FIELD TRIP B4

DIATREMES, DYKES, AND DIAPIRS: REVISITING THE ULTRA-ALKALINE TO CARBONATITIC MAGMATISM OF THE MONTEREGIAN HILLS

by

David Lentz[1], Nelson Eby[2], Serge Lavoie[3], and Adrian Park[1]

[1]Department of Geology
University of New Brunswick
Fredericton, NB E3B 5A3 CANADA

[2]Department of Environmental, Earth, & Atmospheric Sciences, University of Massachusetts,
1 University Avenue, Lowell, MA 01854 U.S.A.

[3] 2000 Peel Street, Suite 760, Montreal, QC H3A 2W5, CANADA

GAC/MAC Joint Annual Meeting, Montréal, Québec
Post-conference field trip

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

We very much appreciate the permission to visit the St. Lawrence Nb mine site from Mrs. Marie Daoust, directrice générale, municipalité d'Oka. M. Hussereau allowed access to his farm property to view outcrops in the Oka complex. Also, we thank NIOCAN for allowing access to their information and drill core on their exploration properties in the Oka region. The Club de Minéralogie de Montréal allowed us to visit their museum and help with access to the quarry at Mont St-Hilaire; in particular, Michel Trudeau helped us on both accounts and also special thanks is extended to Florian Poudrette for his permission given through the mineralogical society. Also thanks are due to the Gault Nature Preserve for access to their park covering much of Mont St-Hilaire. Lastly, thanks to Alain Tremblay (UQAM) and Suzanne Payette (McGill) for their help in logistical organization and of course advice.

ITINERARY

Day 1 – Thursday, May 18th, 2006

Geology of Île Bizard breccia, Ste-Dorothée sills, and Oka region

Meet at 8:30 am just in front of the 201, av. President-Kennedy (the PK building) which is close to the UQAM residence (Montreal)
The bus will head towards the stops at Île Bizard, then Ste-Dorothée, then various stops at Oka.
The bus will return by 6pm to the UQAM residence (Montréal).

Day 2 – Friday May 19th, 2006

Geology of Mont Royal, and Île Ste-Hélène

Meet at 8:30 am just in front of the 201, av. President-Kennedy (the PK building) which is close to the UQAM residence (Montreal)
The bus will head towards the stops on Mont Royal, then to Île Ste-Hélène
The bus will return by 6pm to the UQAM residence (Montréal)

Day 3 – Saturday May 20th, 2006

Geology of Mont St-Hilaire

Meet at 8:30 am just in front of the 201, av. President-Kennedy (the PK building) which is close to the UQAM residence (Montreal)
The bus will head towards the Montreal Mineralogical Society's museum, then proceed to Mont St-Hilaire
The bus will return by 3pm to the UQAM residence (Montréal)

INTRODUCTION

GEOLOGY, GEOCHEMISTRY, AND AGE OF THE MONTEREGIAN HILLS: GEOLOGY AND PETROGRAPHY

Igneous activity in the Monteregian Hills (Figs. 1 and 2) is represented by a variety of magma types ranging from strongly silica undersaturated to silica saturated. There is a geographic pattern to the magmatism in that strongly silica-undersaturated rocks are concentrated in the western half of the province, while silica-saturated rocks generally occur in the eastern half of the province. The general geology of the province has been described by a number of authors (e.g., Philpotts, 1974; Eby, 1987).

The Oka carbonatite complex is located at the western end of the province and consists of a core carbonatite, which has been intruded by a variety of strongly silica-undersaturated rocks: okaite, melteigite, ijolite, and urtite. Alnoitic rocks also intrude the complex and the alnoitic phase of magmatism is confined to the Oka area. A review of the Oka complex can be found in Gold et al. (1986).

Monts Royal, Bruno, Rougemont, and Yamaska intrusions are mafic to ultramafic in character. The dominant lithologies are pyroxenite and gabbro, and in the field these two lithologies tend to be interlayered. This interlayering generally occurs at the outcrop scale so that map units show the dominant lithology. Mappable gabbroic units occur in all of these plutons and they often represent the later stages of igneous activity. None of the pyroxenite and gabbro units carry nepheline, although they are often slightly nepheline normative, because of locally abundant amphibole. Quartz occasionally occurs in contact zones, forming in response to crustal contamination. Layering is often prominent due to the alignment of pyroxene and plagioclase crystals and the layering dips at moderate to steep angles. This layering suggests that the rocks represent crystallization of the magma, in a convecting system, from the walls inward. Locally, there is evidence for movement of material in the partly molten state, although the bulk of the rocks seem to have crystallized at their current level of emplacement. At Monts Royal and Yamaska, the gabbro-pyroxenite sequence is intruded by essexites (nepheline-bearing gabbros) and nepheline-bearing syenites that define a late stage, strongly silica-undersaturated period of magmatism. A review of the geology of Monts Royal and Bruno can be found in Eby (1984). Detailed geologic maps for Monts Bruno and Rougemont can be found in Philpotts (1976). Field trip guides for Monts Royal (Gelinas, 1972) and Rougemont (Philpotts, 1972a) were prepared for the 1972 International Geological Congress.

At Monts St-Hilaire, St-Grégoire (formerly Johnson), Shefford, and Brome, the dominant mafic lithlogies are gabbro, essexite, and diorite. Pyroxenites are either absent or occur as minor components. Syenitic units, either quartz-bearing or nepheline-bearing, are important components of these plutons. Mont St-Hilaire can be conveniently divided into a western half consisting largely of gabbro and an eastern half consisting largely of nepheline- and sodalite-bearing syenites. Mont St-Grégoire largely consists of essexite with an outer annulus of syenite and nepheline-bearing syenite. Monts Shefford and Brome are found in close proximity and are geologically similar.

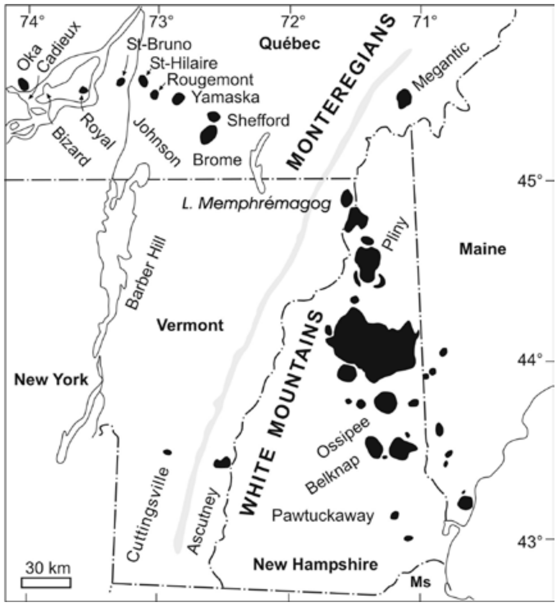


Figure 1. Location and geological setting of the White Mountains and Monteregian Hills (modified after Eby, 1987).

Figure 2. Photograph of Mont St-Bruno (western hill) and Mont St-Hilaire (eastern hill) looking northeast from Mont Royal with downtown Montréal in the foreground.

Shefford has a large central core that is predominately diorite. The diorites are intruded by arcuate bodies of syenite (pulaskite and foyaite) and quartz-bearing syenite (nordmarkite). The core of Mont Brome is pulaskite. To the south this core is partly surrounded by a large, layered, arcuate gabbro body. The gabbro can be divided into a number of zones that apparently represent cycles of magmatic activity. Quartz-bearing syenites are found along the outer edges of the pluton. The central syenite is intruded by late stage nepheline-bearing diorites and syenites. Information on the geology of these plutons can be found in Eby (1984, 1985a), Currie et al. (1986), and Chen et al. (1994). Philpotts (1972a) and Woussen and Valiquette (1972) have published field trip guides for Monts St-Grégoire (Johnson), Shefford, and Brome.

Mont Megantic is located at the extreme eastern end of the province and its assignment to the Monteregian Hills is questionable. The core of the pluton consists of a two-feldspar granite plug that is surrounded by a gabbro-diorite unit and an outer ring dyke of nordmarkite (syenite). The central granite is very similar in appearance and mineralogy to the "Conway" granite of the White Mountain magma series. The gabbros often carry two pyroxenes, which is common for White Mountain mafic rocks but rare in the case of the Monteregian Hills. A review of this pluton can be found in Eby (1985a) and Bedard et al. (1987).

The plutons of the Monteregian Hills are intruded by a variety of mafic and felsic dykes. Dykes are also widely distributed in the country rocks. These dykes tend to lie along a northwest trend. The mafic dykes can be classified as lamprophyres (alnoites, monchiquites, and camptonites), alkali olivine basalts, and basanites. The felsic dykes can be classified as bostonites, solvsbergites, nepheline syenites, and tinguaites. The strongly silica-undersaturated dykes are concentrated towards the western end of the province. The petrography and geochemistry of the Monteregian dykes has been described by a number of authors including Bedard et al. (1988) and Eby (1985c).

Dyke nomenclature used in the Monteregian Hills is as follows. By definition, lamprophyres must be porphyritic rocks that do not have feldspar phenocrysts. Alnoites contain melilite and biotite as essential minerals and are feldspar free. Monchiquites have a groundmass of glass (now recrystallized), analcime or nepheline, and ferromagnesian silicates. Camptonites have a groundmass of labradorite, amphibole, pyroxene, and subordinate alkali feldspar, nepheline, and/or leucite. In the monchiquites phenocrysts are commonly olivine or pyroxene, whereas in the camptonites phenocrysts are commonly amphibole. The basanites are mineralogically similar to the monchiquites while the alkali olivine basalts are similar to the camptonites, but these dykes do not carry phenocrysts. The bostonites are texturally distinctive felsic rocks that have a trachytic or flow texture in which lath-shaped feldspar grains are arranged in rough parallelism or in radiating patterns. Tinguaites are equivalent to phonolites and in the Monteregian Hills often contain sparse feldspar phenocrysts.

GEOCHRONOLOGY, GEOCHEMISTRY, AND ISOTOPE GEOLOGY

A number of geochronological techniques have been applied to the dating of Monteregian igneous activity. Ages determined by Rb-Sr whole-rock methods, conventional K-Ar biotite and amphibole methods, and fission-track methods (apatite and titanite) for the main plutons and dykes are summarized in Eby (1987). These data indicated that there were two distinct periods of igneous activity in the Monteregian province, one centred around 132 Ma and the other around 120 Ma. These ages also seemed to have a petrogenetic significance in that strongly silica-undersaturated rocks were confined to the younger period of igneous activity. Foland et al. (1986, 1989) and Gilbert and Foland (1986) reported the results of $^{40}Ar/^{39}Ar$ geochronology on a number of the Monteregian plutons that indicate that the plutons had a short emplacement history centered around 124 Ma. The studies of Foland and his colleague showed that excess argon could be a problem in the dating of the Monteregian intrusions, particularly in the case of the amphiboles. Most of the previously reported older K-Ar ages were amphibole ages, hence these older ages are suspect. Recently re-determined apatite fission track ages for the Oka complex (reported in this guide) give a mean age of 122 Ma for the Oka complex. Hence, most of the Monteregian intrusions have apparently been emplaced in a relatively short time interval between 122 Ma and 125 Ma. Heaman and LeCheminant (2001), on the basis of U-Pb perovskite and apatite ages, conclude that the emplacement age for the Île Bizard intrusion is 140 Ma. This is a significantly older age than that found for any of the other Monteregian Hills intrusions.

Chemically the rocks of the Monteregian Hills, with the exception of some cumulates, plot in the alkali field on a total alkalis versus silica diagram. Most of the rocks are nepheline normative, although the nepheline normative character of the cumulate rocks is due to the presence of abundant amphibole, rather than the occurrence of nepheline. In the strongly undersaturated series of rocks, there is a strong enrichment trend in total alkalis with respect to silica that is mirrored by the occurrence of abundant modal nepheline. REE abundance patterns show moderate to strong enrichment in the LREE with respect to the HREE, with the strongly silica-undersaturated rocks showing the greatest enrichment. In agreement with alkaline rocks from other parts of the world, the Monteregian rocks are relatively enriched in alkalis and high-field-strength elements.

Sr, Nd, and Pb isotopic data have been reported for the various Monteregian plutons by Eby (1985b), Grunenfelder et al. (1985), Wen et al. (1987), and Chen et al. (1994). These data suggest the presence of a depleted subcontinental lithosphere that served as the source of the Monteregian magmas. During the ascent of the magmas to their level of crystallization interactions occurred with the country rocks. The nature of the isotopic contamination was varied since in some cases the country rocks were of Grenville age, whereas in other cases they were Lower Paleozoic in age. As a general rule, the rocks emplaced last in any particular pluton show the most primitive isotopic signatures, an observation which is generally explained by the earlier magmas coating the magma conduits and isolating the later magmas from the country rocks.

PETROGENESIS

A variety of magmatic sequences can be identified in the Monteregian Hills. Petrogenetic models have been presented by Eby (1984a, 1985a, 1987), Bedard et al. (1987), and Chen et al. (1994). The following sequences have been delineated:

1. Carbonatite and possibly related (through liquid immiscibility) nepheline-rich rocks plus alnoitic dyke rocks.
2. Pyroxenite - gabbro - diorite sequences which occur as significant components in a number of the plutons. These rocks are largely cumulate in nature.
3. Nepheline-bearing diorites and syenites and chemically similar monchiquite dykes.
4. Quartz-bearing syenite and granite.

Chemical, isotopic, and experimental data have been used to outline possible petrogenetic histories for each of these sequences. The isotopic data indicate that the Monteregian magmas were derived from a depleted mantle source. The carbonatites and related rocks are inferred to have been derived from a carbonated garnet lherzolite mantle. The mafic silica oversaturated and undersaturated sequence can most likely be related through AFC processes. The source of these melts is most likely a garnet lherzolite mantle, although a spinel lherzolite mantle provides a better source for some sequences. Given the strong enrichment in incompatible elements found for the initial melts, and the depleted mantle signature shown by the isotopic systems, it is concluded that mantle metasomatism occurred either immediately before, or during, melting. During ascent these magmas underwent various degrees of interaction with the crust producing residua enriched in silica.

GEOCHRONOLOGY OF OKA

Emplacement ages for the Oka complex have been determined by a variety of geochronlogical techniques. Fairbairn et al. (1963) report a Cretaceous Sr biotite age for the complex. Shafiqullah et al. (1970) determined K-Ar mica ages for a number of the intrusive units that comprise the Oka complex and arrived at a mean mica age of 116 ± 4 Ma and a K-Ar isochron age of 120 Ma. Using biotites from the carbonatites and okaites, Wen (1985) obtained a Rb-Sr isochron age of 109 ± 2 Ma. Heaman and LeCheminant (2001) report a perovskite U-Pb age of 115 Ma for an alnoite from the Oka complex.

Apatite fission-track ages for the Oka complex, originally reported in Gold et al. (1986), have been redetermined using the zeta calibration method (Table 1). For this laboratory the zeta calibration is 314 ± 10 for apatite. Complete details of the analytical procedure can be found in Eby et al. (1995). Error estimates for individual ages are standard deviations based on the variation of the mean track density for the induced and spontaneous tracks and the fluence detectors. This approach probably over estimates the error associated with an individual age. There is no apparent relationship between the apatite fission-track ages and lithology, i.e., the ages of the various lithologic units are statistically indistinguishable. Given this, the mean apatite age for the Oka complex is 122.1 ± 3.9 Ma. This age represents the time when the rocks of the Oka complex cooled through the $100^{o} \pm 20^{o}$C (Wagner, 1968; Naeser and Faul, 1969; Naeser, 1981) closure temperature for fission-track retention in apatite. This age is slightly older than that determined by other methods, but is within error of previously reported K-Ar ages.

Table 1. Data for apatite fission -track ages.

Sample	Lithology	Number crystals	Spontaneous Rs	Spontaneous (Ns)	Induced Ri	Induced (Ni)	Dosimeter Rd	Dosimeter (Nd)	Age (Ma)	
Oka										
BOK-3	Okaite	50/50	6.83	820	6.30	756	3.58	2201	120.5	8.4
OL-2	Okaite	50/50	10.90	1338	9.90	1188	3.58	2201	122.4	7.1
OL-5	Ijolite	50/50	7.47	896	6.92	830	3.58	2201	120.0	12.8
OL-6	Ijolite	40/40	3.35	321	2.98	286	3.58	2201	124.9	12.2
A-16-6	Fo-cpx soviet	50/50	11.66	1399	11.14	1337	3.58	2201	116.4	8.7
AB-60-1	Cpx-pyr soviet	100/100	1.20	288	1.08	259	3.58	2201	123.5	17.5
BOK-6	Mel-niocalite sovite	40/40	68.50	6572	60.50	5804	3.58	2201	125.8	4.2
BOK-7	Mont-perov sovite	100/100	2.78	666	2.38	570	3.58	2201	129.8	15.6
G-13-8	Cpx-bio-pyr sovite	50/50	2.92	350	2.70	324	3.56	2201	119.6	19.2
OL-1	Cpx-bio soviet	50/50	10.10	1212	9.70	1164	3.56	2201	115.2	8.7
OL-7	Mont-pyr soviet	50/50	5.27	632	4.74	569	3.56	2201	122.9	14.8
S-43-4	Mont soviet	50/50	7.84	941	6.83	820	3.56	2201	126.9	8.2
A-18-1	Alnoite	50/50	3.75	450	3.48	418	3.56	2201	119.2	12.1
AM-1	Alnoite	50/50	5.02	602	4.52	542	3.56	2201	122.8	11.8
AM-2	Alnoite	50/50	4.85	582	4.43	531	3.56	2201	121.0	12.8
Ile Bizard										
IB1	Alnoite breccia	40/24	5.74	551	5.30	306	3.56	2201	119.8	14.2

DESCRIPTIONS OF FIELD TRIP STOPS

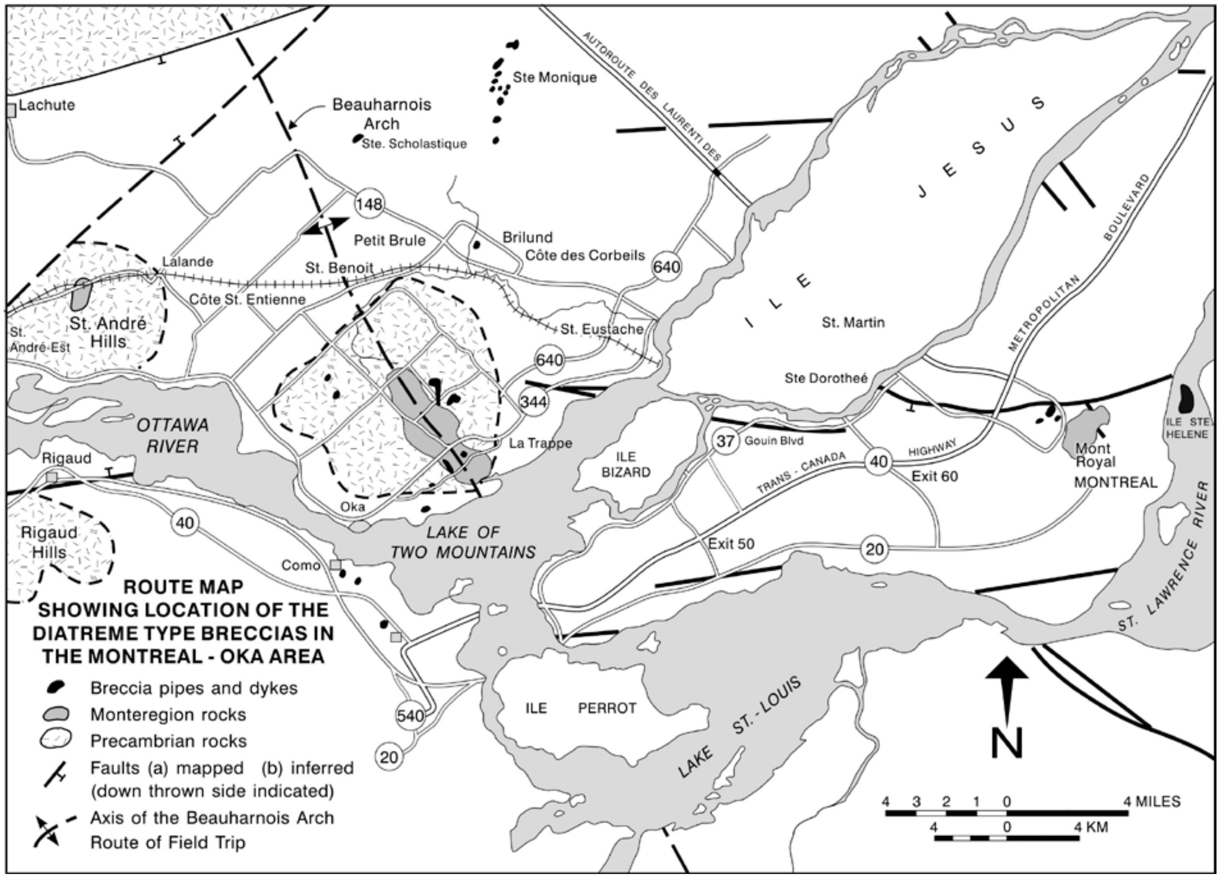


Figure 3. General location map of the field trip area for Day 1 and Day 2 of the field trip (modified after Gold et al., 1986).

STOP 1 (Day 1):

Île Bizard (*N. Eby*)

Location: From Voyageur Bus stop (Maisonneuve/Berri) turn right onto Viger (Rte 720) at 0.4 km from Berri (to Rte 20 following P.E.T. airport/Dorval). At 26.8 km Boul. St-Charles (Exit 48) exit to right (north). At 31.5 km turn right (east) onto Boul. De Pierrefonds. At 33.3 km, turn left (north) onto Boul. Jaques-Bizard. Proceed over bridge to Île Bizard to Chemin Cherrier (34.5 km, turn left 34.5 km). At 35.3 km, turn right (north) onto Rue de l'Église and drive to Chemin Bord-du-lac at 38.2 km (turn left – west). At 38.8 km, turn right onto Terrace Martin and proceed around the crescent to 39.0 km and stop at vacant lot.

Hazards: Please exercise caution here as it is difficult to climb the hill and also it is slippery descending. The hill is very steep, so is easy to fall.

The three breccia mounds that comprise the Île Bizard intrusion (Fig. 4; N45^{o}23'23", W73^{o}54'26") were first described as diatreme pipes (Harvie, 1910). The intrusion was mapped by Clark (1952) and the first detailed description was provided by Marchand (1970), who focused on a satellite fissure of alnoite (Fig. 5). The oval-shaped (60 m by 100 m) breccia pipe, mapped beneath the hill (Fig. 4), now largely removed because of residential construction, contains numerous angular fragments of Lower Paleozoic sandstones, limestones, and shales, and rarer Precambrian gneiss and anorthosite inclusions (Fig. 6). A variety of ultramafic nodules are found in the alnoite, including websterites, lherzolites, and amphibole-clinopyroxene nodules. The igneous matrix consists of serpentinized megacrysts of olivine and orthopyroxene and unaltered phenocrysts of clinopyroxene, phlogopite, and magnesian titanomagnetite in a fine-grained groundmass of serpentine, calcite, melanite, magnetite, and apatite.

Figure 4. Remnants of Île Bizard breccia pipe exposed in residential yards**.**

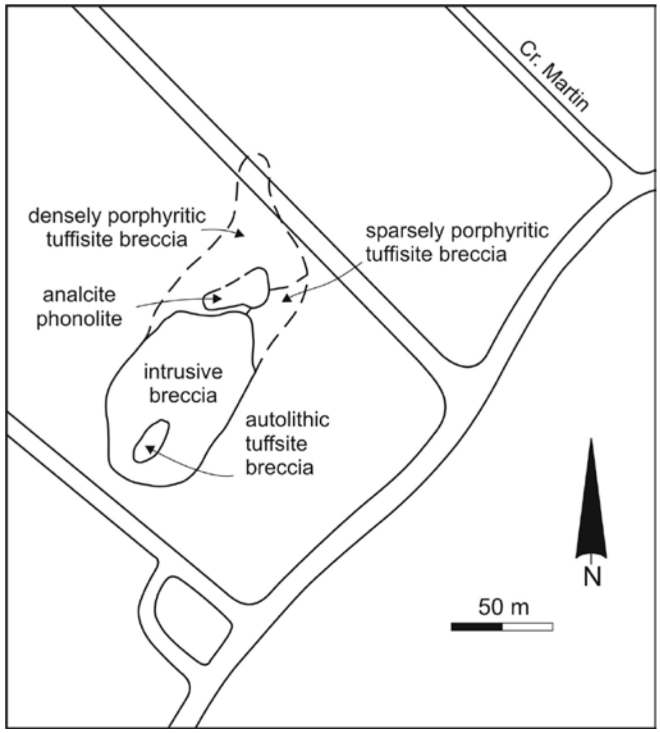


Figure 5. Geological map of the Île Bizard intrusive breccia illustrating the main phases of breccia (modified after Raeside and Helmstaedt, 1982).

Figure 6. Angular fragments of sandstone, limestone, and gneiss in the breccia.

The classification of the Île Bizard intrusion has been a subject of some debate. Marchand (1970) originally classified the rocks as kimberlitic. Mitchell {1979) suggested that they be more properly classified as alnoitic. Raeside and Helmstaedt (1982) re-instituted the name kimberlite to which Mitchell {1983) took vigorous exception. The igneous matrix at Île Bizard seems to have mineralogical and chemical characteristics more closely allied with alnoites. Rock (1984, personal communication in Gold et al., 1986) suggested that the term aillikite be applied to such rocks which do not contain melilite {which is absent at Île Bizard) and Eby (1985c) used this term in reference to the Île Bizard occurrence. More recent authors (Harnois et al., 1990; Heaman and LeCheminant, 2001) have re-instated the term alnoite.

Raeside (1978) identified four igneous breccias: intrusive, densely porphyritic tuffisite, sparsely porphyritic tuffisite, and autholithic tuffisite (Table 2). The breccias were intruded by an analcite phonolite. The tuffisite breccias and the analcite phonolite are either peripheral to or cut across the main intrusive breccia. The igneous matrices of the various breccias are similar except that the autolithic tuffisite breccia lacks melanite. The analcite phonolite does not contain xenoliths and has phenocrysts or pseudomorphed phenocrysts of kaersutite, aegirine-augite, apatite, analcite, barite, and calcite in a trachytic matrix of aegirine-augite, K-feldspar, and analcite. The relative proportions and types of xenoliths and phenocrysts are given in Table II (from Raeside and Helmstaedt, 1982).

Table 2. Relative proportions of xenoliths and xenocrysts in different phases of the Île Bizard intrusion (Raeside and Helmstaedt, 1982, p. 1998).

Type of clast or crystal	Intrusive breccia (%)	Densely porphyritic tuffisite breccia (%)	Sparsely porphyrtic tuffisite breccia (%)	Autolithic tuffisite (%)
Total xenoliths	50	15-20	5-10	5
Beekmantown Group	70	70	70	-
Potsdam Group	10	1	1	-
Basement gneiss	1	-	-	50
Ultramafic rocks	5	15	15	20
Alloclastic fragments	15	-	-	-
Megacrysts	1	15	15	30
Total phenocrysts	10	18	3	-
Serpentin. Ol and Opx	60	60	60	-
Clinopyroxene	15	20	20	-
Phlogopite	15	10	5	-
Mg-titanomagnetite	10	10	15	-

The autoliths range from 2 to 5 mm in diameter and are similar to the matrix material, except with lesser amounts of calcite and serpentine. The autoliths develop on a variety of nuclei and are interpreted as crystal growths developed from late-stage liquids near the base of the crust (Raeside and Helmstaedt, 1982).

The megacrysts consist of aluminous clinopyroxene, phlogopite, and Mg-titanomagnetite.

The clinopyroxenes contain 10-14 mol % jadeite. The phlogopites are much richer in FeO (10.2%) than either the xenolithic or groundmass phlogopites. The Mg-titanomagnetites contain 4-9% MgO. These phases are interpreted to have crystallized in a deep-level magma chamber from the primary magma (Raeside and Helmstaedt, 1982). The ultramafic xenoliths are generally small and well-rounded. They are surrounded by a reaction rim of magnetite-bearing hydrous silicates, and where this rim has been fractured, the xenoliths are extensively altered to serpentine and carbonate. The websterites are two-pyroxene rocks that display possible cumulate textures. The websterites are inferred to represent cumulates derived from magmas in the upper mantle (Raeside and Helmstaedt. 1982).

The peridotitic xenoliths display coarse granular textures and show little evidence of deformation. They apparently are mantle fragments, some of which show evidence of a prior depletion event. Phlogopite replacement is ubiquitous and may indicate a potassic metasomatic event in the upper mantle. From the mineralogy and possible reactions it was deduced that the xenoliths equilibrated at pressures between 2.1 and 2.8 GPa at temperatures less than 1000°C (Raeside and Helmstaedt, 1982).

K-Ar ages of 127 Ma (whole-rock), 127 Ma (phlogopite), and 121 Ma (amphibole), all of which have been corrected to the new decay constants, were determined for Île Bizard by Barton (reported in Marchand. 1970). Of these three ages, the amphibole age might be expected to be least disturbed (highest closing temperature). An apatite fission track age of 120 ± 14 Ma was determined for xenolith-free matrix material (Table I). Heaman and LeCheminant (2001) obtained U-Pb ages for apatite, baddeleyite, perovskite, and melanite from the intrusive breccia. Based on the perovskite U-Pb data the authors concluded that the crystallization age for the alnoite was 139.9 ± 2.6 Ma. The melanite gave a younger less precise age of 109 Ma and the baddeleyites exhibited complex U-Pb systematics and highly discordant ages. It should be noted from the earlier overview of the Monteregian Hills that the 140 Ma age for the Île Bizard intrusion is significantly older than that reported for any of the other Monteregian intrusions.

Marchand (1970) reports an analysis (Table 1, #16) for xenolith-free matrix material. If total iron is set equal to FeO, this material would have an appropriate Mg/(Mg + Fe) ratio for a liquid in equilibrium with mantle olivine, indicating that little fractionation of the liquid occurred during its ascent. Eby (1985c) reports a REE analysis for similar material from Île Bizard. This pattern is typical of that expected for liquids that are in equilibrium with garnet lherzolite, and it was suggested that the magma was generated in a carbonated garnet lherzolite mantle. A more extensive study by Harnois et al. (1990) came to a similar conclusion with regards to the source of the alnoitic magma. Additionally the authors found that the websterite xenoliths were in equilibrium with their alnoite host, whereas the harzburgite xenoliths were depleted mantle fragments.

STOP 2 (Day 1):

Ste-Dorothée monchiquite sills (*N. Eby*)

Location: From Stop 1 retrace route to Boul. Pierrefonds, then turn left (east) at 44.3 km.

Proceed to Boul. Govin (49.0 km) and turn right (east). Drive to Laurentian Boul. (Rte 117) and turn left (north) (57.6 km). Continue to Boul. St-Martin (Rte 148) and turn left (west) at 61.2 km). Follow St-Martin to Rue Champagne (65.6 km) and turn left (south) to Rue Principale (Rte 148) (66.0 km) then turn right (west). Stop in small wooded driveway (to quarry) on north side of road (67.0 km) opposite from Rue Malraux.

Hazards: The road cut section is relatively close to the roadway, so please stay on the grassy part away from the road. Avoid crossing the road if possible as this location is just below the crest of a blind hill.

The village of Ste-Dorothée lies along Rte. 148, approximately half way between the Mont Royal and Oka plutons. Seven sill-like bodies of monchiquite, and three breccia mounds crop out within 1.5 km of the centre of the village (Fig. 7). Although individual sills intrude successively higher strata (in the Beekmantown Group} eastward, their compositional similarity led Clark (1952) to suggest they belong to a single step-like sheet linked by dykes. The sills are of interest petrologically because the spherical blebs (ocelli) and stringer patches, lenses, and vein-like stringer segregations of analcite syenite they contain, have been interpreted as crystallized blobs of felsic liquid that existed immiscibly in the monchiquite melt (Philpotts and Hodgson, 1968). These phenomena are well displayed in the road-cuts through two scarplets on Route 148 (45°31'54", W73°48'44"), about 0.8 km east of the church, and in the quarry (now covered) about 60 m north of the westernmost scarp.

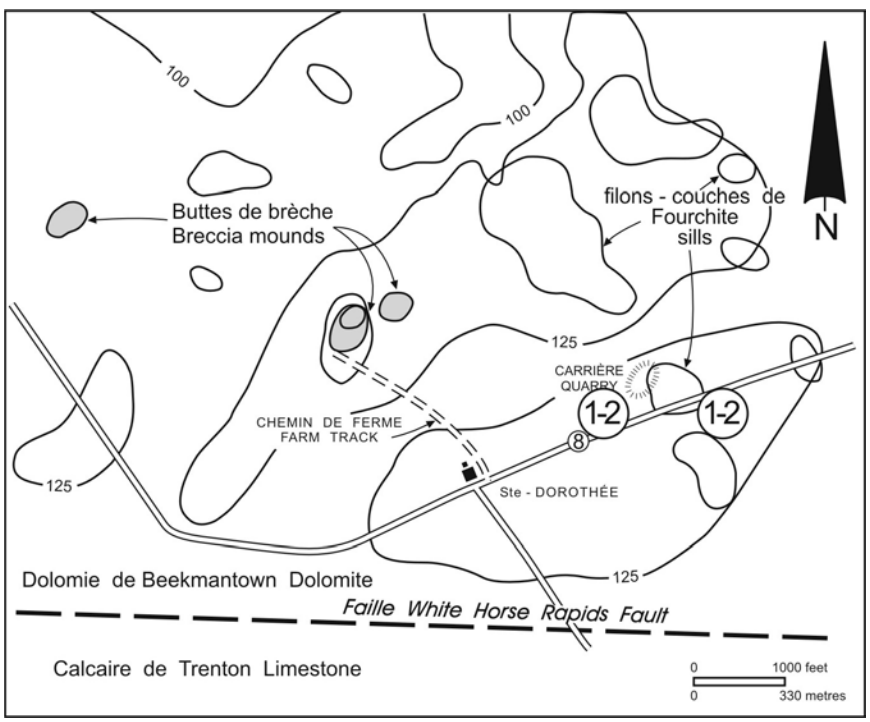


Figure 7. Geological map showing the distribution of the Ste-Dorothée sills and associated breccias (modified from Clark, 1952).

Philpotts and Hodgson (1968) described in some detail the petrographic features of the sill as seen in the small quarry. Although the contacts with the enclosing Beekmantown dolomite were not exposed, evidence of chilling at the top and bottom of the sill suggested that almost a complete cross-section (5.7 m thick) of the sill was exposed. The monchiquite is composed of 1-3% phenocrysts of titanaugite and hastingsite in a groundmass of hastingsite, titanaugite, opaque minerals, apatite, titanite, and a turbid brown aggregate of analcite, plagioclase, and alkali feldspar. In the lower half of the sill five phenocryst-rich horizons were identified. Analcite-syenite veinlets also are common in the lower half of the sill. Near the center of the sill a 1 m thick zone of subvertical syenite veinlets was encountered. A number of inclusions (commonly sandstone and quartzite) were found a short distance above this horizon and occupied a zone 0.5 to 1 m thick. In the upper portion of this zone and upwards to the top margin of the sill, ocelli were encountered and they constituted from 10 to 15 percent of the rock. It was believed that zones of ocelli in the upper portion of the sill could be correlated with the phenocryst horizons in the lower part of the sill (Philpotts, 1972b), suggesting the injection of discrete batches of magma into the sill. The process envisaged was one in which the phenocrysts settled downwards while the ocelli floated upwards, and then injection of a new batch of magma into the centre of the sill which led to a repeat of the process.

The ocelli are variable in shape and mineralogical composition. Many are spherical to oval in shape and have diameters of 5 to 6 mm. Others range up to 10 cm in size, and these tend to be flattened parallel to the sill margins. Other ocelli exhibit features that suggest the coalescing of several ocelli and groups of ocelli appear to merge into veins of syenite. In many of the ocelli, grains are oriented perpendicular to the surfaces, but in others the grains have a somewhat concentric or random arrangement. Mineralogically the ocelli consist of zoned plagioclase laths, commonly overgrown by alkali feldspar, alkali feldspar laths, analcite, acicular brown amphibole, carbonate, apatite, titanite, and brown turbid material. The cores of the plagioclases and the amphiboles have similar compositions and optical properties to the plagioclases and amphiboles found in the monchiquite. Modal proportions of the minerals are variable, some ocelli are composed almost completely of plagioclase with alkali feldspar overgrowths and amphibole whereas other ocelli are predominately alkali feldspar and analcite.

Philpotts and Hodgson (1968) proposed that the ocelli represented crystallized blobs of felsic liquid that existed immiscibly in the monchiquitic magma. They based their conclusions on the presence of mineral phases of similar composition in both the ocelli and the host monchiquite, the shape and size distribution of the ocelli, and melting experiments on similar rocks from Visitation Island that produced immiscible liquids. Philpotts (1972b) subsequently calculated the density, interfacial tension with respect to the monchiquitic magma, and viscosity of the fluid that formed the ocelli, and concluded that this fluid had the appropriate characteristics for a feldspathic liquid. Strontium isotopic data (Philpotts *et al.*, 1970) revealed similar initial ratios for both the ocelli and the monchiquite which suggested that crustal contamination did not play a role in the formation of the ocelli. Eby (1979, 1980) investigated the distribution of trace elements between the ocelli and host matrix both at Ste-Dorothée and elsewhere in the Monteregian Hills. It was found that high-charge-density (HCD) cations were concentrated in the matrix material, relative to the ocelli. In addition, the HCD cations were more strongly partitioned into the matrix material when the ocelli had compositions appropriate for more highly polymerized liquids. These are the types of relationships that would be expected for two co-existing immiscible liquids, and it was concluded that the trace element distributions were consistent with the interpretation that the ocelli-matrix pairs represented immiscible liquids.

Although the quarry has now been covered, exposures along the road (Fig. 8) still permit one to inspect the relationship between the ocelli and their enclosing matrix. At this stop the range of ocelli compositions and morphological features can be observed. Note the rather variable mineralogical composition of the ocelli, which seems to be somewhat related to size. The smaller ocelli tend to be more leucocratic. Also note the shape of the ocelli and the apparent flow and coalescence of the ocelli that in places is evidenced by the alignment of the acicular amphiboles.

Figure 8. Sill along Route 148. Spherical blebs (ocelli), patches, and vein-like stringer segregations of analcite syenite in monchiquite dyke.

Titanite separated from the monchiquite yielded a fission track age of 120 $\pm$ 4 Ma (Eby, 1985c) [the age has been recalculated using the titanite zeta calibration factor for this laboratory], which is consistent with an approximately 120 Ma paleo-pole position obtained by Foster and Symons (1979).

<u>STOP 3 (Day 1):</u>
Château du Sirop Breccia Pipe (*paraphrased from Gold et al., 1986*))

Location: From the Ste- Dorothée stop, Follow Route 148 westward through village toAve des Bois and turn left at 71.1km. Continue to Boul. Arthur-Sauvé and turn right at 71.7 km. Proceed through St-Eustache to route 640 (west) at 77.2 km (heading toward Lachute & Oka). Follow route 640 (west) to route 344 and turn right at 88.4km. Stop at the canteen on right (89.9km) and walk west 50 m to outcrop.

Hazards: The road cut section is relatively close to the roadway, so please stay on the grassy part away from the road.

The Château du Sirop breccia (Fig. 9) is exposed along the road cut and along the hillside, as well as various Precambrian lithologies including quartzite; it is located 500 m east of the Oka Carbonatite Complex (Fig. 3). Like other alnoitic associations, it is considered part of the carbonatitic magmatism of the Oka complex. The heterolithic breccia contains large angular Paleozoic fragments (limestone, dolostone, and hornfels) and more rounded Precambrian xenoliths. Gold et al. (1986) indicated that several intrusive phases are present, with country rock fragments dominating near the margins of the conduit and rounded gabbroic, pyroxenitic, sovite and ultramafic fragments (phologopite-bearing alnöite, dunite, and orthopyroxenite) concentrated within the core of the dyke-like body that is in part cemented by carbonate. These breccias are analogous to other fluidization breccias in the region, indicating vertical mixing of transgressed lithologies indicates a vertical mixing on the order of 10's of kilometres. Please refer to Gold et al. (1986) for a more detailed description of this locality.

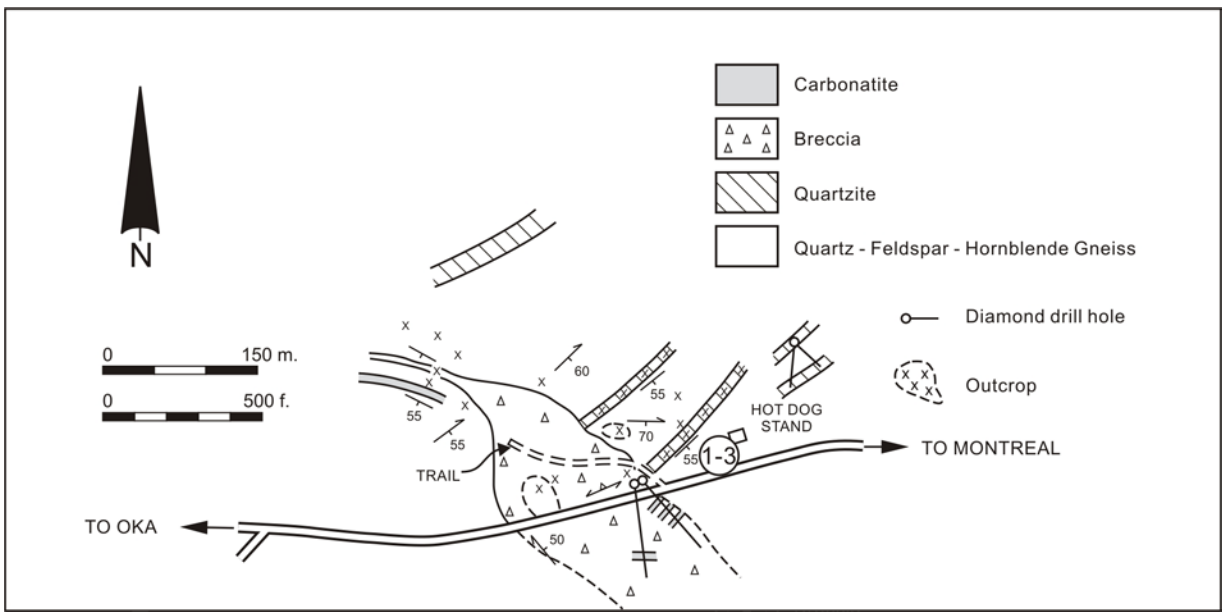


Figure 9. Geological map of the Eastern breccia (Château du Sirop) (modified after Gold et al., 1986).

<u>STOP 4 (Day 1):</u>
Oka Carbonatite Complex

Location: Continue west on Rte. 344 for 1.8 km and turn right (91.7 km) onto Rue Ste-Sophie, and proceed for about 500 m (92.2 km). Park in the entrance to the abandoned St. Lawrence Columbium and Metals Corporation Mine. Examine waste dumps for sovite and ijolite and the relationships in the open pits; you can collect samples from the waste dumps.

Hazards: The access to this site is limited, although we obtained permission from the municipality for this specific trip. It is an abandoned mine site so watch where you walk; please stay away from the open pits and be careful on the slopes of the waste dumps.

The Oka mine was developed in a carbonatite-urtite-ijolite-jacupirangite intrusive complex (Figs. 10, 11) in 1961 by the St. Lawrence Columbium and Metals Corporation (Fig.12). The mine produced a concentrate of niobium oxide that also contained rare earths and thorium. The mine closed in late 1977 due to bankruptcy following a protracted labour dispute, but Niocan Inc. have carried out recent feasibility studies aimed at reopening workings and developing other areas of the carbonatite. The carbonatite occurs as ring-dykes and cone-sheets within the silica-undersaturated syenites and ultramafic rocks that make up most of the outcrop. This complex contains the most extremely differentiated and evolved magmatic rocks in the Monteregian province - such as ijolite (containing 50% feldspathoid, and urtite, containing no feldspar and more than 70% feldspathoid. An ultramafic rock here is jacupirangite, consisting of alkali pyroxene, with minor alkali amphibole, nepheline and apatite. There is also (inevitably) a rock called ‘okaite’ - for the curious this is a hauyne melilitolite. Breccia bodies with alnoite matrix, and alnoite dykes cross-cut the entire complex.

The Oka complex consists of two ring-complexes forming a distorted ‘figure 8' (Gold et al. 1986). It is emplaced into Grenvillian metamorphic rocks, and breccia pipes within the complex contain xenoliths of lower Paleozoic sediments including Trenton Limestone and Utica Shale. Gneisses around the complex have been fenitized extensively. Rocks of the complex can be divided into four series: 1. carbonatites, 2. alnoite and alnoite breccia, 3. melteigite-urtite series, and 4. okaite series.

Carbonatites are a diverse group, but most of the carbonatite in the Oka complex is a coarse-grained calcite-carbonatite (sovite) with accessory amounts of sodian augite, biotite, apatite, nepheline, monticellite, melilite, pyrochlore, perovskite, niocalite [$(Ca,Nb)_4Si(O,OH,F)_9$ - wöhlerite-låvenite series disilicate, Oka is the type locality], richterite, pyrite and pyrrhotite. Different phases of sovite can be identified by their distinctive suites of accessory minerals. Dolomite-bearing carbonatites (rauhaugites) occur mainly in the NW end of the complex. Locally the carbonatites become very micaceous (biotite or phlogopite) and qualify as glimmerite. The economically important rocks here are almost all carbonatites, particularly a pyrochlore-sovite in the northern ring. Alnoite and more usually breccias with alnoite matrix form dykes and plugs scattered around the complex and in the surrounding gneisses. These are typical Monteregian alnoites, i.e. melilite and perovskite are usually absent. Xenoliths include country rock and deep crustal and mantle types (this last

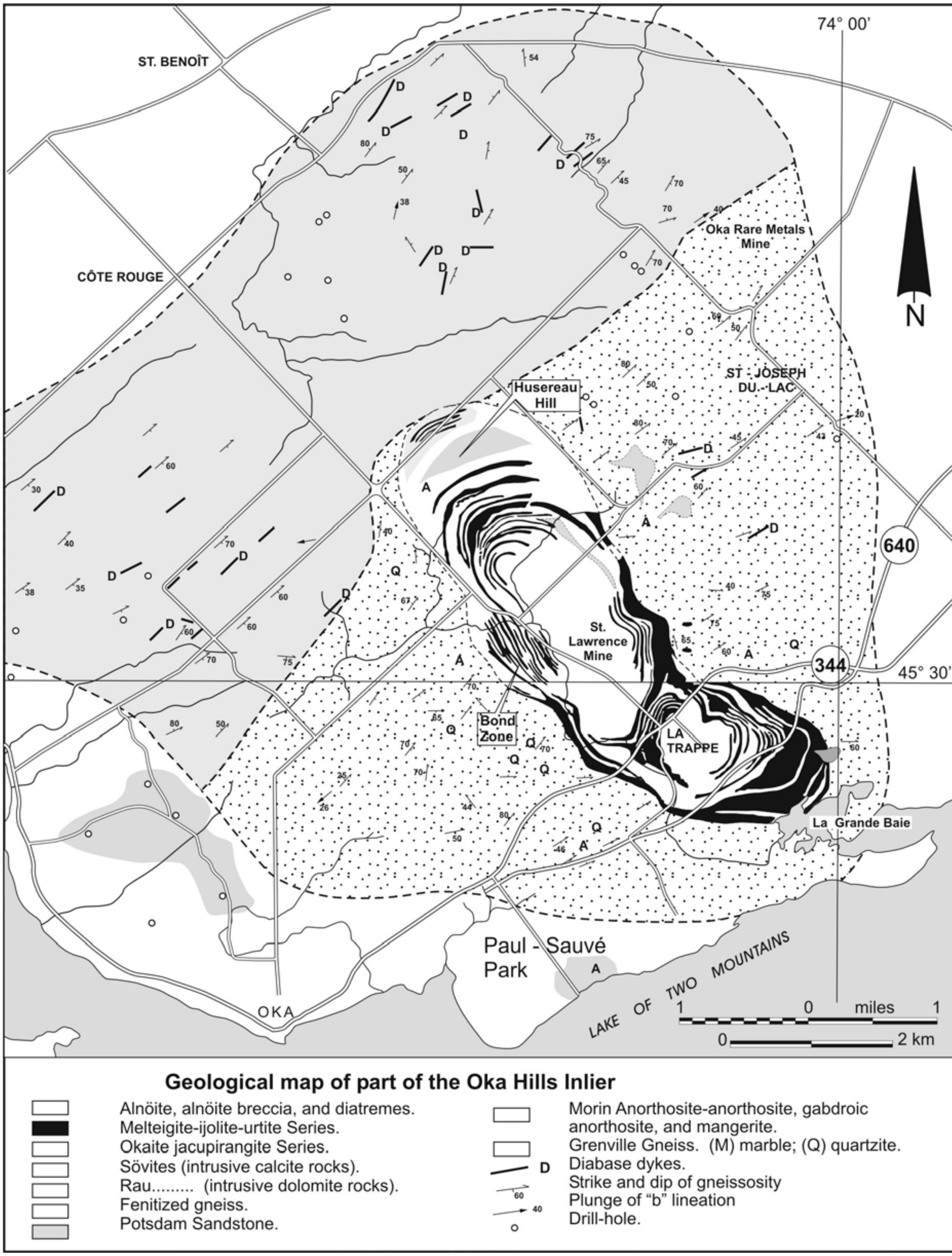


Figure 10. Geological map of the Oka Hills inlier (modified after Gold et al., 1986) showing the Oka Carbonatite Complex within the inlier.

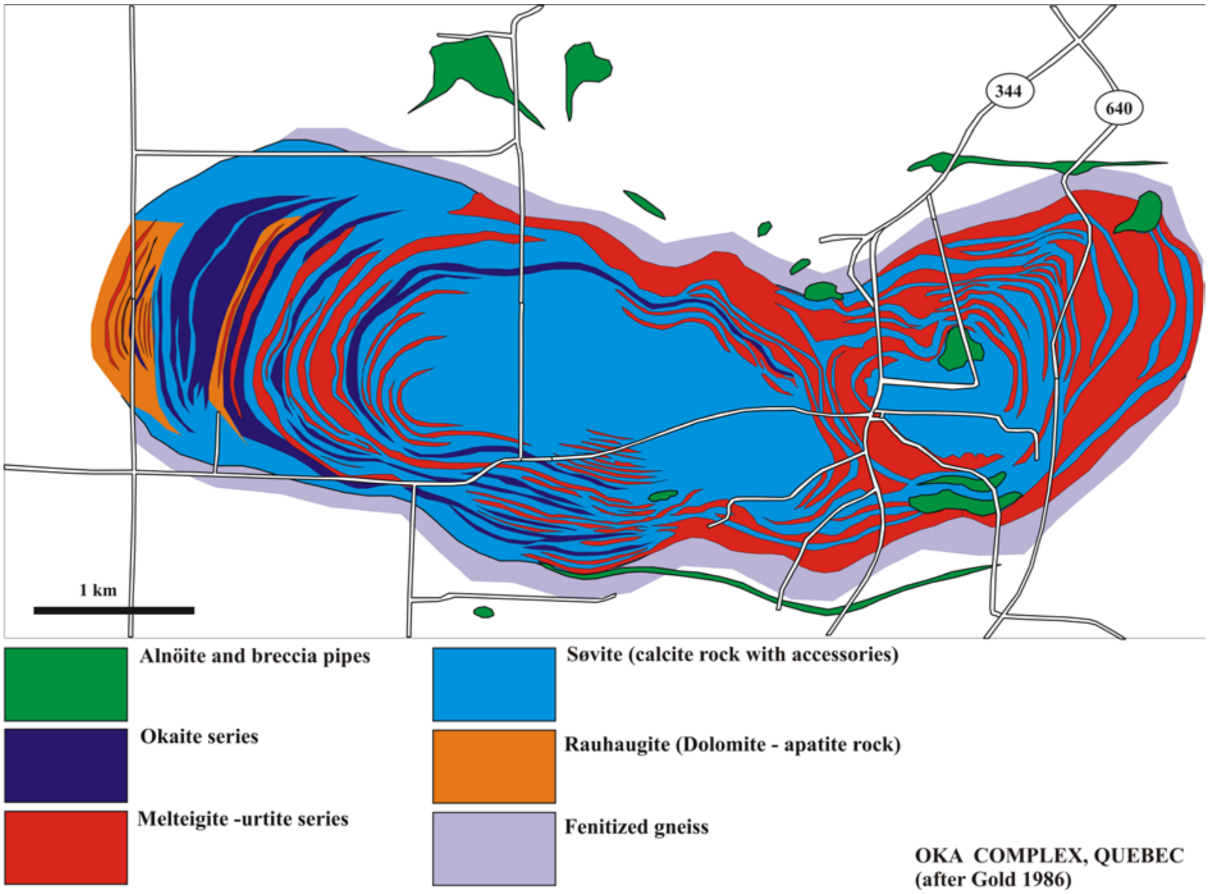


Figure 11. Coloured geological map of the Oka Carbonatite Complex (after Gold et al., 1986) with crosscutting alnoites and associated breccias; the complex is elongated NW-SE.

being a mica-peridotite - none of the lithologies from Île Bizard turn up here).

Melteigite-urtites are the main feldspathoid-bearing species in this complex. Most are fine-grained ijolites - nepheline-bearing (up to 50%) with variable mafic minerals such as alkali pyroxene, alkali amphiboles, biotite and melilite (being feldspar-free). This series ranges from true urtite (>70% feldspathoid) to ultramafic melteigites (pyroxenites). Some varieties contain exotic phases such as melanite garnet and wollastonite.

Okaite is a melilite-rich rock with accessory amounts of nepheline, hauyne, perovskite, apatite, biotite, magnetite and calcite. In this complex, modal variations link the true okaite with a host of unusual relatives, such as nepheline-okaite, hauyne-okaite, titanaugite-bearing nepheline-okaite, and melilite-pyroxenites, such as nepheline-jacupirangite and jacupirangite.

The emplacement history of the complex is considered to be (Gold et al. 1986):

1. Fenitization of the host rocks by precursor fluids to the first magmas, followed by the emplacement of dykes and ring-dykes of sovite. Some of the country rocks may have

been transformed into ijolite by the fenitization (metasomatic addition of Na, Fe^{3+}, P to the Grenville gneisses).

2. Emplacement of early monticellite sovite.
3. Emplacement of okaite-jacupirangite cone sheets.
4. Intrusion of the main pyrochlore sovite, followed by another monticellite sovite.
5. Minor dykes of ijolite, many broken into boudin trains.
6. Hydrothermal activity along cone sheet-type fractures causing biotitization (glimmerites) and thorium metasomatism.
7. Late sovite and rauhaugite cone sheets and dykes (some with rare earth minerals).
8. Late diabase and minette dykes.
9. Alnoite dykes and breccia pipes.

Mine spoil heaps beside the old open pit operations - the open pit (now flooded)- displays the sheeted nature of the intrusion in its walls. The rock types include several types of sovite, okaite and urtite, some of which are rich in apatite, titanomagnetite and pyrochlore (the niobium-bearing ore mineral mined at this locality).

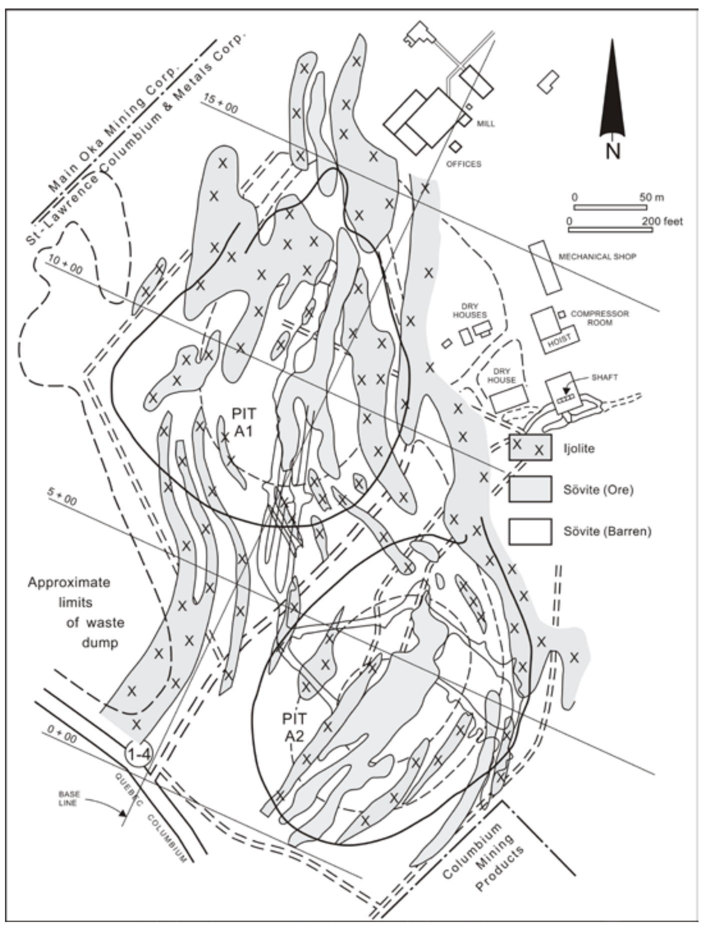


Figure 12. Summary geology map of the two open pits, and underground workings of the St. Lawrence Columbium and Metals Corporation mine (modified after Gold et al., 1986).

<u>STOP 5:</u>
Husereau Hill (*paraphrased from Gold et al., 1986*)

Arcuate Okaite-Jacupirangite Dykes of the "Northern Ring" Structure

Location: From the mine turn northwest on Rue Ste-Sophie for 3.6 km (95.8km) and turn right into the Husereau farm and park near the barn. Walk north on the farm road approximately 1.3 km.

Husereau Hill is located near the northern margin of the "northern ring" of the Oka Complex, and it is the type locality for the melilite-bearing rocks known as okaite and nepheline okaite. It is underlain by arcuate dyke-like bodies of rare rocks that include sovites, rauhaugite, jacupirangite, okaites, a very coarse-grained apatite-magnetite- perovskite-calcite okaite, and two fissure-like bodies of melilite-rich alnoite breccia. There are good sites for collecting these unusual rocks, as well as crystals of melilite, apatite, magnetite, and perovskite. Fission track ages for the okaites range from l18 to 122 Ma.

From the top of the hill there is a good view along the axis of the Oka Complex, with the trenches of the Bond Zone on the right, and the closure of the Northern Ring structure from the left near the abandoned mine working (the former St. Lawrence Columbium and Metals Corporation mine).

The locations of breccia pipes across the Lake of Two Mountains on Île Bizard and Île Cadieux, as well as those in and around the Complex can be seen from here. The southeasterly trending axis of this double ring complex coincides with the regional Beauharnois Arch. Pleistocene glaciers overrode these hills from the north. The gravel quarries where the vehicles are parked are developed in the tail of the Husereau Hill, which drops off steeply on its northern flank to more than 120 m beneath the till, outwash and lake sediments to the north.

STOP 6 (Day 2):
Mount Royal Park (*Adrian Park & David Lentz*)

Location: Begin at Maisonneuve and Berri (0.0 km) and proceed along Maisonneuve and turn right at St. Laurent (0.6 km). Follow St. Laurent to Mt. Royal Avenue (turn left at 2.5 km) and proceed westward to park entrance. Turn left onto Boul. Camillien-Honde (at 3.1 km, which is at foot of hill after lights). Proceed uphill to Outlook/Observatory area. Look at the cross section by bus stop (Trenton Limestone/Utica Shale/gabbro contact and intrusion breccias, then proceed across the cross walk and down the northeast side of the road to the various narrow dykes in the Trenton limestone.

Hazard: Be careful of traffic along the road. Please cross at the cross walk only and as a group.

Location: The party will proceed on foot across the summit of Mont Royal and rejoin the bus in the car park at Maison Smith (Lac aux Castors). We will be looking at layered gabbro, igneous breccia, deformed limestone, felsic dykes and faults along the roadway (300 m of the section) then at a complex outcrop across from the RCMP stables, and finally at some mafic sills and dykes in limestone at the southwest end of the park.

Hazard: Be careful of traffic along the road and crossing the road. Please cross as a group.

The Mont Royal stock consists of one phase of essexite with minor amounts of nepheline monzodiorite, emplaced into the limestones of the Trenton Group (Ordovician) (Fig. 13). The essexites consist of two ‘gabbro’ types, a heterolithic pyroxenite-melagabbro, and a more uniform leucogabbro. The essexites were predated by camptonite dykes and sills, often associated with breccia bodies, and the monzodiorite and essexites are post-dated by a broad range of camptonite and more evolved lamproitic and microsyenitic (tinguaite) dykes and sills. The essexite consists of xenocrysts of olivine wholly or partly enclosed in titanaugite megacrysts, that are themselves fragmental. These sit in a matrix of plagioclase (mainly oligoclase - andesine) with minor nepheline, analcite and sodalite. The feldspathic matrix has reacted with the megacrysts to produce large amounts of subsolidus alkali titanian amphibole (a titanian hastingsite or kaersutite), that co-exists with ilmenite or titanomagnetite. The variation between pyroxenite and leucogabbro is entirely a consequence of modal variations in the amount of feldspathic matrix relative to the titanaugite megacrysts.

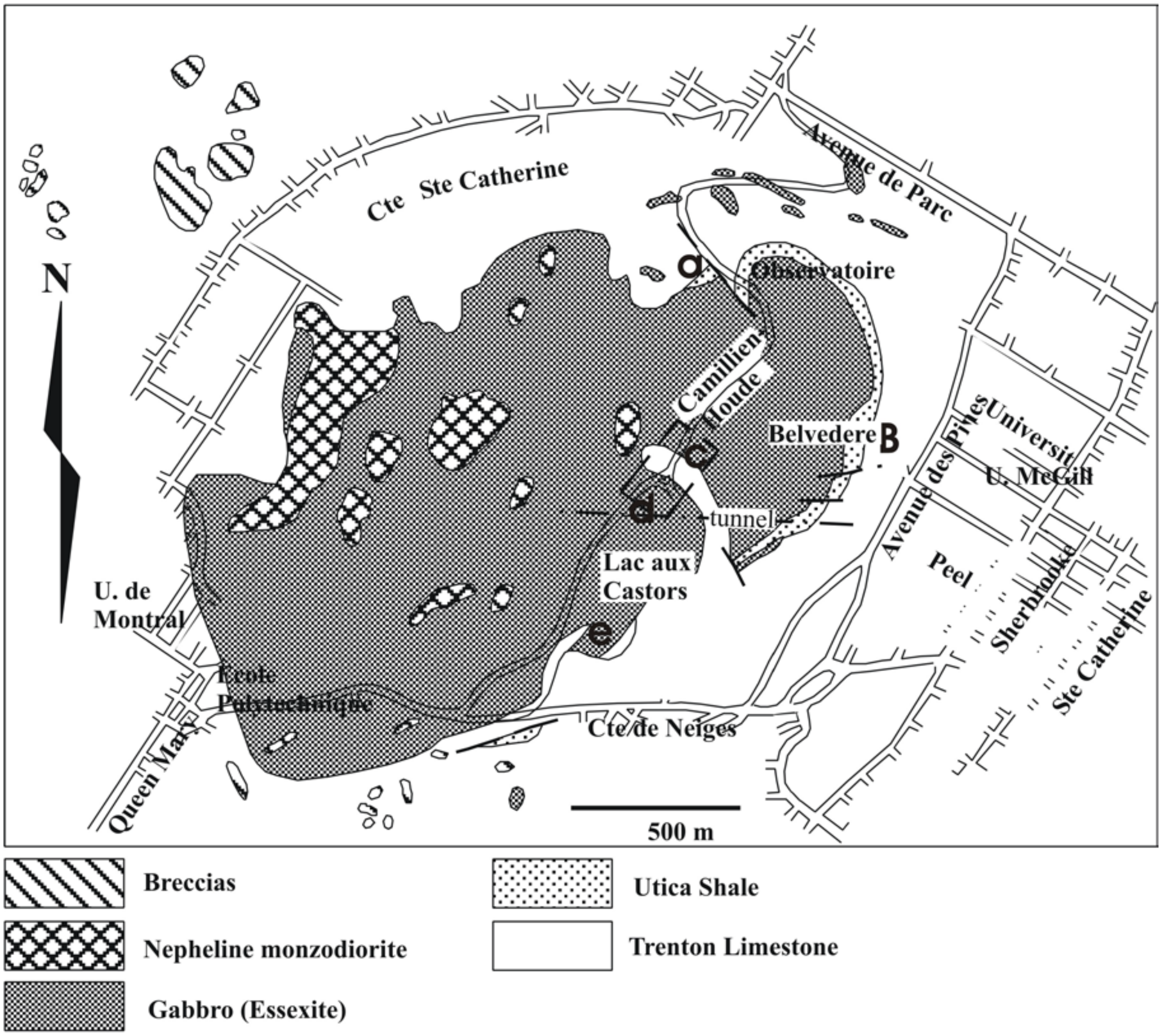


Figure 13. Geological map of the Mont Royal area, with streets in the region and various land marks (after Clarke 1952, Woussen 1970).

Observatory on Boulevard Camillien-Houde (Stop 6a)

Walk out the contact zone through Trenton Limestone to the main gabbro. The limestone has a minor thermal overprint close to the contact, but the actual contact is with a faulted block of Utica Shale, and these are quite baked and hornfelsed. Dykes of camptonite are present in the limestone, some with narrow thermal aureoles. Minor developments of breccia are also associated with camptonite dykes, except in the location beside the first hair-pin bend below the observatory. Here a large patch of brecciated limestone contains only minor amounts of camptonite matrix.

The gabbro is largely the essexite, but very heterolithic. Patchy development of the nepheline monzo-gabbro is seen here (right of the steps behind the shrubbery), also a large xenolith of Utica Shale (right side of the steps, half way up) and veins of the coarse, epitaxial amphibole (beside the steps).

Up the steps and a short walk along the north side of the mountain finds good exposures of the essexite with very prominent, steeply dipping layering. Close examination of clean surfaces reveals that this layering is a modal phenomenon, and not the result of cumulate processes (some of the large pyroxenes have zonation truncated by the anhedral grain outlines).

Near the Belvedere (Stop 6b)

Extensive outcrops of the more 'normal' essexite of the mountain. The rock is a multi-injection breccia with several types of essexite present ranging from ultramafic pyroxenite to feldspathic 'gabbro'. Veins include the feldspathic essexite, and various types of syenite (pulaskite).

Roadcut on Boulevard Camillien-Houde (Stop 6c)

More typical essexites with breccia textures and net veins of various types, including the leucogabbro and a variety of pulaskites. Minor dykes of microsyenite and camptonite. A deeply weathered shear zone is present in the essexite and the sheared material includes a prominent pyroxene lineation. The contact with a limestone screen is preserved opposite the entrance to Cimetière Côte des Neiges (Fig. 14). The limestone itself is both highly metamorphosed - a mix of calcite marble and a greenish skarn of epidote, tremolite, zoisite and diopside - and intensely deformed. This limestone screen can be found 100 m beneath this locality in the Bonaventure railway tunnel.

Outcrop opposite the RCMP station, Boulevard Camillien-Houde (Stop 6d)

Large outcrop of essexite cut by a variety of veins including epitaxial coarse amphibole, carbonate-bearing material, microsyenite and camptonites with gas-breccia characteristics. Some of this material displays harrisitic textures, produced by quenching or rapid magma cooling.

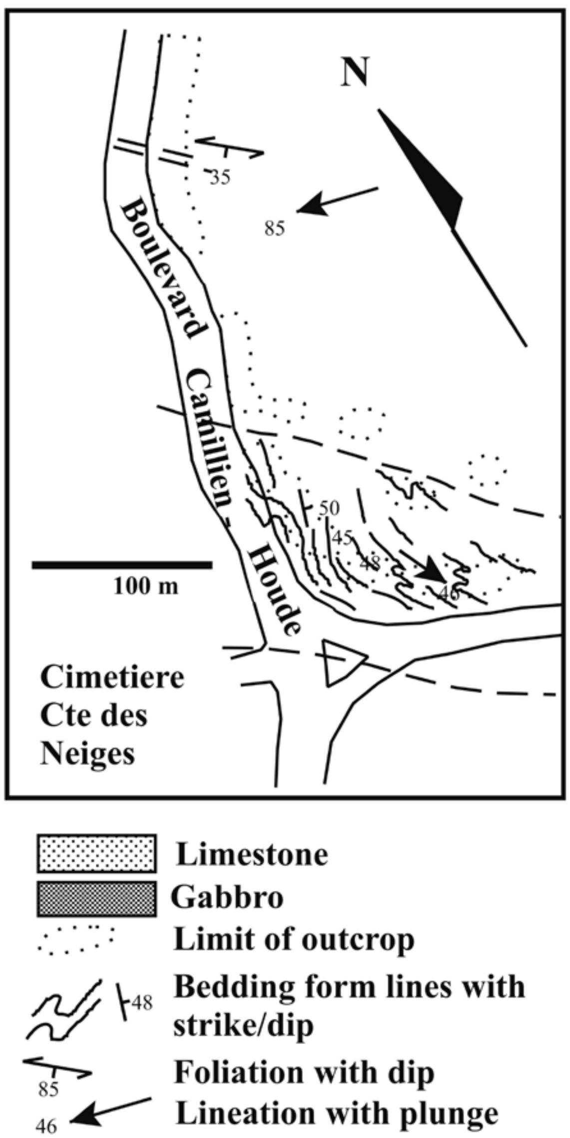


Figure 14. Geological interpretation of part of the Boul. Camillien-Houde section (Stop 6c), Mont Royale.

Woods behind the houses on Avenue des Pines and childrens' play area (Stop 6e)

In the woods southeast of the fields and behind the houses on Avenue des Pines there are extensive outcrops of porphyritic camptonite sills and dykes cutting Trenton limestone. Cross-cutting relationships reveal more than one generation of these sheets. The gabbro outcrops south of the childrens' play area are cut by veins of tinguaite, some of which occur as en echelon arrays.

STOP 7:
Île Ste-Hélène (La Ronde) (*Adrian Park and David Lentz*)

Location: Begin at Voyageur bus terminal. Take Chemin Berri north to Sherbrooke (turn right on to Sherbrooke – Rte 138) at 0.5 km. Turn right onto Chemin Papineau (Rte 134) at 1.6 km and follow Rte 134 to Jacques-Cartier Bridger and cross it (2.5 km). The turn off to Île Ste-Hélène and La Ronde is at 4.1 km. The trip makes 2 stops on Île Ste-Hélène. The first is on a small roadcut just off a tight turn on the east side of the northern hill; it hosts 2 E-W trending narrow mafic dykes in breccia. The second stop is in the car park (west side of island), with a walk through the park looking at the breccias in the valley between the two hills

Hazards: Be careful of traffic (cars, trucks, bicyclers!) in this area. Although the traffic is slow, the roads are narrow.

Accessed from a down-ramp in the middle of the Jacques-Cartier Bridge, this locality was originally two islands, Île Ste-Helene and Île Ronde that were joined at low water (Fig. 15). In 1964-67 the islands were joined by extensive land-fill operations to create the sight for Expo '67 (part of this involved quarrying away much of the hill on Île Ronde, the northern of the two islands. Île Ste-Hélène's hill was spared because of the historic nature of the fort on its summit, built in the late 17th century to protect the Old Port). After the World Fair closed the island was turned into an amusement park, residential development and the location of several exhibition centres.

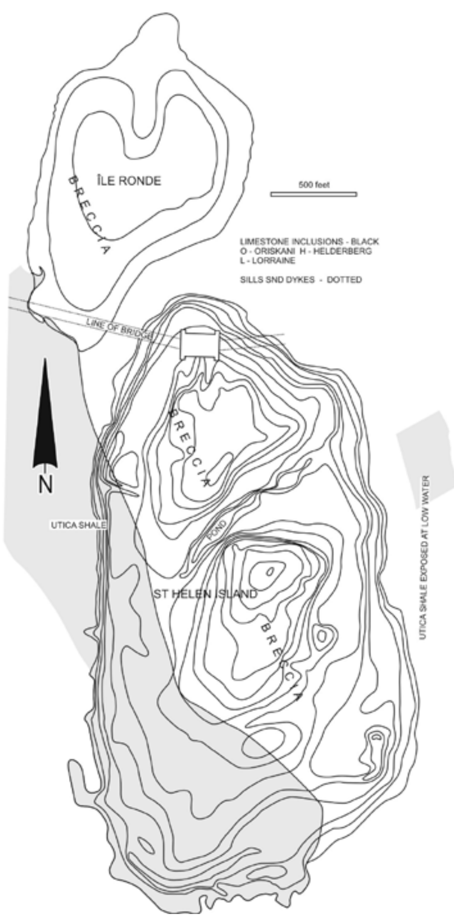


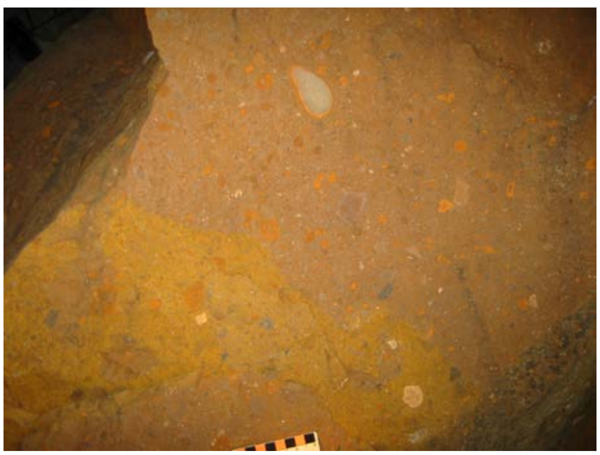
Figure 15. Geological map of the distribution of breccia and Utica Shale (with alkalic mafic dykes) on Île Ste-Hélène and Île Ronde (modified after Osborne & Grimes-Graeme 1936).

The large hill on this island in the St. Lawrence River is a diatreme breccia. A large variety of clasts can be seen, and crucially, at this locality fossiliferous shale and limestone clasts with Devonian brachiopods were found (Helderberg and Oriskany groups - Osborne & Grimes-Graeme 1936). No Lower Paleozoic sediments younger than lower Silurian are currently preserved in the Saint Lawrence lowlands (shales of the Lorraine and Queenston groups), and estimates of the thickness of the missing succession are the basis for estimates of depth of emplacement for the Monteregian intrusions (about 2 km).

In outcrop the Île Ste-Hélène diatreme breccia does not contain igneous clasts, or an igneous matrix

(Fig. 16). However, in 1967 the Metro tunnel to Longueil was excavated beneath the island, and in these excavations a core of camptonite was found within the diatreme breccia (Philpotts, 1973). Loose blocks of a similar breccia were also found in the La Ronde quarry (Clark et al. 1967). Dykes of camptonite are also known from around the island.

Even though the breccia in outcrop does not contain an igneous matrix, the comminuted material supporting the clasts does have a geochemical signature (elevated Ti content especially) and mineralogical characteristics (presence of analcime, perovskite and apatite) consistent with there being an igneous component (Osborne and Grimes-Graeme, 1936; Clark et al., 1967; Philpotts, 1970). The explosive emplacement of this breccia not only shattered country rock through the height of the pipe (accounting for the mix of metamorphic basement clasts, local Trenton limestones and Utica shales, with higher, eroded formations), but mixed this comminuted debris with debris produced by the frothing of the degassing parent magma. Hydrothermal activity after consolidation of the breccia further affected its composition and introduced foreign components (veins carrying calcite, analcime, apatite and rare Ti-minerals).



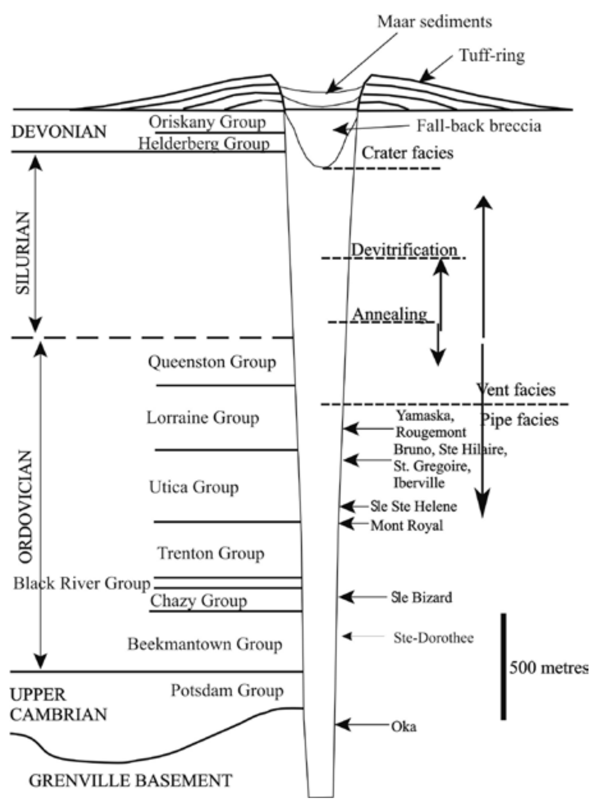


Figure 16 (left). Polymictic breccia under south off ramp (bridge) on Île Ste-Hélène.

Figure 17 (right). Schematic cross section of a diatreme breccia (after Hawthorne, 1975) with the stratigraphy of the St. Lawrence lowlands and emplacement levels of the various Monteregian bodies (compiled from Clarke, 1952; Clark et al., 1967; Philpotts, 1970).

Mont St-Hilaire (*Nelson Eby*)

The Mont St-Hilaire pluton intrudes upper Ordovician shales, siltstones, and limestones (Figs. 17, 18). The pluton is surrounded by a narrow biotite hornfels aureole. The low grade of contact metamorphism is somewhat anomalous considering the apparently high temperatures of the magmas. Near the contact the hornfels dips inward at moderate to steep angles suggesting passive emplacement of the magmas into collapsed material.

Figure 18. Mont St-Hilaire looking northwest.

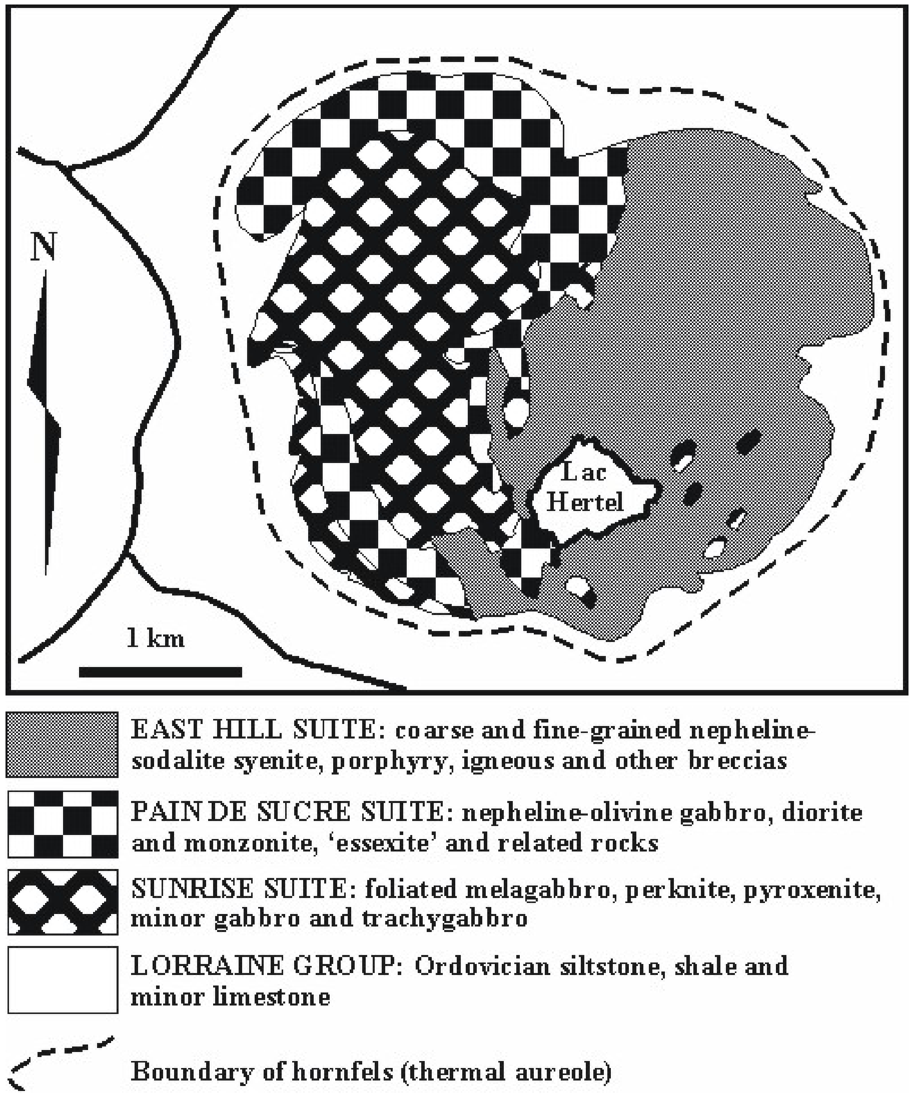


Figure 19. Geologic map of the Mont St-Hilaire pluton (modified after Currie, 1983).

Currie (1983) and Currie et al. (1986) divided the rocks of the pluton into several suites. The Sunrise and Pain de Sucre suites consist of mafic to intermediate rocks and form the western half of the pluton. The East Hill suite consists of peralkaline syenites and forms the eastern half of the pluton. The contact between the western and eastern halves consists of a variety of breccias including igneous and diatreme-like breccias.

The Sunrise suite is apparently the oldest of the igneous groups and consists of pyroxenites and gabbros, with gabbro (Fig. 20) as the dominant lithology. The rocks are strongly foliated, medium grained, and consist of poikilitic amphibole, clinopyroxene, calcic plagioclase, and accessory minerals. Although the rocks are nepheline normative, nepheline is not found in any of the units. There is a regular variation in the mineralogy marked by the replacement of pyroxene by amphibole. These rocks are obviously cumulates and originally occurred as a funnel-shaped mass near the center of the pluton. Currie (1983) defined an igneous stratigraphy for this suite on the basis of a regular decline in color index with distance from the contact.

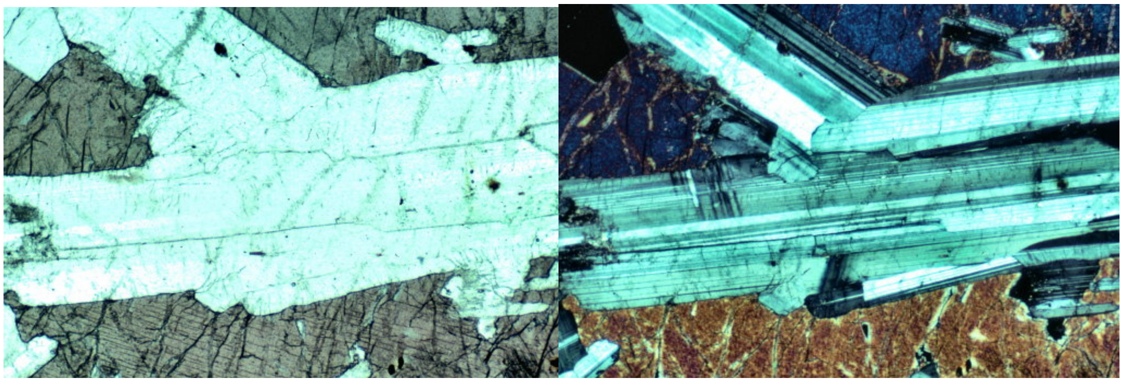


Figure 20. Photomicrographs of gabbro with plagioclase and amphibole; A) Plane polarized light; B) Crossed polarized light (Width of field of view, 5mm).

The Pain de Sucre suite occurs as thick ring dyke intruding the Sunrise suite. The rocks are massive, slightly laminated, nepheline gabbros (essexites), diorites (Fig. 21), and monzonites. Variations within the suite are gradational. Nepheline and occasional olivine occur along with amphibole, biotite, pyroxene, sodic to intermediate plagioclase, and alkali feldspar.

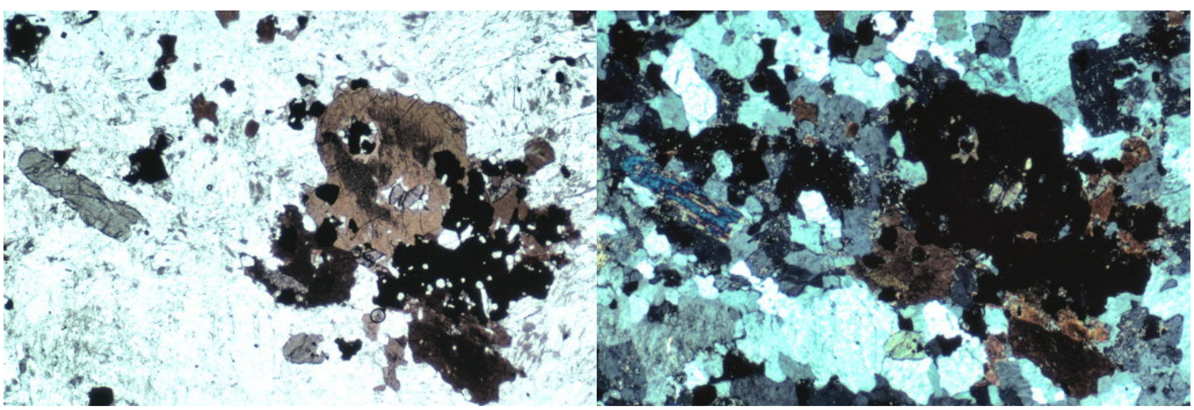


Figure 21. Photomicrographs of nepheline diorite with pyroxene, amphibole, titanite, plagioclase, feldspar, and nepheline. A) Plane polarized light; B) Crossed polarized light (Width of field of view, 5mm).

The East Hill suite consists of peralkaline nepheline syenites (Fig. 22) and porphyries. An early phase of this suite was a coarse-grained nepheline-sodalite syenite (Fig. 23) that is now found as xenoliths in the younger, flow-banded, nepheline syenites and phonolites. Acmitic pyroxenes and Na-rich amphiboles are the major mafic phases. Ilmenite and magnetite are rich in Mn, and both nepheline and/or sodalite are significant minerals, locally comprising as much as 40% of the rock. Elpidite, eudialite, and astrophyllite have been identified in a few specimens.

Currie et al. (1986) outlined a petrogenetic history for Mount St-Hilaire that required two separate magmatic events. The first magma was believed to be an alkali picrite from which crystallized the cumulus rocks of the Sunrise suite. The second magma was hypothesized to be basanitic in composition and the nepheline gabbro - monzonite sequence was formed from this magma through fractional crystallization of pyroxene, magnetite, apatite, and plagioclase. For the East Hills suite they made the rather provocative suggestion that these rocks were the result of the interaction of a basanitic magma with a saline brine at crustal depths. This brine would be rich in Na and Cl, which would explain why nepheline and sodalite are abundant in the syenites.

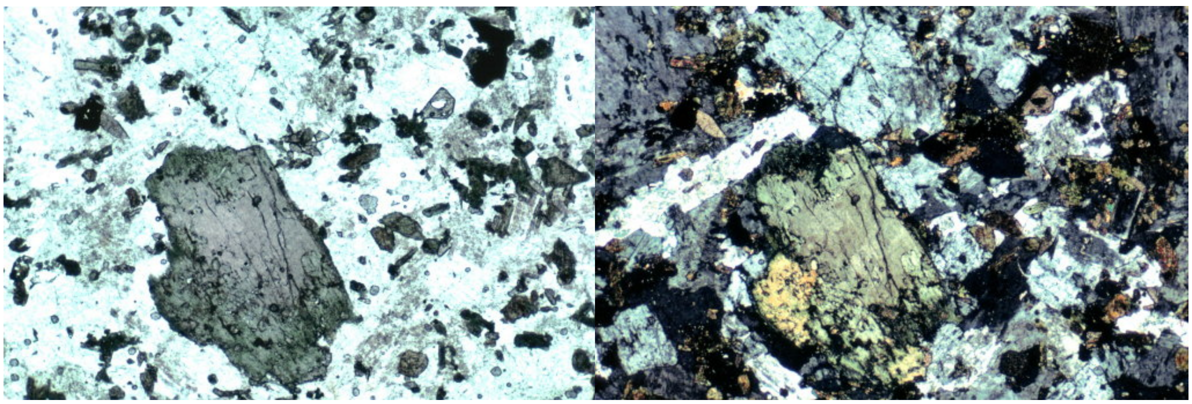


Figure 22. Photomicrographs of nepheline syenite with aegirine, feldspar, and nepheline. A) Plane polarized light (Width of field of view, 5mm); B) Crossed polarized light (Width of field of view, 5mm).

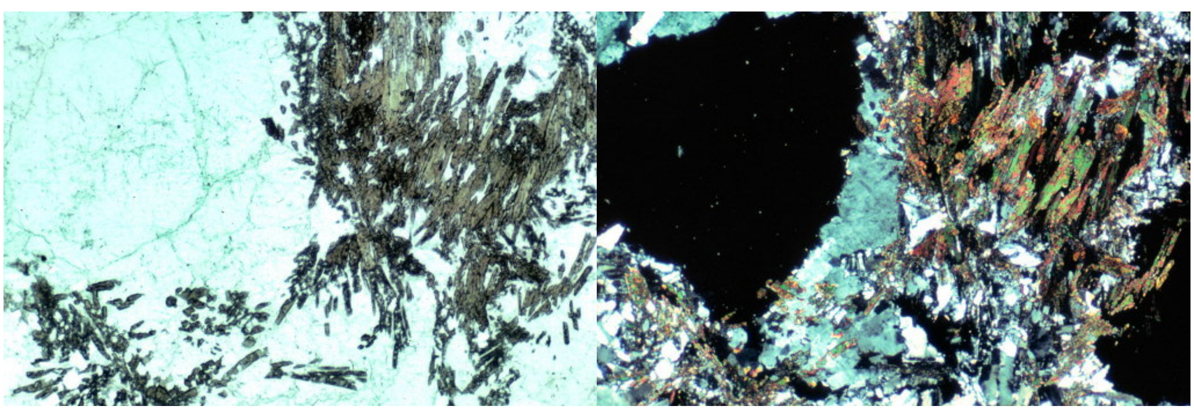


Figure 23. Photomicrographs of coarse-grained syenite, with sodalite, feldspar, and aegirine laths. A) Plane polarized light (Width of field of view, 5mm); B) Crossed polarized light (Width of field of view, 5mm)

The brine hypothesis also has interesting implications with respect to the abundance of rare and exotic minerals that have been identified in the quarries surrounding Mont St-Hilaire. Because their age data indicated a significant hiatus between the emplacement of the Sunrise suite and the other suites, they hypothesized that the magmas were derived by successive melts formed in response to the upward progression of a thermal anomaly.

Subsequent high-precision Ar-Ar dating by Gilbert and Foland (1986) led to the conclusion that the older ages were the result of excess argon and that the emplacement history of the pluton was confined to a time span of 0.5 million years at 124.4 ± 1.2 Ma.

STOP 8 (Mont St. Hilaire)

STOP 8a
Ploudrette Quarry (Mont Ste. Hilaire)

Location: Begin at Voyageur bus terminal. Take Chemin Berri north to Sherbrooke (turn right on to Sherbrooke – Rte 138) at 0.5 km. Turn right onto Chemin Papineau (Rte 134) at 1.6 km and follow Rte 134 to Jacques-Cartier Bridger and cross it (2.5 km). Leave Jacques-Cartier Bridge and follow Rte 20 (Ste-Hyacinth). At 5.6 km veer left and rejoin Rte 20 then veer right at 6.9 km. Follow the river until you meet Autoroute Jean-Lesage at 13.1 km (veer right (Quebec/Sorel). Follow Rte 20 southeast to exit for Rte 133 (at 36.2 km) – turn right. Follow 133 turn right at 36.6 km, then left at 37.1 km. and proceed through St-Hilaire village. Turn left onto Rte 116 at 40.5 km. and join Rte 116 at 40.7 km. Turn right onto Rte 229 at 45.7 km. (Chemin Benoit). Turn right onto Chemin Carrieres at 46.6 km. The entrance to the quarry is at 48.0 km; be careful you proceed in the right direction to the quarry and avoid haulage trucks.

Hazards: Stay away from the quarry face by 5 metres. Also, be careful that large boulders do not roll onto you. Also, be careful of haulage trucks near the collecting area.

STOP 8b

Exposures of igneous and diatreme breccias, Mont St-Hilaire (*N. Eby*)

Location: Exit quarry access road at 49.7 km and turn right onto Chemin Carrieres. Turn right on Rte 227 at 53.8 km (Rue de la RiviereSud). Turn right on Chemin Rouville at 58.7km to Nature Centre. Follow Chemin Rouville to 60.6 km and turn right onto Rang de'Etang. Turn right on Chemin Moulins (see signage to Nature Centre) and proceed to the gate entrance at 62.0 km.

Proceed north along the main trail that follows the valley between the two halves of the mountain. Pass Lac Hertel. On the left (west side) of the trail (45^{o}32'52"N, 73^{o}09'10"W) are scattered outcrops and boulders of both the igneous and diatreme-like breccias (Fig. 24). Most of the lithologies of the pluton can be found as blocks and fragments in these breccias.

Figure 24. Breccia with gabbro and country rock xenoliths.

<u>STOP 8c</u>.

Gabbros and diorites of the Sunrise Suite (*N. Eby*)

Retrace your path southwards to the intersection with the Pain de Sucre trail. Proceed up this trail (west) towards the summit of Pain de Sucre. Outcrops of gabbro (Fig. 25) and diorite of the Sunrise suite are exposed along this trail. In places the rocks are extremely coarse-grained and outcrops are found to carry clots of large radiating amphiboles. Foliation is generally poorly developed in this part of the suite.

Figure 25. Gabbro. Large plagioclase laths show crude sub-parallel alignment.

STOP 8d.

Nepheline diorites and monzonites of the Pain de Sucre Suite (N. Eby)

Continue on to the summit of Pain de Sucre. In the immediate vicinity of the summit is an almost continuous exposure of relatively leucocratic coarse-grained rocks of the Pain de Sucre suite (Fig. 26). The rocks usually have a bluish cast and visible laths of alkali feldspar. Olivine is present locally and nepheline occurs as an interstitial phase.


Figure 26. Nepheline diorite cut by phonolite dike.

The minerals, mineral formula, and rock names of Mont St-Hilaire and the Monteregian Hills. (*Adrian Park*)

This list is from Chao et al. (1967). Three settings are recognised for the rather extensive and varied mineral suites for which this Monteregian hill is famous. All are located in the nepheline syenites. They are 1. veins, 2. vugs, and 3. inclusions in the pulaskite.

1. a Veins showing no signs of alteration in wall-rock

Principal minerals in these veins are: microcline, albite and aegerine

Accessories include:	actinolite	cancrinite	leucophanite	sodalite
aegerine	catapleiite	microcline	hackmanite (sodalite)	
albite	diopside	muscovite	sphalerite	analcime
elpidite	natrolite	wurtzite	ancylite	eudialyte
nepheline	astrophyllite	fluorite	pyrochlore	augite
genthelvite	rhodochrosite	birnessite	ilmenite	serandite
calcite	karpinskyite	soda amphibole		

1. b Altered veins - rich in goethite and chlorite replacing mafic silicates

Principal minerals in these veins are: microcline and/or albite

Accessories include:	actinolite	chlorite	limonite	siderite
aegerine	elpidite	marcasite	sphalerite	albite
epididymite	microcline	zircon	catapleiite	goethite
rutile	apatite	galena	pyrite	

2. a Silicate vugs in nepheline syenite

Principal minerals in these vugs are: analcime, aegerine, microcline, albite and natrolite

Accessories include:	actinolite	cancrinite	microcline	sodalite
aegerine	catapleiite	natrolite	hackmanite (sodalite)	
albite	diopside	polylithionite	sphalerite	ancylite
epididymite	pyrophanite	willemite	andradite	eudialyte
ramsayite	wöhlerite	apatite	fluorite	rhodochrosite
zircon	apophyllite	helvite	rinkite	astrophyllite
hematite	sanidine	augite	ilmenite	serandite
biotite	leucophanite	siderite	burbankite	magnetite
soda-amphiboles		calcite	mangan-neptunite	

2. b Carbonate vugs in nepheline syenite

The principal minerals in these vugs are: siderite and albite

Accessories include:	albite	calcite	soda-amphiboles	synchysite
ankerite	pyrite	sphalerite	zircon	bastnaesite
siderite				

3. a Type A inclusions in nepheline syenite

Principal minerals in these inclusions are: greyish green hornfels cut by quartz veins

Contain unusual minerals such as:			
	calcite	molybdenite (3R)	quartz
	fluorite	molybdenite (6H)	ramsayite
	leucosphenite	narsarsukite	

3. b Type B inclusions in nepheline syenite

Principal minerals in these inclusions are: pale green to purplish, dominated by pectolite

Accessories include:				
	apophyllite	fluorite	phlogopite	
	calcite	microcline	soda-amphiboles	datolite
	pectolite	thomsonite	eudialyte	

3. c Type C inclusions in nepheline syenite

Principal minerals in these inclusions are: calcite with veins and patches of vesuvianite

Accessories include:			
	calcite	vesuvianite	pyrite
	pectolite	apophyllite	natrolite

MINERALS, WITH DEFINITIONS:

Actinolite	silicate, amphibole group $Ca_2(Mg,Fe)_5Si_7O_{22}(OH)_2$
Aegerine	silicate, pyroxene group $NaFe^{3+}(Si_2O_6)$
Albite	silicate, feldspar group $NaAl_3Si_3O_8$
Almandine	silicate, garnet group $Fe_3Al_2Si_3O_{12}$
Analcime	silicate, zeolite group $NaAlSi_2O_6.H_2O$
Ancylite	carbonate $SrCe(CO_3)_2(OH).H_2O$
Andradite	silicate, garnet group $Ca_3Fe^{3+}{}_2Si_3O_{12}$
Ankerite	carbonate $(Ca, Fe, Mg)CO_3$
Apatite	phosphate $Ca_5(PO_4)_3(OH,F,Cl)$
Apophyllite	silicate (related to prehnite) $KFCa_4Si_8O_{20.}8H_2O$
Arsenopyrite	sulphide, FeAsS
Astrophyllite	silicate (pyroxenoid?) $(K,Na)_3(Fe,Mn)_7Ti_2(Si_4O_{12})_7(O,OH,F)_7$
Augite	silicate, pyroxene group $Ca(Mg,Fe,Al)Si_2O_6$
Barite	sulphate, $BaSO_4$
Bastnaesite	carbonate $(Ce,La)CO_3F$
Biotite	silicate, mica group $K_2(Mg, Fe^{2+})_{6-4}(Fe^{3+},Al,Ti)_{0-2}Si_{6-5}Al_{2-3}O_{20}(OH,F)_4$
Birnessite	hydrated oxide $Na_4Mn_{14}O_{27}.9H_2O$
Brookite	oxide, titania polymorph TiO_2
Burbankite	carbonate $(Na,Ca)_3(Sr,Ba,Ce)_3(CO_3)_5$
Calcite	carbonate $CaCO_3$
Cancrinite	silicate, feldspathoid $(Na,Ca,K)_{6-8}Al_6Si_6O_{24}(CO_3,SO_4,Cl)_{1-2}.1\text{-}5H_2O$
Catapleiite	silicate, disilicate $(Na,Ca)_2ZrSi_3O_9.2H_2O$
Chalcopyrite	sulphide $CuFeS_2$
Chlorites	all silicates, distinct group
Datolite	borosilicate, orthosilicate group $CaBSiO_4(OH)$
Dawsonite	carbonate $NaAlCO_3(OH)_2$
Diopside	silicate, pyroxene group $CaMgSi_2O_6$

Dolomite	carbonate $CaMg(CO_3)_2$
Elpidite	silicate $Na_2ZrSi_6O_{15}.3H_2O)$
Epididymite	silicate $NaBeSi_3O_7(OH)$
Eudialyte	silicate, disilicate group $(Na,Ca,Fe)_6Zr(Si_3O_9)_2(OH,F,Cl)$
Fluorite	halide, CaF_2
Galena	sulphide, PbS
Genthelvite	silicate, helvite group (feldspathoid) $Zn_4Be_3Si_3O_{12}S$
Goethite	hydrated iron oxide, FeO(OH)
Götzenite	silicate, disilicate group $Na_2Ca_5Ti(Si_2O_7)_2F_4$
Grossular	silicate, garnet group $Ca_3Al_2Si_3O_{12}$
Grunerite	silicate, amphibole group $(Fe^{2+},Mg)_7Si_8O_{22}(OH)_2$
Gypsum	sulphate, $CaSO_4.nH_2O$
Helvite	silicate, helvite group (feldspathoid) $Mn_4Be_3Si_3O_{12}S$
Hematite	oxide, Fe_2O_3
Hornblende	silicate, amphibole group $(Na,K)_{0-1}Ca_2(Mg,Fe^{2+},Al)_5(Si,Al)_8O_{22}(OH)_2$
Idocrase (Vesuvianite)	silicate, disilicate group $Ca_{10}(Mg,Fe)_2Al_4(Si_2O_7)_2(SiO_4)_5(OH,F)$
Ilmenite	oxide, $FeTiO_3$
Karpinskyite	alteration product of leifite, i.e. leifite + clay
Leifite	$(Na,H_3O)_2(Si,Al,Be,B)_7(O,F,OH)_{14}$
Leucophanite	$(Ca,Na)_2BeSi_2(O,F,OH)_7$
Leucosphenite	borosilicate $BaNa_4Ti_3B_2Si_{10}O_{30}$
Limonite	amorphous hydrated iron oxide
Magnetite	oxide, spinel group Fe_3O_4
Mangan-neptunite	silicate $Na_2LiKMn_2Ti_2(SiO_3)_8$
Marcasite	sulphide, pyrite polymorph FeS_2
Microcline	silicate, feldspar group $KAlSi_3O_8$
Molybdenite (3R)	sulphide MoS_2
Molybdenite (6H)	sulphide MoS_2
Muscovite	silicate, mica group $KAl_2Si_3AlO_{10}(OH,F)_2$
Narsarsukite	silicate $Na_2(Ti,Fe)Si_4(O,F)_{11}$
Natrolite	silicate, zeolite group $Na_2Al_2Si_3O_{10}.2H_2O$
Nepheline	silicate, feldspathoid $Na_3(Na,K)Al_4Si_4O_{16}$
Pectolite	silicate, pyroxenoid group $Ca_2NaH(SiO_3)_3$
Phlogopite	silicate, mica group $KMg_3Si_3AlO_{10}(OH,F)_2$
Polylithionite	silicate, mica group $KLi_2AlSi_4O_{10}(OH,F)_2$
Pyrite	sulphide, FeS_2
Pyrochlore	oxide, $(Ca,Na,Ce)(Nb,Ti,Ta)_2(OH,F)_7$
Pyrolusite	oxide MnO_2
Pyrophanite	$MnTiO_3$
Pyrrhotite	sulphide, FeS_{1-x}
Quartz	silicate, SiO_2
Ramsayite	silicate (lorenzenite) $Na_2Ti_2Si_2O_9$
Rhodochrosite	carbonate $MnCO_3$

Riebeckite (Crocidolite) silicate, amphibole group $Na_2Fe^{2+}{}_3Fe^{3+}{}_2Si_8O_{22}(OH)_2$
Rinkite silicate, epidote group $(Ca,Ce)_4Na(Na,Ca)_2Ti(Si_2O_7)_2F_2(O,F)_2$
Rutile oxide, titania polymorph TiO_2
Sanidine silicate, feldspar group $KAlSi_3O_8$
Serandite silicate, $Na_6(Ca,Mn)_{15}Si_{20}O_{58}.2H_2O$
Siderite carbonate $FeCO_3$
Soda-amphibole silicates, amphibole group
Sodalite silicate, feldspathoid $Na_4Al_3Si_3O_{12}Cl_2$
Sodalite (Hackmanite) silicate, feldspathoid $Na_4Al_3Si_3O_{12}(Cl,S)_2$
Sphalerite sulphide ZnS
Sphene silicate, orthosilicate group $CaTiSiO_4(OH,F)$
Synchysite carbonate $Ca(Ce,La)(CO_3)_2$
Thomsonite silicate, zeolite group $NaCa_2[(Al,Si)_5O_{10}]_2.6H_2O$
Willemite silicate Zn_2SiO_4
Wöhlerite silicate, epidote group $NaCa_2(Zr,Nb)Si_2O_7(OH,F)_2$
Würtzite sulphide, FeS
Zircon silicate, orthosilicate group $ZrSiO_4$

SOME ROCK DEFINITIONS

Aillikite Hypabyssal igneous rock consisting of phenocrysts of olivine, orthopyroxene, clinopyroxene, phlogopite and Mg-titanomagnetite, in a matrix of serpentine, calcite, melanite garnet, magnetite and apatite. It has affinities with alnöite, kimberlite and lamproites, but is distinct from each of them (from Aillik island, Greenland).

Akerite Microsyenite or monzonite with high quartz content. Also contains orthoclase, plagioclase, hornblende, biotite, sometimes augite or alkali pyroxene. Composition approximates a low pressure eutectic (from Aker, Norway).

Alnoite Once included with alkali lamprophyres, now considered related to alkali lamprophyres, lamproites and kimberlites (from Ålnö Island, Sweden). It is an olivine-biotite melilitolite. Accessory phases include perovskite, garnet (melanite, a high-Ti andradite), calcite, nepheline, apatite. Note that the Île Bizard and Oka ‘alnoite’ does not contain modal melilite or nepheline, but both are present in the norm and are occult in a glass phase. Melilite and perovskite were described from a dyke at Ste-Anne-de-Bellvue, and these other examples are rocks with clear affinities to this dyke rock, and have both melilite and perovskite in the calculated norm (in the rock mode these phases are occult in altered glass or titanomagnetite).

Camptonite Gabbroic lamprophyre - essentially a basaltic rock with little feldspar. Minerals are an alkali amphibole (kaersutite here), titanaugite, biotite and sometimes olivine. Any feldspar in the norm is generally occult in glass (from Campton County, New Hampshire).

Carbonatite Intrusive igneous rock consisting of more than 50% carbonate (calcite, dolomite, siderite or ankerite). Other minerals include olivine, alkali pyroxene (usually aegerine or aegerine-augite), alkali amphiboles (richterite, riebeckite, etc), biotite or phlogopite (sometimes tetraferriphlogopite, where Fe^{3+} substitutes for Al^{3+}), perovskite, microlite, knopfite, Nb-Ta oxides like pyrochlore, samarskite, magnetite, apatite, zircon, etc. Varieties are sovite and rauhaugite.

Essexite A mildly undersaturated gabbro consisting of titanaugite with or without olivine, plagioclase and a feldspathoid mineral (usually nepheline or sodalite). May also contain biotite and ilmenite. Strictly speaking 'essexite' should contain more than 2% modal feldspathoid, which is actually unusual in the Monteregian essexites. However, all the Monteregian essexites contain normative nepheline, the phase being occulted by the amphibole content seen in these gabbroic rocks (from Essex County, Massachusetts).

Fenite Rock with the appearance and petrography of an alkali syenite formed by metasomatism around alkaline intrusions, especially carbonatites. Feldspars in the primary material are replaced by albite, pyroxenes and amphiboles are replaced by sodic varieties, quartz is progressively removed. Other hallmarks of fenite include growth of apatite, carbonate minerals and hematite. Process of this type of metasomatism is often called 'fenitization' (from Fen, Norway).

Fourchite Lamproite dyke rock that is essentially an olivine-free monchiquite, i..e. an analcime, augite lamproite (from Fourche Mountains, Arkansas).

Glimmerite Mica-rich rock associated with carbonatites, and usually carbonate-bearing (<50%). Mica can be biotite or phlogopite (or tetraferriphlogopite). Generally a product of metasomatism. From old German term for 'mica.'

Ijolite An extremely undersaturated felsic rock with feldspathoids making up more than 50% of the mode, it is usually feldspar-free. Typically a nepheline-pyroxene rock (from Iivaara, Finland: originally Ijolozero in Russian). Pyroxene is typically an alkali variety such as aegerine. With increasing mafic minerals in mode it is transitional to melteigite; with increasing feldspathoids in mode transitional to urtite.

Jacupirangite An extremely undersaturated ultramafic rock consisting of titanaugite, titanian alkali amphibole (kaersutite or titanian hastingsite) and minor amounts of nepheline and apatite. Essentially an alkali pyroxenite. Other accessory phases include titanomagnetite, ilmenite, perovskite and melanite garnet (from Jacupiranga, Brazil).

Lamproite Mafic to ultramafic hypabyssal rocks with prominent phenocrysts and distinctly K- and Mg-rich. Very diverse group, but all characterized by the present of feldspathoids (esp. leucite), K-feldspar (esp. sanadine) and Ti-phlogopite, as well as unusual Ti-rich phases like perovskite, titanaugite, kaersutite.

Lamprophyre Mafic to ultramafic hypabyssal rocks with prominent phenocrysts. They fall into three categories: 1. Calc-alkaline lamprophyres - minette, vogesite, kersantite and spessartite usually contain feldspar, either both plagioclase and K-feldspar, or just plagioclase, along with biotite, diopsidic augite and olivine. Mafic phases form the phenocrysts as well as groundmass. 2. Alkaline lamprophyres - camptonite and monchiquite - are feldspar-free, and consist of

	olivine, titanaugite, kaersutite, and biotite, again with the mafic phases occurring as phenocrysts and groundmass. 3. Melilitic lamprophyres - alnöite and polzenite - are feldspar-free, contain melilite and feldspathoids.
Melteigite	Mafic rock consisting mainly of alkali pyroxene and nepheline - a mela-ijolite (from Melteig, Norway). A mafic ijolite.
Minette	Calc-alkaline lamprophyre consisting of alkali feldspar, biotite, diopsidic augite, hornblende, with accessory olivine, apatite, calcite and zeolites.
Monchiquite	Alkali lamprophyre consisting of olivine, titanaugite and biotite in a matrix that may include feldspathoid (typically analcime or nepheline). From Sierra de Monchique, Portugal.
Nordmarkite	A quartz syenite. Usually perthite-bearing, and transitional to alkali granite (from Nordmark, Norway).
Okaite	Haüyne melilitolite: an ultramafic undersaturated rock consisting largely of melilite (>75%) with hauyne (sodalite group mineral) as the other essential phase. Also contains titanaugite, ilmenite, pyrochlore and minor nepheline. Oka is the type locality.
Perknite	An amphibole-bearing peridotite - in the Monteregian province this is usually an olivine-titanaugite-kaersutite (or titanian hastingsite) rock (i.e. a feldspar-poor or feldspar-free essexite).
Phonolite	Volcanic equivalent of a feldspathoidal syenite - i.e. an undersaturated felsic to intermediate rock.
Pulaskite	An undersaturated syenite containing plagioclase, orthoclase (or perthite) and a feldspathoid (nepheline or sodalite typically) - from Pulaski County, Arkansas.
Rauhaugite	A dolomite-bearing carbonatite (from Rauhaugen, Norway).
Sølvsbergite	Mafic micro-alkali syenite (from Solvsberg, Norway).
Sovite	A calcite-bearing carbonatite (from Søve, Norway).
Tinguaite	Nepheline microsyenite, having tinguaitic texture: needles of aegerine occur interstitially in mosaic of alkali feldspar and feldspathoids, mainly nepheline (after Sierra de Tingua, Brazil)
Tuffisite	Igneous rock with the characteristics of a tuff but intrusive field relationships, often the matrix to a breccia, and contains evidence for the devitrification of glass shards.
Urtite	An extremely undersaturated felsic rock, essentially a nephelinolite (>70% nepheline) devoid of feldspar (similar to ijolite but with fewer mafic minerals in mode). Apatite may be an important accessory (from Lujavr-Urt, Russia).

REFERENCES

Adams, F.D. 1903. The Monteregian Hills - a Canadian petrographical province. Journal of Geology, 11, pp. 239 - 282.

Bancroft, J.A. & Howard, W.V. 1923. The essexites of Mount Royal, Montreal. Royal Society of Canada Transactions, 17, pp. 13 - 43.

Bedard,J. H. J., Ludden, J. N., & Francis, D. M. 1987. The Mégantic intrusive complex, Québec: a study of the derivation of silica-oversaturated anorogenic magmas of alkaline affinity. Journal of Petrology, 28, pp. 355-388.

Bedard, J. H. J., Francis, D. M., & Ludden, J. 1988. Petrology and pyroxene chemistry of Monteregian dykes: the origin of concentric zoning and green cores in clinopyroxenes from alkali basalts and lamprophyres. Canadian Journal of Earth Sciences, 25, pp. 2041-2058.

Chao, G.Y., Harris, D.C., Hounslow, A.W., Mandarino, J.A., & Perrault, G. 1967. Minerals from the nepheline syenite, Mont St. Hilaire, Quebec. Canadian Mineralogist, 9, pp. 109 - 123.

Chen, J., Henderson, C.M.B., & Foland, K.A. 1994. Open-system, sub-volcanic magmatic evolution: constraints on the petrogenesis of the Mount Brome alkaline complex, Canada. Journal of Petrology, 35, pp. 1127-1153.

Clark, T.H. 1952. Montreal area: Laval and Lachine map-areas. *Department of Mines Province of Quebec Geological Report* 46, 159 p.

Clark, T.H., Kranck, E.H., & Philpotts, A.R. 1967. Ile Ronde breccia, Montreal. *Canadian Journal of Earth Sciences*, **4**, 507 - 513.

Currie, K.L., 1983. An interim report on the geology and petrology of the Mont Saint Hilaire pluton, Quebec. Geological Survey of Canada, Paper 83-18, pp. 39-46.

Currie, K.L., Eby, G.N., & Gittins, J. 1986. The petrology of the Mont Saint Hilaire complex, southern Quebec: An alkaline gabbro-peralkaline syenite association. Lithos, 19, pp. 65-81.

Eby, G.N. 1979. Mount Johnson, Quebec – An example of silicate-liquid immiscibility? Geology, 7, pp. 491-494.

Eby, G.N. 1980. Minor and trace element partitioning between immiscible ocelli-matrix pairs from lamprophyre dikes and sills, Monteregian Hills petrographic province, Quebec. Contributions to Mineralogy and Petrology, 75, pp. 269-278.

Eby, G.N. 1984. Monteregian Hills I. Petrography, major and trace element geochemistry, and strontium isotopic chemistry of the western intrusions: Mounts Royal, St. Bruno, and Johnson. Journal of Petrology, 25, pp. 421-452.

Eby, G.N. 1985a. Monteregian Hills II. Petrography, major and trace element geochemistry, and strontium isotopic chemistry of the eastern intrusions: Mounts Shefford, Brome, and Megantic: Journal of Petrology, v. 26, pp. 418-448.

Eby, G.N. 1985b. Sr and Pb isotopes, U and Th chemistry of the alkaline Monteregian and White Mountain provinces, eastern North America. Geochimica et Cosmochimica Acta, 49, pp. 1143-1154.

Eby, G.N. 1985c, Age relations, chemistry, and petrogenesis of mafic alkaline dikes from the Monteregian Hills and younger White Mountain igneous provinces. Canadian Journal of Earth Sciences, 22, pp. 1103-1111.

Eby, G.N. 1987. The Monteregian Hills and White Mountain alkaline igneous provinces,

eastern North America. *In* Alkaline igneous rocks. Edited by J.G. Fitton and B.G.J. Upton.Geological Society Special Publication No. 30, pp. 433-447.
Eby, G.N., Roden-Tice, M., Krueger, H.L., Ewing, W., Faxon, E.H., & Woolley, A.R. 1995. Geochronology and cooling history of the northern part of the Chilwa Alkaline Province, Malawi. Journal of African Earth Sciences, 20, pp. 275-288.
Fairbairn, H.W., Faure, H.W., Pinson, W.H., Hurley, P.M., & Powell, J.L. 1963. Initial ratio of strontium 87 to strontium 86, whole-rock age, and discordant biotite in the Monteregian Igneous Province, Quebec. Journal of Geophysical Research, 68, pp. 6515-6522.
Foland, K.A., Gilbert, L.A., Sebring, C.A., & Jiang-Feng, C. 1986. Ar-40/Ar-39 ages for plutons of the Monteregian Hills, Quebec: Evidence for a single episode of Cretaceous magmatism. Geological Society of America Bulletin, 97, pp. 966-974.
Foland, K.A., Chen, J.-F., Linder, J.S., Henderson, C.M.B., & Williams, I.M. 1989. High-resolution $^{40}Ar/^{39}Ar$ chronology of multiple intrusion igneous complexes: application to the Cretaceous Mount Brome complex, Quebec, Canada. Contributions to Mineralogy and Petrology, 102, pp. 127-137.
Foster, J., & Symons, D.T.A. 1979. Defining a paleomagnetic polarity pattern in the Monteregian intrusives. Canadian Journal of Earth Sciences, 16, pp. 1716-1725.
Gelinas, L. 1972. Geology of Mount Royal. 24th International Geological Congress, Excursion B-12, 44 p.
Gilbert, L.A. & Foland, K.A. 1986. The Mont Saint Hilaire plutonic complex: occurrence of excess ^{40}Ar and short intrusion history. Canadian Journal of Earth Sciences, 23, pp. 948-958.
Gold, D.P., Eby, G.N., Bell, K., & Vallee, M. 1986. Carbonatites, diatremes, and ultra-alkaline rocks in the Oka area, Quebec. Geological Association of Canada, Mineralogical Association of Canada, Canadian Geophysical Union, Joint Annual Meeting, Ottawa '86, Field Trip 21 Guidebook, 51 p.
Grunenfelder, M.H., Tilton, G.R., Bell, K., & Blenkinsop, J. 1985. Lead and strontium isotope relationships in the Oka carbonatite complex, Quebec. Geochimica et Cosmochimica Acta, 50, pp. 461-468.
Harnois, L., Mineau, R., & Morency, M., 1990. Rare-earth element geochemistry of alnoitic Cretaceous rocks and ultramafic xenoliths from Île Bizard (Québec, Canada). Chemical Geology, 85, pp. 135-145.
Harvie, R. 1910. On the origin and relations of the Paleozoic breccias of the vicinity of Montreal. Royal Society of Canada, Transaction Series 3, pp. 249-299.
Hawthorne, J. B. 1975. Model of a kimberlite pipe. Physics and Chemistry of the Earth, 9, 1 – 15.
Heaman, L.M., & LeCheminant, A.N. 2001. Anomalous U-Pb systematics in mantle-derived baddeleyite from Île Bizard: Evidence for high temperature radon diffusion? Chemical Geology, 172, pp. 77-93.
Kumarapeli, P.S. 1970. Monteregian alkalic magmatism and the St. Lawrence rift system in space and time. Canadian Mineralogist, 10, pp. 421 - 431.
Marchand, M. 1970. Ultramafic nodules from Ile Bizard, Quebec. MSc. thesis, McGill University, Montreal, 73 p.
Mitchell, R.H., 1979. The alleged kimberlite-carbonatite relationship: additional contrary

mineralogical evidence. American Journal of Science, 279, pp. 570-589.
Mitchell, R.H. 1983. The Ile Bizard intrusion, Montreal, Quebec – kimberlite or lamprophyre?: Discussion. Canadian Journal of Earth Sciences, 20, pp. 1493-1496.
Naeser, C.W. 1981. The fading of fission-tracks in the geologic environment: data from deep drill holes: Nuclear Tracks and Radiation Measurements, 5, pp. 248-250.
Naeser, C. W., & Faul, H. 1969. Fission-track annealing in apatite and sphene. Journal of Geophysical Research, 74, pp. 705-710.
Osborne, F.F., & Grimes-Graeme, R. 1936. The breccia on St. Helen Island, Montreal. American Journal of Science, 232, pp. 43 - 54.
Philpotts, A.R. 1970. Mechanism of emplacement of the Monteregian intrusions. Canadian Mineralogist, 10, pp. 395 - 410.
Philpotts, A.R. 1972a. Monteregian Hills: Mounts Johnson and Rougemont. 24th International Geological Congress, Excursion B-14, 18 p.
Philpotts, A.R. 1972b. Density, surface tension and viscosity of the immiscible phase in a basic alkaline magma. Lithos, 5, pp. 1-18.
Philpotts, A.R. 1974. The Monteregian province. *In* The Alkaline Rocks. *Edited by* H. Sorenson. John Wiley, New York, pp. 293-310.
Philpotts, A.R. 1976. Petrography of Mounts Saint-Bruno and Rougemont, Quebec. Ministere des Richesses Naturelles, Report ES-16, Quebec City, Quebec, 106 p.
Philpotts, A.R., & Hodgson, C.J. 1968. Role of liquid immiscibility in alkaline rock genesis. 23rd International Geological Congress, Prague, 2, pp. 175-188.
Philpotts, J.A., Schnetzler, C.C., & Philpotts, A.R. 1970. Monteregian mixed rocks [abstract]: Geological Society of America Abstracts with Programs, v. 2, pp. 652-653.
Raeside, R.P. 1978. A reinvestigation of the Île Bizard kimberlite. MSc. thesis, Queen’s University, Kingston, Ontario, 86 p.
Raeside, R.P., & Helmstaedt, H. 1982a. The Île Bizard intrusion, Montreal, Quebec – kimberlite or lamprophyre? Canadian Journal of Earth Sciences, 19, pp. 1996-2011.
Raeside, R.P., Helmstaedt, H. 1982b. The Île Bizard intrusion, Montreal, Quebec - kimberlite or lamprophyre? Reply. *Canadian Journal of Earth Sciences*, 19, pp. 1496 - 1498.
Shafiqullah, M., Tupper, W.M., & Cole, T.J.S. 1970. K-Ar age of the carbonatite complex, Oka, Quebec. Canadian Mineralogist, 10, pp. 541-552.
Wagner, G.A. 1968. Fission-track dating of apatites. Earth and Planetary Science Letters, 4, pp. 411-414.
Wen, J. 1985. Isotope geochemistry of the Oka carbonatite complex, Quebec. MSc. thesis, Carleton University, Ottawa, 67 p.
Wen, J., Bell, K., & Blenkinsop, J. 1987. Nd and Sr isotope systematics of the Oka complex, Quebec, and their bearing on the evolution of the sub-continental upper mantle: Contributions to Mineralogy and Petrology, 97, pp. 433-437.
Woussen, G. 1970. La géologie du complexe igné du Mont Royal. Canadian Mineralogist, 10, p. 432 - 451.
Woussen, G., & Valiquette, G. 1972. The geology of the Brome and Shefford igneous complexes. 24th International Geological Congress, Excursion B-13, 16 p.