MECHANISM OF EMPLACEMENT OF THE MONTEREGIAN INTRUSIONS

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ABSTRACT

Although there was considerable explosive activity in the western end of the Monteregian province, most of the basic rocks of the main intrusions were emplaced in a passive manner. These intrusions form vertical plug-like bodies in which there is usually a steeply dipping igneous foliation parallel to the contacts. Flat lying sedimentary rocks around the intrusions were neither domed up, nor punched up by the magma. Instead, room for the intrusions was provided by the partial fusion and stoping of the country rocks, evidence of which can be found in the contact zones.

The basic rocks of the Monteregian intrusions were emplaced as plug-like bodies of convecting magma that brought up the necessary heat to continue the partial fusion and stoping process. Some of the partially fused sedimentary rocks were assimilated by the basic magma. However, some may have been transported to depth and later intruded to form bodies of oversaturated rocks.

INTRODUCTION

The Monteregian intrusions are distributed along an east-west trending belt that marks the prolongation of the Ottawa graben across the St. Lawrence lowlands into the Appalachians. Their positions appear to be controlled by the intersection of this belt with north-northeasterly trending faults only some of which cut the Palaezoic rocks of the lowlands, the remainder being found in the underlying Precambrian rocks which are exposed along the northern boundary of the lowlands (Fig. 1). Two such faults extrapolated from the shield to the north, one passing through Mount Royal and the other through Ste. Dorothée, divide the Monteregian province into three distinct petrographic units (Fig. 1). In the eastern one calcic plagioclase is the main felsic constituent of the basic rocks, whereas in the central zone analcite is the only common felsic constituent, and in the western zone melilite is found in most basic rocks. Differences are also found in the leucocratic rocks. For example, quartz-bearing differentiates are found only in the eastern part, and ijolites and carbonatites occur only in the western zone.

The type of emplacement varies with the rock types along this belt. West of Mount Royal explosive activity was predominant, with most of the intrusions forming diatreme breccia pipes and small plugs and dikes in which a considerable amount of brecciated country rocks occurs. Around Mount Royal itself there is a profusion of dikes and sills (Bancroft &

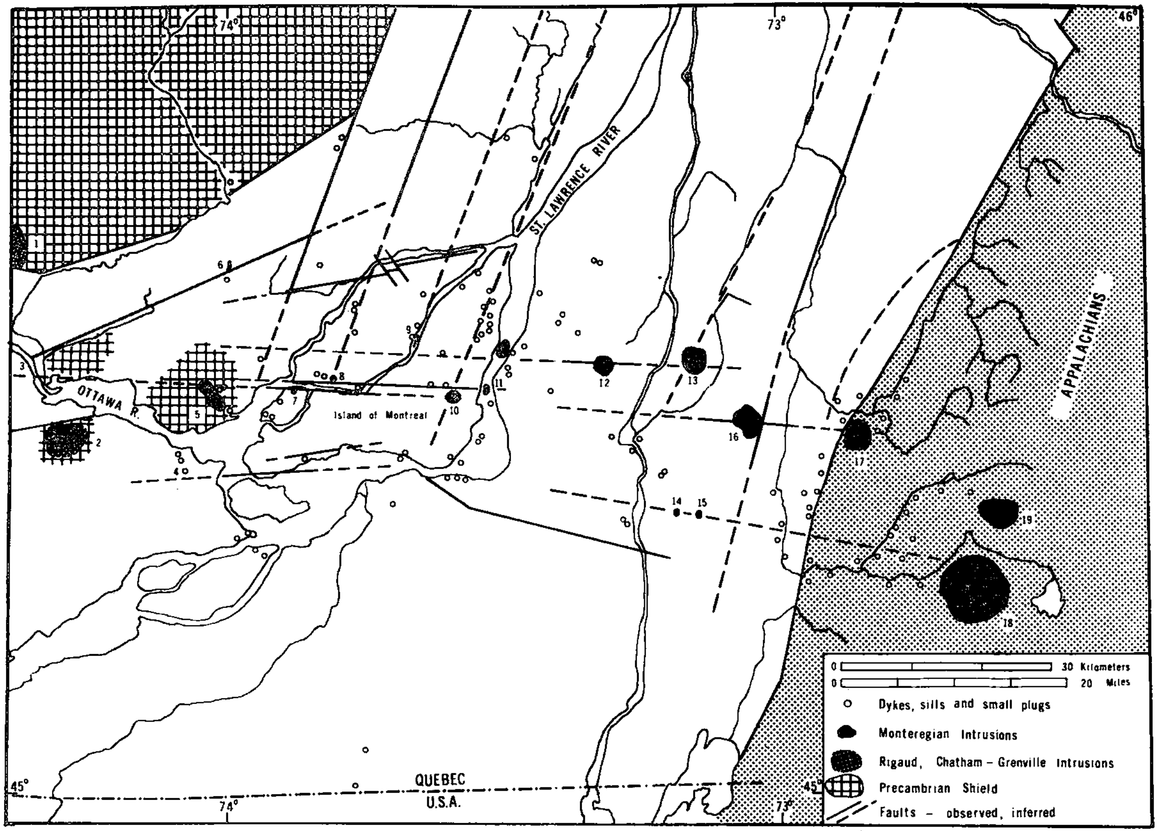


FIG. 1. Regional map of the Monteregian province showing the distribution of the main intrusions (Nos. 3-19), the dykes and sills, and the main structural features. The Chatham-Grenville (1) and Rigaud (2) intrusions are also shown, but these are older than the Monteregian rocks; (3) Carillon; (4) Ile Cadieux; (5) Oka; (6) St. Monique; (7) Ile Bizard; (8) Ste. Dorothée; (9) Visitation Island; (10) Mount Royal; (11) St. Helen's Island; (12) Mount Bruno; (13) St. Hilaire; (14) Iberville intrusion; (15) Mount Johnson; (16) Rougemont; (17) Yamaska; (18) Brome; (19) Shefford.

Howard 1923) and several diatreme breccias, the large one at St. Helen's Island (Osborne & Grimes-Graeme 1936; Clark *et al.* 1967) probably being connected to this intrusion at depth. In the eastern part of the province there is some explosive activity associated with the intrusion of syenites, but the basic rocks of the main intrusions appear to have been emplaced passively by stoping and partial fusion of the intruded country rocks and it is this aspect of the Monteregian activity that is to be discussed here.

General Features

The main intrusions are elliptical or lobate in plan (Fig. 2) and have vertical contacts. Each intrusion contains its own distinct group of rocks which in general fall into two groups, the basic ones ranging from peridotite to gabbro and the syenitic ones. All show primary layering or foliation which commonly parallels the contacts and dips vertically or at steep angles in towards the centers of the intrusions. In a few places shallower dips occur and gravitative settling appears to have taken place. The steeply dipping foliations are concentric about either a single center, as in the case of Mount Johnson, or about several centers as in some of the larger intrusions. The magnetic anomalies over each of the main intrusions indicate no change in the diameters of these bodies with depth, a conclusion supported by the section through Mount Royal along the railway tunnel (Clark 1952, p. 106) and a seismic survey of a buried intrusion in the Port of Montreal (Huntec Ltd. 1965; Fig. 3). These features suggest that each of the main intrusions is a pipe-like body extending to considerable depth. It is possible that such pipes might extend down almost to the source areas of the magmas and hence give rise to the independent nature of the rock types in juxtaposed intrusions, a feature difficult to account for if there is a common, near surface magma chamber from which several intrusions have been derived.

Cross-layering and channelling, such as that described from Mount Johnson (Philpotts 1968), is found in the basic rocks of all the intrusions and attests to the active part played by the magma during the formation of these rocks. In addition, plagioclase laths, hornblende and more rarely augite crystals commonly impart a steeply plunging lineation to the rocks, indicating that magmatic flow was either upward as in a volcanic neck, or downward along the walls as in a convection cell. The imbrication of feldspar laths within the vertical layers of Mount Johnson indicates that in this case, at least, the magma moved down along the walls of the magma chamber (Philpotts 1968 p. 1134). Evidence, to be presented

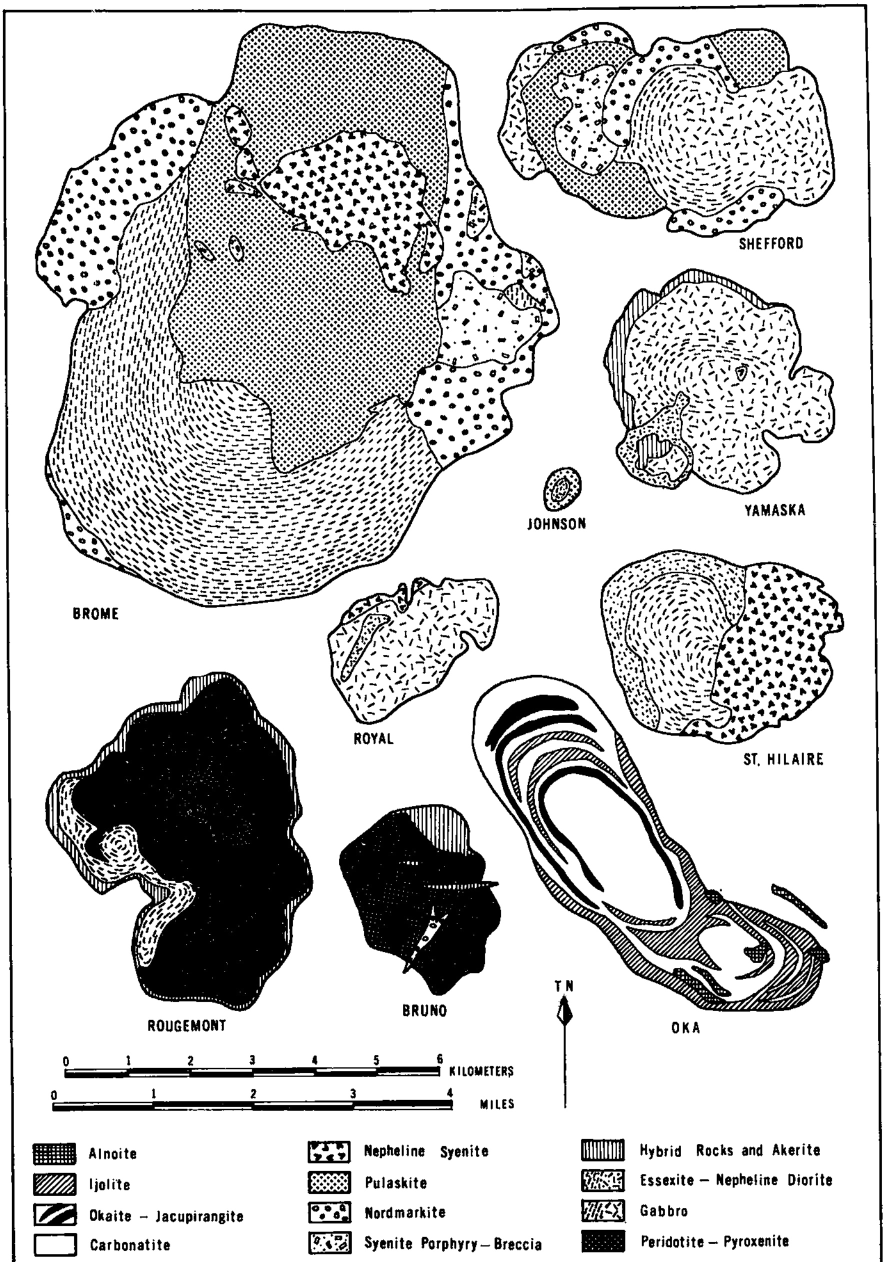


FIG. 2. Relative shapes and sizes of the main Monteregian intrusions. Data from Pouliot, 1969.

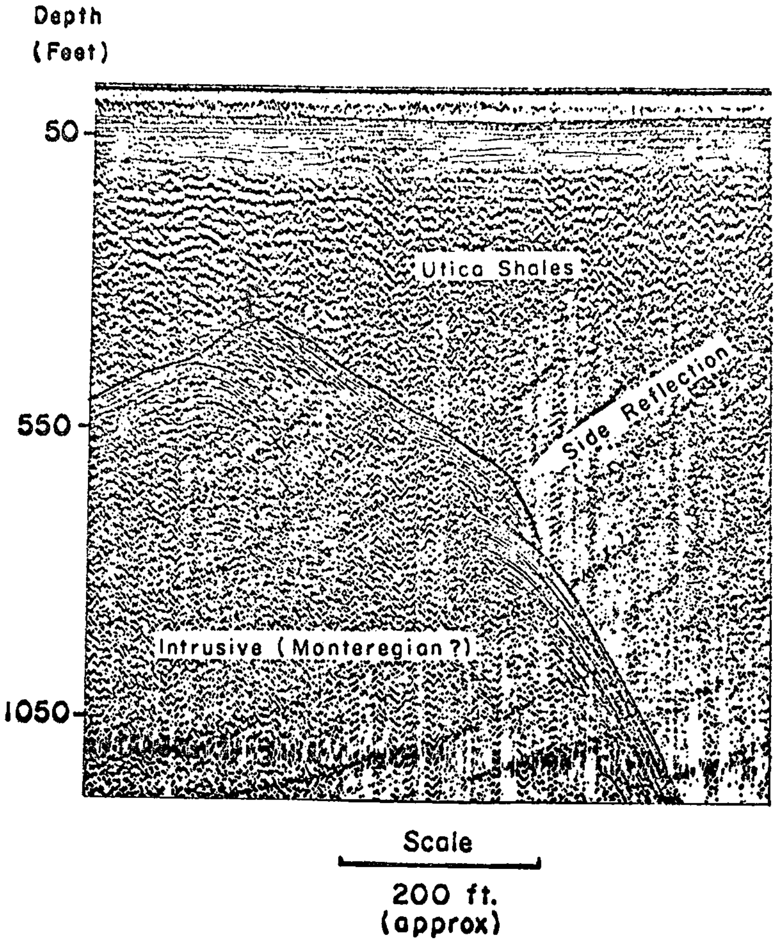


FIG. 3. Hydrosonde survey of the Port of Montreal showing a probable near surface Monteregian intrusion beneath the Utica shale. Survey by Huntec Ltd., Montreal, 1965.

below, from the contact zones of the other intrusions indicates that this type of magmatic movement was operative in each of the intrusions.

Mounts Royal, Bruno, St. Hilaire, Rougemont and Johnson all occur within the St. Lawrence lowlands, where as Yamaska, Shefford and Brome are within the Appalachians. The folded rocks surrounding these last three intrusions do not provide simple reference structures with which to study the effects of intrusion on the country rocks. However, the regional north-northeasterly trending fold axes are not disturbed by the intrusions and those rocks that strike into these bodies are truncated abruptly by the igneous rocks. The lowlands in contrast are underlain by flat-lying lower Palaeozoic sedimentary rocks which provide excellent datum planes with which to study the effects of intrusion.

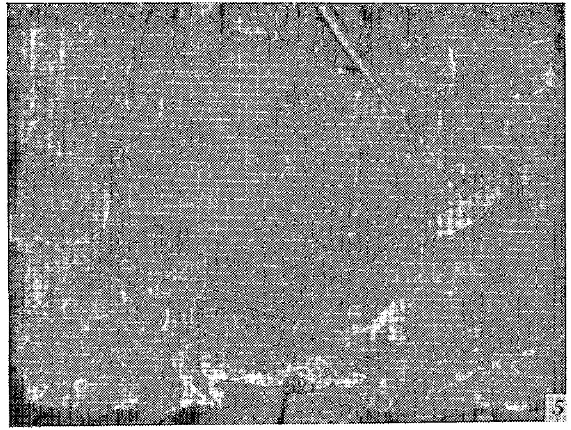
All of the intrusions within the lowlands, except Mount Royal, are found in contact with the Lorraine siltstones and shales. Mount Royal intrudes the Trenton limestone and in a few places is in contact with the overlying Utica shale. The flat-lying rocks around each of the intrusions indicate that there has been no upward doming during intrusion, nor has there been any column of rock punched upward to make room for the igneous rocks. This can be clearly demonstrated in the case of two newly discovered intrusions one of which is only partially exposed at the present level of erosion and the other is still buried beneath the Port of Montreal.

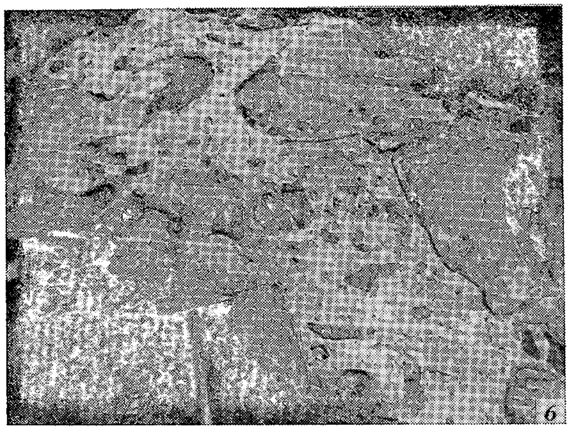
The Iberville intrusion, which is known mainly through its magnetic anomaly, is located 2.5 miles west of Mount Johnson, an intrusion to which it is probably very similar in size (Kumarapeli *et al.* 1968). Very few igneous rocks are exposed and the intrusion is almost entirely capped with Lorraine siltstones which are stratigraphically in their correct position and have not been pushed up by the intrusion.

In the course of a hydrosonde survey of the Port of Montreal in 1965 Huntec Ltd. discovered a body of rock which is intrusive into the Utica shale and comes within 500 feet of the present surface (Fig. 5). Although there is no direct evidence, it would appear that this is a buried Monteregian intrusion. The hydrosonde profile of this intrusion and the overlying flat shales indicates the lack of any upward deformation caused by the intrusion. The geological map of this area (Clark 1952) also indicates no disturbance of the rocks overlying this body.

Contacts

The general features of the intrusions suggest that magmatic stoping must have been one of the main mechanisms of emplacement. Around Mounts Bruno, St. Hilaire, Rougemont and Brome excellent exposures of the contacts between the basic rocks and the surrounding country rocks reveal extensive zones of rheomorphic breccia composed of fragments of refractory sedimentary rock in a matrix formed from the melting of less refractory beds. The development of these breccias can best be described by following the sequence of changes encountered in the hornfels as the contacts with the igneous rocks are approached.





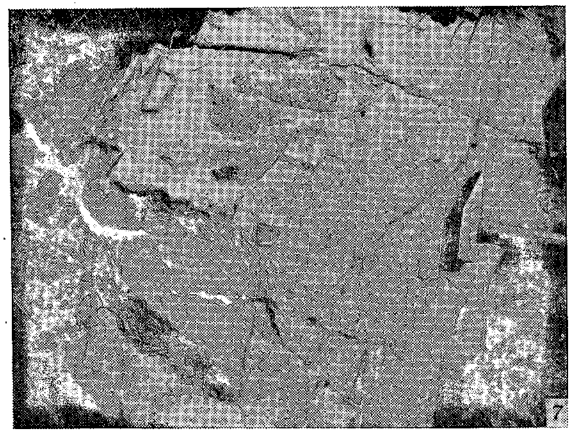


Fig. 4. Inward dipping hornfels near the contact on Mount Johnson.

Fig. 5. Highly mobilised hornfels from near the contact on Rougemont. Note boudins of quartz-rich beds surrounded by a more weathered (less quartz) matrix showing signs of considerable flow.

Fig. 6. Rheomorphic breccia from Rougemont containing fragments of refractory quartz-rich hornfels and fine-grained basic dyke rock in a quartzofeldspathic matrix which still preserves flowage layering.

Fig. 7. Rheomorphic breccia from Rougemont with extremely homogeneous matrix. Note in addition to the quartz-rich fragments there xenoliths of an igneous rock that is slightly more basic than the surrounding matrix. This igneous rock is similar to the matrix of the breccia towards the inside of the intrusion.

Exposures in the lowlands are not abundant, but in the outer parts of the metamorphic aureoles of Mounts Bruno, St. Hilaire, Rougemont and Johnson, hornfels formed from flat-lying siltstones and shales are exposed. These are now composed largely of quartz, biotite and oligoclase, although cordierite is present in the more shaly layers. These rocks are aphanitic except in some thin cross-bedded units of slightly coarser silty material composed almost entirely of quartz. At a distance from the contacts that varies from a maximum of 400 feet at Rougemont down to 75 feet at Mount Johnson, the hornfels begin to dip in towards the intrusions, the angle of dip increasing as the contacts are approached and becoming vertical at the contacts (Fig. 4). Within these zones of inward dips the grain size of the hornfels increases to a maximum of approximately one mm at the contact. During intrusion the rocks within these zones became more plastic with the result that quartz-rich beds tended to boudinage with the more heterogeneous material flowing around them. Close to the contacts the amount of flow was sufficiently great to produce breccias with fragments of the quartz-rich layers completely surrounded by a matrix of quartz, oligoclase and biotite (Fig. 5).

The increase in plasticity of the rocks towards the contacts was due to partial fusion of the more heterogeneous layers. The typical hornfels in the outer parts of the metamorphic aureoles consists of a polygonal aggregate of quartz and oligoclase with interspersed flakes of biotite. However, where the rocks first show signs of having flowed, the quartz is transformed into euhedral, doubly terminated β quartz grains (Fig. 10), and the plagioclase into laths exhibiting albite and carlsbad twins. Quartz grains in the outer part of the metamorphic aureole are free from inclusions, but in the zone of flowage they have cores that are commonly crowded with minute lath-like inclusions of plagioclase showing both carlsbad and albite twins. These features indicate that there must have been some magmatic recrystallization in these rocks.

As the contacts are approached the degree of melting increases until the rocks lose all signs of coherent bedding and become breccias composed of fragments of refractory sedimentary rock set in a matrix of rheomorphic material formed from the partial melting of the heterogeneous layers of sediment (Fig. 6 and 7). These zones of breccia vary considerably in width from 150 feet down to a few feet, but have been found to mark the contacts of the basic igneous rocks on Mounts Royal, Bruno, St. Hilaire, Rougemont and Brome. The contact at Mount Johnson is not exposed, but the zone of inward dipping hornfels is present. Whether rheomorphic breccia zones occur on Mounts Yamaska and Shefford is not known to the author.

The southern contact of the Brome intrusion is slightly different from those in the lowlands. The southern part of the intrusion is composed of layered gabbros that dip at relatively shallow angles in towards the center of the intrusion. The contact, however, is vertical and cuts across the strike of a variety of vertically dipping impure quartzites, phyllites and slate. It is not possible to say whether these country rocks have been folded downward on approaching the contact as around the intrusions in the lowlands. However, they do exhibit partial melting, and an extensive zone of rheomorphic breccia marks the contact. The breccia contains fragments of pure quartz veins and spotted hornfels containing cordierite, corundum, spinel and sanidine formed from the slate. These refractory xenoliths are set in a granitic matrix formed from the melting of the impure quartzite beds. The boundary of the hornfels with this rheomorphic breccia is quite irregular and clearly illustrates the refractory nature of the more aluminous beds (Fig. 8).

The matrices of the breccias change from quartzo-feldspathic compositions close to the hornfels to gabbroic ones on the inside of the breccia zones. In addition to the sedimentary xenoliths, the breccias contain a variety of igneous fragments that become more abundant towards the inside of the zones (Figs. 7 and 9). These igneous fragments, although always of more basic compositions than the matrix in which they occur, are composed of rocks that show clear signs of having been contaminated by the intruded sediments, and in fact, many are fragments of pre-existing breccias in which fragments of still more basic rocks are found (Fig. 9). Rock types exactly similar to those forming the igneous fragments can be found as matrix material towards the inner parts of the breccia zones, making it reasonable to conclude that a continuing process of partial fusion of the hornfels and incorporation of earlier formed hybrid rocks has led to the development of the breccias.

The variety of metamorphic grades preserved in the sedimentary xenoliths also indicate a complex origin for the breccias. Although biotite and quartz are stable in many of the xenoliths, others in close proximity to them may contain the higher temperature assemblage of hypersthene and sanidine. Similarly, the spotted hornfels xenoliths containing corundum, mullite, cordierite, spinel and sanidine in the breccias at the southern contact of the Brome intrusion indicate previous high temperatures far in excess of those indicated by the surrounding matrix assemblage of quartz, biotite and alkali-feldspar.

There are no sharp contacts between the breccias and the main igneous rocks of the intrusions. Instead, the matrix grades into whatever type of basic igneous rock is present in the intrusion and the fragments become

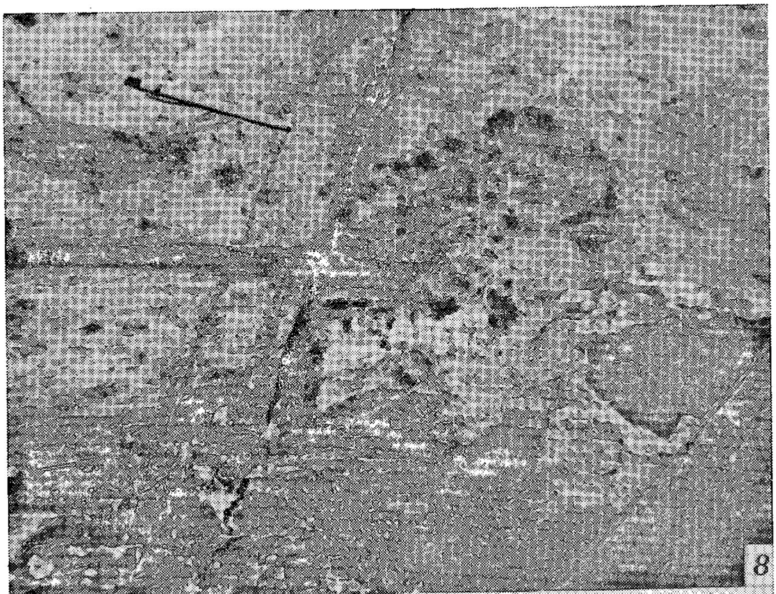


Fig. 8. The light coloured rock is the rheomorphic breccia from the southern contact of the Brome intrusion. The dark coloured rock is the impure quartzite that forms the hornfels along the southern side of this intrusion. Note how thin, highly aluminous beds in the hornfels protrude into the breccia.

Fig. 9. Rounded fragment of igneous rock containing abundant augite phenocrysts from the rheomorphic breccia zone on Mount Bruno. The rheomorphic hornfels also contains fragments of quartzite beds. Note that the igneous fragment also contains fragments of peridotite.

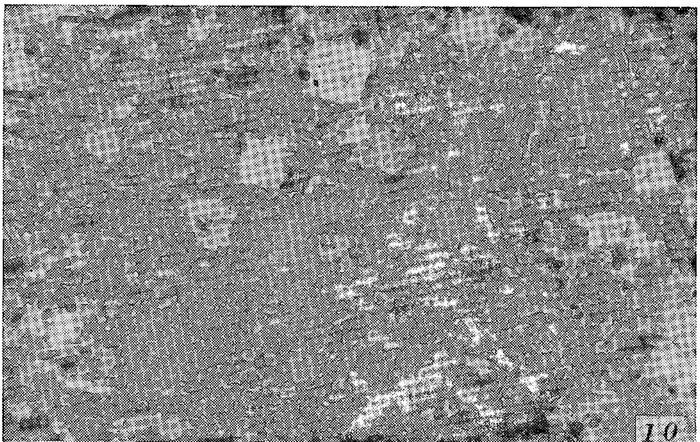


FIG. 10. Matrix of the outer part of rheomorphic breccia zone from Mount Bruno. It consists of high temperature quartz (white) highly zoned plagioclase and biotite. Crossed nicols × 35.

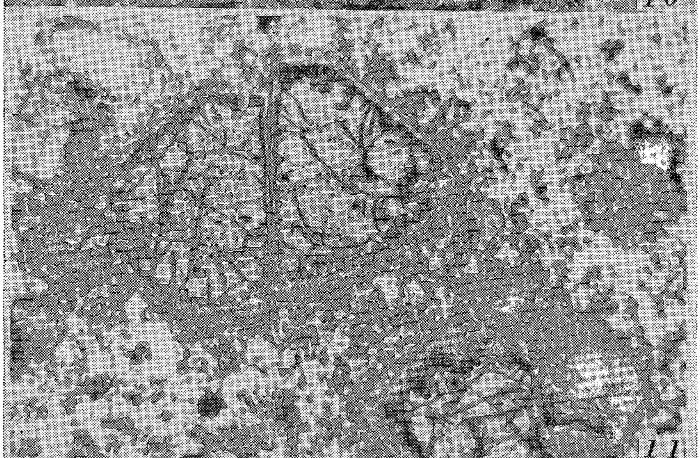


FIG. 11. Euhedral olivine phenocrysts from the quartz-bearing matrix of the rheomorphic breccia on Mount Bruno. The olivine is surrounded by a layer of magnetite which in turn is surrounded by a clear zone of orthopyroxene and then finally rimmed by biotite. Plain light × 15.

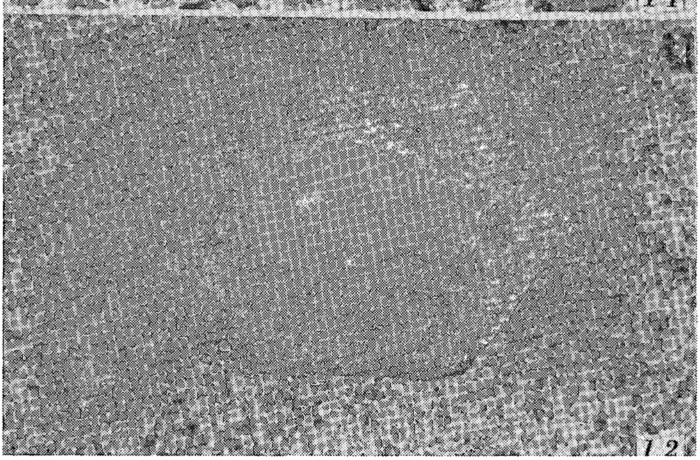


FIG. 12. Euhedral augite crystal partially replaced by intergrowth of orthopyroxene, biotite and quartz in the matrix of the rheomorphic breccia of Mount Bruno. Plain light × 15.

fewer and less well defined until they are no longer visible. On the inside of the breccia zones there is, in most cases, a gabbro which is quite distinct from other typical alkaline gabbros and essexites found in the cores of the intrusions. This gabbro characteristically contains quartz, which close to the breccias commonly forms interstitial granophyric patches. In addition, biotite is the main ferromagnesian mineral and commonly forms large (up to 1 cm) criss-crossing plates. Olivine, if present, is invariably rimmed with hypersthene which, in turn, is commonly rimmed with biotite (Fig. 11). Large augite crystals which are the main ferromagnesian constituents of all the primary basic rocks of the Monteregian intrusions, are accompanied or replaced by hornblende and in some cases replaced by biotite and hypersthene (Fig. 12). In those places where biotite is not abundant, hypersthene is a common constituent of the groundmass of these gabbros. The amount of quartz in the gabbro decreases towards the cores of the intrusions as does the amount of biotite and hypersthene, until the rock passes into the uncontaminated basic rocks of the intrusions.

These relationships leave no doubt to their having been considerable assimilation of country rocks by the primary basic magmas. With present data it is not possible to say what percentage of the rocks on each hill has been affected by contamination, but in the case of Rougemont where the effect of assimilation of Lorraine siltstones by peridotite is easily detected, it is apparent that at least 10 percent of this intrusion has been affected.

Chemistry of Breccia Matrices

In Table 1, analyses are given of the matrices of rheomorphic breccias from Brome Mountain, Rougemont and Mount Bruno. These, in general, reflect the equilibrium of the rheomorphic magmas with quartz-rich and aluminous-rich xenoliths. All contain normative corundum and most contain abundant normative quartz. Compositionally, all of the rocks are quite removed from the low temperature region of the system quartz-albite-orthoclase, indicating that the breccia zones rose well above the minimum melting temperatures. More granitic melts may have existed in the outermost parts of the breccia zones, but it is physically difficult to separate this material from the refractory hornfels for chemical analysis.

The matrix of the breccia from the southern contact of the Brome intrusion (Table 1, No. 1) is somewhat similar to that from the east contact of Mount Bruno (Table 1, No. 6), both being composed of quartz, microperthitic alkali feldspar and biotite. Both contain abundant normative corundum which is due to the presence of sericite as disseminated flakes in the cores of some feldspar grains and as small clots that probably result from the hydration of corundum. In the case of the Brome rocks, similar clots are seen to have developed around corundum grains at the margins of slate xenoliths.

Samples 2 to 5 in Table 1 are from the matrix of the breccia zone surrounding Rougemont. They show a considerable range of composition due to different degrees of mixing of primary magma with rheomorphic magma. All contain plagioclases which are zoned from cores as calcic as labradorite to margins of oligoclase. Biotite and quartz are the only other main constituents of these rocks. It is interesting to note the very reduced state of the iron in these rocks and those from Brome and Mount Bruno. This feature is most likely inherited from the original sedimentary rocks, rather than having been induced by the proximity of large bodies of basic magma, for most of the primary igneous rocks show higher oxidation states than those found in the rheomorphic breccias.

TABLE 1. MATRICES OF RHEOMORPHIC BRECCIAS FROM THE CONTACTS OF (1) BROME, (2–5) ROUGEMONT AND (6) MOUNT BRUNO

	1	2	3	4	5	6
SiO_2	68.40	56.92	63.82	70.79	71.10	60.75
TiO_2	0.90	1.75	1.28	0.79	1.65	0.74
Al_2O_3	17.08	16.53	14.10	14.50	12.86	19.29
Fe_2O_3	0.41	0.78	0.07	1.17	0.18	1.19
FeO	3.76	6.80	6.57	2.08	4.34	5.06
MnO	0.04	0.17	0.14	0.08	0.12	0.11
MgO	1.65	2.86	3.02	0.75	2.04	3.87
CaO	0.59	4.58	3.02	1.36	1.79	1.70
Na_2O	1.20	3.05	1.80	4.43	1.43	1.39
K_2O	5.66	2.25	3.01	2.86	2.52	5.12
H_2O+	1.30	1.75	1.82	0.68	1.68	1.40
Total	100.99	97.44	98.65	99.49	99.71	100.62

CIPW NORMS

	1	2	3	4	5	6
Q	33.69	12.28	26.24	29.28	43.84	20.34
C	7.90	0.75	2.39	1.64	4.52	8.37
or	33.45	13.30	17.79	16.90	14.89	30.26
ab	10.15	25.80	15.23	37.48	12.10	11.76
an	2.93	22.72	14.98	6.75	8.88	8.43
en	4.11	7.12	7.52	1.87	5.08	9.64
fs	5.15	9.26	10.15	1.70	5.32	7.29
mt	0.59	1.13	0.10	1.70	0.26	1.73
il	1.71	3.33	2.44	1.50	3.14	1.41
H_2O+	1.30	1.75	1.82	0.68	1.68	1.40
Total	100.99	97.34	98.65	99.49	99.71	100.62

Conclusions

The general shape and internal structures of each of the main Monteregian intrusions indicate that each was formed from a vertical pluglike body of magma in which there was considerable magmatic flow. The warping of the hornfels, the direction of flow in the zones of breccia surrounding the intrusions and the imbrication of feldspar laths in some layered rocks indicate that magma flowed down the walls of the intrusions as in a convecting cell and not upward as in a volcanic vent. Partial fusion of the intruded country rocks took place and the rheomorphic magma and its fragments of refractory rock were transported downward. The partial fusion of the country rocks also lead to a certain amount of contamination of the primary igneous rocks.

These features can be explained in two ways depending on whether the zones of rheomorphic breccia are interpreted as having been rather static phenomenon around each intrusion or were active zones that played an important role in the intrusive process. It is possible that the zones of breccia were developed around intrusive bodies that were emplaced rapidly by some forceful mechanism. The downward movement of the magma at the margins of these bodies as recorded in the attitude of the hornfels and flow structures in the breccia, could in this case, simply reflect some late stage collapse of the magma columns. On the other hand, the zones of breccia can be interpreted as preserving in their flow structures, evidence of the fusion and stoping mechanism by which convecting bodies of magma were able to penetrate to a high level in the earth's crust. Fresh magma would have convected upward in the cores of the intrusions bringing with it the necessary heat to partially fuse the intruded rocks. In doing this the magma would have been cooled with the result that it would have convected down the walls of the magma chambers, carrying with it the partially fused country rocks and hence making room for more magma to rise in the centers.

The lack of any bowing up or pushing aside of the intruded sedimentary rocks makes any mechanism of intrusion other than stoping very difficult to accept for the basic rocks of the main Monteregian intrusions. The presence, in the zones of rheomorphic breccia, of fragments of earlier breccia indicate that these zones have had a prolonged history and are not the product of a single disruption. The large amount of contamination of the primary igneous rocks also points to a rather prolonged process of intrusion.

It is concluded therefore that the main Monteregian intrusions were emplaced as columns of convecting magma which partially fused and stoped their way up to their present level in the earth's crust. As long as the magmas continued convecting to some considerable depth, heat was brought to the top of the chambers and caused further melting which in turn allowed for intrusion to higher and higher levels, as long as the total magma column remained buoyant with respect to the total thickness of intruded rocks. Intrusion would have ceased when the magma column reached a height where there was neutral buoyancy, or when convection stopped or failed to penetrate to a depth great enough to bring up sufficient heat to continue the fusion process. With such a process of intrusion it is possible that a vertical pipe-like magma chamber is the resulting equilibrium form.

The basic rocks of the Monteregian province which, in large part, were derived from the mantle (Faure & Hurley 1963), now occupy positions that were previously occupied by crustal rocks. If partial fusion and stoping have been responsible for the intrusion of these bodies, considerable quantities of hybrid rocks might be excepted to result from this crust-mantle interchange.

Some of the partially melted country rocks were clearly assimilated by the downward convecting primary magma to produce rocks with such minerals as hypersthene and quartz which are foreign to normal undersaturated alkaline rocks. This material on being transported to depth may have been intruded at a later date to form bodies as the quartz-norite found in the northeastern part of the Mount Bruno intrusion. It is possible that a large part of the fused country rocks did not mix with the basic magmas and was transported to depth from where it may have given rise to later intrusions of oversaturated leucocratic rocks such as those on Shefford and Brome. However, in this connection it is important to consider the rubidium-strontium studies done on these rocks by Faure & Hurley (1963). They showed that a variety of Monteregian rocks including essexite, yamaskite, tinguaite and nordmarkite were derived from a common source with an initial Sr^{87}/Sr^{86} ratio similar to that of basalt and that there had been no appreciable contamination with strontium from crustal rocks. None of the obviously contaminated rocks were included in this study and further work will be necessary to evaluate the magnitude of the effect of contamination on the strontium isotopes in these rocks.

Evidence of contamination is abundant in the outer parts of each intrusion and it is possible that further isotopic studies will reveal other rocks that have assimilated smaller amounts of crustal material. The amount of contamination resulting from the proposed mechanism of intrusion would be expected to show a correlation with the thickness of crust intruded. If the boundary between the Precambrian and Paleozoic rocks is used as a datum plane for indicating the relative thickness of crust throughout the Monteregian province, it can be concluded that the plutons in the east have penetrated a greater thickness than those in the west. This difference might explain the general increase in the size of the plutons and the increase in the silica content of the rocks in going from west to east in the province.

Acknowledgements

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References

Bancroft, J.A. & Howard, W.V. (1923) : The essexites of Mount Royal, Montreal, P.Q. *Roy. Soc. Can. Trans.*, **17**, 13-43.

Clark, T.H. (1952) : Montreal area, Laval and Lachine map-areas. *Quebec Dept. Mines, Geol. Rept.* **46**, 159.

Clark, T.H., Kranck, E.H. & Philpotts, A.R. (1967) : Ile Ronde breccia, Montreal. *Can. J. Earth Sci.*, **4**, 507-513.

Faure, G. & Hurley, P.M. (1963) : The isotopic composition of strontium in oceanic and continental basalts : application to the origin of igneous rocks. *J. Petrol.* **4**, 31-50.

Huntec Limited (1965) : *Hydrosonde demonstration, Port of Montreal.* Rept. published by Huntec Ltd., Montreal.

Kumarapeli, P.S., Coates, M.E. & Gray, N.H. (1968) : The Grand Bois anomaly : the magnetic expression of another Monteregian pluton. *Can. J. Earth Sci.*, **5**, 550-553.

Osborne, F.F. & Grimes-Graeme, R. (1936) : The breccia on St. Helen's Island, Montreal. *Am. J. Sci.*, **32**, 43-54.

Philpotts, A.R. (1968) : Igneous structures and mechanism of emplacement of Mount Johnson, a Monteregian intrusion, Quebec. *Can. J. Earth Sci.*, **5**, 1131-1137.

Pouliot, G. (1969) : Guidebook for the geology of Monteregian Hills. *Geol. Assc. of Canada — Min. Assc. of Canada, Annual Meeting 1969.*