 1, p. 448–455.

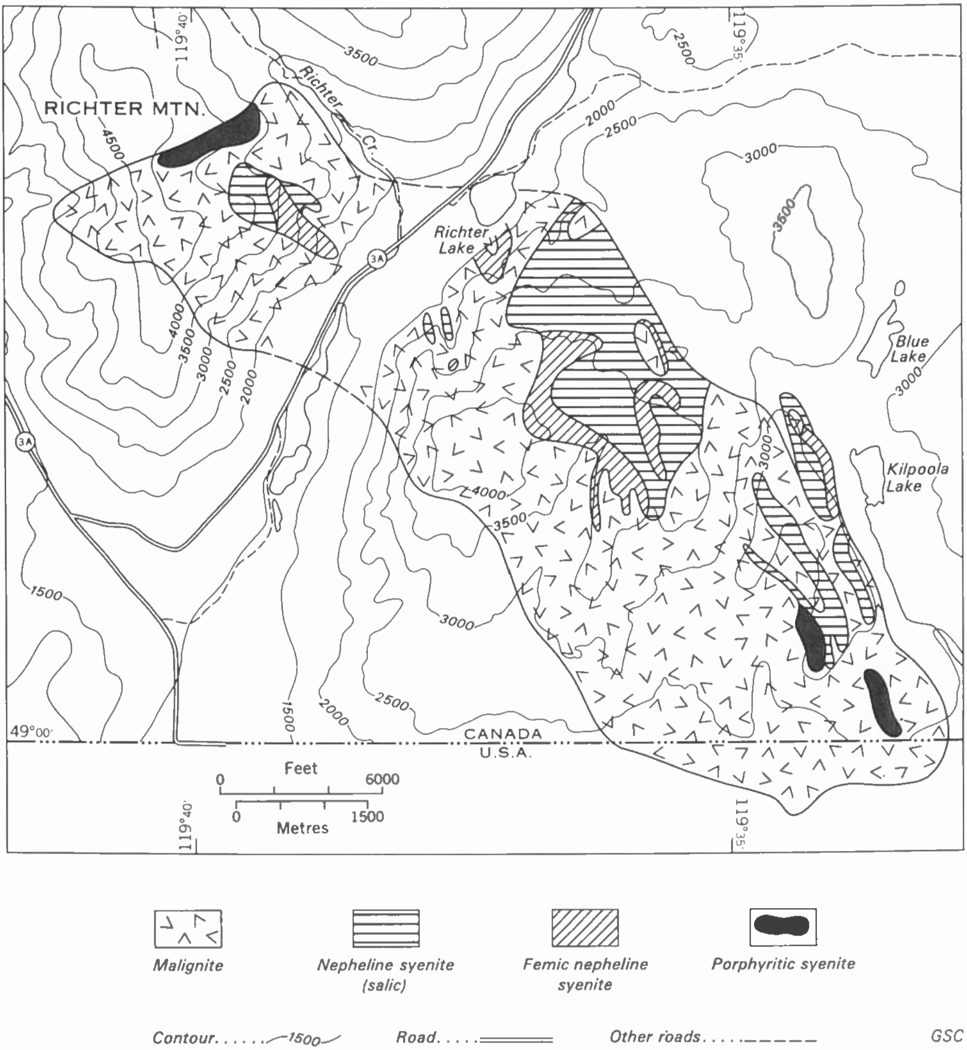

FIGURE 53. Geology of the Kruger syenite (after Campbell, 1939).

Name	Copper Mountain (SR-73a; Fig. 54)
Location and access	Twelve miles south of Princeton, B.C. (49°26′N, 120°36′W). Accessible by highway from Princeton.
Form and structure	A zoned ellipsoidal stock, about 5 miles long, elongated in a northwest direction, intruding deformed and metasomatized Triassic(?) volcanic rocks. Two similar but smaller stocks are found within a few miles of the main stock.
Petrography	The composition varies from syenogabbro at the margins to orthoclase albite pegmatite at the core, the grain size increasing with the salic character of the rocks. The various units of the stock are composed of varying amounts of augite, hornblende, biotite, oligoclase to albite, and microcline with prominent accessory magnetite and apatite. Neither quartz nor feldspathoids occur in the stock, but the analyses (Table 22) are consistently nepheline normative.
Age	K-Ar ages on biotite from the Copper Mountain stock are up to 195 m.y.
Economic aspects	The Copper Mountain copper mine is located on the northeast side of the stock near its contact with brecciated older volcanic rocks. The ore consists of bornite, chalcopyrite, and a little magnetite occurring as disseminations and small grains in the breccia, with a gangue of orthoclase, albite, oligoclase, and biotite. The Copper Mountain stock is believed to be the source of the ore-forming fluids.
Remarks	The Copper Mountain stock may be taken as typical of a number of syenitic intrusions in southern British Columbia that do not show modal feldspathoidal

TABLE 22 *Chemical composition of the various rocks comprising the Copper Mountain stock (after Dolmage, 1934)*

	1	2	3	4	5
SiO_2	43.12	50.60	54.40	62.86	61.84
Al_2O_3	18.19	16.15	19.05	20.41	19.35
Fe_2O_3	6.20	5.68	3.55	0.35	1.03
FeO	6.43	2.50	2.86	0.14	0.53
MgO	6.52	5.06	2.56	.20	.54
CaO	14.00	8.72	6.96	1.20	1.06
Na_2O	2.49	3.86	3.88	4.87	6.07
K_2O	0.81	4.54	5.34	7.35	7.12
H_2O-	.10	0.14	0.04	0.04	0.24
H_2O+	.65	1.36	.66	.59	.76
TiO_2	.50	0.35	.30	.35	.10
CO_2	.17	.10	.00	1.16	.92
P_2O_5	1.00	.58	.36	0.34	.17
S	0.05	.02	.02	.05	Trace
MnO	.12	.14	.11	.01	0.03
F		Trace			
Cl		Trace			
Plagioclase	57.00	48.30	40.00	35.50	29.00
Potash feldspar	9.00	35.10	23.00	20.40	60.00
Augite	20.35	1.00	28.00	35.50	1.00
Biotite	10.10	4.00	4.00	1.80	3.00
Magnetite	3.10	4.00	4.00	5.00	0.00
Hornblende		6.00			

No. 1 is at the extreme edge of the stock at the end of the lower road on the west side of Similkameen River.
No. 2 is 1,200 feet from contact and about 1,000 feet east of the crusher.
No. 3 is 100 yards south of pumping station in Similkameen Canyon.
No. 4 is pegmatite 14 inches from contact in Similkameen Canyon, 2,500 feet south of pumping station.
No. 5 is the central part of pegmatitic core, 1,500 feet from contact in Similkameen Canyon.

minerals, but are distinctly alkaline in chemistry. Without chemical data, these intrusions cannot reliably be separated from calc-alkaline syenites.

Selected reference

Dolmage, V. (1934): Geology and ore deposits of Copper Mountain, British Columbia; Geol. Surv. Can., Mem. 171.

Preto, V. A. (1972): Geology of Copper Mountain; Brit. Columbia Dept. Mines Petrol. Resourc., Bull. 59.

Name Marron Formation and Coryell Intrusions (SR-73b; Fig. 54)

Location and access The Marron Formation is an assemblage of alkaline volcanic rocks occurring as isolated erosional remnants between Penticton and Greenwood, B.C. The largest area occurs just west of Kettle River. The Coryell Intrusions are a group of stocks of alkaline syenites and related rocks of similar chemistry, probably cogenetic. The largest stock occurs about 10 miles north-northeast of Greenwood, B.C. Both types of alkaline rocks overlie or cut pre-Tertiary rocks, which are commonly extensively deformed and metamorphosed.

Petrography The Marron Formation consists of basal biotite-pyroxene phonolite distinguished by primary analcite and rhomb-shaped anorthoclase tablets, succeeded by porphyritic trachyte and trachyandesite with glomeroporphyritic feldspar. The overlying basaltic andesites, andesites, trachyandesites, and trachytes of the Marron Formation are feebly, if at all, alkaline. The Coryell Intrusions consist of various alkali granite, syenite, and monzonite. According to Little (1960), there is considerable confusion about the correct grouping of the intrusive rocks of Tertiary age. He distinguishes the Coryell Intrusions, a more alkaline group of McGregor Intrusions, and a more siliceous group of Sheppard intrusions, but admits that the distinctions are not clear. The alkaline varieties are relatively mafic, and consist of orthoclase, microperthite, andesine or labradorite, augite or aegirine, hornblende, biotite, and accessory magnetite and apatite. Olivine or its alteration products are present in many of the rocks, and altered nepheline is present in several. Fresh nepheline appears to be exceedingly rare in both the Marron Formation and the Coryell Intrusions. Chemical analyses are given in Table 21.

Age Biotite from the Marron Formation gave a K-Ar age of 51.6 ± 3 m.y., in good agreement with the ages of the Coryell Intrusions, whose K-Ar ages on biotite range from 48 to 58 m.y.

Economic aspects Variants of the Coryell Intrusions cut, or occur in close proximity to, many of the ores of the Rossland mining camp, and it is possible that some of the gold-silver-lead-zinc mineralization of this camp may stem from these intrusions.

Selected references

Church, B. N. (1970): The geology of the White Lake Basin; Geology, exploration and mining in British Columbia, 1970; B.C. Dept. Mines Petrol. Resourc., p. 396–402.

Daly, R. A. (1912): Geology of the North American Cordillera, Forty-Ninth Parallel; Geol. Surv. Can., Mem. 31, pt. I, p. 448–455.

Little, H. W. (1960): Nelson map-area, west half, British Columbia; Geol. Surv. Can., Mem. 308, p. 90–93.

Monger, J. W. H. (1968): Early Tertiary stratified rocks, Greenwood map-area (82 E/2), B.C.; Geol. Surv. Can., Paper 67-42.

Name Kamloops garnet syenite (SR-113)

Location and access Ten miles northeast of Kamloops, B.C. (50°40′N, 120°04′W), on Mount Fleet and Mount Lolo. Readily accessible via local logging roads.

Form and structure Three elliptical stocks penetrate highly deformed argillite, quartzite, and limestone of the Carboniferous or Permian Cache Creek Group within a north-trending area of about 6 square miles. One of these stocks is entirely composed of quartz monzonite,

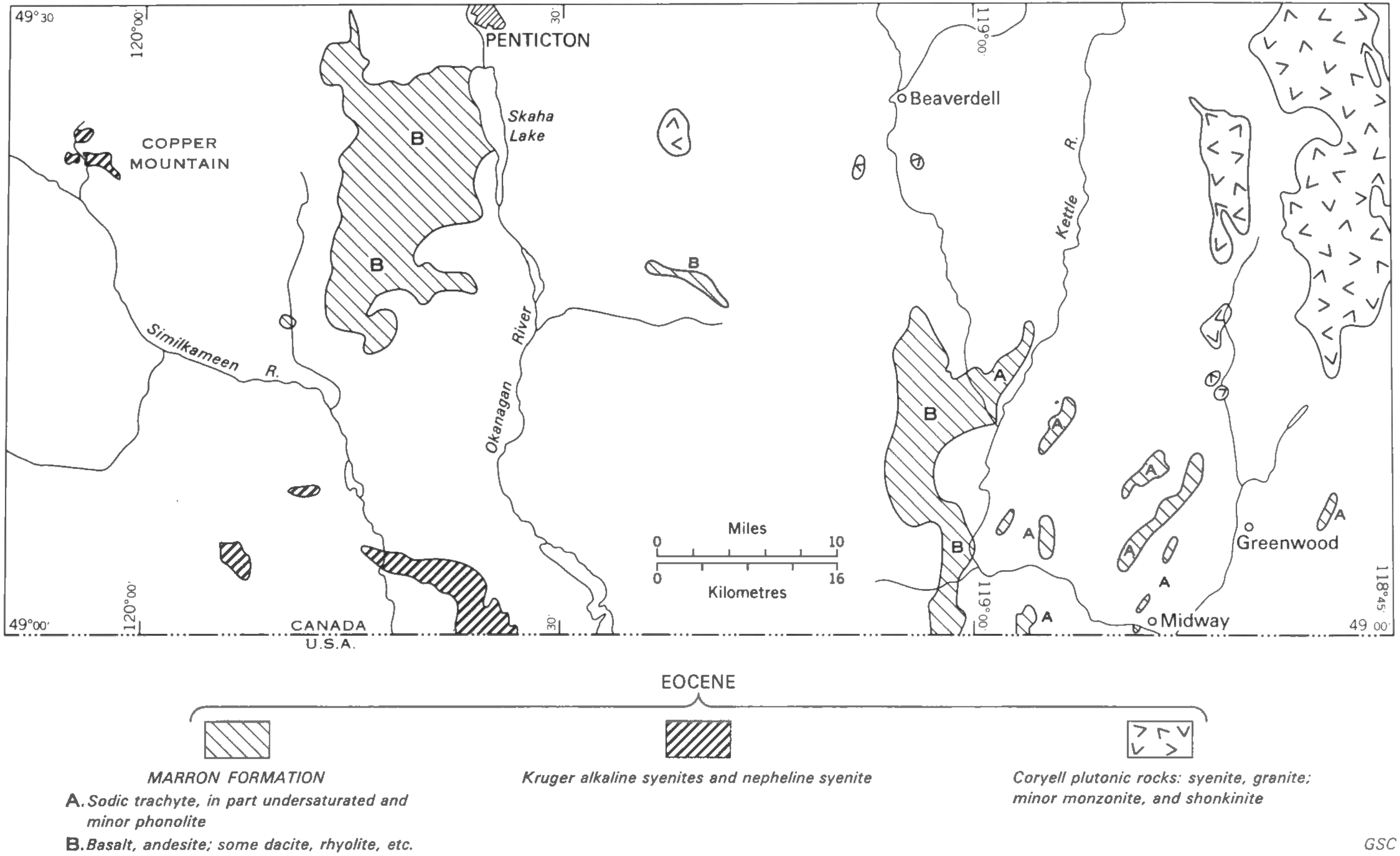

FIGURE 54. The Kruger syenite, Copper Mountain stock, Marron Formation, Coryell syenite, and related alkaline rocks.

and is therefore not alkaline. Alkaline rocks occur in a crudely zoned elliptical pluton, about 1.5 by 3 km, elongated in an east–west direction, and in a small crescentic satellitic mass to the south.

Petrography
The central core of the intrusion is composed of natrolite syenite, in which natrolite and cancrinite are probably secondary after nepheline, which persists as rare remnants. The rim of the syenite is saturated, and may contain minor quartz. All the syenites are composed mainly of large, complexly zoned, microcline-rich phenocrysts, and smaller interstitial grains of albite. Aegirine, partly replaced by hastingsite, is the principal mafic mineral in most rocks, but a zoned yellow garnet, probably approaching melanite, is ubiquitous, and locally appears to replace plagioclase. Eudialyte has been tentatively identified from the most alkaline part of the body, but most of the syenite contains zircon. Opaque minerals, locally abundant, include magnetite with exsolved hematite, and irregular interstitial masses of pyrrhotite and chalcopyrite.

Age
No radiometric age determinations have been undertaken on the Kamloops syenites. Nearby calc-alkaline batholiths, also containing copper mineralization (Guichon Creek batholith), give maximum K-Ar ages on biotite of 200 m.y.

Economic aspects
A low grade of copper mineralization is present. A detailed economic investigation was made by Kennco Explorations.

Remarks
The Kamloops syenite forms one of a persistent chain of alkaline syenites, many of them mineralized with copper, extending from Kruger Mountain on the 49th Parallel to the Stikine River district on the B.C.–Alaska boundary. The rocks show a transition from alkaline to subalkaline types that is relatively common in syenitic rocks, but for which there is no satisfactory theoretical explanation.

Selected reference
Kwak, T. A. P. (1964): A garnet-bearing syenite near Kamloops, B.C.; Univ. of Brit. Columbia, Vancouver, unpubl. M.Sc. thesis.

Name
Goosly Lake area, B.C. (SR-74; Fig. 55)

Location and access
Twenty-five miles southeast of Houston, B.C. (54°10′N, 126°10′W), on the Nechako plateau. The region is accessible by road from Houston, but many of the occurrences can be reached only by aircraft.

Form and structure
Three alkaline stocks are present, spaced at about 8-mile intervals along an east-northeast trend. Two of the stocks are poorly exposed, but the third, 3 miles east of Goosly Lake, is a quadrate body, roughly 2 miles on a side, which cuts early Mesozoic lavas and pyroclastic rocks with some argillite, and seems to be the source of the Eocene Goosly Lake volcanics, mainly composed of trachyandesite and trachyte.

Petrography
The intrusive rocks range from gabbro to syenodiorite, consisting of 65 to 80 per cent plagioclase, commonly as large bladed phenocrysts, 5 to 20 per cent augite as small rounded grains or long prismatic phenocrysts, and accessory biotite, apatite, and magnetite. Interstitial feldspar and, locally, traces of quartz, are present in the more acid varieties. The gabbroic phases are enriched in pyroxene and contain calcite and chlorite pseudomorphs after olivine, and accessory feldspathoid minerals in some samples. The lavas, believed to be associated with the stocks, contain the same minerals, with the addition of occasional hornblende, but in somewhat different proportions. Parts of the volcanic sections are unusually massive, suggesting very thick lava flows, or possibly sills. The chemical composition of the alkaline rocks is shown in Table 23.

Age
A K-Ar age determination on biotite from the intrusives gave 48.8±3 m.y., in satisfactory agreement with the stratigraphic relations.

Economic aspects
Several significant mineral occurrences are associated with the alkaline rocks of the Goosly Lake area. At the east end of the belt the property of Kennco Explorations,

2 miles east of Goosly Lake, is a replacement sulphide deposit consisting of lenses of pyrite-chalcopyrite-tetrahedrite located adjacent to the alkaline stock. Twenty-one miles to the southwest the showings at the Silver Queen mine, thought to be related to alkaline dykes, are fissure veins of pyrite-sphalerite and some galena, with local concentrations of chalcopyrite and some tennantite.

Remark The rare iron phosphate mineral scorzalite is associated with mineralization at the Kennco property.

Selected reference Church, B. N. (1970): Geology of the Owen Lake, Parrot Lakes and Goosly Lake area; Geology, exploration and mining in B.C. (1970); B.C. Dept. Mines Petrol. Resourc., p. 119–125.

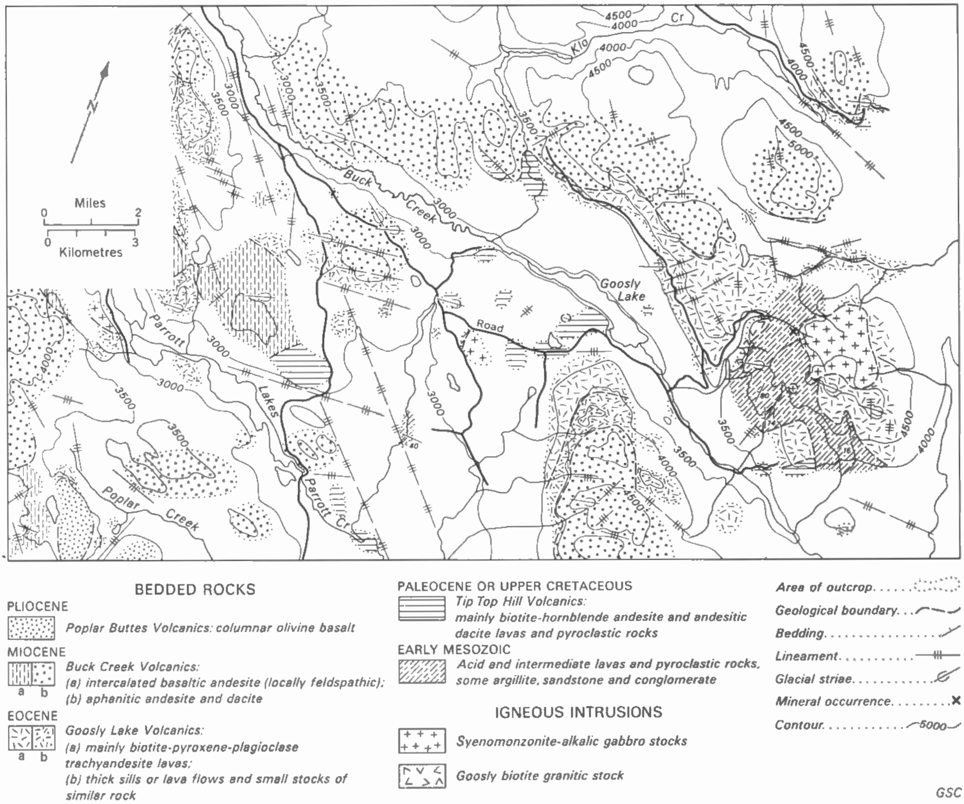

FIGURE 55. Geology of the Goosly Lake area (after Church, 1970).

TABLE 23 *Chemical analyses of the Goosly Lake intrusions and volcanics (after Church, 1970)*

	1	2
SiO_2	51.64	53.90
TiO_2	2.89	1.51
Al_2O_3	16.00	17.25
Fe_2O_3	6.28	5.31
FeO	4.63	2.42
MnO	0.15	0.11
MgO	4.42	3.85
CaO	6.55	7.77
Na_2O	5.42	5.08
K_2O	2.02	2.80
P_2O_5	0.27	0.59
H_2O	3.38	1.99
CO_2	0.10	1.15
TOTAL	103.75	103.73

1. Alkaline gabbro, 3 miles southwest of Goosly Lake.
2. Alkaline monzonite, just west of Upper Parrot Lake.

Name	Rayfield River (SR-75; Fig. 56)
Location and access	About 13 miles east of 70 Mile House, B.C., on the Rayfield River (51°17′N, 21°06′W), accessible by gravel secondary road and bush road from 70 Mile House.
Form and structure	Alkaline rocks outcrop in a poorly exposed, north-trending window some 7 by 3 miles in size through Miocene or Pliocene olivine basalts. Trachytoid foliation in the alkaline rocks is compatible with a zoned subcircular or elliptical pluton elongated in a northwest direction, but the amount of outcrop is so slight that this is only a hypothesis.
Petrography	Assuming that the mass is, in fact, a zoned pluton, it grades from slightly alkaline marginal monzonite through amphibole syenite to leucocratic syenite. The marginal rocks contain about 5 to 20 per cent amphibole heavily altered to biotite, the remainder being composed of about equal amounts of potash feldspar and strongly sericitized plagioclase. The amphibole syenite contains the same minerals, but the proportion of microcline microperthite increases to 50 to 75 per cent, much of the rest being composed of sodic plagioclase. Minor amounts of corroded pyroxene, sphene, apatite, muscovite, and garnet are locally present. The leucocratic syenite forms a northwest-trending, central, dyke-like pod of very pale grey to pinkish grey, foliated syenite composed of microcline perthite, with very subordinate interstitial sodic plagioclase. Biotitized amphibole, muscovite, garnet, and magnetite are present in trace amounts. Nepheline-bearing dykes similar to the leucocratic syenite cut all phases of the complex.
Age	The complex is assumed to be of Jurassic age by comparison with the nearby Thuya batholith, but the age is uncertain.
Economic aspects	Sulphide mineralization containing bornite, chalcopyrite, and rare chalcocite is found disseminated in the syenites, and along 'grey veins,' which are fine breccia and alteration zones parallel the trachytoid foliation. An area 12,000 by 4,000 feet is said to grade better than 0.05 per cent Cu.
Selected reference	Preto, V. A. G. (1970): BD, VB, WIN (Dansey-Rayfield River); Geology, exploration and mining in B.C.; B.C. Dept. Mines Petrol. Resourc., p. 218–222.

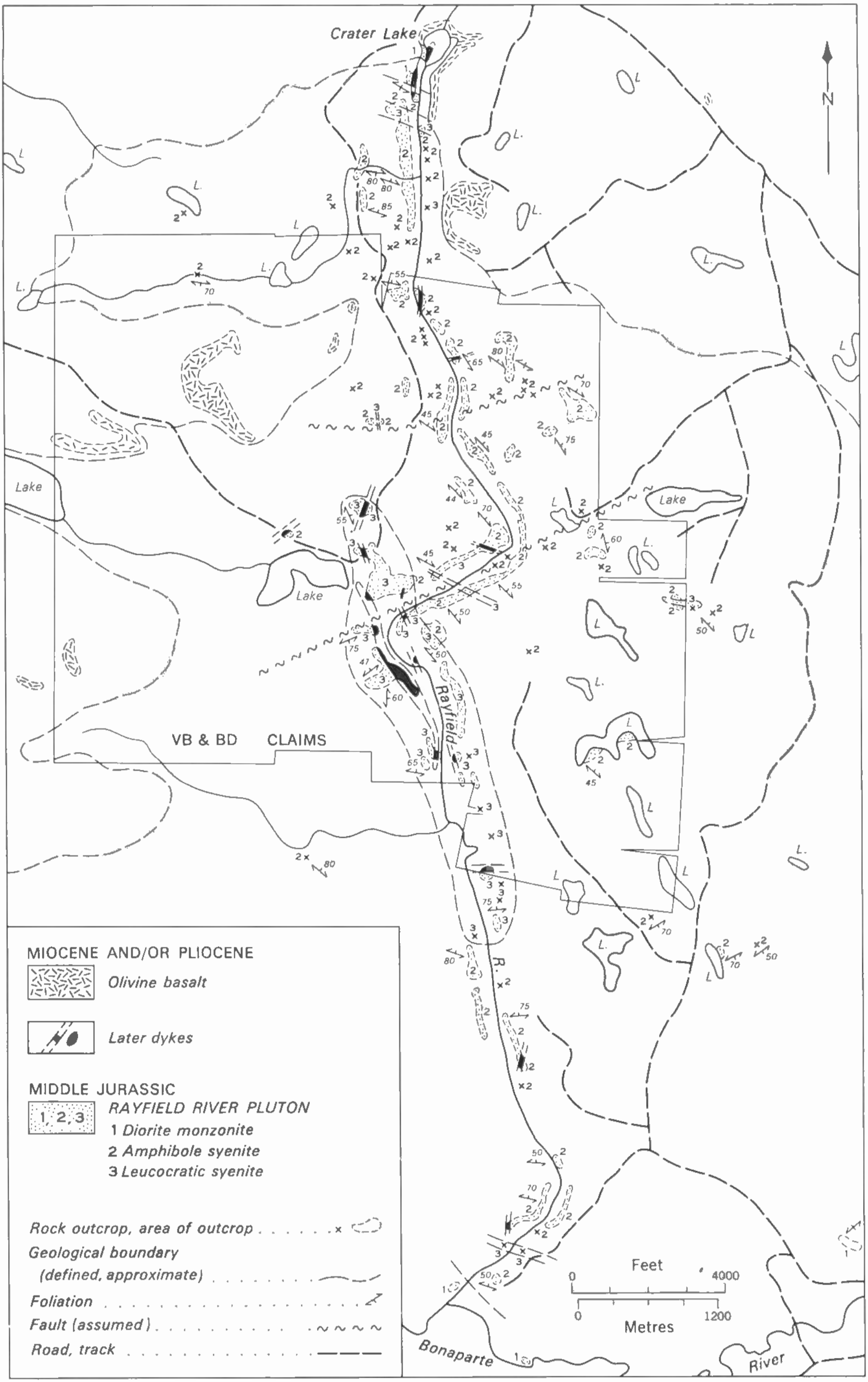

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FIGURE 56. Geology of the Rayfield River nepheline syenite (after Preto, 1970).

Name	Galore Creek, Stikine River district (SR-76; Fig. 57)
Location and access	The chain of syenite bodies follows approximately the course of the lower Stikine River. The Galore Creek body lies near 57°12′N, 131°26′W. Access is difficult, and is principally by helicopter from Stewart, or by the Stewart–Cassiar highway.
Form and structure	At least six syenites occur along a north-northwest-trending belt some 80 miles long. Each forms a composite, subcircular pluton, elongated along the trend of the belt, intruding upper Triassic greywacke, arkose, conglomerate, and fragmental volcanic rocks of basaltic, andesitic, and trachytic composition. The volcanic rocks may be effusive equivalents of the intrusions.
Petrography	The Galore Creek body, which may be taken as typical, consists of at least five phases having intrusive relations to one another. All phases are predominantly composed of orthoclase and epidotized mafic minerals, but the darker marginal phases also contain pseudoleucite phenocrysts, in which the nepheline part has been altered to sericite. Brecciated phases of the syenites contain lenses and pods of intensely metamorphosed biotite-orthoclase-garnet-epidote rocks assumed to have been derived from the surrounding volcanic rocks, some of which also display pseudoleucite phenocrysts. The whole intrusion is altered, presumably by later intrusions of granodiorite, and some parts of it now contain secondary quartz, as well as veins containing carbonates, riebeckite, barite, and fluorite, among other minerals.
Age	The Galore Creek intrusion gives maximum K-Ar dates on biotite of 198 m.y. This is in reasonable agreement with the upper Triassic age of the presumably cognate pseudoleucite-bearing lavas.
Economic aspects	Disseminated pyrite, chalcopyrite, and minor bornite is associated with the mafic minerals of the Stikine River syenites. Minor galena, sphalerite, and molybdenite have also been reported from the Galore Creek body, which was extensively explored from 1960 to 1966 by Stikine Copper Ltd.
Remarks	According to Kerr (1948), three of these syenites contain nepheline. It seems reasonable to suppose that the others are also alkaline.
Selected references	Barr, D. A. (1966): The Galore Creek copper deposits; Can. Inst. Mining Met., Bull. 59, p. 841–853. Kerr, F. A. (1948): Lower Stikine and western Iskut River areas, British Columbia; Geol. Surv. Can., Mem. 246, p. 49–53.

Name	Spotted Fawn Creek (SR-77; Fig. 58)
Location and access	Forty miles northeast of Dawson, Yukon Territory (64°25′N, 38°41′W), in rugged country accessible only by aircraft or by arduous traverse on foot.
Form and structure	Alkaline rocks occur at two localities on the contact between the Late Cretaceous Tombstone batholith and Early Cretaceous orthoquartzites. The alkaline rocks form dyke-like masses up to 4,000 feet wide intruding both rock-types. At a third locality near the centre of the batholith, phonolitic rocks appear to form a gradational phase in enclosing syenite.
Petrography	The alkaline rocks are fresh porphyritic rocks with euhedral phenocrysts of pseudoleucite (nepheline-orthoclase intergrowths in trapezohedral form) up to 2 inches across, and tabular clear orthoclase set in an aphanitic groundmass of biotite, calcite, melanite, and sphene, as well as sparse cancrinite. Nepheline forms small altered grains intergrown with feldspar. Chemical analyses are shown in Table 24. The rocks of the Tombstone batholith range from alkalic syenite at the core to quartz monzonite nearer the margins.
Age	The Tombstone batholith yielded K-Ar ages on coexisting hornblende and biotite of 80 ± 13 and 91 ± 5 m.y., respectively. The age of the phonolite is assumed to be similar.

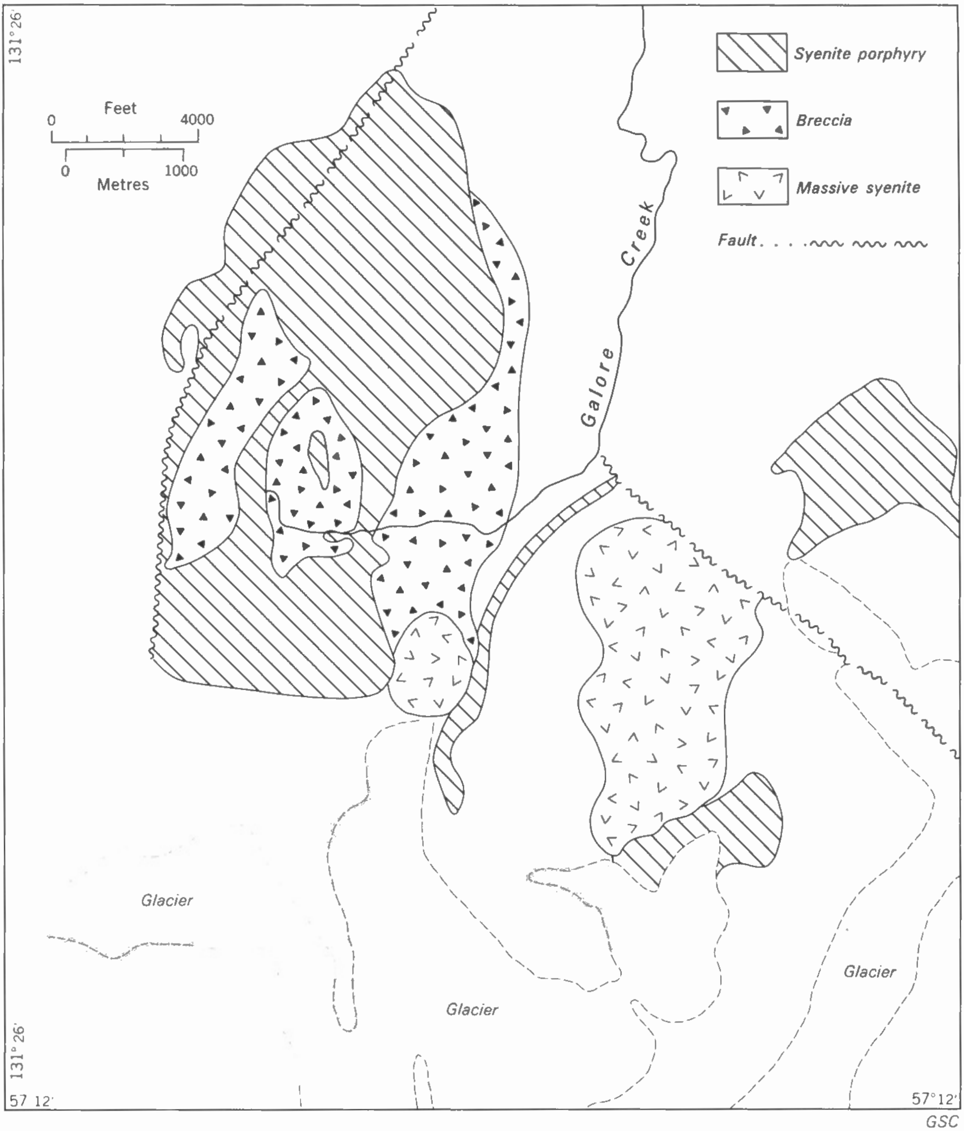

FIGURE 57. Geology of the Galore Creek syenite (after Barr, 1966).

Economic aspects	None at present.
Remark	The Spotted Fawn Creek and Galore Creek occurrences of pseudoleucite suggest that other similar occurrences may be present within the syenitic rocks of the Cordillera.
Selected reference	Tempelman-Kluit, D. J. (1969): A re-examination of pseudoleucite from Spotted Fawn Creek, west-central Yukon; Can. J. Earth Sci., v. 6, p. 55–62.

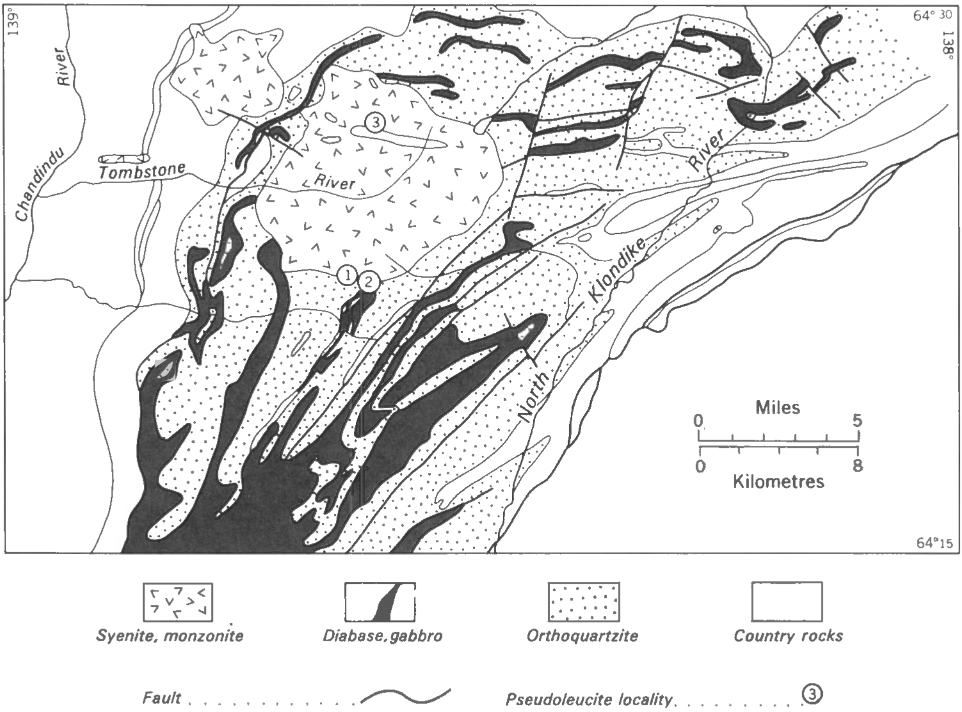

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FIGURE 58. Location and geological setting of the pseudoleucite-bearing rocks in the Tombstone batholith (after Tempelman-Kluit, 1969).

TABLE 24 *Chemical analyses of alkaline rocks from Spotted Fawn Creek*

	1	2
SiO_2	57.86	58.28
TiO_2	0.48	0.36
Al_2O_3	19.42	20.70
Fe_2O_3	0.66	1.50
FeO	2.48	1.55
MnO	0.05	0.04
MgO	.29	.10
CaO	2.18	1.95
Na_2O	3.21	2.23
K_2O	12.41	12.71
H_2O	0.91	1.21
P_2O_5	.15	0.03
TOTAL	100.10	100.66

Analyses from Tempelman-Kluit (1969), p. 61.
1. Pseudoleucite phonolite from locality 1, Figure 58.
2. Pseudoleucite phonolite from locality 2, Figure 58.

Name	Verity (Lemprière) (SR-78; Fig. 43)
Location and access	About 23 miles north of Blue River, B.C., on the east bank of the North Thompson River, B.C. (52°24′N, 119°05′W), reached by highway and cable crossing or by railway from Lemprière station.
Form and structure	The form of the syenitic rocks is unknown, but they are thought to form dykes cutting the deformed and metamorphosed rocks in the Shuswap Complex.
Petrography	Samples are of coarse-grained, massive syenites containing large, tabular feldspar crystals, and either nepheline or sodalite.
Age	Unknown, but granitic intrusions in the same region give Jurassic K-Ar ages.
Economic aspects	The carbonatite lenses in the area have been extensively examined because of their vermiculite and pyrochlore mineralization.
Remarks	These dykes are of considerable interest, but the outcrop is so poor and the terrain so difficult that very little is known about them. They lie only some 30 miles northwest of the Kinbasket Lake occurrence, and conceivably could be related.

Name	Crowsnest alkaline volcanics (SR-79; Fig. 59)
Location and access	Alkaline rocks occur in a north-south strip about 50 miles long and 10 miles wide centred near 49°30′N, 114°30′W. The town of Blairmore, Alberta, is close to the best exposures, and local highways and forestry roads permit access to most of the known occurrences.
Form and structure	Intrusive plugs up to 2 miles long occur on Trachyte Ridge, 35 miles south of Coleman, Alberta, near the junction of Flathead River and Howell Creek. The rest of the alkaline rocks occur in the Crowsnest Formation, which in the lower part comprises mainly tuff and volcanic sandstone, with some minor flows and related dykes, whereas the upper part contains large amounts of agglomerate. The Crowsnest Formation conformably overlies the Lower Cretaceous Blairmore Group, and is disconformably overlain by the Upper Cretaceous Alberta Group. The western part of the formation is hidden by the Lewis thrust sheet.
Petrography	The alkaline rocks are dominantly composed of sanidine, both as phenocrysts and as laths in the matrix. The composition ranges from Or$_{58}$ to Or$_{91}$, with phenocrysts always more sodic than coexisting matrix sanidine. Rhythmic zoning with repeated overgrowth and corrosion, commonly with erratic K-enrichment toward the margin, is ubiquitous. Aegirine, garnet and, locally, analcite are found as inclusions in sanidine, and reddish albite locally replaces it. The most interesting mineral in the Crowsnest alkaline volcanics is analcite, which occurs both in the form of large, partially corroded trapezohedral phenocrysts, commonly zoned, and as ubiquitous interstitial, microphenocrystic material in the matrices of the rocks. Decomposition of analcite to nepheline+albite seems to have occurred locally. Pyroxene occurs as small phenocrysts in the rock, varying from cores of mildly sodic ferrosalite to more sodic iron-rich aegirine in the rim. Melanite garnet, as shiny black twinned dodecahedrons, is a characteristic accessory mineral of the Crowsnest rocks, commonly with strong zoning due to variations in Ti content. Oligoclase, nosean, sphene, calcite, and magnetite are locally present in accessory amounts. Due to variations in the mineral composition, the rocks vary from trachyte to analcite phonolite. Some of the chemical compositions (Table 25) are characterized by extraordinarily high K$_2$O contents.
Age	Sanidine and biotite ages on the Crowsnest volcanics give 98 and 100 m.y., respectively, by the K-Ar method, consistent with their stratigraphic Lower Cretaceous age.
Economic aspects	The intrusive equivalents of the Crowsnest volcanics are feebly mineralized with copper and molybdenum, and have been the subject of some recent exploration work.

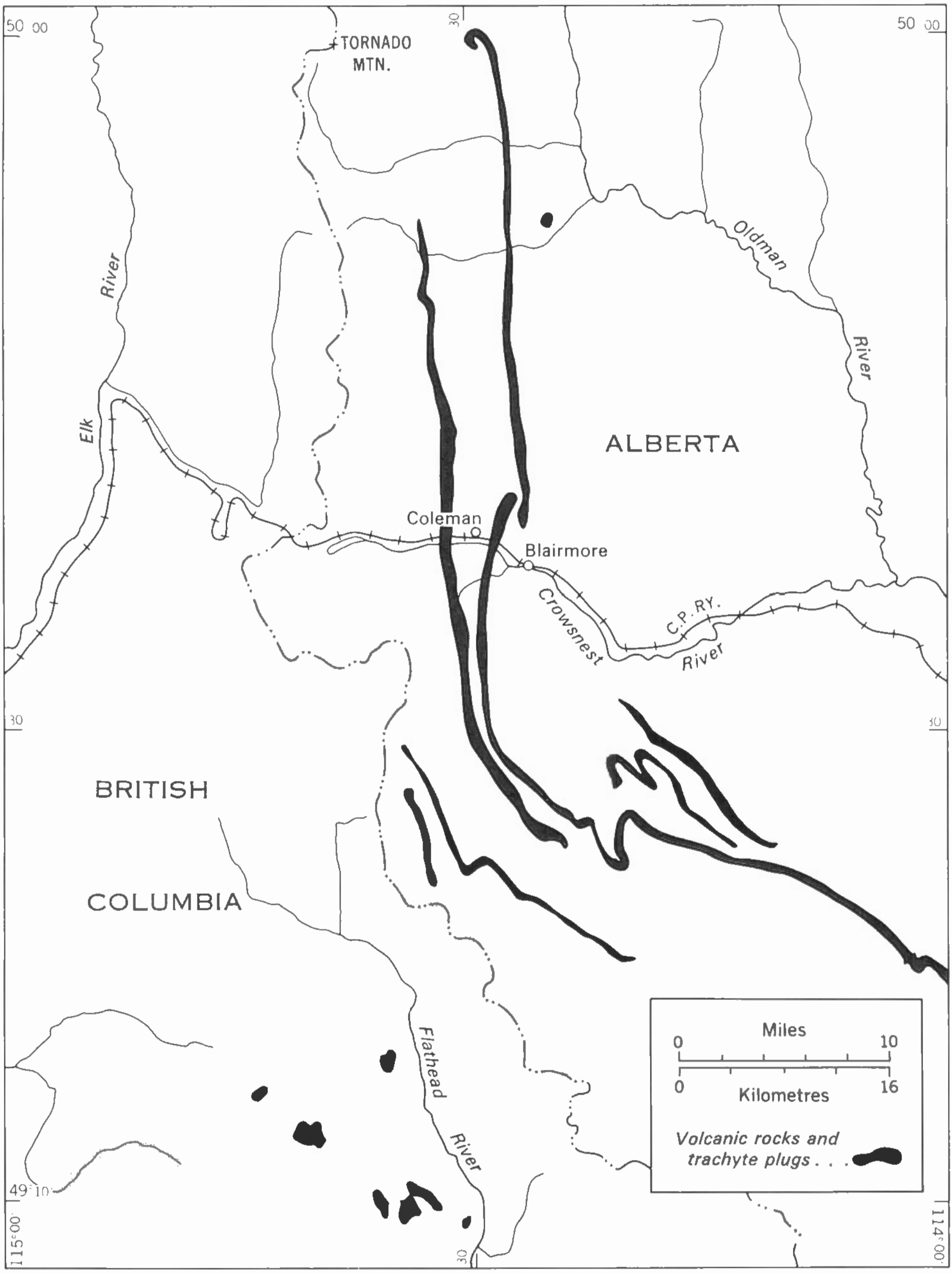

FIGURE 59. Alkaline rocks in the Crowsnest province (modified after Price, 1962).

Selected references	Pearce, T. H. (1970): The analcite bearing volcanic rocks of the Crowsnest Formation, Alberta; Can. J. Earth Sci., v. 7, p. 46–66. Price, R. A. (1962): Fernie map-area, east half, Alberta and British Columbia (82 G,E/2); Geol. Surv. Can., Paper 61-24.

TABLE 25 *Chemical analyses of rocks from the Crowsnest alkaline province (after Pearce, 1970)*

	1	2	3	4	5	6	7
SiO_2	60.6	54.8	54.5	55.7	54.4	51.8	52.7
TiO_2	0.24	0.35	0.94	0.63	0.80	0.97	0.29
Al_2O_3	19.4	20.2	16.6	15.6	16.6	16.9	20.5
Fe_2O_3	1.31	3.00	4.79	5.78	5.55	5.97	2.30
FeO	0.49	1.21	2.87	1.58	2.33	2.82	0.92
MnO	.03	0.17	0.21	0.96	0.62	0.58	.18
MgO	.30	.22	.80	.27	.29	.54	.25
CaO	.31	3.58	3.82	4.30	4.00	3.60	3.65
Na_2O	1.16	3.44	3.88	5.30	5.40	6.18	8.44
K_2O	12.8	8.50	7.58	7.44	6.00	4.32	6.58
P_2O_5	0.06	0.05	0.13	0.12	0.09	0.07	0.06
H_2O CO_2	1.48	3.68	2.51	2.55	3.32	4.80	2.81
TOTAL	98.1	100.2	98.9	100.2	99.5	99.1	99.0

1. Trachyte dyke, Star Creek.
2. Trachyte flow, George Creek (total includes 1.02% SrO).
3. Trachyte block in tuff (total includes 0.23% SrO + BaO)
4. Analcite phonolite, from agglomerate.
5. Analcite phonolite flow, north of Lynx Creek.
6. Analcite-rich phonolite (blairmorite) boulder from conglomerate (0.59% SrO + BaO).
7. Phonolite dyke (0.40% BaO + SrO), Tecumseh Mtn.

Name	Cinder Lake (S-113)
Location and access	About 450 miles north-northeast of Winnipeg (54°56′N, 94°50′N) or some 20 miles northwest of the settlement of Oxford House. The region is readily accessible only by air, although some old canoe routes pass nearby.
Form and structure	Outcrop forms a crescentic mass on the southeast shore of a lake. The exposed alkaline rocks appear to form part of an elliptical mass about 1 mile long and trending to the northeast.
Petrography	Faintly trachytoid, coarse-grained nepheline syenite is exposed, along with some pegmatitic zones containing large melanite garnets.
Age	Unknown, but probably Precambrian.
Economic aspects	Unknown.
Remarks	This complex appears to lie on the same trend as Carb Lake, Big Beaver House, and Schryburt Lake in Ontario.
Selected reference	Gilbert, H. P. and Elbers, F. J. (1972): Parker Lake-Knee Lake-Oxford House area; Man. Dept. Mines Resourc., Env. Manag., Geol. Paper 3/72, p. 36.

Name	Poohbah Lake (S-80; Fig. 60)
Location and access	About 120 miles west of Thunder Bay in Quetico Provincial Park (48°15′N, 91°30′W). Since the park is a wilderness area, access is possible only by boat or by aircraft.
Form and structure	The complex is a zoned syenitic pluton, 5½ miles long by 2½ miles wide, elongated in a northeast direction parallel to Poohbah Lake, which covers much of the pluton. A possible ring dyke occurs 1 mile west of the west end of the intrusion where hornblende syenite forms an elongate mass 200 yards wide wrapping around 30

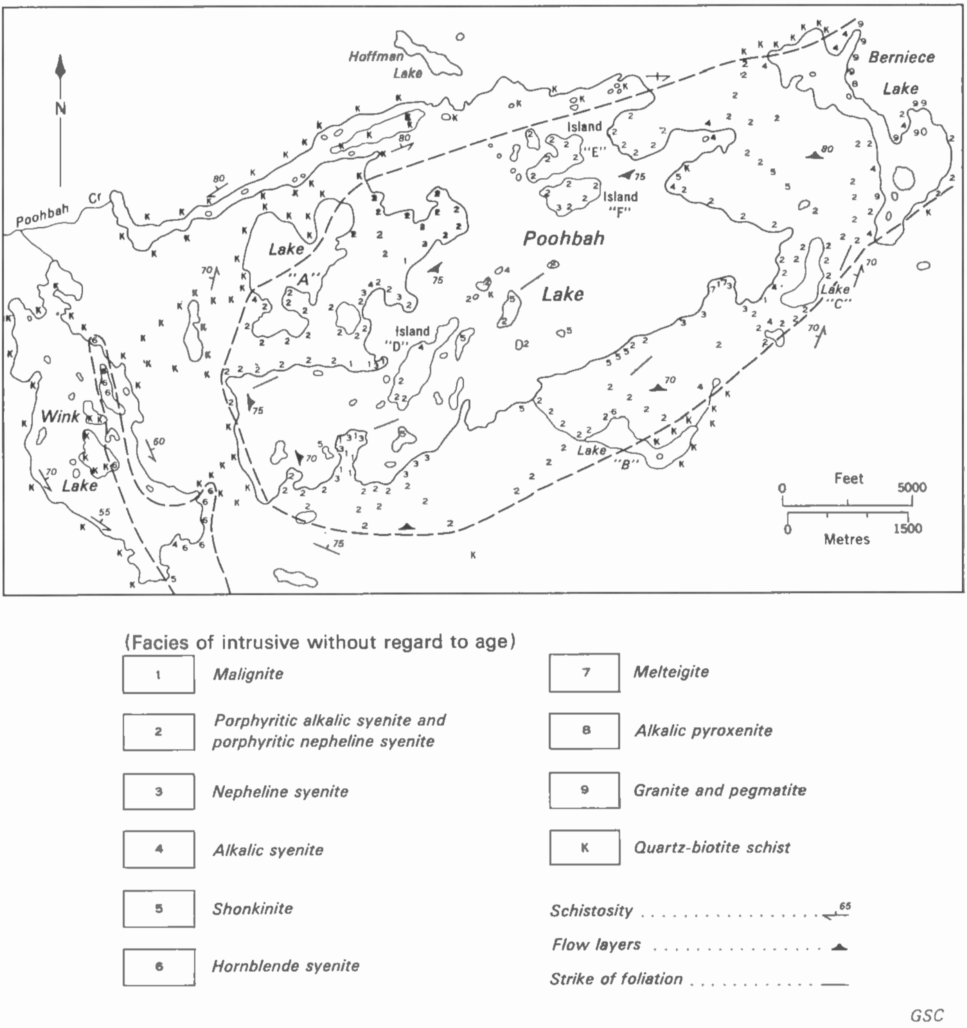

FIGURE 60. Geology of the Poohbah Lake complex (after Allen, 1942).

degrees of arc. The Poohbah Lake complex displays rather well developed internal layering, defining a funnel-like mass dipping toward the centre at an angle of about 70 degrees, and a similar structure is displayed by the enclosing Archean quartz-biotite schists, which wrap around the stock, interrupting their general east-northeast trend. The schists are hornfelsed and brecciated by the intrusion, but little alkali metasomatism is visible.

Petrography The complex grades from feebly alkaline syenite at the margins to more mafic and alkaline rocks at the core. The principal component is porphyritic alkaline syenite composed of large, zoned, platy albite phenocrysts to 2 inches diameter, set in a matrix of aegirine, biotite, and a sodic amphibole resembling arfvedsonite, but with positive elongation. Minor amounts of nepheline are locally present, together with accessory sphene, melanite, and magnetite. Microperthitic feldspar is common in the phenocrysts, including some with microcline, rather than albite matrix. Toward the shore of Poohbah Lake the rock becomes gradationally more mafic and richer in nepheline, forming a porphyritic nepheline syenite in which an anhedral vermicular intergrowth of nepheline and orthoclase is abundant. Most of the nepheline is now altered to thomsonite, but considerable fresh hauyne is present in some of the rocks. Toward the southwest end of Poohbah Lake the rocks become very melanocratic. Both nepheline-bearing mafic syenites (malignite) and nepheline-free varieties (shonkinite) are present. Locally, either feldspar or nepheline and feldspar together may be absent, giving alkaline pyroxenites and melteigites. Chemical analyses are given in Table 26.

Economic aspects — Unknown.

Age — Unknown.

Remarks — The presence of hauyne suggests that the complex is a relatively high level intrusion. This complex is one of the few for which no structural control is known.

Selected reference — Allen, C. C. (1942): The malignites of Poohbah Lake, Ontario; J. Geol., v. 50, p. 134–150.

TABLE 26 | *Chemical analyses of rocks from the Poohbah Lake complex (after Allen, 1942)*

	1	2	3	4	5
SiO_2	45.96	47.85	51.38	51.88	57.14
TiO_2	0.50	nil	0.12	0.33	0.71
Al_2O_3	9.57	13.24	15.88	14.13	16.42
Fe_2O_3	2.79	2.74	1.48	6.45	2.10
FeO	4.56	2.65	4.37	0.94	2.64
MnO	0.13	n.d.	n.d.	n.d.	0.08
MgO	14.79	5.68	4.43	3.44	2.63
CaO	11.85	14.36	8.62	10.81	5.53
NO_2O	2.19	3.72	7.57	6.72	4.33
K_2O	4.12	5.25	4.20	4.57	6.39
P_2O_5	0.20	2.42	0.98	0.96	0.85
CO_2	.45	nil	nil	nil	.10
H_2O	2.08	2.74	0.42	0.18	.42
TOTAL	99.19	100.65	99.45	100.41	99.34

n.d.: not determined.
1. Melteigite.
2. Melanocratic nepheline syenite.
3. Mafic porphyritic nepheline syenite.
4. Mafic porphyritic melanite nepheline syenite.
5. Leucocratic porphyritic alkaline syenite.

Name — Sturgeon Lake (S-81; Fig. 61)

Location and access — One hundred and forty miles northwest of Thunder Bay, near Dryden, Ontario (50°00′N, 90°39′W). The area is readily accessible only by aircraft, although numerous canoe routes exist to Sturgeon Lake.

Form and structure — An elongate bulbous mass some 12 miles long, with a maximum width of 2 miles, trending northeast along the narrows of Sturgeon Lake. The nepheline-bearing parts of the complex are confined to a small island, and adjacent parts of the shore. The contacts with the country rocks are poorly exposed, but syenite appears to intrude an Archean greenstone belt in *lit-par-lit* fashion with few visible contact effects.

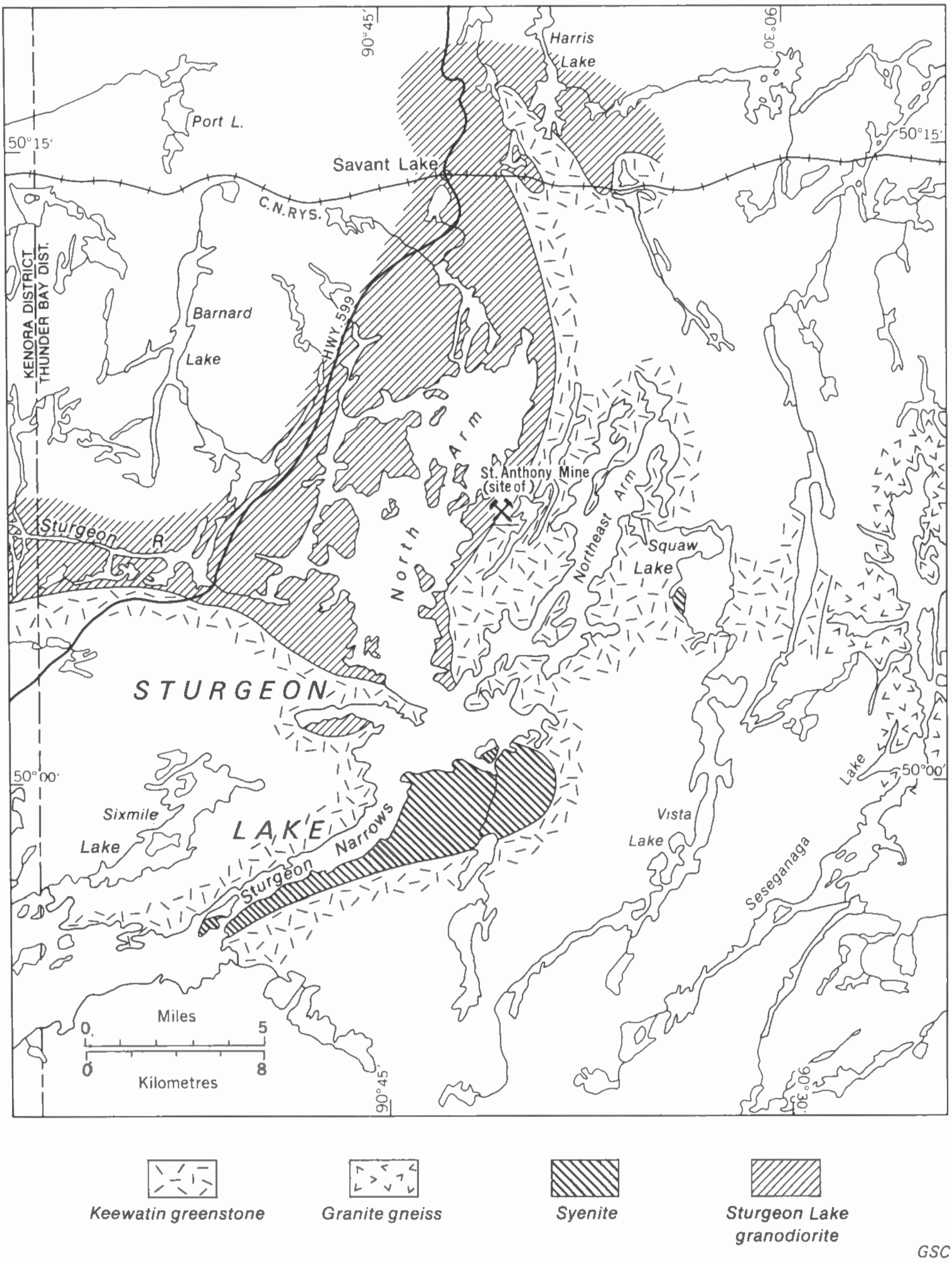

FIGURE 61. Geology of the Sturgeon Lake syenite (after Gledhill, 1924).

Petrography The syenite is a coarse-grained rock principally composed of large tablets of microcline microperthite, set in a fine-grained interstitial matrix which locally seems to corrode and replace the feldspars. In the nepheline-bearing syenites, this matrix is rich in nepheline. Biotite and aegirine form the mafic minerals, and calcite, fluorite, sphene, apatite, and cancrinite are persistent accessories. Veins of fluorite-rich diopsidic carbonatite up to 10 inches wide occur locally. The texture of the rock is commonly coarse to pegmatitic, but strongly foliated phases are locally present. Chemical compositions of the syenite are shown in Table 27.

Age Unknown. The syenite may possibly be a conformable lens within the greenstone, in which case it would be of Archean age.

Economic aspects The St. Anthony gold mine, a former producer, was located less than 2 miles from the syenite, and terrain to the southwest of the syenite is now being intensively explored for base metal prospects. The mineralization has been related to granodioritic intrusions, but it may be linked to the alkaline rocks.

Remarks A smaller body of similar character is said to exist some 7 miles northeast of the Sturgeon Lake syenite.

Selected reference Gledhill, T. L. (1924): Geology along an eastward continuation of Niven's 4th Base Line; Ont. Dept. Mines, Ann. Rept., v. 23, p. 18–39.

TABLE 27 *Chemical analyses of the Sturgeon Lake nepheline syenite (after Gledhill, 1924)*

	1	2	3
SiO_2	52.42	51.47	55.64
TiO_2	Trace	0.32	n.d.
Al_2O_3	25.04	21.67	19.81
Fe_2O_3	1.54	2.08	3.90
FeO	0.64	0.24	
MnO	n.d.	n.d.	n.d.
MgO	1.02	0.15	0.95
CaO	2.24	3.78	2.86
Na_2O	6.00	8.18	8.21
K_2O	8.76	6.70	4.60
P_2O_5	n.d.	n.d.	0.10
H_2O	0.85	2.07	3.14
CO_2	1.52	3.17	
TOTAL	100.03	99.73	99.31

n.d.: not determined.
1. Nepheline-free alkali syenite.
2. Nepheline syenite.
3. Nepheline syenite.

Name Port Coldwell (SC-82; Fig. 62)

Location and access The Port Coldwell complex lies at the northeast corner of Lake Superior, about 220 miles northwest of Sault Ste. Marie, Ontario. The town of Marathon lies within the complex. Most parts of the complex are readily accessible via Highway 17, which crosses it with a series of magnificent road-cuts, via boat from the shores of Lake Superior where superb wave-washed outcrops are exposed, or via local logging roads.

Form and structure The complex forms a funnel-like, layered intrusion some 18 miles in diameter, of which roughly one third is hidden by Lake Superior. The dips at the edges are 50–60° toward the centre, declining to 30–40° in the centre, where a considerable part of altered roof rock is preserved. Nepheline-rich rocks appear to form a slightly younger intrusive ring-dyke type of intrusion in the western part of the complex, and a possibly similar intrusion to the south, most of which is hidden by Lake Superior. Excellent layering is locally observed in all units. Swarms of nephelinitic and analcite phonolite dykes are associated with the intrusion. The country rocks, northeast-trending, acid to intermediate Archean lavas and tuffs with minor greywacke and granite, are intruded and altered by the complex.

Petrography

The lowest and oldest unit of the complex is a locally layered alkaline gabbro, overlain and veined by olivine syenite. The gabbro forms a quasi-continuous band up to 2,600 feet thick around the intrusion. The gabbro consists of labradoritic plagioclase with varying amounts of olivine (Fo_{85}) and weakly pleochroic diopsidic augite. Magnetite and sulphides are present in varying but large amounts and may form discrete layers. Biotite is abundant in the upper parts of the gabbro. Inch scale layering, and cut-and-fill structures and cross layering, commonly with strong lineation of plagioclase and pyroxene, occur locally. Anorthositic phases occur in some bands, and cryptic variation of plagioclase to andesine, and of olivine to Fo_{70} was noted in the layered rocks. Potash feldspar is absent, although small amounts of interstitial albite are present in the upper parts of the gabbro. Hypersthene and sulphides occur in contaminated parts of the gabbro.

Alkaline olivine syenite forms numerous dykes and stockworks within the gabbro and, in places, comes directly in contact with the country rocks, forming lenticular screens of ring-dyke type. Transported and metasomatized inclusions of gabbro, some of very large size, are common in the syenite, readily distinguished by their peculiar texture with clots of biotite and/or kaersutite surrounding relict pyroxene. The syenite is characteristically an olive-brown, very coarse grained rock composed mainly of greenish braid perthite in large aligned tablets, with lesser amounts of oligoclase in smaller elongate prisms. Fayalitic olivine, generally somewhat altered, is the most characteristic mafic mineral, but pyroxene is always present, commonly with augite cores and aegirinic rims, but rarely diopsidic. Amphibole coronas on olivine and pyroxene are common in the upper part of the unit, and the rock passes to a kaersutite syenite. Layering defined by crude alignment of feldspar tablets is present throughout the unit, but is poorly defined. There is a distinct gradation from melanocratic rocks at the base of the unit toward more leucocratic ones at the top, but this is obscured by a great variety of phases including brick-red hematized rock, various types of pegmatites, and various schlieren and veins, some containing a trace of quartz, as well as fluorite, calcite, molybdenite, and riebeckitic amphibole.

The nepheline-rich parts of the complex form a closed ring in the western part, apparently closely associated with the roof. The rocks range from mafic kaersutite-rich types on the outer side of the ring to leucocratic euhedral aggregates of nepheline and complex perthite, with included aegirine and biotite needles in place of kaersutite on the inner side of the ring. The changes in composition are readily visible in pronounced steeply dipping layering, particularly in the southwestern part of the complex. Numerous veins, dykes, and schlieren of alkaline rocks are present, but they contain either the orange-red 'hydro-nepheline' (natrolite + thomsonite) or analcite in place of nepheline. Chemical analyses of the complex are presented in Table 28.

A large remnant of the roof is preserved in the centre of the complex, and smaller fragments are preserved elsewhere. In place of the fine-grained hornfels typical of the lower contact, these rocks display coarse inequigranular textures, and syenitic to quartz syenitic compositions. The original gneissosity is preserved locally in brecciated form, but fenitization is strongly evident in the form of veining by alkali amphibole, pyroxene, and hematization. The rocks are intruded by a swarm of variably altered fine-grained dykes of basaltic composition, presumably derived from the early phases of the Port Coldwell complex.

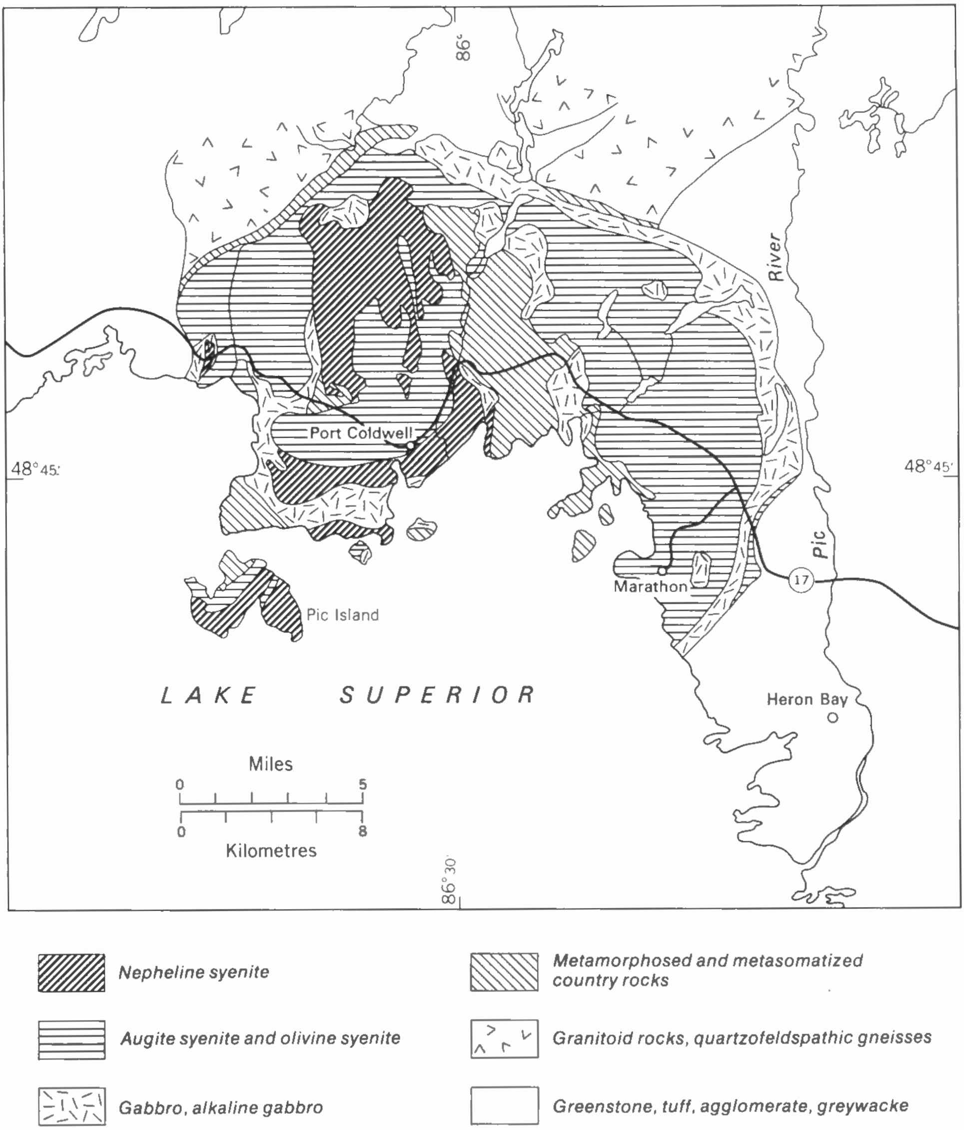

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FIGURE 62. Geology of the Port Coldwell complex (in part after Puskas, 1967).

Ocellar nephelinitic dykes are common in the Port Coldwell complex, but outside the complex the most abundant dykes are analcite-bearing syenite types. The latter extend at least 10 miles from the complex.

Age Two K-Ar ages on biotite from the gabbro and the syenite yielded 1,005 and 1,015 m.y., respectively.

Economic aspects The gabbros have been intensively prospected for Cu-Ni showings. Some of the magnetite seams previously referred to are markedly vanadiferous, and have been tested as a source of vanadium, as well as possible iron ores. Preliminary attempts were made to concentrate nepheline from the nepheline syenites, but milling tests suggested that the Fe content could not be lowered sufficiently to yield a satisfactory product.

Remarks The Port Coldwell complex is striking similar in form, petrography, and age to the Killala Lake complex, some 20 miles to the north. It is similar in age to the Prairie Lake ijolite complex, some 10 miles to the northwest, and displays some dykes of similar chemistry. These data suggest an alkaline rock province, trending radially to the Lake Superior basin, possibly extending as far as the Chipman Lake syenite. A sketch of this supposed province is shown in Figure 63.

Selected reference Puskas, F. P. (1967): Geology of the Port Coldwell area, district of Thunder Bay; Ont. Dept. Mines, Open File Rept. 5014.

TABLE 28 *Chemical analyses of rocks from the Port Coldwell complex*

	1	2	3	4	5	6	7
SiO_2	47.0	45.0	45.8	57.2	50.0	59.5	62.4
TiO_2	0.40	1.20	0.67	0.65	0.55	0.85	0.60
Al_2O_3	12.7	15.9	13.8	15.0	15.5	15.5	17.1
Fe_2O_3	1.9	2.9	1.7	2.2	0.8	2.7	1.6
FeO	6.7	6.5	8.3	7.5	6.7	7.7	2.4
MgO	10.8	6.8	9.9	0.27	8.3	0.2	2.1
CaO	13.6	9.4	9.1	2.9	7.4	3.1	3.8
Na_2O	2.5	4.2	3.0	5.4	4.3	5.3	5.2
K_2O	1.2	1.7	3.1	4.8	3.2	5.0	2.2
P_2O_5	0.32	0.89	0.67	0.11	0.46	0.13	0.26
CO_2	nil	1.3	nil	.3	.1	nil	nil
H_2O	1.4	2.9	2.1	1.3	1.0	1.2	0.8
MnO	0.16	0.18	0.19	0.53	0.15	0.27	.06
TOTAL	98.7	98.9	98.4	98.1	98.5	101.4	98.5

Analyst: S. Courville *et al.*, Geol. Surv. Can., Analytical Chemistry Section, using "rapid methods."
1. Alkaline gabbro, from lower margin of the complex.
2. Lamprophyric gabbro.
3. Melanocratic olivine syenite.
4. Augite syenite.
5. Nepheline syenite.
6. Alkali syenite.
7. Fenitized granodiorite.

Name Killala Lake (SC-83; Fig. 64)

Location and access Forty miles north-northwest of Marathon, Ontario (49°10′N, 86°30′W). The complex can readily be reached only by air, although an old lumber road, now in poor condition, extends from Highway 17, near Little Pic River, to Killala Lake.

Form and structure An almost circular, funnel-shaped layered complex about 5 miles in diameter with a faulted northern extension of syenites some 3 miles long and 1½ miles wide, possibly forming a laccolithic lip. The inward dip of the units is about 70 degrees. The com-

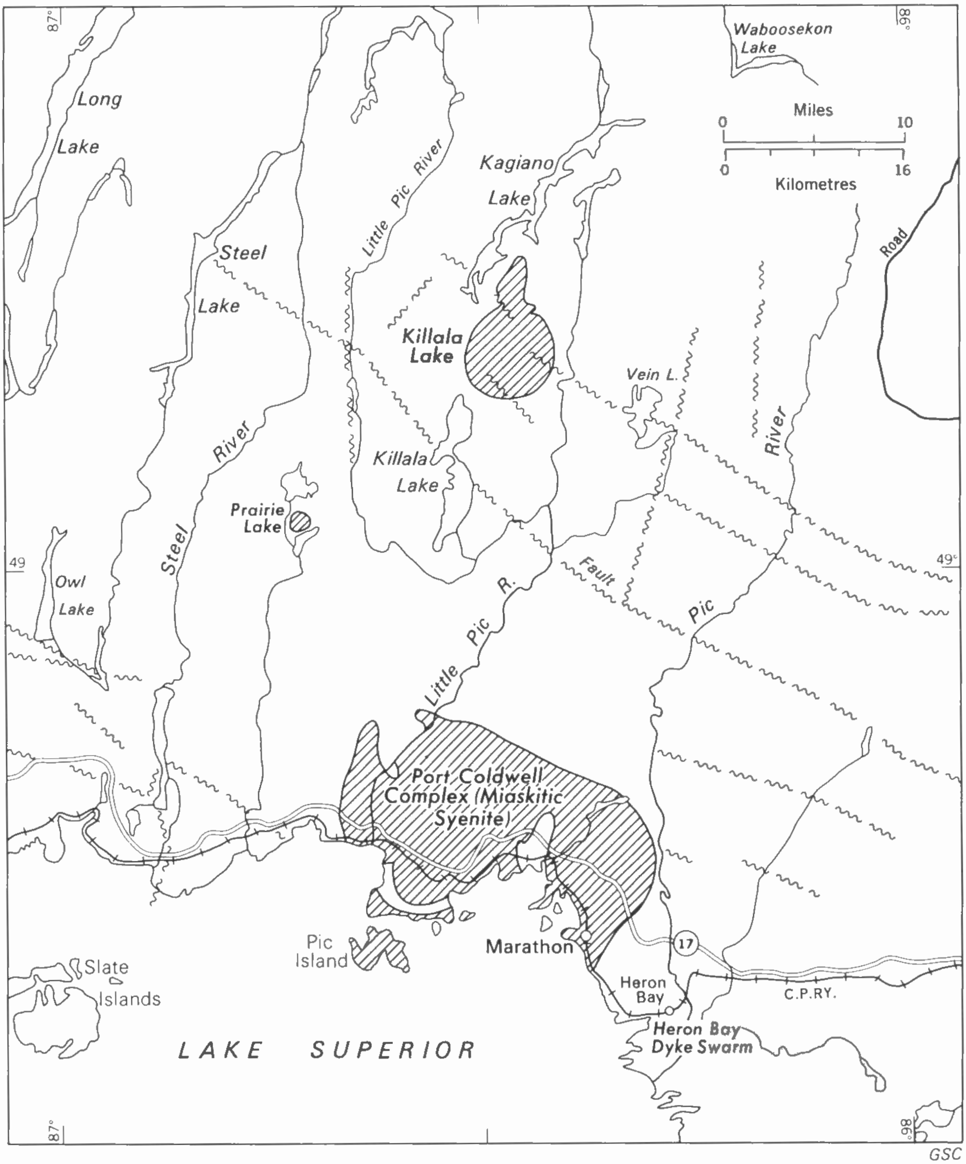

FIGURE 63. Geology of the Port Coldwell alkaline province (after Ont. Dept. Mines Map 2199).

	plex intrudes migmatitic hornblende-biotite-quartz-feldspar gneiss, which has been feebly fenitized with local development of pyroxene.
Petrography	Around the southern two thirds of the complex, irregularly layered gabbros composed of labradorite, chrysolitic olivine, and titanaugite form a thin discontinuous rim. Magnetite-apatite and sulphides are locally abundant, and may form 15 per cent of the rock. Locally, plagioclase has been nephelinized by reaction with the younger syenites which vein and brecciate the rock. The main body of syenite, whose contact with the gabbro is concealed, is a moderately foliated rock due to alignment of feldspar, with local mineral layering. The rock is composed principally of coarse perthite of vein and patch types, with lesser amounts of fine-grained anhedral oligoclase, poikiloblastic hastingsite, and aegirine. Biotite and magnetite are erratically present, associated with the other mafic minerals. Nepheline-bearing rocks form a ring-dyke type mass between gabbro and syenite, and also form a central core to the pluton, and a local rim. The central mass contains fayalitic olivine, but the other rocks have hastingsite and aegirine as the mafic minerals. Nepheline, partly altered to hydronepheline and cancrinite, occurs interstitially, and locally replaces plagioclase. As in the syenites, which they strongly resemble, the nepheline-bearing rocks are dominated by coarse trachytic perthite crystals. Pegmatitic patches of schlieren, and dykes of nepheline-bearing rocks are common, and dykes occur up to 4 miles from the complex. Fluorite, calcite, zircon, and pyrochlore have been reported from the dykes. Nephelinitic lamprophyre dykes cut the Killala Lake complex.
Age	A K-Ar age on biotite from the Killala Lake complex yielded 1,185 m.y.
Economic aspects	The Killala Lake complex has been prospected for Cu and Ni in the gabbros, and for Nb in the syenites. Low copper values are present in the gabbros.
Remark	The presence of pyrochlore in the Killala Lake complex suggests its affinity to the ijolitic Prairie Lake complex.
Selected reference	Coates, M. E. (1970): Geology of the Killala-Vein Lakes area; Ont. Dept. Mines, Geol. Rept. 81.

Name	Chipman Lake (SC-84; Fig. 65)
Location and access	Twenty miles northeast of Longlac, Ontario, in O'Meara Township. Accessible by float-equipped aircraft.
Form and structure	A zoned syenite complex, approximately circular and about 2 miles in diameter, with a thin gabbroic rim around a core of aegirine syenite. Carbonatite dykes cut the weakly fenitized Precambrian hornblende-quartz-feldspar gneisses on the west side of the complex.
Petrography	No detailed data available. Nepheline has not been reported.
Age	Unknown.
Economic aspects	The gabbroic rim contains disseminated chalcopyrite, but lacks nickel, gold, or silver. Pyrochlore has been reported from the carbonatitic dykes.
Remarks	The general description of the Chipman Lake complex suggests a striking similarity to the Port Coldwell and Killala Lake complexes. Prominent faults in the vicinity of the complex strike toward these larger complexes.
Selected reference	Ferguson, S. A. (1971): Columbium (Niobium) deposits of Ontario; Ont. Dept. Mines, Mineral. Resourc., Circ. 14, p. 42–43.

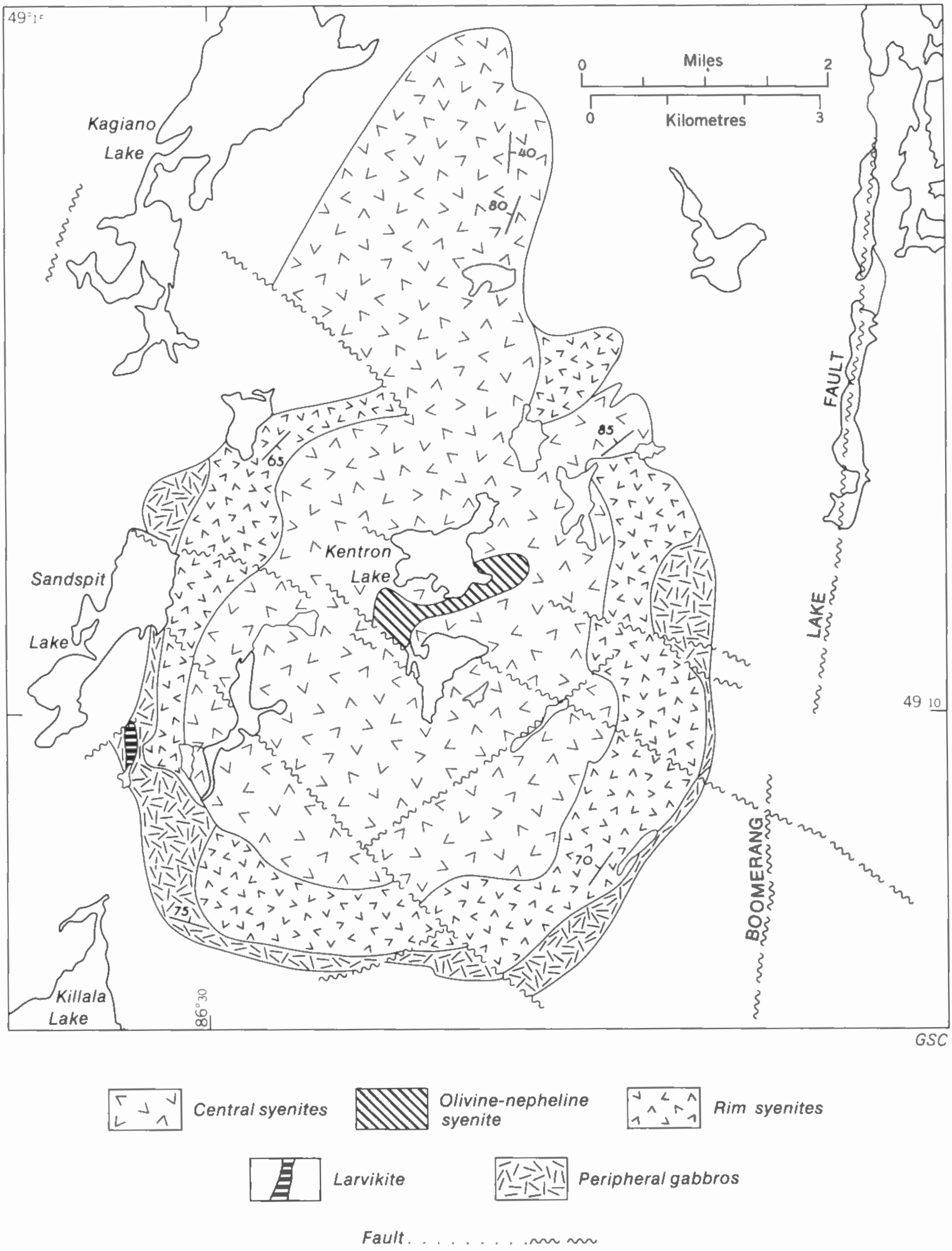

FIGURE 64. Geology of the Killala Lake complex (after Coates, 1970).

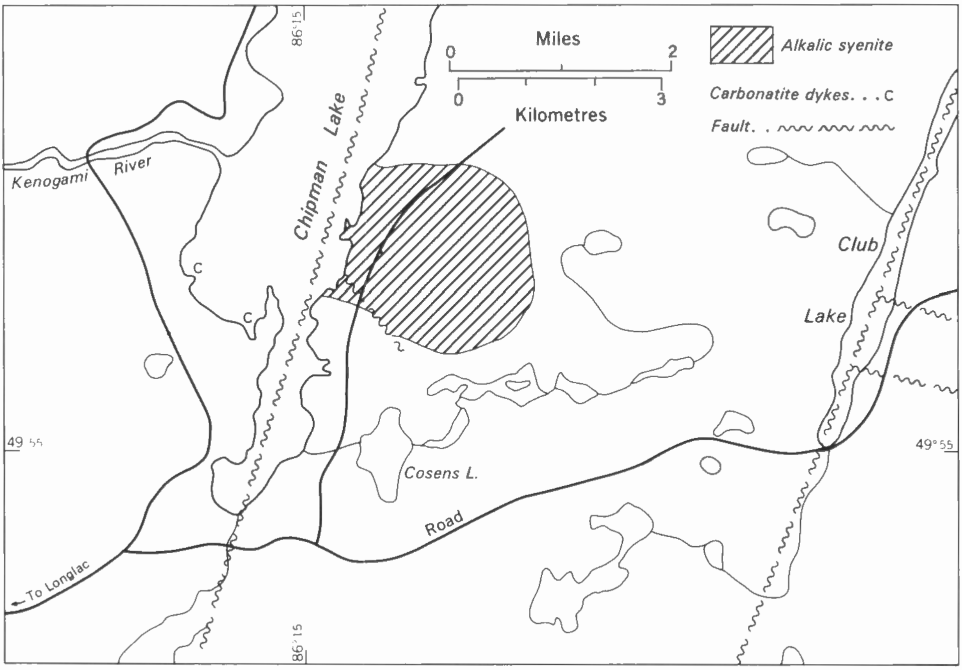

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FIGURE 65. Geology of the Chipman Lake complex (after Ont. Dept. Mines Map P551).

Name	Herman Lake (S-85; Fig. 66)
Location and access	About 10 miles north of Goudreau, Ontario, on the Algoma Central Railway line (48°17′N, 84°31′W). Easily accessible by railway or by aircraft.
Form and structure	The complex appears to have the form of an elliptical stock about 5 by 2 miles centred around Herman Lake and trending northeast. The surrounding Archean greenstones have been sheared and contorted, but not fenitized, at the contact.
Petrography	The rocks are composed of aligned tablets of microcline microperthite, with interstitial nepheline or cancrinite. Biotite is the principal mafic mineral, although aegirine occurs locally. A characteristic feature is the presence of clumps of calcite in the syenite, and the occurrence of thick calcite selvages on syenite dykes cutting the surrounding greenstones. Chemical data are given in Table 29.
Age	Unknown.
Economic aspects	A low tenor of sulphide mineralization is found around the Herman Lake complex.
Remark	The Herman Lake complex appears to be an interesting body, but the available data are obsolescent, and require updating.
Selected reference	Gledhill, T. L. (1927): Goudreau-Lochalsh gold area, district of Algoma; Ont. Dept. Mines Ann. Rept., v. 36, pt. II, p. 58–59.

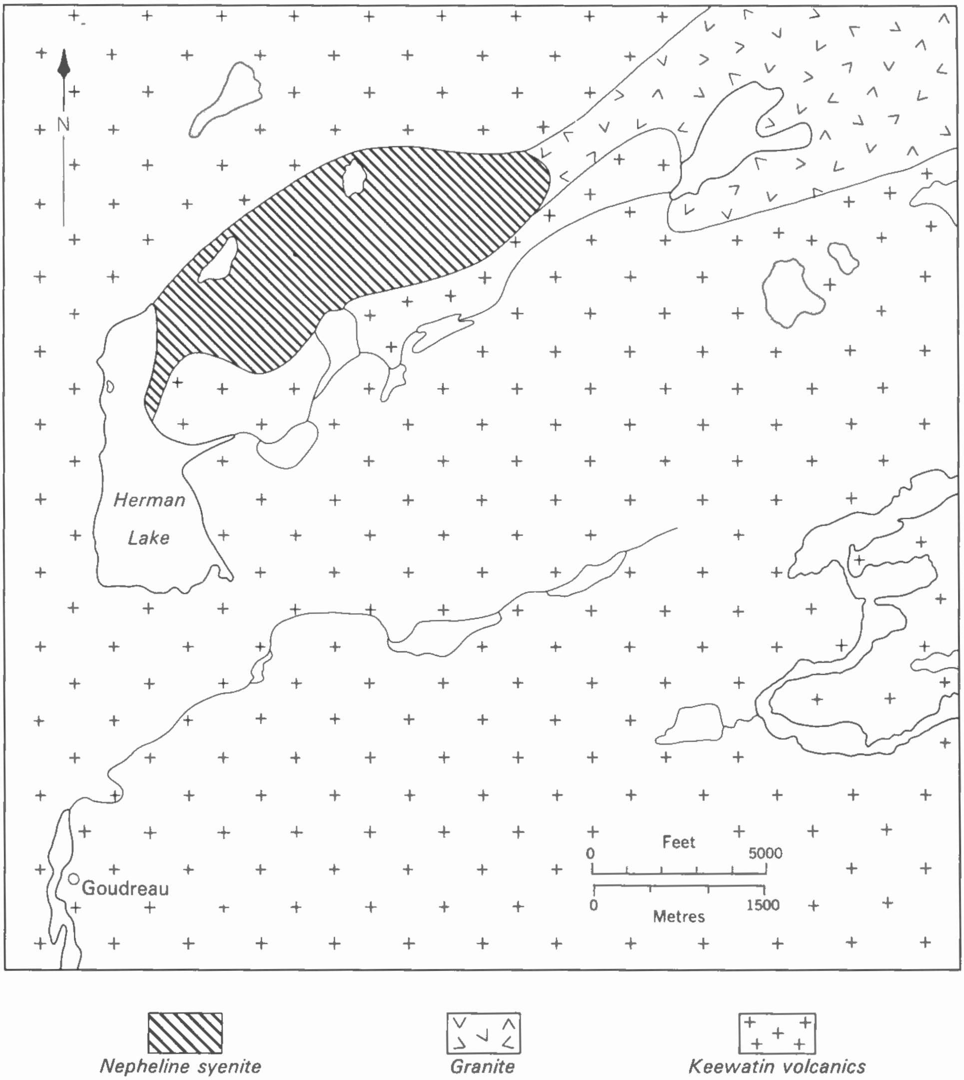

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FIGURE 66. Geology of the Herman Lake syenite (after Gledhill, 1927).

TABLE 29 *Chemical analyses of rocks from the Herman Lake syenite (after Gledhill, 1927)*

	1	2
SiO_2	55.93	46.27
TiO_2	0.49	0.63
Al_2O_3	18.84	20.76
Fe_2O_3	0.73	4.81
FeO	2.30	3.53
MnO	n.d.	n.d.
MgO	1.03	1.77
CaO	4.16	5.69
Na_2O	7.66	8.48
K_2O	5.28	5.24
P_2O_5	n.d.	n.d.
H_2O	0.92	0.65
CO_2	2.91	2.15
TOTAL	100.25	99.98

n.d.: not determined.
1. Leucocratic nepheline-cancrinite syenite.
2. Melanocratic nepheline syenite.

Name	Otto stock (S-86; Fig. 67)
Location and access	Ten miles southwest of Kirkland Lake, Ontario. The stock is almost exactly transected by Highway 11, and all parts are easily accessible by highway or secondary roads.
Form and structure	The Otto stock is almost perfectly circular and about 6 miles in diameter, grading outward from leucocratic quartz syenite to marginal syenite porphyry. The alkaline rocks are found as discontinuous lenticular zones from 300 to 800 feet thick in the latter rock. The stock intrudes mafic and felsic Archean volcanic rocks, and the Round Lake granodiorite batholith to the south. The stock is bisected by a north-south fault with significant left-hand movement.
Petrography	The central part of the stock is composed mainly of microcline with minor quartz and biotite and much mildly alkaline pyroxene. The texture becomes steadily coarser toward the margin, quartz decreases, and the size of the microcline tablets increases. The content of mafic minerals increases erratically, and the more mafic zones contain nepheline in amounts up to 40 per cent, as well as some albite and sphene.
Age	Rb-Sr isochron measurements on the Otto stock give an age of 1,730 m.y., compared to 2,390 m.y. for the Round Lake batholith.
Economic aspects	The contact aureole of the Otto stock is extensively mineralized with copper and gold. Several former minor producers of gold were located in this aureole, which is associated with quartz-carbonate veins, concentrated in relatively acid tuffs and flows.
Remarks	The presence of miarolitic cavities within the syenite, and a narrow, but persistent garnet amphibolite-grade metamorphic aureole suggest high level intrusion of the Otto stock. Similar alkaline syenite stocks occur to the east of the Otto stock in Teck, Lebel, and McVittie tps., which is over a distance of about 25 miles, but no nepheline has been reported associated with them.
Selected references	Lawton, K. D. (1968): Preliminary geological map of the Otto Twp. area; Ont. Dept. Mines, Map P. 330. Lovell, H. L. (1972): Geology of the Eby and Otto area, Dist. of Temiskaming; Ont. Dept. Mines Northern Affairs, Geol. Rept. 99.

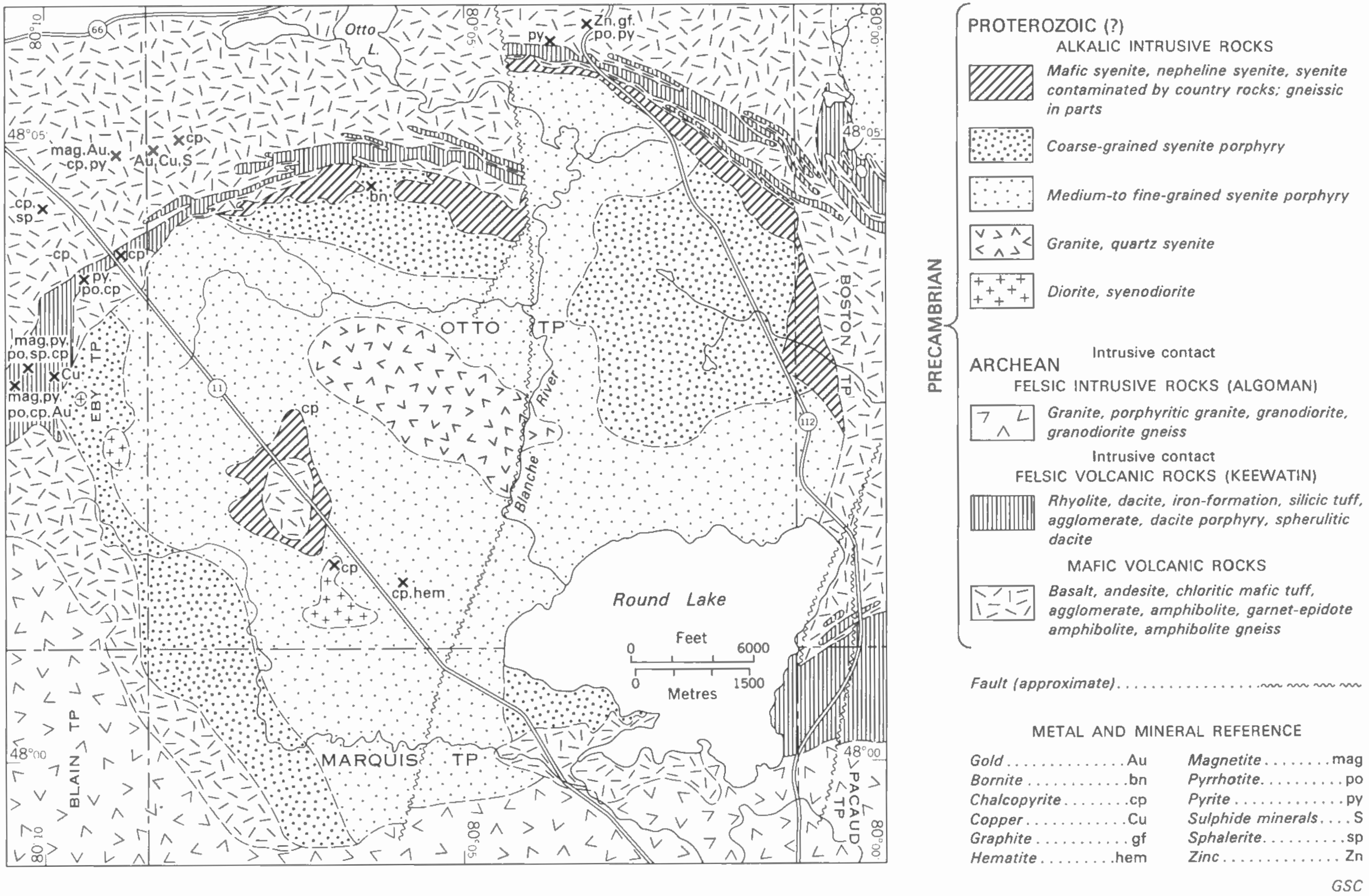

FIGURE 67. Geology of the Otto stock (after Lovell, 1972).

Name	Kirkland Lake trachytes and syenites (S-87; Fig. 68)
Location and access	The alkaline rocks extend from near Swastika, Ontario, about 10 miles to the east into Lebel Township. The occurrences are easily reached by highway and secondary roads.
Form and structure	The alkaline rocks form part of a sequence of volcanic rocks dipping 30–60° to the south. They occur in a stratigraphic section 7,000 to 15,000 feet thick, which disconformably overlies an older calc-alkaline volcanic assemblage, and are intruded by younger Precambrian granitoid rocks.
Petrography	The alkaline rocks occur at three, or possibly four stratigraphic horizons in the form of leucite trachyte, phonolite, tuff, and related syenitic sills. All the rocks are moderately sheared and metamorphosed to lower greenschist facies, but relict features are, in general, well preserved. The more mafic trachytes contain 25 to 60 per cent olivine, augite, amphibole, and biotite, together with trachytic sanidine microlites, whereas the more salic varieties contain augite as the only mafic mineral. Pseudoleucite phenocrysts, in which the nepheline is entirely altered, constitute 5 to 90 per cent of the rock. Despite the alteration of nepheline, chemical analyses (Table 30) leave no doubt of the original feldspathoidal character of the rocks. Flows, tuffs, and agglomerates of similar compositions are found, as well as intercalated conglomerates containing pebbles and cobbles of alkaline rocks. Many of the pebbles contain melanite, a mineral not present in the flows. Mafic syenites of similar chemistry, consisting of about equal amounts of augite and alkali feldspar with minor amounts of olivine and biotite, are found as sills within the volcanic complex.
Age	The age of the alkaline rocks is presumably somewhat younger than the calc-alkaline volcanics which they overlie, and older than the porphyries intruding them. The porphyries give radiometric ages ranging from 2,375 m.y. on biotite to 2,670 m.y. on zircons from lamprophyres, possibly genetically related to the alkaline rocks.
Economic aspects	There is a noticeable tendency for the gold deposits of the Kirkland Lake camp to be associated with the syenite bodies, but the gold occurs in quartz stockworks, and in fissure and gash veins associated with faulting which cuts the alkaline rocks. Hence the association is presumably structural only.
Selected reference	Cooke, D. J. and Moorhouse, W. W. (1969): Temiskaming volcanism in the Kirkland Lake area, Ontario, Canada; Can. J. Earth Sci., v. 6, p. 117–132.

TABLE 30 *Chemical analyses of rocks from the Kirkland Lake alkaline volcanics (after Cooke and Moorhouse, 1969)*

	1	2	3	4	5
SiO_2	46.54	50.10	53.05	51.37	51.19
TiO_2	0.55	0.70	0.21	0.82	0.85
Al_2O_3	15.24	18.07	24.07	16.19	18.02
Fe_2O_3	3.31	3.59	1.80	3.17	2.08
FeO	5.57	3.62	1.99	5.50	6.12
MnO	0.16	0.14	0.11	0.15	0.15
MgO	3.81	2.71	.81	6.05	4.35
CaO	7.14	5.59	2.29	6.94	5.50
Na_2O	3.71	2.64	4.18	2.85	4.09
K_2O	5.38	6.55	6.60	4.67	4.10
P_2O_5	0.35	0.11	0.16	0.49	0.47
H_2O	2.60	1.79	2.04	2.16	2.20
CO_2	5.20	4.90	3.07	1.29	1.43
TOTAL	99.56	100.51	100.38	101.65	100.55

1, 2, 3. Pseudoleucite-bearing trachyte.
4, 5. Olivine trachyte.

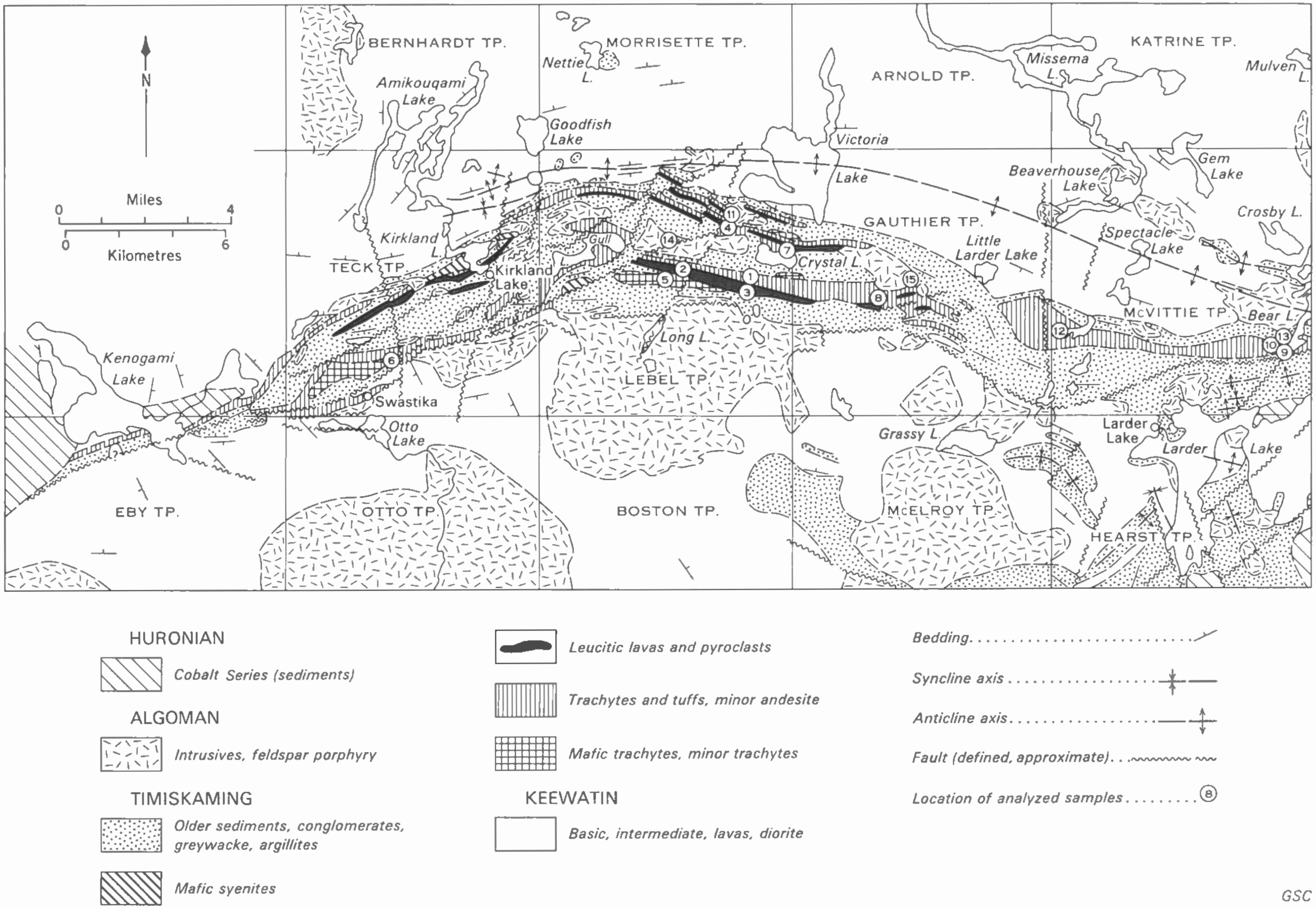

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FIGURE 68. Geology of alkaline lavas in the Kirkland Lake area (after Cooke and Moorhouse, 1969).

Name	Obedjiwan (Gouin Reservoir) (S-88, Fig. 69)
Location and access	North shore of the Gouin Reservoir, Quebec, about 90 miles north of Chibougamau (48°41′N, 75°10′W). The complex is easily accessible only by aircraft, although canoe routes exist.
Form and structure	The complex is roughly circular, and about 5 miles in diameter. A lens-like satellite to the north, 1.5 miles long by 0.5 mile wide, is possibly part of a cone sheet. The complex is zoned from nepheline syenite at the core, through aegirine syenite. Gabbroic rocks are found as inclusions, and may be present as a poorly exposed outer rim. The complex intrudes Grenville migmatite.
Petrography	The central nepheline syenite is composed of lineated to foliated coarse-grained biotite-nepheline-perthitic feldspar rocks. Crosscutting, diabasic-textured areas of similar mineralogy are common. A characteristic feature is nepheline pegmatite dykes 1 to 2 feet wide, commonly with calcite cores, which pass abruptly, but without transgressive contacts, into the surrounding rocks. Some phases of the complex contain cancrinite, and it may occur in the dykes. Locally, the rock is sufficiently rich in nepheline and poor in perthite that it approaches ijolite, particularly on a small island which contains large amounts of aegirinic pyroxene. The aegirine syenite surrounding the central core appears to be a ring dyke about 1 mile wide which consists of perthite and aegirine, with minor magnetite. The rock appears to grade into syenitic gneiss, and thence into the surrounding migmatitic gneisses. The outcrop of the satellitic intrusion consists entirely of massive to gneissic nepheline syenite. The feldspars are very complex, with albite, microcline, and perthite all represented. Some of the nepheline crystals are riddled by apparently exsolved albite blebs. Slabby boulders of biotite-calcite rock and ijolitic rocks, presumably representing outcrop, are abundant around the satellitic intrusion.
Age	K-Ar ages on biotite from the Obedjiwan complex give a range of ages from 1,050 m.y. for the main nepheline syenite to 890 m.y. for the calcite-biotite rock.
Economic aspects	Preliminary tests have been made indicating the possibility of recovering nepheline and nepheline syenite from the Obedjiwan complex.
Selected reference	Gittins, J. (1971): The Obedjiwan alkaline complex, Gouin Reservoir, Toussaint Twp., Abitibi County, Quebec; Que. Dept. Nat. Resourc., Service de la Documentation Technique, No. 27357.

TABLE 31 *Chemical analysis of nepheline syenite from the Obedjiwan complex (after Gittins, 1971)*

SiO_2	54.65
TiO_2	1.07
Al_2O_3	20.91
Fe_2O_3	2.38
FeO	3.79
MnO	0.06
MgO	1.11
CaO	0.56
Na_2O	6.25
K_2O	7.21
P_2O_5	0.05
H_2O	1.14
CO_2	0.64
TOTAL	99.82

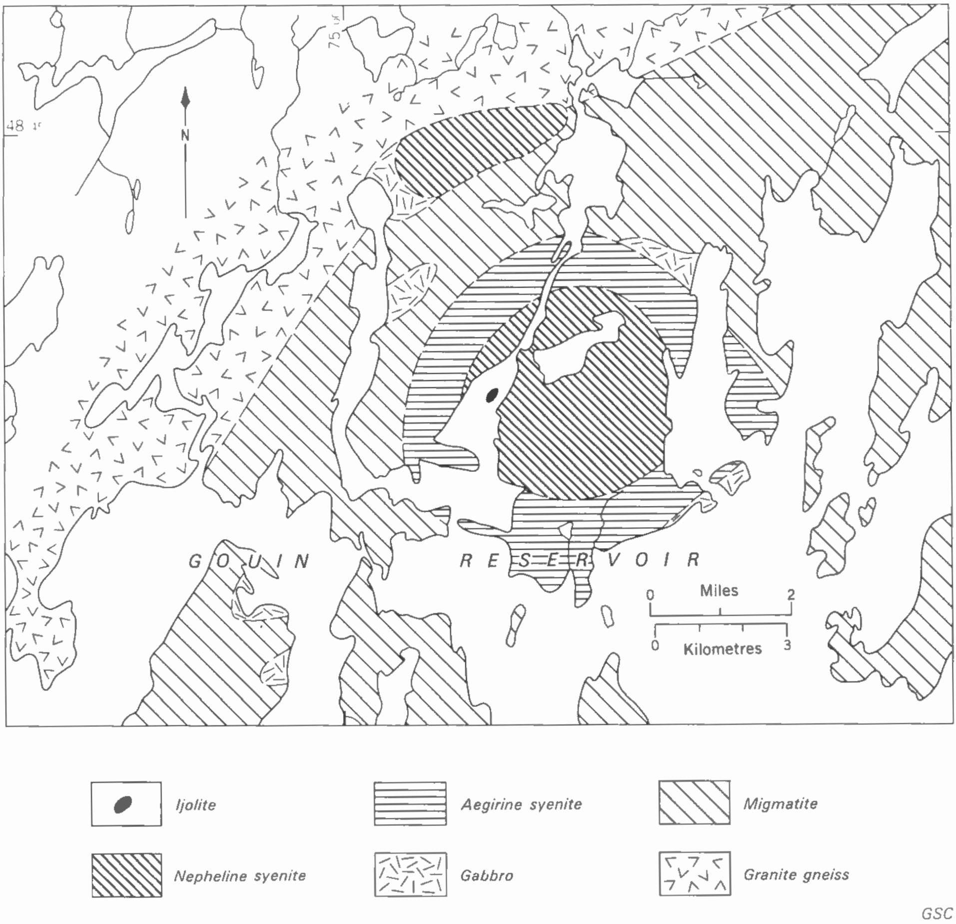

FIGURE 69. Geology of the Obedjiwan complex (after Gittins, 1971).

Name	Thomas Lake (S-89; Fig. 70)
Location and access	About 700 miles north of Regina, Saskatchewan, just across the border in the Northwest Territories (60°09′N, 105°13′W). The complex is accessible only by aircraft.
Form and structure	The form and structure are very uncertain. The aeromagnetic signature suggests a circular complex about 2 miles in diameter. The nepheline syenite shows a distinct foliation.
Petrography	"Of three outcrops examined, two consist of medium-grained, moderately well foliated nepheline syenite that weathers white except for dark-weathering biotite flakes that appear to be wrapped around the felsic minerals. The rock is granular, and besides nepheline consists of cancrinite, orthoclase, and small amounts of albite, green biotite, sphene, apatite and rare arfvedsonite and aegirine-augite.... The third outcrop contains no nepheline and consists dominantly of plagioclase and flame perthite" (Taylor *et al.*, 1970).

Age	Unknown.
Economic aspects	Unknown.
Remarks	Unusual veins of possible carbonatitic affinities have been reported by Hogarth (1957) from the Nisikkatch Lake area (Fig. 70). The northeast-trending veins contain calcite, quartz, hyalophane, barite, apatite, and allanite. The rare-earth content is high. Lamprophyre dykes are found in the same area. The veins strike toward Thomas Lake, about 35 miles to the northeast, and there may be some connection (*see* D. D. Hogarth (1957),The apatite-bearing veins of Nisikkatch Lake, Saskatchewan; Can. Mineral., v. 6, p. 140–150).
Selected reference	Taylor, F. C., Bostock, H. H., and Baer, A. J. (1970): Wholdaia Lake; Geol. Surv. Can., Map 1199A.

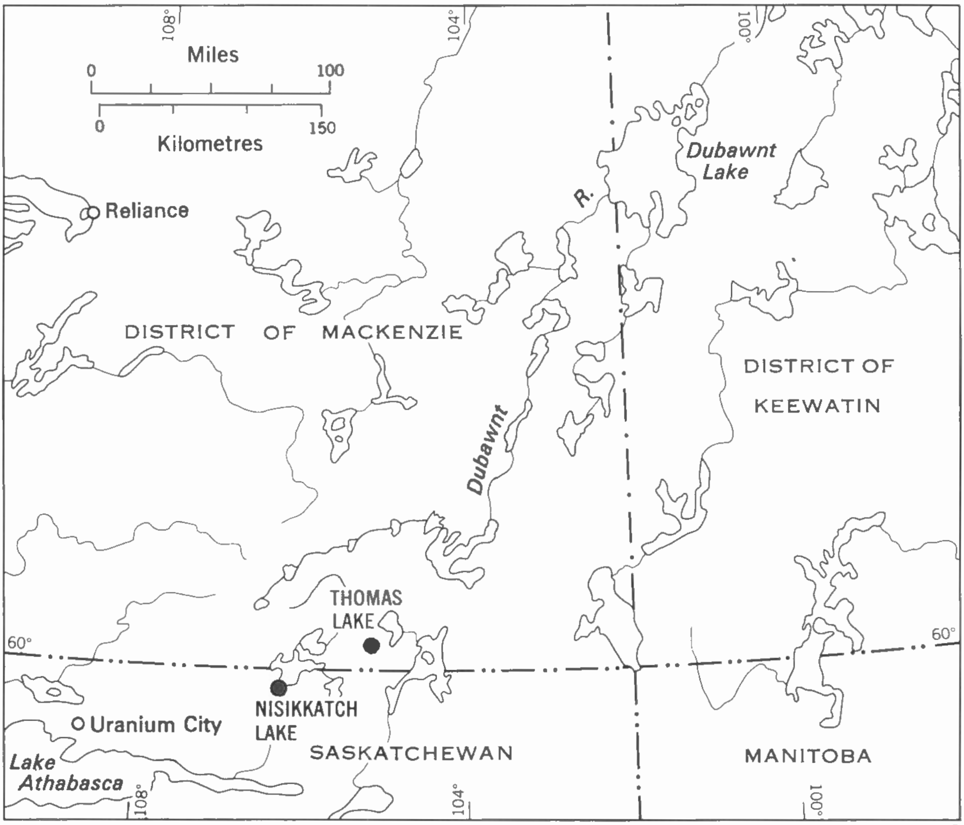

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FIGURE 70. Location of Thomas Lake nepheline syenite, and the Nisikkatch Lake carbonatite dykes.

Name	Sweetgrass Hills (S-90; Fig. 71)
Location and access	Southern Alberta, particularly near Pinhorn, where a butte-like outcrop occurs 2 miles west of the village (49°10′N, 112°14′W). The known outcrops are readily accessible by local roads.
Form and structure.	Dykes, commonly 1 to 5 feet wide, with associated sills.
Petrography	The rocks are all dark in colour and lamprophyric in texture, with prominent biotite books up to ¼ inch across, but when seen under the microscope, they contain abundant potash feldspar, augite, and, commonly, a little olivine.
Age	A K-Ar age on biotite yielded 48 m.y.
Economic aspects	None known.
Remarks	These dykes are an outlying manifestation of the famous potassic Highwood alkaline province of Montana, of which the Shonkin Sag laccolith is the largest member.
Selected reference	Williams, M. Y. and Dyer, W. S. (1930): Geology of southern Alberta and southwestern Saskatchewan; Geol. Surv. Can., Mem. 130, p. 78–80.

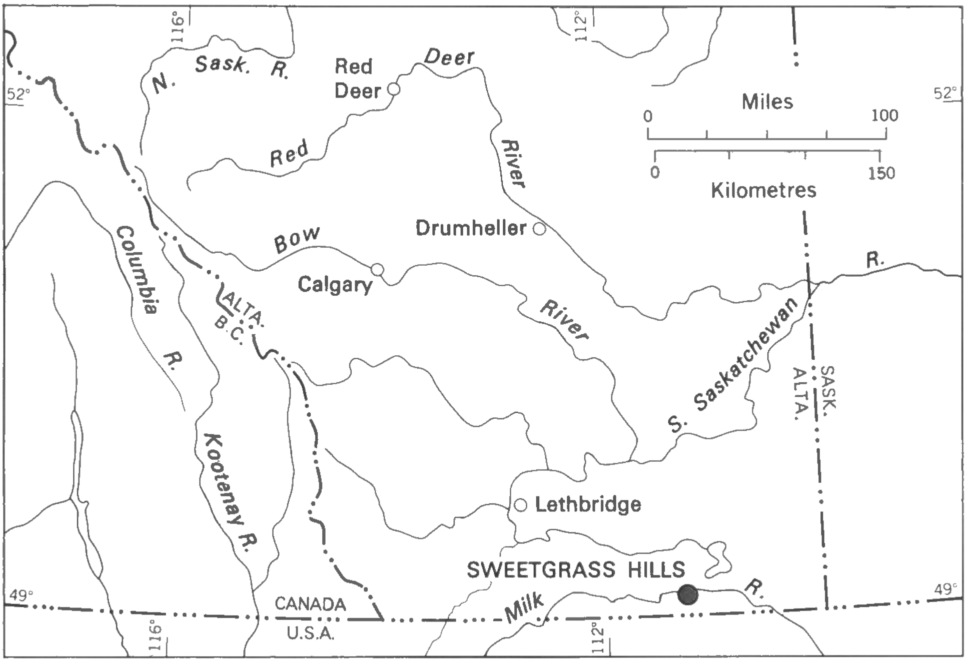

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FIGURE 71. The Sweetgrass Hills lamprophyre dykes.

Chapter VII

Nepheline Syenite Gneiss Complexes

Thus far the discussion has dealt with feldspathoidal syenites of undoubted igneous origin, displaying crosscutting contacts, chilled margins, contact aureoles, and foliation (if any) only of the trachytoid type. Another class of feldspathoidal syenites of entirely different character forms thin, conformable bands in gneissic terranes composed mainly of highly metamorphosed sedimentary rocks. Such syenites display true gneissosity, i.e., mineral layering with granoblastic texture, and typically show evidence of metasomatic formation of nepheline in the form of partly replaced plagioclase and mafic minerals. The margins of the feldspathoidal bands are commonly gradational, passing through a rim of nonfeldspathoidal syenite, which may contain corundum, into the country rocks, where thin bands of nepheline-bearing material can be found beyond the margins of the main mass. Wispy remnants of country rocks are also common within the feldspathoidal rocks. The origin of nepheline gneisses is a celebrated and unsolved petrological problem, but this chapter will deal only with the descriptions of such rocks. In Canada, two belts of nepheline gneiss have been recognized, one rimming the Frenchman's Cap gneiss dome in southeastern British Columbia, and the other passing northeastward through the Grenville structural province from Blue Mountain in Ontario to Lac Albanel, Quebec. The latter zone is some 600 miles long, and it might be forcefully argued that it consists of several related belts, rather than a single all-embracing belt. The recognition of nepheline gneisses is difficult for those unfamiliar with them, and many other occurrences probably exist, even within the known belts.

Name	Frenchman's Cap gneiss dome (Fig. 72)
Location and access	The Frenchman's Cap Dome is located in rugged mountains northwest of Revelstoke, B.C., its closest core zone gneisses lying about 25 miles from that city. Some lumber and mining roads extend into this region, but the most satisfactory access is by helicopter. Arduous climbs are required to visit many of the most interesting localities.
Form and structure	The Frenchman's Cap gneiss dome is the most northerly of a series of culminations in the Shuswap metamorphic complex, a central zone of high-grade metamorphic rocks in the core zone of the Eastern Cordilleran fold belt. Each culmination consists of a core of migmatitic gneisses, surrounded by contorted metamorphosed sedimentary rocks including marble, calc-silicate rocks, and pelitic schists. The structures of the mantling zone tend to be draped around the core, but in detail the styles and orientations of the folds may be vastly different in the two zones. From these differences Reesor (1970) suggested that the domes are the result of exposure of older rocks through a mantle of strongly compositionally contrasting younger rocks into which they have been partly kneaded. The alkaline rocks are found near the boundary of the two zones, in the lowest part of the deformed metasedimentary rocks.

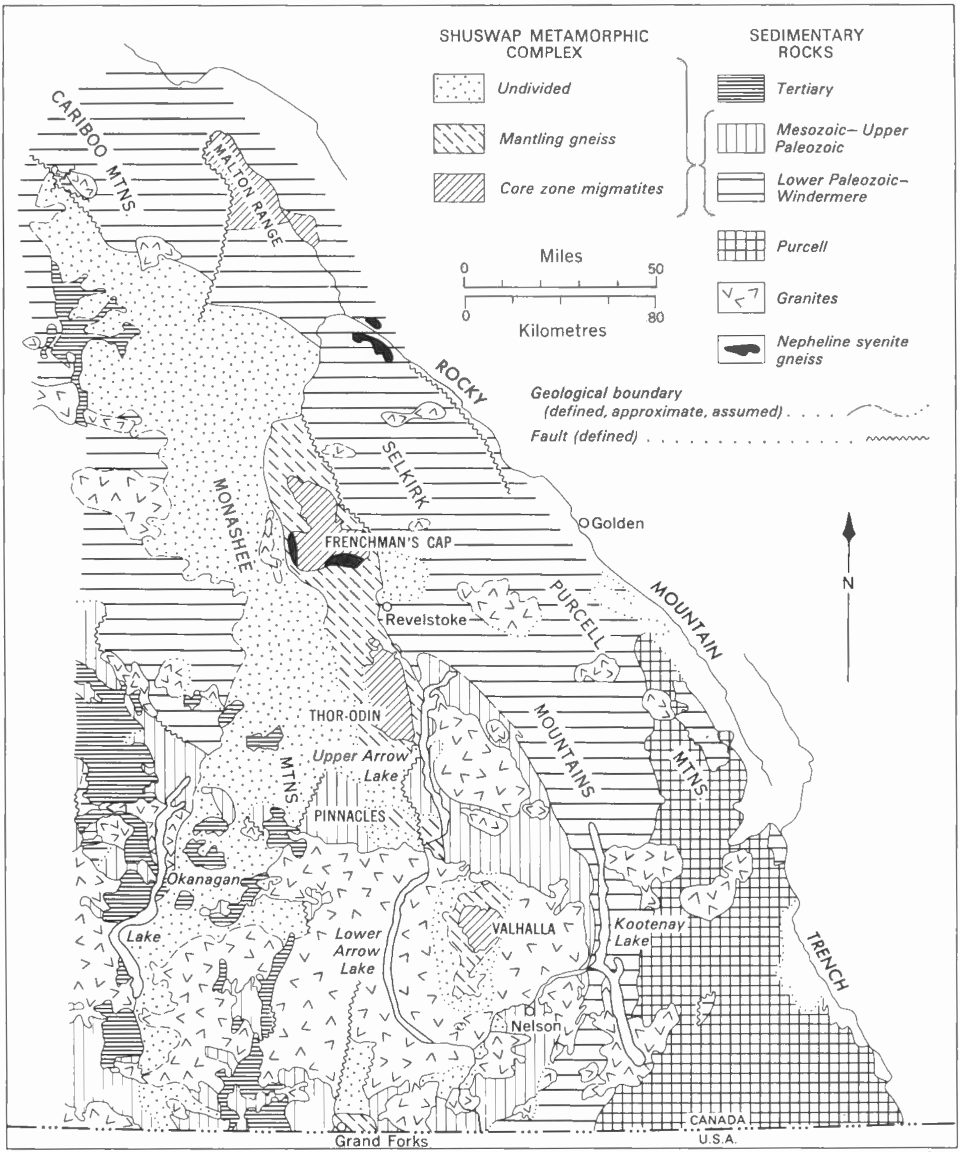

FIGURE 72. Nepheline-bearing gneiss in the region of Frenchman's Cap gneiss dome (modified from Reesor, 1970).

Age

The latest ages recorded in the Shuswap terrane are 45–50 m.y. by the K-Ar method, but this appears to be due to resetting of much older ages by igneous and tectonic activity.

Economic aspects

High-grade metamorphic rocks are generally thought to be unfavourable for prospecting for metals, but molybdenite occurs in all the alkaline rocks, and has been successfully exploited at Mount Copeland (Mt. Copeland Mine of King Resources). Pb-Zn-Ag mineralization occurs in limy metamorphic rocks in the same region.

Selected references

Reesor, J. E. (1970): Some aspects of the structural evolution and regional setting in part of the Shuswap metamorphic complex; Geol. Assoc. Can., Spec. Paper v. 6, p. 73–86.

Wheeler, J. O. (1963): Big Bend map-area, British Columbia; Geol. Surv. Can., Paper 64-32.

Name

Mount Copeland (G-R96; Fig. 73)

Location and access

Fifteen miles northwest of Revelstoke, B.C., on the southeastern flank of the Frenchman's Cap Dome (51°08′N, 118°25′W). The alkaline rocks are centred on Mount Copeland, which is readily accessible by mine road leaving the Trans-Canada Highway just west of Revelstoke.

Form and structure

Nepheline syenite is exposed as part of a generally south-dipping sequence on Mount Copeland, overlying the core gneisses to the north, and again on the flanks of an anticlinal fold to the southeast. The folds in detail are complex, but those controlling the disposition of the units on the surface are basin-like, with moderate plunges to both east and west. The syenite unit appears to pinch out to the southeast, but its continuation to the west has not been traced.

Petrography

The 'core' gneisses north of Copeland Creek consist of medium-grained, grey biotite-andesine-microcline-quartz gneiss, commonly garnetiferous, which displays one or more lineations in outcrop. This unit passes conformably into a prominent white quartzite containing muscovite and tourmaline, which appears in turn to grade to mica schists and quartzite. The sequence that contains the nepheline gneiss begins with grey-green, strongly lineated gneiss mainly composed of quartz-biotite-muscovite-andesine-microcline ± sillimanite, but containing prominent quartz lenticles to 2 feet thick, and numerous thin calc-silicate layers containing tremolite, diopside, and scapolite. This unit is capped by a prominent but thin layer of white, vitreous quartzite. The overlying unit is a fine-grained, calc-silicate rock mainly composed of calcite, diopside, tremolite, epidote, scapolite, idocrase, and labradorite, but with many thin layers of biotite gneiss and schist. These layers pass directly into greenish, granular biotite syenite dominated by potash feldspar which may range from microcline to braid microperthite. Tiny albite laths, yellow biotite euhedra, minor sphene and zircon, and occasional clusters of calcite are also present. Strain and crushing of the rocks are prominent. Where this unit reaches a thickness of more than 2,000 feet, a central zone is separated from the saturated syenite by a discontinuous selvage of amphibolite in which plagioclase is replaced by nepheline. In the central zone the syenite contains 15 to 60 per cent nepheline, commonly euhedral but altered to pinkish 'hydronepheline,' 30 per cent of strongly absorbing aegirine, and a groundmass of interlocking lobate microcline with various amounts of patch and replacement perthite. Cancrinite, sphene, and zircon are commonly present in accessory amounts, and fluorite and rinkite are locally prominent. Overlying the syenite is a prominent quartzite with amphibolite lenses, some of which contain nepheline. The highest structural unit recognized is a brown-weathering augen gneiss, shot full of granitic material. Northeast-trending nephelinitic lamprophyre dykes, 1 to 5 feet wide, contain biotite, faintly sodic augite, and olivine phenocrysts

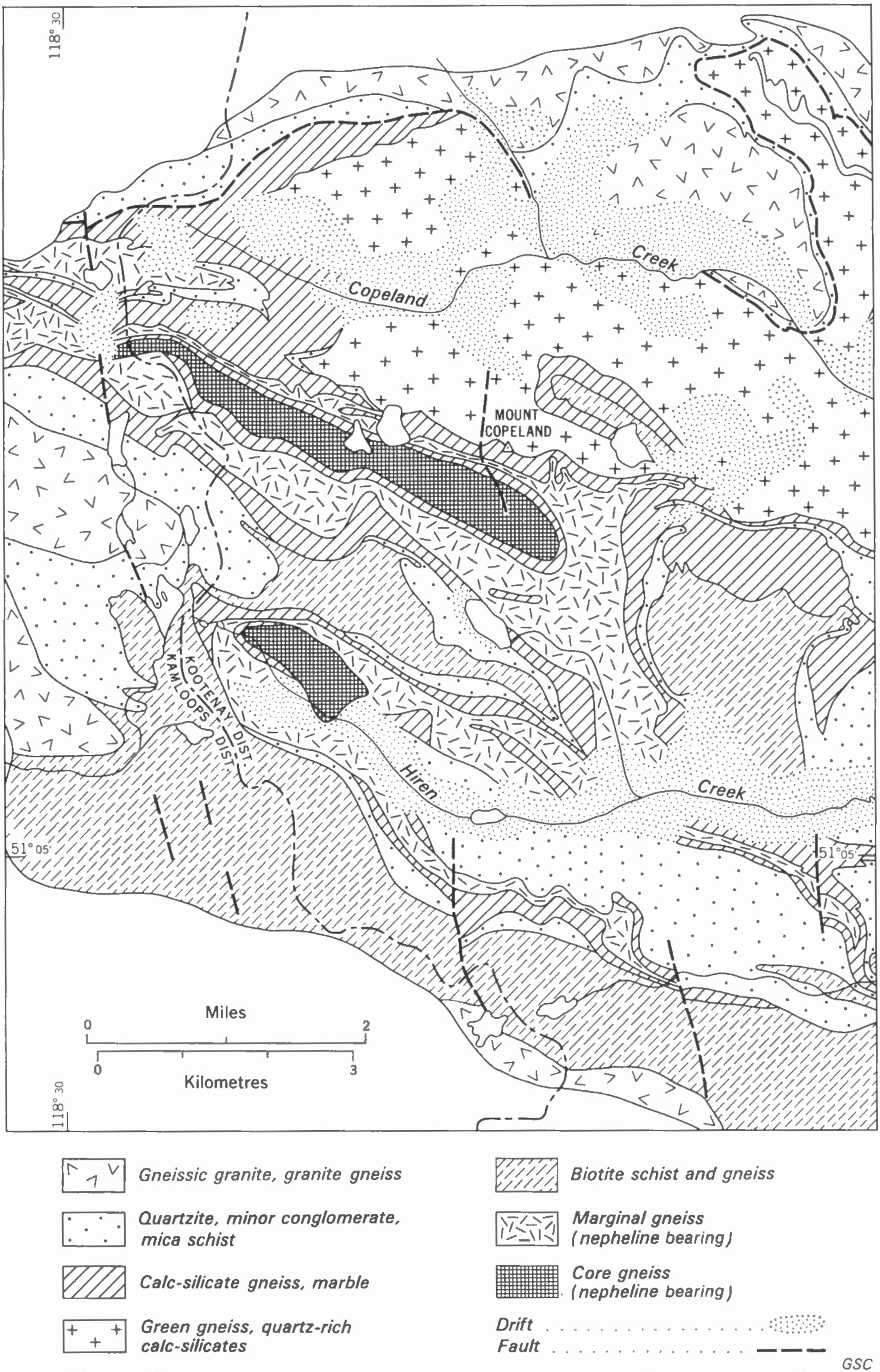

FIGURE 73. Geology of the Mount Copeland nepheline syenite (after Fyles, 1970).

in a matrix rich in calcite and analcite. Feldspar-bearing ocelli are present in several examples. One dyke contains a large inclusion of nepheline syenite.

Age

A K-Ar age on biotite from the lamprophyre gave 45 m.y., whereas biotite from the syenite gave an age of 48 m.y. Both of these ages probably represent the latest resetting of clocks in the region, and not the age of formation of the nepheline gneiss. By lithological comparison, the host rocks are probably of Early Cambrian age.

Economic aspects

The margins of the syenite are persistently mineralized with molybdenite. The best values are associated with a granular aplitic phase of the syenite that occurs as ill-defined pods or veins and seem to be controlled by small folds. A relatively small, but high-grade occurrence on the north side of Mount Copeland is now being mined by King Resources Ltd. About 1.5 miles to the east in a stratigraphically lower marble, a sulphide-rich layer occurs in the green gneiss. Significant lead-zinc-silver mineralization is present, estimated as greater than 3 million tons grading 1.1 oz Ag., 5.1 per cent Pb, and 5.6 per cent Zn.

Selected reference

Fyles, J. T. (1970): The Jordan River area near Revelstoke, British Columbia; B.C. Dept. Mines Petrol. Resourc., Bull. 57.

TABLE 32 *Chemical analyses of rocks from the Mount Copeland complex*

	1	2	3	4	5	6	7	8
SiO_2	45.9	56.9	53.6	39.7	44.2	48.9	60.1	65.2
TiO_2	0.28	0.55	1.63	1.28	5.49	3.07	0.20	0.57
Al_2O_3	26.1	21.0	15.4	13.5	7.5	11.3	12.2	16.5
Fe_2O_3	3.6	2.6	2.6	2.6	8.1	1.3	nil	1.4
FeO	1.6	2.6	6.1	5.4	7.2	10.2	1.5	2.3
MnO	0.28	0.24	0.16	0.14	0.37	0.15	0.06	0.07
MgO	.3	.7	6.0	7.6	7.8	8.4	7.5	1.8
CaO	1.6	1.6	4.8	11.0	9.7	10.1	8.5	2.8
Na_2O	12.53	6.1	2.5	1.9	3.7	2.3	2.0	3.1
K_2O	4.6	7.5	5.1	4.3	3.8	1.6	5.8	4.8
H_2O	0.9	0.5	1.7	1.9	1.2	2.2	0.4	0.6
CO_2	.8	.2	0.1	8.2	0.3	0.6	nil	nil
P_2O_5	.03	.02	.37	1.68	.60	.28	0.06	0.26
TOTAL	98.5	100.5	100.1	99.3	100.0	100.4	99.0	99.4

Analyses by S. Courville *et al.*, Geol. Surv. Can., Analytical Chemistry Section, using "rapid methods."

1. Mafic nepheline syenite from central core.
2. Leucocratic nepheline syenite.
3. Aplitic, saturated syenite from molybdenite ore zone.
4. Ocellar biotite lamprophyre dyke.
5. Mafic amphibolitic fenite.
6. Pyroxene amphibolite, from which 4 is presumed to have developed.
7. Calc-silicate gneiss, north slope of Mount Copeland.
8. Quartz-feldspar-biotite-hornblende augen gneiss.

Name

Perry River (G-R95; Fig. 74)

Location and access

On the west side of Perry River, B.C., in rugged terrain about 14 miles north of Craigellachie on the Trans-Canada Highway, and about 10 miles northwest of Mount Copeland. There is a rudimentary forestry road along the Perry River from Craigellachie, but the area is almost inaccessible except by helicopter.

Petrography

Nepheline syenite gneiss occurs as a band 50 to 1,000 feet thick, between underlying quartzite and micaceous quartzite and overlying calc-silicate rocks. The lower quartzite, about 800 feet thick, rests directly on the migmatitic gneisses of the core of the

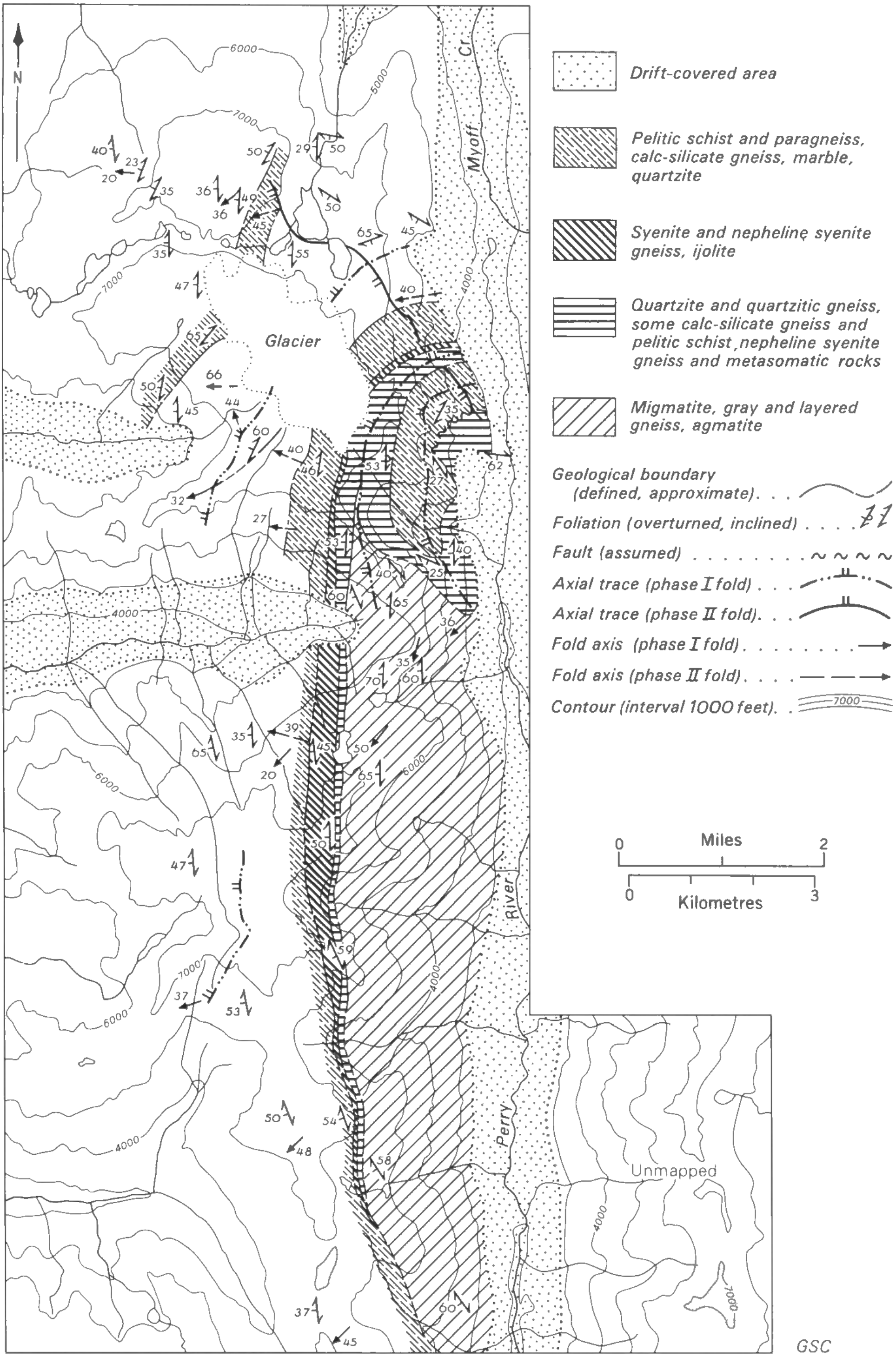

FIGURE 74. Geology of the west flank of the Frenchman's Cap gneiss dome (after McMillan, 1970).

Frenchman's Cap Dome. The syenitic rocks, strongly foliated save for a few pegmatites, contain 10–80 per cent nepheline, together with biotite and microcline perthite. Nepheline is almost always partly altered to cancrinite or hydronepheline. Varying amounts of aegirine, partly altered to riebeckite, and small but persistent amounts of calcite are commonly present. Accessory minerals include zircon, apatite, calcite, sphene, allanite, pyrochlore, and garnet. In the central part of the syenite layer a few feet of medium-grained, golden-weathering ferroan calcite occurs, together with minor biotite, apatite, rare augite, and varying amounts of albite syenite fragments. In an overlying unit of calc-silicate rocks, microcline-rich horizons are developed by replacement of plagioclase, and in some cases nepheline is developed at the expense of plagioclase. Aegirine is found sporadically in otherwise unaffected rocks. The chemical composition of the rocks is shown in Table 33.

Age
Unknown. Presumably the same as that of the Mount Copeland complex.

Economic aspects
Disseminated molybdenite is found in the nepheline syenite, and is now (1972) the object of an economic evaluation.

Remarks
The mineral assemblages in the Perry River occurrence are consistent with upper amphibolite facies metamorphism. McMillan (1973) deduced minimum temperatures of 620 degrees with possible temperatures as high as 840 degrees. Such temperatures are consistent with the existence of some amount of syenitic melt.

Selected references

McMillan, W. J. (1970): West flank, Frenchman's Cap gneiss dome, Shuswap Terrane, B.C.; Geol. Assoc. Can., Spec. Paper 6, p. 99–106.

McMillan, W. J. (1973): Petrology and structure of the west flank, Frenchman's Cap Dome near Revelstoke, B.C.; Geol. Surv. Can., Paper 71-29.

TABLE 33 *Chemical analyses of rocks from the Perry River nepheline syenite gneisses (after McMillan, 1973)*

	1	2	3	4	5	6	7
SiO_2	51.44	57.34	46.18	55.67	51.33	41.77	53.02
TiO_2	0.27	0.30	0.94	0.28	0.38	0.52	0.21
Al_2O_3	24.42	22.98	28.11	23.59	23.57	31.71	27.12
Fe_2O_3	1.32	1.33	2.57	1.45	2.37	1.49	0.46
FeO	1.40	0.59	4.08	0.63	0.44	0.29	1.14
MnO	0.10	.07	0.29	.09	.09	.10	0.09
MgO	.15	.24	1.12	.51	.79	.46	.31
CaO	4.23	.59	4.63	2.06	2.97	3.47	6.33
Na_2O	9.44	5.06	3.00	4.12	7.51	12.23	4.24
K_2O	3.55	10.18	5.80	8.99	6.69	4.70	6.41
P_2O_5	0.16	—	0.60	0.10	0.36	0.16	0.31
H_2O	1.97	0.70	1.50	.78	1.62	.89	1.04
CO_2	1.5	.5	1.1	.6	1.2	.7	0.8
TOTAL	99.95	99.88	99.92	98.87	99.32	98.49	101.48

1. Oligoclase-nepheline-biotite migmatite.
2. Microcline-nepheline-biotite syenite.
3. Microcline-riebeckite syenite with calcite and minor biotite.
4. Leucocratic microcline-oligoclase-nepheline-biotite gneiss.
5. Mesocratic-microcline-oligoclase-nepheline-biotite gneiss.
6. Nepheline-biotite pegmatite.
7. Microcline-oligoclase-nepheline-biotite gneiss.

Name
Trident Mountain (G-R97; Fig. 75)

Location and access
Trident Mountain is located in the Big Bend of Columbia River, about 50 miles northeast of Revelstoke, B.C., and not far from the Mica Dam site (52°00′N, 118°

	10′W). The area is accessible by road to the Mica Dam site from Revelstoke, or by the old Big Bend Highway, but Trident Mountain cannot be reached directly from either road, so that helicopters are the most satisfactory means of access.
Form and structure	Nepheline syenite gneiss occurs as a lenticular mass high on the slopes of Trident Mountain, which displays several long narrow extensions along the strike of the enclosing metamorphic rocks. Thin lenses of nepheline-bearing material are present in the surrounding quartzofeldspathic gneisses, but their exact extent is poorly known. The regional strike is north-northwest.
Petrography	The surrounding gneisses of the Proterozoic Horsethief Creek Group consist of upper amphibolite-grade quartzofeldspathic gneisses, with rare calc-silicate bands. Nepheline-bearing gneisses form conformable lenses at one or more horizons, composed of coarse-grained, crumbly aggregates of nepheline and albite with lesser amounts of cryptoperthitic potash feldspar and a greenish acmitic pyroxene with very strong optic absorption. Calcite and apatite are persistently present in accessory amounts. Nepheline has a characteristic irregular, poikiloblastic habit, even in the local nepheline-rich pegmatitic phases. In the nepheline-poor marginal phases of the syenitic rocks, biotite is the mafic mineral, and aegirine is absent.
Age	Unknown.
Economic aspects	None known.
Remark	Trident Mountain lies considerably to the northeast of the Frenchman's Cap Dome, but the nepheline-bearing rocks are strikingly similar in the two settings.
Selected reference	Wheeler, J. O. (1965): Big Bend map-area, B.C.; Geol. Surv. Can., Paper 64-32.

Name	Kinbasket Lake (G-R98; Fig. 75)
Location and access	The Kinbasket Lake nepheline syenite occurs on the east side of Columbia River where it flows into Kinbasket Lake. Nepheline-bearing rocks are found in two locations at the mouth of Sullivan River (51°52′N, 117°57′W). The locality is readily accessible from the old Big Bend Highway along the Columbia River.
Petrography	The host rocks, belonging to the lower Cambrian Hamill Group, are moderately metamorphosed quartzites and mica schists with rare limy interbeds. The nepheline-bearing rocks display a strong foliation conformable to the surrounding metasedimentary rocks, but are nowhere found in direct contact with them. Crumbly, coarsely granular fabrics of nepheline and albite, with pegmatitic schlieren, are typical of the occurrences. The only known outcrops are poorly exposed plates in the delta of Sullivan River, so that little is known about the occurrence.
Age	Unknown.
Economic aspects	None known.
Remarks	Another poorly exposed mass of syenite is found some 20 miles to the southeast at the headwaters of Chatter Creek, but little or no nepheline seems to be present. The lithologies in the Hamill and Horsethief Creek groups are different; their ages are believed to be substantially different. Even supposing that the rocks involved in the Shuswap Metamorphic Complex are equivalent to one or the other, it is very unlikely that all the nepheline gneisses in this region were originally emplaced at the same stratigraphic horizon.
Selected reference	Fyles, J. T. (1960): Geological reconnaissance of the Columbia River between Bluewater Creek and Mica Creek; B.C. Dept. Mines, Ann. Rept., 1959, p. 103–104.

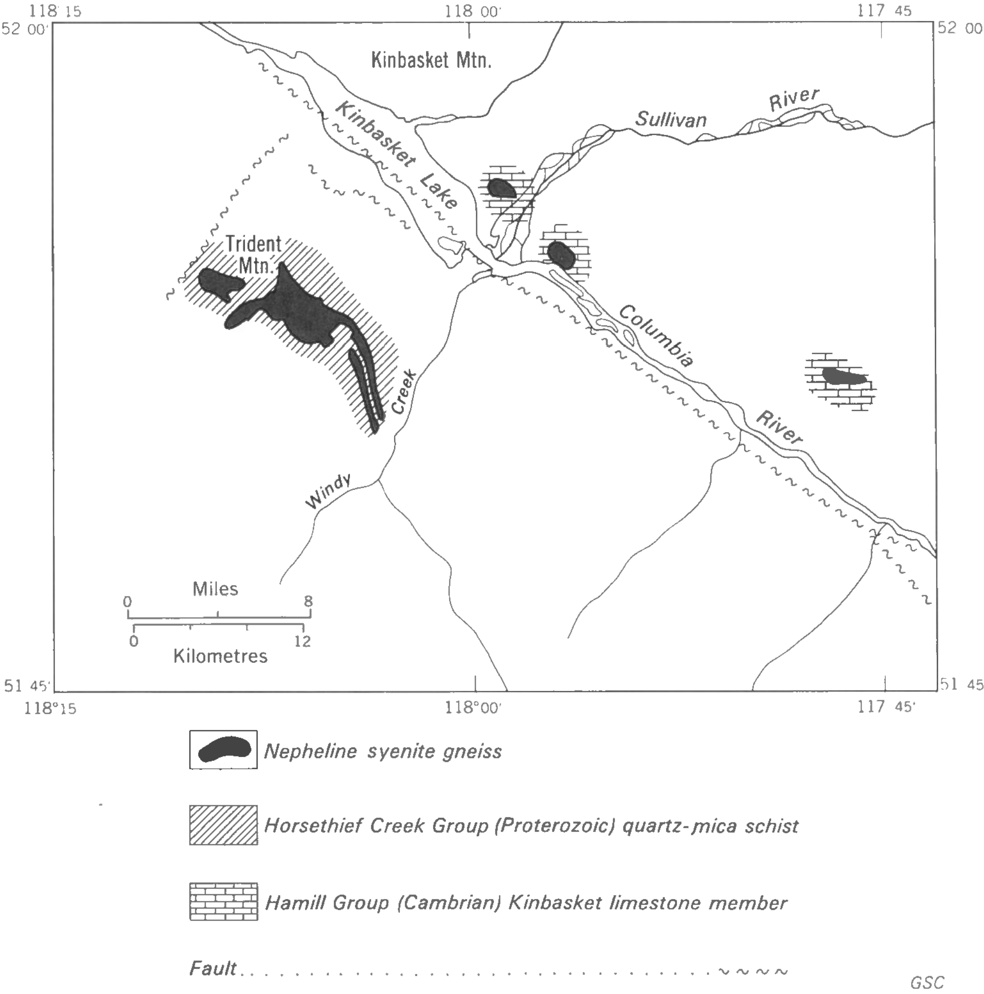

FIGURE 75. Geology of Trident Mountain and Kinbasket Lake nepheline gneisses.

Name	Southeastern Ontario nepheline syenite belt (Fig. 76)
Location and access	Nepheline-bearing, generally gneissic rocks occur in a thin, semicontinuous band extending some 65 miles from Greens Mountain in Glamorgan Township, Haliburton County, to Mount St. Patrick, Brougham Township, Renfrew County. An outlying occurrence of similar character occurs in Burleigh and Methuen townships, Peterborough County, about 25 miles to the south of the main belt. All of the occurrences may be reached with relative ease from highways and secondary roads, and good maps are available as guides.
Form and structure	Nepheline-bearing rocks occur as part of a stratigraphic sequence in which marble and calc-silicate rocks are commonly prominent. Gabbro is commonly present in the vicinity of nepheline-bearing rocks. Granite, where present, clearly intrudes the nepheline-bearing rocks, commonly with replacement effects. The nepheline-bearing rocks occur as thin lenticles, rarely more than a few hundred yards wide, which may

be rather persistent along strike. Even where the lenticles appear to stop, close examination often reveals fine extensions which may widen again farther along strike. The gneissosity is commonly good, but pegmatitic schlieren and veins are a highly characteristic feature. The lenticles of nepheline gneiss are commonly strongly curved, and appear to be wrapped around various tectonic elements of the region. All of the nepheline gneisses except the Blue Mountain deposit occur within upper amphibolite-grade rocks of the Haliburton Highland, whereas the Blue Mountain mass lies within lower amphibolite or greenschist facies rocks of the Hastings basin. The boundary between the metamorphic provinces is regarded by Hewitt (1957) as a major fault.

Petrography

The nepheline-bearing rocks vary from massive, igneous-appearing varieties to nepheline-bearing amphibolite. In general, the igneous aspect decreases from southwest to northeast. The grey or white nepheline-bearing rocks commonly contain biotite as the mafic mineral, although amphibole or pyroxene varieties are locally prominent, particularly at the western end of the belt. The immediate country rocks are invariably distinctive pink or buff syenites, which sporadically contain corundum, and always contain biotite. Nebulous beds and schlieren of amphibolite and biotite gneiss, often displaying coronitic textures, are a feature of this syenite, which is a much more persistent stratigraphic unit than the nepheline-bearing rocks.

Age

Much work has been done on the age of various minerals from the alkaline rocks. With the exception of the Blue Mountain deposit, this work has consistently given ages in the range 900–1,050 m.y., with a mean near 1,000 m.y. Among these results are K-Ar determinations on nepheline, biotite, and muscovite; Pb-U determinations on uraninite and zircon; and Rb-Sr whole rock isochron work. Rb-Sr data on the Blue Mountain complex suggest an isochron age of 1,285 m.y. Thus the least metamorphosed rocks give ages older than the last metamorphism (Grenville metamorphism approximately 1,000 m.y. ago). These older ages may approximate the date of formation of the rocks, whereas the other ages have been reset. The age of formation, if it is 1,285 m.y., is very close to that of the formation ages of the surrounding metasedimentary rocks, as determined by the Rb-Sr isochron method.

Economic aspects

Blue Mountain is the major producer of nepheline syenite in the western world. Many other occurrences in this region have been examined and tested for nepheline production, but no other deposits have yet been brought into production. The belt was extensively examined during the Second World War as a possible source of aluminum, but the recovery of aluminum from nepheline concentrates does not appear economically attractive at present. The alkaline rocks have been extensively prospected for uranium and rare-earths. With the possible exception of the Silver Crater property, it seems very doubtful if any uranium deposits are linked to the alkaline rocks.

Selected references

Adams, F. D. and Barlow, A. E. (1910): Geology of the Haliburton and Bancroft areas, Province of Ontario; Geol. Surv. Can., Mem. 6.

Hewitt, D. F. (1957): Haliburton-Bancroft area; Ont. Dept. Mines, Map 1957b.

Hewitt, D. F. (1960): Nepheline syenite deposits of southern Ontario; Ont. Dept. Mines, Ann. Rept., v. 69, pt. 8.

Name

Monmouth and Glamorgan townships (G-098; Fig. 77)

Location and access

The nepheline-bearing rocks occur in an east-northeast-trending belt stretching from Greens Mountain in Glamorgan Township to the vicinity of Tory Hill in the northern part of Monmouth Township. All the occurrences can readily be reached on foot from Ontario Highways 121, 503, and 507, and local roads.

Form and structure

Nepheline-bearing rocks occur as thin lenticles in the surrounding syenite, which is in turn enclosed in marble. Toward the northeast the lenticles become larger, and more

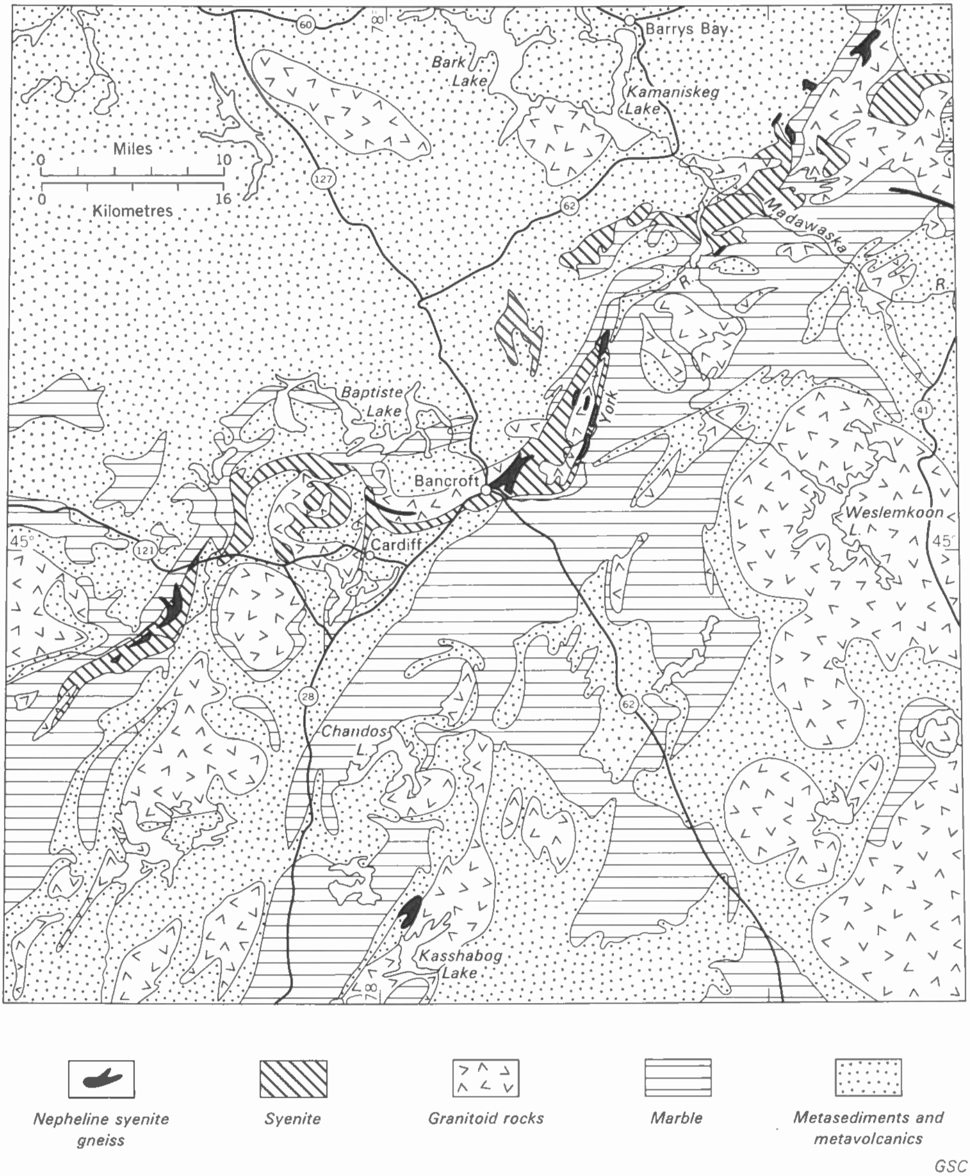

FIGURE 76. Geology of the southeastern Ontario nepheline belt (mainly after Hewitt, 1957 and 1960).

continuous. The gneiss belt follows a sinuous course, some 13 miles long, between granitic masses to the northwest and southeast, and a metagabbro-diorite mass to the south.

Petrography

Nepheline syenite occurs as lenticles, mainly of biotite-nepheline gneiss, enclosed in a lineated, medium-grained, buff hornblende syenite gneiss. At the southwestern end of the belt the syenite is enclosed in marble, but near the Monmouth Township line the syenite band wraps around a metamorphosed gabbro pluton. At this locality the rocks have igneous texture, dominated by laths of albitic plagioclase and cubic nepheline idiomorphs in a matrix of hedenbergite, hastingsite, and occasional biotite. The clinopyroxene grades from purplish titanaugite centres through hedenbergite and coronas of hastingsite plus albite. The nepheline is noticeably more sodic than the Burger Morozewicz composition (Table 34), and contains rod-like inclusions of clinopyroxene. Recalculation of the chemical analyses into the CIPW norm gives moderately calcic plagioclase, compared to the observed albite or oligoclase. These facts, together with the observed plastic 'necking' of many phenocrysts, suggest that some metasomatism and/or metamorphism has been involved in formation of the rocks. Farther northeast in Lot 4, Con. IV, of Monmouth Township, similar rocks contain much more microperthite and a little fayalitic olivine mantled by clinopyroxene. Some finer grained more mafic variants, rich in olivine, are strikingly similar to some of the syenites of the Port Coldwell complex. To the northeast this rock passes gradationally into the usual white biotite-nepheline gneiss, becoming steadily poorer in nepheline, and terminating on the west side of the Irondale River after following the contact of the metagabbro for 12 miles.

To the east of this river, two belts of nepheline-bearing rocks may be followed. The more northerly follows the marble–granite contact, and contains biotite as the mafic mineral. In a few places this band is very rich in nepheline, contains clinopyroxene, and approaches urtite or ijolite. The destructive action of granite on nepheline-bearing rocks is well illustrated in Lot 15, Con. VIII, where both altered inclusions of nepheline-bearing rocks, and alteration of the nepheline-bearing rocks in situ are seen at the contact. A more southerly belt of nepheline-bearing rocks, lying about a mile to the south of those just mentioned, with some small occurrences even farther south, commonly contains hastingsite, as well as biotite, both characteristically rimming the magnetite grains. The two belts may be traced northeastward some 6 miles to an area about 3 miles northeast of Tory Hill, where they are truncated by a granite pluton, expiring in a series of isolated remnants.

Age

Phlogopite and uraninite from nepheline syenite in the vicinity of Tory Hill gave concordant K-Ar and Pb-U ages of 1,060 m.y. This is presumably the age of metamorphism that formed the gneiss. Other K-Ar ages on nepheline-bearing rocks range from 817 m.y. to 1,003 m.y.

Economic aspects

Numerous occurrences of molybdenite have been found near, but not in, the alkaline rocks. One old gold prospect occurs in the nepheline gneiss around the metagabbro, whereas several uranium prospects are sufficiently near the alkaline rocks to suggest a possible connection.

Remarks

The theory of igneous origin for the southeastern Ontario nepheline belt rests heavily on the evidence from Monmouth and Glamorgan townships. Although the textural and chemical evidence of primary igneous nepheline is impressive, there is sufficient proof of metasomatism and metamorphism of these rocks, as well as of a marked stratigraphic persistence, that their primary igneous origin is still slightly doubtful.

Selected references

Gittins, J. (1967): Nepheline rocks and petrological problems of the Haliburton-Bancroft area; *in* Geology of parts of eastern Ontario and western Quebec, S. E. Jenness, ed., Guidebook of the 1967 GAC-MAC-AZOPRO Meeting.

Gittins, J. (1968): Monmouth Twp., Ont. Dept. Mines, Map P. 60 (revised).

Gittins, J. (1969): Glamorgan Twp., Ont. Dept. Mines, Map P. 60 (revised).

Tilley, C. E. and Gittins, J. (1961): Igneous nepheline-bearing rocks of the Haliburton-Bancroft province of Ontario; J. Petrology, v. 2, p. 33–48.

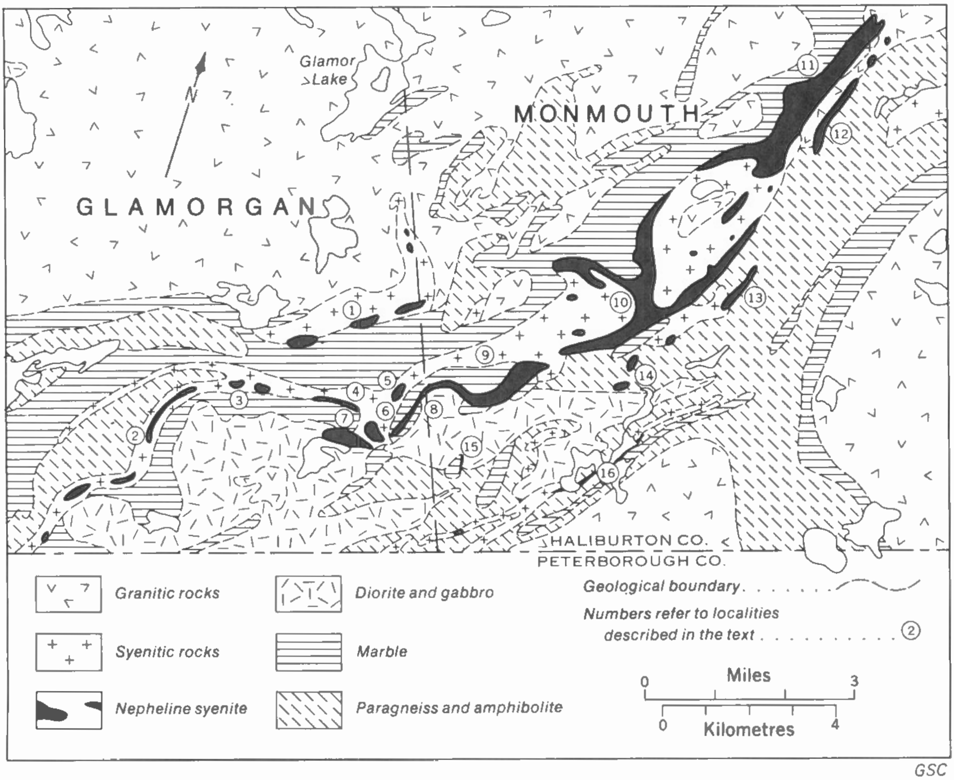

FIGURE 77. Occurrences of nepheline syenite in Monmouth and Glamorgan townships (after Hewitt, 1960).

TABLE 34 *Chemical analyses of alkaline rocks from Glamorgan and Monmouth townships (after Tilley and Gittins, 1961)*

	1	2	3	4	5	6	7	8	9
SiO_2	52.23	51.72	41.79	42.66	43.61	44.40	45.11	47.58	50.70
TiO_2	0.42	0.32	1.48	1.25	nil	nil	0.43	0.77	0.30
Al_2O_3	19.50	19.38	18.07	22.00	33.05	33.14	26.42	21.01	22.89
Fe_2O_3	4.44	4.22	3.94	4.45	0.85	0.18	1.31	4.65	4.86
FeO	5.78	6.70	13.54	9.16			4.78	4.21	2.33
MnO	0.21	0.17	0.24	0.18	0.01	nil	0.04	0.17	0.14
MgO	.20	.45	1.19	1.60	.05	0.05	1.09	.77	.30
CaO	3.52	3.45	9.84	8.05	.53	.36	5.51	4.48	3.25
Na_2O	7.59	7.06	6.61	6.87	16.09	17.17	4.08	7.62	7.95
K_2O	5.41	5.17	1.93	1.60	4.92	3.72	4.49	5.23	5.45
P_2O_5	0.14	0.16	0.34	0.39	—	—	0.10	0.24	0.05
H_2O	.60	.81	1.30	1.51	0.71	0.96	4.69	.91	.87
CO_2	.12	.03	0.15	0.18	—	—	2.08	3.17	1.18
TOTAL	100.16	99.64	100.42	99.90	99.81	99.98	100.13	100.81	100.27

1, 2. Olivine-bearing nepheline syenite of igneous texture, Monmouth tp.
3, 4. Nepheline-rich gabbro, Glamorgan tp.
5. Nepheline from analysis 1.
6. Nepheline from analysis 4.
7. Nepheline-oligoclase-biotite gneiss, Glamorgan tp.
8. Microcline-albite-nepheline-biotite-magnetite gneiss, Highway 121 at Esson Creek, Monmouth tp.
9. Microcline-albite-nepheline-biotite-hornblende gneiss Lot 6, Con. IV, Monmouth tp.

Name	Faraday Township (G-099; Fig. 78)
Location and access	The nepheline-bearing rocks all occur within a narrow belt west of the town of Bancroft, Ontario, along which Highway 123 passes. Thus almost all the occurrences in Faraday Township can be reached in a few minutes by walking from this road. The small occurrences in Cardiff Township can be reached from a loop of road passing from Highway 123 to the hamlet of Deer Lake.
Form and structure	The belt of syenitic rocks containing the nepheline gneiss bends northward in a great arc through Cardiff Township around the complex and contaminated syenitic massif centred on Deer Lake, and then southward through Faraday Township around a granite batholith. The syenite seems originally to have been enclosed in marble, but most of the marble on the side next to the large plutons has been lost. The syenite band narrows markedly in Faraday Township, apparently from tectonic milling, for strong mylonitization is present.
Petrography	In Cardiff Township, bands of hybrid and contaminated syenite are present, including three regions containing corundum with associated negligible amounts of nepheline-bearing rock. In Faraday Township, where the syenite belt is only about a half mile wide, it consists of red biotite syenite, commonly gneissic, with vast numbers of schlieren, blocks, and laminae of amphibolite. Along the southern side of the belt, more massive amphibolites possibly represent metamorphosed basic igneous rocks. Thin lenses of marble are present, but the major marble unit lies farther to the south. Nepheline gneiss occurs as narrow lenses up to 200 yards wide by 2 miles long. The major part of the nepheline gneiss is pinkish nepheline-albite-biotite gneiss, with persistent, and sometimes essential, scapolite. Many of the occurrences appear to be partly replaced and altered by the surrounding syenite. Alkaline skarn occurs at the contact of the basic amphibolite, where nepheline locally appears to replace plagioclase, and masses of nepheline-aegirine-plagioclase-scapolite-crocidolite-garnet rocks are present. Nepheline-bearing mylonite, with 'rolled' inclusions, occurs near Stranyer Lake.
Age	Assumed to be the same as that of other parts of the belt.
Economic aspects	Uranium mineralization and noncommercial apatite deposits are associated with the syenitic rocks. Some authors claim that large calcite-fluorite veins in the syenite are carbonatitic. Molybdenite is locally found in the syenitic rocks, but is more common in the surrounding granite pegmatites. Minor occurrences of corundum are known in the syenite.
Selected reference	Hewitt, D. F. (1957): Geology of Cardiff and Faraday Townships; Ont. Dept. Mines, Ann. Rept., v. 66, pt. 3.

Name	East Road (G-0100; Fig. 79)
Location and access	The East Road area lies to the east of Bancroft, along Ontario Highway 500 (the East Road of geological literature). The principal outcrops can readily be reached from this highway on foot, or from subsidiary roads to Bronson Landing.
Form and structure	The narrow belt of syenite in Faraday Township broadens into a triangular area roughly 5 miles on a side, terminated to the east by another subcircular mass of granite. Nepheline-bearing rocks are present in the very hybrid syenite complex as two bands, locally anastomosing and forming complexly folded pods. Numerous nepheline-bearing pegmatitic veins and pods are present. The main gneiss band extends 4 miles east from Bancroft.
Petrography	Three main varieties of nepheline-bearing rocks are present, and these may be complexly interleaved in a single occurrence. The most common is nepheline-plagioclase-biotite (± corundum) gneiss. Completely conformable layers of these rocks are found within an intricate assemblage of amphibolitic paragneisses, minor

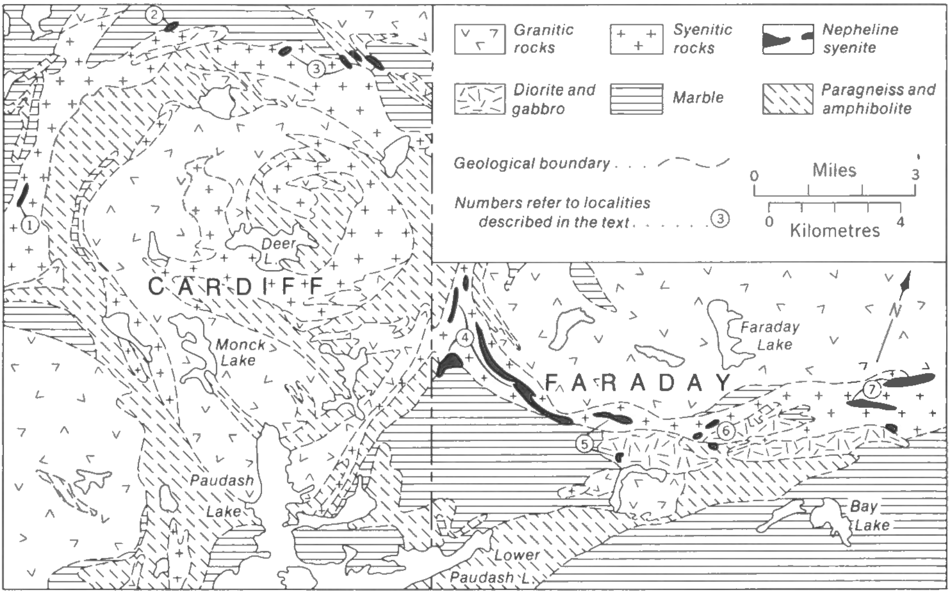

FIGURE 78. Occurrences of nepheline syenite in Cardiff and Faraday townships (after Hewitt, 1957).

marble, and syenite gneiss, in a matrix of pink, leucocratic hornblende syenite gneiss. The nepheline content varies erratically along and across strike, and is notably low near the syenitic rocks, where remaining nepheline is converted to pink 'hydronepheline.' Corundum, if present, is always surrounded by muscovite, and may display haloes of nepheline, or magnetite + spinel. The second type of gneiss, nepheline-plagioclase-scapolite, seems more common where some marble is present in the succession. A purplish blue scapolite is characteristic of some parts of the East Road belt, but the more common grey scapolite is distinguishable from nepheline only with difficulty. Gem-quality scapolite occurs near Bronson Landing in a remnant surrounded by granite. The third type of nepheline-bearing rocks, the pegmatites, occurs as veins or irregular patches in the gneisses. Giant nepheline crystals, commonly exceeding a foot in diameter, are present, along with large albite crystals. Small amounts of biotite, hornblende, calcite, giant zircon crystals, galena, apatite, and molybdenite may be present. Secondary sodalite and cancrinite are characteristically developed on fractures. At the Princess Quarry, 2 miles east of Bancroft, the sodalite alteration zone reaches a width of 3 feet.

Age

K-Ar dating of nepheline and biotite from the Princess Quarry gave concordant ages of 900 m.y., but sodalite gives erratic and much older ages, presumably due to excess argon. K-Ar ages on minerals from another quarry gave a range from 743 m.y. for feldspar to 903 m.y. for nepheline.

Economic aspects

The nepheline pegmatites have been extensively prospected as a source of nepheline, thus far without success. Some old pits were blasted for corundum. The belt is now a famous mineral-collecting locality, and many of the outcrops have been almost obliterated by over-enthusiastic collectors.

Selected reference

Hewitt, D. F. and James W. (1956): Geology of Mayo and Dungannon Townships; Ont. Dept. Mines, Ann. Rept., v. 64, pt. 8.

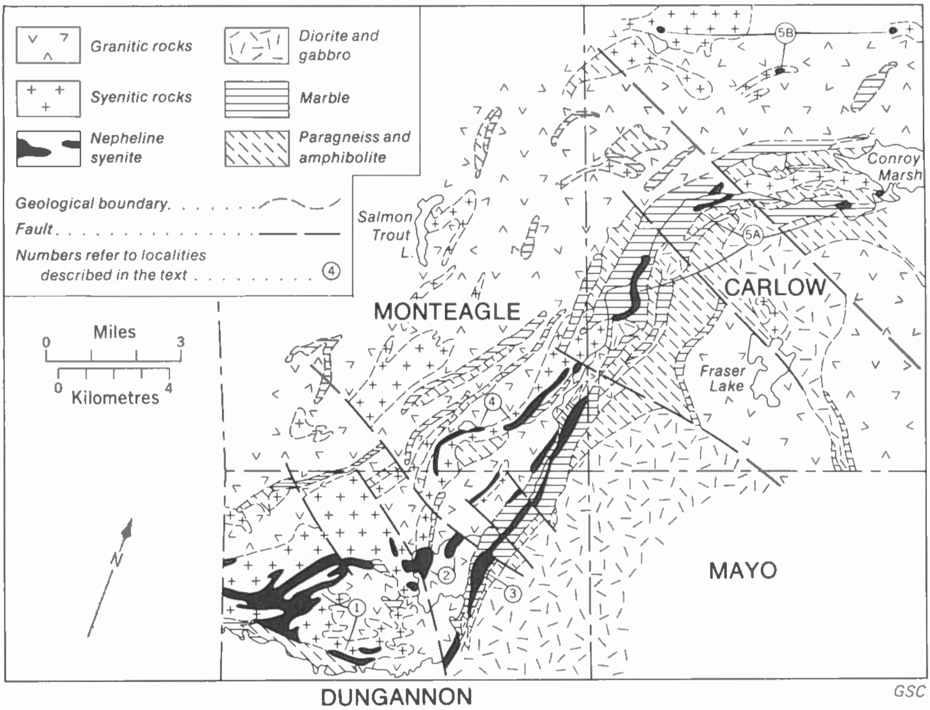

FIGURE 79. Occurrences of nepheline syenite in Dungannon, Monteagle, and Carlow townships (after Hewitt and James, 1956). The circled numbers refer to the following areas: 1. East Road area; 2. Bronson Landing; 3. York River belt; 4. Monteagle corundum belt; 5. Outlying occurrences (A) in the main syenite belt, and (B) outside the main syenite belt.

Name	York River (G-001; Fig. 80)
Location and access	The York River nepheline gneiss belt runs north for some 8 miles from the bridge carrying Ontario Highway 500 over York River. The belt is easily reached from this highway by an old wagon road running along most of its length.
Form and structure	The gneisses form a thin east-dipping sheet between granite on the west and metagabbro on the east. The nepheline-bearing rocks are cut by dykes of granite pegmatite, and at the contact the nepheline gneiss is poor in nepheline and takes on a feldspar-rich composition and a granoblastic texture. The eastern edge of the gneiss belt is composed of marble, converted to amphibolite along the contact with the metagabbro, and many fine marble interbeds occur within the gneisses. The gneiss belt falls into three stratigraphic divisions, readily recognizable in drill core. The lowest is poor in nepheline, the middle member is melanocratic, and the top member is leucocratic.
Petrography	The lower member consists of mesocratic gneisses containing oligoclase, scapolite, and minor nepheline, with biotite and minor blue tourmaline as the dark minerals. Microcline occurs as thin layers and patches that appear to alter and replace nepheline. The middle member is characterized by the occurrence of many thin marble and calc-silicate layers. The rocks appear relatively homogeneous and melanocratic, and may contain up to 60 per cent nepheline plus a ferroaugitic pyroxene, and various amounts of an andraditic garnet, calcite, and albitic plagioclase.

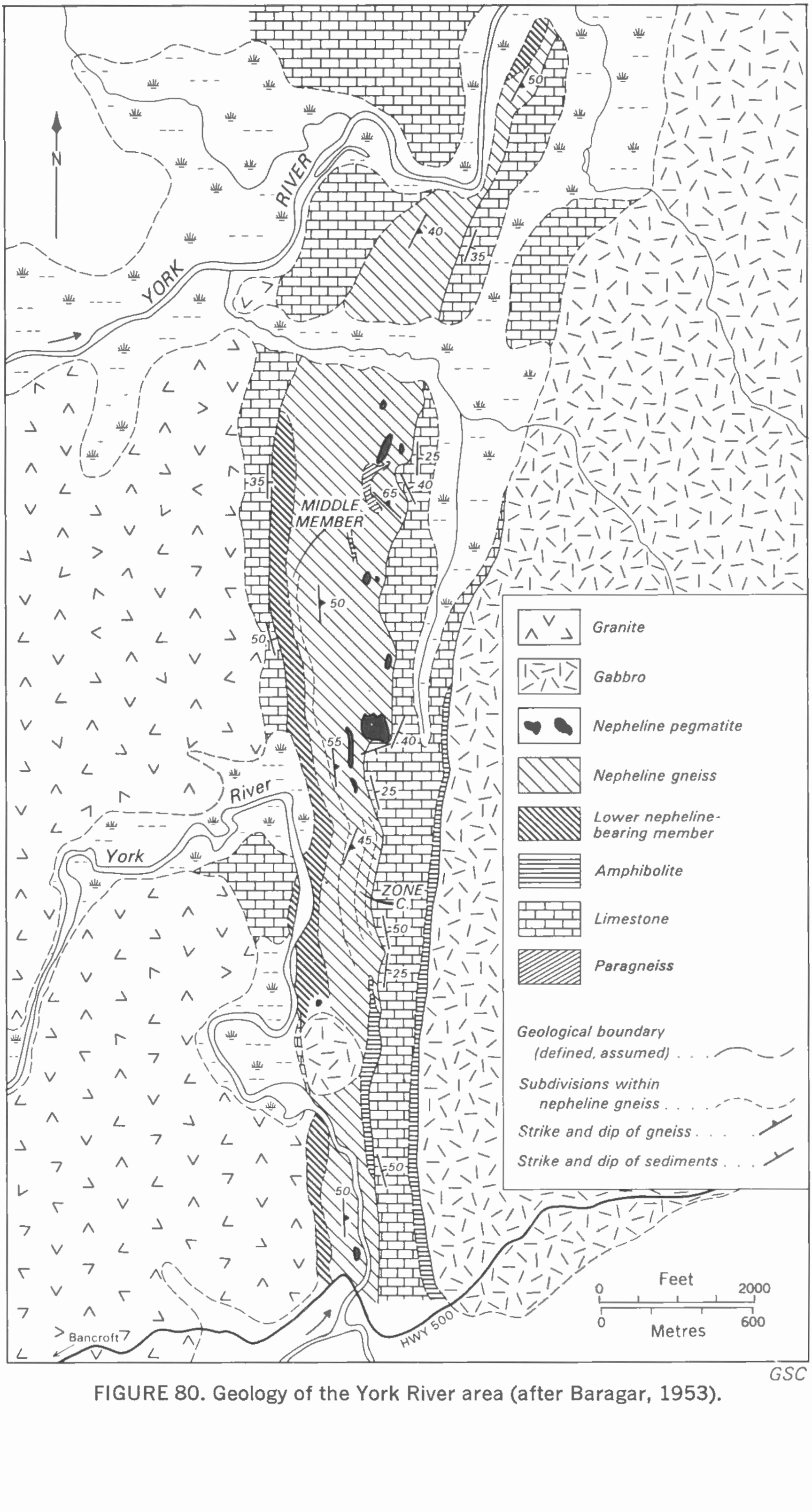

FIGURE 80. Geology of the York River area (after Baragar, 1953).

The amphibolite bands in this member may contain an aegirinic pyroxene. Replacement of plagioclase by nepheline is a characteristic feature of this whole belt, but is particularly prominent in this member. Striking examples of garnet haloes around nepheline, which has apparently replaced pyroxene, are also observed. Toward the top of the unit, this process has produced many pegmatitic patches very rich in nepheline. The upper member of the sequence is a thinly layered, leucocratic nepheline syenite gneiss containing hornblende and minor amounts of aegirine. Thin marble layers are present, and the gneiss often contains small amounts of calcite and/or vesuvianite. The chemical analyses (Table 35) show the similarities of the nepheline rocks to amphibolites derived from the marble.

Age — Nepheline, biotite, and feldspar from an old quarry gave K-Ar ages of 903 m.y., 850 m.y. (average of 3), and 743 m.y., respectively.

Economic aspects — Much prospecting and a little quarrying has been done for nepheline, either for ceramics or for aluminum, in this belt. Most occurrences contain sufficient calcite to ruin the product for ceramic purposes.

Remarks — The York River belt is the classic example of nephelinitization in Canada. Almost all experts on the area are agreed that the nepheline-bearing rocks are the result of metasomatism, and are but distantly, if at all, connected to igneous activity.

Selected reference — Baragar, W. R. A. (1953): Nepheline gneisses of York River, Ontario; Proc. Geol. Assoc. Can., v. 6, p. 83–115.

TABLE 35 | *Chemical analyses of the York River nepheline gneisses* (*after Baragar, 1953*)

	1	2	3
SiO_2	45.22	41.73	39.30
TiO_2	0.96	0.29	1.96
Al_2O_3	14.07	27.48	13.03
Fe_2O_3	4.02	1.84	6.51
FeO	12.49	4.52	12.52
MnO	0.70	Trace	0.74
MgO	2.47	1.24	4.86
CaO	17.78	6.78	16.97
K_2O	0.93	3.16	0.97
Na_2O	5.02	11.05	2.01
P_2O_5	0.23	0.14	0.74
H_2O	.77	.52	.58
CO_2	nil	.93	nil
TOTAL	99.66	99.68	99.89

1. Nepheline-poor part of gneiss.
2. Nepheline-rich (72%) part of gneiss.
3. Amphibolite horizon within nepheline gneiss (note resemblance to analysis 1).

Name — Carlow-Monteagle (G-0102; Fig. 79)

Location and access — The East Road nepheline gneiss belt appears to split into two branches marked by numbers 1 and 2 on Figure 79. The southern continuation forms the York River belt (number 3, Fig. 79), whereas the northern branch (number 4) continues across Carlow and Monteagle townships to the vicinity of Conroy Marsh. Small remnants of nepheline-bearing rocks continue northeastward for another 25 miles (number 5A, Fig. 79) through Raglan, Brudenell, Sebastopol, and Brougham townships, Ontario, into Admaston Township where the belt disappears beneath Paleozoic sedimentary rocks in the Ottawa Valley graben. All of these occurrences are accessible from various highways and secondary roads noted in the general references on the nepheline belt, although the walking conditions in some instances are poor.

Petrography The country rock of all the nepheline occurrences is a buff- to pink-coloured gneissic syenite that locally crosscuts the nepheline-bearing rocks. This syenite and the nepheline-bearing rocks form part of a sequence 2 to 3 miles wide, including paragneiss, amphibolite, and marble, which can readily be traced as far as the eastern boundary of Carlow Township, where it loses its continuity and reappears only as a chain of isolated remnants. Where nepheline is present in the syenite it is nearly always found with corundum, mantled by muscovite. The mafic minerals are typically biotite, hastingsite, and magnetite, and the colour index ranges from 20–30. Garnet and aegirine may be present if the occurrence is close to marble, and scapolite is erratically present, forming a major component in a few cases. Pegmatitic patches are rare. The widespread presence of corundum in these rocks is reflected in extreme Al_2O_3 contents (Table 36). The extreme depletion of these rocks in MgO and FeO is of interest.

Age Assumed to be the same as that of the rest of the belt.

Economic aspects Many of these occurrences formerly produced small amounts of corundum, particularly the Craigmont Mine, but now they are not considered to be of economic significance.

Remarks The eastern termination of the nepheline belt is not known. The easternmost locations, Mount St. Patrick in Brougham Township, and the occurrence in Admaston Township (Quinn, 1952), both overlook younger rocks in the Ottawa Valley graben, and it is possible that the belt extends into Quebec in the region of Quyon.

Selected references

Hewitt, D. F. (1960): Nepheline syenite deposits of southern Ontario; Ont. Dept. Mines, Ann. Rept., v. 69, pt. 8.

Quinn, H. A. (1952): Renfrew map-area, Renfrew and Lanark Counties, Ontario; Geol. Surv. Can., Paper 51-27.

TABLE 36 *Chemical analyses of rocks from the Carlow-Monteagle corundum belt (after Hewitt, 1960)*

	1	2	3	4	5	6
SiO_2	49.38	55.45	45.90	64.37	52.29	57.00
TiO_2	Trace	0.30	0.07	0.15	0.21	0.14
Al_2O_3	30.54	26.10	29.79	19.41	25.67	24.91
Fe_2O_3	0.40	0.81	1.82	1.10	2.35	3.47
FeO	0.06	0.49	1.44	0.80	1.87	1.26
MnO	Trace	.01	0.04	.01	0.03	0.02
MgO	0.19	.13	.71	.06	Trace	Trace
CaO	1.87	3.65	3.16	0.31	1.28	0.50
K_2O	3.70	1.62	3.26	5.73	3.49	3.00
Na_2O	13.94	9.31	8.26	6.77	11.26	7.90
H_2O	0.50	1.64	3.78	0.40	0.83	1.21
P_2O_5	.62	0.01	Trace	Trace	Trace	Trace
CO_2	Trace	.88	1.62	0.11	0.69	nil
TOTAL	101.20	100.40	99.85	99.22	99.97	99.41

1. Nepheline-muscovite syenite, trace of corundum, Craigmont Mine.
2. Corundum-rich nepheline syenite, Craigmont Mine.
3. Nepheline albite-corundum gneiss, Klondike Cuts.
4. Pink leucosyenite produced by metasomatism of (3).
5. Nepheline-muscovite-biotite-albite gneiss, Rosenthal Farm.
6. Pink leucosyenite produced by alteration of the above.

Name	Wolfe belt (G-0103; Fig. 81)
Location and access	The Wolfe nepheline gneiss belt lies in northern Lyndoch Township, about 5 to 10 miles south of the chain of nepheline-corundum occurrences stretching east from Carlow Township. The Wolfe belt is crossed by Ontario Highway 527, and is easily reached on foot from this highway and local farm roads.
Form and structure	The nepheline-bearing rocks form a prominent ridge extending about 4 miles in an east-southeast direction (compared to a northeast direction for the main belt). The nepheline gneiss forms part of a southward-dipping sequence of metasediments dominated by marble, but containing a narrow quartzite band just below the nepheline gneiss, and a thick calc-silicate unit at the top. The metasedimentary belt is truncated at the west end by a corundum-bearing pink syenite, and cut toward the centre by an aegirine-ferrohastingsite-biotite syenite.
Petrography	The lower (northern) half of the alkaline gneisses is composed of oligoclase veined and corroded by albite; perthitic microcline; poikiloblastic nepheline replacing feldspar and mafic minerals; and one or more of hastingsite, andraditic garnet, aegirine, and magnetite, all of which may be rimmed by green biotite. Scapolite is present near the lower marble, and accessory zircon, sphene, and fluorite are ubiquitous. Sodalite replaces nepheline locally, and cancrinite rims calcite inclusions in nepheline. Above a median band of nepheline-riebeckite-biotite amphibolite, locally bearing vesuvianite, is a layer of nepheline-bearing calc-silicate gneiss which comprises the southern half of the Wolfe belt. The rocks normally contain plagioclase (oligoclase to andesine), nepheline, calcic scapolite, hedenbergite partly replaced by hastingsite, and grossular, with calcite a common additional component. Where nepheline is abundant, vesuvianite tends to replace grossular, and sphene and apatite become abundant.
Age	Not clearly known. The development of nepheline postdated a first period of metamorphism, which raised the rocks to amphibolite grade, and predated a second period of deformation.
Economic aspects	None known.
Remark	The metasomatic character of the Wolfe belt seems to be as well attested as that of the better studied York River belt.
Selected references	Appleyard, E. C. (1967): Nepheline gneisses of the Wolfe belt, Lyndoch Township, Ontario. I. Structure, stratigraphy and petrography; Can. J. Earth Sci., v. 4, p. 371–397. Appleyard, E. C. (1969): Nepheline gneisses of the Wolfe belt, Lyndoch Township, Ontario. II. Textures and mineral paragenesis; Can. J. Earth Sci., v. 6, p. 689–719.

Name	Blue Mountain (G-0104; Fig. 82)
Location and access	About 35 miles northeast of Peterborough, Ontario, in Methuen Township. The towns of Nephton and Blue Mountain lie on the deposit, which may be reached by both highway and railway. In addition to two large quarries, a substantial amount of stripping has been done in the area.
Form and structure	The Blue Mountain nepheline syenite gneiss forms a teardrop-shaped mass about 6,500 feet long and 3,000 feet wide, with a narrow elongate tail extending about 6 miles farther west to Stony Lake. The deposit lies in the core of a syncline in metasedimentary rocks of epidote amphibolite grade. Biotite and/or garnet-bearing amphibolite, with lesser amounts of quartzofeldspathic gneisses and a thin, persistent marble occur near the syenite, together with a distinctive leucocratic grey gneiss containing ghost-like fragments slightly darker than the matrix. This sequence is

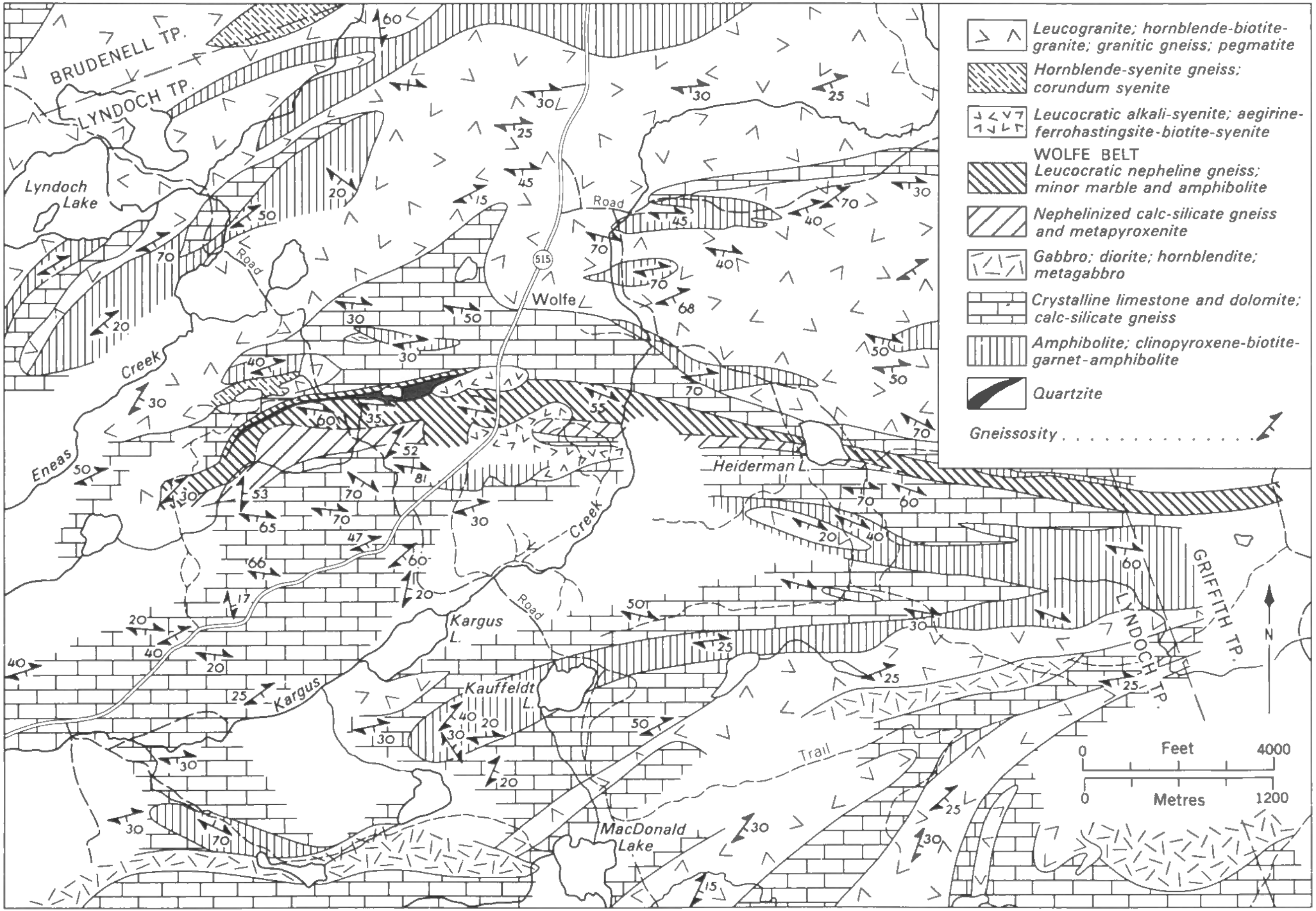

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FIGURE 81. Geology of the Wolfe nepheline gneiss belt (after Appleyard, 1967).

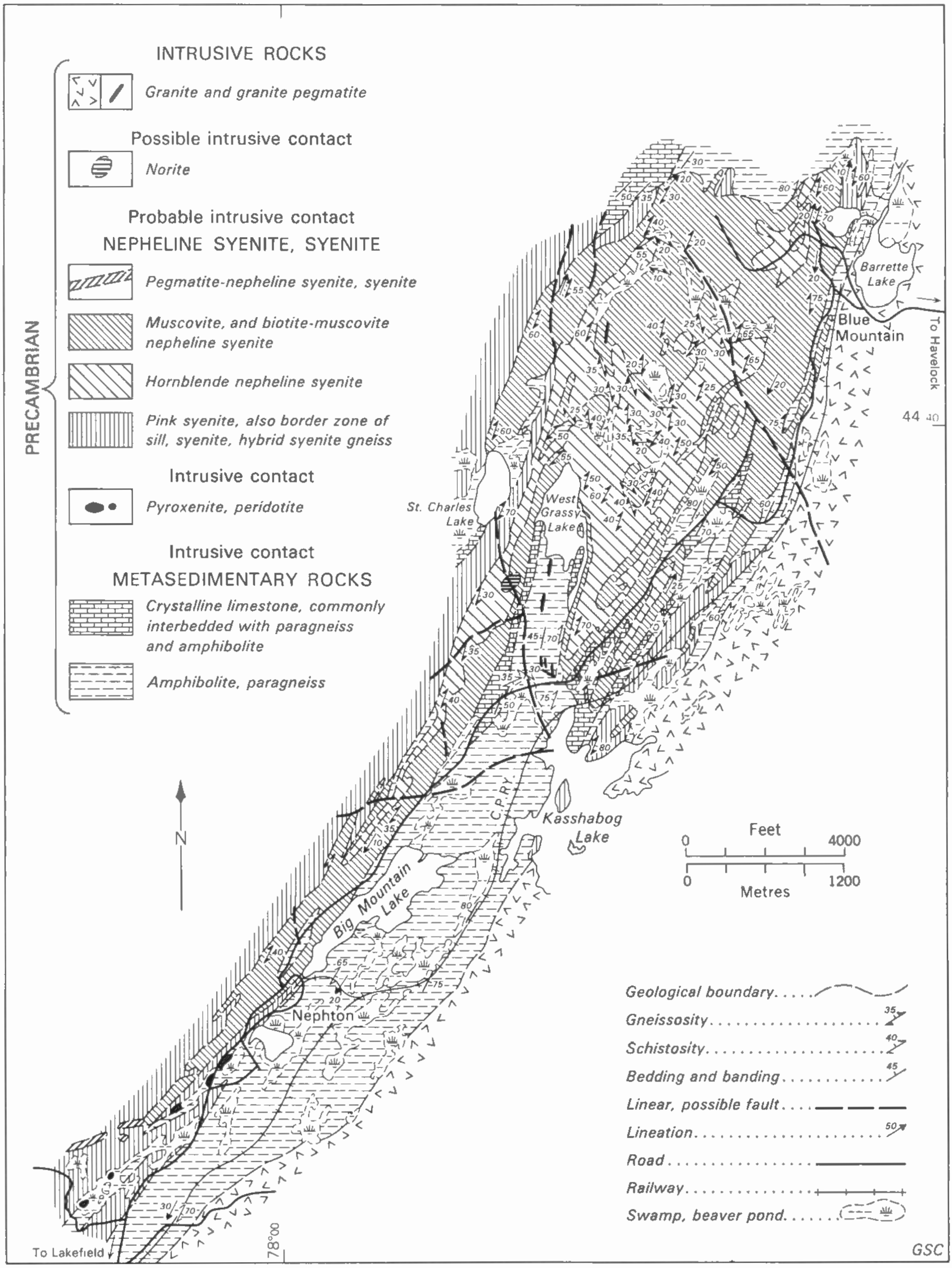

FIGURE 82. Geology of the Blue Mountain nepheline syenite (after Payne, 1968).

believed to overlie a major marble unit to the northwest, and be cut by younger granite to the southeast. The nepheline syenite locally transgresses and includes the metasedimentary rocks, but in other places shows gradational contacts.

Petrography The nepheline syenite is strongly and regularly zoned around a core of hornblende syenite containing accessory aegirine. The median shell is a biotite nepheline syenite with lesser amounts of muscovite, whereas the marginal zones, which are discontinuous, consist of nepheline-poor muscovite syenite with traces of corundum. Cancrinite, calcite, magnetite, zircon, and epidote are present in accessory amounts, and nepheline pegmatites containing sodalite and tourmaline are present in the central parts. All the rocks consist of about 50 per cent albite, with microcline and nepheline together comprising about 45–50 per cent, and all other minerals together comprising up to 5 per cent. To the west of Blue Mountain the nepheline-bearing rocks are invaded by buff syenite and altered to nepheline-poor rocks very rich in albite.

Age K-Ar age on biotite gave 900 m.y., whereas a whole rock Rb-Sr isochron gave 1,060 m.y. A mineral isochron by the Rb-Sr method, however, gives 1,285 m.y., which is presently thought to give the time of formation of the rocks, and the other values date the metamorphism.

Economic aspects Almost the entire North American production of nepheline syenite comes from two quarries on this deposit. Its commercial value stems from the remarkable uniformity of composition (Table 37), the relatively coarse grain size, and the low tenor in mafics. The rock is crushed dry to about −25 mesh, passed through high-intensity magnetic separators, and bagged or shipped in bulk. Production in recent years has exceeded 500,000 tons per year and is increasing.

Remarks Numerous attempts have been made to explain these deposits as the result of igenous intrusion, or of metasomatism. Neither theory has been entirely successful.

Selected references

Hewitt, D. F. (1960): Nepheline syenite deposits of southern Ontario; Ont. Dept. Mines, Ann. Rept., v. 69, pt. 8, p. 105–162.

Payne, J. G. (1968): Geology and geochemistry of the Blue Mountain nepheline syenite; Can. J. Earth Sci., v. 5, p. 259–273.

TABLE 37 *Chemical analyses of the Blue Mountain nepheline syenite (after Hewitt, 1960)*

	1	2	3	4	5	6	7	8	9	10
SiO_2	58.4	58.72	58.57	58.69	59.68	59.80	59.56	58.79	63.32	58.84
TiO_2	nil	0.01	0.05	0.01	nil	0.08	0.13	0.03	0.08	nil
Al_2O_3	24.8	23.07	23.68	22.70	23.48	22.12	24.69	23.77	18.97	23.26
Fe_2O_3	0.75	0.93	0.66	1.31	0.59	1.03	0.44	1.06	2.21	1.43
FeO	.46	.91	.90	0.67	0.37	1.61	1.28	0.81	0.88	0.53
MnO	.01	.04	.02	.04	nil	0.10	0.04	.04	.04	.05
MgO	.14	.03	nil	.07	0.21	.01	.03	.04	.01	.03
CaO	.59	.53	0.35	.56	.26	4.48	.43	.41	1.18	.66
K_2O	4.34	5.23	5.82	4.61	4.68	1.44	3.89	4.42	5.35	4.75
Na_2O	10.48	10.20	9.57	10.51	9.52	8.72	8.80	10.69	7.28	10.09
H_2O	0.42	0.42	0.31	0.19	0.66	0.46	0.60	0.28	0.35	0.19
P_2O_5	.01	.01	.07	.01	nil	.01	.02	.02	.03	.01
CO_2	.10	.14	nil	nil	0.04	.26	.19	.05	.63	.13
Total	100.50	100.24	100.00	99.37	99.49	100.12	100.10	100.41	100.33	99.97

1. White muscovite nepheline syenite gneiss from quarry.
2. Hastingsite-biotite nepheline syenite gneiss.
3. Biotite nepheline syenite gneiss.
4. Andradite-nepheline syenite gneiss.
5. Muscovite-biotite nepheline syenite gneiss.
6. Garnet-hastingsite nepheline syenite gneiss.
7. Nepheline-corundum-albite-muscovite-biotite gneiss, Stony Lake.
8. Nepheline-biotite-muscovite gneiss, Stony Lake.
9. Syenite gneiss (nepheline-free) bounding gneiss of analysis.
10. Nepheline syenite gneiss from quarry.

Name	Bigwood-Rutter (G-105; Fig. 83)
Location and access	The Bigwood-Rutter district lies near the northeast corner of Georgian Bay, just west of Ontario Highway 69, straddling the French River. The district is easily accessible on foot from Highway 69, and various local secondary roads.

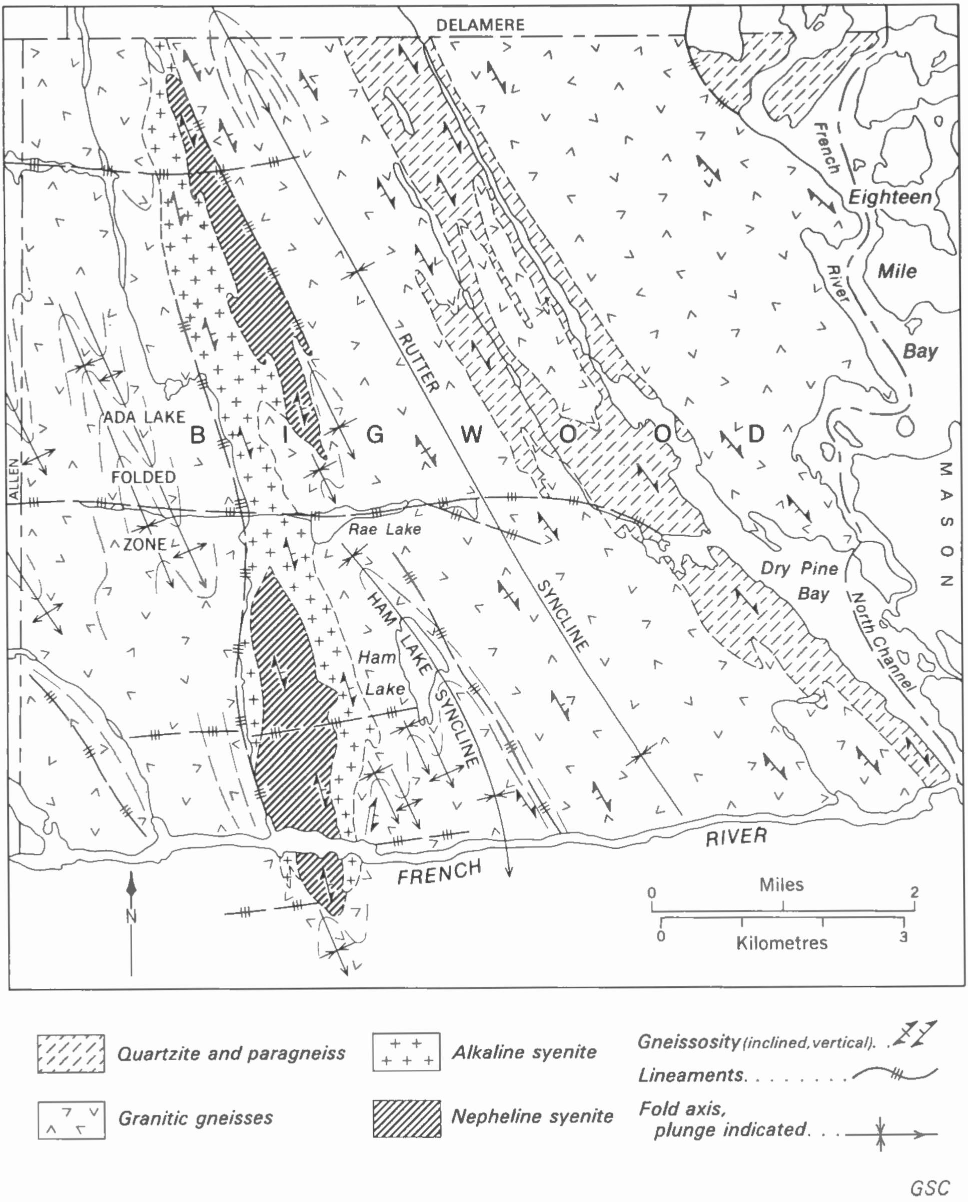

FIGURE 83. Geology of the Bigwood-Rutter nepheline gneiss (after Hewitt, 1960).

Form and structure Nepheline syenite gneiss occurs as lenses within a conformable band of syenite on the west side of a shallow north-trending syncline. The enclosing rocks are generally featureless granitoid gneisses, whereas the horizon equivalent to the nepheline-bearing rocks on the opposite side of the syncline is biotite gneiss. Cross faults parallel to the trend of the French River are prominent, but do not appear to be of large offset.

Petrography Two petrographically distinct lenses of nepheline-bearing rocks are recognized, the northern Rutter syenite, and the southern French River syenite. The northern body is a medium-grained, granoblastic, white, moderately foliated syenite consisting of nepheline (20–50 per cent), albite (40 per cent), microcline (20 per cent), and about 10 per cent of dark minerals, principally hastingsite with traces of aegirine. Complex perthites, and even three-feldspar rocks are present, but where perthite is present the nepheline is severely altered to zeolites. The nepheline throughout this body has a characteristic pink shade. The southern body is composed of nepheline syenite gneiss with about 15 per cent nepheline, 45–60 per cent albite, 10–20 per cent microcline, and 10 per cent biotite. Patch pegmatites rich in nepheline associated with large crystals of blue sodalite, orange and yellow cancrinite, and giant flexed crystals of molybdenite are found within this mass. Much of the nepheline in this body is extraordinarily transparent, and can be mistaken for quartz on fresh surfaces. At the edges of the body there is fine-scale interbedding of nepheline-bearing and nepheline-free gneisses. No evidence of intrusive relations was found. Chemical analyses in Table 38 show that the mineralogical differences correspond to the compositional differences.

Age Not known. The latest metamorphism was during the Grenville orogeny, but some gneisses in this region give much older ages.

Economic aspects None known. The persistent association of molybdenite is of some interest.

Remark The Bigwood-Rutter district shows that the development of nepheline gneiss does not require the presence of marble.

Selected reference Hewitt, D. F. (1960): Nepheline syenite deposits of southern Ontario; Ont. Dept. Mines, Ann. Rept., v. 69, pt. 8.

TABLE 38 *Chemical composition of nepheline gneiss from Bigwood-Rutter district (after Hewitt, 1960)*

	1	2	3	4	5	6
SiO_2	58.27	59.03	56.35	55.90	65.52	65.96
TiO_2	0.63	0.03	0.16	0.05	0.04	0.03
Al_2O_3	20.35	21.81	20.31	22.12	18.61	18.92
Fe_2O_3	1.33	2.34	2.66	0.96	1.00	0.48
FeO	2.92	1.34	4.09	4.33	1.17	.53
MnO	0.22	0.03	0.18	0.14	0.03	.03
MgO	.08	.06	.11	.37	.10	.08
CaO	.21	.53	1.69	.44	.45	.23
K_2O	3.88	4.36	4.86	6.42	5.13	5.90
Na_2O	11.68	10.78	8.31	8.35	7.59	7.17
H_2O	0.31	0.15	0.69	0.57	0.24	0.15
P_2O_5	.07	.02	.04	n.d.	.01	.04
CO_2	.32	nil	.67	0.67	.02	.16
TOTAL	100.27	100.48	100.02	100.32	99.91	99.68

1, 2. Hastingsite (-aegirine) -nepheline syenite gneiss from the northern (Rutter) lens.
3, 4. Biotite-nepheline syenite gneiss from the southern (French River) lens.
5, 6. Syenite enclosing nepheline-bearing rocks along the French River.

Name	Southwestern Quebec nepheline syenite belt (Fig. 84)
Location and access	Regional mapping by Wynne-Edwards *et al.* (1966) has established the presence of at least eight syenite or monzonite bodies in the upper Gatineau River area, some 100 miles north of Ottawa. Some of these bodies contain nepheline in marginal selvages. The bodies may be reached by foot from Quebec Highway 11, and various local connecting roads.

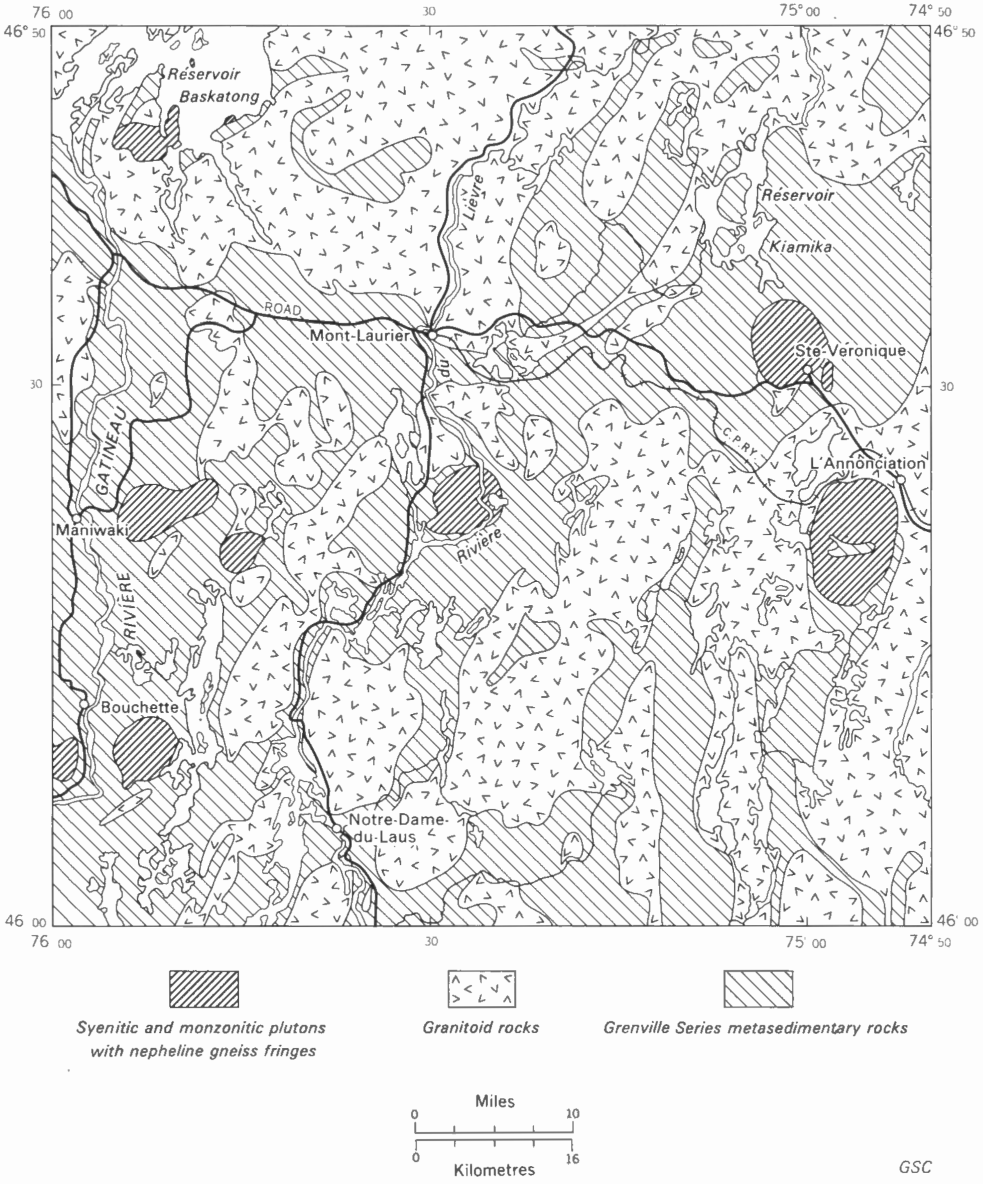

FIGURE 84. Nepheline gneiss in southwestern Quebec (after Wynne-Edwards *et al.*, 1966).

Form and structure	The syenitic bodies tend to be subcircular, 5 to 10 miles in diameter, cleanly punched through their surroundings, and showing distinct displacement of the country rocks. The nepheline-bearing rocks always occur close to the contacts, but within the syenitic rocks. They range from typical gneisses, with nonalkaline septa, to strongly foliated and porphyroblastic rocks approaching igneous textures. The nepheline-bearing parts are rarely more than 100 yards wide and a half mile long.
Petrography	The occurrences contain characteristic pearl-grey platy tablets of perthite arranged in trachytoid fashion in a mafic matrix. The nepheline-bearing rocks often form stringers a few inches thick in a migmatitic red syenite gneiss.
Age	The massive central monzonite at Ste-Véronique has been dated at 967 m.y. by the K-Ar method on biotite.
Economic aspects	None known at present, but no prospecting has been done.
Selected reference	Wynne-Edwards, H. R., Gregory, A. F., Hay, P. W., Giovanella, C. A., and Reinhardt, E. W. (1966): Mont Laurier and Kempt Lake map-areas, Quebec; Geol. Surv. Can., Paper 66-32.

Name	Ste-Véronique (G-106; Fig. 85)
Location and access	The Ste-Véronique nepheline syenite body lies about 2 miles north of the popular vacation resort of Ste-Véronique along an access road to some cottages. The location is readily accessible by auto by continuing straight ahead along the main street of the town.
Form and structure	Nepheline gneiss occurs as lenticles 2 to 3 inches wide in a hybrid zone on the contact of a quartz-feldspar-biotite gneiss complex to the north, and a red migmatitic gneiss complex to the south. The nepheline-containing rocks are themselves migmatitic, and nepheline gneiss is often seen in ptygmatically contorted lenticles. A mile southeast of the occurrence, marble is found on strike from the nepheline gneiss. The massive monzonite noted by Wynne-Edwards *et al.* (1966) lies at least a mile to the southwest.
Petrography	The nepheline-bearing rocks are readily recognized by the pearl-grey perthites arranged in platy crystals in a fine-grained matrix rich in biotite and augite. Nepheline is heavily altered, and is present as interstitial grains.
Age	Not definitely known.
Economic aspects	None known.
Remark	Other nepheline gneiss lenticles may be present in this general area. There are certainly large amounts of buff-coloured syenite, which appears to be a 'carrier' for the nepheline gneiss.
Selected references	Osborne, F. F. (1934): Labelle-L'annonciation map area; Que. Bur. Mines Ann. Rept. 1934, pt. E. Wynne-Edwards, H. R., Gregory, A. F., Hay, P. W., Giovanella, C. A., and Reinhardt, E. W. (1966): Mont Laurier and Kempt Lake map-areas, Quebec; Geol. Surv. Can., Paper 66-32.

Name	Lac Rouge (G-107)
Location and access	Just west of Lac Rouge, at the intersection of two country roads, 3 miles east of Lac des Iles (46°26′N, 75°24′W). The locality can easily be reached by road from the highway through Lac des Iles.
Form and structure	Nepheline-bearing rocks are exposed in a north-trending ridge, some 300 yards wide and a mile long, running through pasture land. Similar, but less alkaline, rocks are

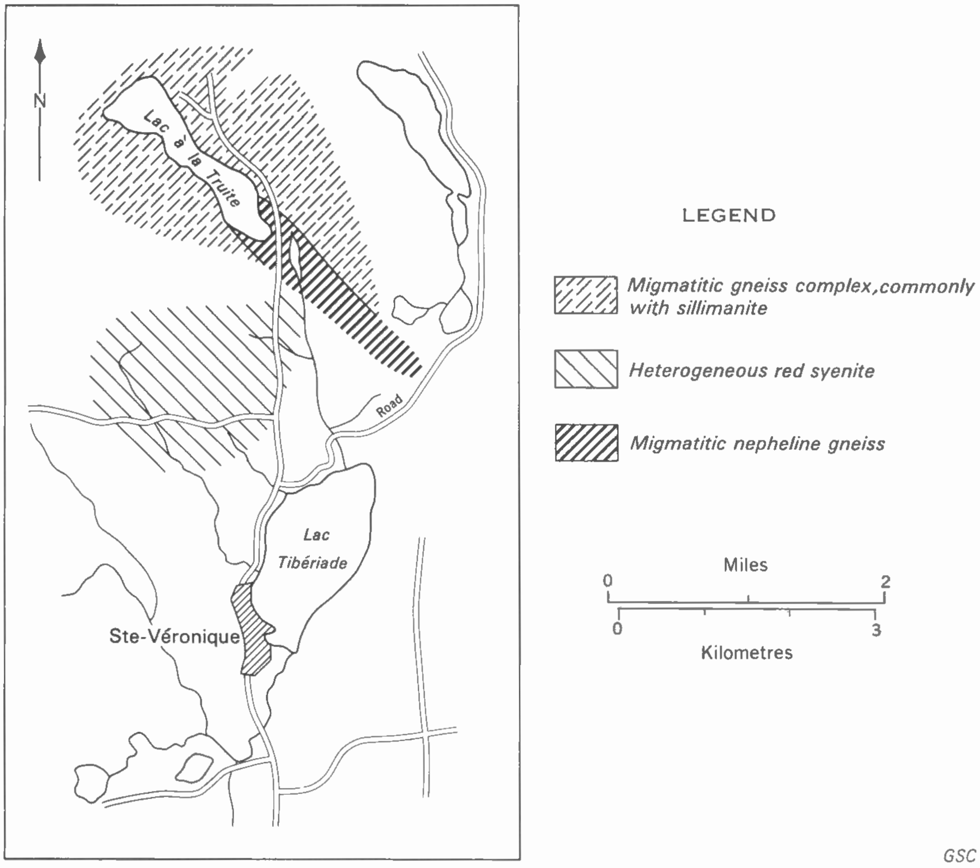

FIGURE 85. Geology of the Ste-Véronique nepheline syenite (modified from Osborne, 1934).

exposed a mile farther north on the road to Kiamika, and again on the east side of the Lièvre River about 3 miles west of Kiamika. The rocks appear to form a conformable lens in migmatitic amphibolitic gneisses. The nepheline-bearing rocks vary from rusty gneisses, with lumpy feldspar phenocrysts in a glomeroporphyritic biotite-rich matrix, to strongly grey syenite with platy perthite crystals up to an inch across, set in a poikilitic biotite-rich matrix. The Lac Rouge monzonite pluton lies at least a quarter mile farther east, although the nepheline-bearing rocks are included within its boundaries on the map (Wynne-Edwards *et al.* (1966)).

Petrography The rocks are buff to grey, mesocratic, coarse-grained syenites, mainly composed of orthoclase microperthite. At the edges of the occurrence nepheline is found in interstitial ribbon-like grains, but in the centre it forms large cubic porphyroblasts, largely replaced by mixtures of cancrinite, thomsonite, natrolite, and sodalite. The major mafic mineral is biotite, although a hastingsite-type amphibole is locally present. Large euhedral zircons are a prominent accessory. Nepheline-rich pegmatites occur as patches or lenses within the host, whereas crosscutting buff-coloured syenite dykes appear to destroy nepheline in the host. The band of nepheline-bearing rocks appears to curve around the edge of the Lac Rouge pluton, dipping toward it at about 30 degrees.

Age	Unknown, but presumed to be about 1,000 m.y.
Economic aspects	None known.
Remarks	The author has also collected nepheline-bearing rocks from the eastern margin of the Lac Kensington pluton east of Maniwaki, and from the edges of the Baskatong Reservoir syenite, along the road from Grand-Remous. These occurrences are all similar to those just described. The rocks are always found close to, but distinctly separated from, syenitic or monzonitic plutons. Although there is much marble in the general region, the occurrence of nepheline appears to be unrelated to proximity to marble.
Selected reference	Wynne-Edwards, H. R., Gregory, A. F., Hay, P. W., Giovanella, C. A., and Reinhardt, E. W. (1966): Mont Laurier and Kempt Lake map-areas, Québec; Geol. Surv. Can., Paper 66-32.

Name	Cabonga Reservoir (G-108)
Location and access	About a mile south of Nadon Bay of the Cabonga Reservoir (46°11′N, 76°29′W). The locality is in dense bush, but can be reached by 8 miles of bush road leaving the highway 3 miles north of the hamlet of Le Domaine.
Form and structure	The nepheline-bearing rocks outcrop in a slightly curving lenticle trending east-west, which is surrounded by mafic amphibolitic gneiss, possibly due to metamorphism of calcareous rocks. The nepheline-bearing rocks, which are moderately gneissic, outcrop over a length of about 1.2 miles and a width of about 400 yards.
Petrography	The rock is a pale to dark grey, coarse-grained syenite formed of plates of perthite, cubic nepheline, and aligned flakes of biotite in the interstices. Splendid blue corundum crystals mantled by biotite are locally present. Along joints, a thin selvage of sodalite is locally developed.
Age	Unknown.
Economic aspects	None known.
Selected reference	Laurin, A. F. (1960): Rapport préliminaire sur la région de Turquetil-Émard, district électoral de Pontiac; Min. Mines, Québec, 424.

Name	Lac Albanel (G-110; Fig. 86)
Location and access	Southeast of Lac Albanel, near 50°42′N, 73°00′W. This remote locality can be reached only by aircraft.
Form and structure	Nepheline-bearing rocks occur in two conformable syenite lenses in high-grade, northeast-trending, southeast-dipping granitoid gneisses. The larger lens, exposed on several hills in a river valley, is about 10 miles long and 2 miles wide, although only a small part of this area contains nepheline. The locality lies about 5 miles southeast of the Grenville Front, separating high-grade metamorphic rocks to the southeast from almost unmetamorphosed Proterozoic sedimentary rocks to the northwest.
Petrography	The surrounding metamorphic complex is mainly composed of *lit-par-lit* biotite and hornblende-biotite gneisses, with some darker garnetiferous amphibolite bands. The contact of the alkaline rocks is marked by faintly gneissic microcline-hastingsite syenite, commonly containing a little quartz, and accessory aegirine, apatite, epidote, sphene, zircon, and biotite. Granular aplitic phases of this rock seem to represent a gradation to the surrounding rocks. The nepheline-bearing rocks occur as a prominent northeast-trending ridge of pale grey, gneissic syenite composed of large platy crystals of potash feldspar (both microcline and orthoclase), and minor albite. Nepheline, which may make up as much as 25 per cent of the rock, forms large euhedral grains riddled with inclusions of cancrinite and strained green biotite. The

	principal mafic minerals are poikilitic and splintered hastingsite, and a feebly pleochroic acmitic aegirine. Garnet is present in accessory amounts, along with epidote, apatite, sphene, and zircon.
Age	Unknown.
Economic aspects	None known.
Selected reference	Neilsen, J. M. (1953): Albanel area, Mistassini Territory; Que. Dept. Mines, Geol. Rept. 53.

Name	Manicouagan (G-109; Fig. 87)
Location and access	Northern parts of the Manicouagan Reservoir, and the lower parts of the Hart Jaune and Mushalagan rivers, about 40 miles north of Manicouagan (51°30′N, 68°35′W). The area can be reached by boat and on foot from Manicouagan, but is more conveniently reached by helicopter.

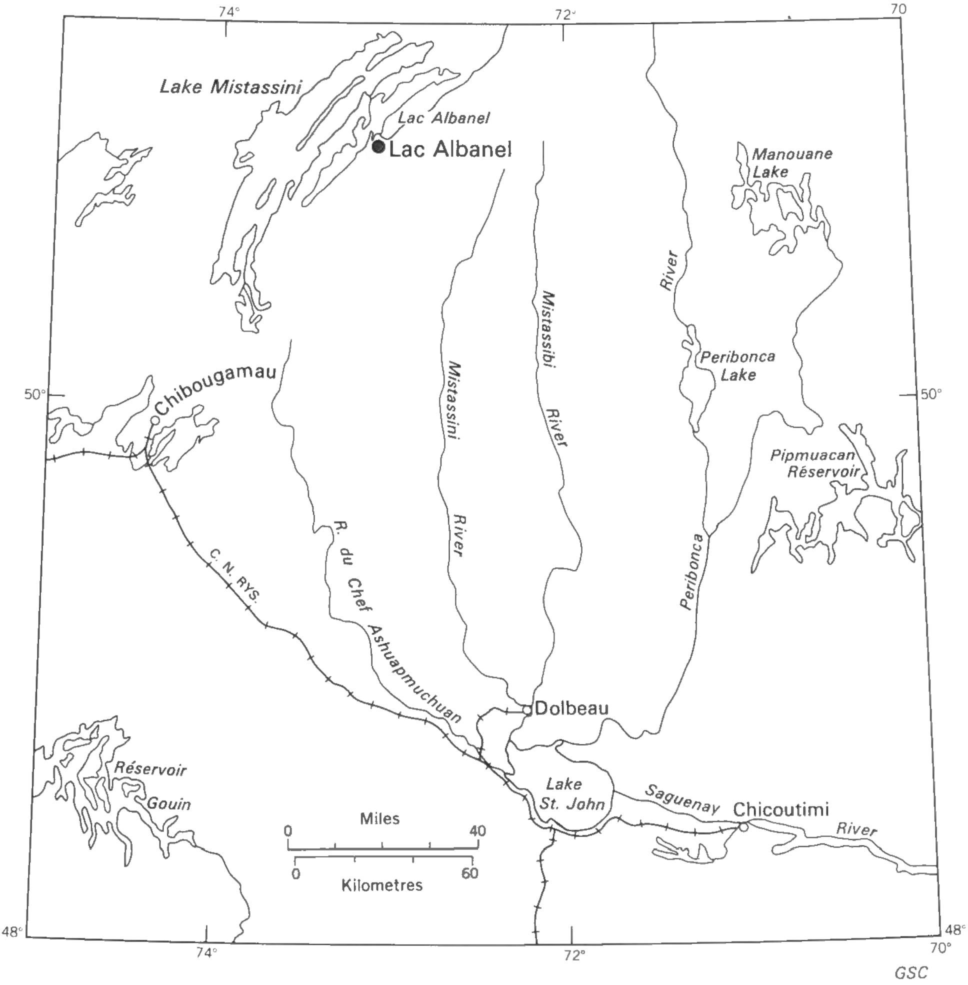

FIGURE 86. The Lac Albanel nepheline syenite.

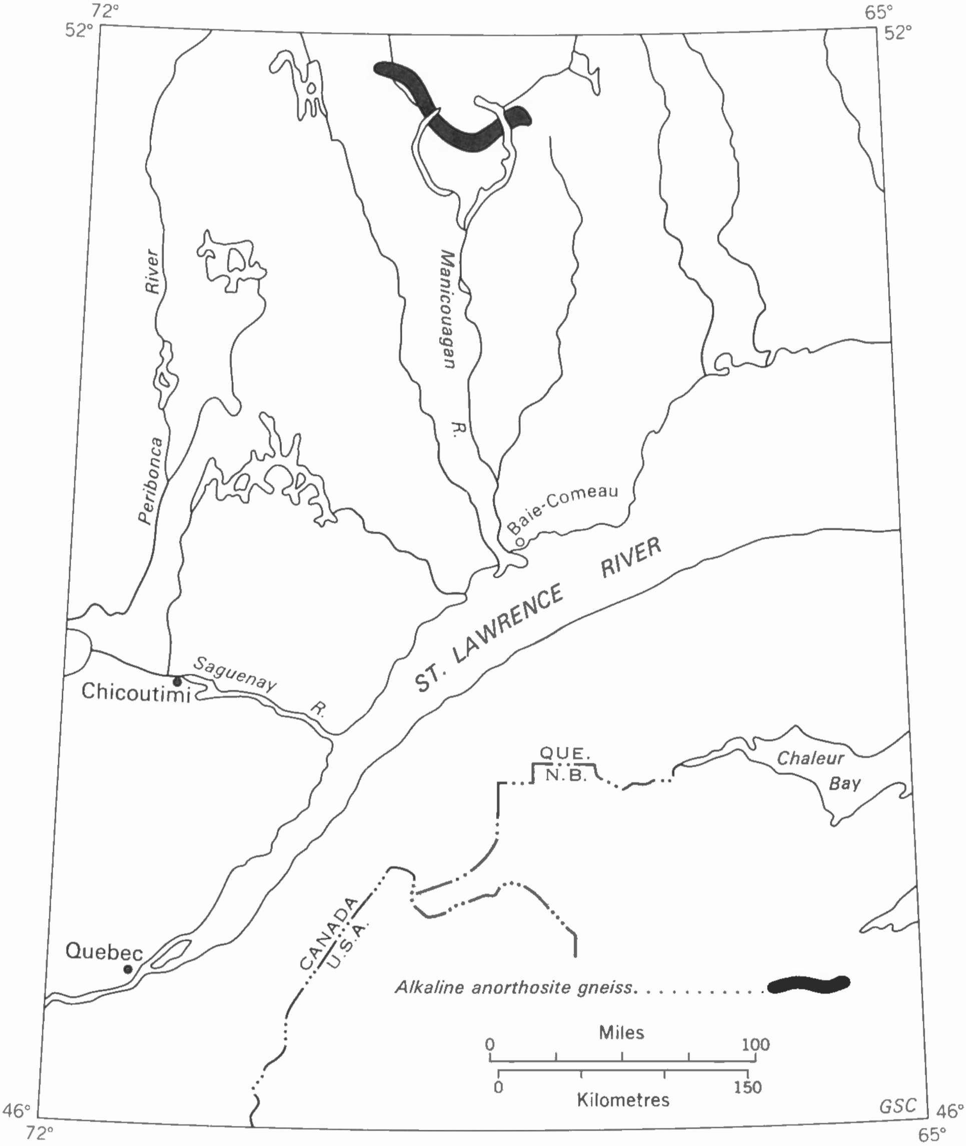

FIGURE 87. The Manicouagan alkaline anorthosite gneiss.

Form and structure

The northern parts of the Manicouagan circular structure are underlain by a peculiar white or pink anorthosite gneiss, flanked by a garnetiferous amphibolite. These rocks form an arc concave to the north, passing from the mouth of the Hart Jaune River some 30 miles to the west up the Mushalagan River. To the east they appear to grade into gabbroic anorthosite, and to the west to fade into plagioclase-rich gneisses. The belt varies in width from 4 to 10 miles.

Petrography	The anorthosite consists principally of a labradoritic plagioclase, variously altered to scapolite and thomsonite, with minor amounts of diopside and pyrope-rich garnet and, rarely, a little hypersthene. The fringing amphibolitic rocks contain the same minerals, but in drastically altered proportions. Both types of rocks show substantial amounts of nepheline in norms computed from the chemical analyses (Table 39).
Age	Unknown, last metamorphosed during the Grenville orogeny.
Economic aspects	None known.
Remarks	The reason for the appearance of nepheline in the norms of these rocks is obscure, since most anorthosites are of tholeiitic affinities. One possible reason seems to be loss of silica, since analyses 7–10 of thomsonite-rich rocks are far too poor in silica for unaltered anorthosites. No source of such metasomatism is now known in this region.
Selected reference	Currie, K. L. (1972): Geology and petrology of the Manicouagan resurgent caldera, Quebec; Geol. Surv. Can., Bull. 198, p. 14–18.

TABLE 39 *Chemical composition of alkaline anorthosite gneiss and related rocks (after Currie, 1972)*

	1	2	3	4	5	6	7	8	9	10
SiO_2	48.4	48.0	49.2	53.2	52.6	52.4	48.6	47.9	48.8	48.1
TiO_2	1.2	1.5	1.0	0.0	0.1	0.2	0.2	0.8	0.2	0.2
Al_2O_3	19.0	21.7	18.8	28.9	26.7	28.8	30.7	15.9	27.4	29.3
Fe_2O_3	4.2	4.7	8.2	0.1	0.5	nil	0.5	2.2	1.3	0.8
FeO	4.0	2.2	1.1	.5	1.3	0.4	1.5	8.0	0.1	1.3
MnO	0.2	0.04	0.3	nil	nil	Trace	0.1	0.2	Trace	nil
MgO	2.0	4.6	3.4	nil	Trace	0.3	1.8	7.9	2.8	1.9
CaO	7.2	11.6	4.7	10.6	10.3	9.4	8.9	11.1	8.9	10.6
K_2O	2.1	0.6	3.3	0.6	0.6	0.6	0.3	0.6	1.2	0.4
Na_2O	6.5	3.6	4.1	5.3	5.3	6.0	5.2	5.4	5.0	4.9
H_2O	4.4	3.8	5.8	0.3	2.3	1.4	2.9	1.2	3.9	2.0
P_2O_5	0.4	0.3	0.2	.02	Trace	nil	nil	nil	Trace	Trace
CO_2	.2	nil	.1	nil	nil	nil	nil	nil	nil	0.2
TOTAL	99.8	102.6	100.2	99.5	99.7	99.5	100.7	101.2	99.6	99.7

1, 2, 3. Garnet amphibolite accompanying anorthosite.
4, 5, 6. Leucocratic garnet anorthosite, containing scapolite and thomsonite.
7, 8, 9, 10. Altered anorthosite, rich in analcite and thomsonite.

Name	Lake Harbour (G-111; Fig. 88)
Location and access	The nepheline–lapis-lazuli deposit near Lake Harbour is located in southern Baffin Island on Soper River (62°58′N, 71°47′W), about 15 miles north of the settlement. This extremely remote location can be reached only by aircraft.
Form and structure	Nepheline-bearing rocks occur in marble as conformable lenses up to 500 feet by 25 feet. The marble forms the core of a tightly folded synform striking northeast and plunging northwest. The synform also includes biotite gneiss, and relatively minor amounts of peridotite.
Petrography	The alkaline rocks consist mainly of hauyne, diopside, and plagioclase disseminated in coarse-grained marble. In some of the more massive occurrences up to 20 per cent of nepheline is present, and traces of sodalite are locally observed. The more common minor minerals are tremolite, phlogopite, sphene, and pyrite or pyrrhotite.
Age	Not definitely known, but rocks in this region give ages of about 1,750 m.y. for the K-Ar method on biotite.
Selected reference	Hogarth, D. D. (1971): Lapis lazuli near Lake Harbour, southern Baffin Island, Canada; Can. J. Earth Sci., v. 8, p. 1210–1217.

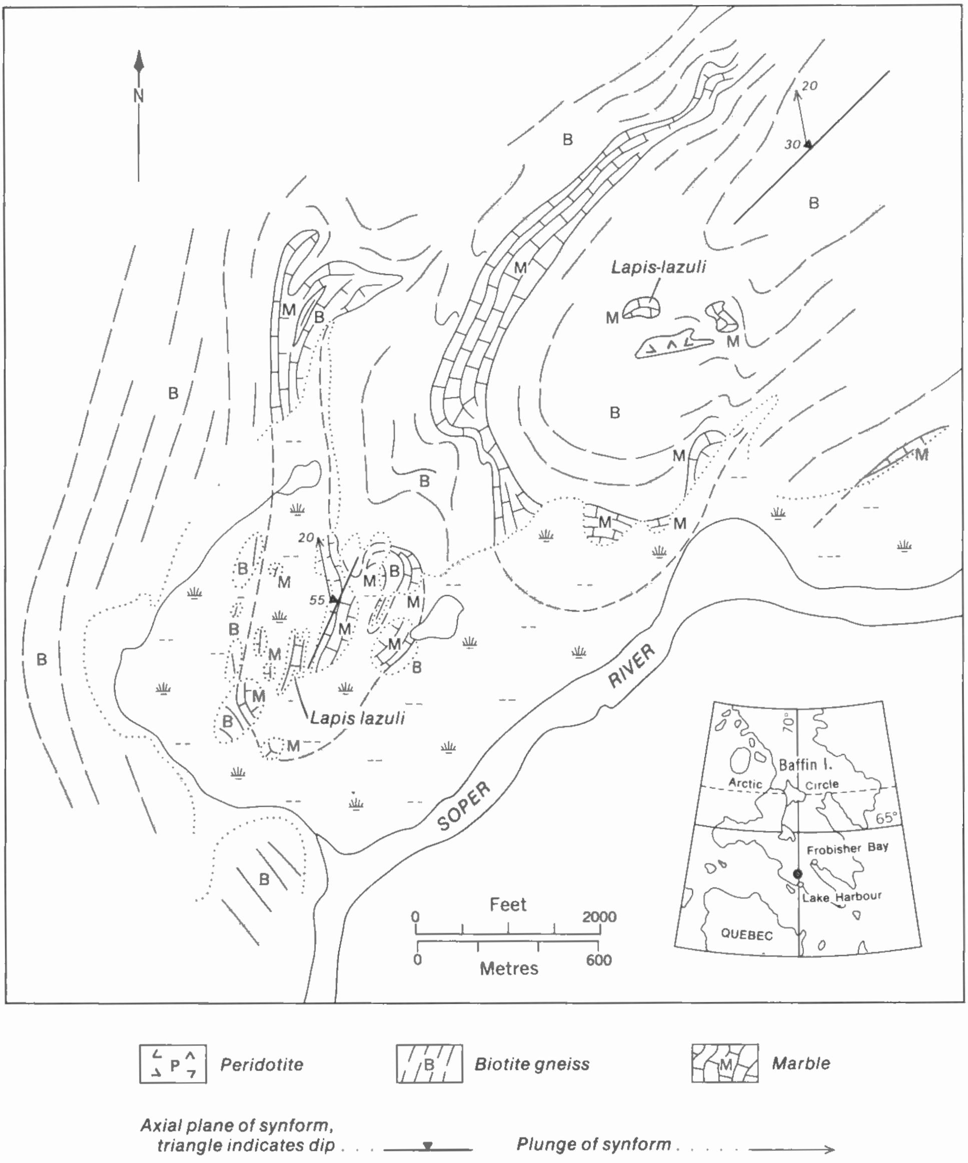

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FIGURE 88. Geology of the Lake Harbour nepheline–lapis-lazuli occurrence (after Hogarth, 1971).

Chapter VIII

Agpaitic Syenite Complexes

In miaskitic syenite complexes the molecular ratio of total alkalis (Na+K) to aluminum is less than 1, commonly substantially less than 1. In a rare class of rocks, however, this ratio, the agpaitic index, becomes greater than 1. At first sight this seems to be an entirely academic distinction, but in fact agpaitic syenites show a mineralogy radically different from that of miaskitic syenites. Small amounts of excess alkalis can be accommodated in alkaline mafic minerals such as aegirine, arfvedsonite, and the like, but strongly agpaitic rocks must contain minerals rich in alkalis in which the agpaitic ratio is greater than 1. The most common mineral of this type is sodalite, and some agpaitic complexes contain sodalite as an early cumulate mineral. Enigmatite is very common as a mafic mineral in agpaitic complexes, along with sodic amphiboles, particularly arfvedsonite. The most characteristic minerals of agpaitic complexes, however, are a group of zirconium, titanium, and rare-earth minerals occurring only in agpaitic rocks, of which the best known is eudialyte. Due to the very high alkali content, the zirconium, rare-earths, and titanium in the rock must combine with alkalis; hence the usual carriers of zirconium (zircon) and titanium (sphene) are replaced by sodic minerals. These minerals are particularly concentrated in late pegmatites, a celebrated source of rare and beautiful minerals.

The origin of agpaitic magmas is poorly understood. Agpaitic rocks show a consistent connection with mildly alkaline plateau basalts, as at Seal Lake, Labrador, the Gardar province of Greenland, the Kola peninsula in Russia, and the Ethiopian plateau. Some authors suggest that crystallization of aluminous mafic minerals could push alkali basaltic liquids toward agpaitic compositions. Others, however, believe the source of at least some agpaitic rocks to be large pyroxene syenite complexes, as at Illimausaq, Greenland. A difficulty with both these concepts is that they should enrich potassium relative to sodium, whereas agpaitic rocks always show a strong dominance of sodium over potassium. Agpaitic magmas tend to show very long solidus–liquidus intervals (Piotrowski and Edgar, 1970), and peculiarities in crystallization, notably very late crystallization of pyroxene. Agpaitic undersaturated lavas are even rarer than agpaitic plutonic rocks, but oversaturated equivalents (commendite, pantellerite) are relatively common. Plutonic equivalents of these agpaitic quartz-bearing rocks also occur. They contain the typical agpaitic mineral suite, as at Blatchford Lake, N.W.T. (Davidson, 1972), suggesting strong links between oversaturated and undersaturated rocks.

Agpaitic undersaturated rocks occur in Canada in three districts: near Kipawa River, Quebec; at Mount St-Hilaire, a few miles east of Montreal; and in the Seal Lake district of Labrador. These occurrences are described in detail below.

Selected references

Davidson, A. (1972): Granite studies in the Slave province; *in* Report of Activities, April to October 1971, Geol. Surv. Can., Paper 72-1, pt. A, p. 109–115.

	Piotrowski, J. M. and Edgar, A. D. (1970): Melting relations in undersaturated alkaline rocks from south Greenland compared to those of Africa and Canada; Medd. Groenland, v. 181, no. 9.

Name	Kipawa River (A-91; Fig. 89)
Location and access	South and west of the Kipawa River at Lac Sairs, in Villedieu Township (46°46′N, 78°28′W). The area can easily be reached by boat from Kipawa, Quebec, about 22 miles to the west.
Form and structure	Alkaline rocks are exposed on a low ridge, some half mile long and a few hundred feet wide, surrounded by drift. The occurrence seems to lie within a much larger occurrence of alkalic syenite or quartz syenite about 15 miles across which forms a lenticular mass in the north-northwest-trending granitoid gneisses of the region.
Petrography	The alkaline rocks consist of spectacular pegmatitic patches or lenses within a very foliated or schistose, medium-grained matrix, which seems to form a conformable lenticle within the surrounding alkalic gneiss. The most important rock-forming minerals appear to be albite, eudialyte, arfvedsonite, and sodic pyroxenes, but an enormous number of rare accessory minerals are present, particularly in the pegmatitic patches, including rinkite, mosandrite, vlasovite, britholite, and hiortdahlite. Calcite-fluorite veins are an unusual feature, and some contain agpaitic minerals. Nepheline and graphite are present in some outcrops.
Age	Unknown, but presumed to be metamorphosed during the Grenville orogeny.
Economic aspects	None known.
Remarks	Lyall mentions another occurrence of nepheline syenite on Ile la Tortue (Turtle Island), in Lac Tortue (Turtle Lake), some 12 miles west-northwest of the eudialyte occurrence. This occurrence is at the nose of a northwest-trending fold, and is strongly gneissic. A report by Hicks (Can. Mineral., v. 6, p. 297 (1959)) of eudialyte from Pontiac County, Quebec, probably refers to the Villedieu Township occurrence.
Selected reference	Lyall, H. B. (1959): Rapport préliminaire sur la région de McLachlin-Booth, District Electoral de Temiscamingue; Min. Mines Québec, Rapt. Prél. 391.

Name	Mount St-Hilaire (A-94; Fig. 10)
Location and access	Mount St-Hilaire lies just east of the town of St-Hilaire, about 2 miles south of Autoroute 20 between Montreal and Quebec City. The agpaitic rocks lie on the eastern half of the mountain, which is operated by McGill University as a biological preserve and is closed to the public. Quarries containing magnificent examples of agpaitic minerals have been opened on the northeast face of the mountain, however, and are accessible by arrangement with the quarry operators.
Form and structure	The agpaitic pluton forms an irregular ellipse 1 by 2 miles oriented north-south, and is composed of crudely zoned nepheline-sodalite syenite or phonolite containing great numbers of inclusions of older rocks. Flow structure is strong everywhere. The relations of these rocks with the alkaline basaltic part of the complex are involved, but the syenite appears, in general, to intrude the basic rocks in the form of dykes radiating from several centres. The contact with the surrounding Ordovician Richmond Formation is not well exposed, but the sedimentary rocks appear to be almost undisturbed, although locally severely metasomatized.
Petrography	Within the crudely funnel-shaped mass of the agpaitic pluton, indistinct layering dips toward a point on the east shore of Lac Hertel. The rocks are olive-brown syenites becoming progressively finer grained toward the centre, although coarser grained patches or dykes are always present. Fragment-rich varieties have been termed igneous breccia, but they seem to differ in no essential aspect from the other

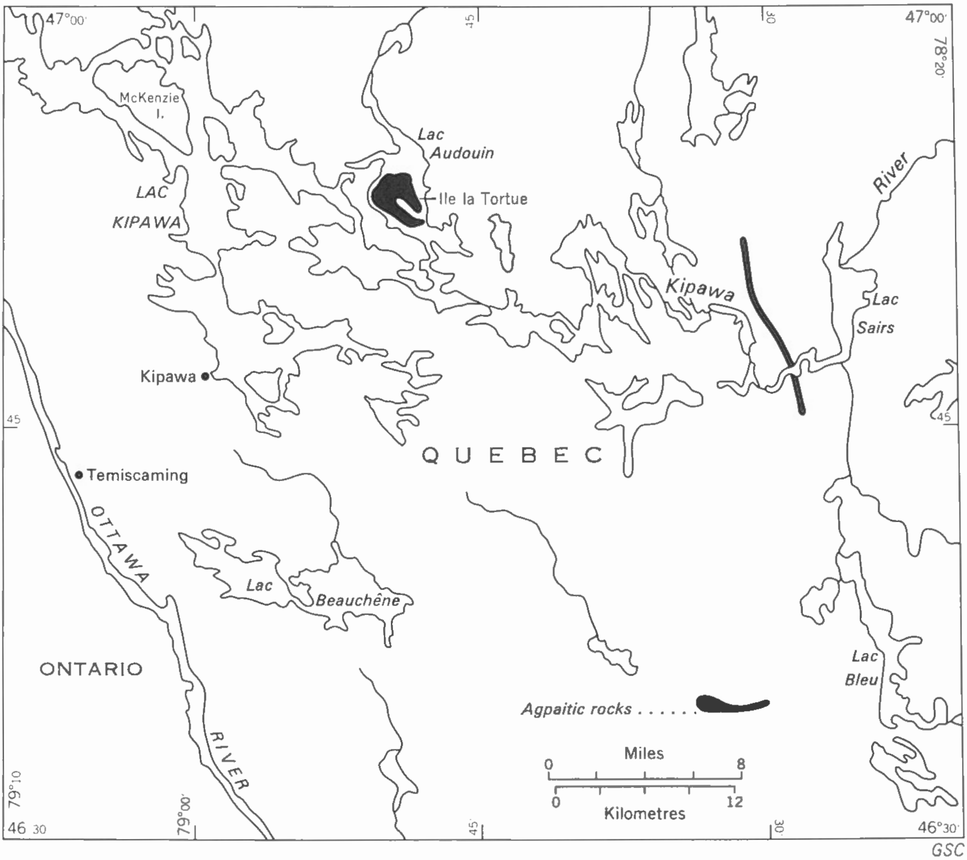

FIGURE 89. The Kipawa River agpaitic rocks.

rocks, all being composed mainly of sodic anorthoclase, either in large phenocrysts with both grid and carlsbad twinning or as fine laths in the groundmass oriented around the phenocrysts. Sodalite is always present, commonly as large phenocrysts or xenocrysts of a distinctive grey or black shade. These crystals are commonly fractured, and complexly zoned. Their number varies greatly. Acmitic pyroxene is commonly present in small needles included in feldspar or floating in the matrix, and phenocrysts of aegirine occur locally. Nepheline forms irregular large grains, commonly replacing albite, but the amount of nepheline is definitely inversely proportional to that of sodalite. Other minerals that are usually present are apatite, natrolite, and analcite, and eudialyte, enigmatite, astrophyllite, and murmanite are found in a few specimens. Pegmatitic patches occur throughout the pluton, but are most common and largest on the north slope. They show a characteristic plumose development of feldspar with albite haloes. The quarries on the north side of the mountain are a world-famous mineral-collecting locality from which more than 90 species have been collected, mainly from vuggy cavities in the pegmatite. An unusual fenite zone occurs on the east side of Mount St-Hilaire, in which an enclave of Richmond shale has been converted to sericitic mica for 20 to 30 feet from the contact, and beyond that to a finely granular aggregate of albite, arfvedsonite, and narsarsukite. Silica does not appear to be depleted in this rock, and may even be enriched. Chemical analyses (Table 40) show the characteristic agpaitic peculiarities, high soda, zirconia, and titania, with low magnesia and lime. The agpaitic index appears to increase irregularly from the centre to the edge of the mass.

Age

The gabbroic part of Mount St-Hilaire has been dated at 99 m.y., and the agpaitic part is believed to be of similar, but slightly younger age.

Economic aspects

A large quarry for a cement plant is operated in the agpaitic rocks.

Selected references

Perrault, G. (1969): Mineralogy at Mt. St. Hilaire; *in* Geology of Monteregian Hills, G. Pouliot, ed., Geol. Assoc. Can. – Mineral. Assoc. Can. Guidebook, Montreal, p. 103–116.

Rajasekeran, K. C. (1967): Mineralogy and petrology of nepheline syenites in Mont St. Hilaire, Quebec; McGill Univ., Montreal, unpubl. Ph.D. thesis.

TABLE 40 *Chemical composition of agpaitic rocks from Mount St-Hilaire*

	1	2	3	4	5	6	7
SiO_2	51.71	57.72	57.36	51.53	50.63	49.34	64.85
TiO_2	1.41	0.28	0.17	0.23	1.33	nil	1.47
Al_2O_3	19.62	18.69	19.32	20.98	20.27	22.90	12.15
Fe_2O_3	3.09	4.81	5.22	3.66	2.40	3.19	3.95
FeO	3.52	0.67	0.60	1.17	3.23	1.85	0.64
MgO	1.22	.20	.13	0.14	1.51	0.08	1.37
CaO	4.46	.63	.91	1.11	4.33	.81	1.57
MnO	0.28	.12	.36	0.21	0.29	0.33	1.46
Na_2O	9.71	11.61	13.10	13.40	10.83	15.34	10.54
K_2O	3.34	4.12	2.31	5.32	3.26	4.36	2.12
H_2O	1.31	0.69	0.74	1.10	0.91	1.07	0.26
CO_2	0.37	.34	0.12	0.26	.17	0.08	.22
P_2O_5	.54	.01	nil	.02	.61	.21	.32
TOTAL	99.58	99.89	100.34	99.13	99.77	99.56	100.92

All analyses quoted from Rajasekeran, 1967, Table 7.1.

1. Fine-grained trachytoid nepheline syenite.
2. Litchfieldite.
3. Aegirine sodalite syenite.
4. Sodalite syenite.
5. Nepheline sodalite syenite porphyry.
6. Sodalite-rich syenite.
7. Metasomatic hornfels on east boundary of intrusion.

Name

Red Wine-Letitia alkaline province (Fig. 90)

Location and access

Central Labrador, near the headwaters of the Red Wine River, extending in an arcuate belt, slightly convex to the north, from 53°54′N, 62°45′W to at least as far as 54°16′N, 62°23′W, and possibly farther. This location can be reached only by aircraft, but a helicopter is needed to work on some of the bodies.

Form and structure

The Red Wine-Letitia alkaline province consists of two major complexes, and an unknown number of small occurrences of alkaline or alkalic rocks. The largest central complex at the southwest end of the belt is a folded lenticular mass about 8 miles in arc length elongate along the belt, and moderately strongly zoned. The other central complex, lying about 18 miles to the northeast, appears to have been a subcircular complex about 2½ miles in diameter, but has been tectonically deformed

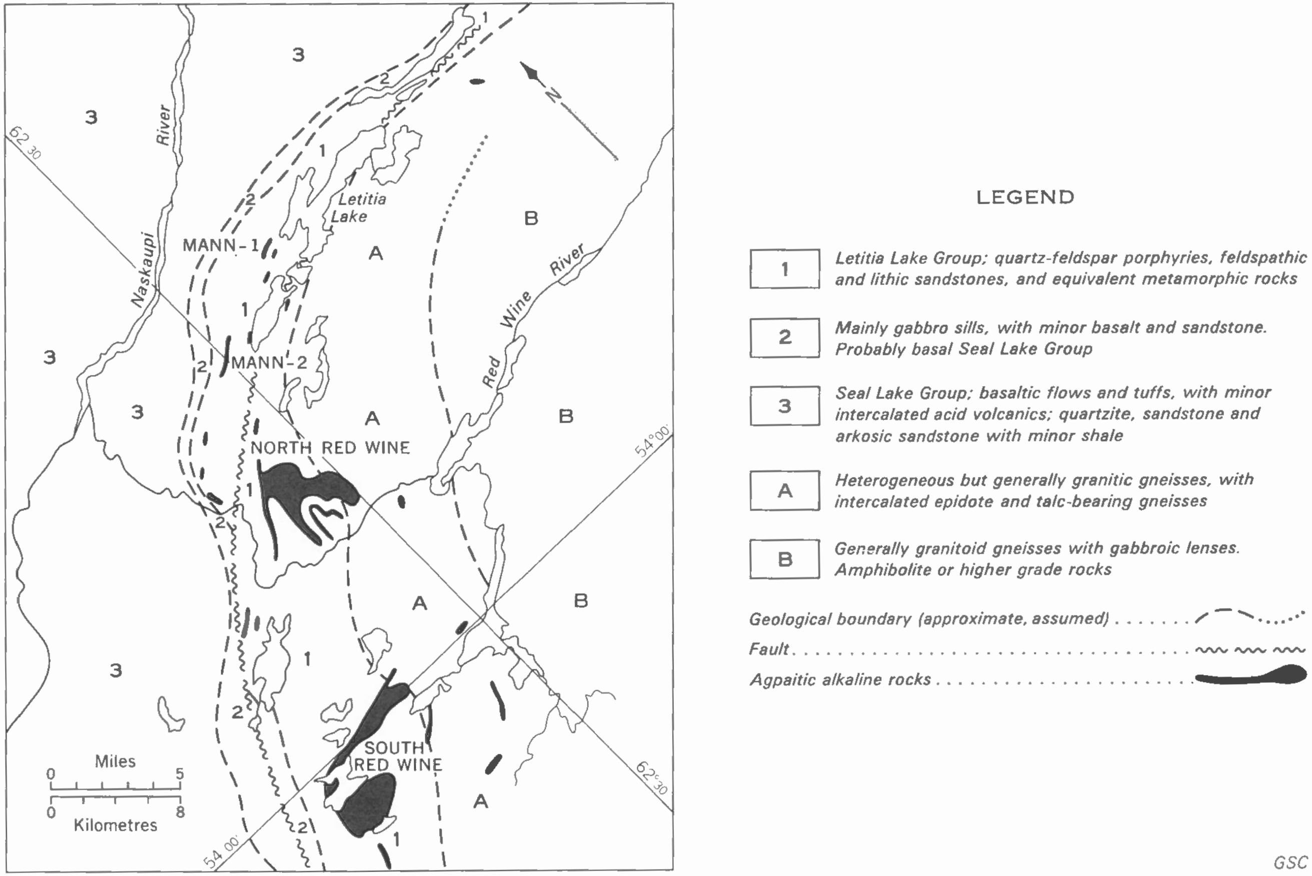

FIGURE 90. Geology of the Red Wine-Letitia alkaline province (based on field work by Currie, Curtis, and Gittins, 1972, and unpubl. GSC map by Roscoe).

and dissected, with intercalation of country rocks into the mass, and strewing out of fragments of alkaline rocks through the country rocks. These fragments, up to several hundred yards across, are found at distances as much as 12 miles from the complex, accompanied by intense metasomatism of the surroundings. In addition, a considerable number of fragmented lenses of alkaline rocks, some probably parts of dykes, are found throughout the province. Structurally, the province is located on the boundary between high-grade metamorphic rocks to the southeast, and relatively low-grade Precambrian lavas and clastic sedimentary rocks to the northwest. The low-grade rocks have been intensely folded, and their boundary with the higher grade rocks is marked by a shear zone several miles wide, which appears to conceal an abrupt increase in metamorphic grade. The low-grade rocks (Seal Lake Group) are intruded by fragments of alkaline dykes, but the main alkaline rocks are emplaced in an older underlying sequence (Letitia Lake Group), which appears to be the source of at least some of the high-grade granitoid rocks.

Age

The relative and absolute ages of the various units in this region are uncertain. Based on K-Ar ages and preliminary Pb-Pb work, the following sequence appears to be most probable. The Letitia Lake Group is about 1,500–1,600 m.y. old, resting on a basement giving ages of 2,700 m.y. The alkaline rocks were emplaced about 1,500 m.y. ago, probably at about the same time as the Seal Lake Group, or slightly later. Latest metamorphism was about 1,000 m.y. ago, accompanied by strong deformation.

Economic aspects

Alkaline rocks in this region have been prospected for uranium, beryllium, and rare-earths. The uranium concentrations are insignificant, although sufficient to produce marked anomalies. Beryllium minerals are found in the fenitized haloes surrounding sheared slices of alkaline rocks. Rare-earths are particularly concentrated in the minerals eudialyte and joaquinite, which are concentrated near the boundaries of the major massifs.

Remarks

Agpaitic rocks are rare. The character and age of the Red Wine-Letitia province suggest links with the similar agpaitic rocks of southern Greenland. On completely unrelated grounds it has recently been suggested that Labrador and southern Greenland were joined as late as Mesozoic time. If this reconstruction is assumed to be correct, it still would not place the Red Wine-Letitia province in direct juxtaposition with the Gardar igneous province of Greenland, for 100 miles of Proterozoic and Aphebian rocks intervene between the Red Wine area and the coast of Labrador. It is unclear whether (a) alkaline igneous activity occurs within these rocks and is presently undiscovered, or (b) these rocks were tectonically emplaced subsequent to the alkaline igneous activity, or (c) there is a genuine gap of more than 100 miles in the alkaline igneous rocks.

Selected reference

Currie, K. L. (1973): The Red Wine-Letitia alkaline province of Labrador; *in* Report of Activities, April to October, 1972, Geol. Surv. Can., Paper 73-1, pt. A, p. 138.

Name

South Red Wine (A-92; Fig. 91)

Location and access

Central Labrador, near the headwaters of the Red Wine River, centred near 53°59′N, 62°37′W. The region is accessible by floatplane from Goose Bay.

Form and structure

The complex is roughly J-shaped, about 8 miles in arc length, with the long axis trending northeast. The shape appears to be the result of at least two periods of folding, which have produced strong, locally schistose foliation, almost completely masking an original igneous layering. The surrounding country rocks are commonly northeast-trending granitoid gneisses, locally displaying a porphyritic structure strongly suggestive of the Letitia Lake Group. To the southeast of the complex recognizable metasedimentary rocks of the Letitia Lake Group are present, and

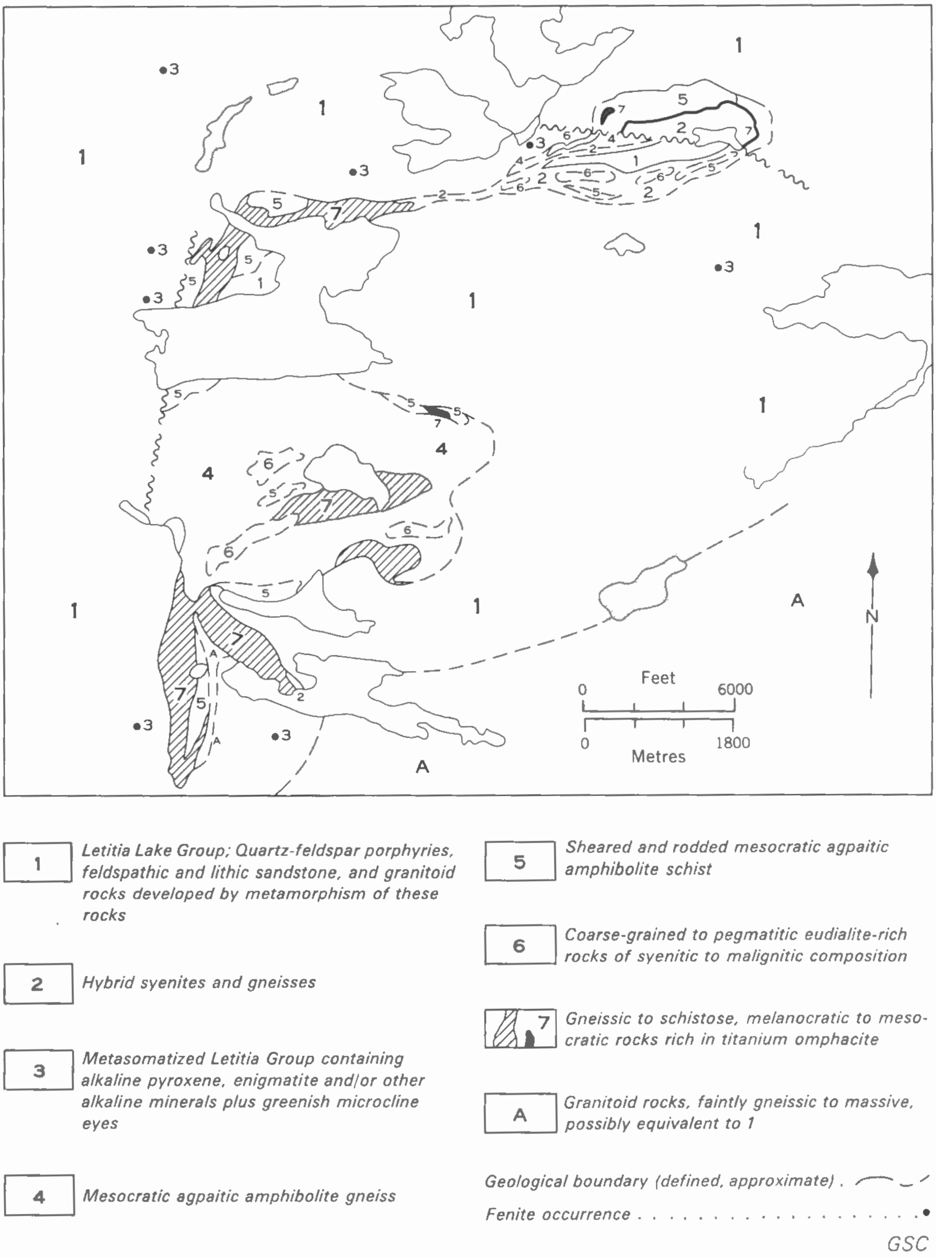

FIGURE 91. Geology of the South Red Wine complex (based on field work by Currie, Curtis, and Gittins, 1972).

numerous inclusions of similar material are found within the alkaline rocks. The present form of the structure is due to complex polyphase deformation involving differential flowage between various units, as well as folding.

Petrography The alkaline rocks consist of agpaitic amphibolites with syenitic schlieren, enveloped in generally granitoid gneisses. Remote from the complex the country rocks tend to be relatively massive, but within a few hundred feet of the contact they display textures characteristic of the Letitia Group, and may contain accessory amount of acmite, enigmatite, eudialyte, astrophyllite, or other sodic minerals. The distribution of this alkali metasomatism is rather irregular, and may reflect tectonic and metamorphic processes rather than part of the original igneous processes. The margins of the alkaline rocks are strongly schistose lineated amphibolites, consisting of black arfvedsonite, a peculiar "bleached" green pyroxene, and alkali feldspar, with a little nepheline and, occasionally, small amounts of eudialyte. The bulk of the complex is composed of a mesocratic, medium- to coarse-grained panidiomorphic rock composed of roughly equal amounts of arfvedsonite, a greenish alkaline pyroxene, and alkali feldspar with accessory nepheline. Very mafic varieties may be present, as well as rare, but spectacular pegmatitic lenses rich in eudialyte and nepheline. The northeastern part of the occurrence contains large amounts of bluish mafic rocks rich in nepheline and a unique pyroxene with spectacular blue pleochroism, best described as titanian omphacite. These rocks are particularly rich in the peculiar sodic minerals such as lamprophyllite, ramsayite, and others that are typical of agpaitic complexes. An unusual feature of all the rocks is the presence of large amounts of idiomorphic pectolite.

Age Unknown, but presumably similar to that of the North Red Wine complex, namely 1,250–1,500 m.y.

Economic aspects The complex has been prospected for uranium, and for the rare-earth and zirconium content of eudialyte, but results were not encouraging.

Remarks The South Red Wine pluton appears to be a metamorphosed central complex of the type of Illimausaq, Greenland, and Lovozero and Khibini, U.S.S.R. Relative to such complexes it is unusually mafic. Whether this feature is due to original magma composition, level of exposure, or metamorphism and metasomatism, or some combination of the three is unknown.

Name North Red Wine (A-93; Fig. 92)

Location and access Central Labrador, near the headwaters of the Red Wine River, centred at 54°07′N, 62°27′W. This locality can be reached on foot from lakes accessible by floatplane, but the walk is arduous and difficult. Helicopter access is easy, since the complex is located on high, barren hills with good outcrop.

Form and structure At present the complex has the shape of an imperfect "W," opening toward the south. This shape appears to be due to three superimposed processes. Remnants of an original layered igneous structure, presumably part of a subcircular pluton, can be made out in the northern and eastern parts of the complex, but these have been strongly modified by isoclinal folding on north-trending axes, which gives the major part of the complex its characteristic U-shape. Axial plane cleavage in the core of this fold is very strong, but most of the fissility in the complex appears to be due to stong penetrative deformation along a northeast-striking zone, which has smeared out the northwest termination of the complex along a belt 6 miles long and only a few hundred yards wide. In this region the 'contacts' of the complex with the country rocks are virtually nonexistent, comprising a very complicated series of screens of alkaline and nonalkaline rocks characterized by extreme shearing and contortion, as well as strong metasomatism of the country rocks.

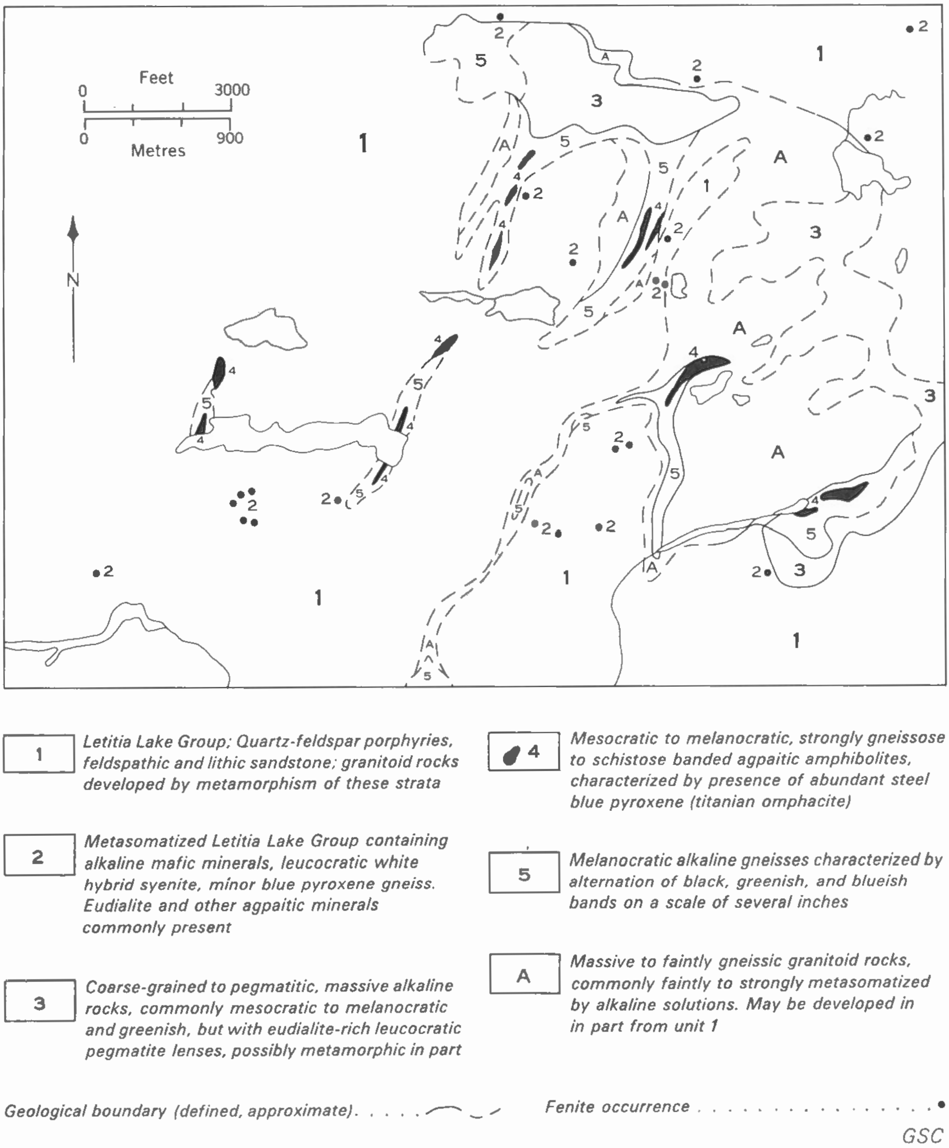

FIGURE 92. Geology of the North Red Wine complex (based on field work by Currie, Curtis, and Gittins, 1972).

Petrography The complex consists of mesocratic to melanocratic amphibolites with pegmatitic syenite schlieren, the whole emplaced into moderately metamorphosed acid flows, tuffs, and slates intercalated with rare gabbro sills. The acid members of the country rocks display a characteristic texture, with blue quartz eyes and equant feldspar phenocrysts, which persists through metamorphism and is readily recognizable in some of the granite gneisses east of the complex, where the grade of metamorphism is relatively high, reaching sillimanite-cordierite facies. Near the complex the country rocks have been converted to syenites of various kinds within 15 to 20 feet of igneous rocks, mainly to a leucocratic, layered, granular syenite containing a low tenor of eudialyte, and varying but often large amounts of joaquinite. Similar phenomena are observed in the numerous inclusions of country rocks in the complex. Where the complex is sheared, metasomatism is much stronger, and the country rocks are converted to granular syenites containing large amounts of acmite, together with some aegirine. The outer parts of the complex consist of rather ordinary amphibolites comprised of roughly equal parts of albite and an arfvedsonitic amphibole. This unit locally appears to grade into the country rocks. Toward the centre of the complex, the amphibolite becomes more mafic and alkaline, culminating in a black gneiss very rich in arfvedsonite, which grades upward over a few feet into a pegmatitic feldspathic pyroxenite with acmite as the pyroxene and albite crystals to 6 inches long. This unit in turn passes upward into a finer grained, more leucocratic and acicular rock which contains abundant nepheline, and local spectacular concentrations of eudialyte in pegmatitic patches. These pegmatites also contain schizolite, pectolite, ramsayite, and many other rare minerals. The horizon of acicular syenite, never more than a few feet thick, is abruptly succeeded by a granular nepheline syenite, passing gradationally into arfvedsonite syenite, and then into a layered sequence consisting of alternating layers of mafic, blue-black amphibolite and bluish nepheline-rich amphibolite interbanded on a scale of a few inches to a few feet. The top of the exposed sequence consists of another layered series comprising blue-black arfvedsonite amphibolites, greenish acmite-ferrohastingsite amphibolites, and mesocratic to leucocratic arfvedsonite syenite alternating in layers a few inches thick. Relict igneous textures can locally be discerned in this unit.

Chemical analyses of the rocks (Table 41) show consistent high iron and sodium contents, and low aluminum, magnesium, and calcium. Compared to the agpaitic rocks known elsewhere in the world they are very mafic-rich, and this is reflected in the high iron content, and relatively high calcium content.

TABLE 41 *Chemical analyses of the North Red Wine agpaitic complex (after Singh, 1972)*

	1	2	3	4	5	6
SiO_2	46.12	47.00	48.80	49.45	52.12	57.51
TiO_2	1.08	1.18	0.82	0.29	0.13	1.08
Al_2O_3	10.33	9.85	13.37	12.99	12.20	14.41
Fe_2O_3	6.75	3.15	6.72	9.86	8.75	7.20
FeO	10.91	18.08	8.78	5.38	4.59	3.49
MgO	2.15	0.72	1.86	0.10	0.26	0.26
CaO	3.31	2.55	1.92	2.77	1.28	1.10
MnO	0.40	0.66	0.28	0.50	0.70	0.09
Na_2O	10.12	10.00	9.53	10.53	9.59	9.27
K_2O	5.41	4.06	4.64	3.85	4.79	5.22
H_2O	n.d.	2.17	n.d.	n.d.	n.d.	0.45
TOTAL	96.58	99.42	96.72	95.72	94.41	100.08

All analyses quoted from Singh, 1972, Table 7.
All analyses are of agpaitic amphibolites, varying from ultramafic types, to varieties relatively rich in nepheline and eudialyte.
n.d.: not determined.

Age A series of six K-Ar determinations on amphibole and nepheline gave results ranging from 978 m.y. to 1,417 m.y. The results appear to fall into two groups, one of 1,028±50 m.y. from rocks near the edge of the complex, and the other of 1,312±105

	m.y. for rocks from the centre of the complex. It seems reasonable to suppose that the latter age is that of emplacement, preserved because of buffering by the surrounding rocks, whereas the other age is the age of metamorphism. A preliminary Pb-Pb age on eudialyte suggests an age of emplacement of 1,500 m.y., with the eudialyte incorporating large amounts of 2,700 m.y.-old lead.
Economic aspects	The North Red Wine complex was prospected and sampled by BRINEX as a possible source of eudialyte to serve as raw material for rare-earth and zirconium extraction. The results were unfavourable.
Selected reference	Singh, S. (1972): Petrological and mineralogical studies of the Joan Lake agpaitic complex, central Labrador; Univ. Ottawa, Ottawa, unpubl. Ph.D. thesis.

Name	Mann-1 (A-114; Fig. 90)
Location and access	Central Labrador, near 54°14′N, 62°23′W, on a large hill. Access is by floatplane to nearby lakes, and then on foot or by helicopter.
Form and structure	The occurrence, about 200 by 1,000 yards in size, lies along the contact between acid porphyries of the Letitia Lake Group and overlying basalt of the Seal Lake Group. The alkaline rocks occur in a lenticular area of intensely metasomatized and altered Letitia Lake Group rocks, which appear to have partly melted and intruded the Seal Lake Group. The occurrence is generally migmatitic in appearance, with the neosome distinctly more alkaline than the paleosome.
Petrography	The rocks, in general, are reddened, fractured, and heterogeneous. The more salic rocks consist mainly of albite and arfvedsonite, with subordinate amounts of aegirine, schizolite, pectolite, and enigmatite. Near the pegmatitic veinlets, small amounts of barylite, eudidymite, and other beryllium minerals are locally found, together with traces of neptunite, niobophyllite, and pyrochlore. The host rock is generally similar to the more salic rocks, but displays a spectacular plumose development of albite, together with occasional traces of eudialyte, neptunite, and pyrochlore. Parts of the syenite display a granular aplitic texture, which grades rapidly into the coarser grained parts richer in agpaitic minerals. Many of the syenitic patches and veins appear to fade imperceptibly into the wall-rocks.
Age	Unknown, but presumably similar to either the major complexes or the age of last metamorphism.
Economic aspects	The Mann-1 occurrence was prospected and drilled by BRINEX in the early 1960s, first as a uranium prospect, and then as a beryllium prospect. Despite considerable trenching, it was not possible to trace the beryllium values.
Remarks	The Mann-1 occurrence appears to be typical of several in the same region, most of which are marked on Figure 90. The other occurrences show less evidence of anatexis and consist of fenitized patches in the Letitia Lake Group, with development of acmite and enigmatite, and a peculiar acicular texture. No alkaline igneous rocks have been found in any of these occurrences, which range in size from a few square yards up to perhaps 200 by 1,000 yards. They appear to be the result of a metasomatic process akin to fenitization, but the mechanism which localized the metasomatic alteration remains obscure.
Selected reference	Evans, E. L. and Dujardin, R. A. (1961): A unique beryllium deposit in the vicinity of Ten Mile Lake, Seal Lake area, Labrador; Proc. Geol. Assoc. Can., v. 13, p. 45–51.

Name	Mann-2 (A-115; Fig. 90)
Location and access	Central Labrador, near 54°13′N, 62°27′W, on a prominent ridge a quarter mile west of the main ridge crest in this area. The occurrence is easily accessible on foot from Ten Mile Lake, about a half mile to the northwest.

Form and structure	The alkaline rocks are dyke-like, but the 'dyke' is,in fact, an allochthonous block about 200 yards wide and a mile long. Its trend is precisely parallel to those of the enclosing, deformed Letitia Lake Group, but the latter can be seen to bend around the ends of the alkaline rocks, making it into a giant boudin. The contacts with the alkaline rocks are strongly sheared, with most of the deformation in the alkaline rocks, and a characteristic stockwork fracture in the surroundings.
Petrography	The alkaline rocks are fine-grained, blue-black, nepheline-rich agpaitic rocks showing a distinct gneissosity. There is little change in composition across the occurrence, although the texture changes considerably as the more sheared and contorted edges of the block are approached. The actual contact is very rich in apple-green acmite, and this mineral is also abundant in the wall-rocks at the contact, particularly along shearing and gneissosity planes. At slightly greater distances, up to 200 to 300 feet, the wall-rocks are recrystallized into granular white rocks containing arfvedsonite and acmite, occasional enigmatite, and fluorite in the fractures.
Age	Unknown. Presumably the alkaline rocks are from a dyke related to the central complexes. Their emplacement in this setting, however, is probably related to the latest deformation.
Economic aspects	This occurrence was briefly prospected as a source of uranium.
Remarks	A chain of similar allochthonous blocks extends from Mann-2 to the southwest for about 5 miles. All are mafic agpaitic rocks surrounded by prominent fenitization haloes. A similar chain extends about 2 miles northeast from the North Red Wine complex. An isolated occurrence, apparently of similar character, is about 13 miles east of Mann-2, near longitude 62°06′W. The large fenitization haloes around these small blocks of alkaline rocks suggest that shearing must release large quantities of alkalis from these agpaitic rocks.
Selected reference	Brummer, J. J. and Mann, E. L. (1961): Geology of the Seal Lake area, Labrador; Geol. Soc. Amer., v. 72, p. 1361–1382.

Appendix I

Glossary of Rock, Mineral, and Petrographic Names Applied to Alkaline Rocks

(Terms marked with an asterisk are used in a special or restricted sense in this report, and are so defined in the glossary.)

absarokite – originally a poorly defined potassic alkaline volcanic rock related to the leucite basalts. Recently resurrected by Joplin to form part of the shoshonite series.

acmite* – $NaFeSi_2O_6$, pure soda-iron pyroxene. Also used for natural pyroxenes containing less than 25 per cent of other components.

aegirine* – any pyroxene intermediate between augite and acmite which displays the characteristic green pleochroism.

aenigmatite – enigmatite

agpaitic* – referring to rocks in which the mol ratio of Na + K/Al is greater than 1. In the literature the term is often used for other values of this ratio varying from 1.0 to 1.3. Also used to designate a suite of minerals characteristic of these rocks.

alkali* – referring to a rock sufficiently rich in Na + K that it shows an agpaitic mineral, but contains no feldspathoid

alkaline* – applied to a rock containing either a modal or normative feldspathoid

allochetite – lamprophyric dyke rock approaching nepheline monzonite

alnoite* – ultramafic rock containing melilite and mica as essential constituents with varying amounts of olivine, clinopyroxene, and calcite

alvikite – an igneous dyke composed essentially of calcite

analcite – $NaAlSi_2O_6.H_2O$, a tectosilicate related to the zeolites, but with feldspathoidal affinities. Commonly occurs in light coloured dodecahedra, if primary

analcimite – a volcanic rock nephelinitic type in which more than 75 per cent of the feldspathoid is analcite

ancylite – approximately $Sr_3Ce_4(OH)_4CO_3.3H_2O$. Occurs in accessory amounts in some carbonatites, and rarely in syenites.

andesite* – a volcanic rock composed of roughly equal amounts of feldspar and ferromagnesian minerals in which the feldspar is less calcic than An_{50}, and potash feldspar is less than 10 per cent of total feldspar

ankaramite – mildly alkaline melabasalt very rich in olivine

ankaratrite* – melanephelinite

apachite – phonolite with enigmatite and sodic amphibole (usually arfvedsonite), as well as aegirinic pyroxene

arfvedsonite – $Na_3(Fe,Mg)_4(Fe,Al)Si_8O_{22}(OH,F)_2$, the typical amphibole of agpaitic rocks, commonly containing appreciable Ca and some replacement of Al by Si. Mg-rich varieties (eckermannite) commonly contain Li.

arkite – mesocratic leucite-nepheline syenite, containing melanite

arsoite – augite trachyte with a little leucite and olivine

assyntite – trachytoid mesocratic nepheline-sodalite syenite

astrophyllite – approximately $Na_3Fe_7Ti_2Si_8O_{24}(OH)_7$, a brownish mineral resembling biotite, typically found in agpaitic rocks

baddeleyite – ZrO_2, rarely found in alkaline rocks associated with carbonatites, as at Palabora, South Africa

barkevikite – about $Ca_2NaFe_5Si_{6.5}Al_{1.5}O_{22}(OH,F)_2$, a rare alkaline amphibole found in some alkaline gabbros. Similar to kaersutite, but lacks Ti.

barylite – $BaBeSi_2O_7$, rarely found in the metasomatic alteration halo of agpaitic rocks

basanite* – a basaltic rock containing more than 10 per cent normative nepheline. Common usage requires olivine to be present, the rock being termed tephrite if it is not.

basalt* – a volcanic or fine-grained rock consisting predominantly of plagioclase more calcic than An_{50} and pyroxene, commonly with subordinate olivine
bastnasite – approximately $CeFCO_3$, a red-brown acicular mineral commonly found in carbonatite
batukite – madupite
beforsite – porphyritic or dyke dolomite of igneous origin
bekinkinite – feldspathic olivine ijolite
beloeilite – sodalite-rich syenite
benmoreite – a volcanic rock falling near the boundaries of trachyandesite, phonolite, and latite. Defined mainly on chemical criteria, and supposed derivation from basalt.
bergalite – lamprophyric hauyne alnoite
berondrite – kaersutite syenogabbro
bigwoodite – hastingsite monzonite
bjerezite – analcite-nepheline monzonite
blairmorite – analcite-rich phonolite
bogusite – analcite gabbro. May contain amphibole in place of pyroxene.
borolanite – melanite-rich nepheline syenite
bostonite – leucotrachyte with prominent plates of potash feldspar
braccianite – feldspathic fergusite
buchonite – olivine-free basanite with a little potash feldspar
caltonite – ocellar analcite-rich basalt or basanite
campanite – feldspathic leucitite or leucite-rich phonolite
camptonite – lamprophyric diorite, commonly mildly alkaline due to kaersutite content
canadite – albite nepheline syenite which contains anorthite in the norm but not in the mode
cancrinite – mainly $NaAlSiO_4.CO_3.2H_2O$ with substitution of K, Ca for Na and SO_4, Cl for CO_3. Common alteration of nepheline, particularly in carbonate-bearing rocks. Volcanic types are rich in Cl (microsomnite), and limited solid solution toward hauyne and sodalite has been claimed.
carbonatite* – an igneous rock composed of more than 50 per cent carbonate
cascadite – melanocratic lamprophyric syenite
catapleite – $Na_2ZrSi_3O_9$, with some Ca for Na. Rarely found as a brownish alteration of eudialyte in agpaitic syenites.
cecilite – melilite leucitite, with some feldspar and olivine
chibinite (khibinite) – a trachytoid agpaitic nepheline syenite
cocite – leucite fergusite containing biotite
columbretite – leucite trachyte
congressite – feldspathic urtite
coppaelite – extrusive equivalent of alnoite
covite – leucocratic potassic nepheline syenite
craigmontite – nepheline-rich corundum syenite
crinanite – analcite olivine gabbro
crocidolite – asbestiform riebeckite
cromaltite – melanite-rich mica-pyroxenite
cuyamite – analcite-rich gabbro
damkjernite – orthoclase-bearing melteigite of lamprophyric texture
dancalite – analcite trachyandesite
deldoradite – leucocratic cancrinite syenite
ditroite – sodalite-bearing nepheline syenite
drakonite – plagioclase-bearing trachyte
dumalite – alkaline trachyandesite
dungannonite – cordundum-bearing nepheline diorite
dysanalyte – niobian perovskite, common in some carbonatites
eckermannite – magnesium-rich arfvedsonite, commonly with Li
elaeolite – (=elaeolith), obsolete name for nepheline
elpidite – $H_6NaZrSi_6O_{18}$(?), a fibrous white agpaitic mineral commonly associated with eudialyte

enigmatite – $Na_2Fe_5TiSi_6O_{20}$, one of the most common mafic minerals of agpaitic rocks, whether alkaline or not. Readily distinguished by intense brown colour, and prismatic form.

espichellite – lamprophyric analcite gabbro

essexite* – nepheline-bearing mesocratic rock with subequal amounts of plagioclase and orthoclase. In the literature this term can be found applied to nearly all intermediate to basic members of the alkali basalt family.

etindite – leucite-rich lamprophyre

eudialyte – approximately $Na_6ZrSi_6O_{18}(OH)$, with major substitution of Ca for Na, rare-earths, Nb, U, and Th for Zr, and F and O for OH. A chemically very complex mineral forming spectacular wine-coloured or brownish aggregates in agpaitic rocks.

eudidymite – $NaBeOHSi_3O_7$, a rare agpaitic mineral found in the metasomatic aureole of some complexes

euktolite – leucite-bearing melilite nephelinite

eustratite – lamprophyric alkaline olivine monzonite

farrisite – alnoite

fasinite – melanocratic nepheline syenite containing a little olivine, and commonly rich in titanaugite

feldspathic – containing feldspar

feldspathoid* – any alkali aluminosilicate with an O/Si ratio greater than 3:1, whether or not other ions are present

feldspathoidal – containing feldspathoids

fenite* – a metasomatic rock produced by solutions emanating from alkaline complexes

fergusite* – plutonic rock composed of roughly equal amounts of leucite and dark minerals

fiasconite – leucite basanite, with anorthitic plagioclase

fourchite – lamprophyric analcite-bearing pyroxenite (no olivine)

foyaite – trachytoid nepheline syenite

gabbro – plutonic rock mainly composed of plagioclase more calcic than An_{50} and pyroxene

gaussbergite – leucite trachyte

gauteite – analcite trachyte

ghizite – olivine-bearing analcite andesite with biotite

glenmuirite – originally an analcite trachyandesite with olivine. Now commonly used for olivine-bearing andesitic rocks containing appreciable potash feldspar.

glimmerite – a rock composed essentially of mica, usually phlogopite

gooderite – albite leucodiorite

hastingsite – $NaCa_2(Fe, Mg)_4(Al, Fe)Al_2Si_6O_{22}(OH, F)_2$, an amphibole typical of intermediate and salic rocks of miaskitic chemistry

hauyne – the sulphatic member of the sodalite group, approximately $(Na, Ca)AlSiO_4.(Na_2S, Na_2SO_4)$. Typically a volcanic mineral.

hawaiite – olivine andesite, usually contains slight nepheline in the norm

hedrumite – porphyritic pulaskite, often trachytoid

heptorite – porphyritic or lamprophyric hauyne-rich nephelinite

heronite – an analcite trachyte dyke rock

heumite – mesocratic nepheline-poor syenite with a little sodalite. Approaches shonkinite.

highwoodite – biotite syenogabbro

hilairite – feldspathic sodalite urtite

hiortdahlite – $(Ca, Na)_3Ti(O, F)Si_2O_8$ with substitution to lavenite and wohlerite. These minerals form yellow or brownish prisms commonly present as accessories in agpaitic syenites.

holmite – alnoite with a little analcite

husebyite – nepheline syenite with andesine

ijolite* – a plutonic rock consisting of approximately equal amounts of nepheline and pyroxene

italite – a rock of plutonic habit containing more than $\frac{2}{3}$ by volume of leucite

jacupirangite – a pyroxenite dominated by titanaugite. May also contain olivine, minor nepheline, and large amounts of opaques.

jadeite – $NaAlSi_2O_6$, a high pressure pyroxene not found in igneous rocks, but admixtures with diopside (omphacite) are found in some deep-seated alkaline rocks such as eclogite, and eclogite nodules in kimberlites.

joaquinite – $NaBa(Ti, Fe)_3Si_4O_{15}$, a brownish waxy mineral found in the metasomatized aureole of agpaitic complexes

jumillite – feldspathic olivine-bearing wyomingite

juvite – nepheline syenite with potash feldspar very predominant over soda feldspar

kaliophilite – a rare polymorph of $KalSiO_4$ found in some ultrapotassic basaltic rocks

kaersutite – $Ca_2NaFe_4TiSi_6AlO_{22}(OH, F)_2$, a red-brown amphibole easily mistaken for biotite which is typical of alkaline gabbros and their derivatives, and also found in some nephelinitic and miaskitic rocks

kaiwekite – oligoclase trachyte with anorthoclase phenocrysts

kajanite – probably lamprophyric fergusite

kakortokite – agpaitic melanocratic syenite with a high tenor of eudialyte. Usually shows layered structure.

kalsilite – a rare polymorph of $KAlSiO_4$ found only in some nephelinitic lavas, and as a contact metamorphic mineral around alkali basalt

kassaite – probably hauyne syenodiorite

katungite – olivine-melilite wyomingite lacking pyroxene

katzenbuckelite – olivine-bearing nepheline-leucite phonolite

kentallenite – olivine monzonite. Occasionally used for similar rocks containing pseudoleucite.

kenyte – olivine-bearing phonolitic trachyte

kimberlite – serpentinized carbonated mica-peridotite containing ultramafic inclusions characterized by high-pressure minerals

kivite – leucite melabasanite

kulaite – nepheline trachybasalt with kaersutite, biotite, and olivine

kvellite – feldspathic olivine-kaersutite perknite

lakarpite – catapleite syenite

lamprophyllite – $Na_3CaTi_3O_2OHSi_3O_{12}$(?), a yellowish flaky mineral resembling biotite found in agpaitic pegmatites

lamprophyre* – a porphyritic-textured rock with prominent, abundant phenocrysts of mafic minerals only in a finely granular groundmass. Feldspar may not appear as a phenocryst.

lapis-lazuli – lazurite, a semi-precious blue stone mainly composed of lazurite ($6NaAlSiO_4$. Na_2SO_4), but containing varying amounts of hauyne. Usually found in metamorphosed marbles.

larvikite – olivine-bearing syenite with rhombic feldspar

latite* – a leucocratic to mesocratic volcanic rock lacking quartz in which the plagioclase is less calcic than An_{50}, and potash feldspar comprises 40 to 70 per cent of total feldspar

laurdalite – nepheline syenite with rhombohedral feldspars

lavenite – $Na_3ZrSi_2O_7$ with appreciable Ca, Fe, rare-earths. A member of the wohlerite group, and typical of agpaitic accessory minerals.

ledmorite – melanite-bearing nepheline melasyenite

leucite – $KAlSi_2O_6$, a tectosilicate found in potassic volcanic rocks in place of nepheline, as in italites and the like. Not found in plutonic rocks, but hexahedral intergrowths of nepheline and potash feldspar in some rocks (pseudoleucite) are thought to originate by breakdown of leucite.

leucitite* – a volcanic rock containing more than 65 per cent feldspathoids of which leucite forms more than half

leucocratic* – leuco-, contains less than 10 per cent by volume of dark minerals

limburgite – ankaratrite with the nepheline occult in glass

linosaite – nepheline-bearing basalt

litchfieldite – nepheline monzonite

lugarite – analcite gabbro and analcite-rich gabbro

luhite – alnoite

lujavrite – a trachytoid or schistose mesocratic, agpaitic nepheline syenite

luscladite – nepheline-bearing olivine trachybasalt madeirite – alkaline melagabbro

madupite* – a volcanic rock composed essentially of leucite and mafic minerals in which the colour index is between 60 and 90

mafraite – a lamprophyric monzogabbro

malignite – nepheline syenite with colour index between 50 and 90

mareugite – hauyne gabbro

marienbergite – natrolite phonolite

mariupolite* – alkaline plutonic rock with albite forming more than 90 per cent of the feldspars and F.I. and C.I. less than 50 per cent

marosite – melasyenite with a little sodalite and nepheline

martinite – leucite trachybasalt

melanite – a brown garnet of the andradite type containing 1 to 5 per cent TiO_2. Typically found in ijolitic alkaline rocks and associated syenites.

melanocratic – mela-*, colour index is greater than 90 for the rock

melilite – a general name for a complex solid solution series approximately equivalent to desilicated feldspars. The principal end members are akermanite ($Ca_2MgSi_2O_7$), gehlenite ($Ca_2Al_2SiO_7$), and soda melilite ($CaNaAlSi_2O_7$). Melilites in igneous rocks are found in nephelinites and carbonatites, and in composition approach $\frac{2}{3}$ akermanite, and $\frac{1}{3}$ soda melilite.

melteigite* – a plutonic rock with colour index between 60 and 90, consisting essentially of nepheline and mafic silicate minerals

miaskite – nepheline monzonite, sometimes sodalite-bearing (sometimes spelled miascite)

miaskitic* – refers to rocks in which the molecular ratio of $NA + K/Al$ is less than 1, commonly substantially less

minette – lamprophyric biotite syenite or melasyenite

missourite* – a rock of plutonic habit with colour index between 60 and 90, consisting essentially of leucite and mafic silicates

modlibovite – lamprophyric monticellite-alnoite with chlorite

mode – the mineral composition of a rock quantitatively measured in volume per cent

modumite – alkaline anorthosite

monchiquite – lamprophyric analcite nephelinite

mondhaldeite – lamprophyric syenogabbro

monmouthite – hastingsite urtite

monticellite – $CaMgSiO_4$, a calcium olivine found in some very silica-poor mafic alkaline rocks of the nephelinite family

mugearite – olivine-bearing andesite with oligoclase as the plagioclase

muniongite – fine-grained nepheline-rich syenite

murite – feldspathic olivine-bearing nephelinite

natrolite – $Na_2Al_2Si_3O_{10}.2H_2O$, this zeolite is by no means an exclusively alkaline mineral but it is a common alteration product of nepheline, and may be primary in some agpaitic rocks

naujaite – a sodalite-rich agpaitic syenite characterized by large poikilitic crystals of sodalite

nepheline – ideally $NaAlSiO_4$, but all natural nepheline contains K in solid solution. Nepheline from plutonic rocks approaches $Na_3Kal_4Si_4O_{16}$ (Burger-Morozewicz composition), whereas that from volcanic rocks is richer in sodium.

nephelinite* – a volcanic rock essentially composed of roughly equal amounts of nepheline and mafic silicate minerals

ngurumanite – ankaratrite or melteigite containing analcite, calcite, and iron-rich mesostasis

norm – a chemical analysis converted into theoretical minerals. For alkaline rocks these theoretical minerals generally bear little resemblance to the actual minerals, but they serve as a guide to the degree of silica saturation of the rocks.

nordsjoite – carbonated feldspathic urtite

nosean – $NaAlSiO_4.Na_2SO_4$, a mineral of the sodalite group chiefly found in certain phonolites and related rocks

okaite – originally defined as a melilite-hauyne rock, but now chiefly used for melilite-nepheline rocks

onkilonite – leucite-bearing nephelinite

ordanchite – olivine-bearing hauyne andesite. Occasionally applied to potassic, alkaline andesites in general.
ordosite – phlogopite melasyenite
orendite – biotite-bearing leucite trachyte
orotvite – amphibole-rich titanaugite pyroxenite
ottajanite – leucite trachybasalt
ouachitite – lamprophyric analcite melteigite with no olivine
parchettite – leucite-rich andesite
parisite – $Ce_2FCO_3.\frac{1}{2}CaCO_3$ = a rare accessory of some carbonatites, related to ancylite
pectolite – $HCaNa_2Si_3O_9$, a wollastonite-like mineral which is locally abundant in agpaitic complexes
penikkavaarite – melanocratic syenogabbro
peperino (peperite) – originally used for leucitic ash flow tuffs, but now generally used for certain types of welded tuffs without distinction as to composition
perovskite – perofskite – essentially $CaTiO_3$ with much substitution of Na, Fe, and rare-earths for Ca, and of Nb for Ti. Found in basic alkaline rocks, and rare-earth types (knopite) in associated syenites.
phonolite* – alkaline volcanic rock with colour index less than 50 in which albite forms more than 60 per cent of the feldspar. Phonolites commonly have feldspathoid indices over 10.
pienaarite – sphene-rich nepheline melasyenite
pollenite – nepheline latite with amphibole
polzenite – alnoite poor in titanaugite
puglianite – leucite melasyenogabbro
pulaskite – leucocratic syenite with less than 10 per cent feldspathoids. In old descriptions the rock may not even be alkaline.
rafaelite – analcite syenogabbro
raglanite – corundum-bearing feldspathic urtite
ramsayite – $Na_2Ti_3Si_2O_9$, found as brownish acicular crystals in agpaitic rocks, and in some late agpaitic differentiates of nephelinitic rocks
rauhaugite – plutonic dolomite carbonatite
rhombenporphyr – rhomb porphyry – porphyritic trachytes or latites characterized by rhombohedral feldspar crystals
riebeckite – $Na_2Fe_2Fe_3Si_8O_{22}(OH,F)_2$, an amphibole occasionally found in nepheline syenite, more commonly in alkali granite. The asbestos-like variety crocidolite is common in fenites.
richterite – $Na_2CaMgSi_8O_{22}(OH,F)_2$, a sodic amphibole rare in igneous rocks, but found in some ultramafic varieties.
riedenite – melilite melteigite
rongstockite – nepheline-bearing trachybasalt
rouvillite – nepheline-rich gabbro
rutterite – leucomonzonite
sannaite – melanocratic nepheline-bearing monzonite rich in pyrite
sarnaite – cancrinite syenite
scanoite – olivine-bearing analcite andesite
schorenbergite – porphyritic fergusite with nepheline and noselite
schorlomite – titanium-rich andradite garnet commonly found in ijolites and associated nepheline syenites. Schorlomite has considerably more Ti than melanite.
sebastianite – biotite gabbro
schizolite – $HNa(Ca,Mn)Si_3O_9$, a pinkish relation of pectolite found in agpaitic syenites
selbergite – nepheline-bearing leucite-rich trachyte with noselite and melanite
shackanite – analcite trachyte
shonkinite – faintly alkaline melasyenite
shoshonite – originally used for trachybasalts, but now used as a general term for alkaline basalts in which K_2O approaches or exceeds Na_2O
silico-carbonatites – mixed rocks consisting of carbonatite and a silicate fraction, usually ultramafic, in about equal amounts

sodalite – $NaAlSiO_4.NaCl$, a feldspathoid often distinguished by blue or green colour but may be grey. Common in nepheline syenite, less so in phonolite and certain basic rocks. May form veins. Also applied to the group of sodalite, nosean, hauyne, and lazurite as a general term (sodalite group).
sorkedalite – alkaline monzogabbro rich in magnetite and apatite
sommaite – olivine-bearing leucite syenogabbro
sovite – plutonic calcite carbonatite
sphene = titanite – $CaTiSiO_5$, a characteristic accessory of alkaline rocks easily recognized by yellowish colour and wedge-like shape. Varieties in mafic rocks may have large rare-earth contents.
sumacoite – nepheline-bearing trachyandesite with a little hauyne
sussexite – nepheline syenite porphyry with nepheline phenocrysts
syenite* – a rock composed essentially of potash feldspar and lacking quartz
synchysite – $CeFCO_3$ (approximately), an occasional rare-earth carrier in carbonatites
tahitite – hauyne trachyandesite
taimarite – noselite leucotrachyte
tamaraite – feldspathic melteigite
tannbuschite – melanocratic olivine nephelinite
tasmanite – melilite zeolite melteigite
tautirite – nepheline trachyandesite
tavolatite – nepheline-leucite vulsinite ± hauyne
tawite – rock composed essentially of sodalite
tephrite – basanite lacking olivine
teschenite – analcite gabbro or melagabbro
theralite – olivine nepheline gabbro or melagabbro
thomsonite – $NaCa_2(Al, Si)_{10}O_{20}.6H_2O$, a zeolite related to natrolite found almost exclusively as a secondary mineral in alkaline basic rocks
tinguaite – porphyritic, fine-grained nepheline syenite
tjosite – lamprophyric feldspathic melteigite
toryhillite – albite-bearing ijolite
trachyte* – a volcanic rock consisting essentially of potash feldspar
trachytic – applied to a texture showing aligned microlites of feldspar
tristanite – a potassic trachyandesite in which K_2O approaches Na_2O in weight per cent. Mainly defined on chemical grounds.
turjaite – melilite-diopside melteigite
tutvetite – leucocratic trachytoid monzonite
tveitasite – an obsolete name for mafic fenites
ulrichite – olivine-bearing nepheline syenite porphyry
umptekite – granular pulaskite
uncompahgrite – alnoite with diopside as the pyroxene
urtite* – a plutonic rock with colour index less than 30 which is more than 50 per cent sodic feldspathoids
venanzite – melilite wyomingite
vermiculite – a talc-like mineral which expands and exfoliates on heating. Generated in mafic alkaline rocks and carbonatites by alteration of mica (biotite or phlogopite).
vesbite – melilite leucitite
vesecite – monticellite alnoite
vetrallite – vulsinite
vicoite – a volcanic rock with colour index less than 50 in which potash feldspar forms 40 to 70 per cent of the total feldspar and coexists with a plagioclase more calcic than An_{50}.
vishnevite – sulphatic cancrinite, commonly displaying substitution of K for Na, and Cl, CO_3 for SO_4, about $NaA1SiO_4.SO_4.2H_2O$
viterbite – leucite vulsinite
vulsinite* – a volcanic rock with colour index less than 50 in which potash feldspar forms 70 to 100 per cent of the total feldspar and coexists with a plagioclase more calcic than An_{50}

wesselite – hauyne-bearing ankaramite
westerwaldite – nepheline melatrachybasalt
wollastonite – $CaSiO_3$, a white pyroxenoid mineral containing appreciable Fe in volcanic varieties, rather common in nephelinitic rocks, and found in some carbonatites.
wyomingite* – a volcanic rock with colour index between 30 and 60, consisting essentially of potassic feldspathoids and mafic silicates
yamaskite – feldspathic titanaugite pyroxenite
yogoite – an alkaline mesocratic syenite

Index