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GEOLOGY OF THE KILLALA LAKE IGNEOUS COMPLEX, ONTARIO.

GEOLOGY OF THE KILLALA LAKE IGNEOUS COMPLEX DISTRICT OF THUNDER BAY, ONTARIO CANADA

by

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science.

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FRONTISPIECE: Aerial photograph of the Killala Lake Complex. National Air Photo Library - Photo number 85-A17808

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Note: Pmg. means photomicrograph

ABSTRACT

The Killala Lake Igneous Complex forms part of an alkalic province of Western Ontario. K-Ar age determinations of the Coldwell and Killala Lake rocks give values of 1250 my. to 1035 my.

The Killala Lake Complex intruded into an Early Precambrian basement composed of metasedimentary migmatite and granitic rocks.

The earliest magma in the Killala Lake Complex had a gabbroic composition; crystallization *in situ* followed an undersaturated differentiation trend. Differentiation was interrupted at a late stage by the intrusion of syenite. Undersaturated differentiation resumed and when the syenites were semi-consolidated, olivine-nepheline syenite was intruded centrally. The terminal stage of plutonic intrusion was a ring-like body of nepheline syenite which was emplaced near the periphery and differentiated *in situ*. Late stage nepheline pegmatites are niobium bearing. Lamprophyre dykes mark the last phase of igneous activity.

Layering is well developed in the gabbro, syenite and nepheline syenite.

Emplacement of the intrusion was by ring fracture stoping, controlled by major regional faults. An association of the alkalic intrusions with crustal rifting seems likely.

INTRODUCTION

Location and Access

The Killala Lake Igneous Complex is situated about 40 km. north of Lake Superior and is approximately 65 km. southeast of Geraldton, Ontario (See Figure 1). Neys, on Trans-Canada Highway No. 17, is about 35 km. due south of the complex. The mining town of Manitouwadge lies 45 km. to the east. An area of 160 square km. mapped is bounded by latitudes 49°06'43" and 49°15'00" and longitudes 86°22'56" and 86°32'11" in the District of Thunder Bay.

Access to the map-area is by float-equipped aircraft from White River, Geraldton, and Pays Plat. The northern parts of the complex are accessible by boat or canoe. Kagiano Lake, which embays the northwestern part of the map-area, is a good water route and can be reached by a road at a point about 10 km. north of the Killala Lake Complex (See Figure 1). A road, which extends from Neys on Highway No. 17 to the southern end of Killala Lake, is no longer passable.

Purpose and Scope of Work

The Killala Lake pluton is a moderately alkaline

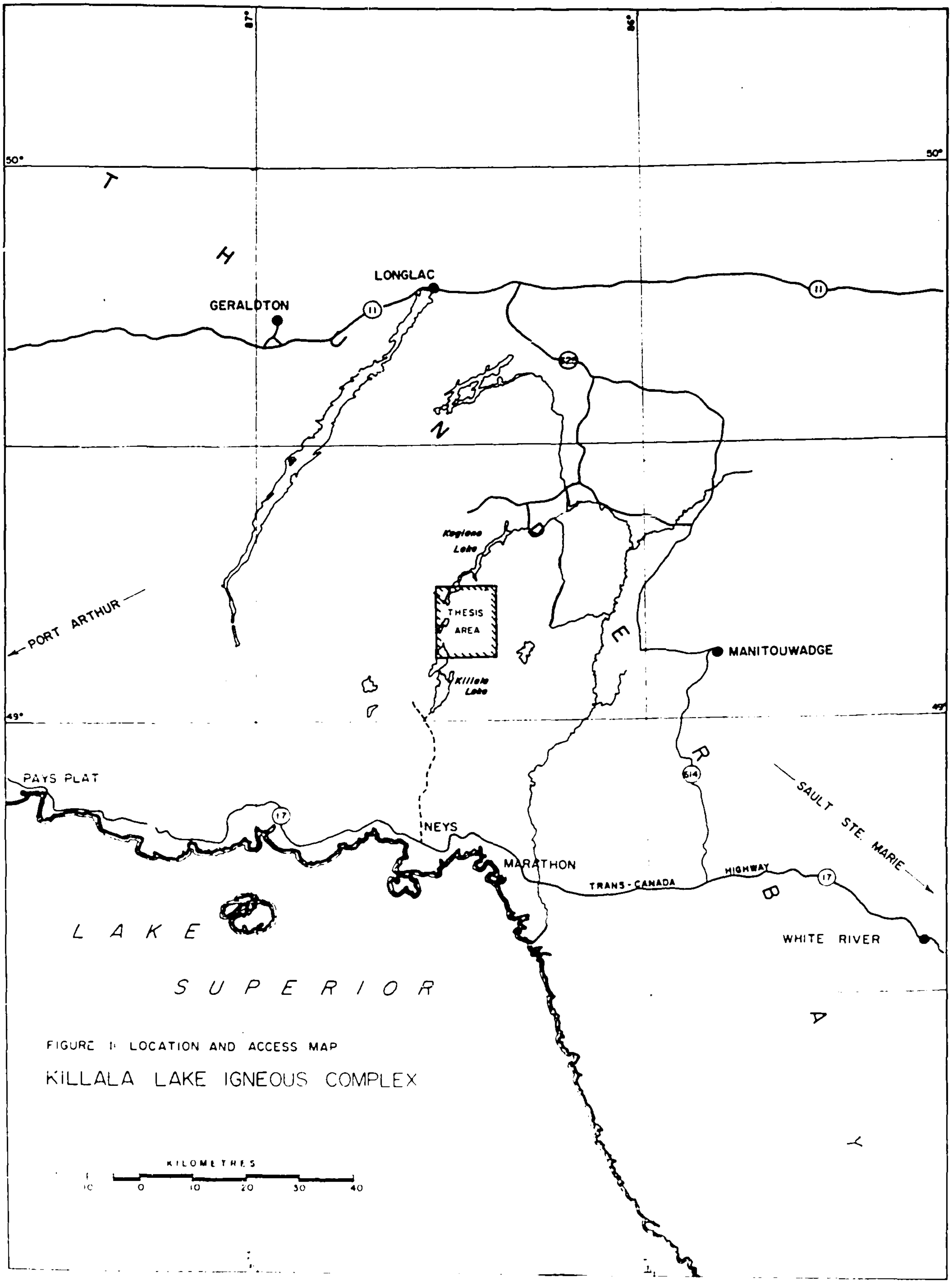


FIGURE 1: LOCATION AND ACCESS MAP

KILLALA LAKE IGNEOUS COMPLEX

intrusive complex. These alkalic rocks, in addition to their interesting petrological character, are of economic significance as they have been found to contain appreciable amounts of copper and niobium.

A close association of alkalic complexes with rift valley structures has been recognized (Kumarapeli and Saull, 1966). Recently, rift valleys have been studied with increasing interest. Since the rifts are regarded by some as fundamental features of the crustal evolutionary process, the associated alkaline rocks are worthy of study as a complementary phenomenon. They may indeed be used as possible indicators of rift systems as yet undiscovered.

The study was undertaken in the hope that it would contribute to our knowledge of this part of the Canadian Shield and the processes that have affected it. It was also thought that something of direct economic interest might accrue. A geological map has been prepared to show the areal distribution of the various rock types encountered. The body of the thesis gives a general geological description of the complex and its component rock types with tentative interpretations. It is hoped that this work will prove to be a useful guide in further economic and petrological studies.

Method of Study

The area was visited briefly by the author in the autumn of 1965. In July, 1966, with four assistants, he spent two weeks in the area collecting specimens and doing geological mapping at a scale of 1:15,840. Base maps were compiled in the field using maps of the Forest Resources Inventory, Ontario Department of Lands and Forests, as a reference. Traverses were plotted on aerial photographs which were enlarged to the scale of mapping. Outcrop areas were outlined using stereographic methods. The final maps have been photographically reduced to a scale of 1:31,680.

About 500 rock specimens were collected; 150 thin-sections were cut and studied and 13 chemical analyses were made of samples from the various units. Staining techniques were used in the macroscopic study of the feldspars and feldspathoids. Modal analyses were performed on each rock type using the standard point-count technique on the fine grained rocks and a second method, designed by the author for the coarse grained rocks. Nepheline-kalsilite minerals were studied by x-ray methods and olivines were examined on the universal stage. C.I.P.W. norm calculations were done with the I.B.M. 7094 computer using a program prepared by F.G. Smith, University of Toronto.

Previous Work

After the discovery of the base metal deposits at Manitouwadge in 1953, the Killala Lake Complex was examined by several exploration companies engaged in a systematic search for copper and nickel deposits. Geophysical surveys, geological mapping and exploratory diamond drilling were done at various locations (See Appendix I and Map No. 2, back pocket).

The only previous published work on the complex is a brief description contained in a report (with accompanying maps) on the regional geology of the Killala-Vein Lakes area (Coates, 1967).

Two other alkalic complexes are found in the same region (See Figure 2). The Port Coldwell Complex was recognized over 120 years ago and a considerable amount of published work is available (Logan, 1846, 1863; Coleman, 1898-1902; Adams, 1900; Kerr, 1910; Barlow, 1913; Fairbairn, 1959; Puskas, 1960; Milne, 1967). A geophysical survey and geological mapping of the Prairie Lake Complex has been done for a

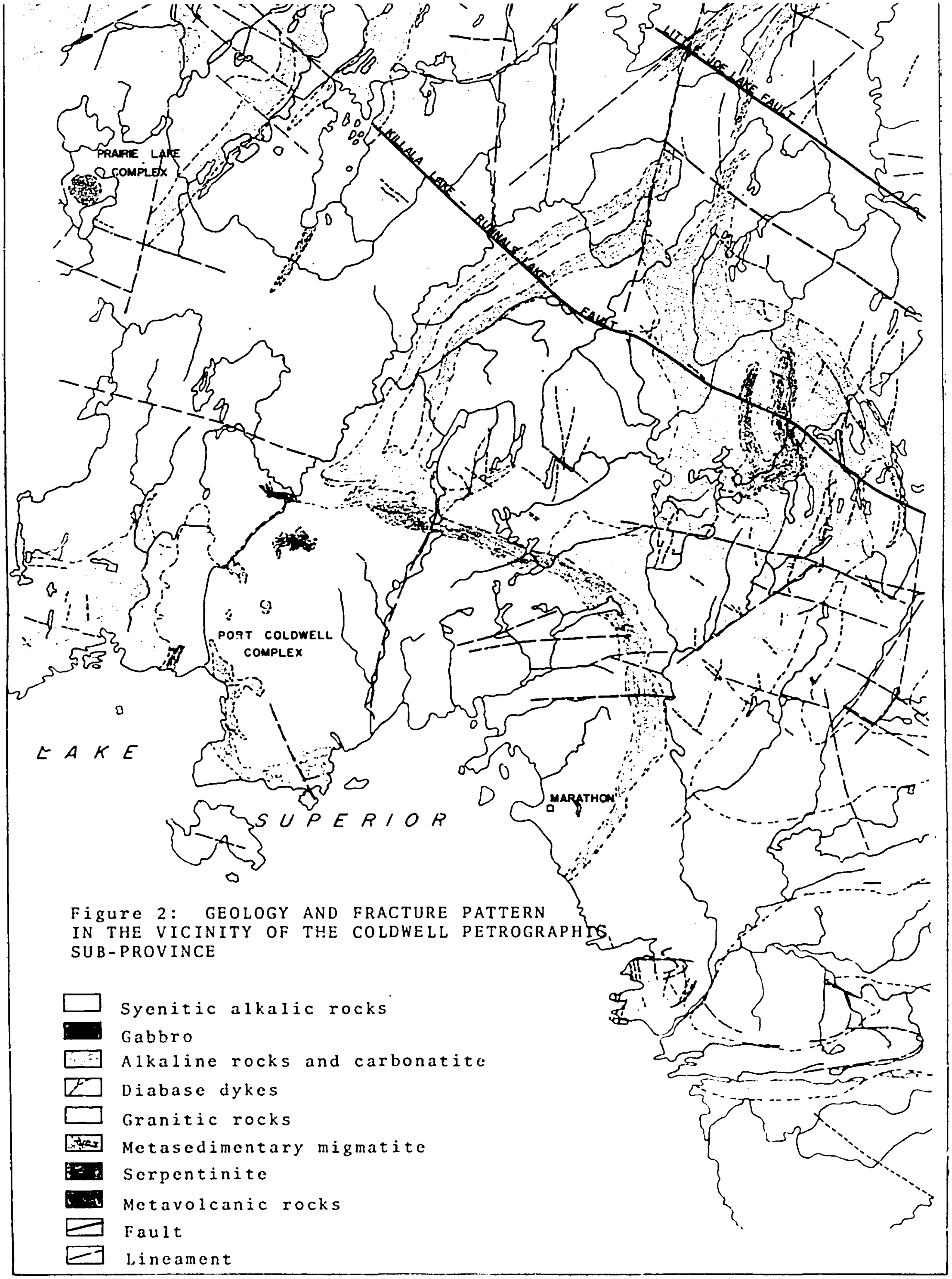


Figure 2: GEOLOGY AND FRACTURE PATTERN IN THE VICINITY OF THE COLDWELL PETROGRAPHIC SUB-PROVINCE

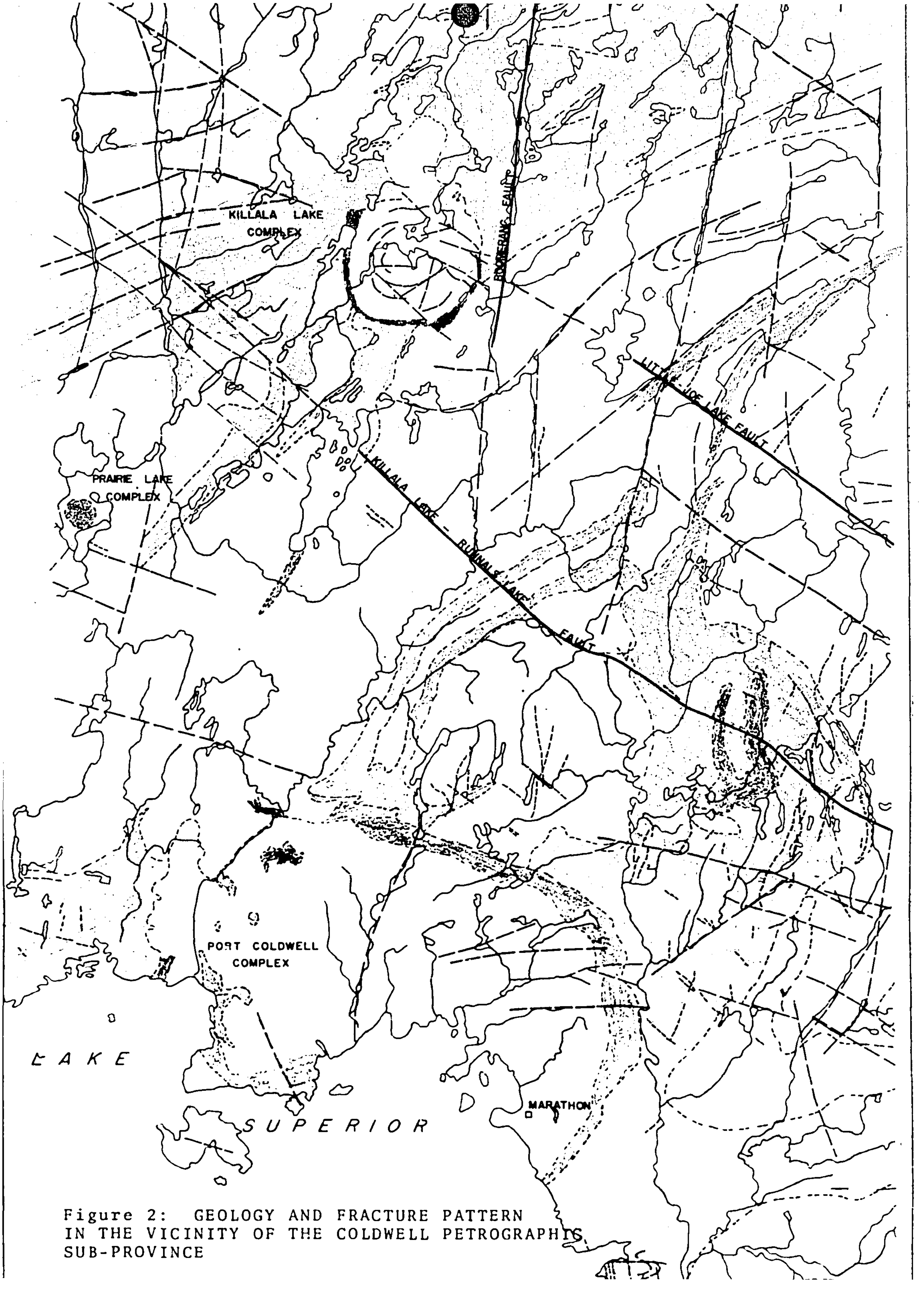


Figure 2: GEOLOGY AND FRACTURE PATTERN IN THE VICINITY OF THE COLDWELL PETROGRAPHIC SUB-PROVINCE

private company and has not been published. (Parsons, 1959).

Acknowledgments

The author wishes to express his appreciation to those who helped in this study.

Dr. J.E. Gill of McGill University supervised the writing of the thesis and provided many helpful suggestions which improved the presentation. Encouragement and guidance from Dr. E.H. Kranck are gratefully acknowledged. Dr. J.S. Stevenson and the staff of the Geology Department, McGill University, assisted the writer by providing research facilities and consultations. Dr. R. Doig did the age determination work on the rocks.

The author is indebted to Dr. J.E. Thomson, and Dr. E.G. Pye of the Ontario Department of Mines for support during the field work and for analytical work on rock-samples from the thesis-area. Thanks are due Mr. D.A. Moddle, Provincial Analyst, Ontario, for painstaking work on the chemical analyses made.

The author was assisted in the field by L.M. Barron,

A. Chalk, John DeGrace and T.A. Trudel. Mr. Barron did half of the traverses; his capable help and friendship during the work was invaluable.

Dr. F. Puskas of Anaconda Brass Co.(Canada)Ltd. provided many references on the thesis subject which were an asset.

Colleagues at McGill University aided in many ways: Norman Gray and T. Ahmedali assisted in the computer work and E. Pattison did optical work on the olivine minerals. John A. MacDonald provided valuable suggestions for improving early drafts of the thesis. The author is very grateful to P.S. Kumarapeli for his patient criticism, countless helpful suggestions and comradeship.

Miss Murielle Gaudette, in the typing of this thesis, took great pains with the presentation of the material; it is a pleasure to acknowledge her assistance.

REGIONAL SETTING OF THE COMPLEX

The Killala Lake Complex is situated in the southern part of the Superior structural province of the Canadian Shield. The rock types composing the surrounding areas are of Early Precambrian age and consist mainly of a metasedimentary-metavolcanic suite and a granitic suite (See Figure 2).

Intermediate to basic volcanic rocks have been metamorphosed to hornblende-plagioclase-epidote gneisses of almandine amphibolite grade at the contacts with the granitic rocks. In the main body of these rocks hornblende-hornfels facies assemblages are present. Subordinate amounts of easily recognizable rhyolitic pyroclastic rocks are also present.

The metasedimentary rocks have been isoclinally folded and intruded by granites forming an extensive migmatitic complex which persists for more than 50 km. to the northwest of Killala Lake. The metavolcanics and migmatites have been intruded by stock-like bodies of post-tectonic quartz-monzonite.

Subsequent earth movements caused fracture and warping which have controlled drainage and indirectly have produced a system of linear features in the topography.

Diabase dykes intrude all the afore-mentioned types.

The alkalic complexes at Port Coldwell, Prairie Lake and Killala Lake represent the youngest known intrusive rocks in the region. They constitute a unique petrographic sub-province which has been dated by Fairbairn (1959) at 1225-1065 my. in age. They will be collectively referred to in the remainder of this work as the "Coldwell Intrusives". The association of the alkalic rocks with major fault structures is suggested by the observed relationship to the regional fracture pattern.

Topography and Drainage

The rocks of the Killala Lake Complex form a roughly oval plateau which stands about 130 metres above the surface of the surrounding peneplain (See Plates 1 and 2). High, arcuate ridges of nepheline syenite form natural ramparts which enclose a bowl-like central depression. The outer slopes of the complex are very steep, often with sheer cliffs over 40 metres in height. Slopes on the interior side of the rim are more gradual. Lakes in the central part of the complex are shallow and stagnant. Narrow linear valleys follow the trends of the

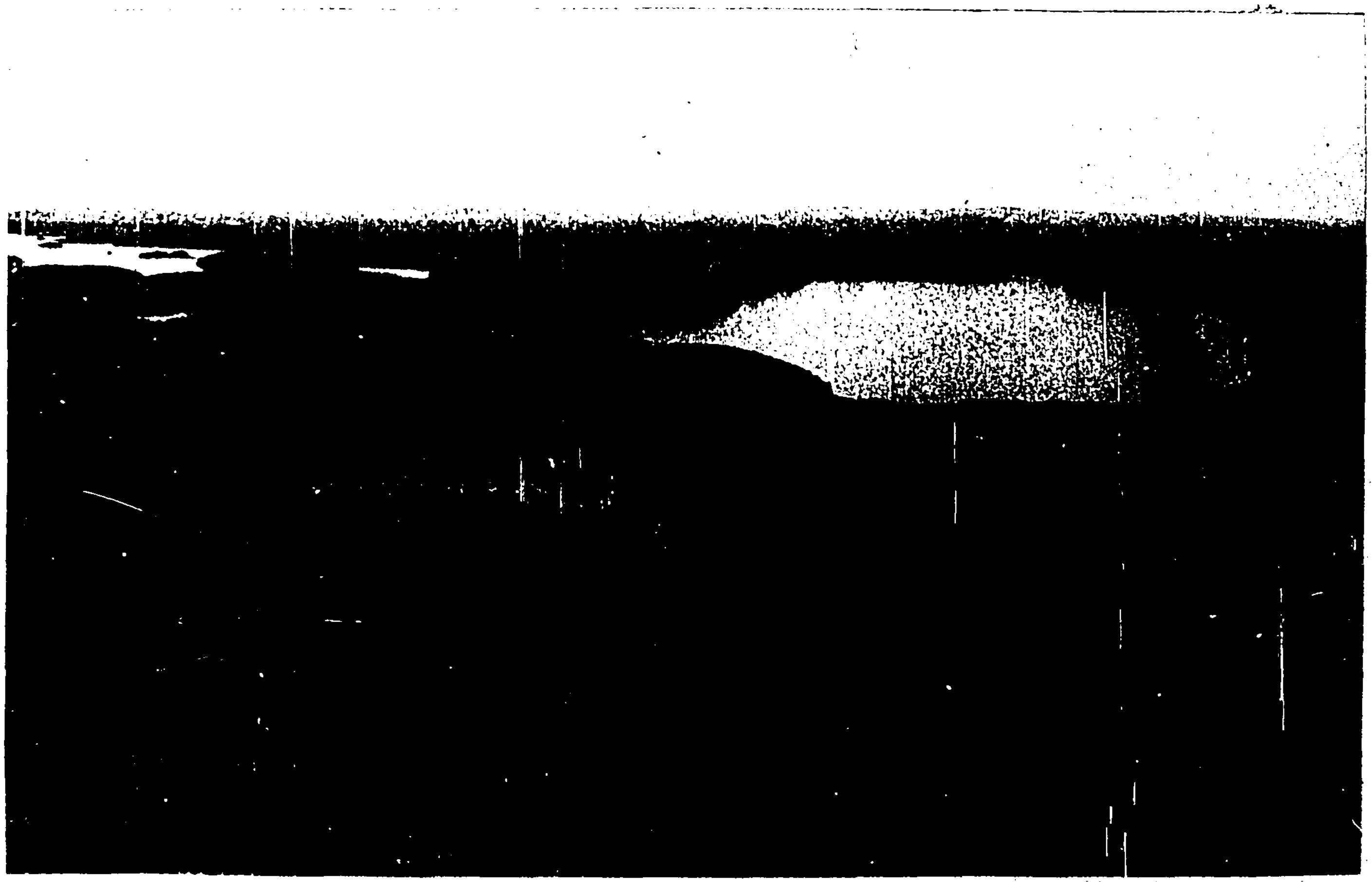


Plate 1 : Looking southwest toward Killala Lake from the base of the Fire Tower

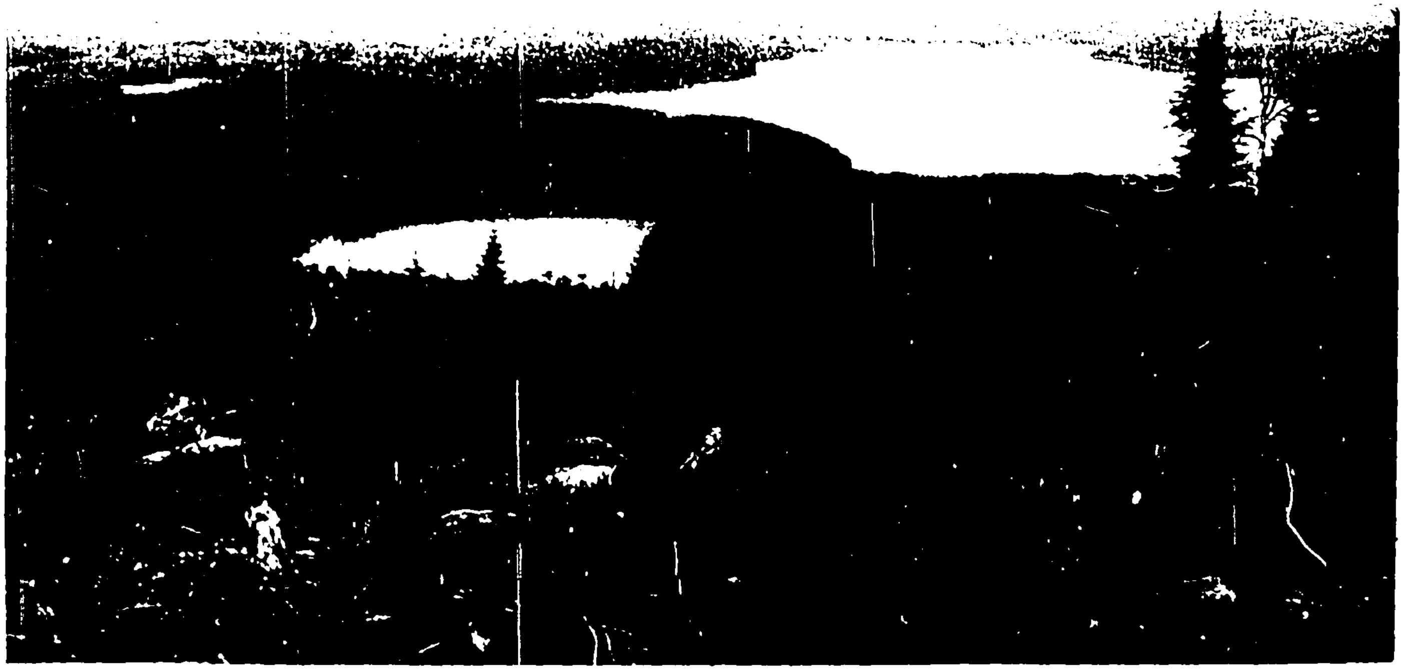


Plate 1 : Looking southwest toward Killala Lake from the base of the Fire Tower

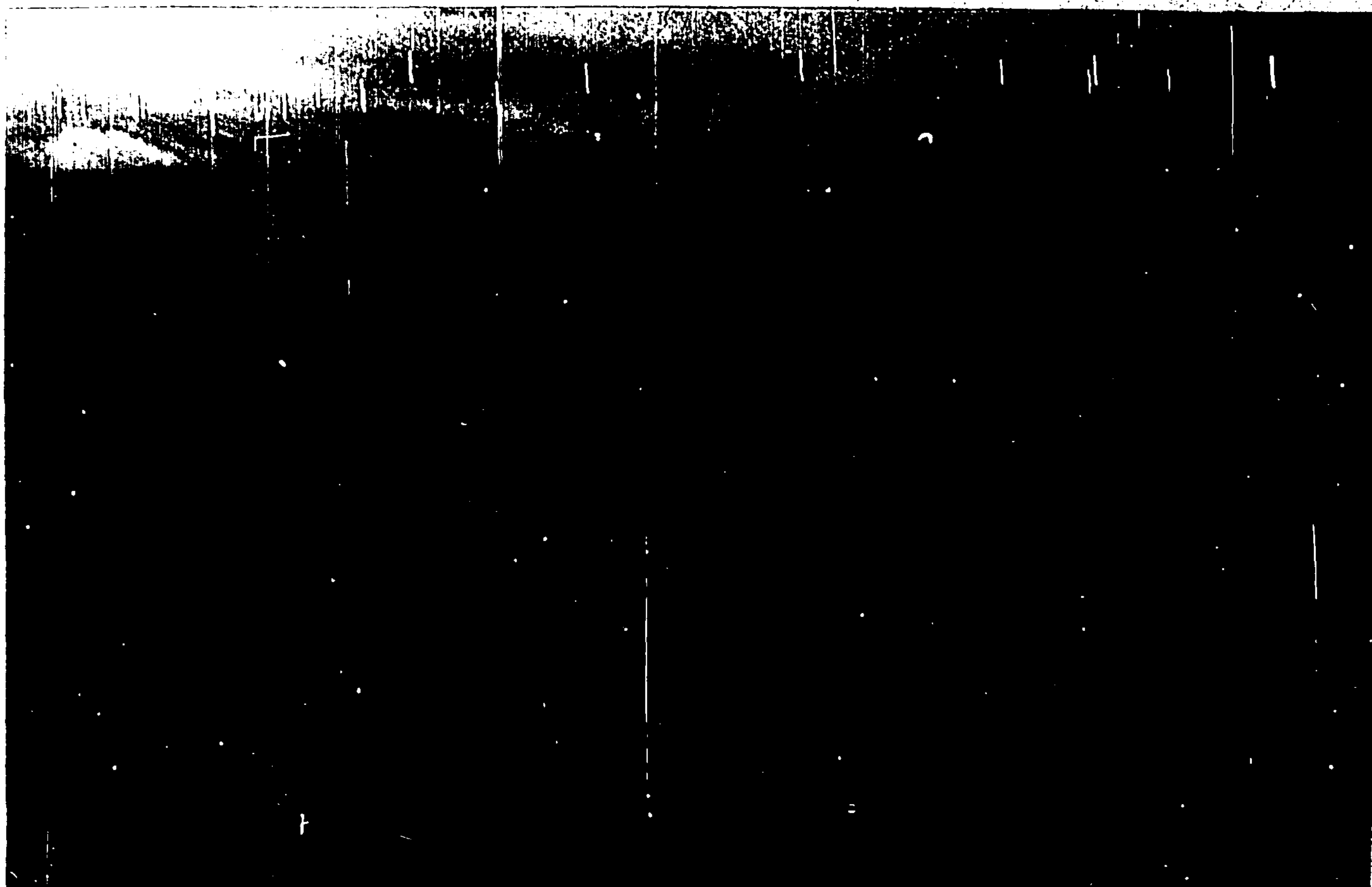


Plate 2 : Looking southeast from the northern escarpment of the Popover Fault

Plate 2 : Looking southeast from the northern escarpment of the Popover Fault

fracture system. A poorly developed annular drainage system ultimately discharges through joint or fault-controlled breaches in the outer rim.

Exposure and General Conditions

The complex is largely concealed by glacial deposits, vegetation and lakes. In the area mapped, about 5% to 7% of the surface is occupied by rock outcrops. The best exposures are found on the shores of the island-studded lakes in the central part of the complex. Good exposures of nepheline syenite are found on steep cliff faces. Outcrops are small and are usually seen at the tops or on the sides of hillocks. Small patches of forest have been burned at some time in the past and the rocks in these areas are better exposed. The gabbroic rocks, which offer little resistance to weathering, form low, rubbly, wooded ridges which are difficult to sample or make measurements upon. The high magnetite content of the gabbro makes the use of a magnetic compass in the immediate vicinity unreliable.

Swampy areas are forested with spruce, tamarack, and arbor vitae while a mixed growth of spruce, alders, birch and poplar clothe the higher ground. Deadfall is abundant and makes traversing difficult in some areas. Beavers have dammed up many of the small streams and the back-up of water has flooded the bottoms of many of the valleys.

Table of Formations

CENOZOIC

Recent: Swamp and stream deposits
Pleistocene: Glacial drift; varved clay, boulders, gravel, sand and till

great unconformity

PRECAMBRIAN

Middle Precambrian *(Proterozoic)?*
Post-tectonic Intrusive Rocks
Alkalic Complexes and Carbonatite (1035-1200 million years)
(Killala Lake Igneous Complex)
Lamprophyre
Nepheline syenite
Olivine-nepheline syenite
Hastingsite syenite
Larvikite
Olivine gabbro (1185 ± 90 my *)

intrusive contact

Diabase dykes

intrusive contact

Early Precambrian *(Archean)?*
Post-tectonic Granitic Rocks

intrusive contact

Syntectonic and Late Tectonic Intrusive Rocks
Migmatite
Granodiorite
Quartz monzonite

intrusive contact

Sedimentary and Volcanic Rocks

* K/Ar age on biotite from olivine gabbro

THE COMPONENT UNITS OF THE COMPLEX

In the following pages, the units of the complex will be described with respect to their field relations, outcrop appearance and mineralogical composition. The classical alkaline rock names have not been used. Units are described by a system of mineral prefixes.

The name "Larvikite", referring to augite-syenite is used locally in referring to the corresponding rock type in the Port Coldwell Complex. Names which imply a specific geographical distribution have been applied to the major intrusive types because the compound rock names are too unwieldy for repeated reference in the text.

A sketch of the complex showing the distribution of rock types is given in Figure 3. A detailed geological map at a scale of 1:31,680 is found in the map pocket at the back of this thesis.

1. The Peripheral Gabbro

Field Relations:

Gabbroic rocks have weathered to low outcrops

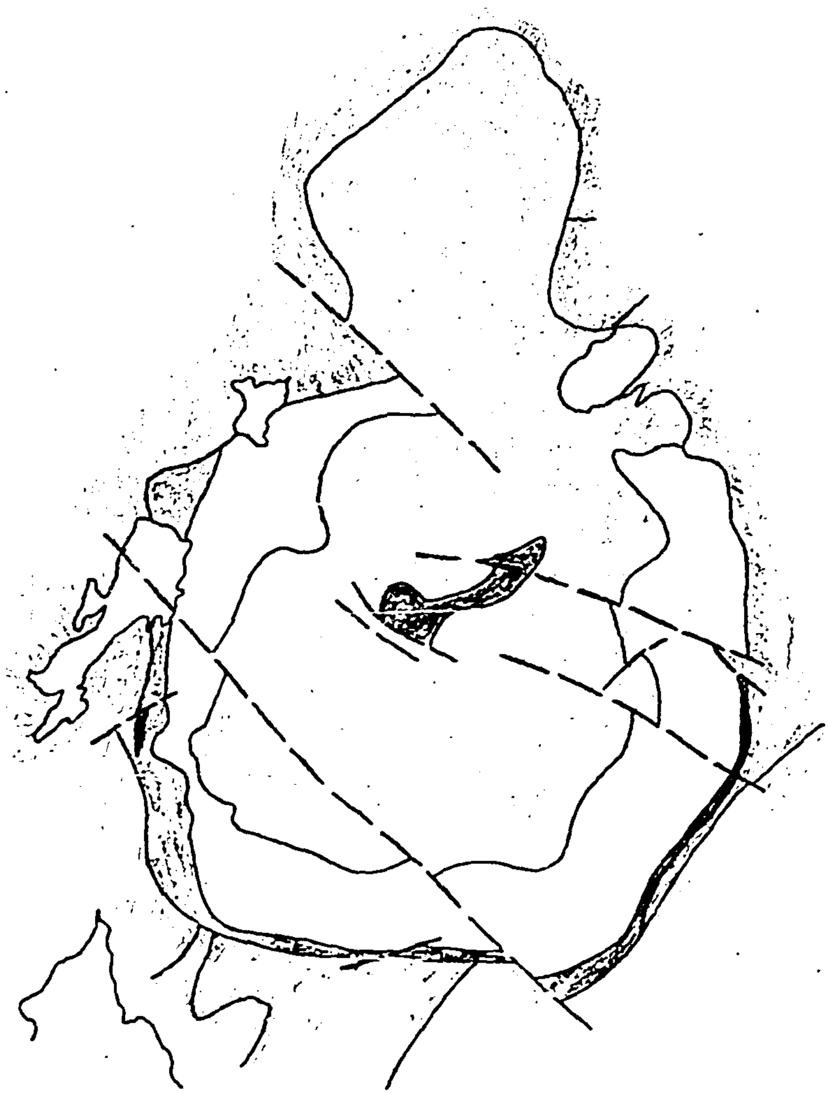


Figure 3

GEOLOGICAL SKETCH MAP
OF
THE KILLALA LAKE COMPLEX
Scale - 1:100,000 (approx.)
LEGEND

LAMPROPHYRE DYKES	LARVIKITE
RIM SYENITES (Nepheline)	GABBRO
OLIVINE-NEPHELINE SYENITE	GRANITIC ROCKS
CENTRAL SYENITE	MIGMATITE

which form an incomplete ring enclosing the southern two-thirds of the Killala Lake Complex. The Peripheral Gabbro is the oldest phase of the complex which was recognized in the field. The contact zone within the enclosing gneisses is marked by a narrow steep-walled valley in most places. No actual contacts with the country rocks were seen. At the inner contact, the Peripheral Gabbro is intruded by stockworks of Rim Syenite. Near the gabbro contact, the Rim Syenite contains many stoped blocks of gabbro.

Olivine gabbro is the main rock type and layered and mineralized phases of it are present locally. Pyroxene gabbro is present as irregular wisp-like bodies within the olivine gabbro. On the eastern shore of Sandspit Lake, pyroxene gabbro occurs as a separate body outside the olivine gabbro. Whether the pyroxene gabbro is an intruded or an included phase in the olivine gabbro could not be determined.

1.1 Olivine Gabbro

Outcrop Appearance and Hand Sample Description:

The gabbroic rocks weather rusty brown and the surfaces of outcrops are rubbly. Where fresh surfaces can be obtained, the rock is medium to dark gray. In the layered portions of the unit, magnetite rich horizons, up to 2 cm. thick, weather high and give the rock a banded appearance. Where the layered character of the rock is not obvious a slight foliation is usually discernible. Grain size varies from medium to coarse but the medium grained varieties predominate. Pegmatitic zones, up to 2 metres in thickness, are present. The texture is usually trachytoidal, sometimes ophitic.

Thin-Section Description:

The rock is essentially composed of plagioclase An_{55-60}, olivine and clinopyroxene. Magnetite, apatite and pyrrhotite are abundant accessories (See Plates 3 and 5). Trace amounts of spinel (hercynite) in association with magnetite were seen in several sections. Plagioclase crystals which are lath-like (.2-3 cm. long), with Carlsbad-albite twinning, make up 30-50% of the rock. The olivine has a high negative optic-axial angle (chrysolite) and makes up about 13% of the rock.

Clinopyroxene displays pink pleochroism and many crystals have a gridded appearance as a result of exsolution of microscopic rods of iron ore along crystallographic planes (See Plate 4). The clinopyroxene content of the rock is highly variable (10-40%).

Plate 3 : Photomicrographs of olivine gabbro showing the textural relationships between magnetite-apatite and olivine. Plain light (x40)

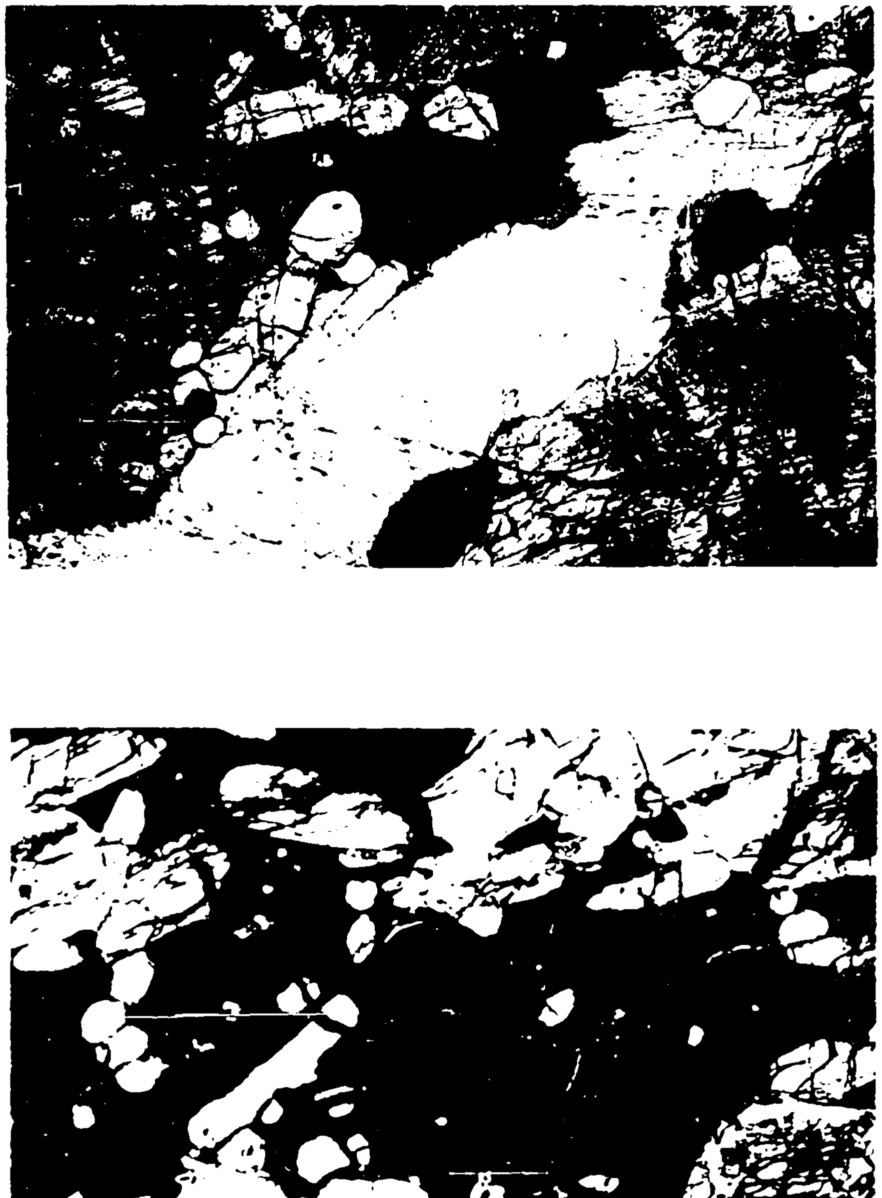


Plate 3 : Photomicrographs of olivine gabbro showing the textural relationships between magnetite-apatite and olivine. Plain light (x40)

Plate 4a : Photomicrograph of olivine-gabbro-pyroxene with exolution lamellae of magnetite. Spinel (hercynite) between magnetite grains. (x80)

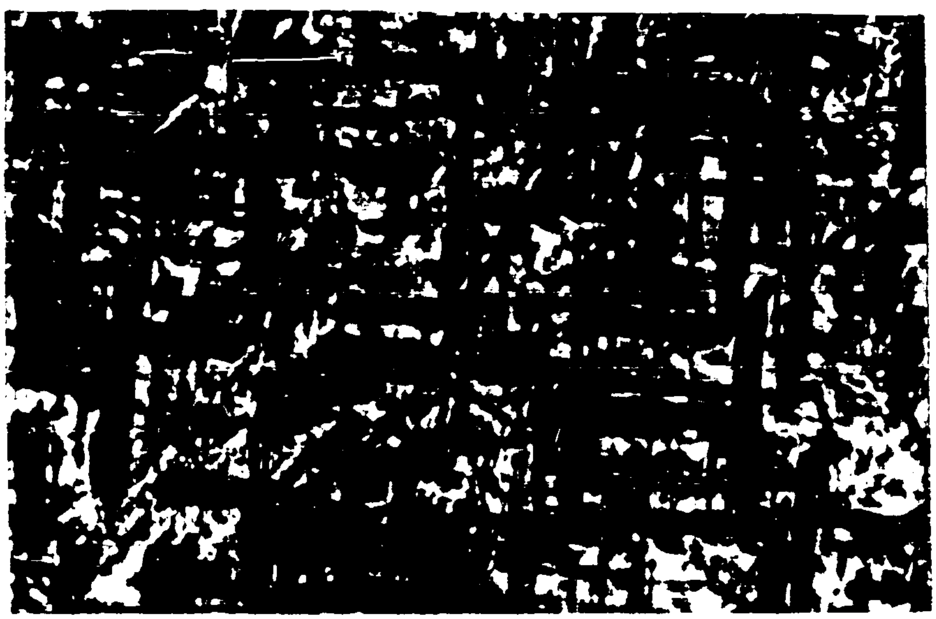
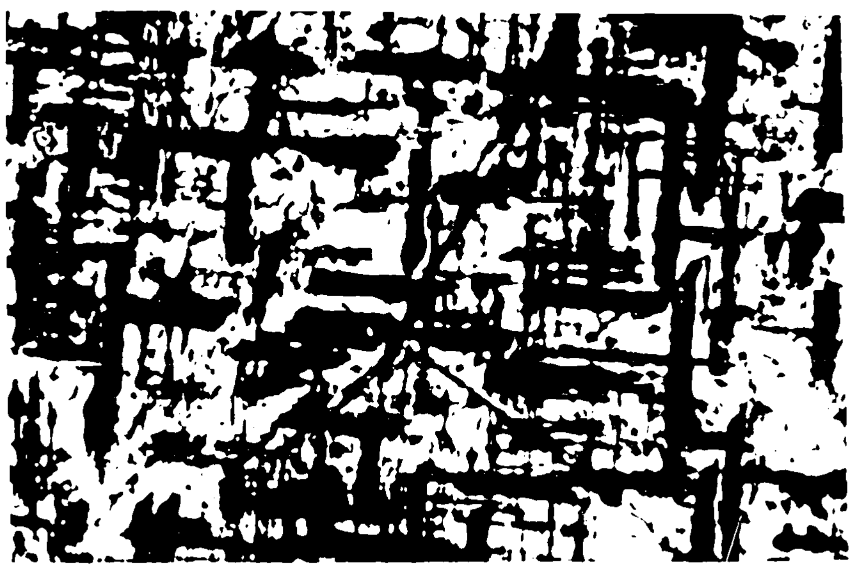


Plate 4b : Photomicrograph of exolution lamellae in pyroxene. (x400)

Plate 4a : Photomicrograph of olivine-gabbro-
pyroxene with exolution lamellae of
magnetite. Spinel (hercynite) between
magnetite grains. (x80)



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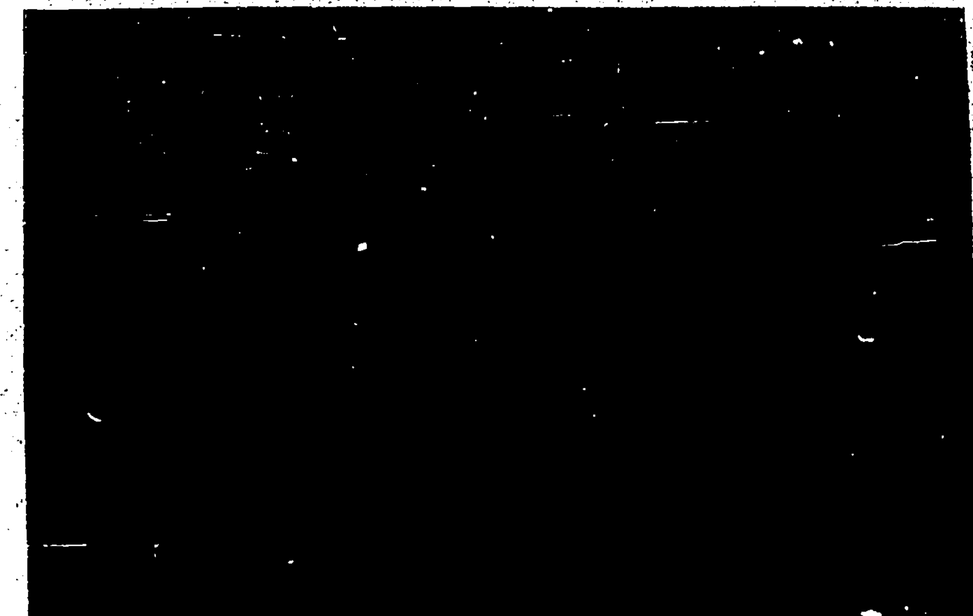


Plate 5a : Olivine gabbro: pyroxene with schiller structure (central); zoned apatite (lower left); olivine enclosing magnetite, central. Plain light (x40)

Plate 5b : Olivine gabbro: olivine showing high order green violet interference colors. Carlsbad twinning in plagioclase (lower left) (x-nicols, x40)

Plate 5a : Olivine gabbro: pyroxene with schiller structure (central); zoned apatite (lower left); olivine enclosing magnetite, central. Plain light (x40)

Plate 5b : Olivine gabbro: olivine showing high order green violet interference colors. Carlsbad twinning in plagioclase (lower left) (x-nicols, x40)

Magnetite and apatite are intimately related and commonly form more than 15% of the rock, apatite always being present in lesser amounts (See Plate 5).

The gabbros are usually very fresh. Clinopyroxene has altered to biotite at the interfaces with magnetite grains. In some cases, complete pyroxene crystals have been altered and magnetite exsolution lamellae within the biotite mark the relict structure of pyroxene.

Chemical analyses of two samples of olivine gabbro are given in Table 1 and corresponding norm calculations are given in Appendix IV. Table II gives modal analyses of the aforementioned samples.

At Drainage Lake, the olivine gabbro is altered and nephelinized (See Tables I and II; 66-KC-23-4). Plagioclase (An_{60}) has been partially replaced by nepheline which occurs as large anhedral growths enclosing some of the crystals. Kelyphytic rims of zeolites and chlorite mark the intergrain boundaries. Large olivine crystals show little alteration beyond the development of bowlingite along fractures. Smaller olivine grains have been completely altered to talc and chlorite. Macroscopically, the gabbro at Drainage

TABLE 1

Chemical Analyses of Olivine Gabbro

MAJOR OXIDES	66-KC-35-3	66-KC-23-4
SiO_2	33.1	46.4
AI_2O_3	14.2	17.4
Fe_2O_3	11.8	2.27
FeO	14.8	5.52
MgO	6.14	5.68
CaO	11.6	14.2
Na_2O	1.57	4.34
K_2O	2.54	0.92
H_2O	0.54	0.11
H_2O-	0.10	0.44
CO_2	0.15	1.53
TiO_2	2.86	0.36
P_2O_5	—	—
S	0.28	0.02
MnO	0.21	0.13
TOTAL	99.9	99.4

Analyst: D.A. Moddle

66-KC-35-3 - Olivine gabbro from north of Sandspit Lake. Diamond drillhole No. 6.

66-KC-23-4 - Nepheline-bearing olivine gabbro from the south shore of Drainage Lake.

See Map No. 2 (back pocket) for exact sample locations.

Lake resembles the previously-described type although the color index is not as high as that of the iron-rich varieties. The alteration is probably due to the close proximity of the nepheline syenite unit.

TABLE II

Modal Analyses of Olivine Gabbro

COMPONENT MINERALS	66-KC-35-3	66-KC-23-4
Plagioclase	48.1	27.8
Clinopyroxene	9.3	33.3
Olivine	13.9	7.5
Bowlingite	1.2	1.0
Nepheline	—	13.6
Chlorite	0.3	3.0
Biotite	3.0	0.6
Magnetite	10.5	0.6
Apatite	11.29	tr.
Alteration	1.1	12.6
Sphene		tr.
TOTAL	98.69	100.0

Sample locations are given at the bottom of Table I.

1.2 Pyroxene Gabbro

Field Relations:

At Sandspit Lake the pyroxene gabbro forms a low ridge 50 metres wide on the outer edge of the olivine gabbro unit. (See Map 1) No definite intrusive relationships were established in the field. Irregular masses of pyroxene gabbro (usually lensoid) occur throughout the olivine gabbro unit but no chilled contacts were discernible.

Outcrop Appearance:

The weathered surface is rusty brown and the weathering effects persist to some depth in most outcrops. Fresh surfaces observed in drill cores were dark gray. Grain-size was uniformly fine in all specimens examined. A slight foliation was observable in most specimens.

Thin-Section Description:

Essential minerals are plagioclase (An_{50}) and hypersthene. Magnetite is present as an accessory in some sections. Plagioclase with Carlsbad twinning occurs as polygonal crystals .5-2 mm. in diameter. In two sections examined, some interstitial orthoclase was present. Hypersthene has pink to blue-gray pleochroism and occurs in stumpy, irregular, crystals .5-1 mm. in diameter. Extinction angle is 0^{o} in longitudinal sections (2V large).

1.3 The Sulphide Mineralization

The mineralized zone which extends from Sandspit Lake to west of Popover Lake, was drilled and sampled by Killala Lake Mines Ltd. in 1954. The best grades reported were 0.32% Cu and 0.16 Ni over narrow widths (See Appendix I).

Sulphides, mainly pyrrhotite with some chalcopyrite are found within and above the layered parts of the olivine gabbro. Pyrrhotite occurs interstitially with plagioclase, magnetite and pyroxene. Generally, the sulphides are localized in crude layers 1 cm. to 3 cm. in thickness which parallel the foliation of the enclosing gabbro. Sulphides are largely confined to the felsic parts of the layered units, which are relatively deficient in magnetite. Some sulphide does occur in association with magnetite in the mafic layers but commonly the zones rich in oxide are sulphide poor. Pyrrhotite commonly occurs as a single layer near the middle of the felsic fraction, although, in some cases, more than one sulphide layer was encountered. Descriptions of the host rock are given in the section on mineral layering. Chalcopyrite is present in minor quantities at the rims of some pyrrhotite crystals and in many cases formed narrow haloes about minute inclusions of gangue contained in pyrrhotite (See Plate 6a). In one case, chalcopyrite appeared to embay pyrrhotite along a fracture (See Plate 6b). The central part of the fracture was occupied by magnetite and gangue.

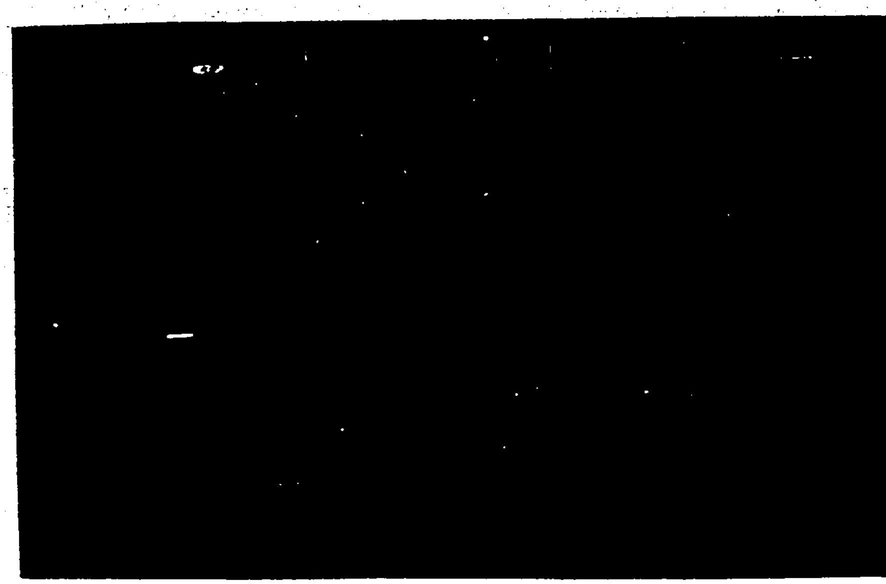


Plate 6a : Pyrrhotite (pink) with haloes of chalcopyrite developed around inclusions of gangue. Magnetite (light gray), lower right; as inclusions in gangue, upper left. (x40)

Plate 6b : Pyrrhotite (pink) embayed by late crystallizing chalcopyrite (x40)

Plate 6a : Pyrrhotite (pink) with haloes of chalcopyrite developed around inclusions of gangue. Magnetite (light gray), lower right; as inclusions in gangue, upper left. (x40)

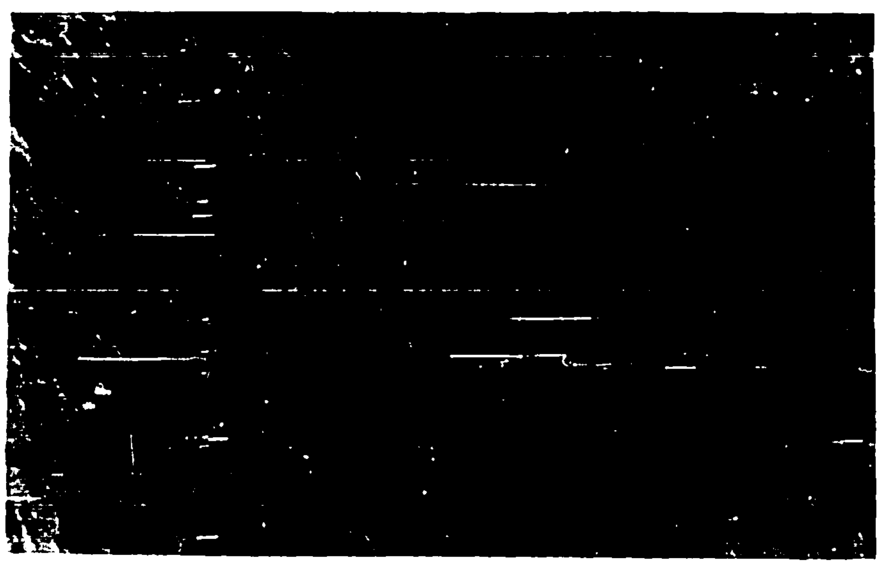


Plate 6b : Pyrrhotite (pink) embayed by late crystallizing chalcopyrite (x40)

2. The Larvikite

Field Relations:

The larvikite which outcrops west of Popover Lake appears to be a sheet-like body, approximately conformable to the trend of the enclosing olivine gabbro.

Outcrop Appearance:

The weathered surface is buff-brown; fresh surfaces are dark green to black. The rock is about 90% composed of feldspar and is uniformly coarse-grained. Some orthoclase crystals display a lustrous, blue schiller effect. Pyroxene and amphibole are seen as angular dark patches on the weathered surface.

Thin-Section Description:

Essentially the rock is composed of orthoclase, augite and olivine. Plagioclase, magnetite and apatite are accessories. Texture is allotriomorphic-granular.

Orthoclase (large 2V) occurs as anhedral crystals (.4 mm. to 1 cm.) which show faint zoning. In some cases, vestigal albite twinning is present in the cores of the larger crystals. The more potassic feldspar of the crystal rims often encloses polycrystalline aggregates of finer grained feldspar (1 mm.).

Pale gray-green augite (30° extinction) occurs in irregular to wedge-like forms (1 mm. to 2 cm.) interstitial to orthoclase.

Olivine (hyalosiderite) occurs as small subhedral crystals adjoining augite in the interstices between feldspar crystals.

Magnetite (.5 mm.) enclosing smaller crystals of apatite occurs at the fringes of olivine crystals and separately among the feldspar grains. Plagioclase occurs as small subhedral crystals (.5-1 mm.) mantled by orthoclase.

The rock appears fresh in thin-section. Table 3 gives a modal analysis of larvikite.

3. The Central Syenites

Field Relations:

The Central Syenites form the middle and northern parts of the pluton. The main body of olivine-nepheline syenite has intruded the Central Syenites in the area between Kentron Lake and Blank Lake. The contact with the Rim Syenites which border the unit were thought to be gradational at the time of mapping. Abrupt changes

TABLE 3

Modal Analysis of Larvikite

CONSTITUENT MINERALS	66-KC-6-32
Orthoclase	85.1
Plagioclase	.9
Apatite	.6
Augite	7.8
Olivine	2.8
Magnetite	2.6
TOTAL	99.8

66-KC-6-32 - Larvikite sample from west of Popover Lake in nepheline content discovered in the course of laboratory studies suggest that the Rim Syenites may have been intruded into the Central Syenites. The central syenite has not been seen to cross-cut any of the other units.

Outcrop Appearance:

The rock weathers buff-white and is of similar color on fresh surfaces. Grain-size is uniformly coarse. Mafic minerals, mainly amphibole, make up about 15% of the rock. The remaining 85% is feldspar. A slight foliation is usually present due to a preferential arrangement of rectangular feldspar crystals. Mineral layering has developed locally giving the surface of some outcrops a banded appearance.

Thin-Section Description:

Essential constituents are perthitic orthoclase, plagioclase, pyroxene and amphibole. Accessory amounts of biotite, magnetite and calcite are usually present. Texture is hypidiomorphic-granular, locally porphyritic. Grain-size is coarse (See Plate 7).

Perthite of vein and patch varieties occurs as stubby crystals often displaying protoclastic texture. Grain-size (.5 cm. to 2 cm.).

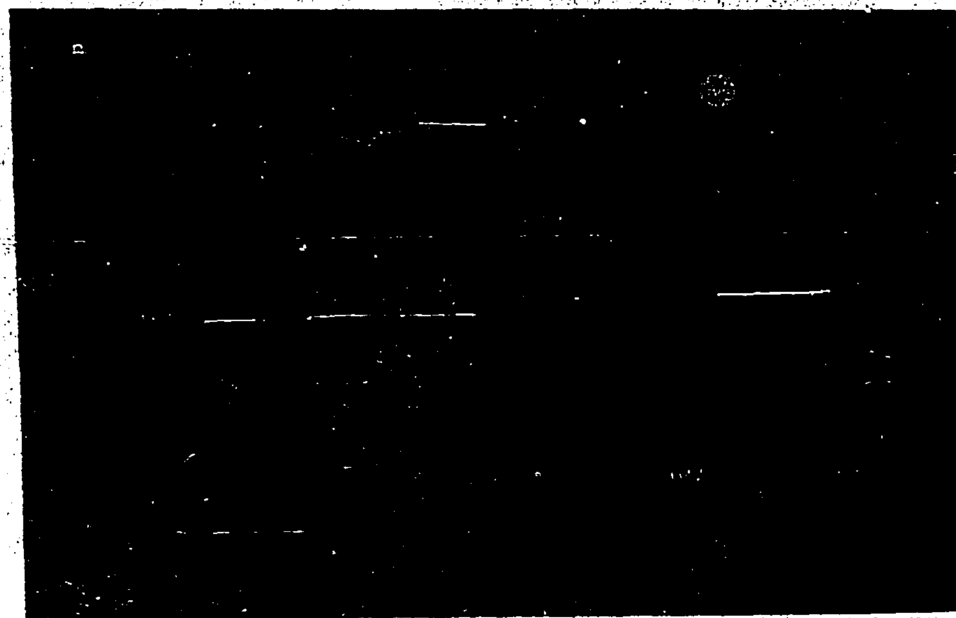


Plate 7a : Central syenite on an island in Blank Lake

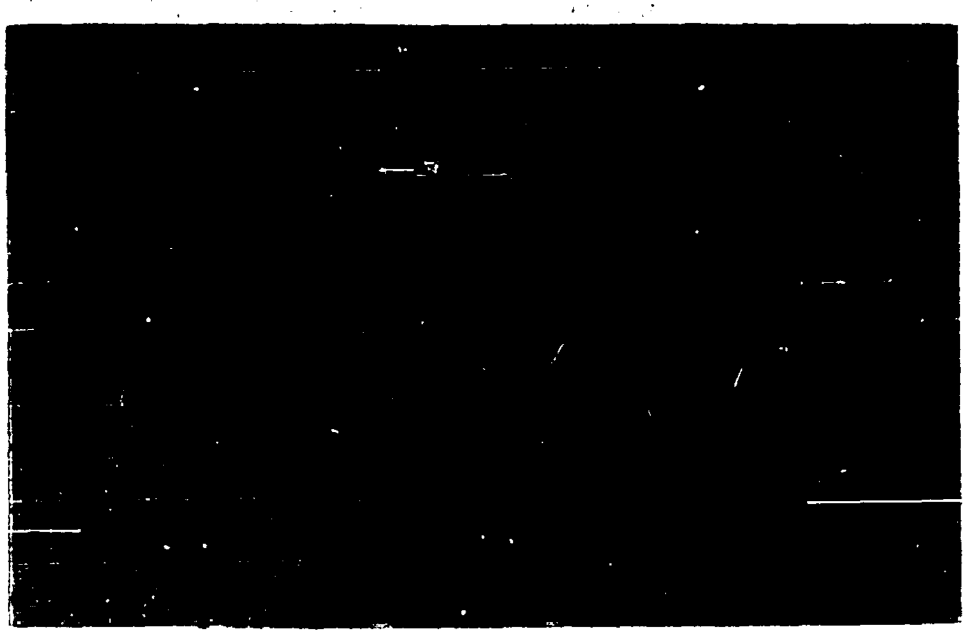


Plate 7b: Photomicrograph aegirine-hastingsite-oligoclase syenite (colored) plain light (x40)

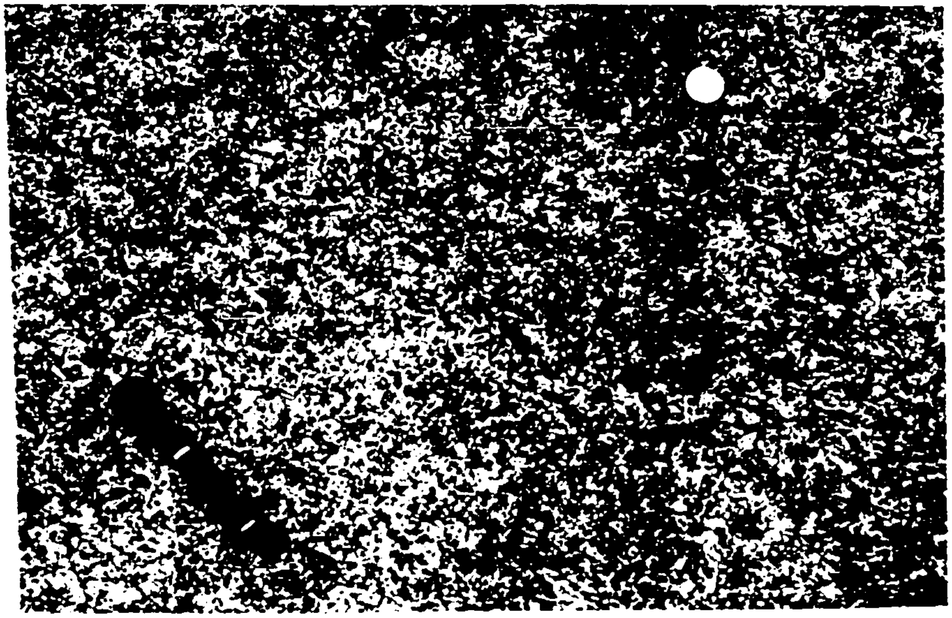


Plate 7a : Central syenite on an island in Blank Lake

Plate 7b: Photomicrograph aegirine-hastingsite-oligoclase syenite (colored) plain light (x40)

Plagioclase (An_{22}) is found interstitially as anhedral crystals (2 mm. to 4 mm.) and has well developed albite twinning. The small patches in the perthite are composed of albitic plagioclase.

Amphibole (10%) is present as large sub-hedral to anhedral crystals (2 mm. to 3 cm.), the larger crystals having a poikioblastic habit, enclosing smaller perthite and plagioclase. Amphibole is deep brown to green, strongly pleochroic, with an extinction angle of 2^{o} to 9^{o} (hastingsite).

Pyroxene (3%) is bright green, pleochroic and occurs as small anhedral crystals (1 mm. to 2 mm.) partially or totally enclosed in amphibole, Extinction angles vary from 5^{o} to 18^{o} (Aegirine-augite).

Biotite and magnetite occur in association with the other mafic constituents. Apart from minor replacement of amphibole by biotite and rock shows very few signs of alteration.

Table 4 gives chemical analyses of the central syenites. A modal analysis of the central syenite is given in Table 5. See Appendix IV for norm calculations.

TABLE 4

Chemical Analyses of Central Syenites

MAJOR OXIDES	66-KC-25-2E	66-KC-1-16H
SiO_2	58.4	57.9
AI_2O_3	20.8	19.4
Fe_2O_3	1.32	1.35
FeO	3.45	3.34
MgO	1.07	2.09
CaO	3.30	3.01
Na_2O	5.18	5.90
K_2O	5.48	5.16
H_2O	0.33	0.57
H_2O-	0.11	0.22
CO_2	0.30	0.10
TiO_2	0.36	0.54
S	0.01	0.01
MnO	0.14	0.13
TOTAL	100.3	99.7

Analyst: D.A. Moddle

66-KC-25-2E - Aegirine-hastingsite oligoclase syenite from the island in Kentron Lake.

66-KC-1-16H - Aegirine-hastingsite oligoclase syenite from the northern escarpment of the Popover Fault near the nepheline syenite contact

TABLE 5

Modal Analysis of Central Syenite

CONSTITUENT MINERALS	66-KC-25-2
Orthoclase	56.0 ± 2.27
Oligoclase	30.4 ± 2.11
Mafics (Aegirine and hastingsite)	13.6 ± 1.57
TOTAL	100.0

66-KC-25-2 - Aegirine-hastingsite-oligoclase syenite from the island in Kentron Lake. (See Appendix IV)

4. The Olivine-Nepheline Syenite

Field Relations:

Olivine-Nepheline Syenite occurs as an east-west elongated body 2 km. long approximately in the centre of the complex. Also, it occurs as dykes in the Central Syenite. On the south shore of Kentron Lake, the contact between the main unit and the Central Syenite is exposed. The contact zone is gradational over a distance of 4 metres. The Central

Syenite in the contact zone has developed a gneissic foliation parallel to the contact, and contains lenses of sugary-textured syenitic material with very low mafic content.

Outcrop Appearance:

The rock is gray to brown on weathered surfaces while freshly broken surfaces are dark green. Texturally, it is fine to medium grained, porphyritic, with 10% to 15% coarse phenocrysts of orthoclase (See Plate 8a). Mafic constituents which comprise about 35% of the rock are commonly concentrated in irregular clots, .5-1 cm. in diameter. About 25% of the mafic content is uniformly distributed throughout the rock. A slight foliation is usually discernible.

Thin-Section Description:

The rock appears fresh in thin-section. It is essentially composed of orthoclase, plagioclase (An_{30}), nepheline, hornblende, augite and olivine (hyalosiderite). Biotite, magnetite, apatite and zircon are accessories. Orthoclase is euhedral with an average grain size of 1-3 mm. Crystals are elongated and some show Carlsbad twinning. The texture is sub-trachytoidal, glomeroporphyritic (See Plate 8b).

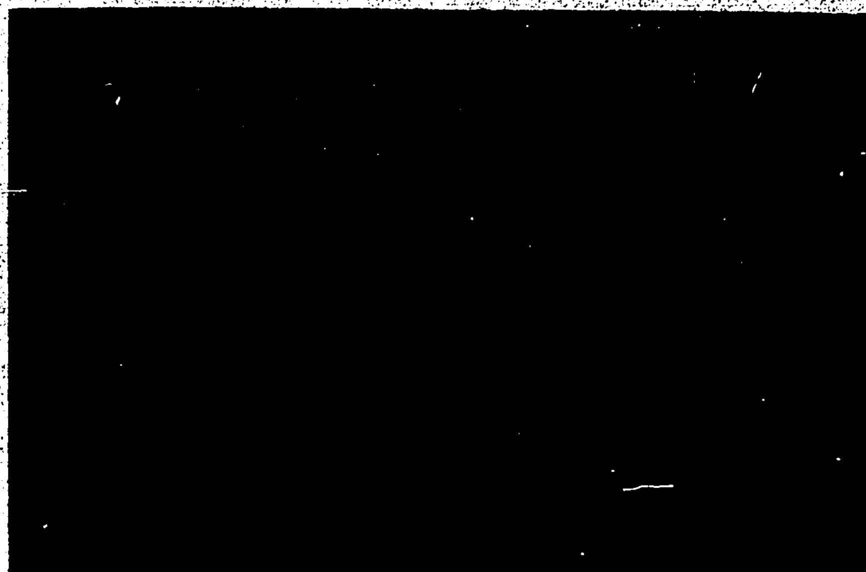


Plate 8a : Olivine-nepheline syenite. Note the clots of mafic minerals and large phenocrysts of orthoclase.

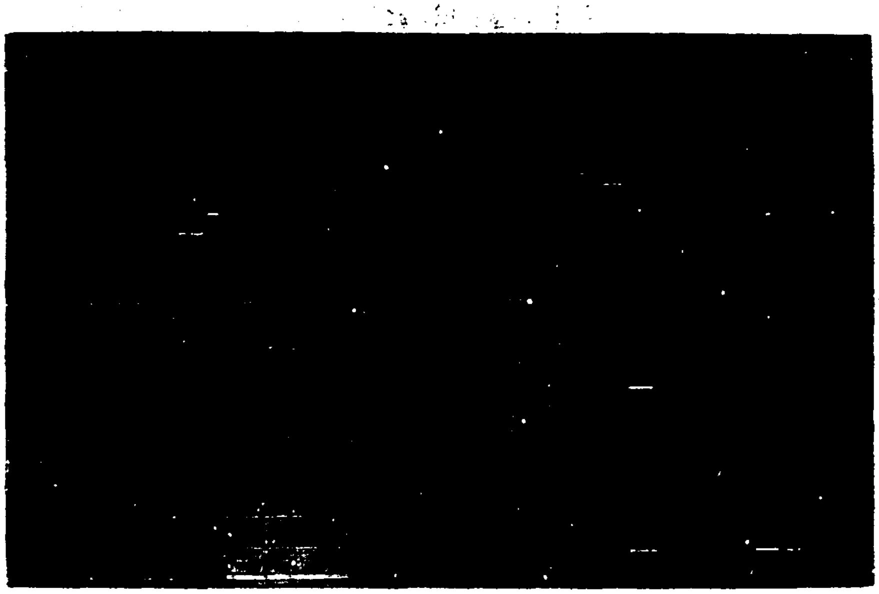


Plate 8b : Color photomicrograph of olivine-nepheline syenite: Olivine with high green interference colors. Nepheline; gray with micaceous replacement (cancrinite-hydronephelite). (x-nicols, x40)

Plate 8a : Olivine-nepheline syenite. Note the clots of mafic minerals and large phenocrysts of orthoclase.

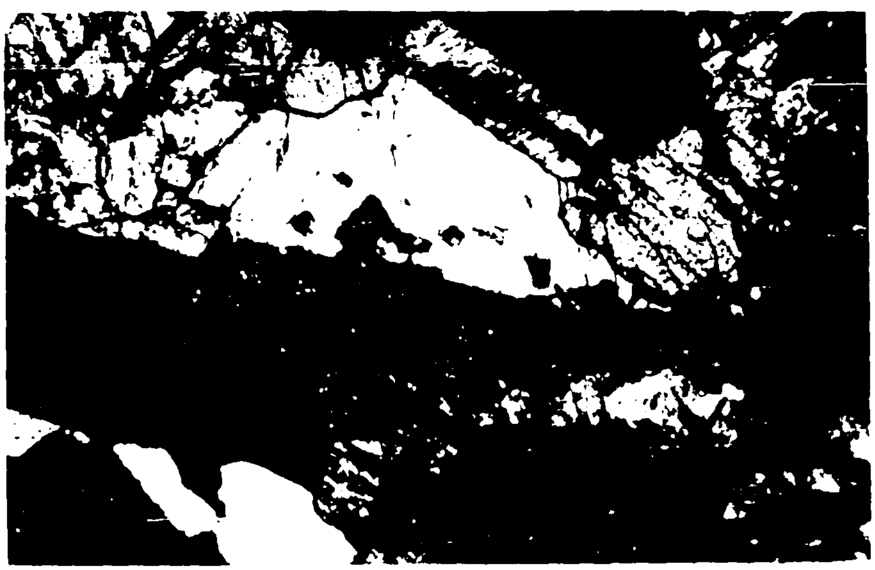


Plate 8b : Color photomicrograph of olivine-nepheline syenite: Olivine with high green interference colors. Nepheline; gray with micaceous replacement (cancrinite-hydronephelite). (x-nicols, x40)

Plagioclase with Carlsbad-albite twinning occurs interstitially as sub-hedral crystals .5-1 mm. in diameter.

Nepheline occurs interstitially as sub-hedral crystals and as irregular replacement intergrowths in feldspar. Nepheline has been partially altered and replaced by cancrinite which occurs as a micaceous intergrowth.

The mafic constituents are assembled in glomeroporphyritic aggregates enclosed in orthoclase. Clear, sub-hedral to anhedral crystals of olivine, partially altered to bowlingite along curved cracks are generally enclosed by dark brown pleochroic hornblende. Pale green augite has been partially altered to amphibole along the fringes of crystals. Brown biotite with prominent disintegration haloes is found in close association with magnetite and apatite, often enclosing them. At the rims of ore grains, the biotite has a deep reddish colouration. A modal analysis of olivine-nepheline syenite is given in Table 7. Chemical analyses are shown in table 6. See Appendix IV for norm calculations.

TABLE 6

Chemical Analyses of Olivine-Nepheline Syenite

MAJOR OXIDES	66-KC-25-8	66-KC-31-4
SiO_2	53.0	57.5
AI_2O_3	16.8	18.9
Fe_2O_3	2.58	1.60
FeO	7.37	3.93
MgO	1.67	1.07
CaO	4.85	3.50
Na_2O	5.15	5.74
K_2O	5.16	5.72
H_2O	0.37	0.56
H_2O	0.10	0.14
CO_2	0.10	0.53
TiO_2	.84	0.23
P_2O_5	——	——
S	0.06	0.02
MnO	0.25	0.15
TOTAL	98.3	

Analyst: D.A. Moddle

66-KC-25-8 - Sample from main unit, east shore of Kentron Lake.
66-KC-31-4 - Dyke rock from an island in Blank Lake

TABLE 7

CONSTITUENT MINERALS	66-KC-29-8E
Orthoclase	29.2
Plagioclase	14.6
Nepheline	10.2
Olivine	4.3
Pyroxene	6.50
Hornblende	17.9
Biotite	1.2
Bowlingite	1.2
Magnetite	2.46
Apatite	2.66
Zircon	tr.
TOTAL	100.2

5. The Rim Syenites

Field Relations:

The Rim Syenites occur as a ring-like body within, and immediately adjoining the peripheral gabbro. Blocks of gabbro are included in the syenite near the contact and stock-works of nepheline syenite occur within the gabbro. The internal contact with the Central Syenite appeared to be gradational in the field, but petrographic work has indicated an abrupt drop in nepheline content in the vicinity of the contact indicated on the accompanying geological map. The actual status (intrusive or gradational) of the contact is not known.

Dykes and veins of nepheline syenite pegmatite, some of which are replacement type, are found within the Central Syenite, the Olivine-Nepheline Syenite and Nepheline-Cancrinite Syenite dykes (See Plates 9 and 12).

Northeast of Barron Lake, xenoliths of migmatite have been included in the syenite (See Map 1).

The following description of the Rim Syenite has been divided into three groups. Nepheline Syenite is the main rock unit; Nepheline Pegmatite and Nepheline-Cancrinite Syenite are late stage phases.

5.1 Nepheline Syenite

Outcrop Appearance:

The rocks on weathered surfaces are generally buff-white. The color is variable depending on the amount of nepheline present. Near the outer rim, nepheline is present in abundance (15% to 35%) as coarse grained (5 mm. to 3 cm.) pink to rose-red subhedral crystals. Consequently, the syenites have a definite pink cast, particularly on fresh surfaces. Toward the central parts, the grain size and nepheline content decrease (5% to 10%) and the mineral color changes to gray. Thus, the syenites nearer the central part are finer grained and buff-white on both weathered and fresh surfaces, containing minor amounts of gray nepheline. Nepheline weathers recessively and its exposed surface has an appearance similar to that of frosted glass. Feldspars are lath-like, trachytoidally arranged and comprise 55% to 80% of the rock. Amphibole and pyroxene (10% to 15%) in wedge-like forms are present interstitial to the feldspar.

Thin-Section Description:

Esentially the rock is composed of nepheline, cryptoperthite, amphibole and pyroxene. Accessories are magnetite, apatite, biotite and occasionally fluorite. A well developed trachytoidal texture is normally present.

Cryptoperthite in large lath-like Carlsbad twinned crystals with undulose extinction in the range (3^{o} to 13^{o}) make up 55% to 80% of the rock.

Nepheline (Ks_{25-30}) occurs interstitially to the feldspar in imposed wedge-shaped forms or in large polycrystalline masses of euhedral to subhedral rectangular or hexagonal sections. In some cases, it has replaced feldspar but in the majority of cases, nepheline occurs as discrete crystals.

Amphibole with dark brown color and intense pleochroism ($0^o$to 5^o extinction; hastingsites) is characteristic of the Rim Syenite. Intensity of pleochroism decreases and extinction angles increase toward the central parts.

Pyroxene (5^o to 9^o extinction; aegirine) with brilliant green color and moderate to strong pleochroism occurs as skeletal or subhedral rectangular crystals interstitially.

Accessories are minor and are usually found in association with the mafic constituents. Fluorite is present in dykelets of syenite which intrude the gabbroic rocks.

With the exception of nepheline, rocks usually appear quite fresh. Toward the central part of the complex where the nepheline content diminishes, it is commonly replaced by hydronephelite or cancrinite.

TABLE 8

Chemical Analyses of Rim Syenites

MAJOR OXIDES	66-KC-35-2B	66-KC-12-127a
SiO_2	53.7	55.6
AI_2O_3	20.6	22.2
Fe_2O_3	3.24	1.28
FeO	3.93	3.31
MgO	0.57	1.65
CaO	2.90	1.85
Na_2O	6.01	6.52
K_2O	6.07	7.33
H_2O	0.91	0.46
H_2O-	0.23	0.12
CO_2	0.63	0.40
TiO_2	0.28	0.21
S	0.01	0.02
MnO	0.31	0.18
TOTAL	99.4	101.8

Analyst: D.A. Moddle

66-KC-35-2B - Nepheline syenite from the eastern shore of Sandspit Lake.

66-KC-12-127a - Nepheline syenite from south of Gentian Lake.

Alteration near the gabbro contact is slight. Chemical analyses of nepheline syenite are given in Table 8. Table 9 gives a modal analysis of nepheline syenite. See Appendix IV for norm calculations.

TABLE 9

Modal Analysis of Rim Syenite

CONSTITUENT MINERALS	66-KC-12-127a
Microperthite	71.4
Nepheline	21.0
Aegirine	2.3
Hastingsite	3.6
Biotite	.3
Magnetite	1.2
Apatite	.2
TOTAL	100.0

66-KC-12-127a - Nepheline Syenite from south of Gentian Lake.

5.2 Nepheline Pegmatite

Field Relations:

As previously mentioned, veins and replacement dykes of nepheline-pegmatite cut the central syenite, the olivine-nepheline syenite, and nepheline-cancrinite dykes. Three occurrences were seen at Blank Lake, one at Kentron Lake and one on an island in Kagiano Lake.

Outcrop Appearance:

The pegmatites have two modes of occurrence; regular dyke-like bodies and irregular, sinuous veins. A dyke, situated on a narrow isthmus between two islands in Blank Lake is about .65 metres in width and is exposed over a strike length of 10 metres. Nepheline pegmatite replaces both the syenite and a dyke of olivine-nepheline syenite which intersects the zone obliquely. No offsetting of the Olivine-Nepheline Syenite dyke contacts has taken place; in fact, vestiges of the replaced dyke can be traced through the pegmatitic material to a continuation in the opposite wall (See Plate 9).

The dyke is buff-colored, with a tone similar to that of the enclosing syenites. The surface is deeply pitted; circular to oval pock-marks 2 cm. to 15 cm. in diameter are caused by the recessive weathering of rose-colored nepheline. Zircon in octahedral (1 mm) crystals is an abundant (2% to 3%) accessory in the dyke.

Most of the pegmatites are coarse grained, (See Plate 12), although, in some cases, aphanitic syenitic material with sugary texture encloses or intermingles with the coarser parts.

Thin-Section Description:

Essentially the rock is composed of feldspar and nepheline with minor amounts of aegirine in 3:1

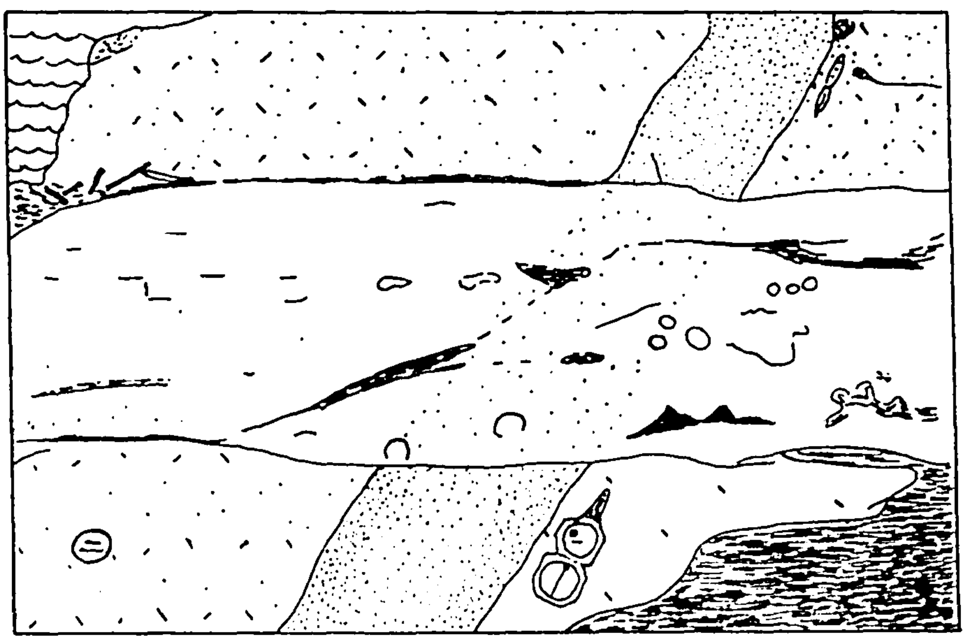
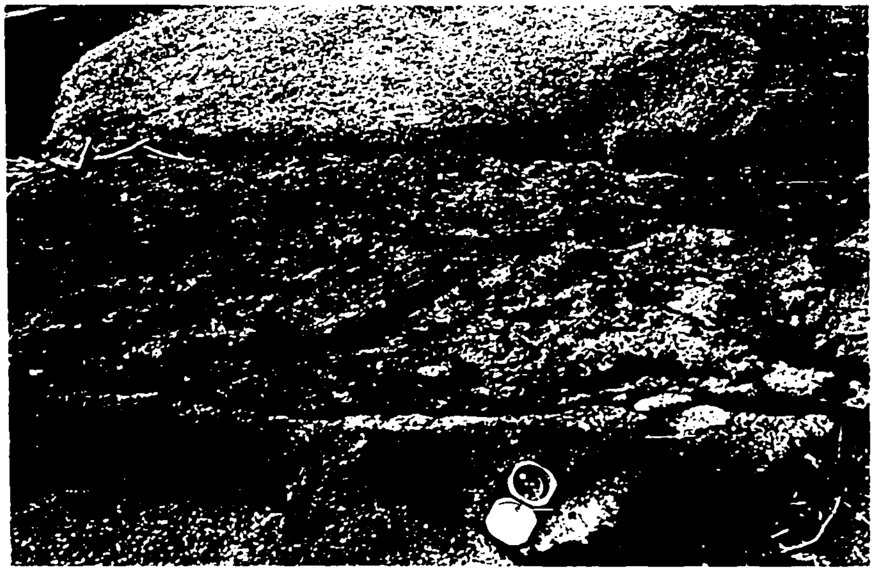


Plate 9 : Nepheline syenite replacement pegmatite with accompanying *camera lucida* drawing. Pock-marked surface is due to recessive weathering of orbicular concentrations of nepheline.



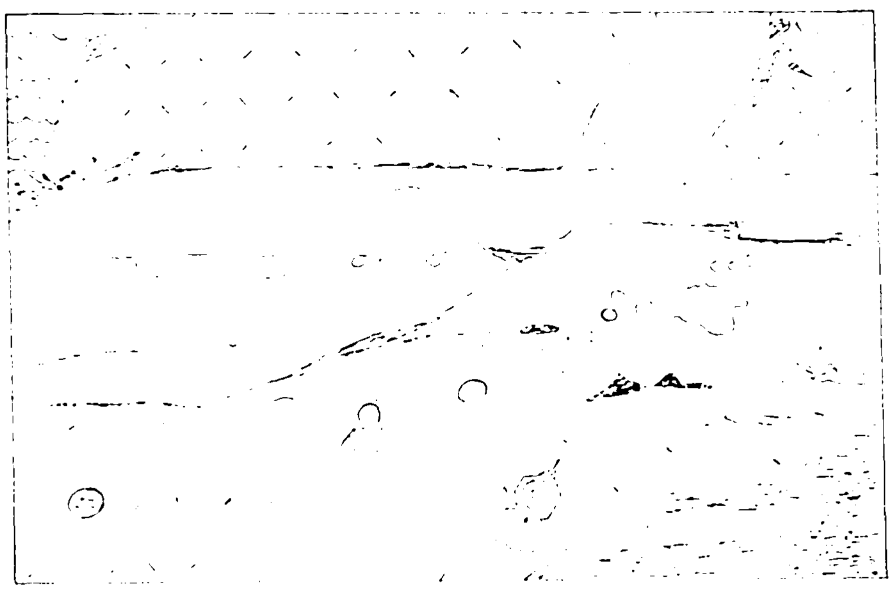


Plate 9 : Nepheline syenite replacement pegmatite with accompanying *camera lucida* drawing. Pock-marked surface is due to recessive weathering of orbicular concentrations of nepheline.

ratio. Accessories are zircon, magnetite, tourmaline apatite, calcite and pyrochlore. Texture is aplitic (See Plate 10).

Feldspar occurs in felted masses of blade-like crystals (.25 mm. - .5 mm.) with sutured rims and is enclosed in larger grains of nepheline (See Plate 10). Feldspar possesses properties of the orthoclase-microperthite-low-albite series (Opt-ve; 2V 45° to 50°). Nepheline is present as irregular polycrystalline masses of subhedral to anhedral grains (2 mm. to 3 mm.) which in some cases show zoning.

Zircon crystals (.5-1.5 mm.) show strong zoning and irregular distribution throughout the rock.

Tourmaline, biotite, and magnetite occur in trace amounts interstitial to nepheline. Aegirine is a common accessory in the pegmatite veins.

Pyrochlore, in small square or octagonal grains, (.1 mm. in diameter) is honey yellow to golden brown in thin-section and occurs as irregular clusters, irregularly distributed throughout the feldspathic portions.

(Table 10 gives assay values for a series of samples analyzed for elements of the Rare Earth group).

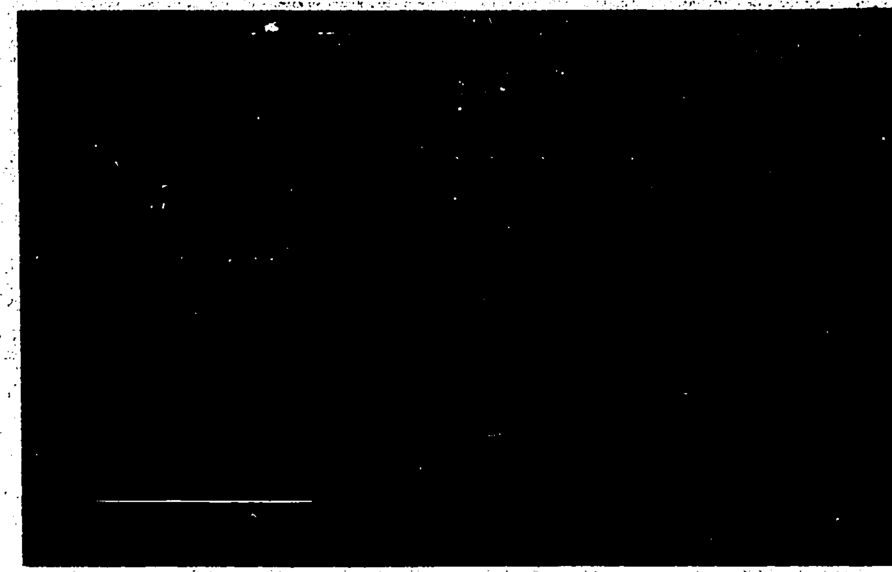


Plate 10a : Color photomicrograph of nepheline-pegmatite, replacement variety; microcrystalline orthoclase and zircon in a groundmass of nepheline. (x-nicols, x40)

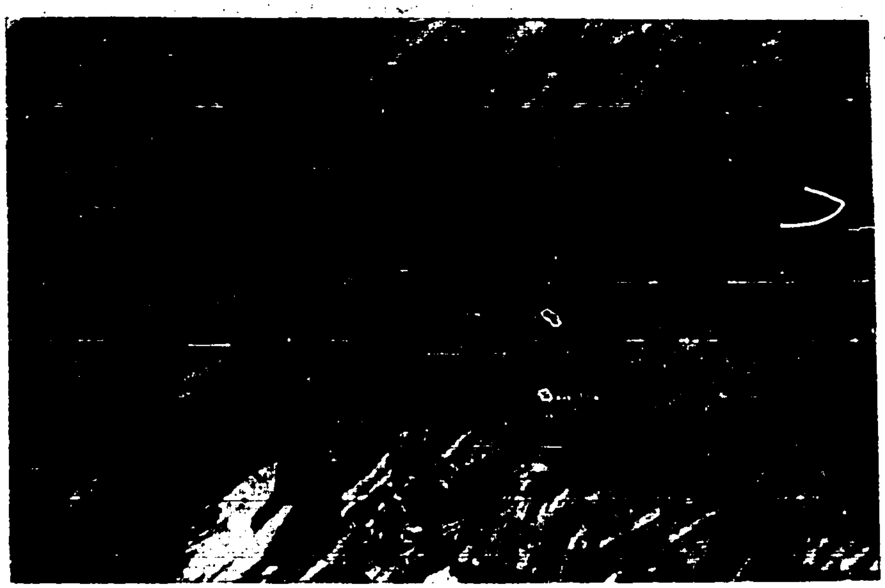


Plate 10b : Photomicrograph of nepheline pegmatite (as above) (x-nicols, x40)

Plate 10a : Color photomicrograph of nepheline-pegmatite, replacement variety; microcrystalline orthoclase and zircon in a groundmass of nepheline. (x-nicols, x40)

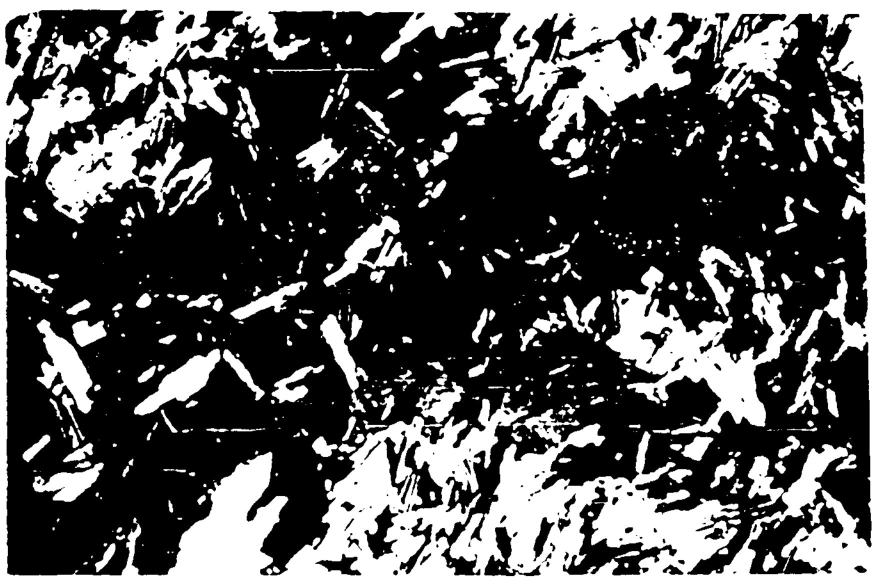


Plate 10b : Photomicrograph of nepheline pegmatite (as above) (x-nicols, x40)

TABLE 10

SAMPLE NO.	Nb_2O_5	Y	Yb	La	RADIOACTIVITY
66-KC-31-5E	0.35	Trace	Trace	Trace	0.012% U_3O_8 Equivalent
66-KC-31-23E	0.05	ND	ND	ND	0.006% U_3O_8 Equivalent
66-KC-31-18E	ND	ND	ND	ND	0.003% U_3O_8 Equivalent
66-KC-35-2D	ND	ND	ND	ND	

The niobium mineralization occurred as a late stage in the evolution of the complex. Large quantities of volatiles escaped and reached higher levels along zones of weakness; joints, fissures, faults and dykes. The nepheline pegmatites represent a period of pneumatolisis in which the principal components were H_2O, CO_2, F, Cl, B and minor amounts of Th and the Rare Earths. Radioactive mineral content was low in the pegmatites sampled.

It is likely that most of the deposits have been removed by erosion.

5.3 Nepheline-Cancrinite Syenite

Field Relations:

A dyke of nepheline-cancrinite syenite has intruded migmatite country rocks on an island in lower

Kagiano Lake. The dyke, where exposed, forms the southern extremity of the island. It is at least 10 metres thick and strikes northwest-southeast. Veins of nepheline pegmatite cut the dyke.

Outcrop Appearance:

The rock is mottled gray, black and white and has a rough, pitted weathered surface. On close examination, the pitting is seen to be due to the recessive weathering of rose-colored cancrinite. The mottled appearance is due to the irregular distribution of mafic minerals which make up about 25% of the rock. White, lath-like, medium to coarse grained feldspar crystals, trachytoidally arranged, give the rock a strongly foliated appearance. Numerous basic inclusions, some angular and others showing remobilization effects at their boundaries, occur within the dyke. Some syenitic inclusions are texturally and mineralogically similar to the central syenite (See Plate 11). Nepheline pegmatites with coarse euhedral crystals of nepheline (up to 3 cm.) occur as flat lying veins within the dyke (See Plate 12).

Thin-Section Description:

The rock is essentially composed of orthoclase, cancrinite, nepheline, aegirine and sodic amphibole.

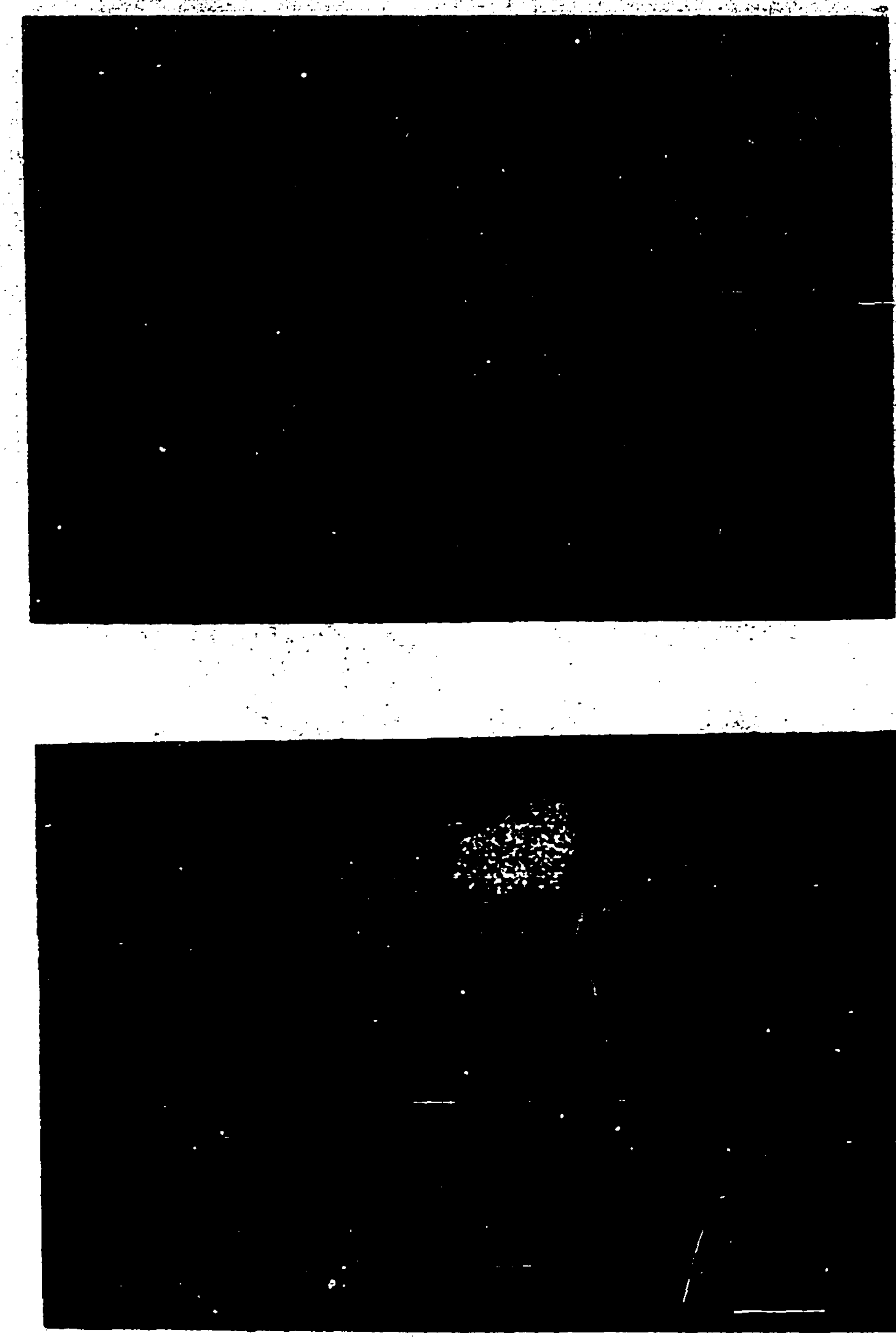


Plate 11 : Nepheline-cancrinite syenite dyke with mafic and syenitic inclusions

Plate 11 : Nepheline-cancrinite syenite dyke with mafic and syenitic inclusions

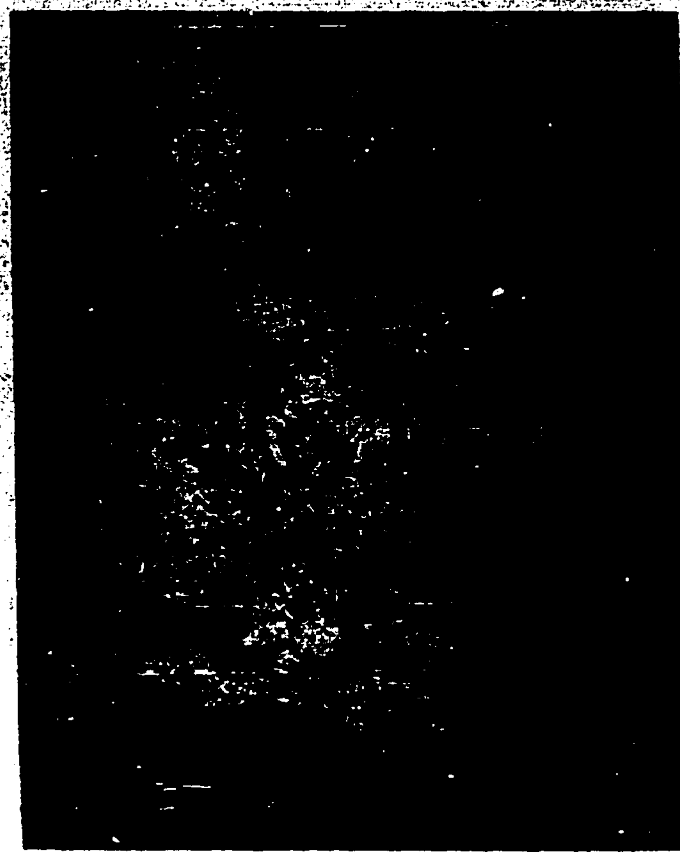


Plate 12 : Nepheline pegmatite cutting nepheline-cancrinite syenite dyke

Plate 12 : Nepheline pegmatite cutting nepheline-cancrinite syenite dyke

Accessories are calcite and fluorite. Orthoclase crystals (50%) are medium grained (2 mm. - 1 cm.) and have sutured rims. Elongate orthoclase crystals are aligned trachytoidally. Usually, they consist of a single Carlsbad twin. Nepheline (10%) and cancrinite (15%) occur interstitially as aggregates of small (.5-1 mm.) sub-hedral crystals. Neither show alteration. Aegirine (5%) and intensely pleochroic green amphibole (15%) are found in *glomeroporphyritic* clots. Fluorite and calcite occur within the mafic segregations and are usually enclosed by amphibole. Fluorite is colorless in most grains but some are deep violet.

6. Lamprophyre

Field Relations:

Lamprophyric dykes cut all the plutonic rocks of the complex and have been identified at several localities in the migmatite.

Outcrop Appearance:

The dykes are dark green to black and range in width from 8" to 10'. Flow layering is well developed in most of the dykes with phenocrysts arranged in zones parallel to the dyke walls (See Plates 13a and 14a). Zones with abundant phenocrysts weather most readily and those parts of the dykes have a pitted

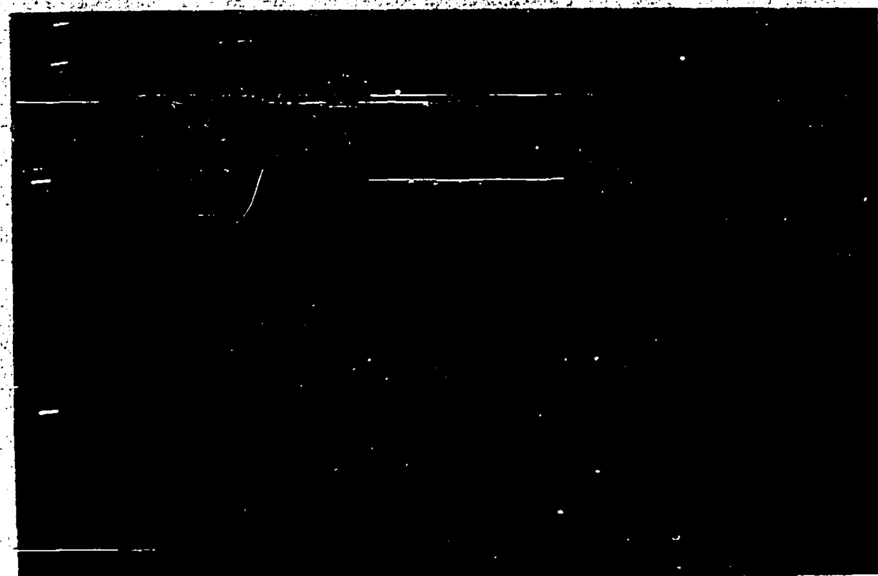


Plate 13a : Lamprophyre dyke from the north shore of Kentron Lake (chemical analysis)

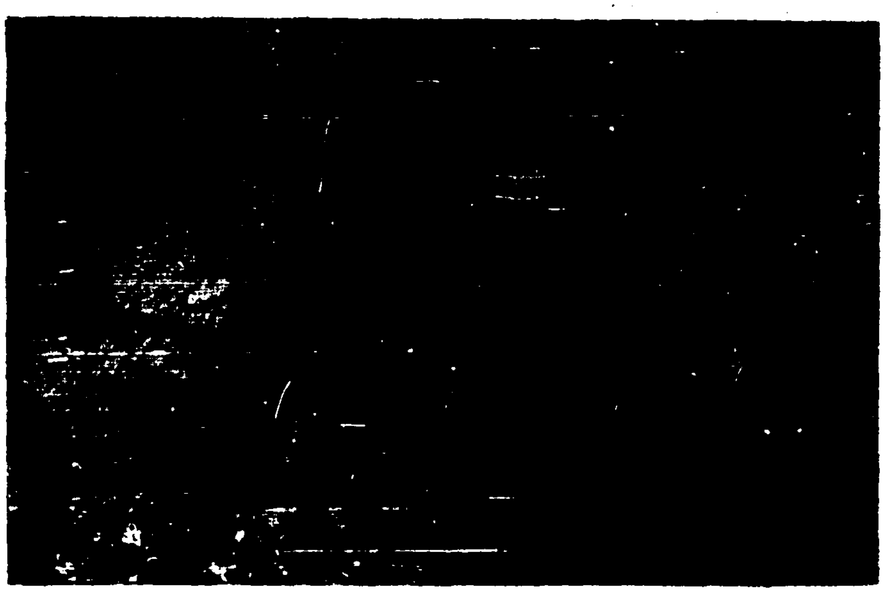


Plate 13b : Photomicrograph of lamprophyre from the dyke shown in Plate 12a. (x80), plain light

Plate 13a : Lamprophyre dyke from the north shore of Kentron Lake (chemical analysis)

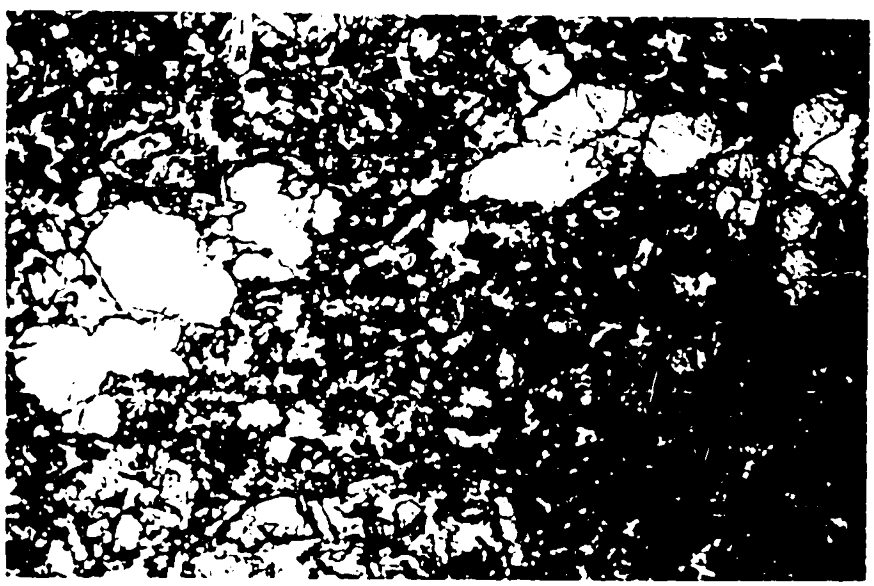


Plate 13b : Photomicrograph of lamprophyre from the dyke shown in Plate 12a. (x80), plain light appearance. In many of the dykes lustrous green crystals of serpentine (after olivine) are a characteristic feature.

Thin-Section Description:

Essentially the rock contains euhedral phenocrysts of olivine and augite within a groundmass of micro-crystalline mafic minerals and glass. Augite crystals are strongly zoned, pale pink and show faint pleochroism. Olivine occurs as clear phenocrysts (.5 mm. to 1 cm.) with exsolution rims of magnetite. It has a high negative optic-axial angle (chrysolite) (See Plate 13b). In many of the dykes the olivine has been altered to radial masses of serpentine. Augite crystals show little or no alteration. A modal analysis of a sample from a lamprophyric dyke (See Plate 13a) gave the following results:

Olivine	- 8.0%
Augite	- 7.6%
Groundmass	- 84.4%

Chemical analyses of lamprophyre are given in Table 11. See Appendix IV for norm calculations.

TABLE 11

Chemical Analyses of Lamprophyre

MAJOR OXIDES	66-KC-25-5B	66-KC-35-1-G
SiO_2	40.7	41.7
Al_2O_3	14.2	13.2
Fe_2O_3	4.33	5.35
FeO	8.48	8.95
MgO	7.36	9.06
CaO	10.4	12.20
Na_2O	1.96	2.76
K_2O	4.29	1.47
H_2O	3.16	0.89
H_2O-	0.40	0.16
CO_2	2.70	0.93
TiO_2	0.77	1.53
S	0.10	.08
MnO	0.26	.27
TOTAL	99.1	98.55

Analyst: D.A. Moddle

66-KC-25-5B: Lamprophyre dyke from the northern shore of Kentron Lake

66-KC-35-1-G: Lamprophyre dyke from the north-western shore of Killala Lake

Plate 14a : Lamprophyre dyke from the northwestern shore of Killala Lake (chemical analysis); displaying flow layering

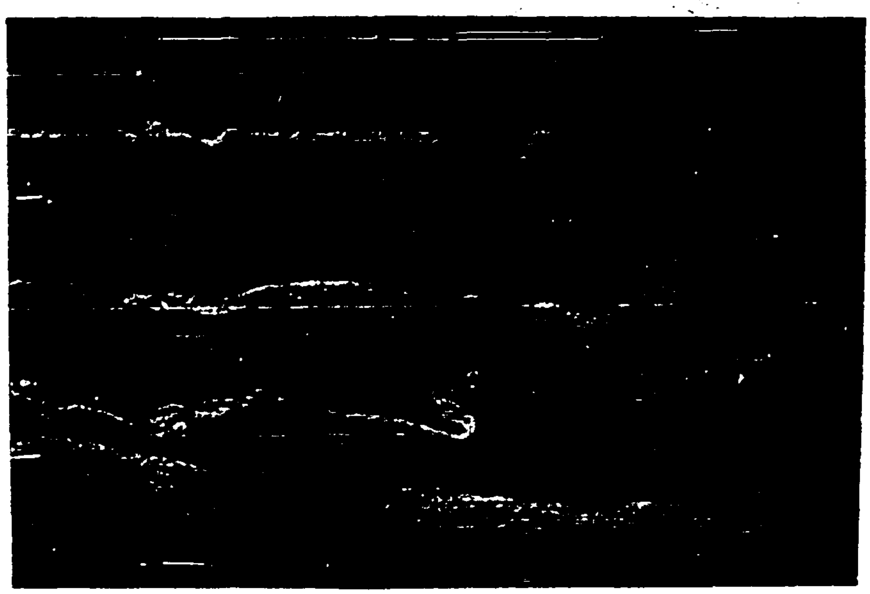


Plate 14b : Migmatite on the western shore of Sandspit Lake

Plate 14a : Lamprophyre dyke from the northwestern shore of Killala Lake (chemical analysis); displaying flow layering

Plate 14b : Migmatite on the western shore of Sandspit Lake

COLLAR ROCKS

Migmatite

Field Relations:

Steeply dipping migmatitic rocks enclose the complex on all but the southeastern flank. Metasedimentary rocks form between 25% and 75% of the migmatite unit, the remainder consisting of *lit-par-lit* injected pegmatite and larger scale stratiform bodies of quartz monzonite (See Plate 14b).

Outcrop Appearance:

The metasedimentary rocks are fine grained (less than 1 mm.) and moderately foliated biotite-quartz-feldspar gneisses. They weather light brown or gray while the fresh surfaces are blue-gray. In the vicinity of the contact, the metasedimentary fraction is rusty brown on weathered and fresh surfaces.

Thin-Section Description:

Essential minerals are biotite (20%), quartz (30%), albite-oligoclase (40-45%) and orthoclase (5-10%). Garnet and magnetite are occasionally present as accessories. Near the contact with the complex, the metasediments have been metamorphosed to a high grade.

The following assemblages have been seen:

1. Hypersthene-andesine-biotite
2. Hypersthene-cordierite-andesine-biotite

Both assemblages correspond to the pyroxene hornfels facies of contact metamorphism (Winkler, 1965). In some of the sections examined, cordierite had well developed seive structure.

Granitic Rocks

Field Relations:

Bodies of granite and granodiorite gneiss are in contact with the complex at several localities. Granodiorite gneiss composes a batholith to the southeast of the complex. Smaller bodies to the northeast and southwest have the composition of quartz monzonite.

Outcrop Appearance:

The granitic rocks are leucocratic; color is variable from white to pale pink. A slight foliation is present in most of the granitic rocks. The gneissosity of the granodiorite is accentuated in places by the presence of elongated amphibolite remnants and schlieren.

Near the contacts with the complex the granitic rocks are rusty-red, much contorted and recrystallized.

Thin-Section Description:

The granitic rocks are essentially composed of plagioclase, less orthoclase or microcline, quartz (30% to 35%) and biotite (2% to 5%).

In the vicinity of the gabbro contact, quartz has been replaced while the feldspar crystals are clouded by alteration products and have irregular sutured boundaries.

CONTACTS OF THE COMPLEX

External Contacts

The contacts between the country rock and the complex in most cases were not exposed. The gabbro-country rock contact is marked by linear valleys at the foot of the outer slopes of the pluton. The valleys have a fairly constant curvilinear trend, so it is probable that the contacts are sharp. Gneissic rocks near the contacts have been remobilized locally and the gneissosites are highly contorted. Granitic rocks are stained bright red and the metasedimentary fraction has a rusty bleached appearance.

The contacts with the Rim Syenites northeast of Barron Lake are more disruptive. Much interfingering has taken place between the syenite and the migmatite and stoped blocks of migmatite were found within the syenite.

The external contacts of the central syenite in the northern parts are quite regular with some xenoliths of migmatite occurring near the contacts.

Review of Internal Contact Relationships

(i) Relations between the gabbro and Larvikite:

As previously mentioned, the Larvikite was mapped at one location only. The Larvikite near Popover Lake appears to be a sheet-like body, approximately conformable to the trend of the enclosing olivine gabbro.

(ii) Relations between the Larvikite and the Central Syenites:

No contact between larvikite and the central syenites was seen in the field. Possible relations are dealt with in Petrogenesis.

(iii) Relations between the Rim Syenites and the Peripheral Gabbro:

The Rim Syenites occur as a ring-like body between the Peripheral Gabbro and the Central Syenites. Dykelets of syenite cut the gabbroic rocks and xenoliths of gabbro are found within the syenite.

(iv) Relations between the Olivine-Nepheline Syenite and the Central Syenite:

Olivine-Nepheline Syenite and related dyke equivalents intrude the Central Syenites. On the southern shore of Kentron Lake, the contacts between the two units are exposed. The contact zone is gradational over a distance of about 10 feet. The Central Syenite in the contact zone has developed a gneissic foliation parallel to the contact, and contains lenses of sugary-textured, syenitic material with very low mafic content.

Many dykes of similar composition are found throughout the central part of the complex. Olivine-Nepheline Syenite dykes in the central complex have sharp contacts but no chilled margins.

(v) Relations between the Olivine-Nepheline Syenite and the Rim Syenites:

Dykes of Nepheline Pegmatite tentatively grouped with the Rim Syenites cross-cut the Olivine-Nepheline Syenite at Kentron Lake. The plutonic masses are not in contact at the present level of erosion.

(vi) Relations between the Rim Syenites and the Central Syenites:

The contact of the Rim Syenites with the Central Syenites was not observed in the field. At the time of mapping, it was thought to be gradational. Staining of the syenite specimens to detect the presence of nepheline has indicated a sharp demarkation of the unit.

Many veins and dykes of Nepheline Pegmatite occur within the Central Syenites at Blank Lake. Some of these, notably the one illustrated in Plate 9, have been found to be replacement-type.

MINERAL LAYERING

1. The Layered Gabbro

Magnetite-rich rhythmically-layered gabbro occurs in discontinuous zones throughout the main unit. The layering dips toward the centre of the complex at an angle of 40° to 50°. Layers are not readily seen in outcrops due to the friable nature of the weathered surface of the gabbro. One group observed in drill core at Sandspit Lake included thirty layers ranging in thickness from 15 cm. to 1 metre. Black, magnetite-rich layers grade gradually into dark gray layers composed largely of plagioclase with less pyroxene (See Plate 15). The dark portion of the layer is normally slightly thinner than the felsic part. Lath-like plagioclase crystals (An_{50}) give the rock a trachytoidal texture. The interstitial spaces are occupied by olivine (which has been partially altered to serpentine), intimately intergrown magnetite and apatite, and minor amounts of pyroxene and biotite. Table 12 gives modal analyses of light and dark layers. The lighter-colored fraction in twenty-three of the thirty layers examined had layers of pyrrhotite up to 2 cm. in thickness which occurred at several levels. In most cases only one layer was present and it occurred near the middle of the felsic part. The pyrrhotite commonly shows sharply-defined interstitial textures.

2. Hastingsite-oligoclase syenite

The mineral layering is quite discontinuous.

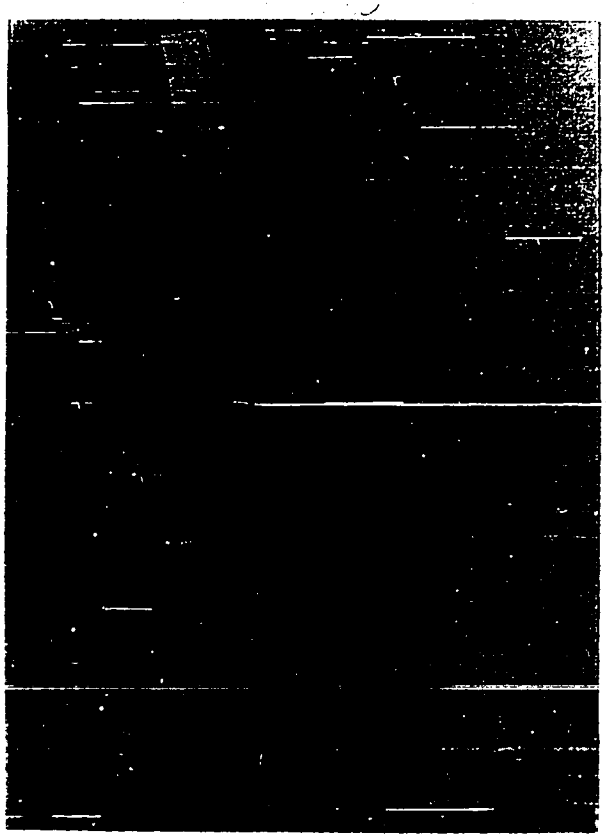


Plate 15 : Rhythmic layering in the Peripheral
Gabbro

Plate 15 : Rhythmic layering in the Peripheral Gabbro

TABLE 12

Modal Analyses of Layered Gabbro

CONSTITUENT MINERALS	Felsic Layer	Mafic Layer
Plagioclase	50.9	5.0
Apatite	11.1	16.8
Pyroxene	10.5	14.5
Mica	3.0	0.2
Olivine	10.4	27.3
Magnetite	10.5	36.2
Pyrrhotite	3.6	

Layered gabbro from north of Sandspit Lake.

(Diamond drillhole No. 3; footage 206.0-207.0)

Layers up to 5 cm. in thickness with a hastingsite content of about 40% separate thick feldspar-rich layers (See Plate 16). The feldspathic layers contain 5-12% hastingsite, about 20% oligoclase and orthoclase and patch perthite.

3. Nepheline syenite

The nepheline syenite has a well developed trachytoidal texture. Platy crystals of cryptoperthite, usually with Carlsbad twinning are sub-aligned and account for the laminated appearance. Aegirine, nepheline and small amounts of magnetite occur in the interstices. Zones of abundant feldspar are recurrent over short distances (5 mm. - 2 cm.) (See Plate 17). The dip of the layers toward the central part of the complex ranges from 30° to 50°.

4. Dyke Rocks

Many of the dyke rocks in the complex have trachytoidal textures. In the case of the lamprophyres, many show concentrations of phenocrysts which lie parallel to the walls of the dyke. These features would suggest that the magma had been partially crystallized at the time of intrusion.

Plate 16 : Mineral layering in the central syenites

Plate 16 : Mineral layering in the central syenites

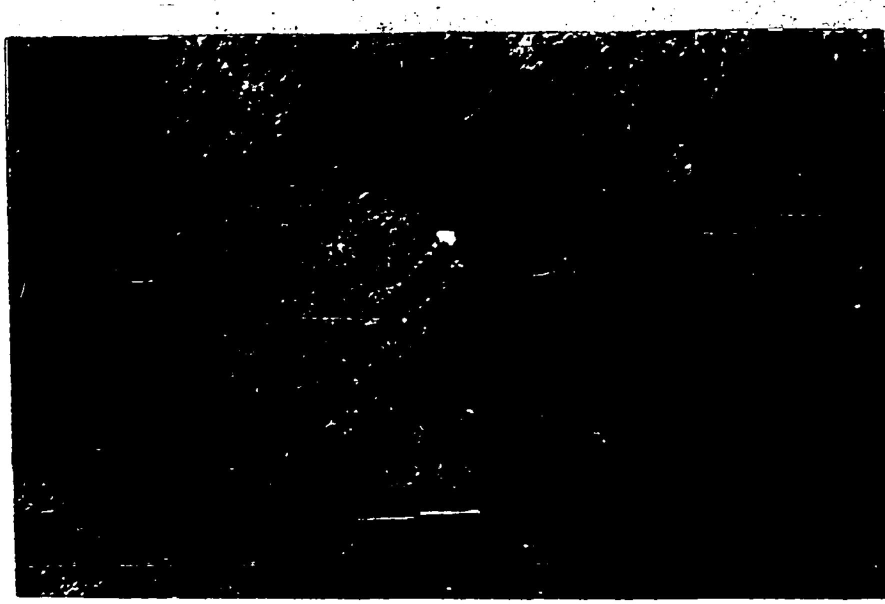


Plate 17 : Igneous lamination in the Rim Syenites
east of Sandspit Lake

Plate 17 : Igneous lamination in the Rim Syenites east of Sandspit Lake

STRUCTURAL GEOLOGY AND TECTONIC SETTING

Faults and Joints

Extensive faulting, pre - and post-intrusive in age, has taken place in the region surrounding the Killala Lake Complex. The major regional fault structures conform to the following general trends.

1. North-south to N-15^{o}-E
2. Northwest-southeast
3. Northeast-southwest
4. Parallel to the strike of the migmatite country rocks.

Faults of north-south trend, in particular the Boomerang Fault, have been sites of igneous activity. Many diabase dykes occur within the fault zones and older mafic dykes with *net-veining* have also been encountered (See Map No.1, back pocket).

Faults trending northwest-southeast show the most recent evidence of movement. These faults displace the north-south trending set and the rocks of the complex as well. Sheared and hematitized pegmatite and veins of quartz have been cut by diabase dykes. Later movement has brecciated and sheared the diabase dykes, usually along one flank. At several localities the sheared diabase contained veinlets of calcite and quartz with small amount of chalcopyrite. Rocks in the vicinity of the faults have been hematitized, albitized and silicified. Small veinlets of fluorite were seen in the boundary rocks at three localities. A breccia, with a mafic igneous groundmass, which outcrops on an island in the southern arm of Killala Lake, is within a fault zone which is parallel to the northwest-trending Killala Lake-Runnals Lake fault.

Faults with northeast-southwest trend, which corresponds to the direction of glacial movement, have been scoured and filled with glacial drift. Minor faults and an occasional resistant diabase dyke remnant at the margins of the fault valleys were taken as evidence of activity.

Many strike-shears are found in the migmatitic rocks to the northeast of the complex. These shears usually have rusty weathered surface and contain narrow quartz veins with pyrite, pyrrhotite and abundant graphite.

Jointing:

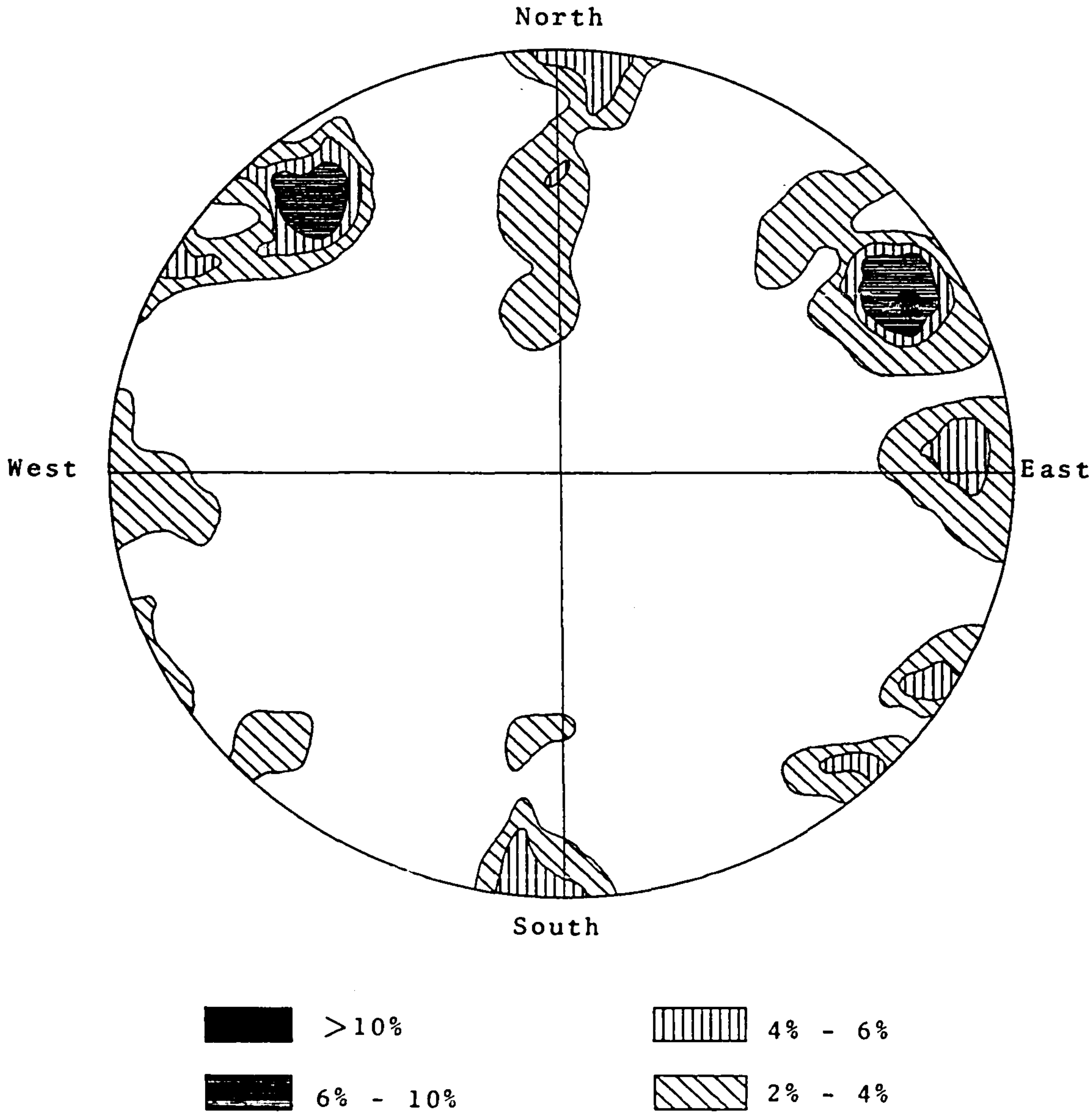
Syenitic rocks of the complex are well jointed. Both shear and tensional joints were recognized but were not recorded separately in the field. A plot of poles to the joint surfaces is shown in Figure 4.

Joints near the rim of the complex dip steeply inward. These joints are represented by an incomplete girdle distribution in the π diagram. As the central parts of the complex are approached joint surfaces have progressively shallower dips. Horizontal joints are present in the centre.

A concentration of poles for joints present at 062 degrees represents a set of joints of northwest-southeast trend which dip steeply to the southwest. This set is subparallel to the trend of the Popover Fault as well as a major regional fault trend. Possibly the joint set coincides with normal step-block faulting toward the Lake Superior Basin.

Form of the Intrusion

The complex is roughly oval in plan; 12 km. in the north-south dimension and 7.5 km. east-west.



Total number of joint determinations 87

Figure 4 : II diagram of all joint determinations from the syenitic rocks of the Killala Lake Complex.

The external contacts of the complex dip inward at an angle of 45° or greater. Such bodies were called lopoliths by Grout (1918). The rocks which compose the body are distributed in a characteristic confocal arrangement with the outermost zone being the narrowest (Shand, 1922). The outer zone is not complete in this case as the Peripheral Gabbro does not appear in the northern parts of the complex. Aeromagnetic data suggest that the gabbroic unit may be present beneath the northern syenite. The northern syenite may be a sheet-like body of restricted vertical extension, or petaloid (Holmes, 1965, p. 256). If so, at greater depth, the complex would be roughly circular in plan.

Very few inclusions are found within the Killala Lake Complex and the external contacts are quite regular. Ring fracture stoping with the consequent ejection or elevation of a conical block probably dictated the actual form.

Mechanics of Emplacement

There has been much conjecture about the mechanics of intrusion of alkaline igneous bodies and several hypotheses which developed from the consideration of the problem are given below.

Shand (1928) gave a lengthy discussion of the problem. He cited doming, stoping, blasting or melting as possible mechanisms but rejected all but stoping.

Holmes proposed an upward migration of a basaltic cupola by progressive melting of the overlying material. Convection was invoked as the mechanism for upward transfer of heat (Holmes, 1931).

Backlund (1932) suggested a process of piercement in which a symmetrical plug of crustal material was explosively removed and replaced by alkalic magma. This process, he termed *epeirodiatresis*. Since alkaline bodies occurred in stable continental areas and were post-deformational features she believed that the regularity of the outline related directly to, and could be used as a measure of crustal stability.

Von Eckermann (1948) also proposed an explosive origin. He showed that alkaline rocks at Alno Island were emplaced along sets of conical ring-fractures. By projecting each set of cone fractures to depths he was able to estimate the level at which the related explosive activity had occurred.

Primarily, the magmatism seems to have been controlled by the regional fracture pattern. The complex occurs at the intersection of several regional faults, each of which has been the site of igneous activity at various times in the past.

DISCUSSION OF GEOPHYSICAL DATA

The plutons of the Coldwell province correspond to pronounced anomalies on the aeromagnetic maps (Aeromagnetic series, 1965). The strong circular anomaly associated with the Killala Lake Complex aroused the interest of the author in 1964 (See Figure 5). As mentioned previously, the present work is actually the result of an investigation into the geophysical data.

A strong positive magnetic anomaly of 2200 gamma corresponds to the outcrop trace of the Olivine Gabbro which has a high magnetite content. Magnetic profiles across the complex show curves which are skewed toward the central part. This skewness is probably due to the inward dip of the gabbro. Magnetite content of the syenitic rocks is low, varying from about 3% in the nepheline syenite to less than 1% in the central syenite. Consequently, magnetic responses in the central and northern parts of the area are low.

In the neighbouring Port Coldwell Complex, Milne has observed that the gabbroic rocks evoke an extreme negative magnetic anomaly (Milne, 1967). This, he suggested, was probably due to a strong reverse remnant

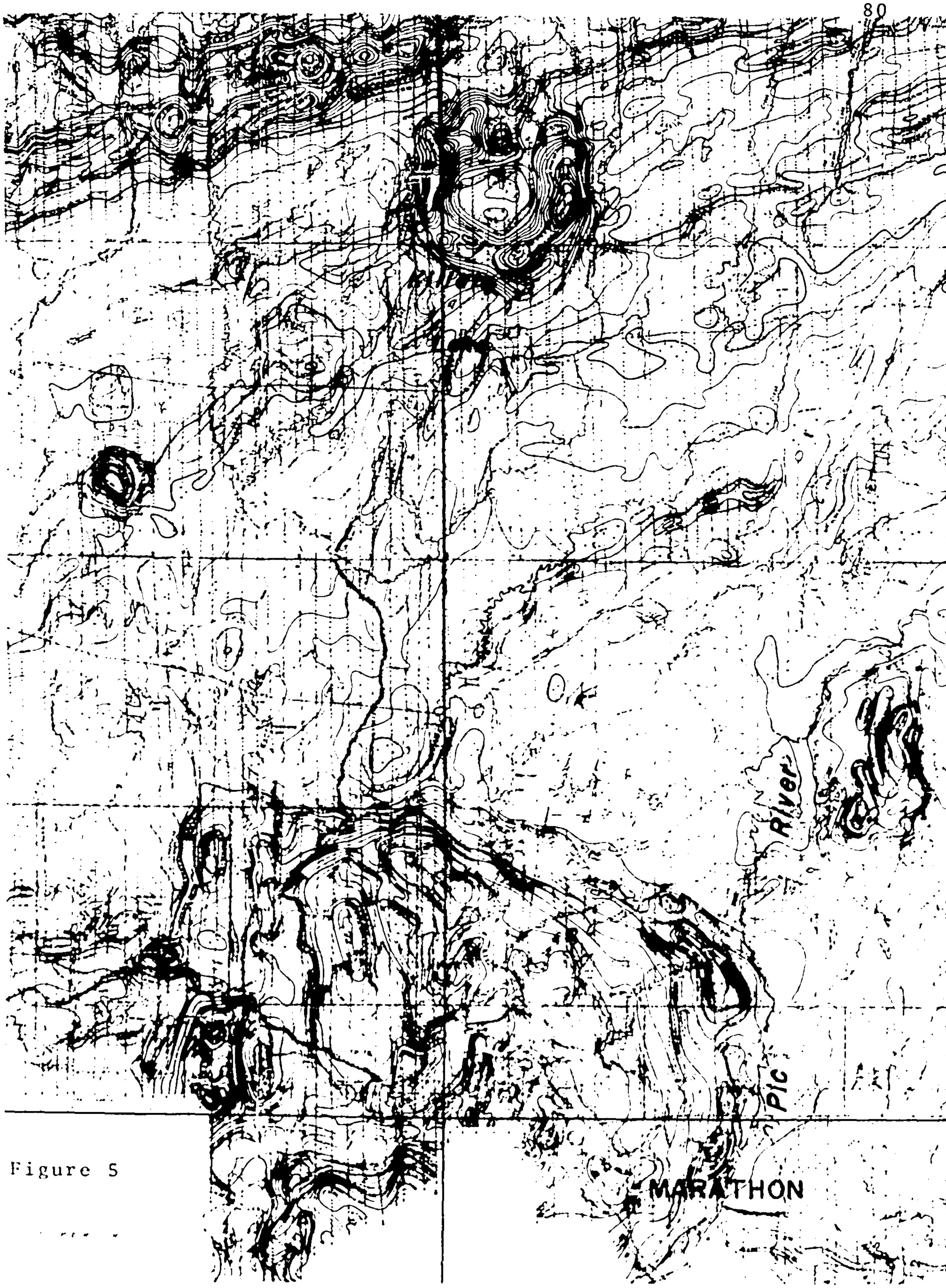


Figure 5

Aeromagnetic map; in the vicinity of the Coldwell petrographic sub-province.

magnetism in the gabbro. The negative response is in contrast with the observed condition at the Killala Lake Complex which exhibits a positive anomaly of comparable intensity. This contrast would seem to indicate that, although the two units have a similar petrological character, an appreciable amount of time may have elapsed between the respective epochs of emplacement, with pole reversal taking place in the interim. Alternatively, the magnetic response may be a simple function of the size of the occurrence.

PETROGENESIS

The processes involved in the origin of alkalic rocks are multiple. Some of the suggested mechanisms are listed below:

1. Simple fractional crystallization of primary olivine basalt magma.

2. Gaseous transfer and thermodiffusion.

3. Differential movement of alkalis in the magma (1, 2 and 3; Barth, 1962).

4. Desilication of granitic magma by assimilation of limestone (Daly, 1928; Shand, 1923).

5. Complete or partial fusion of subcrustal materials, followed by reaction or differentiation at depth (Tilley, 1957; Holmes, 1931; Turner and Verhoogen, 1960; Yoder and Tilley, 1962).

The historical development of ideas, and alternative suggestions are given in the works of Shand (1923-1945), Smythe (1927) and Bowen (1928).

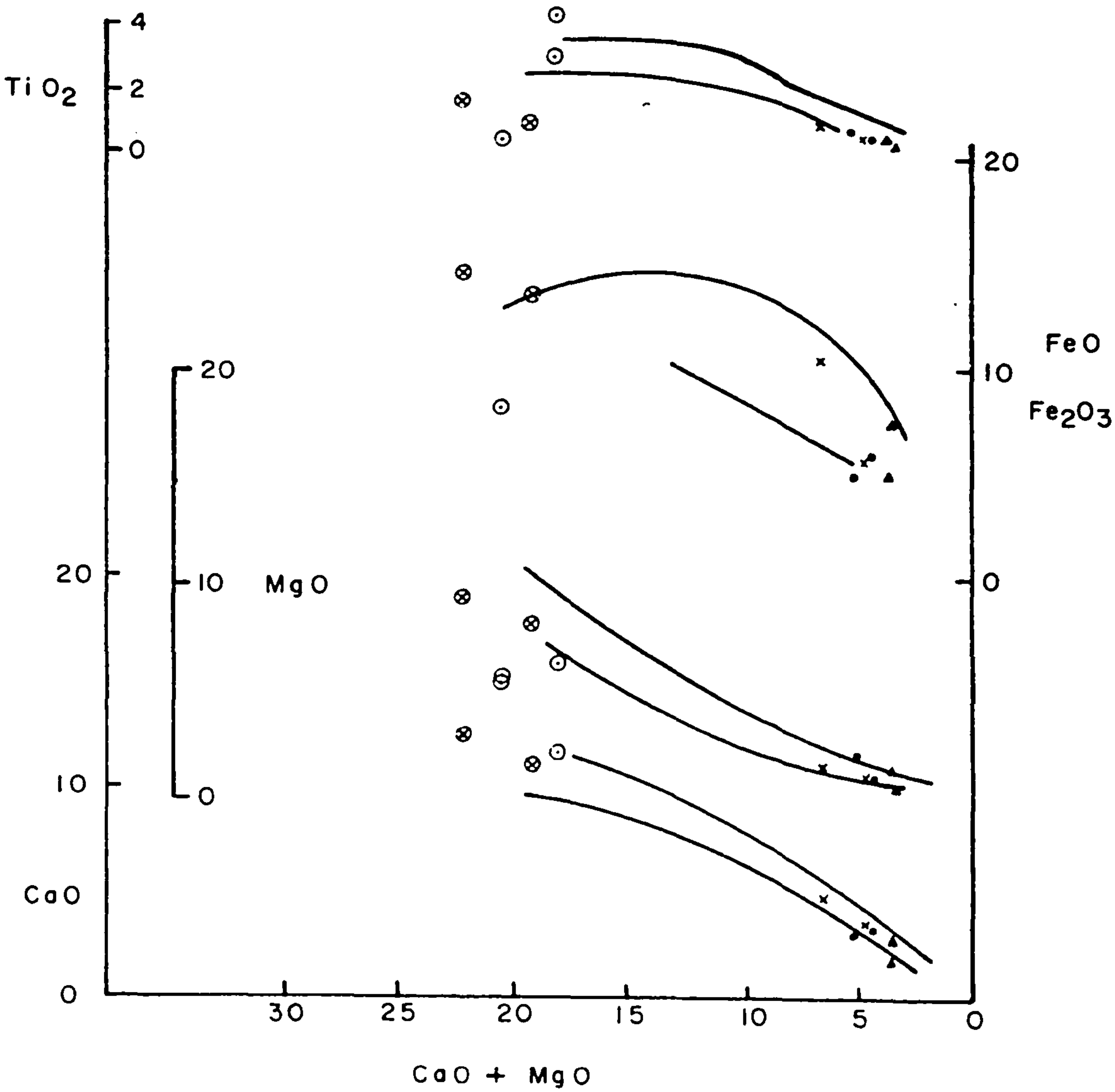
Experimental work on eclogite has shown that by varying conditions of temperature-pressure equilibrium, liquids associated with garnet and omphacite might be committed to one or another of the divergent differentiation trends characteristic of the tholeiitic and alkaline basalt at low pressure (Yoder and Tilley, 1962). Work by Osborne (1959) has indicated that the fugacity of oxygen in a cooling magma is one of the factors which dictates the nature of the final residua.

Most petrologists agree that the prevalence of phonolitic rocks among the late differentiates is attributable to undersaturation of the parent basaltic magma in silica (Turner and Verhoogen, 1960). Notable departure in either direction from the saturated conditions normally persists into the final differentiates (Barth, 1962).

Chemical Data

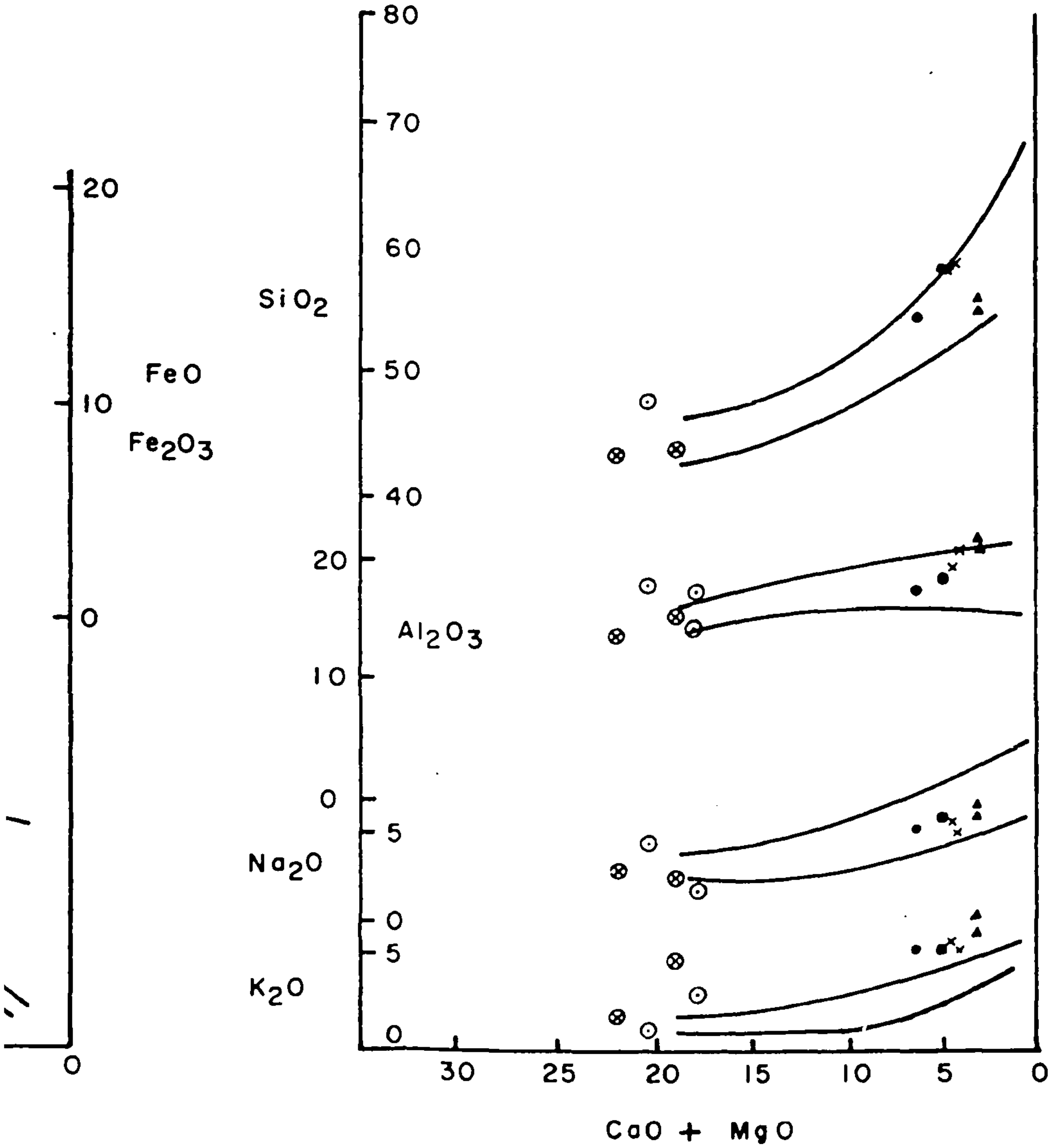
Chemical analyses of the several rock types reflect the strongly differentiated character of the intrusion. Two groups of rocks with contrasting $CaO + MgO$ content are represented in the intrusion (See Figure 6). Early accumulative rocks and late lamprophyre dykes comprise one group with $CaO + MgO \geq 17\%$. The late syenitic differentiates comprise the second group in which $CaO + MgO \leq 8\%$. Rocks of intermediate composition from which the gabbroic accumulates were subtracted are not evident in the intrusion.

The irregular oxide distribution in the gabbroic rocks is a reflection of the extreme fractionation which the initial magma has undergone. The *in situ*



◦ Olivine gabbro • Central syenite × Olivine-n

Figure 6: VARIATION OF THE MAJOR OXIDES
(Theoretical Curves after S.R



× Olivine-nepheline syenite △ Nepheline syenite ⊗ Lamprophyre

ꜱJOR OXIDES IN THE ROCKS OF THE KILLALA LAKE COMPLEX
s after S.R. Nockolds, unpublished data)

crystallization trend in the early stages was toward iron enrichment of the residual liquid (See Figure 7). In the late stages of crystallization, deposition of iron oxide was effected and In the terminal stages of differentiation the trend was toward strong alkali enrichment of the residual liquid. Fractionation was quite complete; no phases of intermediate composition are present.

The rocks of the Killala Lake Complex all contain normative nepheline and several of the syenites contain normative corundum (See Appendix IV). Compositionally, the rocks fall within the *malignite-miaskite* series of Barth (1962, p. 198).

Compositions of nepheline from the Rim Syenite and from pegmatites determined by the X-ray method of Hamilton and Mackenzie (1961) were in the range Ks_{25-30}. This composition range is indicative of low temperature (subsolvus) crystallization for the nepheline syenites (Tilley, 1957).

Proposed Sequence of Events

The earliest magma was of gabbroic composition. The emplacement was controlled by faulting and achieved

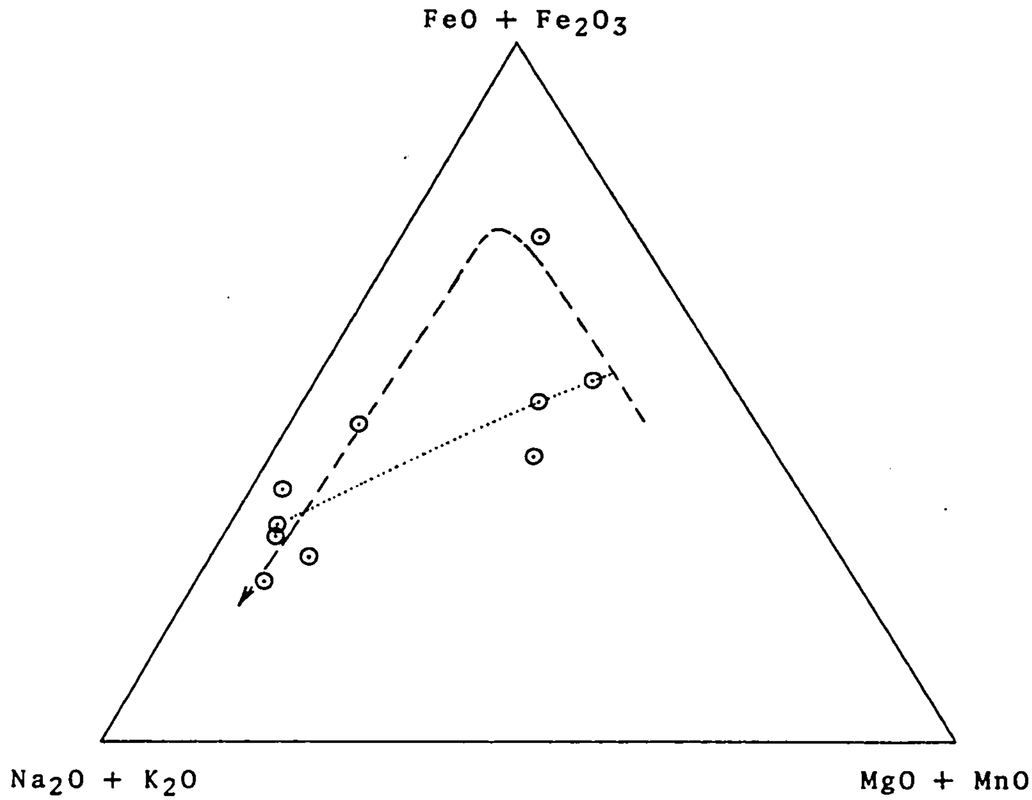


Figure 7: Variation in the olivine gabbro-nepheline series at Killala Lake. (method after Turner and Verhoogen, 1960, p. 198) Dashed line indicates a hypothetical differentiation trend for the plutonic types. Dotted line is a hypothetical differentiation trend for the dyke rocks.

by ring fracture stoping. The gabbros chilled against the country rocks and cooling took place in a closed funnel-shaped chamber from the margin inward. Differentiation proceeded along an undersaturated alkaline trend toward iron and alkali enrichment giving ferro-gabbro and Larvikite in the upper levels (See Figure 7). This was a period of prolonged tectonic quiescence.

The unusual rhythmic deposition of magnetite and pyrrhotite in the layered gabbro was a consequence of variation of the partial pressures of Sulphur and Oxygen in the cooling magma. The layering in the gabbro was effected by convection currents in a fractionally crystallized magma. Gravitational settling resulted in minor post-depositional modifications.

In the late stages of this *in situ* differentiation an injection of syenitic magma occurred, which perforated the gabbro, enlarging and extending the magma chamber with the emplacement of a laccolithic (northern) extension. Differentiation of the syenitic magma with the development of rhythmic layering took place *in situ*.

Olivine-Nepheline Syenite was emplaced when the Central Syenites were in a semi-consolidated state and some hybridization took place along the contacts.

The Rim Syenites were intruded selectively as a ring-like body along parts of the re-activated gabbro-syenite contact. Slow cooling of the body under the influence of convection resulted in the development of igneous laminations in the unit. Fractures which developed in the overlying Central Syenite and Olivine-Nepheline Syenite served as passageways for some of the escaping volatiles which had concentrated in the late differentiates. Dykes and veins of nepheline pegmatite in the overlying units are representatives of this late stage, volatile rich phase.

The Lamprophyre dykes which cut all the other rock types represent the last recognizable phase of igneous activity in the area.

THE RIFT FAULTING HYPOTHESIS

Studies of the Lake Superior basin have revealed the presence of a high positive gravity anomaly beneath the lake (Smith, Steinhart, and Aldrich, 1966). Seixmic reflection work indicated the presence of a high velocity crust probably of gabbroic composition at a depth of 4-6 km.

Depth to the M-discontinuity was observed to vary from 20 km. west of Lake Superior to 55 km. in the eastern half of the lake. These features led Smith (et al) to conclude that the Lake Superior basin might be the site of a "fossil rift". For analogous cases in the Baltic Shield, Khain (1963) has come to similar conclusions. As evidence for the presence of the "abyssal faults" of continental rifting, he cites the following criteria:

1. Abrupt change in the depth to the M or Conrad discontinuities.

2. Presence of intense, positive, linear, magnetic anomalies.

3. Igneous petrological evidence: regional belts of granitoids or lines of volcanoes (Supporting evidence is found in O'Hara and Yoder, 1962; Schairer and Bailey, 1961).

Kumarapeli and Saull (1966) suggested that the Lake Superior basin was possibly an older continental extension of the St. Lawrence rift system. They regarded the alkalic plutons of the Coldwell subprovince as igneous-petrological analogs of the Monteregian hills (See Figure 8).

To the east of the Coldwell Intrusives, a linear positive gravity anomaly occurs. This anomaly, "the Kapuskasing high" extends northeast to Hudson Bay (See Figure 8). On the eastern margin of the gravity high, the parallel Kapuskasing magnetic high corresponds to horst blocks of magnetic granulite which are bordered and divided by major northeast-striking faults (Brown, Bennett and George, 1967). Alkalic and ultrabasic rocks, which have been dated as Proterozoic and Mid-Devonian respectively (Gittens et al, 1967), occur on the flanks of the horst blocks and in the vicinity of the gravity anomaly. The gravity pattern marks a major tensional feature of the crust, a fracture zone extending to great depth which has provided the channel for access to the surface of basic material giving rise to the gravity anomaly. Wilson and Brisbin (1965) state that the gravity anomaly can be explained by a pronounced upwarp or ridge in the Conrad discontinuity.

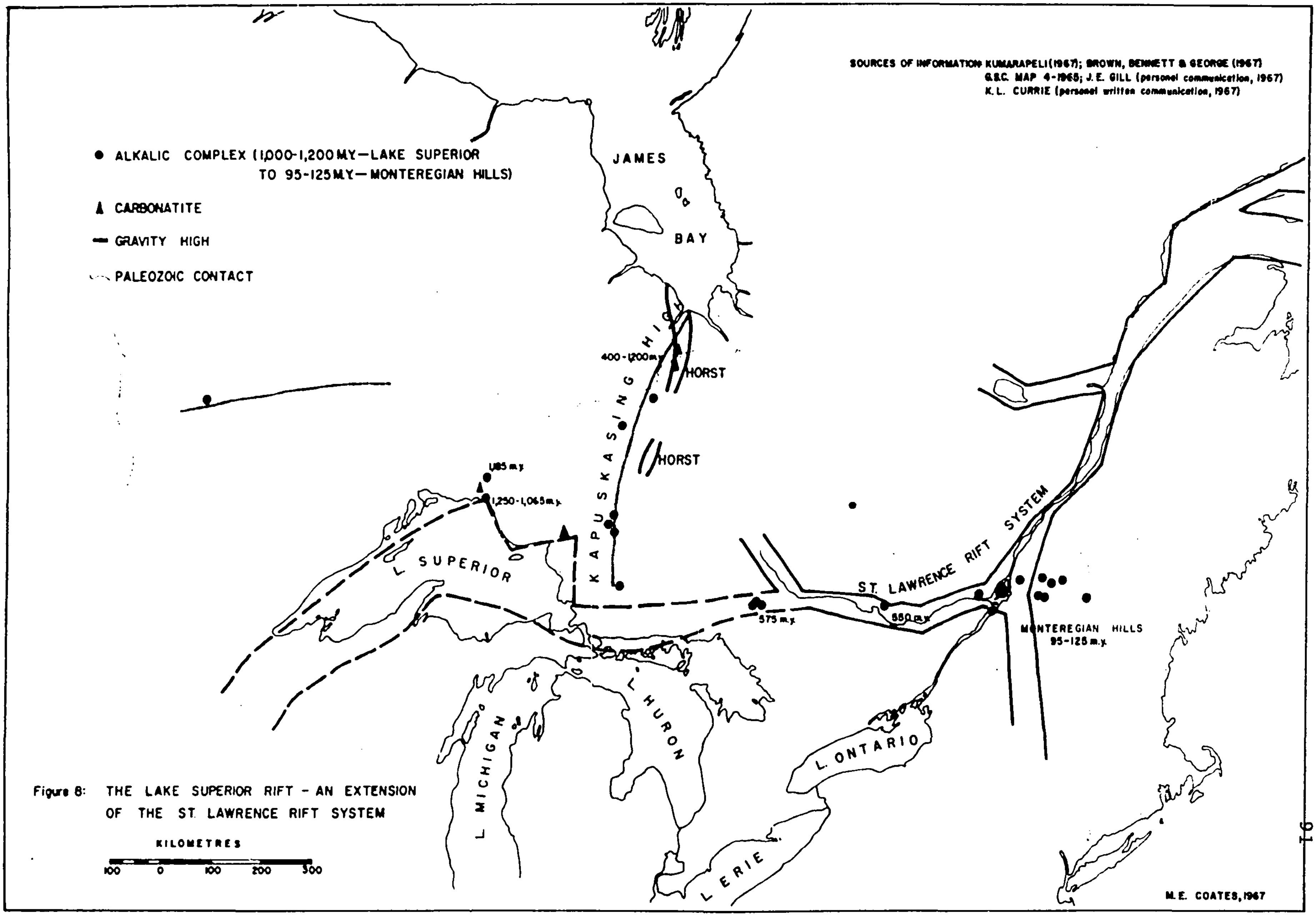


Figure 8: THE LAKE SUPERIOR RIFT - AN EXTENSION OF THE ST. LAWRENCE RIFT SYSTEM

Another linear positive gravity anomaly and associated alkaline rocks occur northwest of Lake Superior (See Figure 8). No data were available for this area at the time of writing but a similar relationship seems probable.

The association of alkaline activity with rifting has been discussed by Holmes (1964) and Dixie (1956). The prevalent occurrence within and immediately adjoining rift zones was emphasized by both authors. For recent rifting, abundant geomorphological evidence of the association exists. Studies of rift zones has shown that rifting occurs at the crests of crustal upwarps (Holmes, 1965; De Sitter, 1964). Beloussov (1962) has found that rift zones often occur on the flanks of crustal swells rather than at the crests. Thus, alkaline activity on the flanks of upswells might be expected.

Currie suggests that alkaline activity in the Canadian Shield of Paleozoic age can be correlated with present height-of-land (Currie, K.L. Personal written communication, March 1967). His reasoning is as follows:

> During the Paleozoic, the Precambrian was covered by a mantle of sedimentary rocks. These rocks are of onlap type, and therefore, a drainage pattern was preserved on the Precambrian surface

> beneath the sedimentary blanket. In the late Paleozoic, swells developed arching the cratonic cover. These swells may still be active in some parts. At any rate, they produced relatively linear topographic highs on the Precambrian surface. As the cratonic cover was stripped off, these highs would normally become the drainage divides, but if there were a strongly developed drainage pattern on the exhumed surface, this might interfere with the position of the drainage. Similarly, drainage pattern might be let down from the Paleozoic above. I, therefore, argue that the line of maximum topographic elevation is a relatively reliable indicator of uplift. This line can easily be established from small scale maps. I found maps at scales of about 1:1000,000 to 1:10,000,000 most satisfactory. The line of elevation may be cut up by drainage, but is often still obvious.

The Late Precambrian Coldwell Intrusives occur about 50 km. south of the height-of-land computed by Currie (1963). This may be regarded as a fortuitous occurrence, or alternatively, it may be a suggestion of repeated oscillatory crustal movements within the same general zone in the past. Determined ages for the alkalic complexes indicate sporadic recurrence of alkaline intrusion in the region (See Figure 8).

CONCLUSIONS

1. The localization of the complex was fault controlled, the entry of magma being effected along zones of weakness associated with deep penetrating faults.

2. The alkaline magma was intruded into a platform of high stability which accounts for its regular outline.

3. Emplacement was by ring fracture stoping.

4. Earliest magma was gabbroic and differentiated thoroughly after emplacement.

5. Inner rocks are more alkali-rich and much younger than the gabbroic rocks. The inner structure is independent of the gabbroic fraction.

6. The time which elapsed between the intrusion of the gabbroic magma and the intrusion of syenitic magma was a period of general tectonic quiescence in the region.

7. The syenitic rocks represent the end product of differentiation in a deep-seated magma source.

8. Liquid immiscibility of sulphide and oxide phases with the silicate melt or variation in the fugacities of oxygen and sulphur are factors which may have played a major role in the localization of magnetite, pyrrhotite and chalcopyrite in the layered gabbros. Deposition was by gravitational settling.

9. Niobium mineralization is associated with late stage nepheline pegmatites.

APPENDIX I

Mineral Exploration

The following is a brief account of exploration work done on the Killala Lake Complex. A tabulation of work reports available for reference is given in the following section on assessment work.

1. The Sandspit-Popover Occurrences

A self-potential survey of the western flank of the Killala Lake Igneous Complex was done by Killala Lake Mines Ltd. in 1954. A continuous anomaly about three miles in length was detected, and diamond drilling was done at two locations; one north of Sandspit Lake, and the second, south of Popover Lake. Eleven inclined holes were drilled at each location (See Map No. 2 for drill hole locations). In all, about 10,000 feet of drilling was done and the core was stored near the drill-sites. At the time when the present author visited the storage sites, the supporting racks had collapsed and the cores were badly disarranged.

Drilling was completely confined to the coarse grained olivine gabbro unit which forms the periphery of the alkalic complex. The gabbro is particularly rich in magnetite, apatite and pyrrhotite in certain layers. Small amounts of chalcopyrite were found in association with the pyrrhotite.

Sixty-five assay samples were taken. The best grade indicated, at the Popover Occurrence, was 0.32% Cu; .07% Ni over a ten foot length of core. The best nickel value reported was 0.16% Ni; over a nine foot length. Most of the values were considerably lower. No further development work has been done on the occurrences since 1954.

2. The Prospectors Airways Occurrences

Airborne magnetic and scintillometer surveys of the eastern half of the Killala Lake Igneous Complex were carried out in the summer of 1954. Geological mapping of claim blocks near Drainage Lake and north of Kentron Lake was done during the ground investigation of the geophysical results. The olivine gabbro at Drainage Lake yielded a strong magnetic anomaly and was subsequently stripped and trenched. Seven samples which were taken and assayed for nickel gave values ranging from trace to 0.03% Ni.

No further work was done on the property by Prospector Airways.

3. The Baseline Mines Occurrences

In November 1954, Baseline Mines did geological mapping, trenching and diamond drilling in the area between Drainage Lake and McKergows Baseline on the southern flank of the Killala Lake Igneous Complex. Two holes were drilled near the north end of Drainage Lake to intersect the olivine gabbro. Three additional holes were drilled near McKergows Baseline to test the southern extension of the gabbro. Pyrrhotite, magnetite and up to 3.0% chalcopyrite were reported. No assay values are given. Native copper is reported to have been seen on the weathered outcrops and gold was allegedly panned from the stream at the north end of Drainage Lake.

Assessment Work Reports

Several geophysical reports, as well as some logs of diamond-drill holes have been submitted to the Ontario Department of Mines to be recorded as assessment work. Reports only are on file at Toronto; reports and drill logs are on file with the resident geologist in Port Arthur. The company names and types of information are given below.

COMPANY	TYPE OF INFORMATION
Killala Lake Mines Ltd.	Diamond Drill Logs Geophysical Maps
Prospectors Airways Ltd.	Geological Maps Geophysical Maps
Baseline Mines Ltd.	Diamond Drill Logs Geological Maps

APPENDIX II

Stain Techniques

Feldspar and feldspathoid minerals were difficult to distinguish in the rocks of the complex. To facilitate mineral identification for the purposes of modal analysis (See Plate 18) two staining methods were used. They are as follows:

(i) Nepheline: Slabs of rock are coated with concentrated (80%) phosphoric acid and allowed to stand for 2 to 3 minutes. Slabs are then rinsed and the etched face immersed in a dilute (.25 normal) solution of methylene blue. In 1 to 3 minutes, nepheline stains deep indigo-blue.

(ii) K-feldspar: Slabs of rocks are immersed in concentrated HF for ½ to 2 minutes, then rinsed and suspended, face down, in a saturated solution of sodium cobaltinitrite. After one minute, K-feldspar will be stained a bright canary yellow. It is important that the slabs be placed in the solution face down, otherwise sodium cobaltinitrite will precipitate on the etched surface and mask the reaction.

In some cases, it may be necessary to stain for plagioclase as well. A procedure for combined K-feldspar

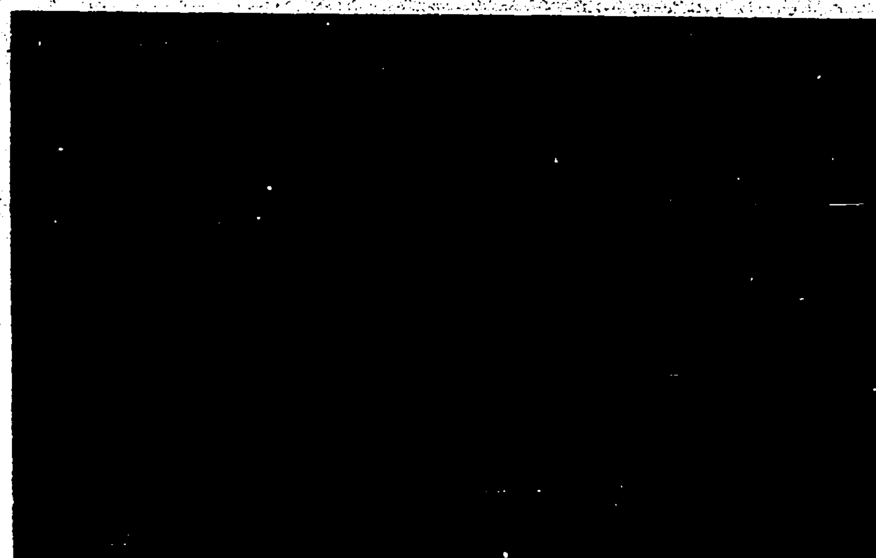


Plate 18 : Block of aegirine-hastingsite-oligoclase syenite - K-feldspar is stained yellow. Points on the cube faces were counted to give a modal analysis (See Table 5 and Appendix III)

Plate 18 : Block of aegirine-hastingsite-oligoclase syenite - K-feldspar is stained yellow. Points on the cube faces were counted to give a modal analysis (See Table 5 and Appendix III)

and plagioclase stain given by Bailey and Stevens (1960, p. 1022-1025) is as follows:

1. Place specimen polished surface down in well-ventilated hood over a vessel filled with HF and allow fumes to etch surface for about 3 minutes.

2. Remove specimen (using rubber gloves), dip in water, and dip twice quickly in and out of barium chloride solution.

3. Rinse briefly in water and immerse it face down for 1 minute in the sodium cobaltinitrite solution.

4. Rinse gently tilting it back and forth in tap water until the excess of cobaltinitrite reagent is removed. The K-feldspar is stained bright yellow if the specimen has been adequately etched. If the K-feldspar is not bright yellow remove the etch residue by rubbing the surface under water, dry, etch again for a longer period and repeat procedure from step 2.

5. Rinse briefly with distilled water and cover the surface with rhodizonate reagent. * Within a few seconds the plagioclase feldspar becomes brick red. When the red is of satisfactory intensity, rinse the specimen in tap water to remove excess.

* Rhodizonate reagent - dissolve 0.05 g of rhodizonic acid potassium salt in 20 ml of distilled water. Make fresh in a small dropping bottle as the reagent solution is unstable.

This procedure will give brilliant colors. When fine details of structure are to be studied, a short period of etching is desirable. Also textures not readily seen by the single stain become clearly visible by this method. Modal analyses or grain counts can be easily made.

Treatment times vary for different rock-types. Some experimentation is usually necessary to determine the proper duration of exposure to each reagent. Rocks which are highly altered seldom give definitive reactions.

Porosity or fractures cause difficulty in staining because the chemicals are retained and may later escape and either prevent staining or discolor the stains. This problem may be eliminated by soaking or coating the surface to be tested in molten paraffin. Excess paraffin is then wiped off and the flat surface polished with fine abrasive and dried. Pores and fractures could also be filled with plastic sprays, Canada balsam or other cements.

Caution : The methods have been designed to distinguish particular minerals, but some other minerals may also give the same response. Be sure to confirm identifications with other properties.

For further discussions on staining procedures, consult the works of Chayes, 1952; Dawson and Gabriel, 1929; Hayes, 1959; Rosenblum, 1956.

APPENDIX III

Modal Analysis of Coarse Grained Feldspar-feldspathoid Rocks, -A method

Many of the syenitic rocks of the Killala Lake Complex are too coarse grained to use the conventional Rosiwal point-count method and obtain reliable percentage estimates. As an alternative, it was decided to make the component determinations macroscopically on roughly-polished cubes of the rock, using staining techniques to facilitate the mineral identification. By means of staining, it is possible to develop good color contrast between some minerals. (Orthoclase: yellow; Feldspathoid: blue or green; Plagioclase: natural or red). (See Appendix II for staining procedures).

Cubes of rock 4.5-5cm on an edge were given a rough polish and stained for the various minerals. After drying, a clear plastic spray was applied to the surfaces to preserve the stain. Clear plastic sheets with regularly spaced dots, by PARA-TONE INC. were trimmed to size and applied to the six faces of the cubes. (Sheets are available with a number of different point spacings; about ½ the mean grain-diameter is suitable). The faces were point-counted using a binocular microscope with low magnification and the results from the opposing faces were recorded as three sets, each with two values. The results of one count are given on page 112.

An assessment of the reliability of this method was made by K. Schryver using statistical methods on data from counts on a block of syenite from Blank Lake. His conclusions were that data from one face provide an estimate of volume % of the component minerals, in this case orthoclase, oligoclase and mafics, with errors not significantly greater than the counting error.

He estimated that at the 95% confidence level, the composition of this rock, using data from the six faces of a cube with a 4.5 cm. edge, could be stated to be :

Orthoclase	56.0% ± 2.27%
Oligoclase	30.5% ± 2.11%
Mafics	13.5% ± 1.57%

Leaf 106 - 111 omitted in page numbering.

66-KC-25-2-E

Macro-mode of sub-solvus syenite from Blank Lake

Analyses done on a block (4.5 cm.)^3. Point interval -2 mm.

SET	FACE	ORTHOCLASE(Pts./%)	OLIGOCLASE(PTS./%)	MAFICS(Pts/%)	
I	1	296	148	63	507
		58.5%	29.2%	12.4$	100.1%
	2	302	156	69	527
		57.3%	29.6%	13.1%	100.0%
II	1	276	179	74	529
		52.2%	33.9%	14.0%	100.1%
	2	294	154	81	529
		55.6%	29.2%	15.3%	100.1%
III	1	308	161	60	529
		58.2%	30.4%	11.4%	100.0%
	2	289	161	79	529
		54.7%	30.5%	14.9%	100.1%
TOTAL		1765	959	426	3150
Av.%		56%	31.5%	13.5%	100.0%

Percentages calculated with slide rule --- 0.2%

APPENDIX IV

NORM CALCULATIONS

NEPHELINE-OLIVINE GABBRO

TOTAL CHEMICAL ANALYSES SAMPLE 66-KC-23-4-F

QUARTZ	0.00
ORTHOCLASE	5.44
ALBITE	13.35
LEUCITE	0.00
NEPHELINE	12.65
ANORTHITE	25.27
CORUNDUM	0.00
ACMITE	0.00
CACPX	14.89
MGCPX	8.99
FECPX	5.02
ENSTATITE	0.00
FERROSILITE	0.00
FORSTERITE	3.61
FAYALITE	2.23
WOLLASTONITE	0.00
MAGNETITE	3.29
HAEMETITE	0.00
ILMENITE	0.68
RUTILE	0.00
CHROMITE	0.00
APATITE	0.00
CALCITE	3.48
TOTAL NORMATIVE MINERALS	98.91
TOTAL WEIGHT OXIDES	98.85

WEIGHT PERCENT ANORTHITE IN PLACIOCLASE 65.44

WEIGHT PERCENT CLINOPYROXENE 28.91
COMPOSITION OF CPX WO 51.52 EN 31.10 FS 17.38

WEIGHT PERCENT ORTHOPYROXENE 0.00
COMPOSITION OF OPX FS 0.00

WEIGHT PERCENT OLIVINE 5.84
COMPOSITION OF OLIVINE IN WEIGHT PERCENT FA 38.12

COLOUR INDEX 39.15

TOTAL CHEMICAL ANALYSES SAMPLE 66-KC-25-2-E

AEGIRINE-HASTINGSITE-SYENITE

QUARTZ	0.00
ORTHOCLASE	32.39
ALBITE	41.94
LEUCITE	0.00
NEPHELINE	1.02
ANORTHITE	14.47
CORUNDUM	1.04
ACMITE	0.00
CACPX	0.00
MGCPX	0.00
FECPX	0.00
ENSTATITE	0.00
FERROSILITE	0.00
FORSTERITE	1.87
FAYALITE	3.79
WOLLASTONITE	0.00
MAGNETITE	1.91
HAEMETITE	0.00
ILMENITE	0.68
RUTILE	0.00
CHROMITE	0.00
APATITE	0.00
CALCITE	0.68

TOTAL NORMATIVE MINERALS 99.80

TOTAL WEIGHT OXIDES 99.80

WEIGHT PERCENT ANORTHITE IN PLAGIOCLASE 25.66

WEIGHT PERCENT CLINOPYROXENE 0.00
COMPOSITION OF CPX WO 0.00 EN 0.00 FS 0.00

WEIGHT PERCENT ORTHOPYROXENE 0.00
COMPOSITION OF OPX FS 0.00

WEIGHT PERCENT OLIVINE 5.66
COMPOSITION OF OLIVINE IN WEIGHT PERCENT FA 66.99

COLOUR INDEX 9.32

TOTAL CHEMICAL ANALYSES SAMPLE 66-KC-1-16-H

AEGIRINE-HASTINGSITE-SYENITE

QUARTZ	0.00
ORTHOCLASE	30.49
ALBITE	39.98
LEUCITE	0.00
NEPHELINE	5.38
ANORTHITE	11.20
CORUNDUM	0.00
ACMITE	0.00
CACPX	1.30
MGCPX	0.68
FECPX	0.57
ENSTATITE	0.00
FERROSILITE	0.00
FORSTERITE	3.17
FAYALITE	2.93
WOLLASTONITE	0.00
MAGNETITE	1.96
HAEMETITE	0.00
ILMENITE	1.03
RUTILE	0.01
CHROMITE	0.00
APATITE	0.00
CALCITE	0.23

TOTAL NORMATIVE MINERALS 98.92

TOTAL WEIGHT OXIDES 98.92

WEIGHT PERCENT ANORTHITE IN PLAGIOCLASE 21.89

WEIGHT PERCENT CLINOPYROXENE 2.56
COMPOSITION OF CPX WO 50.87 EN 26.72 FS 22.41

WEIGHT PERCENT ORTHOPYROXENE 0.00
COMPOSITION OF OPX FS 0.00

WEIGHT PERCENT OLIVINE 6.10
COMPOSITION OF OLIVINE IN WEIGHT PERCENT FA 48.03

COLOUR INDEX 11.77

TOTAL CHEMICAL ANALYSES SAMPLE 66-KC-31-4-E

OLIVINE-NEPHELINE-SYENITE

QUARTZ	0.00
ORTHOCLASE	33.80
ALBITE	36.80
LEUCITE	0.00
NEPHELINE	6.37
ANORTHITE	8.90
CORUNDUM	0.00
ACMITE	0.00
CACPX	2.14
MGCPX	0.70
FECPX	1.51
ENSTATITE	0.00
FERROSILITE	0.00
FORSTERITE	1.38
FAYALITE	3.31
WOLLASTONITE	0.00
MAGNETITE	2.32
HAEMETITE	0.00
ILMENITE	0.44
RUTILE	0.00
CHROMITE	0.00
APATITE	0.00
CALCITE	1.20

TOTAL NORMATIVE MINERALS 98.87

TOTAL WEIGHT OXIDES 98.87

WEIGHT PERCENT ANORTHITE IN PLAGIOCLASE 19.48

WEIGHT PERCENT CLINOPYROXENE 4.35
COMPOSITION OF CPX WO 49.29 EN 15.98 FS 34.73

WEIGHT PERCENT ORTHOPYROXENE 0.00
COMPOSITION OPX FS 0.00

WEIGHT PERCENT OLIVINE 4.69
COMPOSITION OF OLIVINE IN WEIGHT PERCENT FA 70.55

COLOUR INDEX 11.93

END-OF-DATA ENCOUNTERED ON SYSTEM INPUT FILE.

TOTAL CHEMICAL ANALYSES SAMPLE 66-KC-25-8-E

OLIVINE-NEPHELINE-SYENITE

QUARTZ	0.00
ORTHOCLASE	30.49
ALBITE	24.53
LEUCITE	0.00
NEPHELINE	10.31
ANORTHITE	7.47
COLUNDUM	0.00
ACMITE	0.00
CACPX	6.69
MGCPX	1.97
FECPX	4.97
ENSTATITE	0.00
FERROSILITE	0.00
FORSTERITE	1.53
FAYALITE	4.25
WOLLASTONITE	0.00
MAGNETITE	3.74
HAEMETITE	0.00
ILMENITE	1.60
RUTILE	0.01
CHROMITE	0.00
APATITE	0.00
CALCITE	0.23
TOTAL NORMATIVE MINERALS	97.80
TOTAL WEIGHT OXIDES	97.77

WEIGHT PERCENT ANORTHITE IN PLAGIOCLASE 23.35

WEIGHT PERCENT CLINOPYROXENE 13.64
COMPOSITION OF CPX WO 49.07 EN 14.48 FS 36.46

WEIGHT PERCENT ORTHOPYROXENE 0.00
COMPOSITION OF OPX FS 0.00

WEIGHT PERCENT OLIVINE 5.78
COMPOSITION OF OLIVINE IN WEIGHT PERCENT FA 73.52

COLOUR INDEX 25.32

TOTAL CHEMICAL ANALYSES SAMPLE 66-KC-12-128

NEPHELINE-SYENITE

QUARTZ	0.00
ORTHOCLASE	43.32
ALBITE	21.09
LEUCITE	0.00
NEPHELINE	18.45
ANORTHITE	6.65
CORUNDUM	1.10
ACMITE	0.00
CACPX	0.00
MGCPX	0.00
FECPX	0.00
ENSTATITE	0.00
FERROSILITE	0.00
FORSTERITE	2.88
FAYALITE	3.87
WOLLASTONITE	0.00
MAGNETITE	1.86
HAEMETITE	0.00
ILMENITE	0.40
RUTILE	0.00
CHROMITE	0.00
APATITE	0.00
CALCITE	0.91
TOTAL NORMATIVE MINERALS	100.52
TOTAL WEIGHT OXIDES	100.53

WEIGHT PERCENT ANORTHITE IN PLAGIOCLASE 23.97

WEIGHT PERCENT CLINOPYROXENE 0.00
COMPOSITION OF CPX WO 0.00 EN 0.00 FS 0.00

WEIGHT PERCENT ORTHOPYROXENE 0.00
COMPOSITION OF OPX FS 0.00

WEIGHT PERCENT OLIVINE 6.74
COMPOSITION OF OLIVINE IN WEIGHT PERCENT FA 57.31

COLOUR INDEX 10.05

TOTAL CHEMICAL ANALYSES SAMPLE 66-KC-35-2-B

NEPHELINE SYENITE

QUARTZ	0.00
ORTHOCLASE	35.87
ALBITE	28.02
LEUCITE	0.00
NEPHELINE	12.36
ANORTHITE	10.40
CORUNDUM	0.33
ACMITE	0.00
CACPX	0.00
MGCPX	0.00
FECPX	0.00
ENSTATITE	0.00
FERROSILITE	0.00
FORSTERITE	0.99
FAYALITE	3.59
WOLLASTONITE	0.00
MAGNETITE	4.70
HAEMETITE	0.00
ILMENITE	0.53
RUTILE	0.00
CHROMITE	0.00
APATITE	0.00
CALCITE	1.43
TOTAL NORMATIVE MINERALS	98.23
TOTAL WEIGHT OXIDES	98.24

WEIGHT PERCENT ANORTHITE IN PLAGIOCLASE 27.08

WEIGHT PERCENT CLINOPYROXENE 0.00
COMPOSITION OF CPX WO 0.00 EN 0.00 FS 0.00

WEIGHT PERCENT ORTHOPYROXENE 0.00
COMPOSITION OF OPX FS 0.00

WEIGHT PERCENT OLIVINE 4.58
COMPOSITION OF OLIVINE IN WEIGHT PERCENT FA 78.30

COLOUR INDEX 10.33

TOTAL CHEMICAL ANALYSES SAMPLE 66-KC-25-5-B

LAMPROPHYRE

QUARTZ	0.00
ORTHOCLASE	22.56
ALBITE	0.00
LEUCITE	2.19
NEPHELINE	8.98
ANORTHITE	17.27
CORUNDUM	0.00
ACMITE	0.00
CACPX	7.24
MGCPX	4.25
FECPX	2.60
ENSTATITE	0.00
FERROSILITE	0.00
FORSTERITE	9.86
FAYALITE	6.64
WOLLASTONITE	0.00
MAGNETITE	6.28
HAEMETITE	0.00
ILMENITE	1.46
RUTILE	0.01
CHROMITE	0.00
APATITE	0.00
CALCITE	6.14
TOTAL NORMATIVE MINERALS	95.48
TOTAL WEIGHT OXIDES	95.45

WEIGHT PERCENT ANORTHITE IN PLAGIOCLASE 100.00

WEIGHT PERCENT CLINOPYROXENE 14.09
COMPOSITION OF CPX WO 51.38 EN 31.18 FS 18.44

WEIGHT PERCENT ORTHOPYROXENE 0.00
COMPOSITION OF OPX FS 0.00

WEIGHT PERCENT OLIVINE 16.51
COMPOSITION OF OLIVINE IN WEIGHT PERCENT FA 40.25

COLOUR INDEX 40.16

APPENDIX V

COLLECTED CHEMICAL ANALYSES

TABLE 13

CHEMICAL ANALYSES: KILLALA LAKE IGNEOUS COMPLEX

	OLIVINE GABBRO		CENTRAL SYENITE		OLIVINE-NEPHELINE SYENITE		NEPHELINE SYENITE		LAMPROPHYRE	
Sample	-35-3D	-23-4F	-25-2E	-1-16H	66-KC -25-8E	-31-4E	-35-2B	-12-128B	-25-5B	-35-1-G
SiO_2	33.1	46.5	58.4	57.9	53.0	57.5	53.7	55.6	40.7	41.7
Al_2O_3	14.2	17.4	20.8	19.4	16.8	18.9	20.6	22.2	14.2	13.2
Fe_2O_3	11.8	2.27	1.32	1.35	2.58	1.60	3.24	1.28	4.33	5.35
FeO	14.8	5.52	3.45	3.34	7.37	3.93	3.93	3.31	8.48	8.95
MgO	6.14	5.68	1.07	2.09	1.67	1.07	0.57	1.65	7.36	9.06
CaO	11.6	14.2	3.30	3.01	4.85	3.50	2.90	1.85	10.4	12.20
Na_2O	1.57	4.34	5.18	5.90	5.15	5.74	6.01	6.52	1.96	2.76
K_2O	2.54	0.92	5.48	5.16	5.16	5.72	6.07	7.33	4.29	1.47
H_2O+	0.54	0.11	0.33	0.57	0.37	0.56	0.91	0.46	3.16	0.89
H_2O-	0.10	0.44	0.11	0.22	0.10	0.14	0.23	0.12	0.40	0.16
CO_2	0.15	1.53	0.30	0.10	0.10	0.53	0.63	0.40	2.70	0.93
TiO_2	2.86	0.36	0.36	0.54	.84	0.23	0.28	0.21	0.77	1.53
S	0.28	0.02	0.01	0.01	0.06	0.02	0.01	0.02	0.10	.08
MnO	0.21	0.13	0.14	0.13	0.25	0.15	0.31	0.18	0.26	.27
Total	99.9	99.4	100.3	99.7	98.3	99.6	99.4	101.8	99.1	98.55

Note: These analyses with their respective sample locations have been tabulated separately and appear within the text accompanying the descriptions of the related units.

Analyst: D.A. Moddle

TABLE 14

CHEMICAL ANALYSES: VOLATILE CONSTITUENTS DELETED

	OLIVINE GABBRO		CENTRAL SYENITE		OLIVINE-NEPHELINE SYENITE		NEPHELINE SYENITE		LAMPROPHYRE	
Sample	66-KC--35-3D	-23-2E	-25-2E	-1-16H	-25-8E	-31-4E	-35-2B	-12-128B	-25-5B	35-1-G
SiO_2	33.51	47.79	58.76	58.61	54.19	58.42	55.05	55.52	43.89	43.24
Al_2O_3	14.37	17.88	20.88	19.64	17.19	19.18	21.12	22.17	15.31	13.69
Fe_2O_3	11.95	2.33	1.32	1.36	2.63	1.62	3.31	1.28	4.66	5.54
FeO	14.93	5.68	3.46	3.37	7.53	3.99	4.02	3.31	9.15	9.27
MgO	6.21	5.84	1.07	2.11	1.70	1.08	.48	1.65	7.93	9.38
CaO	11.73	14.60	3.31	3.04	4.95	3.55	2.97	1.85	11.22	12.65
Na_2O	1.58	4.45	5.20	5.98	5.26	5.83	6.15	6.51	2.11	2.86
K_2O	2.57	0.94	5.50	5.22	5.27	5.81	6.21	7.32	4.62	1.52
TiO_2	2.89	0.36	0.36	0.54	.85	0.23	0.28	0.21	0.83	1.58
MnO	.21	0.13	0.14	0.13	.25	0.15	0.31	0.18	0.28	0.27
U.C.T. *	98.82	97.32	99.5	98.82	97.83	98.34	97.61	100.13	92.75	96.49
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* Uncorrected component-totals - Components are expressed as percentages of the total oxides remaining after volatile constituents were deleted. These data are represented in Figures 6 and 7. See Table 13 for original analytical weight percentages.

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