GEOLOGY AND PETROGRAPHY OF MOUNT ROYAL,

MONTREAL

THE GEOLOGY AND PETROGRAPHY OF A SECTION ALONG THE TRAMWAY, MOUNT ROYAL, MONTREAL, P.Q.

by

F. C. BUCKLAND.

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C O N T E N T S.

A B S T R A C T.

The tramway on Mount Royal exposes a complete east-west section of the alkaline gabbro, from the contact with the lowest part of the Utica Shale, which is covered by the tunnel on the east, to the tip of a screen of Trenton limestone which extends into the mass from the west. The alkaline gabbro is not simple but is a complex of intrusive masses of somewhat similar character. In general, the early facies, which contains olivine, is the most mafic-rich, and the younger facies are correspondingly richer in plagioclase, which is more sodic in composition than that of the early facies.

All the facies are derived from the same magma and are essentially of the same age. However, the early facies had time to become rigid before the younger facies, which now form irregular dykes within it, were intruded. In some places the dykes entered along fractures and include angular fragments of the early rocks; but the joint systems to which these fractures belong appear to be very local. These relationships suggest that the advance of the magma was progressive and continued despite consolidation in the mass, and that progressively later facies were formed from a magma differentiating beneath. The extensive brecciation on the zone mapped is, perhaps, to be attributed to the influence of the screen of limestone which allowed two parts of the magma to come together along the line.

The period of intrusion and consolidation of the alkaline gabbro was followed by the intrusion of numerous dykes of pegmatite, camptonite, syenite, and monchiquite.

The minerals of the alkaline gabbros are plagioclase zoned from An.92 to An.30 in the basic facies; olivine in the mafic-rich facies only; augite in all the alkaline gabbros; hornblende, or femahastingsite of the hastingsite group of amphiboles; biotite; ore minerals, magnetite, pyrrhotite, ilmenite, and chalcopyrite; epidote; quartz in pegmatites and hydrothermal veins; calcite as an alteration product and in veins; and nepheline, spinel, orthoclase, and zircon in pegmatitic and syenitic dykes.

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INTRODUCTION.

MOUNT ROYAL - Mount Royal which has given its name to a city and a petrographical province is surrounded by Greater Montreal. It is one of eight similar mountains rising above the plain of the Saint Lawrence Valley or the St. Lawrence Lowland. From west to east the mountains are - Royal, St. Bruno, St. Hilaire, Rougemont, Johnson, Yamaska, Shefford, and Brome. Brome Mountain is the largest, having an elevation of 1755 feet and an area of 30 square miles; Mount Johnson is the smallest, having an elevation of 875 feet and an area of 0.422 of a square mile. Mount Royal, sixth in order of size, has an elevation of 769.6 feet and an area of about two square miles. The mountains are a geographical unit known as the Monteregian Hills. The intrusive rocks composing them, with certain minor intrusives, form the Monteregian Petrographical Province. [1]. The hills are unequally spaced along a slightly-curved, east-west line, which is about 50 miles long. Mount Johnson alone stands somewhat south of the line. This suggests that the hills were localized by lines of weakness or deep-seated fracture. The form of the intrusions is unknown. Some hills may be denuded laccoliths and others volcanic necks or plugs.

(1) F.D. Adams. The Monteregian Hills. Jour. Geol. XI. P.243. 1903.

AGE OF INTRUSIVE ROCKS - The age of the rocks is uncertain, they cut the flat-lying Ordovician limestones, and some breccias hold fragments of Helderberg and Oriskany limestones showing that the intrusions are younger than the lower Ordovician. On the east the St. Lawrence Lowland is bounded by the Appalachian uplift. Dresser(2) states that the igneous rocks of Brome Mountain are somewhat foliated and have in places an incipient, schistose structure. This, though less schistose, is parallel in direction with the foliation of the surrounding sediments and represents a late stage in the folding of the Appalachian uplift. The evidence is inconclusive; the Monteregian Hills may represent a comparatively young intrusion.

LOCATION OF SECTION STUDIED - Mount Royal, because of its accessibility from, and proximity to the City of Montreal, has received much attention from geologists of McGill University. Published papers by F.D. Adams(3), and by J.A. Bancroft and W.V. Howard (4), as well as unpublished theses, contain much information. This information has been obtained from a railway tunnel driven through Mount Royal, quarries, excavations, and outcroppings on its flanks. In 1928, the Montreal Tramways Co. Ltd. completed a tramline from the north-west foot of the mountain to a point a few hundred feet south-west of the summit. During the construction of this line it was

(2) Dresser, J.A. Geology of Brome Mountain. Geol. Surv. Canada. Annual Rept. 1905. P.6G.
(3) Adams, F.D. The Monteregian Hills. Geol. Surv. Canada. Guide Book No.3. P.29. 1913.
(4) Bancroft J.A. and Howard W.V. The Essexites of Mount Royal, Montreal, P.Q. Trans. Roy. Soc. Can. 1923.

necessary to make a rock-cut almost continuously from the north end of Fletcher's Field to the upper terminus. The lower part of the cut is through Trenton limestones. The upper 2500 feet is in alkaline gabbro traversed by numerous dykes. It is the purpose of this paper to present the results of a study of the exposed section from the limestone to the upper terminus of the tramway.

REVIEW OF DEFINITIONS AND LITERATURE ON ESSEXITES AND THERALITES.

Alkaline gabbros related to theralites and essexites form over ninety percent of the rocks exposed in the section along the tramway. It is advisable, therefore, to consider the published work on these and similar types of rock and the definitions of each type.

LOCATION OF ESSEXITE INTRUSIVES - Essexite is known in very few localities and the area of all outcrops is probably less than one hundred square miles. Among the known localities are Essex County, Massachusetts, from which essexite was named, the Monteregian Hills, two small bosses in Scotland, Christiania District in Norway, Madagascar, Mount Monadnock in Vermont, a small outcrop in Bohemia, Julianehaab in Greenland, and a doubtful occurrence in northern New South Wales, Australia.

ORIGIN OF TERM "ESSEXITE" - The name "Essexite" was introduced by Sears(5) to designate a rock from Essex County, Massachusetts, really an olivine-free soda-gabbro containing nepheline. According to the original definition, the rock consisted of augite, hornblende, biotite, and plagioclase, with subordinate amounts of orthoclase, nepheline, and sodalite. Sears regarded this as the earliest and most basic part of the Salem Neck nepheline-syenite magma. Rosenbusch(6) expanded the term to include olivine-bearing types and included Norwegian rocks that Brögger had called Olivine-gabbro-diabase.(7) Rosenbusch does not insist upon the presence of feldspathoids or hornblende.

WASHINGTON'S DESCRIPTION OF ESSEXITE - In a description of the essexites of Massachusetts, Washington(8) says, "They are dark grey, almost black, rocks, of a granitic structure, and usually fine-grained, though varying to some extent in this respect. --- Biotite and feldspar phenocrysts and small round spots of augite and hornblende are seen in most specimens, but are not prominent. --- The feldspar is mostly a plagioclase showing clear twinning lamellae, whose extinctions vary, but which correspond to compositions ranging from $Ab_4 An_1$ to $Ab_1 An_2$. --- An alkali-feldspar is not uncommon, generally anhedral, and often microperthitic. This and a microcline occasionally met with are apparently rich in soda. Nepheline is fairly

(5) Sears, J.H. Elaeolite Zircon Syenites and Associated Granitic Rocks in vicinity of Salem, Essex County, Mass. Bull. Essex. Inst. XXIII. 1891. P.145.
(6) Mikroskopische Physiographie. 4th Ed. P.404. 1908.
(7) Bailey. Geology of the Glasgow District. Memoirs of Geol. Surv. of Scotland. 1911. P.128.
(8) Washington, H.S. The Petrographic Province of Essex County, Mass. Jour. Geol. VII. P.53. 1899.

abundant, generally interstitial, but occasionally in well shaped crystals." Washington does not agree with Rosenbusch when he includes rocks that have a hyperitic[(x)] structure and appear to be a dioritic facies of the magma with the essexites.

HOLMES' DEFINITION OF ESSEXITE - The present usage of the term "Essexite" is given by Holmes[(9)] as:- "Essexite - a phanerocrystalline igneous rock regarded as an alkali variety of gabbro, containing green and purple pyroxenes and plagioclase (andesine to bytownite) with or without soda amphiboles and olivine. Among the felsic minerals nepheline or analcite may occur in small amounts, and orthoclase or soda-orthoclase is always developed. By decrease in potash-felspar and increase of the felspathoid minerals the type passes into theralite."

HARKER'S DEFINITION OF ESSEXITE - Harker's[(10)] definition differs from that of Holmes in that no distinction is made between the ferro-magnesians. He says, "Olivine is usually present, and the other ferro-magnesian minerals may include augite, hornblende, and biotite in various proportions, a purplish titaniferous augite being the most abundant."

ESSEX COUNTY - In Essex County the essexites are confined to the immediate vicinity of Salem Neck where they occur in large masses accompanying and cut by nepheline syenite.

(x) "Hyperite." - A term at first synonymous with Norite, now extended to include somewhat granular hyperstene-feldspar rocks with or without augite, diallage or garnet. - A. Holmes, Nomenclature of Petrology. P.121. 1920.
(9) Holmes. "The Nomenclature of Petrology." P.93.
(10) Harker. "Petrology for Students." Sixth Edition. P.85.

They are quite distinct from the syenites and few, if any, transition facies are seen. On the other hand, they appear to grade into the diorites of the neighborhood, from which it is difficult to separate them.[11]. Washington believes the essexites of Salem Neck were differentiated into a laccolithic structure which forms approximately one percent by area of the petrographical province of Essex County. This province consists of 342 square miles along the coast of Massachusetts from the New Hampshire line south to Lynn and stretching inland for from 5 to 15 miles. The rocks consist of granites, quartz-syenites, syenites, nepheline-syenites, essexites, diorites, and gabbros but by numerous dykes and later flows of rhyolite. They have broken through Precambrian and Lower Cambrian strata and are supposedly Pre-Carboniferous.[12]

<u>ESSEXITE A HYBRID ROCK</u> - Sears[13] is of the opinion that the essexites of Salem Neck are not true igneous rocks but are a hybrid or contact metamorphosed gabbro or gabbro-diorite. To quote Sears, "The conclusion is, therefore, that the essexite of Salem Neck is not a differentiate of the alkaline or nephelite syenites, but is a contact metamorphosed gabbro or gabbro-diorite of the Salem type or in some places a metamorphosed olivine-bearing diabase. --- The essexites of Salem Neck undoubtedly grade into the gabbro-diorites; they are brecciated by the Syenites; and they occur only in the contact breccia zone and never as distinct intrusions into the gabbro-diorite.

(11) Washington. H.S. The Petrographic Province of Essex County, Mass. Jour. Geol. <u>Vll</u>. P.53. 1899.
(12) Washington. H.S. "The Petrographic Province of Essex County, Mass." Jour. Geol. <u>Vl</u>. 1898.
(13) Sears. "Geology of the Igneous Rocks of Essex County, Mass." U.S.G.S. Bull. 704. 1921. P.124.

These structural considerations strongly support the conclusion that the essexite is of hybrid origin." Sears follows this with analyses of Salem Neck essexites[14], Mount Johnson essexites, and an average analysis of essexite worked out by R.A. Daly. Conclusions drawn from the analyses are that the Salem Neck essexite does not differ essentially from the average essexite, or from the essexite of Mount Johnson which, he states, is almost assuredly a normal differentiate of an alkaline magma. Final conclusions are that these hybrid rocks may resemble closely a "normal igneous rock."

<u>LENNOXTOWN, SCOTLAND</u> - The Scottish occurrences at Lennoxtown and Crawfordjohn in the Glasgow district have been studied with considerable care. At Lennoxtown[15] an essexite, "with teschenitic and theralitic affinities and at the same time not very far removed from the gabbro stock," occupies a boss 700 yards long and 100 yards wide. In hand specimens this essexite presents the appearance of fine-grained gabbro in which black augite and white feldspar can be distinguished clearly. Microscopically, purple augite, olivine, and plagioclase feldspar make up the bulk of the rock. Flakes of red-brown biotite, grains of titaniferous magnetite, long needles of apatite, and interstitial patches of analcite are conspicuous. Orthoclase and nepheline are present but not common. The plagioclase feldspars are in lath-shaped sections showing no zonal structure. The majority of them are basic,

(14) Sears. Geology of the igneous rocks of Essex County, Mass.. U.S.G.S. Bull. 704 1921.
(15) Bailey. "Geology of the Glasgow District" Memoirs Geol. Survey of Scotland. 1911. P. 113.

bytownite being present. Bailey claims that this is not a typical essexite, being poor in orthoclase, but that it strongly resembles the Christiania essexites described by Brögger. The age of the boss has not been ascertained.

CRAWFORDJOHN, SCOTLAND - At Crawfordjohn, Scotland,[16] Scott describes an essexite, similar in outcrop size to the Lennoxtown occurrence, which consists of numerous crystals of olivine and euhedral lath-shaped feldspars accompanied by, and occasionally included in, large phenocrysts of purple augite. Ilmenite and apatite are fairly abundant and sporadic flakes of biotite also occur. The interstices are filled with nepheline and analcite. Zonal structure is common in the plagioclase which was found to be basic labradorite. It is commonly enclosed by augite and in some places by olivine. Orthoclase is not common. Iron ores are plentiful and are in places surrounded by rings of biotite. As the edge of the intrusion is approached, the grain size diminishes until at the margin the rock is thoroughly aphanitic, none of the minerals being distinguishable in the hand specimen. The age of the intrusion is considered to be Permo-Carboniferous.

THERALITE - The terms "Essexite" and "Theralite" have suffered somewhat from lack of definition and discrimination in their use. Rosenbusch suggested the term "Theralite" for plagioclase-nepheline rocks of plutonic habit, and chose as the original type a rock from the Crazy Mountains, Montana, in which nepheline was stated to be present. This was a mistake, as the rock proved to be a shonkinite, and recognizing this Rosenbusch afterwards took the unequivocal theralite of Duppan,

(16) A. Scott. "The Crawfordjohn Essexite." Geol. Mag. 1915. P.455.

Bohemia, as the type example. Lacroix, however, proposed in 1902 to use theralite for melanocratic alkali-syenites. The term "Theralite" he reserves for mesocratic rocks which differ from essexites in having a smaller proportion of potash-feldspars and in general a higher ratio of nepheline to feldspars. In essexites, as in the type rock of Salem Neck, there is a noticeable quantity of orthoclase or soda-orthoclase; interstitial nepheline may be present, and hornblende is a constant ferromagnesian constituent. From the theralites proper Lacroix separates two types in which the nepheline-feldspar ratio is lower and the plagioclase more calcic than in the normal members of the group[17]. The Crawfordjohn "Essexite" is a British example of theralite characterized by general absence of hornblende and the presence of olivine and often biotite[17]. The montrealite of Mount Royal is a coarse-grained melanocratic variety of theralite[17].

HOLMES' DEFINITION OF THERALITE - Holmes gives the definition for a theralite as "a phanerocrystalline rock composed essentially of labradorite, nepheline, and purple augite, and often containing soda-amphiboles and biotite, or both. Analcite may be present, and most examples are olivine bearing.[18]"

(17) Holmes, A. Geol. Mag. Vol.57. P.185. 1920.
Review of The Classification of the Plagioclase-Nepheline Granitoid Rocks. A. Lacroix. Comptes Rendus. t.170. P.20. 1920
(18) Holmes, A. The Nomenclature of Petrology. P.225. 1920.

DESCRIPTION OF MINERALS.

The igneous rocks of the Mount Royal Tramway have a suite of minerals which varies little throughout the different rock types of the section. Alkaline gabbros and dykes contain the same group of minerals. Plagioclase, augite, and femahastingsite are the most prominent. Small percentages of biotite and olivine are scattered throughout the section,and iron ores, apatite,and sphene are common accessories. The alkali metals enter into the composition of the ferromagnesian minerals. Free silica is not common, although quartz may be found in small amounts in pegmatites and hydrothermal quartz-calcite veins.

A paucity of silica is indicated by the norms of the alkaline gabbros. Nepheline is found in the norms of plagioclase and amphibole, if their analyses are recalculated according to the normative system as igneous rocks.

PLAGIOCLASE - Plagioclase feldspar occurs in all the rocks of the section studied along the tramway. In places it forms over ninety percent of the rock, but elsewhere augite and hornblende may exceed it greatly in amount. Some facies of the gabbros have as little as ten percent plagioclase. All anhedra of feldspar show a range in composition from calcic feldspar at the core to sodic at the margin. Ranges from An.32 to An.80 are quite common. In the plagioclase of the alkaline gabbros a range from An.24 to An.91 was measured. Dyke rocks contain plagioclase of a much lower calcity; zoning from pure albite to An.40 is common. Twinning after the albite, Carlsbad, and pericline laws is almost universal. Alteration to calcite and white mica or sericite is found, but in most of the thin-sections the plagioclase is fresh, except for small specks of these alteration products.

Analyses of feldspars from the Monteregian Hills are given by T. Sterry Hunt[19] and by Bancroft and Howard[20].

(19 - Geology of Canada. 1863. P.476 - 479.)
(20 - Essexites of Mount Royal, Montreal. Trans. Roy. Soc. (Can. P.23. 1923.)

	1.	11.	111.	1V.	V.	Vl.	Vll.
SiO_2	49.06	65.70	63.25	46.90	61.10	53.10	53.60
TiO_2	0.14						
Al_2O_3	30.96	20.80	22.12	31.10	20.10	26.80	25.40
Fe_2O_3	0.55			1.35	2.90	1.35	4.60
MgO	0.15			0.65	0.79	0.72	0.86
CaO	13.05	0.84	0.56	16.07	3.65	11.48	3.62
Na_2O	4.79	6.52	6.29	1.77	5.93	4.24	undet.
K_2O	0.50	6.43	5.92	0.58	3.54	9.71	undet.
MnO	0.04						
Ign	0.76	0.50	0.93	1.00	0.40	0.60	0.80
	100.00	100.79	99.07	99.42	98.41	99.00	----

1. Bancroft & Howard. "Essexites of Mount Royal, Mont. P.Q. P.23. 1923. Analyst, M.F. Connor. Plagioclase from "diabase-gabbro phase of essexite" from C.N. Railway tunnel.

11. Orthoclase from "granitoid trachyte" of Brome Mt. T. Sterry Hunt. Geology of Canada, 1863. P.476.

111. Orthoclase from Shefford Mt. T. Sterry Hunt. Geology of Canada. 1863. P.476.

1V. Feldspar from Yamaska Mt. T. Sterry Hunt. Geology of Canada. 1863. P.476.

V. Feldspar from "Granitoid Micaceous Trachyte," Yamaska Mt. T. Sterry Hunt. Geology of Canada. 1863. P.479.

Vl. Feldspar from "Periodotic Dolerite," St. Bruno Mt. T. Sterry Hunt. Geology of Canada. 1863. P.479.

Vll. "Peridotic Dolerite" similar to Vl, from Mount Royal. T. Sterry Hunt. Geology of Canada. 1863. P.479.

Concerning analysis 1., Bancroft and Howard[21] state,: "The specific gravity of this feldspar is 2.705 and its mean index of refraction is 1.565, which would indicate a chemical composition equivalent to Ab_{35} An_{65} or SiO_2, 517; Al_2O_3, 30.8; CaO, 13.4; and Na_2O, 4.0. Taking the Na_2O; CaO ratio, which is 77:117 or about 40:60, the analysis suggests a composition for the feldspar of Ab_2An_3. This, however, would require 53 percent SiO_2 or 3.94 per cent more than is shown in the analysis. A feldspar containing 49.06 per cent SiO_2, if of normal composition, would correspond to $Ab_{24}An_{76}$ approximately, which should contain 2.75 per cent of Na_2O. In other words, although the ratio of Na_2O:2CaO in the analysis suggests a composition of $Ab_{40}An_{60}$, the Na_2O is considerably too high in proportion to the CaO for the amount of SiO_2 present to fulfil this ratio. The above considerations strongly suggest that a certain amount of the triclinic nepheline, carnegieite, enters into the composition of the feldspar."

The presence of carnegieite in the feldspar and of normative nepheline in the hornblende help to explain the presence of nepheline in the norm of the rock.

<u>Orthoclase</u> - Orthoclase is a very minor constituent of the alkaline gabbro, but is prominent in the pegmatites and syenite rocks of the tramway section. It is zoned and is commonly of a soda rich variety, extinctions ranging from 5 deg. to 13 deg. ($\alpha \wedge a$ on the 010 face). The richness of orthoclase of rocks of the Monteregian province in soda is well shown in analyses <u>11</u> and <u>111</u>. Here the soda is in greater amount than

(21) Bancroft & Howard. The Essexites of Mount Royal, Mont., P.Q. Trans. Roy. Soc. Can. 1923. P.23.

the potash. Orthoclase normally contains about 20 percent of its alkalis (Na_2O+K_2O) as soda. The soda-rich orthoclase is stable only at high temperatures but is not rare as a metastable substance at ordinary temperatures.[22]

In some of the pegmatite dykes, orthoclase and albite are intergrown in what appears to be a perthitic intergrowth but on closer examination albite is seen to be intimately replacing the orthoclase.

<u>AUGITE</u> - Augite constitutes as much as 70 percent of some facies of the alkaline gabbro, but the average content of all rocks of the section is about 25 percent. It is colorless to slightly flesh-colored and non-pleochroic. Very little of the purple pleochroic variety described by Bancroft and Howard[23] was seen. The augite is optically positive, highly birefringent and has an extinction angle ($Z \wedge C$) of 38 deg. to 45 deg., and an optic axial angle (2V) of approximately 60 deg. Dispersion is marked $\rho > v$ on the optic axis B emerging near the 001 face, but is not distinct on optic axis A. The augite is common as short prisms, but in facies of the gabbro showing flow structure, especially near the contact between two facies, it is granulated and may occur as masses of small individuals sometimes showing an attempt at orientation of the longest direction of the grains in the direction of flowage. Augite and hornblende are intergrown in most of the sections examined, and biotite may also enter the intergrowth, although not commonly. Inclusions in the augite are of iron ore as black irregular

(22) Winchell. Elements of Optical Mineralogy. Part 11. P.322
(23) Bancroft & Howard. Essexites of Mount Royal, Montreal. 1923. P.18.

grains or dust-like particles, apatite, sphene, and plagioclase. Several inclusions of plagioclase were found to have a composition of An88 to An91; the composition of most of the inclusions could not be obtained. A few specimens showed alteration to calcite, chlorite, epidote, and hornblende, but, in general, the augite is quite fresh.

Analysis 1. is given by Bancroft and Howard(24) from an olivine-rich type of essexite found on Cote des Neiges Road and analysis 11. is given by T. Sterry Hunt(25) for augite from "the olivinitic dolerite" of St. Bruno Mountain.

	1.	11.	111.
SiO_2	50.89	49.40	47.54
TiO_2	0.78	-	3.00
Al_2O_3	4.21	6.70	4.14
Fe_2O_3	1.43	7.83	5.64
FeO	4.18		6.42
MgO	15.97	13.06	10.05
CaO	22.38	21.88	21.57
Na_2O+K_2O	-	0.74	1.50
MnO	0.17	-	0.36
H_2O	0.23	0.50 - Volatile.	-
	100.24	100.11	100.21

Analysis 1.(26) "corresponds very closely to the formula $17RSiO_3$ $(Al,Fe)_2O_3$ where R=Ca, Mg, Fe and Mn, with 2(Na,K). If this analysis be recalculated according to the Quantitative Classification of Igneous Rocks, it will be found that the augite possesses the following norm:-

(24) Bancroft & Howard. Essexites of Mount Royal, Mont. P.19.
(25) Geology of Canada, 1863. P.468.
(26) Bancroft & Howard. Essexites of Mount Royal, Montreal. 1923. P.19.

Anorthite -	11.40	Olivine -	4.81
Diopside -	78.60	Magnetite -	2.09
Hyperstene -	1.56	Ilmenite -	1.52

Analysis <u>111</u>[27] is from a titaniferous-angite from tinguaite, Two Buttes, Colo.. The TiO_2 content of this specimen is much higher than that from Mount Royal, in fact, analysis <u>1</u>. is not a true titaniferous-angite, but is somewhat between a normal angite and the titanium-bearing variety.

<u>HORNBLENDE</u> - The hornblende of the section belongs to the hastingsite group of amphiboles. It rarely exceeds twenty percent of the rock although as much as 45 percent was discovered in one facies. The average over the entire tramline is about 14 percent. It is a strongly pleochroic variety with a light straw-yellow, Y a dark reddish-brown, and Z a dark reddish-brown, with $X<Z<Y$ or $X<Y=Z$, the former being the more abundant although the latter is very common. This slight variation in the pleochroism suggests that its chemical composition may not be constant. Bancroft and Howard describe optically positive hornblende but none was found in thin-sections from the tramway. The hornblende is optically negative and has an extinction angle ($X \wedge C$) ranging from 18 deg. to 24 deg.. The optic axial angle (2V) is approximately 80 deg. The dispersion is difficult to determine due to the intense brown color of the interference figure; it is very weak $\rho<v$. In nearly all sections, the hornblende is intergrown with and molded upon angite.

(27) Iddings. Rock Minerals. P.298.

Inclusions of magnetite in large grains or small opaque specks are common and it is not uncommon to find lines of small dark inclusions probably marking points at which crystallization was not active and specks of magnetite were able to adhere to the surface of the hornblende crystal. In places these lines formed several times during the crystallization of the amphibole.

Analyses of Mount Royal hornblendes:- (28).

	1.	11.	111.
SiO_2	35.65	39.23	38.633
TiO_2	7.99	4.53	5.035
Al_2O_3	11.94	14.38	11.974
Fe_2O_3	5.92	2.92	3.903
FeO	12.04	8.56	11.523
MgO	11.01	13.01	10.200
CaO	11.21	11.70	12.807
Na_2O	2.33	3.05	3.139
K_2O	0.99	0.98	1.489
H_2O	0.36	0.36	0.330
MnO	0.10	0.65	0.729
NiO	0.04	-	-
SrO	0.01	-	-
	99.59	99.37	99.762

(28) Bancroft & Howard. Essexites of Mount Royal, Montreal. P.20. Analyses 1. and 11. from Mount Royal. Analysis 111. from Mt. Johnson.

1. From "fresh dioritic phase of the rock" 2000 feet from its eastern contact in the Mount Royal tunnel.

11. From "Essexite," Mount Royal.

111. From "Essexite," Mount Johnson. Guide Book No.3. 1913 P.70.

If calculated as if it were a rock analysis, No.1. has the following norm(29):

Anorthite	21.13	Olivine	14.67
Nepheline	10.79	Calcium Orthosilicate	1.45
Leucite	4.80	Magnetite	8.58
Diopside	23.46	Ilmenite	15.20

Marland Billings(30) shows that the classification of the hastingsite group is based most logically on the ratio of ferrous iron to magnesia, using molecular proportions; if FeO/MgO exceeds two, the mineral is ferrohastingsite; if FeO/MgO is less than two but greater than one-half, the mineral is femahastingsite; if FeO/MgO is less than one-half, the mineral is magnesiohastingsite.(31) The molecular ratio FeO/MgO for analysis 1. is $\frac{16.78}{27.52}$ = 0.610. This ratio makes the amphibole a femahastingsite very closely related to magnesiohastingsite. Examination of zoning in the hastingsite group of amphiboles showed that the older part or core tends towards magnesiohastingsite and the periphery tends towards ferrohastingsite. These relations were found in the Mount Royal amphiboles as well as others of the group.(32)

(29) Bancroft & Howard. Essexites of Mount Royal. P.22.
(30) Billings. The Chemistry, Optics, and Genesis of the Hastingsite group of Amphiboles. Amer. Min. Vol.13, 1928. P.287
(31) Ibid. P.292.
(32) Billings, M. Chemistry, Optics, and Genesis of the Hastingsite Group of Amphiboles. American Mineralogist. P.293. 1928.

BIOTITE - Biotite forms approximately three percent of the rocks of the tramway section. Some facies of the alkaline gabbro have as much as twenty percent of this mineral but one or two percent is more common. Biotite is found intergrown with and molded upon both femahastingsite and augite, as rims around magnetite grains, and in reaction edges around olivine. In all cases it is strongly pleochroic, light straw yellow to dark brown often with a reddish tinge. Biotite was one of the latest minerals to crystallize. No analysis of Mount Royal biotite is available. The analysis submitted is for lepidomelane from Corporation Quarry.(33)

SiO_2	32.96
TiO_2	2.80
Al_2O_3	10.34
Fe_2O_3	8.85
FeO	27.19
MnO	2.79
CaO	0.64
MgO	0.73
Na_2O	0.98
K_2O	7.75
Li_2O	0.03
H_2O	4.36
	99.42

(33) B.J. Harrington. Trans. Roy. Soc. Can. Part 111. P.26. 1905.

<u>OLIVINE</u> - Olivine is not a common mineral of the rocks of the tramway section. Less than one-fifth of the thin-sections examined contained this mineral. When present it was never found to form more than two percent of the rock. In the majority of sections containing olivine, only one or two grains of the mineral are present. It is a very pale green, almost colorless, variety which is optically negative. Analyses show 25 percent FeO which is in accordance with the negative property, the inversion from positive to negative being at about 13 percent FeO(34).

Analyses of olivine from essexites of the Monteregian Hills:-

	1.	11.	111.	1V.
SiO_2	37.12	38.05	37.13	37.17
TiO_2	0.30			
Fe_2O_3	1.72			
FeO	25.66	25.17	22.57	22.54
CaO	2.10	2.16		
MgO	33.78	34.62	39.36	39.68
	100.68	100.00	99.06	99.39

Analyses 1. and 11. from Mount Royal Olivine, Bancroft and Howard, Essexites of Mount Royal. P.25

Analyses 111. and 1V. from St. Bruno Mountain Olivine. Geology of Canada. P.464. 1863.

Reaction rims around the grains are almost invariably present. The rims contain biotite, magnetite, colorless pyroxene, and apatite. In almost all cases the olivine

(34) Winchell. Elements of Optical Mineralogy. Part 11. P.166.

grains are serpentinized along cracks. In several places the grains are entirely altered to serpentine. Bancroft and Howard describe exceptional alteration of olivine essexite(35) in detail. Insufficient amounts of olivine essexite are available along the tramway to make possible a detailed study of this alteration.

ORE MINERALS - The ores are, in order of abundance magnetite, ilmenite, pyrrhotite, pyrite, chalcopyrite, spinel, and hematite. Together they form about 5 percent of the rock but 10 to 12 percent is quite common in thin sections. In polished sections examined with reflected light spinel is found to be intergrown with magnetite parallel to (100) and appears as two lines of dashes on the magnetite. Ilmenite is found on the edges of magnetite suggesting that it crystallized later. It is found also intergrown with magnetite parallel to the octahedron 111. A discussion on the intergrowths of magnetite, ilmenite and spinel has been published by Osborne(36). Chalcopyrite replaces pyrite in every occurrence observed in Mount Royal rocks.

APATITE - Apatite is found in all facies of the alkaline gabbro along the tramway. It seldom forms more than one percent of the rock, although as much as four percent is present in one section. It crystallized early but not before augite had commenced to crystallize. It commonly occurs as minute needles scattered evenly throughout a thin-section, but bluish-gray sections of hexagonal pyramids attaining to

(35) Bancroft & Howard. Essexites of Mount Royal, Montreal. Trans. Roy. Soc. Can. P.25. 1923.
(36) Osborne F.F. Certain Magmatic Titaniferous Iron Ores and their origin. Economic Geology. No.7 & 8. P.905. 1928.

the dimensions of the grain of the rock are present in many places. Most of the apatite has the minute inclusions, such as are commonly found in apatite. This gives a purplish or mauve tint to the mineral which is noticeable in the larger grains.

SPHENE - Sphene, optically positive with very small optic axial angle is a common accessory in the rocks of the section but is present in very minor amounts. Some of the facies of essexite show no sphene in the thin-section, but the majority of sections show several greyish-brown wedge-shaped sections of the mineral. It does not form as much as one percent of any thin-section. The sphene is slightly pleochroic suggesting a content of alkaline earths. It does not show any radioactive haloes; either because the rock is not old enough or because the sphene is non-radioactive.

NEPHELINE - Nepheline was not found in any of the alkaline gabbros examined under the microscope, but small quantities are present in several small dykes of the section. It is either in syenite dykes or in injections which have come after the first intrusion of the dyke in which it is found. Two occurrences are doubtful, the mineral being greatly altered to white mica. Nepheline has been recorded from the essexite 100 yards west of the Lookout on Mount Royal and from the eastern end of the railway tunnel[37]. It is possible that these occurrences of nepheline are later injections such as are found in the dykes of the tramway.

The presence of carnegieite, triclinic nepheline, in the

(37) Bancroft & Howard. Essexites of Mount Royal. P.26

plagioclase has been discussed, P.12, and the presence of nepheline in the norm of the amphibole has been shown. P.17.

CALCITE - Calcite is found in small veins in the essexite and in vesicles in some of the camptonite dykes. In all cases it is later than the other rock forming minerals and has accompanied quartz in injections of vein material. It is a common alteration product of augite and plagioclase.

QUARTZ - Quartz accompanies calcite in the later injections of vein material. It is not found as an original constituent of any of the rock types of the tramway except pegmatites. It crystallized immediately before the calcite, small quartz crystals having grown from the walls of the veins containing a calcite filling. This mineral is found also as aggregates of small idiomorphic crystals in essexite. In this latter case it has been injected probably at the time the quartz-calcite veins were formed.

ZIRCON - Small zircon crystals are present in two of the thin-sections and are surrounded by radio-active haloes. This is the first time radio-active haloes have been reported from the Monteregian Hills. The zircon is found in syenite dykes which contain about 98% feldspar, orthoclase and plagioclase, and one percent biotite with magnetite and spinel. The haloes are immature and suggest that the rock is much younger than Palaeozoic. In fact the haloes resemble those found in Tertiary rocks.

SPINEL - A green spinel, pleonaste, is present in minor quantities in the syenite dykes containing zircon. Pleonaste or hercynite occur in the magnetite (discussed on Page 20).

EPIDOTE - Although epidote was not found in any of the thin-sections from the tramway, considerable quantities may be seen in some places in the alkaline gabbro. Small amounts of epidote are present in some of the most basic facies of the complex, but the largest quantity observed is in a rock which probably has no plagioclase feldspars more calcic than An.75.

ALTERATION PRODUCTS - The alteration of plagioclase to specks of white mica and calcite is found in every thin-section of the alkaline gabbros. The alteration seldom amounts to more than a few flakes of mica, but in places where it is further advanced it has affected the calcic core of the plagioclase more than the outer zones.

Augite has altered to calcite, amphibole and sericite in several localities. In places it has been serpentinized and later changed to an amorphous gray-brown substance resembling talc. Accessive alteration is caused by hydrothermal action[38].

Femahastingsite has altered to sericite and biotite.

Alteration to muscovite and magnetite has been active on some biotite.

In several dykes which were originally camptonite or monchiquite the groundmass has entirely altered to zeolites which, in places, show a radiating structure. Phenocrysts of amphibole in these dykes have been changed to calcite and chlorite.

Most of the rocks of the section are quite fresh but along edges of some of the dykes and along small faults where the ground waters have been able to circulate the essexite is almost entirely rotten and is colored reddish-brown from iron oxide

(38) Bancroft & Howard. Essexites of Mount Royal. P.38

stain. In the western end of the section there are several small dykes which appear to have been fairly late injections and which have entirely altered. These dykes can be pulled to pieces with the bare hands. Much of this alteration may have been caused by hydrothermal action.

THE ALKALINE GABBRO.

The exposures studied along the tramway give a complete cross-section of the alkaline gabbro of Mount Royal. The contact of altered Utica sedimentary rocks is covered by the lining of the tunnel on the east end of the section. The terminus of the tramway near the summit of the mountain is on the eastern tip of a mass of limestone that extends from the west as a vertical screen in the intrusive rock. This limestone is relatively narrow but, where cut by the C.N.R. tunnel beneath Mount Royal, is the same width as at the surface showing the contacts are nearly vertical. It is perhaps the wedge which accounts for the brecciation of the alkaline gabbro as exposed along the section.

MAFIC-RICH FACIES - The earliest rock of the series of alkaline gabbro intrusions is black, holocrystalline, medium-grained with a granitoid texture. In hand specimens, augite crystals ~~as~~ 1cm. by ½cm. are seen to be abundant. Spots of grayish-white plagioclase give the specimens a mottled appearance. A few specks of pyrite or pyrrhotite are the only other visible constituents. Examination of thin sections show the rock is approximately 60 percent augite, 10 to 30 percent plagioclase which is zoned from An.90 at the core of An.28 at the margin, about 10 percent hornblende, and 10 percent biotite. One specimen has 20 percent biotite; the greatest amount of this mineral found in any specimen from the tramway. Iron ores are plentiful, forming, in places, as much as 10 percent of the rock. Plagioclase is included within the ferromagnesian minerals as well as interstitial to them. Crystals of olivine are found in sections of these rocks. Olivine invariably is surrounded by reaction rims containing all the other essential minerals. The inner zone of the rim is commonly pyroxene which is surrounded on the outer edge by hornblende, biotite, magnetite, and apatite in a mixed mass. The ferromagnesian minerals tend to be idiomorphic. Well defined crystals of augite, femahastingsite and, less commonly, biotite are found with interstitial lath-shaped plagioclase feldspars.

The black facies of the gabbro is intruded by later facies with a light gray to black color. The intrusions of the later rocks, although in some places in definite and persistent dykes, are generally in indefinite dyke-like masses which appear to have been intruded before any major jointing system had formed in the original facies. Thus, although the contacts between the facies are sharp they are jagged in outline and do not hold any direction for more than a few inches. These irregular intrusive forms give the section a very brecciated appearance. The successive intrusions of alkaline gabbro have formed banded and schlieren structures in many places.

<u>YOUNGER FACIES</u> - In the lighter-colored schlieren, the percentage of augite is less than in the black facies and there is a corresponding increase in the percentage of plagioclase and a slight increase in the percentage of femahasting-

site. Biotite is in about the same amount as in the older facies but no olivine is found. In the hand specimens, laths of hornblende, as much as 2 cm. long with a cross-section of 0.4 cm., are prominent. With increasing amounts of plagioclase the rock assumes a mottled black on gray appearance instead of the original gray on black. Augite is present but is commonly in much smaller crystals than those of the earlier facies. In thin sections, the plagioclase is found to be less calcic than that of the dark facies. In facies in which femahastingsite exceeds augite, the zones of the plagioclase range from approximately An.72 to An.30. The outer zones of the plagioclase of all the gabbros are between An.28 and An.32. The most calcic central zone measured is An.92. All gradations in composition between An.30 and An.92 are found. The more sodic feldspars are in the later intrusives (the last of the facies to crystallize). The average composition of the feldspar is labradorite.

<u>FLOW STRUCTURE</u> - A flow structure is common in the lighter colored facies. As the rock becomes lighter in color the size of the ferromagnesian crystals decreases and larger laths of plagioclase appear. This may be accompanied by a gneissic banding in the rock with elongation of the small crystals of augite, femahastingsite, and plagioclase in the direction of movement. The banding is due to a different proportion of plagioclase and ferromagnesian minerals in adjacent streaks. At the time of formation of this structure the intruded mass was probably viscous and allowed the injection of a magma rich in plagioclase. Repeated injections of more material, which, due to differentiation, was more feldspathic than the original magma, would give the gneissic bands. Light and dark bands in

a few of the gabbro dykes may be due to differential movements of the magma along the walls. The earlier-crystallized ferromagnesian minerals carried up with the intrusion would become attached to the walls giving a lighter-colored centre of plagioclase-rich rock. This structure is not common.

DYKES OF ALKALINE GABBRO - Probably all the younger facies of the alkaline gabbro of the tramway section are in dykes showing sharp and regular contacts against the main mass. The main body of alkaline gabbro had, by the time of these later intrusions, been stressed and fractured along sharply defined joints. The younger facies contains over 60 percent plagioclase, zoned from An.65 to An.30, and is almost pegmatitic in character. Femahastingsite and biotite together exceed the augite.

A common structure throughout the later facies of the section is the parallel arrangement of the larger crystals of femahastingsite. The oriented crystals are larger than those of the other alkaline gabbros and so must have had suitable conditions in which to grow. They have oriented themselves at right angles to the walls of the dyke or injected mass. The crystals are all idiomorphic in a matrix of plagioclase which seldom has zones more calcic than An.72. The large size of the amphiboles and the unusual relationship to the walls of the dykes allow several conclusions to be drawn. The crystals must have been developed while the magma was quiescent because slight movement would have broken the slender crystals. Furthermore, an adequate amount of material to form amphibole must have been available in the magma and, since in some facies the amount is almost 75 percent of the total, little plagioclase could have been present. The large size of the amphiboles, furthermore, suggests slow cooling with few centres of crystallization, but the plagioclase associated with the rock shows much zoning which is commonly taken to indicate a rapid cooling.

EXAMPLE OF ORIENTED CRYSTALS - The most prominent example of oriented amphibole crystals is a dyke No.2304 on the western end of the section. This dyke, shown in figure 6, three feet wide with a steep dip to the east, is composed of amphibole crystals, up to 4 inches long by 1 inch in cross-section, and plagioclase with accessory minerals. The amphibole is about 60 percent of the rock. The plagioclase is zoned from An.72 to An.30. The amphibole crystals are oriented in a V-shape, with some irregularities. The point of the "V" is downwards in the centre of the dyke. The height of the "V" is about one foot. In this case it is possible that the crystals grew with their longest crystallographic axes perpendicular to the walls of the dyke. If after crystallization of the femahastingsite a slight downward movement occurred in the still viscous matrix the amphibole crystals would move with the matrix. Assuming that the centre of the dyke was less viscous than the sides, the centre would tend to move back faster than the sides and a "V" shape would result. The amount of backward movement is shown by the displacement of the crystals, approximately one foot.

CONTACT BETWEEN TWO FACIES - The contact between different facies of the gabbro is well shown by specimen 2335-2. The older rock (section No.2335) is composed of augite 50 percent, plagioclase 15 percent, femahastingsite 15 percent, biotite 8 percent, and accessories including olivine 2 percent.

The plagioclase is zoned from An.75 to An.27. The augite is in aggregates of crystals cut by small stringers of plagioclase zoned from An.49 to An.42. This rock is intruded by a facies richer in plagioclase and amphibole. The plagioclase is zoned from An.70 to An.33. The thin section (No.2336) shows several large augite and two large hornblende crystals in a matrix of augite, hornblende, plagioclase, feldspar, and iron ore. Near the contact with the older rock some chilling is shown by the development of a fine-grained aggregate of pyroxene, plagioclase and iron ore. Some of this marginal facies consists entirely of aggregates of very fine augite individuals. Immediately beyond this margin and in the intruding facies hornblende crystals up to 0.5 cm. long and 0.1 cm. cross-section are developed. On the contact with the chilled material the amphiboles lie parallel to the contact. Half a centimeter away there is no definite arrangement of the crystals. Thin-section NO.2338 is taken from the contact of the chilled and intruding facies. The chilled facies consist entirely of augite and plagioclase with iron ore, the intruding facies of hornblende, plagioclase and iron ore. On the pyroxene side of the contact the plagioclase zoning ranges from An.72 to An.22 and on the amphibole side from An.62 to An.30. Less than 2.5 cm. from the contact, augite appears in the intruding rock. When the rock was chilled the augite was crystallizing out with the plagioclase and tended to gather along the contact. Chilling prevented the further crystallization of augite, so hornblende resulted. Farther from the contact, in the younger rock, the chilling was not effective and the normal crystallization of augite resulted.

STRUCTURAL RELATIONSHIPS - The igneous rocks of Mount Royal were intruded into a neck or plug which may have been connected with volcanic activity, but there is no evidence to show that the intrusives reached the surface. /The first magma to intrude into this plug was basic in character and consolidated into a dark colored rock, described on Page 24 During crystallization of the magma, differentiation took place causing the magma to become less calcic. After the basic facies had crystallized it was intruded repeatedly by magmas which were products of differentiation of the original magma. Thus an intrusive complex has been formed which consists of almost identical rocks except that the younger facies are more acidic than the older, illustrated by the appearance of more sodic feldspars in the younger rocks.

On the summit end of the tramway section, the normal order of successive intrusions containing more sodic plagioclase has not been followed. Here there appears to have been two sets of intrusions. A basic facies intrudes a facies containing more sodic feldspar. The proximity of the mass of limestone in the centre of the mountain may explain this departure from the normal order of intrusion. Differentiation on the north side of the limestone screen may have proceeded faster than on the south side. Finally, the magma from the south welled around the limestone barrier and intruded the apparently younger rocks to the north.

FRACTURE SYSTEM - At the time of intrusion of the earlier facies of alkaline gabbro into the original basic facies, no system of extensive joints had been developed and, consequently, the intrusions of the earlier facies have caused the rocks of the section to have a pronounced brecciated appearance. The later facies are in large dykes which hold their dip and strike persistently.

The dykes of the section have followed almost vertical joints. No system could be determined. The joints strike irregularly and the joint planes are curved in many places. A few joints have been developed with dips of 60 deg. to 70 deg. but in general these are not well defined.

A system of horizontal joints has been developed later than the other types. These vary somewhat in dip but are not inclined more than 15 deg. to the horizontal. The joint planes tend to parallel the slope of the hill. This system probably was developed by relief from loading brought about by weathering. Sheet joints of this type developed from relief are a common phenomenon in granite quarries.

CLASSIFICATION.

A system of classification for rocks satisfactory to everybody is still to be sought. The diversity of the rocks of the tramway section as well as the scarcity of rocks of such composition has caused the usual differences of opinion regarding nomenclature. Three systems will be discussed.

SYSTEM USED BY BANCROFT AND HOWARD - A system that has found wide usage is based on the now-discarded conception that a gabbro shall be characterized by augite and a diorite by amphibole. By this system, if pyroxene predominates the rock is a gabbro and if amphibole predominates the rock is a diorite. No allowance is made for the presence of olivine or biotite or for the calcity of the plagioclase, all of which have a direct effect upon the chemical composition of the rock. Bancroft and Howard have classified the basic rocks of Mount Royal on this basis. Chemical analyses given by them for andesine gabbro and diabase gabbro (analyses 3 and 4) show 42.50 and 41.55 percent silica or 8 percent more silica than an analysis of a "dioritic phase" (analysis 8). This of itself is an anomaly as common usage holds that a diorite is more siliceous than a gabbro.

SHAND'S CLASSIFICATION - S.J. Shand[39] has classified igneous rocks on the basis of the degree of saturation of the bases with silica. The rocks of the tramway section are in the group of "Undersaturated Rocks," Part B, (with alkalis undersaturated) Group 11. They are "Rocks which contain more anorthite than the sum of the orthoclase and leucite present." No instance is known to Shand of a leucite rock which satisfies this definition so illustrations are drawn from the nepheline and analcime rocks. "We shall therefore give the name dioroid (or essexite) to rocks with less than 50 percent of heavy minerals, and gabbroid (or theralite) to those with a color-index greater than 50[40]." In his definition of heavy minerals Shand has chosen 2.8 as the critical density because minerals less dense than this are inclined to be light colored; minerals with greater specific gravity are inclined to be dark. The essexites of St. Hilaire and Yamaska Mountains are placed in the dioroid group[41]. As the greatest mass of rock on the tramway section is dark colored and contains large percentages

(39) Shand, S.J. Eruptive Rocks. 1927.
(40) Ibid. P.287.
(41) Ibid P.288

of heavy minerals the rocks of this locality would be gabbroids or theralites.

CLASSIFICATION BASED ON PLAGIOCLASE - Classification may be based on the calcity of the plagioclase. As the calcity bears a relationship to the chemical composition of the rock, this system classifies rocks almost according to their chemical composition. Diorites then contain andesine and gabbro, labradorite and the dividing line is at An.50. As the average composition of the plagioclase is greater than An.50 in every thin-section examined, the rock is a gabbro. The high percentage of alkalis in the chemical composition show that the rock is a gabbro with alkaline affinities. The mineralogical composition, the paucity of silica, the appearance of nepheline in the norms of the rock, and the presence of ferromagnesian minerals having considerable amounts of alkalis in their composition show that the rock is related to the essexite theralite family.

Adopting the last method of classification, all the rocks of the tramway section are alkaline gabbros, or since they have no free nepheline but considerable normative nepheline they are perhaps more properly theralite-gabbros. The class into which they fall is therefore the same as under Shand's classification. Variations may be designated on the basis of prominent mafic minerals, such as olivine-theralite-gabbro, augite hornblende-theralite-gabbro.

ORDER OF CRYSTALLIZATION.

The minerals of the alkaline gabbros from Mount Royal tramway have not followed Rosenbusch's Rule of crystallization in igneous rocks but have formed according to a series starting with olivine and very calcic plagioclase.

Olivine and anorthite were the first minerals to crystallize. These were followed by augite and less calcic plagioclase. The olivine probably had finished crystallizing before augite started. The most calcic plagioclase found had a composition of An.92; this was included by an augite crystal. The first augite to crystallize was a titaniferous variety colored slightly pinkish. When the plagioclase reached the composition of An.72, approximately 1/20 of the plagioclase had crystallized and 1/10 of the augite. At this point, An.72, hornblende started to crystallize and the augite changed to colorless or slightly greenish because the titanium which had formerly been used by the augite was demanded for the amphibole. The first hornblende to crystallize was magnesiohastingsite. Crystallization continued with plagioclase, augite and hornblende crystallizing together. The hornblende changed in composition to femahastingsite and finally, in the nepheline syenites, to ferrohastingsite. The crystallization of hornblende took 30 percent of the remaining plagioclase out of the magma and accounts for a definite break in the zones of the plagioclase between An.55 and An.65. Biotite began to crystallize somewhat later than the hornblende; the commencement of crystallization of this mineral was not determined.

The accessories began to crystallize after augite had started. Magnetite is found included by augite of the earlier generations and is also found later than some of the hornblende, but was earlier than biotite. Apatite is very commonly included by the sodic zones of plagioclase but is rare as inclusions in early augite crystals. It probably crystallized about the time of formation of the femahastingsite. Ilmenite is somewhat later than augite and may have crystallized at about the same time as apatite.

DYKE ROCKS.

The intrusion of the alkaline gabbro complex into Mount Royal was followed by a period of intrusion of dykes related to the alkaline magma. Many types of dykes have been described from Mount Royal. In the tramway section the dykes include pegmatites, camptonites, syenites, monchiquites, calcite veins, and alkaline gabbros saturated with later syenitic material. No order of intrusion could be worked out except that the dykes are younger than all facies of the alkaline gabbro. Pegmatites are the most numerous of the satellites but camptonites are common also. The largest dyke is eight feet wide but the average width of all the dykes is less than one foot.

PEGMATITES - Most of the pegmatites of the tramway section consist of feldspar, 90 to 98 percent, with quartz and accessories in minor amounts. The granularity is medium coarse to very coarse. Drusy cavities are common.

The feldspar is plagioclase and soda-orthoclase. The plagioclase is zoned from An0 to An.30. Soda-orthoclase and albite form microperthitic intergrowths which in places are in reaction relationship to the plagioclase. Accessory minerals are those common to the alkaline gabbros; iron ores, apatite and sphene. Inclusions of fragments of the main intrusive body are quite common.

In two of the pegmatites large crystals of quartz, up to 2.5 cm. long by 1.5 cm. in cross-section, are found in the centre of the dykes. Small quartz crystals are common in nearly all the pegmatites, but are found to have grown from the sides of small veins containing quartz and calcite.

The pegmatites were followed by hydrothermal solutions which caused the alkaline gabbro to be altered in a similar manner to the exceptional alteration of "essexite" described by Bancroft and Howard(42). Large masses of the rock in the section are cut by numerous small pegmatite dykes and are greatly altered. In hand specimens this altered rock has the appearance of a normal alkaline gabbro cut by numerous parallel veinlets about 1 mm. to 2 mm. wide. These veinlets widen into globs of medium hard amorphous material. The globs show rounded outlines and are up to 1 cm. in diameter. In thin sections under the microscope the veinlets are found to consist of quartz and calcite with albite and orthoclase in minor amounts and sphene as an accessory. Small idiomorphic crystals of quartz have formed from the sides of the veins. The globs consist of an amorphous substance stained brown with iron oxide and are derived from the alteration of olivine and augite. No fresh olivine is present in the thin-sections of these altered rocks.

<u>CAMPTONITES</u> - The camptonites are gray to greenish-gray, fine-grained rocks commonly containing amygdules of calcite.

The plagioclase of the camptonites is zoned from An.60 to

(42) Bancroft and Howard, Essexites of Mount Royal, Montreal, P.Q. Trans. Roy. Soc. Can. 1923. P.34.

An.10 although individual crystals showing the entire zoning range are not common. Orthoclase is present in small amounts. Feldspar is approximately 40 percent of the rock.

Two varieties of camptonite are found. Of the seven camptonite dykes examined under the microscope, four are hornblende-camptonites and three are biotite augite-camptonites. In both types the ferromagnesian minerals form 25 to 50 percent of the rock and in both types there are amygdules of calcite.

The camptonites have been extensively altered by weathering near the surface. Pseudomorphs after amphibole are common. These pseudomorphs give blue interference tints and are pale green chlorite. Plagioclase is altered to zeolites and in one dyke no feldspar survived this alteration; the entire thin section of this rock consists of pseudomorphs after amphibole in a groundmass of zeolites, calcite, and magnetite.

Iron ores are present in the camptonites and form in places 15 percent of the rock. They are found as anhedra up to the size of the grain of the rock but are more common as dust-like particles scattered throughout the other minerals.

<u>SYENITE</u> - The syenite dykes are pegmatitic. They contain 95 percent plagioclase and soda-orthoclase with small amounts of biotite, hornblende and augite.

In one dyke (Number 2370) the plagioclase is zoned from An.0 to An.52. Small patches of white mica are found interstitial to the fresh feldspar and may indicate the former presence of nepheline. None of the original mineral remains in these patches.

In another dyke (No.2359) pleonaste is an accessory and small radio-active haloes surround opaque mineral grains which may be zircon. These haloes are small and resemble those found in rocks of Tertiary age. The plagioclase is zoned from An.24 to An.28.

MONCHIQUITE - In the hand specimen this dyke is fine grained and dark colored. In the thin section under the microscope it is seen to consist of large pseudomorphs after olivine. These pseudomorphs contain analcite, calcite and white mica and are set in a groundmass of calcite, zeolites, and magnetite. Pseudomorphs after augite and hornblende consist of calcite. The plagioclase has been altered entirely to zeolites.

ALKALINE GABBRO (ALTERED) - This rock may be an intermediate type between the essexite and nepheline syenite.

In the hand specimen phenocrysts of augite and hornblende are seen in a groundmass of plagioclase and small ferromagnesian minerals.

In the thin section, phenocrysts of augite, hornblende, biotite and plagioclase are seen in a groundmass of plagioclase and nepheline. The plagioclase has a composition of An.28 in the phenocrysts and An.10 in the groundmass.

The rock is very rich in accessories - magnetite, sphene, apatite and zircon.

Augite is present in large idiomorphic crystals the outer edges of which have been altered by reaction to green hornblende.

VEINS - Small veins of calcite and quartz are common in the tramway section. In most cases these veins are less than half an inch wide but in places where they have followed dykes and large joints they are as wide as six inches.

In thin section the veins are found to consist of calcite 85 percent, Quartz 5 percent, orthoclase 5 percent, and accessories 5 percent. Inclusions of minerals of the alkaline gabbro are replaced by calcite. Quartz and orthoclase have crystallized earlier than the calcite and are found as small idiomorphic crystals. The calcite is finely crystalline. The minerals are stained in places by iron oxide from weathered pyrite. Pyrite can be seen in hand specimens.

SEDIMENTARY ROCKS.

UTICA - The contact between the igneous rocks of the tramway section and the hornfels derived from Utica shale extends from the north portal of the tunnel to the lower end of the section. This contact is covered by the lining of the tunnel and by the ballast of the tramline so that it can be observed only at the northern end where it crosses the cutbank. At this point the altered Utica dips steeply towards the contact. On the east side of the north entrance to the tunnel the beds dip away from the intrusive mass and are locally contorted.

Thin-sections of this rock show that the shale has been altered to a hornfels composed of albite and diopside with small amounts of biotite and iron ores. The rock is fine-grained and shows some alignment of minerals. Metacrysts are small and consist of albite and diopside. The shale is very finely bedded but most of the bedding has been obliterated by metamorphism caused by the intrusive. An almost horizontal sheet jointing has been formed and obscures the bedding planes.

On the east side of the north portal, the Utica is cut by a large dyke (No.2354, described on P.38). Within one foot of the contact with the dyke the hornfels consists of biotite, albite, diopside, iron ore, and quartz injected by plagioclase and apatite. Biotite has recrystallized. Diopside is in poikilitic arrangement with the biotite and albite.

TRENTON - Trenton limestone underlies the Utica on the north end of the tramway section and outcrops at the tramway terminus near the summit.

The Trenton conforms with the Utica in strike and dip at the northern outcrop. Here it is locally folded against the intrusive mass and dips steeply under the Utica. Further down the tramway towards Fletcher's Field the limestone is undisturbed by the alkaline gabbro and dips gently to the south. In thin-section, the folded Trenton is a calc-silicate-hornfels. It is very fine-grained and the minerals present could not be determined accurately. Colorless pyroxene, probably diopside, garnet, quartz, calcite, and iron ore are present. Calcite is in minor amounts; the rock has been almost completely silicified.

The weathered surface of the rock gives it a creamy appearance but the fresh surface is greenish-gray.

At the summit end of the section, a mass of limestone extends from the west as a vertical wedge in the intrusive rock. This limestone is narrow but extends vertically to the C.N.R. tunnel through Mount Royal. In the tunnel it is the same width as at the surface showing that the contacts are almost vertical. No thin-section of this limestone was examined. It is not located on the map of Mount Royal Tramway in the appendix but outcrops about 100 yards south of the last outcrop of alkaline gabbro.

SANDSTONE INCLUSION (POTSDAM). - There is an inclusion of sandstone in the alkaline gabbro eighty-five feet from the south portal of the tunnel on the east side of the tracks. The inclusion is about 10 inches wide by 30 inches high and consists of irregular quartz grains, up to ¾ mm. in diameter, cemented by calcite. According to Dr. T.H. Clarke it is perhaps upper Potsdam. This formation is about 2000 feet below and such a fragment must have been brought up in the flow of the magma. The quartz is untwinned suggesting that it has not been heated above 575 deg. C. despite its inclusion in the magma.

Surrounding this inclusion there is up to four inches of fine-grained greenish rock which, under the microscope, is found to be albite, 98 percent, of the composition of An.0 to An.8. Accessories in the albite are iron ores, biotite, apatite, and rutile. The feldspar is altered greatly to white mica and the rock is stained by iron oxide. Pelletier[43] has shown that in the assimilation of sandstone inclusions in the alkaline magma of Mount Royal Heights, feldspathization has been the dominant factor. Quartz grains give place to a zone of acid feldspars along an irregular dividing line broken here and there by minute irregular stringers of feldspar penetrating the inclusion along cracks between the quartz grains.

(43) Pelletier, RA. Absorption of Inclusions of Potsdam Sandstone by an Alkalic Magma, Mount Royal Heights, Montreal. McGill University Thesis, 1924. Unpublished. P.13

APPENDIX 1.

CHEMICAL ANALYSES.

CHEMICAL ANALYSES OF MONTEREGIAN
INTRUSIVES.

	1.	11.	111.	1V.	V.
SiO_2	44.66	43.10	42.50	41.55	40/62
TiO_2	2.27	2.80	2.60	3.92	2.42
Al_2O_3	9.64	13.94	13.67	14.84	5.94
Fe_2O_3	4.98	4.92	5.13	6.62	4.03
FeO	6.65	6.93	7.20	8.24	12.18
MgO	12.83	8.86	9.73	7.83	21.16
CaO	13.11	14.65	12.98	14.64	9.16
Na_2O	2.07	2.50	3.18	1.93	1.68
K_2O	1.17	0.89	1.05	0.25	0.80
H_2O	0.90	0.70	1.30	0.19	0.70
MnO	0.19	0.14	0.11	0.15	0.24
P_2O_5	0.24	0.27	0.21	0.10	0.67
CO_2	0.37	0.64	0.43	0.19	0.47
Cl	0.07	Tr.	0.27	Tr.	Tr.
Cr_2O_3	-	-	-	none	0.07
SO_3	-	none	-	none	0.04
$Fe\ S_2$	0.22	-	-	-	0.21
Fe_7S_8	Tr.	-	-	-	0.02
S	-	0.22	0.38	0.16	-
SrO	0.03	0.03	-	none	-
BaO	none	0.03	-	none	-
Sum	99.40	100.62	100.74	100.61	99.96

Analyses of Mount Royal Essexites from Bancroft and Howard, Transactions of the Royal Society of Canada, 1923.

1. Montrealite.

Cote des Neiges Road near Reservoir.

Class 1V. Order 2. Section 2. Rang. 2.
Subrang 2.

2. Essexite.

Lookout, Mount Royal.

Class 111. Order 6. Rang. 4. Subrang 4.

3. Andesine Gabbro.

Mount Royal Tunnel.

Station 232 + 70

Class 111. Order 6. Rang 3. Subrang 4.

4. Diabase Gabbro.

Mount Royal Tunnel.

Station 204 + 85.

Class 111. Order 5. Rang 4. Subrang 5.

5. Wehrlite.

Mount Royal Tunnel.

Station 204 + 00

Class 1V. Order 2. Section 3. Rang 3.
Subrang 2.

	VI.	VII.	VIII.	IX.	X.
SiO_2	39.00	37.50	34.28	39.97	43.91
TiO_2	1.82	3.57	5.25	4.05	3.80
Al_2O_3	7.97	8.22	16.01	8.68	19.63
Fe_2O_3	3.51	8.27	5.01	8.63	4.61
FeO	11.04	9.70	9.59	7.99	5.55
MgO	19.43	12.11	8.67	10.32	5.20
CaO	10.00	17.10	12.48	15.18	9.49
Na_2O	1.89	1.08	2.62	1.19	4.49
K_2O	1.61	0.83	1.38	0.74	1.51
H_2O	1.90	0.70	1.50	0.57	0.53
MnO	0.14	0.13	0.10	0.19	0.07
P_2O_5	0.20	0.08	2.32	0.10	0.32
CO_2	1.30	0.71	0.16		
Cl	-	0.16	0.10	-	-
Cr_2O_3	-	-	-	-	-
SO_3	0.03	-	0.05	-	-
FeS_2	0.20	-	0.60	1.01	-
Fe_7S_8	0.25	-	0.04	-	-
S	-	0.35	-	-	-
SrO	-	-	0.17	-	-
BaO	Tr.	-	0.03	Rest – 2.16	Rest 1.15
Sum.	100.29	100.51	100.36	99.77	99.81

Vl. Vll. Vlll. from Bancroft and Howard, Transactions of the Royal Society of Canada, 1923.

6. Wehrlite.

Essexites of Mount Royal, Bancroft & Howard.
Mount Royal Tunnel, Station 298 + 03, Class lV.
Order 1, Section 3, Rang 2, Subrang 2.

7. Pyroxenite.

From Essexites of Mount Royal, Bancroft & Howard.
Mount Royal Tunnel, Station 247 + 80
Class lV. Order 2. Section 2. Rang 2. Subrang 2.

8. Dioritic Phase of Essexite.

From Essexites of Mount Royal, Bancroft & Howard.
Mount Royal Tunnel, Station 215 + 00. Class 111.
Order 7, Rang 4. Subrang 4.

9. Yamaskite.

Yamaska Mountain.
From Ann. Report Geology Survey of Canada.
Vol. XVl. Part H. Dr. G.A. Young.

10. Essexite.

Yamaska Mountain.
From J.J. O'Neill. Memoir 43. Geology Survey of Canada. G.A. Young, Analyst.

	XI.	XII.	XIII.	XIV.	XV.
SiO_2	48.85	48.69	50.40	49.96	51.26
Al_2O_3	19.38	17.91	-	18.83	23.78
Fe_2O_3	4.29	3.09	5.58	2.52	1.81
FeO	4.94	6.41		6.64	2.70
MgO	2.00	3.06	-	3.52	1.96
CaO	7.98	7.30	6.77	7.42	8.00
Na_2O	5.44	5.95	6.24	5.25	6.72
K_2O	1.91	2.56	2.56	2.58	2.16
H_2O+	0.68	0.95	-	0.60	0.65
H_2O-	-	-	-	-	-
BaO	-	0.08	-	-	-
TiO_2	2.47	2.71	1.17	2.40	1.66
P_2O_5	1.23	1.11	0.09	0.25	-
MnO	0.19	0.15	0.77	0.20	0.10
Sum.	99.36	100.02		100.17	100.00

11. Normal Essexite (Andose).

Mount Johnson.

From F.D. Adams, Guide Book 3, Geol. Survey of Canada, 1913.

12. Olivine-bearing Essexite (Essexose).

Mount Johnson.

From F.D. Adams, Guide Book 3, Geol. Survey of Canada, 1913.

13. Rock forming transition from Essexite to Pulaskite, Mount Johnson.

From F.D. Adams, Guide Book 3, Geol. Survey of Canada, 1913. Partial analysis.

14. Essexite.

St. Hilaire Mountain.

From J.J. O'Neill, Memoir 43, Geol. Survey of Canada. M.F. Connor, analyst.

15. Rouvillite.

St. Hilaire Mountain.

From J.J. O'Neill, Memoir 43, Geol. Surv. of Canada. Anaylsis incomplete.

	XVl.	XVll.	XVlll.	XlX.	XX.
SiO_2	45.44	44.62	40.68	53.15	45.37
Al_2O_3	5.85	7.90	19.83	17.64	6.21
Fe_2O_3	2.84	4.22	4.68	3.10	2.40
FeO	6.49	5.67	6.49	4.65	8.09
MgO	16.24	14.00	7.67	2.94	18.67
CaO	18.16	19.44	17.64	5.66	14.47
Na_2O	1.03	1.20	1.10	5.00	0.85
K_2O	0.38	0.31	0.27	3.10	0.37
H_2O+	1.51	0.75	0.27	1.10	0.88
H_2O-	0.10	0.07	0.08	-	-
TiO_2	1.50	1.87	2.04	1.52	1.50
P_2O_5	-	-	-	0.65	-
MnO	0.24	0.10	0.10	0.46	-
BaO	-	-	--	0.13	-
Rest.	-	0.61	-	0.07	0.62
Sum	99.42	100.75	100.85	99.84	99.43

16. Olivine-Yamaskite.

Rougemont Mountain.

J.J. O'Neill, Memoir 43, Geol. Survey of Canada. M.F. Connor, Analyst.

17. Essexite (Rougemont Type).

Rougemont Mountain.

J.J. O'Neill, Memoir 43, Geol. Survey of Canada. M.F. Connor, Analyst.

18. Rougemontite.

Rougemont Mountain.

J.J. O'Neill, Memoir 43, Geol. Survey of Canada.

19. Essexite (Akerose).

Shefford Mountain.

J.A Dresser, Ann. Rept. Geol. Survey of Canada. Vol. XIII. Part L. 1900.

20. Essexite (medium composition).

St. Bruno Mountain.

J.A. Dresser, Memoir 7, Geol Survey of Canada.

	XX1.
SiO_2	44.00
Al_2O_3	27.73
Fe_2O_3	2.36
FeO	3.90
MgO	2.30
CaO	13.94
Na_2O	2.36
K_2O	0.45
H_2O	0.80
TiO_2	1.90
P_2O_5	0.20
MnO	0.08
FeS_2	-
Rest.	-
Sum.	100.02

21. Essexite (Hessose).

Brome Mountain.

J.A. Dresser, Amer. Jour. Science, May 1904.

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APPENDIX 11.

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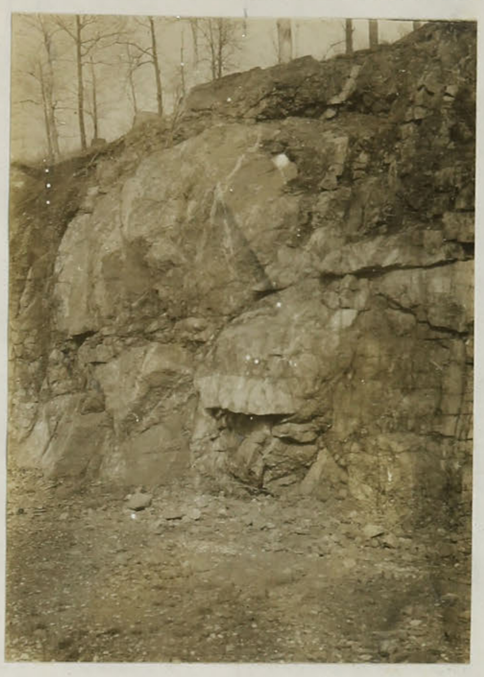
APPENDIX 111.

PHOTOGRAPHS.

Fig. 1.



Alkaline gabbro complex, showing irregular dykes of younger facies.

Fig. 2.

Altered alkaline gabbro complex cut by pegmatite dyke.

Fig. 3.

South portal of tunnel. Mafic-rich facies near tunnel. Complex of younger facies on right foreground.

Fig. 4.

Hornfels on east side of north portal cut by dyke No.2354. Page 38.

Fig. 5.

Contact between Trenton and Utica. North-east end of section. Trenton on right of photograph.

Fig. 6.

Large femahastingsite crystals in dyke No.2304. Western end of section. Page 28.

The hand specimens and thin sections used in the preparation of this thesis are available in the Petrographic Laboratory of the Department of Geological Sciences and are numbered according to the system used on the maps accompanying this thesis. Reports on each thin section are filed under the same number in the systematic set.

APPENDIX 1V.

MAPS OF TRAMWAY SECTION.

PART 1.

MOUNT ROYAL TRAMWAY

F.C. BUCKLAND
MCGILL UNIVERSITY. 1931–1932

SCALE 1 INCH = 20 FEET

LEGEND ON PART 4

TOPOGRAPHY BY J.J. HARRIS & R. BYERS


PART 2
MOUNT ROYAL TRAMWAY
PORTAL
SOUTH
710
705
700
695
690
685
680
675
670
A
B
F.C.BUCKLAND
MCGILL UNIVERSITY 1931-1932
SCALE 1 INCH = 20 FEET
LEGEND ON PART 4
TOPOGRAPHY BY J.J.HARRIS & R.BYERS


PART 3
MOUNT ROYAL TRAMWAY
F.C. BUCKLAND
McGILL UNIVERSITY 1931-1932
SCALE 1 INCH = 20 FEET
LEGEND ON PART 4
TOPOGRAPHY BY J.J. HARRIS & R. BYERS
B
C


PART 4
MOUNT ROYAL TRAMWAY
LEGEND
DRIFT
FILL
TRENTON LIMESTONE
CONTOURS
HORNFELS FROM UTICA SHALE
OUTCROP BOUNDARY
SANDSTONE INCLUSION
POWERLINE POLES
CAMPTONITE DYKES
CAR TRACKS
PEGMATITE DYKES
CONNECTION POINTS BETWEEN PARTS OF MAP
ALKALINE GABBRO DYKES
ROCK CONTACT
INTRUSIVE COMPLEX ALKALINE GABBRO
LOCATION OF SPECIMEN
F. C. BUCKLAND
MCGILL UNIVERSITY. 1931–1932
SCALE 1 INCH = 20 FEET
TOPOGRAPHY BY J.J. HARRIS & R. BYERS