NEPHELINE METAGABBRO AND ASSOCIATED HYBRID ROCKS FROM MONMOUTH TOWNSHIP, ONTARIO

By

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ABSTRACT

A petrographic study has been made of the contact relations between metagabbro and nepheline gneiss underlain by marble, in Monmouth township, Haliburton County, Ontario.

A band of hornblende-nepheline-garnet gneiss about 80 feet wide trending north-south is underlain at a shear contact by marble. Round inclusions up to 18 inches across of red pyroxene with some spinel and rimmed by olivine occur in the marble a few feet below the contact. For a few inches above the contact the nepheline gneiss sometimes is biotite-bearing. To the east the nepheline gneiss grades into a band of hybrid nepheline metagabbro (containing pink augite) about 50 feet wide. This in turn is followed by a zone of garnetiferous clinozoisite metagabbro about 220 feet wide. Clinozoisite persists in the metagabbro for 100 feet beyond this zone and is followed by hornblende-(pyroxene)-plagioclase metagabbro. Pyroxene-garnet-(nepheline) skarn is interlayered with nepheline gneiss at one outcrop near the fault contact with marble.

It appears that gabbroic magma has intruded limestone and developed a skarn at the contact. Assimilation of lime by the magma has developed pink augite (titanaugite ?), clinozoisite and grossularite in the gabbro. Subsequent injection of a highly fluid nepheline magma, or of solutions containing soda, alumina and iron and not saturated with silica, formed nepheline-bearing rock between marble and gabbro. Soda metasomatism produced a hybrid nepheline gabbro adjacent to the nepheline-bearing rock. Regional metamorphism later imparted a foliation to the marble and nepheline rock, and produced a metamorphic texture in the gabbro. Faulting of an unknown age brought nepheline gneiss and marble into sharp contact and probably trapped the skarn as horses only one of which is now exposed.

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INTRODUCTION

Monmouth township in Haliburton County is approximately one hundred miles northeast of Toronto, in the Province of Ontario, and comprises about ninety square miles. Most of the population of the township is centred about the communities of Essonville, Tory Hill and Wilberforce (Fig. 1). Good motor roads lead into Essonville and Tory Hill from Haliburton and into Tory Hill and Wilberforce from Kinmount. A number of earth roads are passable by motor vehicle and provide access to most of the township. Old lumber roads, some of which date from the early part of the century, can be seen from the air and can generally be followed on foot without difficulty and occasionally by four-wheel drive vehicle. In addition, the Canadian National Railways line from Kinmount to Bancroft passes through Tory Hill and Wilberforce.

The township is entirely within the Grenville province of the Precambrian Shield. Geologically it is one of the most complex townships on the map accompanying the report of Adams and Barlow (1910). Theirs is the only previous work in the area with the exception of rather localized investigations (Foye, 1915, 1916; Kinser, 1937; Goldich, 1939; Satterly, 1943; Hewitt, 1946). During 1955 and 1956 the township was mapped by Armstrong and the writer at a scale of four inches to one mile, for the Ontario Department of Mines; this constitutes the most detailed investigation so far undertaken and has afforded the opportunity of studying certain of the geological features of the area in some detail. For the past year or two an accelerated exploration programme has been


HALIBURTON
HIGHLANDS
Rosseau
Huntsville
60
11
Baysville
35
Bracebridge
69
Gravenhurst
Haliburton
Essonville
Wilberforce
45°
Tory Hill
Minden
Gooderham
28
Miners Bay
Kinmount
Union Creek
KAWARTHA LAKES
12
Orillia
46
36
Bobcaygeon
Fenelon Falls
LAKE
SIMCOE
48
Lindsay
7
Peterborough
7A
Rice
Uxbridge
115
47
Aurora
400
Stouffville
2
Port Hope
44°
45
Oshawa
401
Toronto
79°30′
79°
78°30′
Index Map
Scale: 1 inch to 14 miles
Monmouth Township

directed by a number of mining companies toward the occurrences, within the township, of radioactive minerals. Although most of this work is unpublished much of it has been available to the Ontario Department of Mines and has contributed to the geological mapping of the township.

Two common rock types in Monmouth township are metagabbro and nepheline-bearing gneiss. It has generally been assumed that the nepheline gneiss is younger than the metagabbro (Foye, 1916, pp. 662, 679; Hewitt, 1954, p. 11, 1955, p. 7) but exposures of the two rock types in contact are rare. This thesis is a petrographic study of one such exposure of which a map has been prepared at a scale of 1 inch to 100 feet, (Fig. 14) in Lots 2, 3, Con. III, Monmouth township. The rocks are exposed along and to the north of a low ridge about thirty feet high which is bounded on the east, west and south by swampy ground. An old lumber road follows the ridge and leads to a driveable road from Gooderham. Thus the area is accessible on foot at all times of year. In reasonably dry weather, depending on the state of several pole-bridges, a four-wheel drive vehicle can reach the outcrops. For the past fifty years the road has been used intermittently for lumbering and prospecting activities. Largely as a result of rain-wash following a succession of forest fires the outcrops are fairly well exposed in mixed deciduous and coniferous forest, although in one or two places trenching and blasting have been necessary to obtain unweathered material from critical localities.

The nepheline gneisses were described briefly by Adams and Barlow (1910, p. 282) but no mention is made of the metagabbro. Few other exposures of metagabbro in contact with nepheline-bearing rock are recorded within the Grenville province. One of these is in Carlow township (Hewitt, 1955, p. 17); another is in Glamorgan township in the woods north of Trooper's Lake. In addition, Harrison (1953, p. 33) has reported that, " ... approximately one quarter of a mile south of the Pusey mine a dark, olive-green gabbro occurs not more than 200 feet from a large mass of nepheline syenite." Further gabbro - nepheline syenite occurrences from outside the Grenville province have been reported from Port Coldwell, Ontario, by Kerr (1910, p. 225) and briefly described by Thompson (1932, pp. 57-62), and from Salem Neck, Essex County, Mass. by Clapp (1921, pp. 92, 124).

The present investigation is of a preliminary nature. It is proposed to carry out a more detailed investigation during the next two years (1956-58) at the University of Cambridge.

GENERAL GEOLOGICAL SETTING

Monmouth Township

The wide variety of rock types in the township can be grouped under the general headings: pegmatite, granite and syenite, nepheline gneiss and nepheline pegmatite, basic intrusive and meta-intrusive rocks, and the Grenville metasediments. The metasedimentary rocks are generally considered to be the oldest and have been extensively metamorphosed. They can be divided into three general groups: marble, quartzite and paragneiss.

Marble. - The least-silicated type of marble encountered is white, medium to coarsely crystalline with accessory graphite and phlogopite. Types containing diopside, tremolite, actinolite, biotite, chondrodite, quartz, feldspar or pyrite in various amounts are abundant. All variations are found between carbonate rocks and calc-silicate rocks. The widespread occurrence of phlogopite and diopside does not seem to be related to metasomatism by intrusive bodies but rather suggests metamorphism of the constituents of the original limestone. Calcareous and siliceous diopside rocks are sometimes found interbedded with thin layers of quartzite suggesting an original limestone and quartz-sandstone sedimentary sequence.

The marbles are cut by feldspar-quartz pegmatites.* Sometimes there is a narrow selvage of diopside at the border of the pegmatite but

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*Mineral names are listed in decreasing order of abundance.

frequently the contact is sharp without any evidence of reaction. Irregular, broken and sometimes drag-folded bands of pegmatite are not uncommon in the marble. The marble in many places has yielded by flowage.

Quartzite. - Quartzite is common in Monmouth township but does not occur in the immediate area of this study. It is a medium to coarse-grained ($\frac{1}{2}$ to 5 mm.) rock often containing up to 30 per cent green diopside. A rude foliation in bands a few inches to a few feet thick generally is present and is probably relic bedding.

Paragneiss. - The commonest paragneisses are well-laminated, dark-coloured, hornblende-plagioclase, biotite-plagioclase, and hornblende-biotite-plagioclase gneisses. Scapolite is usually present and may completely substitute for feldspar. The mafic content varies considerably but generally exceeds 50 per cent, and true amphibolites are not uncommon. In addition there are quartzo-feldspathic gneisses and dark-coloured, siliceous pyroxene-bearing gneisses.

The paragneisses mostly reached equilibrium in the amphibolite facies of metamorphism but occasional grains of epidote indicate the epidote-amphibolite facies, as a result of either lower-grade metamorphism or diaphthoresis.

Basic Intrusive and Meta-intrusive Igneous Rocks. Gabbroic rocks which have not suffered some recrystallization are rare but metagabbro (including metadiorite and metapyroxenite) is not uncommon in the Grenville of southeastern Ontario (Adams and Barlow, 1910; Hewitt, 1954, 1955). Several square miles of Glamorgan and Monmouth townships are underlain by metagabbro. Occurrences in Glamorgan were described by Harrison (1953) and those from the immediate vicinity of the present study are described later.

Nepheline-bearing Group. - Nepheline-bearing rocks are common in Monmouth township, generally occurring as bands of grey gneiss varying from fifty to several hundred feet wide, and also as pegmatites.

The gneisses are conformable with the enclosing country rocks. There are two main groups, characterized by the presence of biotite or of hornblende. Plagioclase and scapolite usually are essential constituents; garnet or pyroxene may be present. The nepheline content varies from less than 10 per cent to as high as 80 per cent but seldom exceeds 30 per cent; it varies markedly across the strike of the gneisses. Nepheline may be either fresh with characteristic blue-grey weathered surface, or it may have been changed to a number of variously coloured alteration products known in the field as gieseckite and hydronephelite.

Nepheline-albite pegmatites are characterized by extremely large grain size: nepheline individuals up to three feet across have been recorded. Pegmatite stringers a few inches wide cut the nepheline gneisses both conformably and disconformably.

Intrusion of syenite, granite, and granitic pegmatite has resulted in extensive metasomatism which has formed a grey peristerite syenite from the nepheline gneiss. Porphyroblasts of white and pink feldspar are commonly present. This feldspathization has been extensive and it is apparent that the nepheline-bearing rocks were far more abundant at one time than they are now. The feldspathization also may account for the variation between nepheline-rich and nepheline-poor gneisses.

Granite and Syenite. - These rocks are divisible into the granitic and syenitic gneisses which generally are rather large bodies, and the massive fresh granites which usually are small well-defined bodies.

Granitic gneisses are the most abundant but syenitic varieties are ubiquitous, so that at any one outcrop of granitic gneiss it is almost always possible to find associated syenitic gneiss. Biotite and hornblende are the two commonest mafic minerals; one is usually present to the exclusion of the other. Grain size ranges from medium to coarse. These large bodies of gneiss are bordered by migmatitic paragneisses with which they are conformable. In almost every case the origin of these granitic complexes is uncertain. Some small granite bodies, usually less than one square mile in area, differ in that they are quite massive. They have well-defined borders, in some cases with a development of endomorphic and exomorphic contact zones. They are fine to medium-grained with a low mafic content and appear to be younger than the granitic gneisses.

Pegmatite. - Feldspar-quartz pegmatites are extremely abundant. Two types are present: a white feldspar-quartz pegmatite and a much commoner pink feldspar-quartz pegmatite. Their width varies from less than one half inch to several hundred feet. The larger bodies are conformable with the enclosing rocks and typically show pinch-and-swell structure in outcrop as well as in depth. The smaller pegmatites commonly show ptygmatic folding and are particularly common in areas of granitic gneisses. Zoning is not a common feature of the pegmatites. In many places they have had no discernible effect on the enclosing rocks but where the host rock is metagabbro or hornblende-plagioclase gneiss, potash metasomatism has resulted in extensive feldspathization. The great abundance of granitic pegmatite poses a problem of considerable interest.

Immediate Area of Study
(Lots 2, 3, Con. III,
Monmouth Township)

The location of this study has already been described briefly (p. 2).

Marble outcrops on the west side of the ridge and is overlain by a belt of nepheline gneiss approximately 800 feet long and 80 feet in outcrop width. Both nepheline gneiss and marble strike northerly and dip easterly at a fairly high angle. The undulent fluted contact is exposed along the west-facing slope, and the presence of associated grey mylonitized marble suggests that this is probably a shear contact. Skarn is present at the contact at one locality where it occurs in a few small outcrops. The nepheline gneiss is well-foliated near its contact with the marble but becomes progressively more massive toward the metagabbro and finally passes gradationally into a hybrid zone of nepheline metagabbro about 80 feet wide. These hybrid rocks are bounded on the east by garnet and clinozoisite-bearing metagabbro. Garnet occurs eastward from the nepheline metagabbro for about 220 feet; clinozoisite overlaps this zone and continues 100 feet farther in the metagabbro.

PETROGRAPHY

The Nepheline Gneisses

There are two varieties of nepheline gneiss: biotite-bearing nepheline-plagioclase-garnet gneiss and hornblende-bearing nepheline-plogioclase-garnet gneiss.

The biotite-bearing gneiss is light coloured (colour index 10 - 20); on the weathered surface the nepheline is a pale grey; and scattered through the rock at one outcrop are red-brown, euhedral to subhedral garnets up to 5 mm. across. It is well-foliated and breaks into slabs 2 to 3 inches thick. Biotite-bearing gneiss is restricted to a layer a few inches to a few feet thick which overlies and is in contact with the marble. It grades in a short distance into hornblende-bearing gneiss. The biotite-bearing gneiss generally contains altered, waxy-white nepheline, but there are occasional seams of fresh material.

Biotite-bearing gneiss (with a little hornblende) also occurs as lenses about 3 feet long and 10 inches thick, completely enclosed in marble.

The hornblende-bearing rock is foliated in outcrop but is seldom fissile in hand specimen. The mafic content varies but is usually fairly high (colour index 50 to 80). Alternation of nepheline-rich bands with dark, mafic bands, gives a variable appearance to the rock. Irregular grains of hornblende up to one inch across stand out as knobs on the weathered surface.

A pegmatitic variety is exposed on a cliff face on the west side of the ridge. It consists of black hornblende up to 3 inches across, with interstitial, fresh, glassy, anhedral to subhedral nepheline grains. The rock grades into a medium-grained, massive variety, and appears to be an irregular patch rather than a well-defined body.

Mineralogy. - The essential minerals are nepheline, plagioclase, hornblende, biotite, garnet and scapolite with accessory sphene, microcline, carbonate, zircon, apatite, sulphides, pyroxene and graphite.

Nepheline generally occurs as large, irregularly-shaped grains which may be fresh or completely altered. Tiny inclusions of plagioclase, hornblende and pyroxene are common. Alteration to a fine-grained, micaceous material has begun along fractures and frequently has consumed the entire grain, but "islands" of recognizable nepheline may remain. The result is a felted, micaceous aggregate with fairly high birefringence.

Weathered nepheline usually presents a surface varying in colour from a pale grey to a bluish grey occasionally tinted with a delicate shade of pink; a fine tracery of whitish veinlets is commonly present. With some experience nepheline can be identified fairly easily on a fresh surface, where it possesses a characteristic lustre and greenish or brownish colour, but it is sometimes almost impossible to distinguish nepheline from scapolite. If it is highly altered it is more readily identified on the fresh than on the weathered surface, but this requires a familiarity with the many alteration products of nepheline. Only one variety of altered nepheline is found in the area of this study. It has a blue-grey weathered surface but the fresh material is opaque, waxy white.

Plagioclase is the dominant feldspar but a little microcline and a few grains of microperthite are present in the biotite-bearing gneiss.

Plagioclase forms fresh, discrete, polysynthetically twinned grains. It is usually albitic (An_{10-15})* but is more calcic (An_{45-50}) in the biotite-bearing variety where it forms larger, more highly twinned grains. Zoning is expressed by uneven extinction of grains but has no symmetrical or regular disposition. Even where nepheline is completely altered the feldspar has remained fresh.

Black hornblende grains up to 2 cm. across are seen in hand specimen and have the following optical properties: X yellow brown, Y deep brownish green, Z blue green; $Z > Y > X$ $-2V$ small; $Z \wedge c = 10^{\circ}$; imperfect extinction; moderate dispersion. This is close to ferrohastingsite. (Billings, 1928).

Pale green, non-pleochroic pyroxene in small, fresh, discrete grains occurs as a minor constituent; it has $+2v$ small and is probably a hedenbergite.

The biotite is probably a phlogopite but resembles biotite in hand specimen and has been so called to avoid confusion with the pale phlogopite of the marble. It forms elongate grains with X pale straw (almost colourless), Y, Z light brown; $X < Y \leqslant Z$. It is quite fresh.

The garnet is red-brown in hand specimen and seems to be most abundant in the more mafic parts of the gneisses. In thin section it is pale pink, and parts of some grains are anisotropic. It appears to be a grossularite (refractive index 1.79).

Scapolite, varying in amount and grain size, is present in all the nepheline gneisses and shows no evidence of alteration.

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*All plagioclase determinations were made by universal-stage measurements, using Rittman's method.

Texture. - Nepheline appears to have partly replaced plagioclase. It always forms large, irregularly shaped grains which, when altered, have crenulate borders and may penetrate plagioclase grains. Elongate flakes of biotite are aligned and are interstitial to the coarse plagioclase grains. Small grains of pyroxene are generally associated with larger hornblende grains but there is no evidence that hornblende formed from pyroxene. Garnet is idioblastic to all other minerals and commonly forms porphyroblasts containing numerous tiny inclusions of the other minerals of the rock. In one exposure of biotite-bearing gneiss, biotite surrounds garnet grains in "bird's eye" structure.

Nepheline-bearing Metagabbro*

Between the nepheline gneiss and the metagabbro occurs a 50 foot zone of nepheline-bearing metagabbro. The rock consists essentially of nepheline, augite, garnet, scapolite and plagioclase with accessory apatite, spinel, sulphides, carbonate, sphene and zircon. Nepheline-rich metagabbro can not be distinguished in hand specimen from nepheline-hornblende gneiss. It is coarse-grained, crumbly weathering and studded with hornblende grains up to 1 cm. in diameter in a matrix of blue-grey nepheline. On the western side of the zone this rock merges insensibly into nepheline gneiss; on the east it passes into clinozoisite-garnet metagabbro by decrease of the nepheline content. It is devoid of foliation.

Mineralogy. - Nepheline in the metagabbro immediately adjacent to the nepheline gneiss is fresh except for slight alteration along fractures,

*Modes of the nepheline metagabbros and metagabbros were determined by point counter and are listed in the Appendix with brief petrographic descriptions of the slides.

but within a few feet of the contact it becomes completely altered and continues in that state across the full width of the zone.

The characteristic mineral is pink augite. The fresh material has the following optical properties: +2V medium (about 50°); X greenish pink, Y clear pink (reddish), Z pink; high dispersion $r < v$; low birefringence. Alteration varies from partial to complete uralitization, the latter accompanied by a corona of hornblende and oligoclase. The presence of oligoclase rather than quartz is somewhat unusual. In partly altered aggregates the pyroxene is non-pleochroic and pale green and is seamed with veinlets of fibrous, dark-green hornblende. Toward the east side of the zone garnet appears as tiny blebs in the pyroxene.

Garnet occurs principally as coronas of finely granular aggregates around fresh or altered nepheline, and occasionally around carbonate grains. In some specimens every grain of nepheline is encircled by pink, generally isotropic, garnet.

Scapolite forms smaller grains than in the nepheline gneisses. Generally it has haphazard distribution but occasionally forms coronas about nepheline grains.

Plagioclase is not abundant; there are a few large, twinned labradorite (An_{60-65}) grains but the remaining plagioclase is oligoclase, occurring as tiny, fresh, untwinned grains in the hornblende coronas.

The rocks adjacent to the nepheline gneiss contain about 4 per cent apatite but this amount diminishes rapidly toward the metagabbro. The spinel is very minor in amount and is green in thin section.

<u>Texture</u>. - The nepheline-bearing metagabbro is characterized by an extreme variability in the grain size of its constituent minerals.

Large, ragged, partly uralitized pyroxene grains are in sharp contrast with clusters of tiny plagioclase grains and sieve-like coronas and aggregates of hornblende and oligoclase. The hornblende coronas first appear as narrow rims completely encircling fresh, pink augite. Eastward across the zone these coronas increase in width until all that remains of the original pyroxene is a small core of fibrous, green amphibole distinguishable from the corona by a difference in interference colours. In the wider coronas small interstitial grains of plagioclase and scapolite are common. Garnet first appears as narrow, continuous rims on nepheline and carbonate grains, gradually increasing in size to coronas composed of granular aggregates.

Metagabbro

The metagabbros mostly are massive rocks forming rounded outcrops, but in the finer-grained varieties a slight foliation can sometimes be discerned. They are very dark green to black in colour, tough, hard, and generally break into roughly triangular blocks bounded by joint surfaces.

Four varieties can be distinguished:

a) a fine-grained ($<$ 1 mm.), slightly foliated, melanocratic rock composed largely of acicular prisms or needles of lustrous black hornblende, with interstitial plagioclase and scapolite; it is probably a metamorphosed microgabbro;

b) a fine-grained ($<$ 1 mm.) massive, melanocratic hornblendite composed almost entirely of black hornblende; it often shows exfoliation weathering in outcrop;

c) a medium-grained (1 to 5 mm.), mesocratic metagabbro composed of 60 to 70 per cent hornblende (partly derived from pyroxene), and 30 to 40 per cent plagioclase and scapolite ;

d) a coarse-grained (5 to 50 mm.) melanocractic, metamorphosed pyroxenite composed almost entirely of pyroxene.

Although the composition of the plagioclase (An_{60-67}) is in the range for gabbro, the content is generally low. Some representative modes are given in Appendix I. The metagabbros contain pyroxene, hornblende, plagioclase and scapolite, with accessory titanite, biotite, and tourmaline. In the metagabbro adjacent to the nepheline-bearing zone, two other minerals, garnet and clinozoisite, assume essential proportions and form two well-defined zones. (Fig. 14).

Mineralogy. - The pyroxene is a pale green, non-pleochroic variety which is generally uralitized and contains irregularly shaped patches of hornblende and tiny grains of garnet. The garnet inclusions become less abundant to the east, the last appearing about 220 feet from the nepheline-bearing metagabbro.

Two varieties of hornblende are distinguished by their pleochroism.- One has X medium green, Y blue green, Z blue green; $X < Y \leqslant Z$; the other is pleochroic through shades of yellow brown and deep brown.

The plagioclase content varies from negligible in some of the metapyroxenites and hornblendites to as much as 30 or 40 per cent in the finer-grained metagabbro. Its composition changes from An_{60-65} close to the nepheline-bearing zone to An_{67}. 400 feet to the east. Some grains are zoned with cores of An_{65} grading out to An_{35} at the rim. In some of the fine-grained rocks the plagioclase forms lath-shaped grains and often contains small patches of alteration. In other types it forms ragged, twinned grains or small, untwinned, fresh grains.

Clinozoisite first appears at the eastern limit of the nepheline-bearing metagabbro and persists for about 320 feet into the metagabbro. Colourless, prismatic grains with anomalous interference colours occur singly or in clusters, and a few irregularly shaped porphyroblasts were noted. Its optical character varies from positive to negative and the extinction from parallel to inclined.

Scapolite has a similar manner of occurrence to that of previously described rocks, but some grains have suffered alteration to a material very similar to altered nepheline, rendering identification difficult.

Texture. - The texture of the metagabbro is generally equigranular-granoblastic but a few rocks are composed of large, ragged, uralitized pyroxene grains with irregular borders. Some varieties composed of clusters of small rounded hornblende and pyroxene grains bounded by broad laths of twinned plagioclase have a relic igneous texture. These presumably are remnants of the original gabbro that have escaped severe metamorphism. Garnet occurs only in the fibrous, uralitized pyroxene and never in the hornblende. In some grains it follows fractures but does not traverse the hornblende coronas. Pyroxene may be riddled with these tiny garnet grains which appear to have developed from pyroxene during its uralitization. Clinozoisite is idioblastic toward the other minerals of the rock and the grains generally are without linear orientation. There are no replacement textures to suggest its development from some other mineral.

Marble

Medium to coarsely crystalline (2 to 10 mm.), well-foliated marble underlies the nepheline gneiss conformably. Its thickness is probably about 200 feet but it is exposed for only about twenty feet below the contact. The principal constituent is calcite which is generally cream-coloured with pale grey streaks of finely disseminated graphite. Phlogopite varies in colour from a very pale straw (almost colourless) to deep amber. This latter variety is not common but is sometimes found within a few inches of the contact with nepheline gneisses. Graphite occurs as small ($\frac{1}{2}$ mm.) flakes. A little sheared, mylonitic marble is found locally at the contact. This rock is very finely crystalline with numerous streaks of grey graphite, presumably developed during shearing.

Within the marble and a few feet below the contact with nepheline gneiss are rounded inclusions up to 18 inches across composed of a red pyroxene and a small amount of spinel. They are surrounded by a rim $\frac{3}{4}$ to 2 inches wide of partly serpentinized olivine with accessory calcite, phlogopite and spinel, and have sharp borders against the marble. The pyroxene is dark, red-brown in hand specimen, resembling garnet; in thin section it is pleochroic through shades of pink, and may be a titanaugite. The spinel is green and is very similar to the spinel found in some of the nepheline-bearing metagabbro. These inclusions appear to have been rolled during flowage of the marble.

Skarn

Skarn is found interlayered with nepheline gneiss (Fig. 14) as a small outcrop which appears to have marble on each side. The skarn is a dark, fine-grained, garnet-pyroxene rock with accessory nepheline, microcline, calcite, scapolite, pyrrhotite and hornblende. Mineral proportions vary considerably over small distances. The pyroxene is a pale-green, non-pleochroic diopside or hedenbergite. The garnet is a grossularite with refractive index 1.79, and in places it is anisotropic. Dusty, cloudy alteration extends along fractures in the garnet and through some of the pyroxene grains. Nepheline when present is completely altered and in hand specimen resembles gieseckite. Some specimens of the skarn are well-foliated.

PETROGENESIS

The main problems to be considered are set out in the following paragraph.

The metagabbro consists mostly of hornblende and plagioclase with some pyroxene. The presence in it of relic igneous texture and local banding which resembles igneous stratification suggests the metagabbro is of igneous origin. Toward the nepheline gneiss it grades with increasing pyroxene content into clinozoisite-bearing metagabbro, then garnetiferous metagabbro, and finally into a hybrid nepheline metagabbro in which pink augite is prominent, apatite is relatively abundant, and coronas of hornblende and garnet are present. This hybrid zone merges to the west with a band of hornblende-nepheline gneiss containing some biotite-nepheline gneiss. The nepheline gneiss is underlain by marble at a shear contact. Skarn is interlayered with nepheline gneiss close to marble at one outcrop.

There are a number of possible hypotheses to explain these assemblages.

1) Gabbroic magma intruded limestone and solidified; subsequent introduction of nepheline magma or nepheline-forming solutions produced nepheline-bearing rock between gabbro and marble; regional metamorphism, with shearing of the marble, accompanied or followed nepheline formation.

   a) clinozoisite and garnet zones are due to hybridization of gabbro by limestone; the hybrid nepheline gabbro was developed later by contact metasomatism or assimilation of gabbro by nepheline magma or solutions;

b) clinozoisite and garnet zones are due to contact metamorphic effects of the nepheline magma or solutions on the gabbro;

c) clinozoisite and garnet zones are due to hybridization of gabbro and nepheline magma or solutions, coeval with the development of hybrid nepheline gabbro;

d) clinozoisite and garnet zones are due to regional metamorphism and unrelated to the development of hybrid nepheline gabbro.

2) Nepheline magma or solutions were emplaced against limestone; this was followed by intrusion of gabbroic magma with contemporaneous or subsequent regional metamorphism;

a) clinozoisite and garnet zones are due to hybridization of gabbroic magma with nepheline-bearing rock;

b) clinozoisite and garnet zones are due to autometamorphism in cooling gabbro and the hybrid nepheline gabbro was formed by hybridization of the magma with nepheline-bearing rock;

c) clinozoisite and garnet zones are due to regional metamorphism.

3) Gabbroic magma has intruded limestone and given rise by desilication to nepheline rocks; regional metamorphism was contemporaneous or subsequent;

a) clinozoisite and garnet zones are due to the same desilication.

b) clinozoisite and garnet zones are due to autometamorphism in the cooling gabbro, and are unrelated to desilication;

c) clinozoisite and garnet zones are due to regional metamorphism.

Many of the rocks are well-foliated, which suggests that the last major episode in the geological history of the region was regional metamorphism.

The age relations of the nepheline rocks and metagabbro are not known with certainty but Hewitt (1954, p. 17) has reported gabbro cut by nepheline pegmatite in Carlow township, and the gabbros in this part of the Grenville have generally been interpreted as older than the nepheline rocks. This suggests that the second hypothesis is unlikely. Elsewhere in the Haliburton-Bancroft district similar nepheline-bearing rocks are not associated with metagabbro. Hence the third possibility seems unlikely but it can not be discarded. The first hypothesis (1) appears to be the most tenable.

The relative abundance of apatite in the nepheline metagabbro suggests introduction of material from the nepheline gneiss, yet the presence of calcic minerals such as clinozoisite and grossularite, together with absence of albite suggest no extensive introduction of soda. If the clinozoisite had originated by simple metamorphism of the gabbro albitic feldspar should also be present. Hence 1 b, c, d do not seem likely. It is possible of course that albite has been absorbed by hornblende (Harker, 1952, pp. 282-283, referring to Lacroix, 1917) but it is doubtful if the grade of metamorphism reached here was sufficiently high. The presence of a pink augite, which presumably is a titanaugite, may indicate assimilation of lime by gabbro magma as at Scawt Hill (Tilley, 1931).

It appears that the clinozoisite, garnet and pink augite rocks are hybrids developed during the intrusion of gabbro magma into limestone, and the nepheline-bearing gabbro was formed by metasomatism or assimilation during subsequent emplacement of nepheline magma or solutions.

The coronas are probably of metamorphic origin and formed fairly late in the evolution of these rocks, as suggested by Buddington (1939, p. 297) for the metagabbros of the Adirondack region and Sutton and Watson (1951) for some of the Highland epidiorites.

The question of whether the skarns formed by reaction of nepheline magma or solutions with limestone, or gabbro magma with limestone and subsequent nephelinization, is of some importance. Skarns of similar mineralogy have developed by both reactions in the Grenville of southeastern Ontario, but this skarn contains less gieseckite than most nepheline - limestone skarns and therefore is more likely to be a nephelinized gabbro and limestone skarn. There are two possible explanations of why this skarn is not more extensive. Marble and nepheline gneiss have been brought into fault contact and during the accompanying shearing skarn may have been trapped as a series of horses not visible at the present erosion level. Alternatively skarn may have been developed only where the limestone was magnesian. It is perhaps significant that very little phlogopite is present in the marble. The presence of rolled inclusions in the marble below the fault contact supports the former explanation; the pink pyroxene and spinel assemblage are suggestive of a gabbro and limestone hybrid. Probably these inclusions are fragments of such a hybrid that have been rolled during the deformation of the marble.

The olivine layer surrounding these inclusions may have developed at the same time as the pyroxene-spinel core or during later metamorphism. These inclusions have not yet been studied in detail. The way in which the pink augite has developed is not known unless it is analogous to that of Scawt Hill.

Petrographic evidence shows that in the metagabbro, hornblende and grossularite developed from augite, and suggests that scapolite has developed at the expense of plagioclase feldspar. The reaction augite $\longrightarrow$ hornblende* has apparently taken place throughout the metagabbro; it requires the addition of a little soda, alumina, magnesia and lime, and releases silica. Similarly the reaction augite $\longrightarrow$ grossularite requires the addition of lime and releases silica. Now the alteration of a calcic plagioclase (An_{65}) to scapolite would require only the addition of silica and a small amount of lime or soda, and chlorine and it seems likely that the silica released by these two reactions has entered scapolite. Enough chlorine probably was camouflaged in the gabbro to satisfy the requirements of scapolite.

Clinozoisite probably formed from hornblende by addition of lime and alumina; the reaction would liberate magnesia, iron and a little silica and soda. The magnesia might be used up in the formation of more hornblende from augite, the iron would probably enter pyrrhotite and silica and soda would go into scapolite. Availability of lime seems to have been the controlling factor in the development of clinozoisite. It should be emphasized that the conversion to clinozoisite may have

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*All reactions are discussed in terms of constant volume.

followed immediately upon the breakdown of augite without the intervening crystallization of hornblende. This would explain the absence of replacement textures.

It appears that an intrusion of gabbro magma has assimilated some limestone providing the lime necessary for the formation of clinozoisite and garnet, and has probably produced titanaugite in the immediate contact area. The titanaugite, clinozoisite and garnet zones then are not metamorphic zones but zones of hybridization. The interval between intrusion of the gabbro and emplacement of the nepheline rocks is not known, but it seems likely that the gabbro had already consolidated and any subsequent reactions were between nepheline magma or solutions and solid gabbro.

There does appear to have been some introduction of soda from the nepheline magma or solutions. Whether nepheline or the constituents of nepheline were introduced to form the hybrid nepheline gabbro, it is in effect a soda metasomatism. Further evidence of the introduction of soda in the hybrid zone is the presence of oligoclase in the hornblende coronas. Farther away from the nepheline gneiss there does not appear to have been sufficient soda for oligoclase to form from the hornblende. In the hybrid rocks nepheline appears to have been the last mineral to crystallize; it contains many more inclusions of other minerals than the nepheline of the nepheline gneisses. Its textural relations suggest that it is a later interstitial mineral which has occasionally replaced plagioclase.

It was probably during the last stages of the emplacement of nepheline rock that the garnet coronas developed in the hybrid. There is generally very little calcic plagioclase in the nepheline gabbro. It may be that soda-alumina-silica solutions having approximately the composition of albite penetrated the metagabbro and with addition of lime, chlorine and CO_2 reacted with the anorthite content of the plagioclase to form scapolite and grossularite. This might explain the garnet rims on nepheline and carbonate grains and their association with scapolite.

The scapolite in the nepheline gneiss probably has a different mode of origin to the scapolite in the metagabbro; the grains are fairly large and fresh, whereas the scapolite of the metagabbro is sometimes altered; this might suggest compositional differences which would in turn suggest different modes of origin. It seems likely that it has developed by reaction of alumina, soda and silica from the nepheline magma or solutions with lime from the marble, rather than from plagioclase. Some scapolite also occurs in coronas on nepheline, as blebs in the garnet coronas on nepheline, and as minute blebs and veinlets traversing altered nepheline. It may have formed by addition of chlorine and silica to nepheline and the soda and alumina released would aid the reaction augite $\longrightarrow$ hornblende.

The plagioclase in the hornblende-bearing nepheline gneiss is generally an oligoclase (An_{10-15}) but in certain biotite-bearing varieties it is an andesine (An_{45-50}). There appear to be two possible explanations, both of which must remain speculative at present. The biotite-bearing variety might be a nephelinized sedimentary bed in the original limestone. Alternatively the nepheline accompanying the calcic plagioclase in the biotite rock might be sodic with potash taken up in the biotite, while in the hornblende rock the lime might have entered hornblende, leaving a potassic nepheline and a more sodic plagioclase.

It may be that the alteration of nepheline close to its contact with marble is a cancrinite produced by the action of CO_2 released from the underlying marble. If this is so it suggests that lime, rather than being a factor in the formation of nepheline, has been responsible for its subsequent alteration.

It remains to be decided whether the nepheline-bearing rocks were formed by consolidation of a nepheline magma or from solutions. It is not possible to say with certainty, but considerable volatile material seems to have been present, and it was probably a highly fluid magma or even a solution containing soda, alumina and iron and not saturated with silica. The source of such a solution is unknown.

All the changes discussed so far with the possible exception of corona development are assumed to pre-date the regional metamorphism. To what extent regional metamorphism has changed the original mineralogy is not known but the assumption has been made throughout that there have been no important changes. This metamorphism has been largely dynamic. The conversion of pyroxene to hornblende probably was a deuteric alteration during cooling of the gabbro rather than a result of regional metamorphism.

Conclusions

The interpretation arrived at must be considered tentative in view of the information at present available.

Gabbroic magma appears to have intruded limestone and formed a skarn at the contact. Contamination of the gabbro magma by lime produced zones of clinozoisite, garnet and titanaugite in the gabbro parallel to the contact. Intrusion of nepheline-forming solutions after consolidation of the gabbro formed a hornblende-nepheline rock and some biotite-nepheline rock between the limestone and the gabbro. Soda metasomatism in a 50 foot zone of the gabbro adjacent to the nepheline-bearing rock formed a hybrid nepheline gabbro. Regional metamorphism followed at some subsequent date and developed a foliation in the marble and nepheline rock (now nepheline gneiss) and a slight foliation and metamorphic texture in the metagabbro. Faulting of an unknown age brought nepheline gneiss and marble into sharp contact and trapped the skarn as horses only one of which is now exposed.

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Fig. 2

Nepheline metagabbro. Titanaugite (Ti) with hornblende (Hb) - oligoclase (Ol) corona. Plane polarized light. x 56

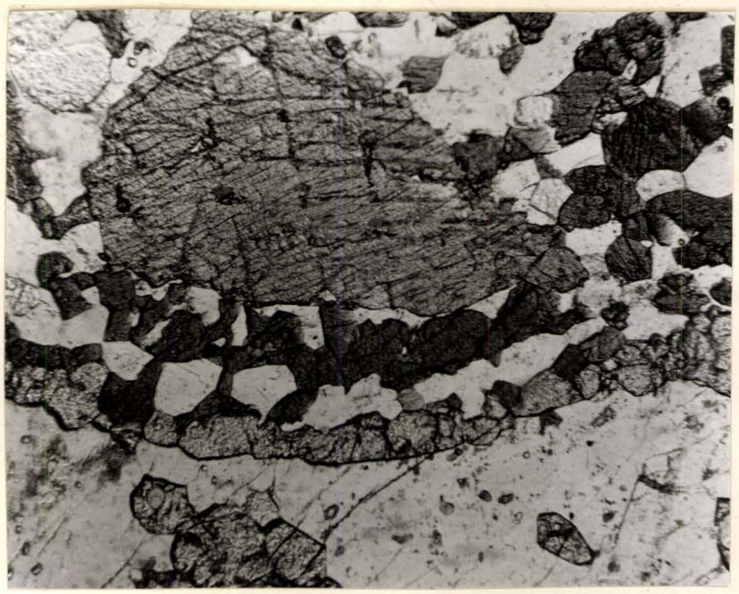


Fig. 3

Nepheline metagabbro. Titanaugite with hornblende-oligoclase, and scapolite coronas (Sc) adjacent to garnet corona (Gt) on nepheline. Plane polarized light. x 56

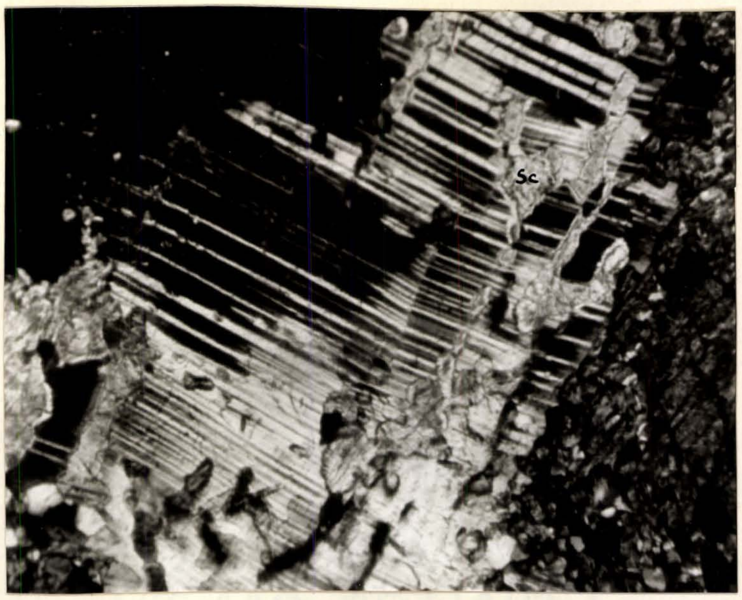


Fig. 4

Nepheline metagabbro. Polysynthetically twinned plagioclase grain partly replaced by scapolite (Sc). Crossed nicols. x 56

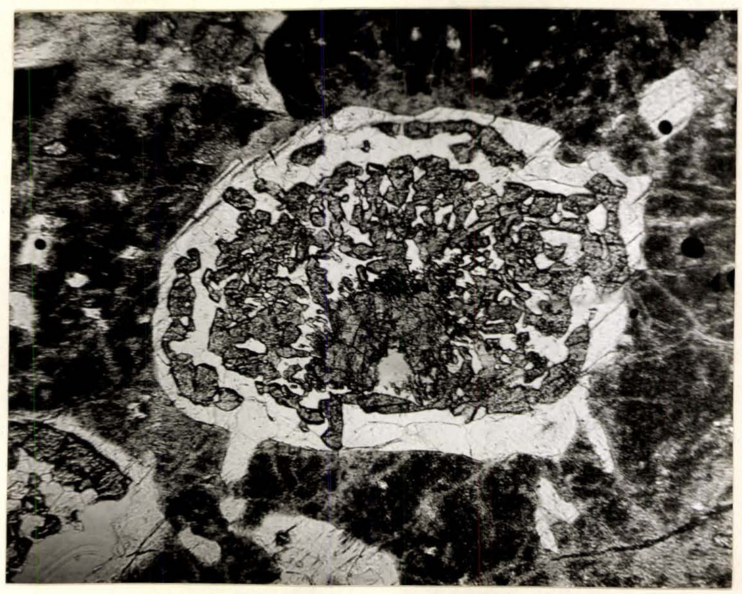


Fig. 5

Nepheline metagabbro. Altered nepheline (Ne) with skeletal aggregate of hornblende-oligoclase and scapolite (Sc) corona. Plane polarized light. x 56

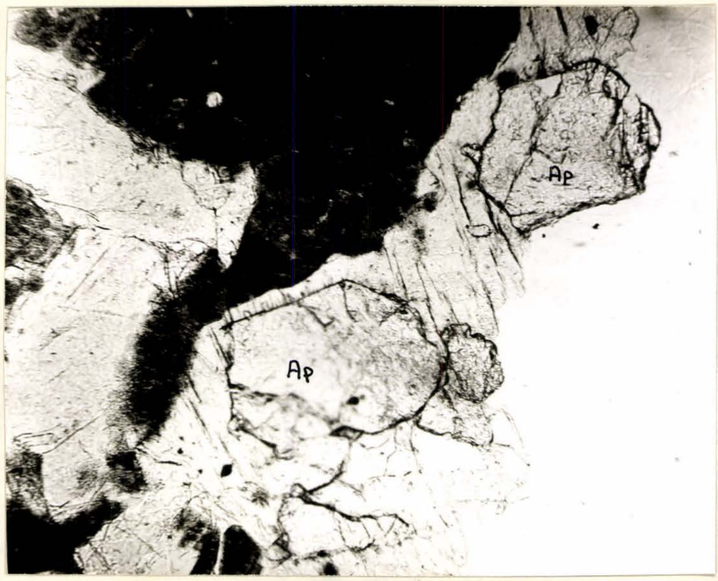


Fig. 6

Nepheline metagabbro. Subhedral grains of apatite (Ap); altered nepheline with crenulate border against plagioclase. Plane polarized light. x 56

APPENDIX

SOME REPRESENTATIVE MODES

	R372	R374	R378	R380	R381	R382	R384
Hornblende	31.8	29.4	26.7	4.7	16.1	39.3	9.1
Pyroxene	30.0	38.0	28.7	73.8	61.6	37.9	61.3
Scapolite	15.4	0.2	7.4	1.4	5.5	11.1	2.4
Plagioclase	7.6	2.5	23.6	....	0.5	1.6	10.5
Clinozoisite	....	....	3.1	1.3	7.6	3.3	0.7
Garnet	....	27.7	7.9	17.7	8.2	4.5	15.3
Pyrrhotite	0.1	0.7	0.4	0.8	0.1	0.1	0.7
Apatite	4.0	0.8	0.1	0.3	....	....	....
Nepheline	8.9	....	....	....	....	....	....
Alteration*	....	0.3	1.6	....	....	....	....
Zircon	....	0.3	0.7	....	0.1	....	....
Carbonate	2.6	0.1	....	....	0.3	2.3	....
	100.4	100.0	100.2	100.0	100.0	100.1	100.0

	R385	R387	R388	R390	R391	R392	R395
Hornblende	17.0	79.9	5.5	27.6	5.7	16.3	68.3
Pyroxene	58.1		74.9	57.0	70.7	50.3	....
Scapolite	14.3	1.0	5.5	12.7	7.0	24.8	0.5
Plagioclase	2.2	....	....	....	12.6	2.4	31.2
Clinozoisite	7.6	3.3	11.1	1.1	1.9	4.3	....
Garnet	....	13.8	1.2	Tr	....	....	....
Pyrrhotite	....	0.9	0.6	0.1	....	1.0	0.1
Apatite	....	0.3	....	....	0.1	0.1	....
Nepheline	....	....	0.8	0.7	....	....	....
Alteration*	....	0.4	....	....	2.0	0.9	....
Zircon	....	....	....	0.2	....	....	....
Carbonate	1.0	0.3	0.2	0.7	....	....	....
	100.2	99.9	99.8	100.1	100.0	100.1	100.1

*Sericitized Plagioclase and Altered Scapolite.

R372 Nepheline metagabbro. Partly uralitized pink augite with irregular interstitial grains of completely altered nepheline. A few skeletal aggregates of hornblende and oligoclase rimmed by scapolite. Scapolite interstitial to pyroxene and hornblende.

R374 Garnetiferous metagabbro. Deep green pyroxene riddled with minute grains of garnet and extensively altered to hornblende.

R378 Clinozoisite-garnet metagabbro. A granoblastic hornblende-pyroxene-plagioclase aggregate. Pale green pyroxene slightly uralitized. Garnet in discrete idioblastic grains.

R384 Metagabbro. Abundant pink pleochroic augite; fairly fresh. Interstitial twinned plagioclase, some strongly zoned. Idioblastic grains of pink garnet.

R385 Scapolite-clinozoisite metagabbro. Abundant uralitized pyroxene with cores of pink augite. Interstitial scapolite and idioblastic clinozoisite.

R387 Garnetiferous metagabbro. Abundant uralitized pyroxene with relic pink augite; riddled with garnet blebs.

R388 Clinozoisite-scapolite metagabbro. Similar to R385.

R380 Garnetiferous pyroxenite. Green pyroxene extensively altered to blue-green hornblende and riddled with garnet.

R381 Clinozoisite-garnet pyroxenite. Similar to R380 but contains idioblastic elongate grains of clinozoisite.

R382 Scapolite metagabbro (pyroxenite). Abundant uralitized pyroxene, and hornblende with interstitial scapolite. A few elongate grains of clinozoisite and a few blebs of garnet in the pyroxene.

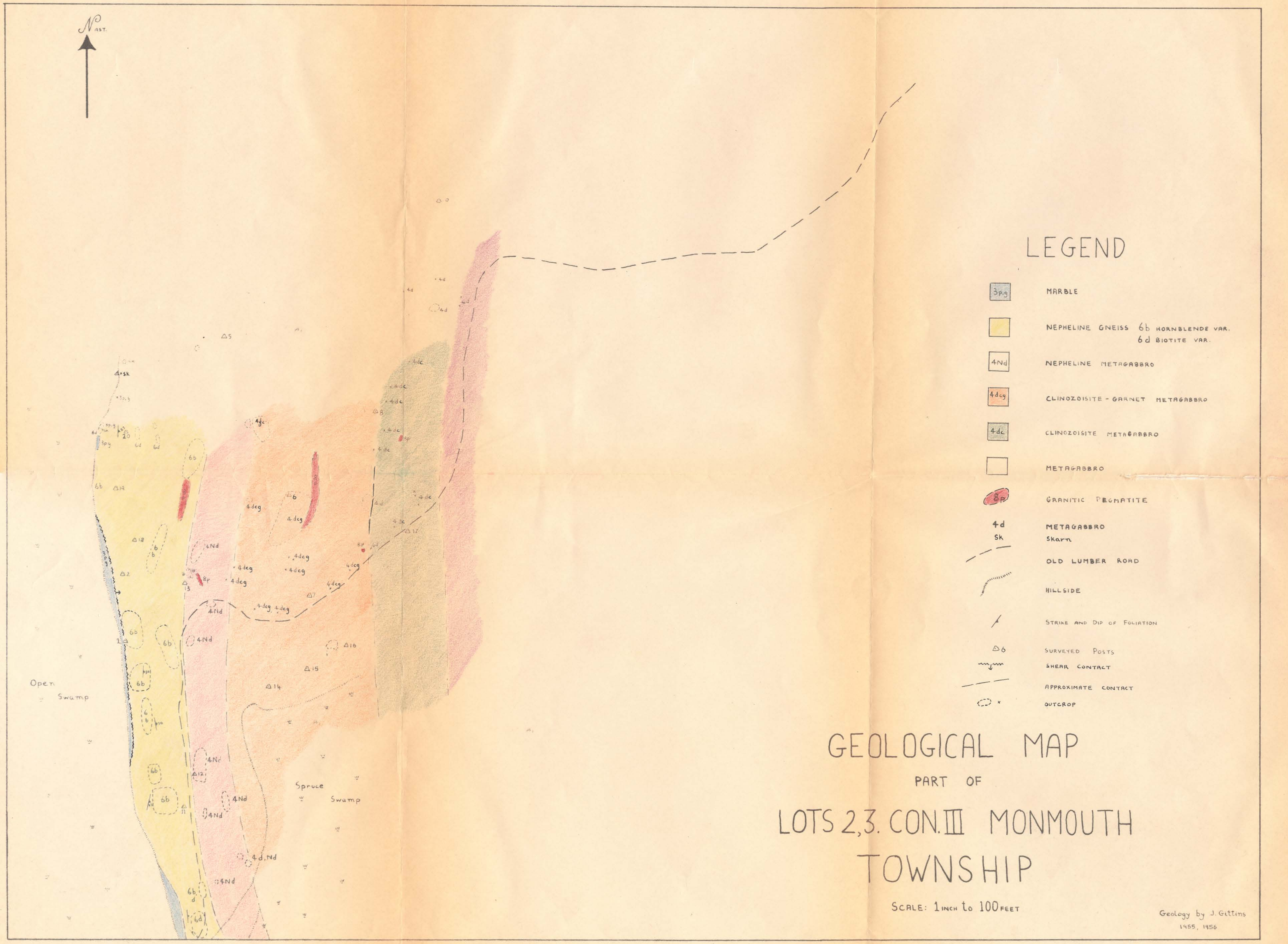
R390 Scapolite metagabbro. Similar to R382.

R391 Metagabbro. A granoblastic pyroxene-hornblende-plagioclase rock.

R392 Scapolite metagabbro. Pyroxene extensively altered to hornblende with abundant interstitial scapolite. Occasional porphyroblasts of clinozoisite.

R395 Metagabbro. A granoblastic rock with abundant hornblende and fairly fresh plagioclase.


SPECIMEN LOCATION
MAP
SCALE: 1 INCH to 100 FEET



N AST.
LEGEND
3pg MARBLE
NEPHELINE GNEISS 6b HORNBLENDE VAR.
6d BIOTITE VAR.
4Nd NEPHELINE METAGABBRO
4dcg CLINOZOISITE - GARNET METAGABBRO
4dc CLINOZOISITE METAGABBRO
METAGABBRO
8p GRANITIC PEGMATITE
4d METAGABBRO
Sk Skarn
OLD LUMBER ROAD
HILLSIDE
STRIKE AND DIP OF FOLIATION
△6 SURVEYED POSTS
SHEAR CONTACT
APPROXIMATE CONTACT
OUTCROP
Open Swamp
Spruce Swamp
GEOLOGICAL MAP
PART OF
LOTS 2,3. CON. III MONMOUTH
TOWNSHIP
SCALE: 1 INCH to 100 FEET
Geology by J. Gittins
1955, 1956