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FIELD TRIP 21: GUIDEBOOK

CARBONATITES, DIATREMES, AND  
ULTRA-ALKALINE ROCKS IN THE  
OKA AREA, QUEBEC

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PART I. GENERAL GEOLOGY  
BY D.P. GOLD, G.N. EBY, AND KEITH BELL

Introduction: Montereian Hill  
Petrographic Province

The term, Montereian Hills Province (Fig. 1), was applied by Adams (1903) to the erosional remnants of alkaline plutons that are preserved as prominent hills from Montreal eastward across the St. Lawrence Lowlands. Since then, this petrographic province has been extended both east- and westward (Gold, 1967) to include all Lower Cretaceous age dykes, sills, plugs, pipes and fissures with alkalic and carbonatitic affinities.

The linear trend of this province from the St. André carbonatite complex in the Ottawa Valley-Bonnechere graben 60 km west of Montreal, across the St. Lawrence Lowlands into the Appalachian mountains 200 km to the east, suggests emplacement was controlled by a deep-seated fault, uninfluenced by the overlying crustal tectonic units (Precambrian Shield, St. Lawrence Lowlands basin and the Appalachian Fold Belt). There is a progressive change westward from plutons with silica-saturated rocks in the eastern part of the province through undersaturated nepheline normative rocks to highly undersaturated rocks with modal nepheline and/or melilite, as well as carbonatites, in the Oka region. The associated dyke rocks likewise have regional characteristics in which alkali olivine basalts and camptonites dominate in the east, fourchites and monchiquites in the center, and alnöites in the west.

From fission track data, Eby (1985a) suggested these rocks were emplaced during two distinct time intervals, an early (141-129 Ma), voluminous, largely alkali picrite magmatic event from a garnet lherzolite source, and a later (121-117 Ma) event that produced lesser amounts of silica-undersaturated rock by partial melting of a metasomatized spinel lherzolite, as well as carbonatites and K-rich alnöites from a metasomatized garnet lherzolite source. Eby (1985c) inferred that these magmas were derived from a depleted subcontinental mantle based on Sr and Pb isotopes. He speculated that partial melting in the mantle was initiated by

a rising thermal front associated with a mantle diapir.

The general geology of the Montereian Hills has been described by Gold (1967), Philpotts (1974), and Eby (1984b). The westernmost plutons are the carbonatite complexes at Oka and St. André. These consist of sövite and rauhaugite and associated okaites, melteigite, ijolite, and urtite. Alnöites intrude the Oka Complex and a number of diatremes and breccia pipes are found in the immediate vicinity. Features indicative of explosive igneous activity are confined to the western end of the province, from Oka to Montreal. The west-central intrusions, Mount Royal, St. Bruno, Rougemont and Yamaska, are largely composed of pyroxenites, gabbros and diorites. These rocks tend to be slightly silica undersaturated to saturated. Late-stage dykes at Mount Royal, St. Bruno, and Rougemont are silica saturated. Mount St. Hilaire is a composite pluton consisting of a sequence of pyroxenites to gabbros in the western half and nepheline-sodalite syenites in the eastern half. The mafic rocks are correlative with similar rocks found elsewhere in the western Montereian Hills. A second, and later period of igneous activity is represented by a strongly undersaturated series consisting of nepheline-bearing diorites through nepheline syenites. This series is found at Mount Royal, Yamaska, St. Hilaire and Mt. Johnson.

The eastern intrusions, mounts Shefford, Brome, and Megantic, have significantly greater volumes of both felsic rocks and quartz-saturated rocks. The mafic rocks are largely gabbros and diorites and the felsic rocks at mounts Shefford and Brome are slightly undersaturated (pulaskite) to slightly oversaturated (nordmarkite) syenites. At Mount Megantic a gabbro-diorite body and a nordmarkite ring dike surround a central granite. A second magmatic event is identified at both mounts Shefford and Brome, which resulted in the emplacement of strongly silica-undersaturated nepheline-bearing diorites and syenites.

On petrographic criteria (Eby, 1984b) has recognized a number of genetic rock series. These

have been modified into the following groups:

1. Carbonatites-okaïtes-ijolites and urtites;
2. K-rich lamprophyres-aillikites-ahnöites;
3. Feldspathoid-bearing diorites - monzonites-syenites;
4. Pyroxenites - gabbros - diorites - syenites, lacking quartz (slightly undersaturated to saturated trend);
5. Gabbros - diorites - syenites - quartz syenites (quartz saturated trend); granites; and
6. Metaluminous biotite granites.

Trace element and isotopic data suggest that the rocks of series 1 to 5 are derived from the mantle whereas the rocks of series 6 have either a crustal source or a significant crustal component (Eby, 1985).

The K-rich lamprophyre -Aillikite -Ahnöite  
Series of the Western Montereian Province

Not only the peridotite and diatreme breccia pipes, but also rocks of the carbonatitic and ultra-alkaline series are restricted to the westernmost part of the Montereian belt (Fig. 1). Despite the close spatial relationships of these rocks in the Montereian belt, their distinct modes of intrusion and associations suggest that they are not directly related in origin, though generation of their magmas undoubtedly was associated with the latest phase of major tectonic movement along the St. Lawrence Rift System (Kumarapeli, 1970). The main associations of ultramafic rocks are:

- a) as dykes and sills of monchiquite or fourchite\*, such as exposed at Ste. Monique, Ste. Dorothée and St. Lin;
- b) with carbonatite activity, as ring-dykes and cone-sheets of jacupirangite, okaïte, melteigite and ijolite, such as in the Oka Complex, and the St. André carbonatite body;
- c) with diatreme activity in small pipes, fissures, as breccia masses, as tuffisite breccia (ahnöite breccia, and kimberlite (?)), and as mica peridotite

\* the term FOURCHITE is retained to distinguish the olivine-free variety of MONCHIQUE.

(porphyritic ahnöite, and poikilitic monticellite-phlogopite-olivine rocks).

The diatreme-type breccia bodies exposed in the essentially flat-lying St. Lawrence Lowlands generally underlie small hills, knolls or mounds, whereas those mapped in the Oka inlier (see Fig. 2) commonly underlie shallow depressions. They commonly exhibit a positive radiometric anomaly. Most have a tough, orange to rust weathered matrix of carbonated, tuffaceous material, highly charged with inclusions representing a wide range of rock types and environments. Matrix types include olivine basalt, ahnöite, analcite-carbonate-aegirine (analcitic type), carbonate-orthoclase (carbonatitic type) and carbonatite-cemented comminuted country rocks.

Although the lamprophyres are similar chemically (see Table 1), they differ in intrusive habit (sills versus dykes and pipes), mineralogy (equilibrium to disequilibrium mineral assemblages), texture (porphyritic, tuffaceous, and poikilitic), degree of contact metamorphism, and the amount and nature of inclusions. They may be consanguinous, representing different stages during the differentiation of a single magma, with different rates of ascent and stages of emplacement. In the aillikites, the presence of high-pressure mineral assemblages in disequilibrium with the matrix, suggests that the aillikite magma was generated at depths greater than 60 km and rose rapidly to the surface.

Most of the 50-odd mica peridotite and diatreme breccia pipes and dykes known in the Montreal and Oka area (see Fig. 1) are located in and around the Oka Complex, and along conjugate lines, trending symmetrically north-northeast and east, about the long axis of the Complex. This distribution corresponds geometrically with the expected shear and tension joints on a fold centered in a culmination over the Oka Hills. The location of the Oka Complex at the intersection of the Beauharnois arch and the extension of the Ottawa graben, suggests both deep-seated and near surface structural control.

A suggested classification, based on texture, composition, and reactivity of the matrix, for the fissure and pipe like bodies in the area, as well as the terminology of the lamprophyric rocks, (Gold,

TABLE 1 - Chemical Composition of Alnôites and Kindred Rocks from the Montreal - Oka Region

Location Sample #	1 Como	2 Ile Cadieux	3 IC-3	4 Ste-M	5 Brilund BR-1	6 BR-2	7	8	9 Oka Complex A-368	10	11 P-111	12 NEB-5
SiO <sub>2</sub>	30.27	33.26	30.0	31.63	31.94	49.03	30.13	27.81	35.41	30.78	30.37	37.95
TiO <sub>2</sub>	2.84	2.15	3.04	2.44	1.97	1.93	2.38	1.33	2.57	3.33	2.39	1.50
Al <sub>2</sub> O <sub>3</sub>	10.00	5.90	6.4	10.60	5.87	13.26	11.02	7.59	11.25	1.49	9.20	11.95
Fe <sub>2</sub> O <sub>3</sub>	4.88	5.30	6.09	4.56	5.87	3.54	7.34	8.67	6.72	5.64	5.55	3.81
FeO	6.95	6.54	6.81	6.42	5.77	10.40	4.17	6.57	5.07	10.34	6.02	4.15
MnO	0.16	0.15	0.23	0.11	0.22	0.22	0.52	0.08	0.24	0.10	0.35	0.30
MgO	20.11	26.41	22.0	17.82	21.51	7.02	12.01	11.21	13.29	16.35	10.70	5.71
CaO	14.73	14.47	15.2	17.16	17.38	10.88	22.48	28.06	18.42	22.02	15.31	12.90
SrO	-	-	0.18	-	0.11	0.02	-	-	0.12	-	0.26	0.22
BaO	-	0.08	0.21	-	0.23	0.01	0.89	-	0.22	-	0.33	0.29
Na <sub>2</sub> O	1.49	1.23	1.16	0.61	0.52	1.98	1.43	1.47	2.53	2.85	1.54	5.29
K <sub>2</sub> O	2.85	0.82	1.85	2.48	2.23	0.42	2.07	1.26	2.20	0.67	3.79	2.33
P <sub>2</sub> O <sub>5</sub>	0.95	0.76	0.28	1.09	0.75	0.15	2.88	1.66	1.05	2.07	0.87	-
CO <sub>2</sub>	3.24	1.10	1.68	4.92	1.97	-	1.17	2.51	0.24	2.78	9.88	11.78
H <sub>2</sub> O <sup>+</sup>	2.17	1.91	1.59	0.93	2.45	0.67	0.82	1.24	1.21	0.98	1.96	1.82
H <sub>2</sub> O <sup>-</sup>	-	0.09	-	-	0.36	0.19	0.13	0.11	0.00	0.00	0.36	-
F	-	-	0.10	-	0.11	0.02	-	-	-	-	0.40	-
Rest	-	0.27	-	-	-	-	0.63	-	-	-	0.02	-
Total	100.64	100.44	99.80	100.78	99.26	99.74	100.05	99.57	100.09	00.40	99.30	100.00

Location Sample #	13 Oka NEB-6	14 Ste-A	15 St-Ch	16 ← Ile Bizard →	17	18	19 ← Ste. Dorothee 1-0	20 1-M	21 Papineau 7-0	22 Avenue 7-m	23	24 Ste-H
SiO <sub>2</sub>	35.39	35.91	29.24	33.58	30.2	32.4	44.43	50.52	42.35	44.1	39.2	39.80
TiO <sub>2</sub>	1.87	0.23	2.40	2.27	2.1	1.9	3.03	1.37	3.86	1.7	3.8	1.45
Al <sub>2</sub> O <sub>3</sub>	10.37	11.51	11.40	6.93	5.9	7.1	14.02	21.72	14.89	15.7	15.4	8.32
Fe <sub>2</sub> O <sub>3</sub>	3.19	2.35	5.84	13.20*	12.0*	11.2*	4.86	2.02	5.95	1.7	6.1	0.14
FeO	5.84	5.38	4.74	nd	nd	nd	6.09	2.82	4.92	5.5	6.2	8.19
MnO	0.18	-	0.19	-	-	-	0.04	0.19	0.27	0.2	0.2	0.18
MgO	6.86	17.54	10.38	20.08	18.0	16.4	4.08	2.02	4.88	3.9	7.1	4.62
CaO	13.12	13.59	18.35	12.89	18.6	20.5	11.53	3.89	10.04	11.8	10.2	13.30
SrO	0.13	-	0.15	-	-	-	-	-	-	-	-	-
BaO	0.09	-	0.24	-	-	-	-	0.12	0.09	0.07	0.05	-
Na <sub>2</sub> O	3.09	1.75	1.44	0.18	0.3	0.3	4.14	8.54	4.59	4.1	3.5	2.75
K <sub>2</sub> O	3.52	2.87	2.42	0.77	1.5	0.5	1.73	2.13	2.19	2.1	1.5	1.44
P <sub>2</sub> O <sub>5</sub>	-	-	2.10	1.16	0.9	1.1	0.83	-	-	0.6	0.5	1.88
CO <sub>2</sub>	15.35	-	5.02	8.76	6.0	3.0	2.77	-	-	7.6	5.2	17.30
H <sub>2</sub> O <sup>+</sup>	1.00	9.40	5.05	0.00	4.5	6.7	1.96	-	-	-	-	0.45
H <sub>2</sub> O <sup>-</sup>	-	-	1.04	-	-	-	-	-	-	-	-	0.00
F	-	-	-	-	-	-	-	-	-	-	-	-
Rest	-	-	0.50	-	-	-	-	-	-	-	-	-
Total	100.00	100.51	100.46	99.82	100.0	101.1	99.51	95.34	94.03	99.07	98.95	99.82

\* Total Fe as Fe<sub>2</sub>O<sub>3</sub>

1. Monticellite-mica peridotite, Como. Analyst, W.V. Howard, 1922.
2. Monticellite-mica peridotite (melilite-rich), Ile Cadieux. Analyst, H.S. Washington, 1922.
3. Monticellite-mica peridotite, Ile Cadieux. Analysts, J.B. Bodkin and C.O. Ingamells, 1969.
4. Monchiquite, Ste. Monique. Analyst, W.V. Howard, 1922.
5. Monticellite-mica peridotite, Brilund pipe, Côte des Corbeil. Analyst, C.O. Ingamells, 1967.
6. Diabase, Brilund pipe, Côte des Corbeil. Analyst, C.O. Ingamells, 1967.
7. Monticellite alnôite, Husereau Hill, Oka Complex. Analyst, F.R. Ennos, 1923.
8. Monticellite alnôite, Husereau Hill, Oka Complex. Analyst, W.V. Howard, 1922.
9. Alnôite, Bond Zone, Oka Complex. Analyst, H. Ulk, 1962.
10. Biotite peridotite (alnôite), La Trappe, Oka. Analyst, C.P. Doland, 1922.
11. Lamproite in St. Lawrence Columbian open pit, Oka Complex. Analyst, C.O. Ingamells, 1967.
12. Analcitic-type breccia, Northeast Dyke, Oka Complex. Analyst, J. Moore, 1971 (average of 7 analyses summed to 100).
13. Carbonatitic-type breccia matrix, Northeast Dyke, Oka Complex. Analyst, J. Moore, 1971 (average of 4 analyses summed to 100).
14. Alnôite, Ste. Anne de Belleville dyke. Analyst, P.H. Le Rossignol, 1913.
15. Alnôite dyke, Pointe St. Charles. Analyst, M.F. Connor, 1913.
16. Kimberlite (sic. Aillikite) matrix, Ile Bizard. Analyst, M. Marchand, 1969.
17. Sparsely porphyritic tuffisite breccia matrix, Ile Bizard. Analyst, F. Dunphy, 1982).
18. Densely porphyritic tuffisite breccia matrix, Ile Bizard. Analyst, F. Dunphy, 1982).
19. Monchiquite, Ste. Dorothee. Analyst, W.V. Howard, 1922.
20. Monchiquite ocelli, Ste. Dorothee. Analyst, G.N. Eby, 1980.
21. Monchiquite matrix, Ste. Dorothee. Analyst, G.N. Eby, 1980.
22. Camptonite ocelli, north end of Papineau Avenue bridge, Rivière des Prairies. Analyst, A.R. Philpotts, 1976.
23. Camptonite matrix, north end of Papineau Avenue bridge, Rivière des Prairies. Analyst, A.R. Philpotts, 1976.
24. Matrix, Ste. Helen's Island breccia pipe. Analyst, W.H. Herdsman, 1936.



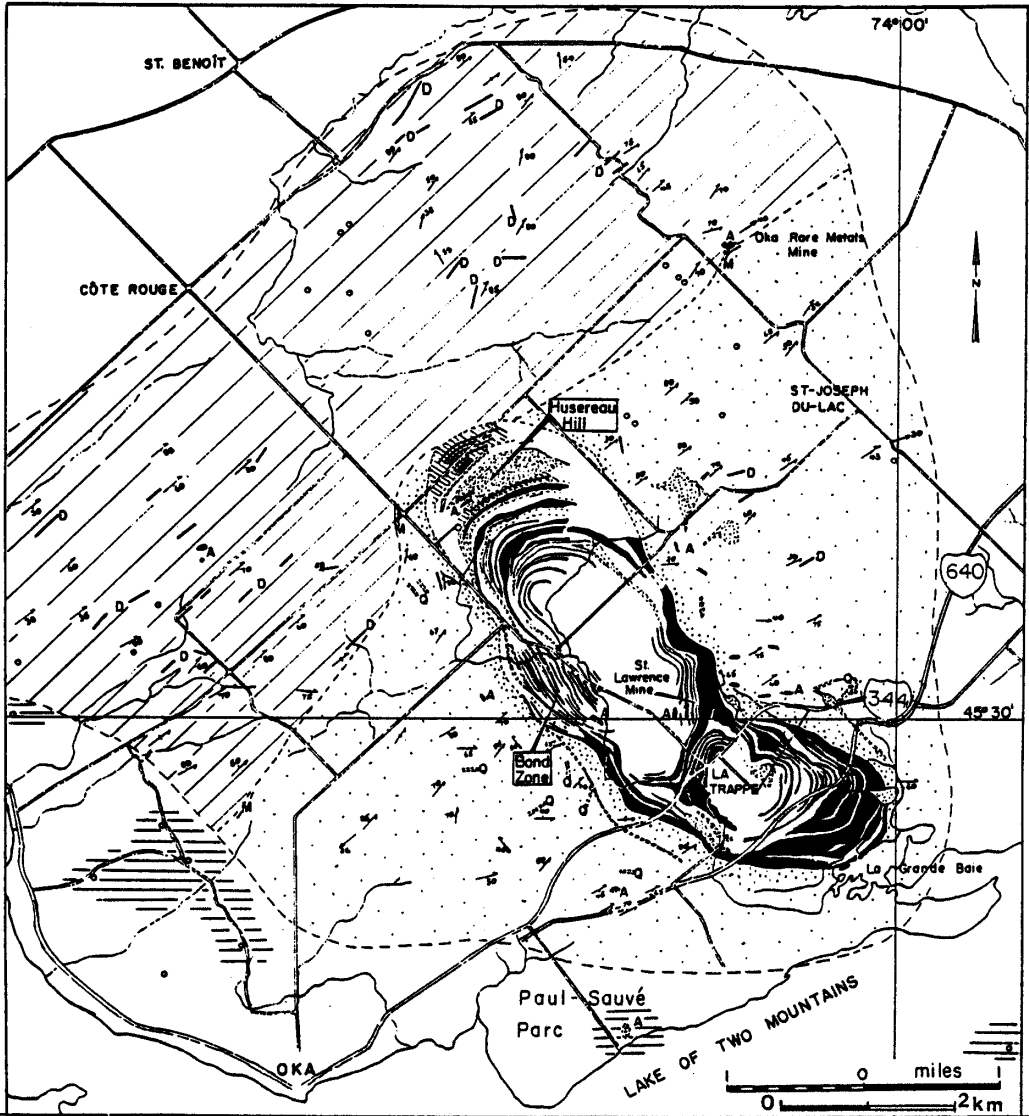


Figure 2. Geological map of part of the Oka Hills Inlier.

	Alnöite, alnöite breccia, and diatremes.		Morin Anorthosite-anorthosite, gabbroic anorthosite, and mangerite.
	Melteigite-ijolite-urtite Series.		Grenville Gneiss. (M) marble; (Q) quartzite.
	Okaite jacupirangite Series.		Diabase dykes.
	Sövites (intrusive calcite rocks).		Strike and dip of gneissosity.
	Raubaugite (intrusive dolomite rocks).		Plunge of 'b' lineation.
	Fenitized gneiss.		Drill-hole.
	Potsdam Sandstone.		

D.P. Gold, 1968, 1986

1972) is summarized in the following pages.

1. Lamprophyres (porphyritic texture).

LAMPROPHYRE is a porphyritic dyke rock of ultramafic to intermediate composition: it is usually rich in alkalis, and commonly contains accessory apatite, calcite, perovskite and opaque oxides. The phenocrysts are solely of mafic minerals. In MINETTE and KERSANTITE the phenocrysts are dominantly biotite in a base containing orthoclase or plagioclase respectively. Similarly, VOSGESITE and SPESSARTITE contain phenocrysts of augite or hornblende in a base respectively of orthoclase or plagioclase. The OLIVINE BASALT of the Ile Ronde breccia (Clark et al., 1967), which contains phenocrysts of diopside and olivine in a matrix of plagioclase, augite, hornblende, and ilmenite, could also be considered as an OLIVINE SPESSARTITE. In CAMPTONITE the phenocrysts are pyroxenes or amphiboles in a plagioclase-bearing matrix. In MONCHIQUITE the phenocrysts are titanite, barkevikite, olivine, and titanomagnetite in a base of analcite or glass. The old term, FOURCHITE, still is retained for the olivine-free variety. ALNOITE consists of phenocrysts of biotite (phlogopitic), titanite, olivine and locally lamprobolite in an aphanitic to glassy matrix containing disseminated magnetite grains in a diffuse background of melilite, calcite, melanite, apatite, and perovskite (see Tables 1 and 2 for some matrix and phenocryst compositions). The best examples are the Bond Zone and the La Trappe pipes. Some varieties are rich in melilite and monticellite, i.e., the MONTICELLITE MELILITITES on Husereau Hill. AILLIKITE is the term suggested by Rock (1984, personal communication) for the controversial fissure intrusion on Ile Bizard. It consists of phenocrysts of olivine, orthopyroxene, clinopyroxene, phlogopite, and magnesian titanomagnetite in a matrix of serpentine, calcite, melanite, magnetite and apatite. While it exhibits kimberlitic affinities (Marchand, 1970; Raeside and Helmstaedt, 1982) in its chemistry (Table 1) and suite of "cognate" xenoliths (Table 8), both the spinels and garnets (Table 2) have a distinct alnoitic trend (Mitchell, 1983).

2. Mica peridotites (poikilitic texture). MICA PERIDOTITES consist essentially of olivine (commonly two compositions) and mica (commonly phlogopite),

with different amounts of melilite, nepheline, pyroxene, apatite, perovskite, magnetite and calcite. MONTICELLITE MICA PERIDOTITES correspond to the MONTICELLITE ALNOITES of some authors (Bowen, 1922; Howard, 1922), and these are exposed in the Ile Cadieux, Brilund and Como pipes (see Table 7 for compositions). In these, forsterite occurs as euhedral grains and as chadacrysts in a coarse-grained matrix, principally of monticellite and phlogopite oikocrysts, but which locally is rich in melilite.

3. Breccia bodies (fragmental and/or globular textures). Most of the breccia bodies exposed in the Montreal and Oka areas (Clark, 1952) are thought to be associated with Montereian igneous activity. Besides those of igneous origin, classified as (a) shatter-zone breccias, (b) diatrema-type breccias, (c) intrusive breccias, and (d) replacement breccias, there are collapse and intraformational breccias, fault breccias, and possibly some of impact origin (Clark, 1962). The SHATTER-ZONE BRECCIAS result from vein networks of igneous material in country rocks caused either by stoping or forceful injection, and grade from igneous masses with a few xenoliths to veined country rock. The DIATREMA BRECCIAS contain many varieties of inclusions in either a comminuted country rock plus carbonate matrix (POLYMICT BRECCIA) or in an aphanitic, tuffaceous, lamprophyric matrix (TUFFISITE BRECCIA). The INTRUSIVE BRECCIAS contain partially assimilated fragments (mainly igneous) in a later igneous matrix, and may represent the melt phase. The REPLACEMENT BRECCIAS result from the incomplete transposition of one rock type into another, and are particularly common in the ijolitic rocks at Oka. DIATREMA is a general term for a volcanic vent or pipe drilled through enclosing rocks by the explosive energy of gas charged magmas. The drilling and venting of the pipe is envisaged as a gas streaming process above a viscous outgassing magma, rather than as the result of a violent explosion.

4. Mixed types (diatrema and intrusive breccias). These are perhaps the most interesting of the pipe and fissure rocks in that they are combinations of the above rock types, and as such they record many stages of their evolution and emplacement history. They are heterolithic rock

Location Sample #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19		
	Ile Bizard															O-NEB A15-675		Oka Complex A-368		O-NEB	
	Ile Cadieux Ste-Anne de Belleville															Como		Bizard		Xenoliths	
	Ile Bizard															Oka Complex 5-82		Oka Complex 5-40		60-core 60-rim	
SiO2	27.32	51.30	47.0	51.5	0.6	0.5	40.81	36.8	39.10	51.71	41.6	50.6	35.9	52.7	38.99	38.70	37.65	36.20			
TiO2	8.04	1.48	0.64	1.3	0.7	14.2	6.1	3.15	4.7	0.14	0.87	5.2	3.95	1.2	3.45	1.33	3.73	2.94			
Al2O3	1.36	12.38	4.72	9.3	4.5	9.1	3.6	14.54	15.6	17.12	5.45	11.5	6.7	15.2	3.45	11.74	14.52	18.25	16.65		
Fe2O3	50.31	nd	nd	0.0	0.3	34.2	54.4	nd	nd	nd	nd	nd	nd	nd	6.86	5.99	1.43	2.98			
Cr2O3	30.59	9.28*	5.19	9.6	3.5	31.2	29.0	9.91*	10.2	3.50*	7.04	6.35*	4.25*	7.3*	4.9*	4.36	5.46	5.28	5.71		
FeO	0.08	0.66	0.1	0.1	0.4	0.1	0.00	0.1	0.00	0.09	0.05	0.00	0.01	0.0	0.35	0.10	0.10	0.07			
MnO	4.93	0.66	17.09	10.3	15.7	8.7	5.1	13.72	17.1	24.61	14.64	11.25	15.4	24.1	15.7	8.56	15.51	20.96	17.77		
MgO	40.92	18.85	21.1	21.4	0.2	0.1	12.13	0.1	0.00	17.67	23.25	20.1	0.05	20.1	22.56	13.08	0.57	1.86			
Na2O	0.00	1.33	1.4	1.4	0.5	0.5	2.12	0.6	0.00	1.72	0.55	0.7	0.5	0.55	1.03	1.14	0.61	0.94			
K2O	0.00	0.00	0.0	0.0	0.0	0.0	2.05	9.6	10.90	0.00	0.0	0.0	9.65	0.0	0.21	2.42	9.30	7.85			
P2O5	nd	nd	nd	nd	nd	nd	4.1*	nd	nd	nd	nd	nd	nd	nd	0.13	0.33	0.08	0.18			
H2O+	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.27	1.22	1.10	3.78			
H2O*	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.06	0.02	0.00	1.47			
F	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.02	nd	0.18	0.25			
C02	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.56	0.00	0.00	0.68			
Total	95.31	92.04	99.12	100.2	99.8	99.1	99.4	98.43	99.1	95.37	99.27	99.75	98.95	96.66	98.40	99.15	99.82	99.24	99.33		

Location Sample #	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38		
	Ile Bizard Matrix															Oka Complex 5-82		Oka Complex 5-40		60-core 60-rim	
SiO2	49.9	39.4	35.8	49.6	39.9	55.6	65.1	64.56	56.35	0.08	0.7	0.3	44.10	41.3	40.09	57.73	54.1	52.7	52.89		
TiO2	1.0	0.1	1.9	1.1	2.5	0.0	0.1	nd	nd	0.20	0.3	0.3	0.1	0.1	0.11	0.11	0.5	0.94			
Al2O3	5.6	15.2	10.2	4.1	13.3	23.3	18.3	19.44	23.09	49.98	60.7	44.6	22.12	22.4	0.11	2.73	3.4	3.9	4.92		
Fe2O3	1.2	0.2	2.6	0.1	0.1	0.0	0.0	nd	nd	15.42	5.6	21.2	1.17	1.3	nd	0.44	1.0	0.9	0.91		
Cr2O3	3.9	3.5	nd	13.5	18.5	0.0	0.1	nd	nd	15.05*	7.3	10.3	7.27*	9.6	9.64*	5.54*	6.9	2.6	4.35		
FeO	0.0	0.0	0.1	0.8	0.4	0.0	0.1	nd	nd	18.31	22.4	18.8	21.59	18.5	51.16	33.42	33.0	16.2	15.34		
MgO	15.5	26.1	0.7	9.2	8.9	0.4	0.0	0.00	0.18	nd	nd	nd	5.52	5.3	0.60	0.5	21.0	20.58			
CaO	21.4	0.2	34.5	19.8	9.6	0.0	0.5	0.61	12.64	nd	nd	nd	nd	nd	nd	0.2	1.4	0.00			
Na2O	1.1	0.7	0.0	2.4	4.0	10.5	0.2	16.17	0.07	nd	nd	nd	nd	nd	nd	nd	nd	nd			
K2O	0.1	9.9	0.0	0.0	1.3	8.2*	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd			
H2O+	nd	4.2*	nd	nd	2.0*	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd			
Total	99.7	99.5	100.9	100.6	100.5	98.3	99.9	100.72	92.33	99.04	100.5	100.7	101.77	99.4	101.00	100.57	99.1	99.5	99.93		

\* Total Fe as FeO; \* Water estimated from assumed structural formulae

- Magnetite megacryst in allilite. Analysis by M. Marchand, 1970.
- Hydrogarnet megacryst in allilite. Analysis by M. Marchand, 1970.
- Augite megacryst in allilite. Analysis by M. Marchand, 1970.
- High-Al clinopyroxene megacryst in allilite (Raeside & Helmstaedt, 1982).
- High-Si clinopyroxene megacryst in allilite (op cit.).
- Magnesium titanomagnetite megacryst in allilite (op cit.).
- Kaersutite from nodule in allilite. Analysis by M. Marchand, 1970.
- Phlogopite megacryst in allilite (Raeside & Helmstaedt, 1982).
- Phlogopite phenocryst in allilite. Analysis by M. Marchand, 1970.
- Subcalcic augite megacryst in monticellite-mica peridotite. Analysis by L. Emrhizer, 1986.
- Transalite rims to endopside phenocrysts in alnoite (Hodgson, 1968).
- Endopside phenocryst in alnoite (op cit.).
- Phlogopite phenocryst in alnoite (op cit.).
- Endopside phenocryst in monticellite-mica peridotite (op cit.).
- Titanomagnetite phenocryst in alnoite nodule. Analysis by M.H. Hertsman, 1964.
- Lamprophylite megacryst in alnoite nodule. Analysis by H. Ulk, 1962.
- Phlogopitic biotite phenocryst on alnoite. Analysis by M. Marchand, 1970.
- Phlogopitic biotite phenocryst in alnoite. Analysis by M. Marchand, 1970.
- Chromite megacryst in alnoite. Analysis by M. Marchand, 1970.
- Chromite megacryst in alnoite. Analysis by M. Marchand, 1970.
- Spinel (core) in garnet therzollite nodule (Raeside & Helmstaedt, 1982).
- Spinel (rim) in garnet therzollite nodule (op cit.).
- Pyrope garnet in therzollite nodule 1a. Analysis by M. Marchand, 1970.
- Garnet in garnet therzollite xenolith (Raeside & Helmstaedt, 1982).
- Olivine in therzollite nodule 1a. Analysis by M. Marchand, 1970.
- Enstatite in therzollite nodule 1a. (op cit.)
- Orthopyroxene in garnet therzollite nodule (Raeside & Helmstaedt, 1982).
- Clinopyroxene in garnet therzollite nodule (op cit.).
- Clinopyroxene in therzollite nodule 1a. Analysis by M. Marchand, 1970.
- Chromite megacryst in alnoite. Analysis by M. Marchand, 1970.

TABLE 2 - Analyses of Phenocrysts, Megacrysts, Matrix and Xenolith Minerals from Lamprophyric Rocks in the Montreal-Oka Region

bodies and are distinguished by the number and nature of inclusions, and the composition and texture of the matrix.

a) Xenolith-rich (diatreme breccias). The inclusions commonly represent a great variety of rocks with varying degrees of rounding and polishing.

POLYMICT BRECCIAS comprise angular inclusions in a matrix of comminuted country rock and carbonate cement. These are generally considered breccias of non volcanic detritus. The Ste. Helen's Island breccia, as well as the Northeast and the Eastern breccia pipes are examples of this type, but also show gradations into the carbonatitic breccias.

CARBONATITIC BRECCIAS consist of subangular inclusions, commonly with reaction rims in a fine-grained carbonate-orthoclase matrix, which in places contains phenocrysts of phlogopitic biotite, magnetite and/or ilmenite, and aegirine. Chalky white rims of carbonate and zeolite surround the inclusions, and embayment and replacement of these by carbonates attest to a reactive matrix. The Ste. Dorothee (Stop 2-1), the Southeast breccia pipe, the central portion of the Eastern pipe (Stop 1-3), and part of the Northeast Breccia dyke are examples of this type.

ANALCITIC BRECCIAS are constituted of angular fragments in a matrix of analcite and ferrodolomite, in which there is little or no reaction with the inclusions. The iron is more oxidized, and they contain more Ba and Na than the carbonatitic breccias.

TUFFISITE BRECCIAS are characterized by the presence of globules or lapilli from 0.1 mm to 5 cm across, and subrounded to rounded xenoliths, some of which are polished. Commonly the lapilli envelope phenocrysts, and there is little or no reaction with the inclusions. They grade from heterolithic breccias poor in lapilli, to autolithic tuffisite breccias composed essentially of lapilli of different size.

The ALNOITE TUFFISITE BRECCIA, so common around the Oka Complex, tends to be autolithic, with small globules constituting a matrix with interstitial carbonates, zeolites and analcite. On the hill south of the St. Lawrence Mine, the

matrix is a later generation alnöite. In the Northeast breccia dyke there is a great variety of xenoliths and some of the matrix consists of analcite and ferrodolomite. Surrounding the globules in the MONTICELLITE MELILITE BRECCIA on Huserreau Hill (Stop 2-3) is a trachytic-textured matrix of monticellite and melilite. In some, the matrix is essentially calcite with lesser amounts of magnetite and phlogopite.

b) Xenolith poor (intrusive breccias). These grade from intrusive breccias such as the ALNOITE BRECCIA near the Monastery to massive lamprophyre with rare xenoliths such as the alnöites of the Bond Zone (Stop 2-4). The xenoliths tend to be of kindred type to the host matrix, and commonly exhibit reaction rims.

The alnöite types classified above, closely resemble the massive brecciated and tuffaceous kimberlites of Dawson (1967). However, the kimberlites differ in their commonly serpentinized matrix, high water content, presence of pyrope garnet, chrome diopside, and magnesium ilmenite, and the absence of melilite. The AILLIKITE TUFFISITE BRECCIAS on Ile Bizard (Stop 1-2) have affinities to both Kimberlites and alnöites, and the reported find of ten small diamonds (Surette, 1969) has not helped resolve this issue. Some clue to its origin may lie in the matrix chemistry (Table 1), the composition of the megacrysts and xenocrysts (Table 2), and the mineral assemblage of the cognate xenoliths. These include websterites, orthopyroxenites, dunites, harzburgites, garnet and garnet-spinel lherzolites, garnet websterites, and garnet clinopyroxenites, some of which (banded varieties) represent a cumulate phase in the upper mantle, and the rest, samples of unmelted mantle material (Raeside and Helmstaedt, 1982). Although the temperature and pressure estimates for the garnet lherzolites range from 880 to 980°C and 2.1 to 2.8 GPa (21 to 28 Kb), they do not outline a paleogeotherm (op. cit.). An ANALCITE PHONOLITE from this same pipe consists of phenocrysts of kaersutite, aegirine-augite, apatite, analcite, barite and calcite in a trachytic matrix of aegirine-augite, K-feldspar, and analcite.

The Carbonatite-Okaite-Ijolite Series  
of the Oka Complex

The Oka Complex (Fig. 3) underlies an oval-shaped depression, 7.2 km by 2.4 km in size, in the Oka Hills (Fig. 2). These "hills" rise to a height of 215 m (700 feet) above the St. Lawrence Lowlands and represent an inlier, some 115 km<sup>2</sup> (45 square miles) in extent, of Precambrian gneisses intruded by Montereian alkalic rocks and surrounded by Palaeozoic sedimentary rocks. The Complex lies in the southeast part of the Oka Hills in an area of rolling topography with a maximum relief of 92 m (300 feet). The highest point is Husereau Hill, 166 m (540 feet) above sea level, a ridge about 1.2 km long that parallels the northern margin. The northern part of the Complex consists of a central valley bordered by discontinuous arcuate ridges and a shallow depression that coincides with the contact. The bedrock topography, with a relief of as much as 215 m (700 feet), more clearly defines a crater-like morphology. The early topography was modified by glacial erosion and deposition (lodgment and ablation tills) during the Pleistocene, and by the accumulation of sand, silt, clay and gravel deposits in the pro-glacial Champlain Sea. These sediments cover most of the Complex, and are locally as much as 60-120 m (200-400 feet) thick. Many terraces, the highest at 150 m (500 feet), the lowest at 22 m (72 feet), attest to the intermittent lowering of the Champlain Sea. Most of the arable land is developed on sediments.

Northern and southern "ring structures" intersect near La Trappe, giving the Complex the form of a distorted figure 8 (Fig. 3). The lithostructural units are essentially concentric and define either ring-dykes or cone-sheets. In the Southern Ring the dips are everywhere outwards and increase toward the margin. In the larger, Northern Ring, inward dips prevail in the central part, outward dips near the margin. Alkaline silicate rocks occur in crescent-shaped masses, arcuate (concordant and discordant) dykes, and discontinuous tabular bodies. The carbonate rocks are layered; foliation is defined by layer-concentrations of ferromagnesian minerals and magnetite 1-5 cm thick, spaced 5-30 cm

apart. Flow features such as boudins and disrupted dykes are common. Most of the disrupted "dykes" are concordant with the foliation of the host rock, and as such they could represent either dykes disrupted by late movement or inclusions picked up by rheological deformation of the carbonate rocks. Many of the "dykes" indicated on the map are actually discontinuous. However, discordant dykes, locally disrupted in boudins, attest to both late dykes and post-crystallization movement of the carbonate rocks. Some of those boudins are interpreted as immiscible silicate blebs in carbonatitic melt (Treiman and Essene, 1985).

Alteration zones composed mainly of calcite plus biotite and/or serpentine, and rare-earth carbonate-bearing minerals, occur as inward-dipping arcuate tabular bodies centimeters to tens of meters thick. They are interpreted as cone-sheet fractures, along which hydrothermal solutions passed.

Late lamprophyre dykes occur locally in the country rocks, and igneous and diatreme breccia pipes and dykes occur in places along lineaments that have a symmetrical arrangement about the long axis of the Complex (Gold, 1963). These planes are similar to the conjugate (shear) and parallel (tension) fractures developed over an arch or fold, and suggest a structural control to their emplacement. The dykes are rarely more than 3 m thick. Many of the pipes have dyke-like digitations, probably representing local "blow-outs" along dykes. Inclusions of sandstone, limestone and hornfels in the breccia pipes indicate a Palaeozoic cover, up to at least the Utica Formation, at the time of emplacement.

The petrology of the Oka Complex is both unusual and varied. The rocks are classified into five main groups on mineralogical, textural and structural considerations. The proportions of essential minerals in these rock types are summarized in Table 3. The chemical compositions and trace element content of some of these are given in Table 5.

1) Carbonate rocks of at least ten mineralogical types underlie about half of the surface area of the Complex. Most types are coarse-grained layered sövites, with minor and accessory minerals such as sodian augite, biotite,

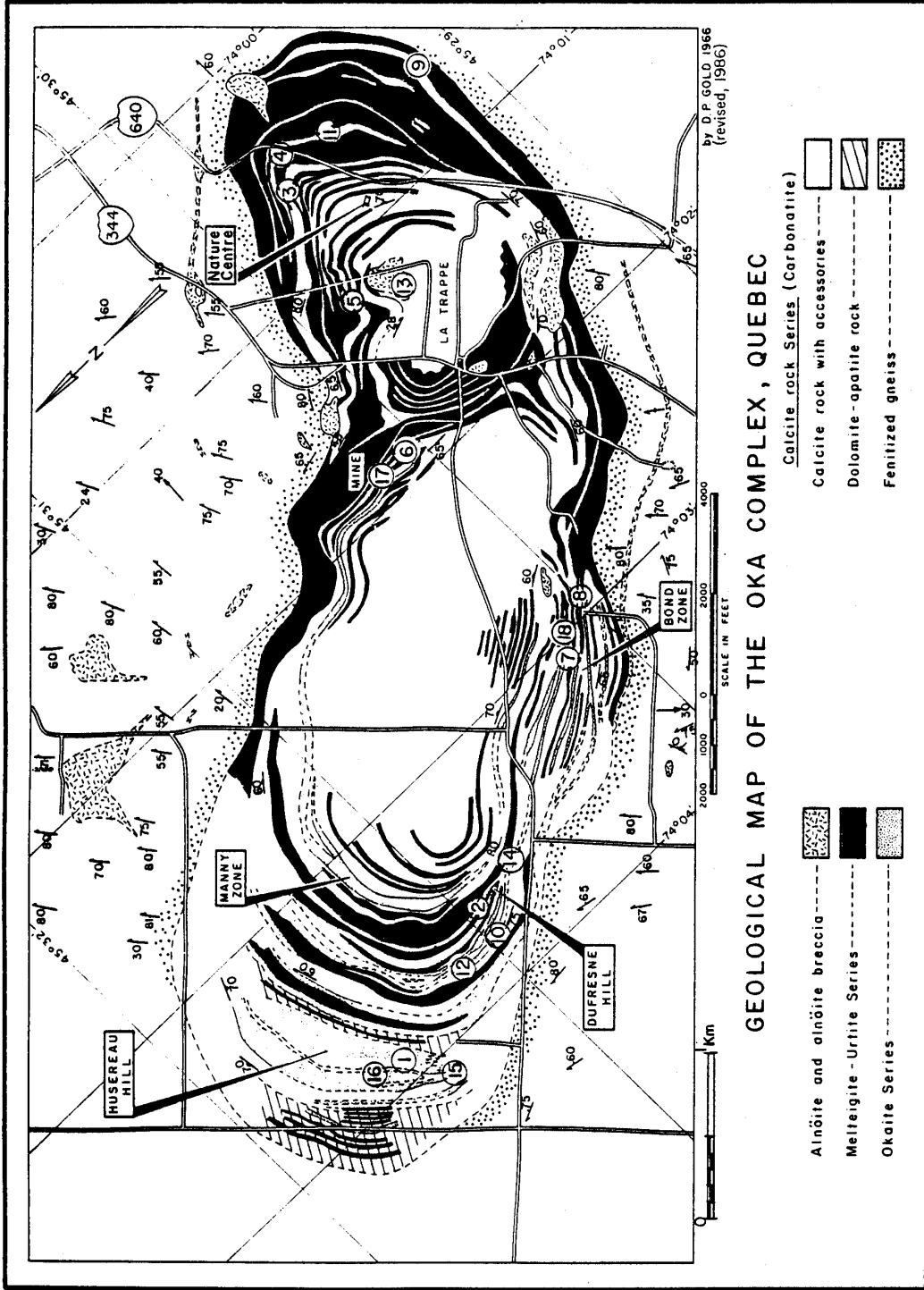


Figure 3: Geological map of the Oka Carbonatite Complex, showing the localities of samples used for determining the apatite fission-track dates reported in Table 6.

TABLE 3 — Summary of the Mineralogy of the Main Rock Types

<b>Carbonate Rocks:</b> sövite (calcite), and rauhaugites (dolomite).	
1. Flow-layered calcite rock with accessory pyroxene, biotite, magnetite.	
2. Layered soda pyroxene-biotite-magnetite-calcite rock, with pyrochlore.	
3. Monticellite calcite rock, with accessory perovskite.	
4. Coarse-grained calcite rock (relatively pure).	
5. Very coarse-grained "pegmatitic" calcite rock.	
6. Soda amphibole calcite rock, with accessory pyrochlore.	
7. Melilite calcite rock.	
8. Niocalite calcite rock, commonly with accessory melilite and magnetite.	
9. Nepheline calcite rock, commonly with minor melanite and pyroxene.	
10. Forsterite calcite rock (rare), with accessory pyrochlore and magnetite.	
11. Fine-grained apatite calcite rock.	
12. Dolomite rock, locally with accessory pyrochlore.	
<b>Okaite-Jacupirangite Series:</b> melilitites and pyroxenites, commonly with accessory magnetite, apatite and perovskite.	
1. Okaite.....	60-90% melilite; 40-10% nepheline, hauynite, apatite, perovskite, magnetite, biotite.
2. Nepheline okaite.....	40% nepheline; 40% melilite; 20% hauynite, calcite, magnetite, biotite.
3. Hauynite-titanaugite okaite.....	30% melilite; 10% titanaugite; 40% hauynite; 10% biotite, apatite, calcite.
4. Jacupirangite.....	60-70% titanaugite; 20-15% nepheline; 10-2% magnetite; 10-15% apatite, biotite, perovskite.
5. Magnetite-apatite rock.....	60-90% magnetite; 30-10% apatite; 10-5% calcite.
<b>Ijolite-Urtite Series:</b> nephelinites, with accessory calcite, melanite, apatite.	
1. Melteigite.....	65% soda pyroxene; 35% nepheline.
2. Calcite melteigite.....	65% soda pyroxene; 30-5% nepheline; 5-30% calcite.
3. Ijolite.....	50% soda pyroxene; 50% nepheline.
4. Melanite ijolite.....	30% melanite; 40% nepheline; 30% pyroxene.
5. Melanite-wollastonite ijolite.....	25% melanite; 25% wollastonite; 25% nepheline; 25% soda pyroxene.
6. Calcitic ijolite.....	50% pyroxene; 40-20% nepheline; 10-30% calcite.
7. Urtite.....	70-90% nepheline; 30-10% soda pyroxene
8. Wollastonite urtite.....	55% nepheline; 20% wollastonite; 25% soda pyroxene, melanite.
<b>Lamprophyres (see Part I)</b>	
1. Alnöite.....	phenocrysts: olivine, augite, biotite, lamprobolite, magnetite, melilite, calcite, melanite, apatite, perovskite, glass.
2. Alnöite breccia.....	matrix: polymict fragments in an alnöitic matrix.
3. Carbonatitic breccia.....	phenocrysts: ilmenite, magnetite, augite, phenocrysts in a carbonate matrix.
4. Biotite fourchite.....	titanaugite, barkevikite, titanomagnetite and biotite phenocrysts in an analcite or glassy matrix.
<b>Replacement Rocks (deuteric alteration and metasomatically altered country rock).</b>	
1. Glimmerite.....	50-80% biotite; 40-20% calcite; 20-10% zeolites, magnetite, rare earth carbonates.
2. Fenites.....	allochemically metamorphosed quartzofeld-gneisses, minor anorthosites.

apatite, nepheline, monticellite, melilite, pyrochlore, perovskite, niocalite, richterite, pyrite and pyrrhotite. Only in the northern part around Husereau Hill is rauhaugite common. The most common and most persistent of these are indicated on the map (Fig. 3). Economic concentrations of pyrochlore occur in the soda pyroxene-biotite-magnetite sövite, the monticellite sövite, the soda-amphibole sövite, and locally in the rauhaugites.

2) Melilitites and pyroxenites occur only in the Northern Ring and constitute the genetically related okaite-jacupirangite series. They form crescentic-shaped masses and arcuate dykes that vary

in composition from okaite (melilite with minor or accessory amounts of nepheline, hauynite, perovskite, apatite, biotite, magnetite and calcite), through nepheline and hauynite okaite and titanaugite-bearing nepheline okaite (a melanocratic rock consisting mainly of titanaugite with variable amounts of nepheline, and accessory magnetite, hercynite, apatite, calcite and perovskite), to nepheline jacupirangite and jacupirangite.

3) Nephelinitic rocks of different ages are common. Most are fine-grained mesocratic ijolites (equal amount of nepheline and pyroxene); close to the margin of the Complex, leucocratic urtite (predominantly nepheline) and juvite (nepheline and alkali feldspar) predominate. Relict textures and the heterogeneous nature of these latter rock types suggest that they are ultra-fenites. Biotite-rich rims of variable thickness occur in the nephelinites adjacent to sövite. The larger bodies of nephelinite are generally veined by sövite, whereas smaller bodies occur as boudins within the sövite. Only locally are good cross-cutting relationships observed. Melteigite (melanocratic, pyroxene-rich) occurs locally in the Southern Ring. There are also large tabular bodies of coarse-grained wollastonite and/or melanite-bearing ijolites. These latter varieties are restricted in occurrence to the Southern Ring, but are chemically similar to the okaites restricted to the Northern Ring.

4) Glimmerites occur in zones within and across lithostructural units. They consist chiefly of biotite and calcite with minor zeolite and rare-earth carbonates in a decussate textured rock of variable grain size. They represent the product of late hydrothermal reactions with silicate rocks. Not all the hydrothermally altered zones are represented by these biotite replacement rocks. Serpentine is developed in the monticellite-bearing rocks, and fine aggregates of cebollite, vesuvianite, wairakite and zeolite minerals are developed in the melilite-bearing rocks.

5) Late lamprophyres and intrusive breccias occur as dykes or in irregular pipe-like bodies. Whereas the lamprophyre dykes are mainly minettes, the pipes are made up of either (a) polymict breccia of country rock fragments in a matrix of comminuted country rock, calcite, chlorite and rare phlogopite;

(b) polymict fragments in an alnöite matrix; or (c) massive alnöite. The latter consists of phenocrysts of olivine, augite, phlogopite and hornblende in a calcite-rich matrix containing melilite, apatite, perovskite, magnetite, phlogopite, titanaugite, olivine and nepheline.

Concentric zoning of the pipes is reflected by the alignment of inclusions. The centres contain ultramafic and high-grade gneissic rock inclusions (from the mantle and crust), whereas the margins contain Palaeozoic rocks from upper stratigraphic levels. Polished and rounded fragments of gneisses and pyroxenites together with lapilli in the alnöite breccias, suggest that the pipes were penetrated by a streaming gas which comminuted the country rock, generated cells within it and provided a conduit up which welled a viscous alnöite magma. A similar process is envisaged for the emplacement of the Schwabian tuff volcanoes (Cloos, 1941; Reynolds, 1954) and kimberlites in Lesotho (Dawson, 1964).

Mineralogy. An impressive list of rare and unusual minerals have been found associated with the Oka Complex. These are listed in Table 4.

TABLE 4 - Minerals Identified from the Oka Complex

SILICATES	Pectolite	Britholite
Aegirine	Phlogopite	Fluorapatite
Aegirine-augite	Quartz	Monazite
Albite	Richterite	Wilkeite
Andradite	Sericite	
Arfvedsonite	Serpentine	OXIDES
Augite	Sphene	Hematite
(Sodian augite)	Tremolite	Hercynite
(Titanaugite)	Vermiculite	Ilmenite
Biotite	Vesuvianite	Latrappite
Cancrinite	Wollastonite	Maghemite
Cebollite		Magnesianferrite
Chlorite	ZEOLITES	Magnetite
Chrysolite	Analcite	Periclase
Diopside	Gonnardite	Perovskite
Fassaite	Natrolite	Pyrochlore
Forsterite	Thompsonite	Rutile
Garnet (zirconian)	Wairakite	
Grossularite		SULFIDES
Hauyne/Nosean	CARBONATES	Alabandite
Hornblende	Ancylite	Chalcopyrite
Kaolinite	Calcite	Galena
Labradorite	Dolomite	Pyrite
Melanite	Parisite	Pyrrhotite
Melilite (soda Ak)	Siderite	Sphalerite
Microcline	Strontianite	OTHERS
Monticellite	Synchisite	Barite
Nepheline		Brucite
Niocalite	PHOSPHATES	Fluorite
Orthoclase	Apatite	Jarosite

Paragenesis. The paragenetic sequence for the Oka Complex rocks is interpreted as follows:

- 1) Fenitization of gneissic rocks by precursor fluids, followed by emplacement as dykes and ring dykes of an early sövite phase injected into ultra-fenites and ijolitized rocks. Remobilized ijolitic rocks may appear either as boudinaged inclusions (early) or as dykes within the sövite.
- 2) Emplacement of an early monticellite sövite.
- 3) Emplacement of the okaite-jacupirangite rocks as a crescentic-shaped mass and as a series of concentric arcuate dykes.
- 4) Intrusion of the main pyrochlore sövite, followed by emplacement of a late monticellite sövite.
- 5) Minor ijolite and microijolite transgressive dykes, many of which are broken into boudin trains.
- 6) Hydrothermal activity along cone-sheet type fractures, causing biotitization and thorium metasomatism.
- 7) Intrusion of Late sövite and rauhaugite dykes, some of which carry rare-earth carbonates, pyrite and galena.
- 8) Late diabase and lamprophyre dykes.
- 9) Emplacement of alnöite, alnöite breccia pipes and dykes. Stages 6 and 9 may be parts of a single event.

Major and Trace Element Geochemistry. The silicate rocks of the Oka Complex are either under-saturated meta-aluminous or critically ultra-alkaline in character; the carbonate rocks host the rare minerals and a number of trace elements. The major, minor and trace element compositions of some of these rocks are given in Table 5. The sövites are enriched in Nb, Ta, Zr, Ce, La, Nd, Sr, Ba, P, Mn, Fe, Ti, Na, K, F, S, Cu and Cr, with respect to the average sedimentary carbonate rock (Gold, 1966b). Locally, Nb, P and rare-earths are sufficiently concentrated to invite mineral exploitation. The silicate rocks are characterized by enrichment in Ti, Fe, Mn, Sr, Ba, P, Zr, Nb, Ce, La, Cr and CO<sub>2</sub>. The similarity of the trace element content, particularly of the carbonate rocks, to that of pegmatites is noteworthy in that it suggests they both crystallized from late-stage, volatile-



TABLE 5 - Chemical Composition of the Main Rock Types of the Oka Complex

Rock Type Sample #.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Sövites								Okaites								
	Na-P-1	M-14	80A2-8	AZ-T-C	A-434	790k23	80B9-4	80B9-7	A-467	A-206	A-436	A-403	A-147	ARL-5-460	A-463 790k10		
SiO <sub>2</sub>	8.32	14.68	3.04	1.51	6.04	16.2	12.8	4.23	17.35	4.26	0.67	7.35	1.29	1.73	0.16	30.58	31.3
TiO <sub>2</sub>	0.64	0.87	0.05	0.06	0.14	0.69	0.49	0.05	1.24	0.43	0.15	0.00	0.32	0.00	0.03	1.64	2.08
Al <sub>2</sub> O <sub>3</sub>	4.09	2.37	0.05	0.26	4.41	1.35	1.08	0.43	2.87	0.49	0.02	3.05	2.40	0.89	0.02	9.52	11.3
Fe <sub>2</sub> O <sub>3</sub>	4.02	4.03	-	0.32	2.67	-	-	-	15.33	2.85	0.65	0.66	8.24	4.35	7.56	9.17	-
FeO	2.46	3.24	1.37	0.78	1.57	10.9	9.88	1.59	8.50	1.50	0.29	0.43	1.47	3.21	-	4.50	11.3
MnO	0.80	1.31	0.64	0.94	0.43	1.03	0.86	0.24	3.27	1.23	0.40	0.26	1.07	0.10	0.93	0.83	0.53
MgO	3.51	9.46	2.86	1.83	0.62	2.29	1.79	0.74	4.20	5.76	1.09	0.48	3.07	15.67	19.0	6.40	5.74
CaO	43.68	37.84	47.5	48.09	49.64	36.6	37.7	49.4	27.19	45.58	51.22	45.67	43.05	29.68	32.1	26.26	22.3
SiO <sub>2</sub>	1.18	0.43	0.11	0.22	2.28	0.75	0.62	1.40	2.24	2.24	1.95	3.23	1.30	1.06	0.89	0.71	0.41
Na <sub>2</sub> O	0.36	0.46	0.02	0.23	0.34	0.55	0.50	0.16	0.58	0.19	0.12	0.12	1.69	0.10	0.47	0.11	0.30
K <sub>2</sub> O	0.28	0.37	0.02	0.12	0.48	0.11	0.11	0.16	1.84	0.11	0.14	1.38	0.21	0.30	0.03	4.29	4.34
P <sub>2</sub> O <sub>5</sub>	2.54	5.50	2.97	1.10	1.98	2.23	5.41	4.45	3.71	2.70	1.81	0.94	0.00	0.16	0.00	0.71	1.14
CO <sub>2</sub>	25.05	18.53	0.46	0.36	2.14	2.44	2.06	0.10	-	0.56	0.14	-	11.56	7.16	1.91	1.84	2.00
H <sub>2</sub> O <sup>+</sup>	0.44	0.52	0.05	0.05	0.10	0.10	0.10	0.10	13.18	32.16	40.44	35.21	24.01	34.68	-	-	0.06
H <sub>2</sub> O <sup>-</sup>	0.10	0.03	36.70*	0.02	0.00	17.5*	14.4*	33.6*	0.51	0.11	0.03	0.79	0.04	0.15	-	-	2.13
F <sub>2</sub>	-	-	-	0.12	-	-	-	-	0.01	0.04	0.05	0.00	0.05	0.00	35.8*	0.02	1.23*
SO <sub>3</sub>	-	-	-	0.73	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	99.82	99.83	96.97	99.93	100.67	92.8	88.51	96.60	100.36	100.39	99.66	100.47	99.77	99.59	98.92	100.09	94.21

Trace elements in parts per million																	
Be	0.5	0.5	-	1	0.5	-	-	-	12	1.5	8	1	0.5	0.5	-	5.5	-
Sc	17	14	-	3	14	-	-	-	14	4	5	4	14	16	10.3	24	-
V	280	90	-	140	160	-	-	-	300	230	56	76	340	30	185	-	-
Cr	50	50	-	10	50	-	-	-	10	10	10	14	50	50	10.5	20	-
Co	-	6	-	-	-	-	-	-	-	-	-	-	-	-	-	31	-
Ni	6	6	-	10	6	-	-	-	10	10	10	10	6	6	-	4	-
Cu	18	12	-	5	28	-	-	-	5	1120	9	13	30	18	-	9.5	-
Zn	-	-	-	-	-	-	-	-	-	190	86	28	58	46	-	71	-
Y	120	200	-	43	160	-	-	-	60	45	58	64	28	28	10	56	340
Zr	130	1200	85	47	130	510	425	0	60	4000	900	800	3000	225/6	-	780	491
Nb/Ta	16780	1300	-	2500	15000	-	-	-	1278	2672	1928	1500	640	640	180	300	1281
La	1320	1000	514	520	1600	3184	6717	4190	3500	920	1100	1100	1000	720	1040	1500	384
Ce	4600	2400	1591	900	3400	877	1572	1170	-	-	-	-	-	-	385	-	45.5
Nd	-	-	313	-	-	87	208	126	-	-	-	-	-	-	42.3	-	16.3
Sm	-	-	41.7	-	-	126	208	126	-	-	-	-	-	-	11.7	-	4.4
Eu	-	-	13.9	-	-	40.8	56.5	37.7	-	-	-	-	-	-	3.3	-	6.3
Tb	-	-	4.3	-	-	12.5	15	9.5	-	-	-	-	-	-	3.1	-	4.2
Yb	12	14	6.8	2.5	12	92	80	14.2	13	2	5.4	1.5	5	4.2	0.3	-	0.5
Lu	-	-	1.2	-	-	3.6	0.9	0.9	-	-	-	-	-	-	-	-	-

Stable isotope ratios of carbonates in per ml ( <sup>13</sup> C vs PDB; <sup>18</sup> O vs SMOW)			
<sup>13</sup> C	-5.41	-4.84	-
<sup>18</sup> O	+6.99	+7.83	-
	-5.12	-5.09	-4.91
	+7.82	+7.22	+7.17
	-4.22	-	+7.71

- Soda pyroxene-biotite sövite ore; pit A-1. Analyst, H. Ulk, 1962.
- Monticellite sövite; drill-core in M-Ring. Analyst, H. Ulk, 1962.
- Monticellite-dioptside sövite. In Treiman & Essene, 1985.
- Soda amphibole sövite; pit A-2. Analysts, Bodkins, & Ingamells, 1969.
- Niocalite sövite; Bond zone. Analyst, H. Ulk, 1962.
- Niocalite-melilitite-dioptside sövite. In Treiman & Essene, 1985.
- Niocalite-melilitite-dioptside sövite. In Treiman & Essene, 1985.
- Niocalite-melilitite-dioptside sövite. In Treiman & Essene, 1985.
- Niocalite-melilitite-dioptside sövite; Northern Ring. Analyst, H. Ulk, 1964.
- Melilitite-apatite sövite; Northern Ring. Analyst, H. Ulk, 1964.
- Coarse-grained sövite; Northern Ring. Analyst, H. Ulk, 1962.
- Pegmatitic richterite sövite; Southern Ring. Analyst, H. Ulk, 1962.
- Nepheline-soda pyroxene sövite; S-Ring. Analyst, H. Ulk, 1962.
- F-g apatite-magnetite sövite; Husereau Hill. Analyst, H. Ulk, 1961.
- F-g apatite radhaugite; drill-core from North of Husereau Hill. Analyst, H. Ulk, 1964.
- Periclase-brucite-dolomite sövite; Husereau Hill. In Treiman & Essene, 1984.
- Okaites; Dufresne Hill. Analyst, H. Ulk, 1964.
- Melilitite; Husereau Hill. In Treiman & Essene, 1985.

TABLE 5 - (continued)

Rock Type	18 790K14	19 790K13	20 790K8	21 A-72	22 A-172	23 S9-370	24 790K12	25 A=227	26 790K25	27 790K28	28 8089-12	29 A-297	30 P-111	31 A-478	32 A-218a	33 A-383	34 A-368							
Sample #	Okaités-mellitites								Ijolites								Lamprophyres		Urtite		Fenite		Alnöite	
SiO <sub>2</sub>	22.9	34.2	33.4	34.90	31.91	33.53	34.2	41.91	40.4	37.5	40.0	39.39	30.37	34.31	48.21	59.53	35.41							
TiO <sub>2</sub>	1.13	1.88	1.11	1.16	2.11	3.44	3.50	0.63	0.63	1.00	0.55	0.45	2.39	2.74	0.25	0.75	2.57							
Al <sub>2</sub> O <sub>3</sub>	5.88	14.4	18.4	15.99	14.69	13.20	10.5	20.59	10.2	11.1	9.58	15.95	9.20	13.58	26.55	16.21	11.25							
FeO <sub>3</sub>	18.1	10.9	9.04	3.82	3.38	3.41	15.2	2.42	8.56	5.47	7.80	4.05	5.55	7.08	0.59	1.01	6.72							
MnO	1.50	0.56	0.45	0.72	0.63	0.40	0.23	0.90	1.23	1.09	1.19	0.71	0.35	0.29	0.09	1.83	5.07							
MgO	5.21	4.16	2.75	5.02	5.98	8.66	9.01	3.27	7.73	6.73	8.12	1.30	10.70	5.67	0.13	2.31	13.29							
CaO	27.5	20.5	16.8	18.49	19.14	19.14	21.0	8.93	20.6	20.7	21.4	19.77	15.31	15.90	9.18	5.57	18.42							
SiO	0.73	0.49	0.46	0.72	0.27	0.25	0.08	0.12	0.30	0.35	0.44	0.12	0.26	0.18	0.17	0.18	0.12							
BaO	0.32	0.00	0.05	0.14	0.27	0.35	0.05	0.35	0.00	0.13	0.12	0.89	0.33	0.12	0.23	0.33	0.22							
Na <sub>2</sub> O	1.63	5.46	7.38	7.27	7.55	2.45	0.48	11.57	3.89	4.42	3.27	7.79	1.54	4.43	8.82	7.21	2.53							
K <sub>2</sub> O	0.47	1.89	2.95	2.08	0.98	2.16	0.53	2.69	2.41	2.10	2.36	2.57	3.79	0.88	2.18	5.02	2.20							
P <sub>2</sub> O <sub>5</sub>	0.69	1.23	0.61	0.68	2.15	2.37	1.05	0.41	1.29	0.90	0.95	0.74	0.87	1.21	0.10	0.24	1.05							
Nb <sub>2</sub> O <sub>5</sub>	0.04	0.08	0.06	-	-	-	0.02	-	0.00	0.18	0.24	-	-	-	-	-	-							
CO <sub>2</sub>	-	-	-	1.29	1.87	2.34	-	1.16	-	-	-	3.38	9.88	3.54	1.32	0.00	0.24							
H <sub>2</sub> O*	-	-	-	0.60	1.19	1.64	-	1.55	-	-	-	1.69	1.96	3.27	1.48	0.51	1.21							
H <sub>2</sub> O*	*1.01	10.6*	0.77*	6.92*	0.02	0.05	1.08*	0.02	2.31*	6.16*	0.31*	0.00	0.36	0.33	0.05	0.00	0.00							
F	-	-	-	-	-	-	-	-	-	-	-	-	0.40	0.13	-	-	-							
SrO	-	-	-	-	-	-	-	-	-	-	-	-	-	1.10	-	-	-							
Trace elements in parts per million	96.7	96.52	100.38	100.18	100.12	100.70	96.97	99.27	99.55	97.02	96.38	99.98	99.30	99.96	99.92	100.73	100.09							
Be	-	-	-	4	2	2.6	-	3.8	-	-	-	2.6	9.5	-	3.1	1.5	1.4							
Sc	-	-	-	6	15	23	-	8	-	-	-	17	13	-	7	10	37							
V	-	-	-	255	270	400	-	91	-	-	-	325	790	-	50	125	440							
Cr	-	-	-	20	20	20	-	8	-	-	-	19	66	-	20	20	20							
Co	-	-	-	28	36	40	-	8	-	-	-	16	130	-	23	13	47							
Ni	-	-	-	14	4	4	-	18	-	-	-	16	130	-	23	4	145							
Cu	-	-	-	120	135	76	-	20	-	-	-	14	7.9	-	95	8	105							
Zn	-	-	-	42	46	55	-	27	-	-	-	88	36	-	9	35	32							
Zr	0.0	425	170	285	220	320	425	9	255	85	85	315	225	-	8	90	250							
Nb/Ta	280	560	419	285	270	480	140	80	0.0	1288	1678	300	110	-	100	-	100							
La	563	418	285	270	490	780	6	600	440	386	247	300	150	-	39	190	120							
Ce	1279	987	587	580	760	840	269	600	774	902	868	740	150	-	150	350	150							
Md	325	240	134	-	-	-	84	-	645	280	240	-	-	-	-	-	-							
Sm	34.0	21.1	23.9	-	-	-	15.7	-	45.4	37.6	35.2	-	-	-	-	-	-							
Eu	10.3	11.1	7.4	-	-	-	15.5	-	12.4	13.6	-	-	-	-	-	-	-							
Tb	2.8	3.6	2.1	-	-	-	5.1	-	3.9	6.5	-	-	-	-	-	-	-							
Tm	4.7	5.2	3.9	3.7	3	4.7	1.8	2.5	12.5	8.8	8.1	7	5.7	-	1	2.8	3.5							
Lu	0.5	0.4	0.3	-	-	0.3	0.3	-	2.8	1.8	2.5	-	-	-	-	-	-							

Stable isotope ratios of carbonates in per mil ( <sup>13</sup>C vs PDB; <sup>18</sup>O vs SMOW)

<sup>13</sup>C  
-5.17  
<sup>18</sup>O  
+8.08

- 18 - Okaité; Huserau Hill. In Treiman & Essene, 1985.
- 19 - Nepheline meltite; Huserau Hill. In Treiman & Essene, 1985.
- 20 - Nepheline okaité; Huserau Hill. In Treiman & Essene, 1985.
- 21 - Nepheline okaité; Huserau Hill. Analyst, H. Ulk, 1964.
- 22 - Hauynite-titanagite okaité; Huserau Hill. Analyst, H. Ulk, 1964.
- 23 - Jacupirangite; drill-hole in S-9 in N-Ring. Analyst, H. Ulk, 1961.
- 24 - C-g Jacupirangite; Huserau Hill. In Treiman & Essene, 1985.
- 25 - Ijolite; composite sample from St. Lawrence Mill site. Analyst, H. Ulk, 1961.
- 26 - Ijolite; trench 9, Bond Zone. In Treiman & Essene, 1985.
- 27 - Ijolite; trench 1, Bond Zone. In Treiman & Essene, 1985.
- 28 - Ijolite; trench 9, Bond Zone. In Treiman & Essene, 1985.
- 29 - Mollastonite Ijolite; Southern Ring. Analyst, H. Ulk, 1961.
- 30 - Lamproite pit A-1. Analyst, C. O. Ingamells, 1967.
- 31 - Fourchite dyke; Southern Ring. Analyst, J. Bodkin, 1969.
- 32 - Urtite; Southern Ring. Analyst, H. Ulk, 1964.
- 33 - Foyaitic fenite; Southern Ring. Analyst, H. Ulk, 1961.
- 34 - Alnöite; Bond Zone. Analyst, H. Ulk, 1962.

rich phases. Ringwood (1955) has shown that cations with high ionic potential tend to form stable complexes with O, OH, F, Cl and other anions. These complexes rarely dissociate in a magma, and tend to accumulate with volatiles in the late-phase differentiates either as discrete minerals or by replacement of  $\text{SiO}_4$  tetrahedra in silicate minerals. In the carbonatite environment, the paucity of silica and the size and high valence charge of trace elements (Nb, Ta, Ti, Rare Earths) favour the formation of some rare, discrete minerals (perovskite, niobium perovskite, pyrochlore, monazite, britholite, etc.). In contrast, mono and divalent cations of low ionic potential do not complex readily and occur as free ions in the magma; these are commonly camouflaged by or may substitute for other cations of similar charge and ionic radius in minerals, e.g. Ba and Sr for Ca, Mn for Mg and Fe.

Eby (1973, 1975) described the Sc and REE (rare-earth elements) geochemistry of the rocks and minerals of the Oka Complex. These data are briefly reviewed here and are discussed in terms of more recent information on the nature of the Oka Complex and the behavior of trace elements.

In terms of REE and Sc geochemistry, the following general conclusions were drawn for the minerals and rocks of the Oka Complex:

1. The ore minerals (niocalite, perovskite, and pyrochlore) are the major hosts for Sc; the ferromagnesian silicate minerals (garnet, pyroxene, and biotite) are of lesser importance.

2. For apatite and calcite there appears to be a linear relationship between Sc content and total REE.

3. Apatite and the ore minerals are the major hosts for the REE, and whole-rock REE abundances will be very sensitive to the relative proportions of these phases. Total REE concentrations in apatite vary from 9,200 to 40,000 ppm, in niocalite from 13,000 to 15,000 ppm, in pyrochlore from 34,000 to 87,000 ppm, and in perovskite from 19,000 to 42,000 ppm. Given appropriate smelting techniques, the latter two minerals could be REE ore minerals.

4. With the exception of garnet, all of the minerals are significantly enriched in LREE with respect to HREE. The apatites show pronounced negative Eu anomalies; some of the pyroxenes, the

biotites, and the feldspar and feldspathoid minerals show positive Eu anomalies.

5. In terms of whole-rock abundances, the alnoites and carbonatites have the highest Sc concentrations whereas the okaites and carbonatites have the highest REE concentrations.

Estimated  $(\text{La}/\text{Yb})_{\text{cn}}$  ratios range from 100 - 280 in the sövites, from 160 to 280 in the okaites, and from 60 to 300 in the alnöites that intrude the Oka Complex. The other silicate rocks (urtites, ijolites, and melteigites) have much lower  $(\text{La}/\text{Yb})_{\text{cn}}$  ratios ranging from 25 to 60. Similar  $(\text{La}/\text{Yb})_{\text{cn}}$  ratios and absolute REE abundances have been observed elsewhere in the Monteregian Hills for rocks which are inferred to have crystallized from basanite magmas (Eby, 1984; 1985). Previous investigators have generally assumed that all of the rocks in the Complex are co-magmatic. The fission-track geochronology, however, suggests that at least some of the sövites may have been emplaced well before the silicate rocks and may not be related to the processes which formed the silicate rocks.

Strictly on the basis of REE geochemistry, it is tempting to construct four magmatic lineages: 1) the sequence melteigite-ijolite-urtite; 2) the okaites; 3) the sövites; and 4) the alnöites. The okaites may represent extreme differentiates of the magma(s) which gave rise to the melteigite - urtite series (which may in part be metasomatic), but the alnöites and sövites seem to represent separate magmatic groups. The question of the extreme LREE and total REE enrichment in the sövites has still not been successfully resolved. Experimental work (Wendlandt & Harrison, 1979) has shown that the REE will be enriched in a carbonate liquid which immiscibly coexists with a silicate liquid, and the LREE will be relatively enriched in this carbonate liquid. However, it would appear that at least some of the carbonate rocks in the Oka Complex pre-date the silicate rocks, and thus liquid immiscibility can not explain their high REE contents. In addition, the mineralogical disparities between the sövites and the silicate rocks cast doubt on an immiscibility process.

\* cn = chondrite normalized

#### Geochronology and Isotope Geochemistry of Oka.

The age and the isotope geochemistry of the Oka Complex have been studied from a variety of perspectives, ranging from K-Ar and Rb-Sr dating to the geochemistry of the sub-continental upper mantle. Several lines of investigation confirm that the Oka Complex is Cretaceous in age. Fairbairn et al. (1963) were the first to show this and later work by Shafiqullah et al. (1970), using K-Ar data from several intrusive units first recognized by Gold (1963), yielded mica ages with a mean of  $116 \pm 4$  Ma, and a K-Ar isochron age of 120 Ma. Confirmed during this latter study were small, but significant, amounts of excess argon. More recently Wen (1985) has obtained a well-defined Rb-Sr isochron based on biotite data from both carbonatite and okaite that corresponds to a date of  $109 \pm 2$  Ma.

Isotopic tracer studies, in particular C, O, Nd, Pb and Sr from the carbonatite, have shown that the Oka Complex is remarkably uniform in its isotopic composition. On the basis of well over six hundred analyses Deines (1970) showed that the Oka carbonatite has an average  $\delta^{13}\text{C}$  of  $-5 \text{‰}$ , a value typically of many mantle-derived materials; the corresponding  $\delta^{18}\text{O}$  value is  $+7.4 \text{‰}$ .

Because carbonatites are so enriched in Sr and their Rb/Sr ratios are so low, they are ideal for Sr isotope ratio studies. In the first Sr isotopic ratio study of the Oka Complex, Powell et al. (1966) showed that initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios from both silicate and carbonate rocks of were essentially the same, suggesting they were co-magmatic. Significantly higher values from Grenville marbles ruled out the possibility that the Oka carbonatite was just a re-mobilized limestone. Patterson (1974) obtained similar Sr isotopic ratios for the Oka sövites.

Much evidence has now accumulated to show that most carbonatites and related rocks from the Canadian Shield have been derived from a part of the upper mantle that is depleted in the LIL-elements. Analyses from Oka rocks were included in an initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio study of the sub-continental mantle that involved direct measurements of the Sr isotopic compositions of carbonatites and related rocks intruding the Grenville and Superior Provinces of the

Canadian Shield (Bell et al., 1982). One conclusion of this study was that a large part of the Canadian Shield is underlain by an Archaean LIL-element depleted mantle with a Rb/Sr ratio of  $0.018 \pm 0.002$ , a value much lower than that of "Bulk Earth" (DePaolo and Wasserburg, 1976a; O'Nions et al., 1977). "Bulk Earth" is a primitive starting material for the Earth. The different ages of the complexes studied, from 2700 Ma to 110 Ma, suggested that this residual sub-continental upper mantle had remained coupled to the continental crust for a considerable period of time and until at least 110 Ma ago. Additional initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios from apatite, calcite, and nepheline (Grünenfelder et al., 1986) supported this model and showed that at the time of its formation Oka had an initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio of  $0.70331 \pm 0.00002$  ( $2 \sigma$  level). Selected pyrite, melilite and calcite samples have initial Pb isotope ratios averaging  $^{206}\text{Pb}/^{204}\text{Pb} = 19.65$ ,  $^{207}\text{Pb}/^{204}\text{Pb} = 15.56$  and  $^{208}\text{Pb}/^{204}\text{Pb} = 39.00$ . These relatively low ratios also indicate an origin for most of the Pb in a LIL-element depleted mantle source.

Both the initial Sr and Nd ( $^{143}\text{Nd}/^{144}\text{Nd} = 0.51271$  to  $0.51284$ ) isotopic compositions of silicate and carbonate whole rocks and separated mineral phases (andradite, apatite, calcite, melilite, and monticellite) from Oka are surprisingly uniform (Wen, 1985), suggesting that the rocks of the Oka Complex were probably derived from an isotopically homogeneous source. A useful method of evaluating the source region of the Oka rocks is to plot their initial  $^{143}\text{Nd}/^{144}\text{Nd}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios on the same diagram. In the resulting anti-correlation diagram (DePaolo and Wasserburg, 1976a; 1976b), the Nd and Sr isotopic data from the Oka rocks lie in the depleted quadrant (Wen, 1985; Wen et al., 1985), supporting derivation of these rocks from an ancient LIL-element depleted source. Low Sm/Nd ratios (average = 0.11), of the Oka rocks are inconsistent with the measured initial  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios (Wen, 1985); the latter are much too high to be generated from a source which had such a Sm/Nd ratio for any substantial period of time. A model in which the Sm/Nd ratio of the source region is lowered either during or shortly before the carbonatite magma was formed would be consistent with the isotopic data (Wen, 1985).

The surprisingly uniform isotopic composition of the Oka Complex places constraints on its origin and suggests that the carbonatite magma was derived from a source characterized by low U/Pb and Rb/Sr ratios and a high Sm/Nd ratio. Such a source is considered to be residual mantle left behind after extraction of continental crust from a more primitive mantle almost 3,000 Ma ago (Bell et al., 1982; Bell and Blenkinsop, 1983).

Apatite fission-track geochronology. Apatite fission-track ages were determined for the various lithologies of the Oka Complex. The population method (Naeser, 1976) was used, and 50 to 100 grains

were counted for spontaneous and induced tracks. Because of questions that have arisen concerning the precision of a single fission-track age determination, a number of the ages were done in duplicate. The ages and uranium content of the apatites are reported in Table 6.

The fission-track ages indicate that magmatism in the Oka complex extended over a period of about 12 million years. Of considerable interest is the older ages of some of the sövites, relative to the silicate rocks, which suggest that the silicate and carbonate magmas are not necessarily related. Within the sövites, two periods of magmatic activity, which are petrographically identifiable, are found. One period has a mean age of 132 Ma and is represented by the emplacement of olivine- and monticell-

TABLE 6 - Apatite Fission Track Ages of Oka Rocks

Lithology	Location Number	Sample #	Age (Ma)	Error	U (ppm)
Okaite	1 (Husereau Hill)	BOK-3	118	4	11.6
Apatite okaite	16 (Husereau Hill)	Oka-1	118	6	80.0
Okaite	2 (Dufresne Hill)	OL-2	122	2	18.1
Ijolite	3 (Southern Ring)	OL-5	121	2	12.4
Ijolite	4 (Southern Ring)	OL-6	123	2	12.2
Fo-cpx-sövite	5 (Southern Ring)	A-16-6	133	11	6.7
Cpx-pyrochlore-sövite	6 (St-Law. Mine)	AB-60-1	126	6	2.0
Cpx-pyrochlore-sövite	17 (St-Law. Mine)	Oka-1a	112	5	
Mel-niocalite-sövite	18 (Bond Zone)	Oka-4	108	8	
Mel-niocalite-sövite	7 (Bond Zone)	BOK-6	125	4	105.0
Mont-perovskite-sövite	8 (Bond Zone)	BOK-7	130	2	3.6
Cpx-biot-pyrochlore-sövite	9 (Southern Ring)	G-13-8	125	18	1.6
Cpx-Biot-sövite	10 (Dufresne Hill)	OL-1	124	7	6.7
Mont-pyrochlore-sövite	11 (Southern Ring)	OL-7	132	4	2.5
Mont-sövite	12 (Northern Ring)	S-43-4	126	8	11.8
Alnöite	13 (Southern Ring)	A-18-1	119	12	6.0
Alnöite	14 (Dufresne Hill)	AM-1	122	11	7.8
Alnöite	15 (Husereau Hill)	Am-2	121	12	7.7

Note: Measurements on samples keyed to locations 1 to 15 are by G.N. Eby; samples keyed to locations 16 to 18 are by D. P. Gold.

Error is  $2\sigma$  of mean based on duplicate determinations, or gaussian error if only one determination was done.

Uranium concentrations are estimated to have an error of 10 to 20%.

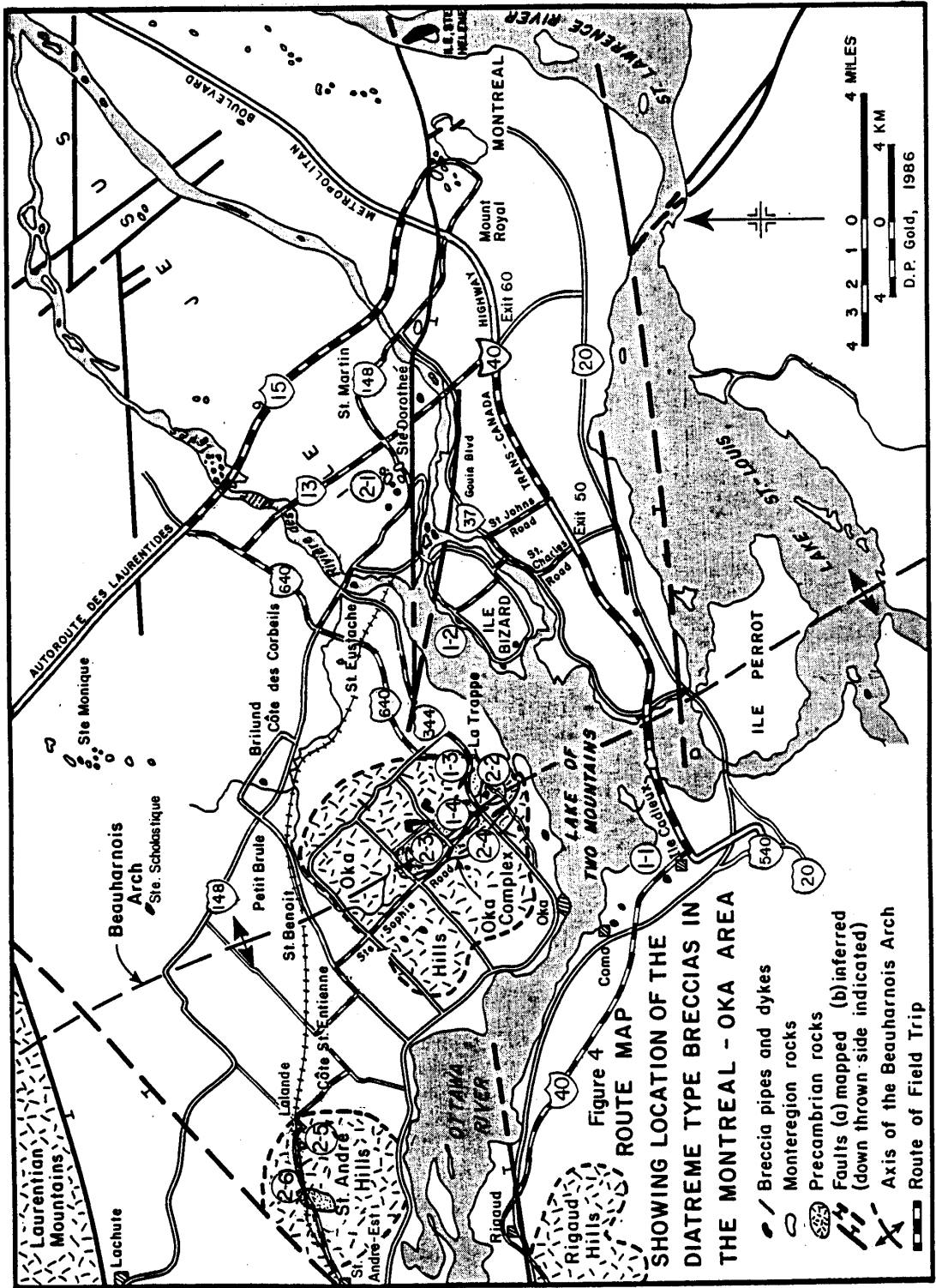
\*All dates calculated using the decay constants recommended by Steiger and Jäger (1977).

ite-bearing sövites ( the one exception is sample S-43-4). The second period has a mean age of 125 Ma and is represented by the emplacement of pyroxene-bearing sövite and the melilite + niocalite sövite in the Bond zone. The okaites and ijolites which form the ring dikes have essentially identical mean ages of 120 Ma and 122 Ma, respectively, which within experimental error may be correlated with the younger age of sövite emplacement. The alnöites were apparently the last rocks emplaced into the Complex and the mean age of the alnöites is 121 Ma, identical with that of the other silicate rocks.

The sample localities are shown on Figure 3 (the numbers correspond to those in Table 6). The older period of sövite emplacement is found in both rings (nos. 5, 8, and 11) while the silicate rocks are essentially the same age regardless of their geographic location. Apatite fission-track ages are generally reset at geologic temperatures in excess of 100°C. The older ages, therefore, should be considered as minimum crystallization ages. In addition, the persistence of these older ages suggests that cooling was relatively rapid and/or that intrusion temperatures may have been relatively low.

In terms of the Montereian Hills petrographic province, Eby (1984a) has reported ages for a number of the other core complexes and for the dykes (Eby, 1985b). These ages generally range from 117 Ma to 141 Ma with two major pulses of igneous activity centered about 134 Ma and 119 Ma. Based on the fission-track data two similar periods of igneous activity are found in the Oka Complex, although the sövites span the time range between the two periods of igneous activity. Within the main Montereian plutons, the younger period of igneous activity is represented by the emplacement of strongly silica-undersaturated rocks: nepheline diorites, foyaites, and tingvaites. Similarly, the strongly under-saturated rocks at Oka (okaites and ijolites) were emplaced during the same time period.

The fission-track ages for the Oka Complex fall in the the same time span as previously determined K-Ar ages (Shafiqullah et al., 1970). However, these ages are significantly older than the recently determined Rb-Sr biotite isochron of 110 Ma. The reasons for this difference is not known. It may be due to analytical or calibration discrepancies, or the ages may represent different stages in the evolution of the Complex.



PART II. ROAD LOG, OTTAWA '86 FIELD TRIP NO. 21  
CARBONATITES, DIATREMES AND ULTRA-ALKALINE ROCKS IN THE OKA AREA, QUEBEC

Day 1

Today's route goes from Ottawa to Ile Cadieux, Ile Bizard, La Trappe (Oka), and ends in Montreal (McGill University). See Fig. 4 for location and Part III for detailed descriptions and location maps.

Approx. Dist.	Cum Dist.	Schedule
0 km	0 km	Start at Carleton University, drive eastward toward Montreal on Rte. 417.
90	90	Quebec border: note the change in route number from Ontario 417 to Quebec 40.
20	110	Stop and park vehicles on the right hand side of the highway, near road-cut through the low hill. (This is 2 km east of the Como exit and 5 km west of the intersection with Rte. 540).

STOP 1-1 ILE CADIEUX MONTICELLITE-MICA PERIDOTITE

SILL(?).

Leader: D.P. Gold

Figures: 4 and 5.

Detailed descriptions of this and subsequent stops are given in Part III.

Cross the drainage ditch and examine the road-cut where phlogopite crystals are exposed in a coarse-grained decussate textured rock, containing rare olivine xenocrysts(?), and dunite xenoliths. Outcrops are abundant on the low knoll to the south (please do not damage the fence when crossing). The main phase consists of phlogopite (up to 1 cm across) as oikocrysts that are easy to spot, but difficult to identify. Local phlogopite-melilite-rich stringers and pods, and zeolite-carbonate rock alteration zones may have developed in an early joint set. Note the ultramafic nodules, particularly near the western flank of the hill, and

their characteristic green reaction rims. An augite (Table 2) megacryst, 17 cm long, was recovered from this site. The restriction of mica peridotite outcrops to the hill, and the lack of continuity in magnetic signature off the hill, led earlier workers to suggest a pipe-like habit for this body.

However, a flow fabric and the similar setting of another monticellite-mica peridotite body 3 km to the northwest, near Como, suggest that they may represent the erosional remnants of a sill, about 10 m thick. A cooling age of approximately 120 Ma is indicated from a paleomagnetic pole determination. Historically, this outcrop is of interest because of Bowen's studies on these rocks, which bear on the role of the nepheline-diopside system in experimental petrology, and on the role of nepheline-rich solutions in the generation of alkalic rocks.

5	115	Return to vehicles and drive eastward to intersection with Rte. 540. Continue left, on Rte. 540 East. Cross bridge (Le Pont de Ile Aux
7	122	Tourtes). The island to the left (due west) is Ile Cadieux, and the body of water to the north and northwest represents a widening of the Ottawa River into the Lake of Two Mountains. The view to the north reveals the twin peaks of the Oka Hills across the Lake of Two Mountains, and the Oka Carbonatite Complex in the valley between them. The mine dumps and the abandoned head-frame and mill of the St. Lawrence Mining Company (defunct since 1976) should be visible from the bridge. The main branch of the Ottawa River joins the St. Lawrence River a few km southeast of the bridge. Other branches flow northeast to form a group of islands on which the City of Montreal and many of its suburbs are built. Dykes and sills associated with the Montereian event are



- responsible for some of the rapids and narrows, and other barriers to navigation in this complex river system. Our next stop is on Ile Bizard, the large island due east of the Oka Hills.
- 13 135 Turn left off Rte. 40 at exit #50 and drive northwestward on St. Charles Boulevard.
- 2.5 137.5 Turn right onto Boulevard Gouin.
- 2 139.5 Turn left and drive northwest for 1 km, across the bridge to Ile Bizard to the T intersection.
- 1 140.5 Turn left and drive southwestward for 0.8 km to the center of Ile Bizard village.
- 0.8 141.3 Turn right onto road (Rue de l'Eglise) beside the church, and travel northwest for 2.7 km to stop sign at the end of the road.
- 2.7 144 Turn left for approximately 200 m, then right into the housing development for about 100 m and part near the low hill on the left side of the access road. The low hill is the Ile Bizard breccia mound.

STOP 1-2 ILE BIZARD DIATREME PIPE AND KIMBERLITE(?)\*

Leaders: G. N. Eby and D.P. Gold  
Figures: 4 and 6.

Walk to the top of the steep-sided hill about 100 m to the south and note the shape, size, and composition of the fragments and the matrix that constitute this diatrema. Quarrying for aggregate during the past decade has removed a large block of Chazy Limestone from the southwest margin, and has produced some spectacular exposures of a polymictic breccia (matrix supported) in a greenish carbonatitic (dominantly dolomite and phlogopite) matrix. Amongst the subangular to angular fragments are Potsdam sandstone and Paleozoic limestones and shales, but there are a few sub-rounded to rounded

\*A less controversial term for the rock is AILLIKITE.

gneiss and anorthosite xenoliths and rare ultramafic nodules. During the past decade, the exploration pits that were dug in 1970 to expose a satellite kimberlite(?)\* plug along the northeastern margin, have been filled in and landscaped into recreational housing plot. Part of this satellite plug still is exposed, and fragments of fresh kimberlite(?) on the graded surface are seen to consist of altered olivine and orthopyroxene megacrysts, and phenocrysts of glassy augite, ilmenite and phlogopite in a dove-grey matrix of serpentine, phlogopite, calcite, magnetite and apatite. Many ultramafic nodules, including websterites, lherzolites, and eclogites have been collected from this site. Some temporary excavations from 1976-1978 revealed additional intrusive phases. These were mapped (Raeside, 1978; Raeside and Helmstaedt, 1982) as autolithic and porphyritic tuffisite breccias, and an analcrite phonolite. They are clearly post-Ordovician intrusions with Monteregean affinities, and the 121-127 Ma K-Ar ages for the Kimberlite(?) phase (Marchand, 1970) probably slightly overestimate the true age. Due west, across the lake, are the Oka Hills, an inlier of Precambrian gneisses and anorthosites, with the Oka Carbonatite Complex in the central depression.

LUNCH STOP - Lunch has been scheduled at the Ile Bizard diatrema. Please return all your garbage to the vehicles.

- 9 153 Return to vehicles and retrace the route between the Ile Bizard bridge to St. Charles Boulevard and exit left to rejoin Rte. 40 East.
- 1 154 Drive northeastward on Rte. 40 to exit #60, and left onto Rte. 13 North.
- 16 170 Drive northwest across Ile J'esus to exit #22 and turn left on Rte. 640
- 17 187 South to junction with Rte. 344. Turn right on Rte. 344 and park vehicles in the lot near the Hot Dog stand on the right hand side of the road. Examine the nature of the contact of a diatrema breccia pipe in Grenville gneiss exposed in the road-cut, and the diatrema up the hill to the north.

STOP 1-3 CHATEAU DU SIROP BRECCIA PIPE.

Leaders: D.P. Gold and Marcel Vallée  
Figures: 4 and 7.

Precambrian gneiss and quartzite are exposed on the hill behind the burnt-out ruins of the Château du Sirop, and the breccia pipe is exposed along the hill to the west and in the road-cut. Paleozoic rock fragments are common and one should note that they are larger and more angular than xenolith of Precambrian rocks. Many intrusive phases are present, and the juxtaposition of diverse clast lithologies indicates a vertical mixing over 10's of kms that could be accomplished only by a fluidization process in a gas streaming system. This diatreme is located about 500 m east of the northeastern contact of the Oka Carbonatite Complex. It is considered to be part of a late stage alnöitic event associated with the Oka Complex.

- 2 190 Return to vehicles and continue west on Rte. 344 to the refectory at La Trappe Monastery. Brief stop to purchase some of the famous Oka cheese and other farm produce. Restroom facilities are available.
- 0.5 190.5 From La Trappe parking lot, cross Rte. 344 and drive northwest on Rue Ste. Sophie for about 500 m. Park the vehicles near the entrance to abandoned St. Lawrence Columbian and Metals Corporation Mine. Cross the ditch and fence to examine contact relationships between sövites and ijolites in the two open pits, and collect samples from the waste dumps.

STOP 1-4 ABANDONED MINE WORKINGS OF THE ST. LAWRENCE COLUMBIUM AND METALS CORPORATION.

Leaders: Marcel Vallée and D.P. Gold  
Figures: 4 and 8.

This mine was opened during 1961 as a 500 ton/day operation, drawing ore from two open pits.

Late in 1967 it converted to an all underground operation and production was expanded to 2500 tons a day. With an annual production of approximately 5 million pounds of pyrochlore concentrate, it was a leading world producer of niobium until its bankruptcy early in 1977, following a protracted labour strike. This mine is located in the "northern ring" of the Oka Carbonatite Complex, and it will be the prime locality for examining contact relationships in the pit walls, and for collecting samples of a variety of coarse-grained sövites [monticellite, soda-pyroxene, and Na-richrichterite-bearing carbonate rocks, with (ore) and without (barren) accessory pyrochlore], as well as microijolite and glimmerite (biotite replacement rock). A general age of approximately 120 Ma for the Oka Complex coincides with the main phase of intrusive activity for the Monteregian Hills. The range in age from 110 to 132 Ma is a function both of rock type and dating method.

- 0.5 191 Drive back (southeast) towards La Trappe and turn left (northeast) on Rte. 344.
- 3 194 Turn left at traffic light on Rte. 640. Remain on Rte. 640 (northeast) for about 22 km, and turn right at Exit #20 onto Rte. 15 South (Laurentian Auto Route), and follow it southeast into Montreal.
- 22 216
- 20 236 Exit left (northeast) at intersection with Rte. 40.
- 1.5 237.5 After 1.5 km on Rte. 40, exit right onto Boulevard St. Lawrence.
- 6.5 244 After 6.5 km turn right onto Sherbrooke Street.
- 1 245 After approximately 1 km turn right
- 0.5 245.5 onto University Street and the McGill University Campus. The dormitory is located about 500 m up University Street.

OVERNIGHT STOP AT MCGILL UNIVERSITY. After you have registered at the dormitory, the rest of the evening is open. Breakfast will be served from 6:30 a.m. Vehicles will leave from outside the dormitory at 8:00 a.m.

Day 2

This itinerary includes Montreal, Ste Dorothée, St. Eustache, Oka Complex (Paul Sauvé Park Nature Centre, Husereau Hill, Bond Zone), St. André-Est, Grenville, Hawkesbury, Ottawa (Carleton University). Detailed maps and descriptions of stops are given in Part III.

Approx. Dist.	Cum Dist.	Schedule
0	245.5	Start at McGill University Campus; follow Pine Avenue west for 2 km to Côte des Neiges. Turn right and cross over Mount Royal. Note the campuses of the University of Montreal and Ecole Polytechnique on the right.
2.5	250	Turn left onto Queen Mary Avenue. Shrine of Brother André on left.
1.8	251.8	Turn right at Decarie Autostreet and follow Rte. 15 North for approximately 4 km to cloverleaf interchange beneath Rte. 40, and travel northwest on Rte. 117 (The Laurentian Boulevard) past Cartierville Airport (on left), across Rivière des Prairies bridge to junction with Rte. 148 in St. Martin.
4.2	256	Turn left onto Rte. 148 and drive southwest about 7 km to Ste. Dorothée. Stop along the road side at the bottom of the second scarplet on the outskirts of the town of Ste. Dorothée.
10	266	
7	273	

STOP 2-1 STE. DOROTHEE MONCHIQUE SILL AND BRECCIA MOUNDS.

Leaders: G.N. Eby and D.P. Gold  
Figures: 4, 9 and 10.

The Ste. Dorothée sills and diatreme pipes are located on a direct line, and about halfway between Mount Royal and the Oka Complex. Seven sill-like bodies of monchiquite and diatreme pipes are exposed

within 1.5 km of the center of the village. Although individual sills intrude successively stratigraphically higher units of the Beekmantown Group eastward, their compositional similarity led Clark (1952) to suggest they belong to a single step-like sheet, linked by dykes. Exposures of the sill along Rte. 148, and in a small quarry (now covered) 60 m to the north of the road carry vein, stringer, and bleb-like ocelli, which may represent crystallized blobs of felsic (analcite syenite) liquid that existed immiscibly and was deformed by shear flow in the monchiquite melt. The ski hills about 0.8 km to the west, and in the field behind the church, are underlain by polymict diatreme breccias. Although the diatremes and the sills are considered to be Monteregean events, only the emplacement age of the sill has been constrained by a paleomagnetic pole date of approximately 120 Ma (Foster and Symons, 1979), and a fission track age of 119 Ma (Eby, 1985b).

9	282	Continue west on Rte. 148, across the Rivière des Mille Isles, through St. Eustache to the junction with Rte. 640.
13	295	Turn left on Rte. 640, and drive west to the Nature Centre in the Paul Sauvé Parc du Oka. Park vehicles at the Nature Centre, in the eastern part of the "Southern Ring" of the Oka Carbonatite Complex.

STOP 2-2a to 2-2f NATURE CENTRE - THE "SOUTHERN RING" STRUCTURE.

Leaders: D.P. Gold and Marcel Vallée  
Figures: 4, 11.

Six stops are scheduled on this walk of approximately 1 km through the eastern part of the "southern ring" to examine outcrops of metasomatically altered rocks (fenite and ultra-fenites), coarse-grained ijolite and melanite ijolite, urtite, melanite sövite, a very coarse-grained richterite-pyrochlore sövite, and a late fourchite sill. Details of the walk are given in Part III and Fig. 11.

Persons who do not enjoy, or are unable to walk far, are advised to remain at the outcrops of "pegmatitic" richterite sövite behind the Nature Centre, and pick through the grus for pyrochlore crystals.

Regroup at the Nature Centre, use restroom facilities, and return to vehicles.

- 2 297 Return to Park Road to junction with Rte. 640/344.
- 3 300 Turn left at traffic light onto Rte. 344 and drive approximately 3 km west to La Trappe, and turn right onto Ste. Sophie Road.
- 4.5 304.5 Drive northwest for about 4.5 km to Husereau Farm, and turn right into farm yard. Continue on dirt road for 0.5 km and park near inactive quarry.
- 0.5 305 Leave vehicles for a walk of about 500 m, and lunch at a spring on the western flank of the hill.

STOP 2-3a to 2-3e ARCUATE OKAITE-JACUPIRANGITE DYKES OF THE "NORTHERN RING" STRUCTURE, EXPOSED ON HUSEREAU HILL.

Leaders: D.P. Gold, Marcel Vallée and G. N. Eby  
Figures: 4 and 12.

This 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 sövites, rauhaugite, jacupirangite, okaites, a very coarse-grained apatite-magnetite-perovskite-calcite okaite, and two fissure-like bodies of melilite-rich alnöite 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 118 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 (Stop 2-4) on the right, and the

closure of the Northern Ring structure from the left near the abandoned mine working (the former St. Lawrence Columbian and Metals Corporation mine). The locations of breccia pipes across the Lake of Two Mountains on Ile Bizard and Ile 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.

LUNCH STOP - Lunch will be served at the spring that developed from an exploration drill hole. Please carry your garbage back to the vehicles with you. On the way back to the vehicles you may pause to examine some of the glacial erratics in the quarry.

- 0.5 305.5 Return to Ste. Sophie Road and turn left.
- 2 307.5 Drive southeast towards La Trappe Monastery for 2 km and turn right onto the dirt road, a few meters west of the bridge.
- 0.1 307.6 Park about 100 m in, near the barn. Leave vehicles for an approximately 1.3 km walk over the hill to the west. This ridge is located near the western margin of the "northern ring" of the Complex, and is referred to on the maps as the Bond Zone.

STOP 2-4a to 2-4e EXPLORATION TRENCHES IN THE BOND ZONE.

Leaders: D.P. Gold, Marcel Vallée and G. N. Eby  
Figures: 4 and 13.

The Bond Zone has the best economic potential of any part of the Oka Complex. It is underlain by steeply, inward-dipping, litho-structural units of monticellite sövites, soda-pyroxene sövites, and

niocalite-melilite sövite, that contain disrupted (boudinaged) dykes(?) of microijolite, outward dipping dykes of okaite, and an alnöite plug. This is a good locality for collecting niocalite (the type locality of this niobium silicate mineral, that still is unique to Oka), latrappite (niobium perovskite), and fresh samples of the magmatic phase of alnöite. Apatites from these rocks have yielded fission track ages ranging from 109 Ma (Gold) to 130 Ma (Eby).

Most of the trenches (T 1-4, and T 7-12) were excavated during the late 1950's and early 1960's, and are now overgrown to some degree by bushes and trees. The most recent excavation (circa 1982) is located a few meters southeast of the fence on the Columbian Mining Products property, and is identified as T 13 on the map (Fig. 13). We will walk to trench T 4 (niocalite-melilite sövite), through the tops of T 8 and T 7, and across the fence to T 13 and T 1 (monticellite sövites, with latrappite and pyrochlore-bearing units), and then down to the dirt road to the east to examine some outcrops of alnöite. Please keep close to the guides and follow the marked trail through the brush. Return to the vehicles.

- 0.1 307.7 Turn left onto Ste. Sophie Road and
- 9.3 317 drive northwestward for 9.3 km.
- 2 319 Turn left (southwest) at T inter-
- section.
- 3 322 Turn right at intersection and drive
- 3.7 325.7 northeastward 3.7 km, and turn left at
- 0.6 326.3 the T intersection to Lalande siding.
- 0.5 326.8 Turn right (northwest) and follow main
- road for 0.5 km, with a left turn
- westward) to St. André-Est at the
- intersection.
- 1 327.8 Another inlier of Precambrian rocks is
- exposed in the low hills, about 10 km
- west of the Oka Hills. Park the
- vehicles near the base of the St.
- André Hills, by the roadside, about 1
- km from the inter-section and opposite
- the gated road to the south. Climb
- through the gate, cross the railway
- lines and follow right hand fork of
- trail for 100 m westward to the aband-

oned quarry, about 25 m south of the railroad. This is the Lalande quarry, that was operated for aggregate during the construction of the adjacent Canadian National Railway line. The quarry is partially filled with water, and it is used by the local inhabitants as a swimming hole and boating pond.

STOP 2-5 LALANDE QUARRY (CANADIAN NATIONAL RAILWAY).

Leader: D.P. Gold

Figures: 4 and 14.

A number of diabasic, lamprophyric, and carbonatitic dykes, sills(?) and veins(?), that intrude and transgress the foliated quartz monzonite host rock, are exposed in the partially stripped area east of the quarry, and in the quarry walls. We will examine the early diabase dikes (generally east-west strike and steep dip, with thicknesses of up to 1 m and more), the thinner (average about 10 cm) and gently inclined lamprophyre dikes or sills, and late carbonate veins and tufa sill(?). The latter is exposed in the east quarry wall, and consists of a fine-to medium-grained druzey white carbonate ledge up to 120 cm thick. In this finely crystalline carbonate rock, a crude wavy layering on the mm to cm scale is preserved, along with "cabbage-head" structures 1-2 cm across. Some of these textures are similar to those found in hot spring deposits.

Please be aware of the unstable and dangerous condition of the quarry walls, and that most of the dykes are exposed in the glaciated outcrops (whale-backs) in the partially cleared area for some 150 m east of the quarry. Local concentrations of Potsdam Sandstone float in this glacially scoured terrain suggest that the present surface is close to exhuming the Precambrian-Cambrian unconformity. Not much is known of the foliated quartz-monzonite country rock, which is considered to be part of the Rigaud Syenite Complex (Wilson, 1946) of Late Precambrian age (Doig, 1968). The crystallization age of the Lalande Quarry lamprophyres is bracketed by K/Ar determinations (J.O. Wheeler, Geol. Surv.

Canada, pers. comm., 1973) of  $128 \pm 6$  Ma on hornblende from one dyke and  $123 \pm 4$  Ma on phlogopite from another. These emplacement ages compare well with the paleopole position of  $169.0^\circ\text{W}$ ,  $72.4^\circ\text{N}$ , and  $120 \pm 4$  Ma age for 10 lamprophyre sample sites at the Lalande Quarry (Foster and Symons, 1979).

These ages indicate that the lamprophyre intrusions are part of the Monteregean igneous event. The associated carbonate dykes and younger replacement(?) veins may be related to the St. André Carbonatite Complex, located 2 km to the west.

2.2 330 Return to vehicles and continue west for 2.2 km, and park vehicles beyond the railroad crossing, near the road intersection. The eastern margin of the main carbonate phase of the St. André Carbonatite Complex is located about 350 m to the east. We have a walk of about 1 km through the fields to the southwest and back to the road, where the vehicles will pick us up.

#### STOP 2-6 THE ST. ANDRÉ CARBONATITE COMPLEX.

Leader: Marcel Vallée

Figures: 4 and 15

The St. André Carbonatite is not well documented, even though an initial exploration phase of trenching and drilling (1968) and the follow-up geophysical surveys and diamond-drilling programs were completed prior to 1976. A summary of some of the exploration data is given for the first time in Part III of this guidebook. Its topographic setting as a depression between low hills underlain by Precambrian gneisses is similar to that of the Oka Complex, only 20 km to the east-southeast. However, it differs mineralogically in the dominance of dolomite as the main carbonate phase over much of the Complex. Some syenites and monzonites have been intersected in drill-holes around the margin of the  $1.3 \times 1.5$  km rauhaugite core ("rusty carbonatites" unit of Vallée). The relationship between these

silicate rocks and the carbonatite is not clear, but the foliated quartz monzonite terrane of the St. André Hills suggest that they may be phases of the country rock.

If the carbonate dykes in the Lalande Quarry are associated with the St. André intrusion, then this carbonatite will represent a Monteregean event, similar to the Oka Complex. This "guilt by association" may be fortuitous, because it has more in common with the older carbonatites of Quebec and Ontario, than the Oka Complex.

Because of the paucity of outcrops, we will walk 400 m to the southwest to examine the remains of an exploration trench in a "rusty carbonatite" of the central plug, and then through the fields to the west for some 600 m to the main road. Be sure to examine the boulders along the fence rows and in the stone piles for float from this intrusion that has been carried off the fields.

- 1 331 Rejoin vehicles on the main road, and
- 3.6 334.6 drive west approximately 3.6 km to St. André-Est.
- 25 360 Turn right in St. André-Est, and follow Rte. 344 west approximately 25 km to Grenville.
- 4 364 At the junction in Grenville, turn left onto Rte. 34 South and drive south, across the Ottawa River into Ontario for 4 km to Hawkesbury and intersection with Rte. 17 West.
- 66 430 Exit right onto Rte. 17 West and drive via Alfred, Plantagenet, and Rockland along the south bank of the Ottawa River to Ottawa and Carleton University.

END OF FIELD TRIP.

### PART III. DETAILED DESCRIPTIONS OF STOPS

#### STOP 1-1: THE ILE CADIEUX AND COMO MONTICELLITE MICA

##### PERIDOTITE

Leader: D.P. Gold

The Ile Cadieux monticellite-mica peridotite "pipe" is exposed as a low hill approximately 200 m across, 1 km west-northwest of the Ile Cadieux Railroad Station. The Trans Canada Highway (Quebec Rte.40) exposes bedrock in the northern flank of the hill, 2 km west of the intersection near Vaudreuil with Rte.20. It was mapped in 1916 as part of a Road Materials Survey of this area (Picher, 1917), and the petrology was described by Bowen (1922) in a classic paper involving experimental studies on the system  $\text{NaAlSi}_3\text{O}_8\text{-CaMgSi}_2\text{O}_6$  at 1 bar, and the role of nepheline-rich solutions in forming monticellite and/or melilite-bearing rocks, by pyroxene desilicification.

The knoll rises about 10 m above the surrounding, rather flat farmlands, which are underlain "by deposits of unconsolidated boulder clay, gravel, stratified clays and sands" (Picher, 1917) of Pleistocene to Recent age. The contact with the country rock is not exposed. Northwest of

Como as much as 150 m of Potsdam Sandstone was intersected in the Aumacho River Mines drill-holes (see Fig. 5), as well as thin lamprophyre sills between 84 and 144 m below the surface. Similar rock types are exposed about 3 km to the northwest, near Como (Howard, 1922), and near Côte des Corbeil (Brilund pipes) 12 km to the north-northeast, where a pipe has been delineated by drilling (Gold and Marchand, 1969). The flat magnetic profile, and similarity in setting to the partially eroded monchiquite sill near Ste. Monique, 16 km to the north-northeast (Fig. 1 and 4), suggest that the Ile Cadieux and Como "plugs" may be remnants of a sill at or near the base of the Potsdam Formation. All of these bodies have a remarkably similar chemical composition (Table 7) and intercumulus texture, and it is suggested that they crystallized from an aillikitic or kimberlitic magma with minimum loss of volatiles, and under near equilibrium conditions beneath 2 to 3 km of cover rocks. Although no radiometric dates are available, these rocks are presumed, by virtue of location, mineralogy and

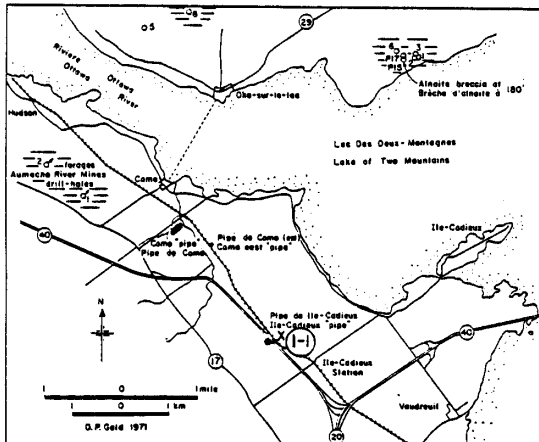


Figure 5: Locations of the Ile Cadieux and Como monticellite-mica peridotites (Stop 1-1). Circles represent drill-hole intersections of lamprophyre dykes and sills; the ruled areas represent sub-outcrop of Potsdam Sandstone. From Gold (1972).

TABLE 7 - Analyses of monticellite-mica peridotites from Ile Cadieux, Como and Côte des Corbeil

	1	2	3	4	5	6	7
SiO <sub>2</sub>	33.26	30.85	33.0	31.10	83.31	30.27	31.94
TiO <sub>2</sub>	2.15	2.87	3.04	2.73	0.64	2.84	1.97
Al <sub>2</sub> O <sub>3</sub>	5.90	8.21	6.4	10.08	4.46	10.00	5.87
FeO <sub>2</sub>	5.30	3.33	6.09	3.64	1.10	4.88	5.87
FeO	6.54	6.52	6.81	3.35	0.45	6.95	5.87
MnO	0.15	0.21	0.23	0.09	tr	0.16	0.22
MgO	26.41	23.16	22.0	12.25	0.28	20.11	21.51
CaO	14.47	16.46	15.2	22.77	2.87	14.73	17.38
SO	—	—	0.18	—	—	—	0.11
BaO	0.08	—	0.21	—	—	—	0.23
Na <sub>2</sub> O	1.23	1.01	1.16	1.95	1.42	1.49	0.52
K <sub>2</sub> O	0.82	1.43	1.85	3.56	4.02	2.85	2.23
P <sub>2</sub> O <sub>5</sub>	0.76	1.90	0.28	2.01	—	0.95	0.75
CO <sub>2</sub>	1.10	3.04	1.68	4.94	—	3.24	1.97
H <sub>2</sub> O	1.91	1.22	1.59	0.76	1.02	2.17	2.45
H <sub>2</sub> O	0.09	0.05	—	0.46	0.18	—	0.36
F	—	—	0.10	—	—	—	0.11
SO <sub>2</sub>	0.22	—	—	—	—	—	—
Cr <sub>2</sub> O <sub>3</sub>	0.05	—	—	—	—	—	—
	100.44	100.26	99.80	99.69	99.75	100.64	99.26

1. Melilite-rich, monticellite mica peridotite, Ile Cadieux. Analyst, H. S. Washington, 1922.
2. Melilite-poor, monticellite mica peridotite, Ile Cadieux. Analyst, H. S. Washington, 1922.
3. Monticellite mica peridotite, Ile Cadieux. Analysts, J. B. Bodkin and C. O. Ingamells, 1969.
4. Melilite-biotite rock, Ile Cadieux. Analyst, H. S. Washington, 1922.
5. Aplitic inclusion in monticellite mica peridotite, Ile Cadieux. Analyst, H. S. Washington, 1922.
6. Monticellite mica peridotite, Como. Analyst, W. V. Howard, 1922.
7. Monticellite-mica peridotite, Brilund pipe. Analyst, C. O. Ingamells, 1967.

geochemistry to be a Montereian event. Paleomagnetic measurements on samples cored from here in 1972 indicate a stable normal primary thermomagnetic magnetization acquired during one polarity interval, approximately 120 Ma ago (Foster and Symons, 1979).

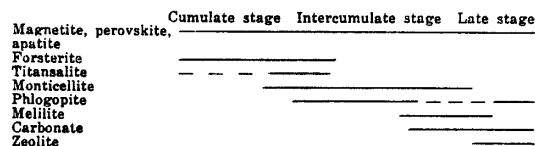
No compositional layering is apparent in these tough, dense ( $\rho = 3.23$ ), dark blue-grey rocks, but local mineral alignments suggest a horizontal flow régime. These rocks consist of phlogopitic biotite, monticellite, forsterite, titansalite, melilite, with accessory apatite, magnetite, perovskite, calcite, scapolite, and zeolite. Except for some fine-grained varieties, these rocks are characterized by a poikilitic texture with phlogopite and/or monticellite oikocrysts as much as 1 cm across, which are easily discernable but not readily recognizable in hand specimen. The fine-grained variety contains olivine phenocrysts in a trachytic textured matrix of mica and melilite. Veins of pale green to cream coloured amorphous material occur in joint-like pattern. These alteration veins, ranging from 1 to 50 cm thick, consist almost entirely of biotite and melilite with subordinate amounts of apatite, chrysolite, monticellite, perovskite, magnetite and calcite (Table 7, No. 4) and probably represent a deuteric reaction by mobilized intercumulus liquids.

Inclusions are rare, but locally comprise up to 5% of the rock. A siliceous aplite (Table 7, No. 5), syenite, carbonate analcites and ultramafic nodules (websterites, harzburgites and dunite), as well as augite xenocrysts have been identified. The ultramafic nodules are rounded and have rims of magnetite, up to 1 mm thick, over rims of degraded or comminuted host mineral. Monticellite, dolomite and phlogopite are developed in the rim zone of some nodules. A magnetite rind also surrounds the carbonate nodule, and the rim zone, about 2 mm thick contains an intergrown mixture of dolomite, aegirine, fibrous zeolite, and apatite.

Although chemical variations of the host rock are slight, there are marked variations in mineral proportions, particularly in the melilite content and composition. Phlogopite occurs as oikocrysts enclosing forsterite, monticellite, pyroxene, melilite, magnetite, and perovskite as well as small plates in the matrix associated with melilite,

fibrous zeolite, calcite and apatite. It is more Mg-rich adjacent to forsterite grains. Monticellite also occurs as oikocrysts enclosing principally forsterite and magnetite, marginal to inclusions, and locally is intergrown with melilite. Forsterite (F<sub>90</sub>) occurs as euhedral and subhedral grains up to 2 mm long and as smaller chadacrysts, and locally may be mantled with monticellite. Pyroxene also occurs as sub- and anhedral crystals in the matrix and as chadacrysts. It is a pale khaki-brown titansalite ( $Z^c$ , 32° to 41°) and Hodgson (1968) reports rare grains that exhibit a clear core of endiopside. Fine-grained carbonate occurs interstitially in the matrix and locally as oikocrysts enclosing melilite and apatite.

Small (0.01 to 0.05 mm) euhedral magnetite grains are ubiquitous, within other minerals and throughout the matrix, and in places are spatially associated with perovskite. Local patches and embayments of fibrous zeolite, calcite, and phlogopite are interpreted as late alteration products. The crystallization sequence envisaged is given schematically below:



In summary, these rocks have textural features indicating the fractionation of intercumulate phases that are richer in alkalis in the sequence Ca and K (monticellite and phlogopite) to Na plus Ca and H<sub>2</sub>O (interstitial Na-melilite, carbonate and zeolite). The sharp boundaries and euhedral nature of the forsterite chadacrysts, and the lack of corona textures are difficult to reconcile with Bowen's hypothesis that it (and pyroxene) reacted with nepheline solutions to produce monticellite, melilite, and phlogopite, all of which may be zoned. However, all inclusions show advanced stages of assimilation so that many of the reactions may be essentially complete. Bowen suggested that the residual solutions produced analcite-rich rocks, which could be the source for analcite-carbonate matrix in breccia dykes and pipes elsewhere in the western Montereian area.



STOP 1-2: THE ILE BIZARD INTRUSION

Leader: G. N. Eby

The three breccia mounds mapped by Clark (1952) about 15 km west of Montreal, near the western shores of Ile Bizard, were described as diatreme pipes by Harvie (1910). The first detailed description (Marchand, 1970) focussed on a satellite fissure of kimberlite(?)\* that extends for approximately 60 m northward from the main breccia pipe into the Chazy Limestone beneath a wave-cut terrace. The oval-shaped (60 m by 100 m) breccia pipe, mapped beneath the hill, contains numerous angular fragments of Lower Paleozoic sandstones, limestones, and shales, and rarer Precambrian gneiss and anorthosite inclusions. A variety of ultramafic nodules are found in the kimberlite(?),\* 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.

Temporary excavations in 1976-1978 provided more exposure and the intrusion was mapped at this time (Raeside, 1978). A variety of intrusive phases (Table 1) were identified including porphyritic and autolithic tuffisite breccias, intrusive breccias, and an analcite phonolite (Fig. 6). The tuffisite

\*Footnote:

The classification of the Ile 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 alnöitic. Raeside and Helmstaedt (1982) re-instituted the name kimberlite to which Mitchell (1983) took vigorous exception. The igneous matrix at Ile Bizard seems to have mineralogical and chemical characteristics more closely allied with alnöites. Rock (1984, personal communication) has suggested that the term aillikite be applied to such rocks which do not contain melilite (which is absent at Ile Bizard) and Eby (1985) has used this term in reference to the Ile Bizard occurrence.

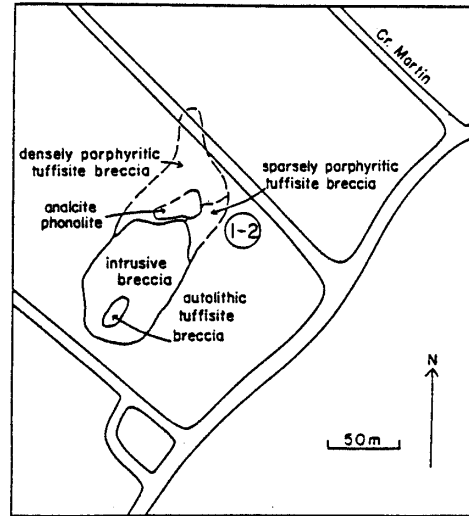


Figure 6: Map of the Ile Bizard intrusion (Stop 1-2), showing the main diatreme phase underlying the breccia mound, and the satellite tuffisite breccia bodies to the north. From Raeside and Helmstaedt (1982).

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 to the description above with the exception 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 8 (from Raeside and Helmstaedt, 1982). The composition of some phenocrysts and xenocrysts are given in Table 2.

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, and 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).

TABLE 8 - Relative proportions of xenoliths and xenocrysts in different phases of the Ile Bizard intrusion

Type of clast or crystal	Intrusive breccia (%)	Densely porphyritic tuffisite breccia (%)	Sparsely porphyritic tuffisite breccia (%)	Autolithic tuffisite breccia (%)
Total xenoliths	50	15-20	5-10	5
Beekmantown Group	70	70	70	-
Potsdam Group	10	1	1	-
Basement Greiss	1	-	-	50
Ultramafic rocks	5	15	15	20
Alloclastic fragments	15	-	-	-
Megacrysts	1	15	15	30
Total phenocrysts	10	18	3	-
Serpentinized olivine & opx	60	60	60	-
Clinopyroxene	15	20	20	-
Phlogopite	15	10	5	-
Mg-titanomagnetite	10	10	15	-

Data from Raeside and Helmstaedt, 1982, p. 1998

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 which 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 beneath 2.1 to 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 Ile Bizard by Barton (reported in Marchand, 1970). Of these three ages, the amphibole age might be expected to be least disturbed (highest closing temperature). Apatite was separated from a sample of xenolith-free matrix material and a fission-track age of 119 ± 14 Ma was determined using the population method. This age is in good agreement with the K-Ar amphibole age, and also is identical to the emplacement ages of alnöites in the Oka complex.

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 (1985) reports a REE analysis for similar material from Ile Bizard. This pattern is typical of those expected for liquids which are in equilibrium with garnet lherzolite, and it was suggested that the magma was generated in a carbonated garnet lherzolite mantle.

#### STOP 1-3: THE EASTERN (CHATEAU DU SIROP) BRECCIA PIPE

Leader: D.P. Gold

A teardrop-shaped diatreme breccia pipe (Fig. 7) is exposed in the road-cut and up the hill to the north, intruding northeast trending Grenville gneisses and quartzite. The pipe is exposed for about 150 m in the roadcut and tapers north-northwestward over 300 m into a dyke.

Diatreme breccia cored in drill holes to the southeast suggests that this pipe represents a local blow-out along a fissure. Generally, the pipe is filled with a polymict breccia, which is highly charged with fragments 5 mm to 50 cm in diameter set in a fine-grained, carbonate-rich matrix, which locally exhibits a well developed flow layering. This pipe is of interest for the variety of rock types represented in the inclusions, the angular nature of these, and their great range in size. Disrupted blocks many meters across are exposed near the road, where the pipe grades through shattered and fractured country rock into massive gneiss. Alnöite lapilli are rare, but the presence of rounded and smooth inclusions and the persistence of the Precambrian quartzite fragments throughout this level of the pipe suggest it was drilled, eroded and emplaced by a gas streaming process. It is interpreted as representing the upper vent zone of a fluidization diatreme pipe, where the maximum amount of stratigraphic mixing occurred.

Country rock fragments (Precambrian gneisses and quartzites) are most common near the margin of pipe where the matrix consists mainly of carbonate-cemented comminuted country rock fragments and chlorite. Fragments of Paleozoic rocks (mainly hornfels, limestone and dolostone) generally are angular and occur mixed with gneissic fragments and

smaller subrounded to rounded "nodules" of gabbro, titanite gabbro, pyroxenite, richterite sövite and other carbonatitic rocks, and rare ultramafic xenoliths (alnöite, dunite, and orthopyroxene-phlogopite rocks) in the central portion of the pipe. Here the matrix is flow layered and contains fragmented megacrysts of apatite, calcite, pyroxene, magnetite (partly oxidized), skeletal ilmenite, and a fine-grained mosaic consisting mainly of carbonate and phlogopite. Except for the hornfels fragments, reaction between the xenoliths and the matrix is minor, but replacement by carbonate and zeolite may be extensive. The matrix type represented is the analcitic type, grading into a carbonate-cemented comminuted country rock. A characteristic of the matrix is the abundance of apatite xenocrysts. The carbonate xenocrysts and xenoliths exhibit strain features such as twinning, kinking and undulose extinction.

The presence of Trenton Limestone and Utica Shale fragments in this, as well as the large breccia pipe 3 km to the north-northwest, indicate at least 3 km of Paleozoic strata covering the Oka Hills at the time of intrusion. A paleomagnetic age of approximately 120 Ma (Foster and Symons, 1979) for the latter pipe indicates these are Montereian events. The country rock surrounding the pipe is fractured and veined, with incipient fenitization in

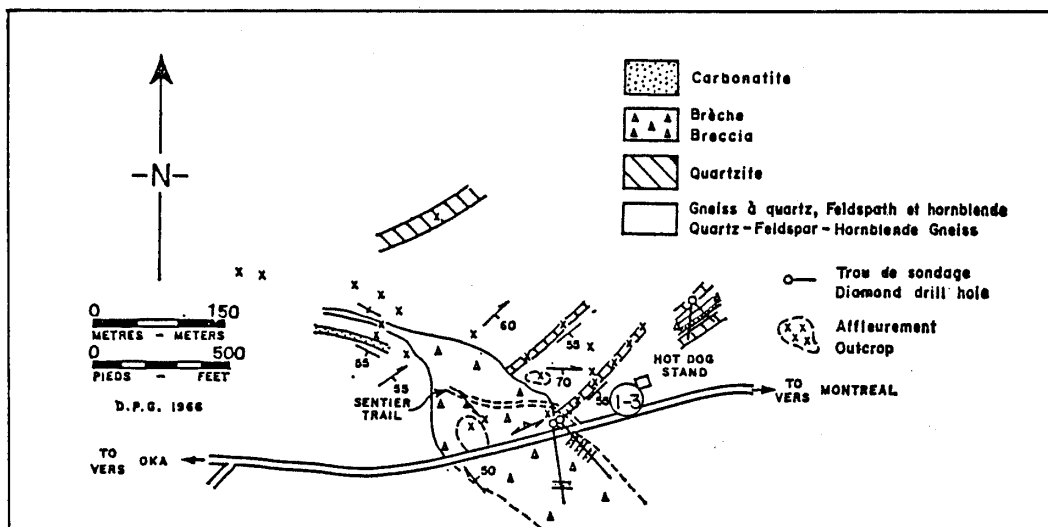


Figure 7: Geological map of the Eastern (Château du Sirop) breccia pipe (Stop 1-3). From Gold (1972).

the rocks adjacent to the carbonate and chlorite-bearing veins. The coarse-grained carbonate dyke, that parallels the northwestern extremity of the pipe, probably is an apophysis of the Oka Complex, only 500 m to the west. The presence of Oka carbonatite inclusions in the breccia pipe suggests it was emplaced into the fenitized aureole of the Complex, probably as part of the late-stage alnoite event (Gold, 1972).

STOP 1-4: THE ST. LAWRENCE COLUMBIUM AND METALS CORPORATION MINE AND MILL SITE

Leaders: D.P. Gold and Marcel Vallée

History. Modern mineral exploration in the Oka Hills started in 1953 with the discovery of radioactive minerals in outcrops that were shown later (Rowe, 1958; Gold, 1963) to be part of the Oka Carbonatite Complex. Magnetometer and scintillometer surveys soon delimited the Oka Complex as the target area, and during the period 1954 to 1959, approximately 72,000 m of diamond drilling was completed in, and close to the Complex. Although the early exploration was for uranium, it was soon realized that the economic potential of the "Carbonatite Complex" lay in niobium (columbium), and that the main economic mineral would be pyrochlore. Zones of pyrochlore-bearing sövite were found in a number of localities within the Complex and considerable resources (over 200 million tons) of low grade (0.4% Nb<sub>2</sub>O<sub>5</sub>) sövite have been outlined. A consequence of the variable chemical composition of Oka pyrochlores (see Table 9) is different ore dressing characteristics. Considerable test work as well as geological studies (Gold et al., 1967; Perrault, 1968) were done to link pyrochlore type to mineral assemblage and lithology (Table 10) to ensure successful exploitation.

Despite the large reserves and current exploration, only one mine on the St. Lawrence Columbium and Metals Corporation property has been brought into production. Erection of the mill and concentration plant began during 1960, and the open pit mining operation was started during October 1961 (Fig. 8). Ore production for the first 3 1/2 years came from two open pits, which reached depths of respectively 55 m (180 feet) in the A-1 zone, and

110 m (360 feet) in the A-2 zone (see Fig. 8). During 1965, an underground adit system was developed from the A-2 pit to gain access to lenses of ore near the pit walls. Later, this was developed into an inclined adit ramp system serving the lower levels of the A-1 zone (under pit A-1), and also the lower levels of the A-2 zone. During January to September 1966, a four compartment vertical shaft, with six stations (four for operating levels and two for loading pockets) was sunk to a depth of 410 m (1335 feet), and this was deepened during October 1970 to May 1971, to 593 m (1930 feet) with three additional stations. By the Spring of 1967, all the ore was hoisted from the shaft. The shift to selective mining methods in an underground operation is illustrated by the following extraction figures for the first decade of mining:

	<u>Ore</u>	<u>Waste</u>
Open pits	2,108,000 tons	4,016,000 tons
Underground	1,790,000 tons	236,000 tons

The original 500-ton per day mill was expanded first to 1000 tons in November 1962, and to 2500 tons in September 1969. Production of concentrates (containing approximately 52% Nb<sub>2</sub>O<sub>5</sub>) was increased from about 250,000 pounds (113,000 kg) to level off at approximately 5 million pounds (2.25 million kg) per annum in the early 1970s. During 1969 a ferrocolumbium plant was started on the property.

As a leading world producer with substantial reserves (5,225,000 tons of 0.502% Nb<sub>2</sub>O<sub>5</sub> within 310 m of the shaft for March 1971), and the only North American mine in production, the future seemed unassailable. However, the mining operation never recovered from a protracted labour dispute and strike in 1976, and the Company went bankrupt early in 1977. Part of the mine and mill equipment were sold off after foreclosure during 1977.

General Geology. The A ore zone is situated in the east central part of the Complex, and structurally is part of the Northern Ring. The sövites and accompanying ijolites and nepheline okaites have a general strike of N20°E and dip 80° westward. The main rock types in the A ore zone are:

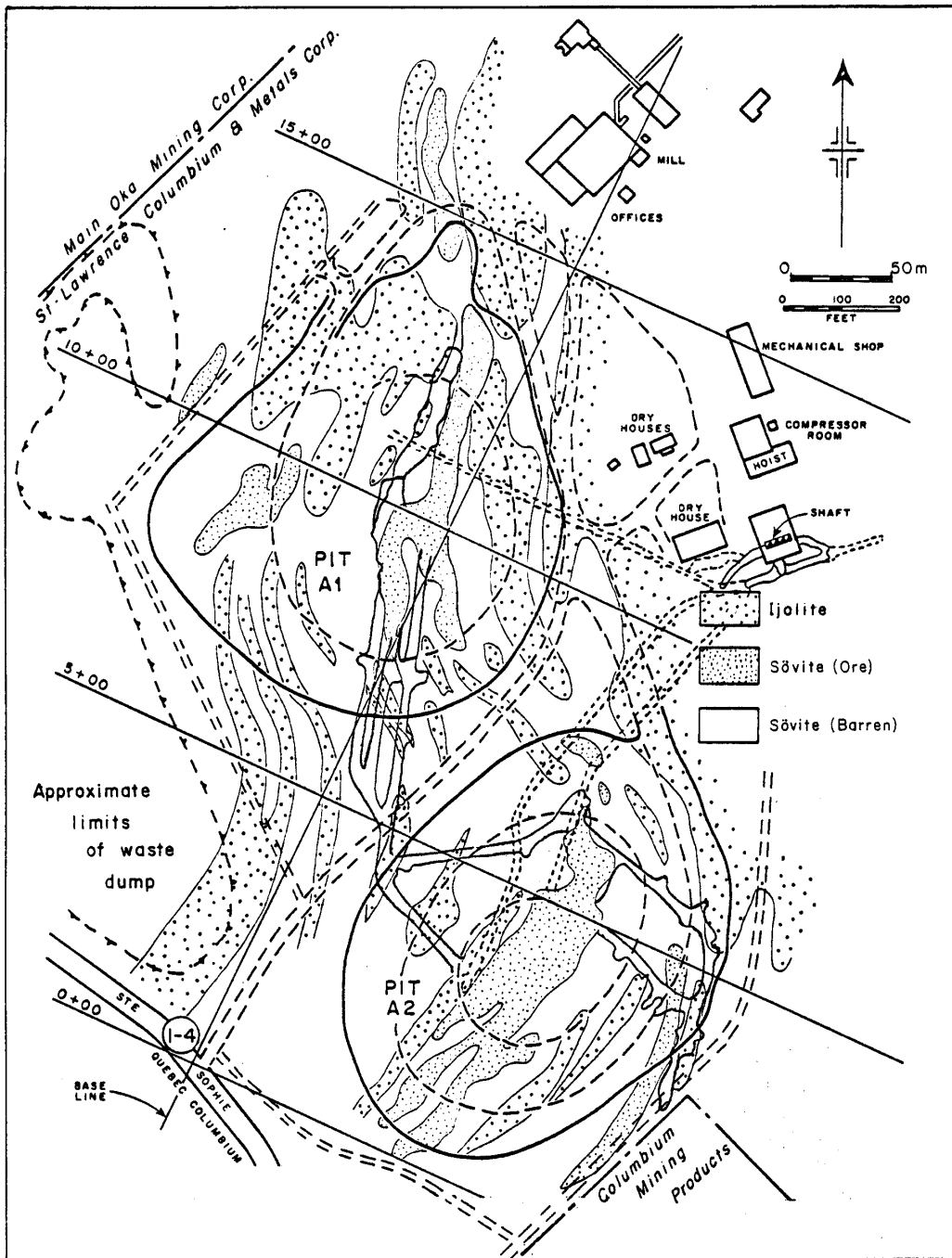


Figure 8: Geological map showing the underground workings, open pits, and mill area of the the St. Lawrence Columbian and Metals Corporation mine (Stop 1-4). From Gold (1972b).

Table 9 —Chemical Composition of Pyrochlore from the Oka Complex

(Gold, 1966b)

	1	2	3	4	5	6	7	8	9	10	11
Nb <sub>2</sub> O <sub>5</sub> .....	40.53	46.97	48.04	48.80	54.80	55.80	56.30	57.97	60.00	47.40	65.80
Ta <sub>2</sub> O <sub>5</sub> .....	3.08	2.18	2.77	2.10	0.75	0.50	0.25	0.26	0.50	3.54	0.04
TiO <sub>2</sub> .....	10.42	7.49	8.64	7.20	5.80	6.52	5.20	5.36	4.50	6.38	2.59
Fe <sub>2</sub> O <sub>3</sub> .....	—	1.98	—	1.90	1.66	2.70	1.14	1.08	2.70	1.89	0.56
FeO.....	1.80	—	2.06	—	—	—	—	—	—	—	—
ZrO <sub>2</sub> .....	1.45	0.99	1.99	0.95	0.66	1.00	2.03	2.09	1.00	4.10	0.60
Na <sub>2</sub> O.....	2.88	2.39	1.46	2.30	5.10	4.50	5.10	5.25	3.50	2.05	6.20
K <sub>2</sub> O.....	0.00	—	0.00	—	—	—	—	—	0.60	—	0.00
CaO.....	17.11	18.68	20.32	19.80	17.20	15.08	17.90	15.11	15.08	19.80	15.80
SrO.....	0.65	0.49	0.67	0.47	0.32	1.09	0.76	0.78	0.60	0.26	0.93
BaO.....	tr	—	tr	—	—	—	—	—	—	—	—
MgO.....	0.00	0.15	tr	0.42	—	—	0.68	0.56	1.00	—	0.00
MnO.....	1.17	0.08	0.09	0.08	0.06	0.07	0.05	0.06	0.37	0.28	0.00
Ce <sub>2</sub> O <sub>3</sub> .....	2.20	7.70	8.87	7.06	7.34	3.00	3.78	4.09	3.00	8.66	1.63
La <sub>2</sub> O <sub>3</sub> .....	—	1.45	—	1.39	1.09	0.70	0.68	0.70	0.70	1.22	0.37
Nd <sub>2</sub> O <sub>3</sub> .....	—	1.89	—	1.82	1.06	—	1.83	1.89	—	1.22	0.39
Y <sub>2</sub> O <sub>3</sub> .....	0.20	0.07	0.10	0.07	0.12	0.12	0.08	0.08	0.12	0.21	0.17
U <sub>2</sub> O <sub>8</sub> .....	1.83	0.72	0.59	0.69	0.02	0.45	0.08	0.08	0.10	0.56	0.03
ThO <sub>2</sub> .....	7.23	1.15	1.08	1.10	0.02	0.63	1.47	1.51	0.23	0.03	0.20
Gd <sub>2</sub> O <sub>3</sub> .....	—	—	—	—	—	0.20	—	—	0.20	—	—
SnO <sub>2</sub> .....	0.00	—	0.00	—	0.20	—	—	—	—	—	0.00
TiO <sub>2</sub> .....	—	—	—	0.12	0.03	—	0.03	—	—	—	0.00
F.....	2.17	3.93	2.30	3.80	3.92	3.69	2.13	2.19	3.69	2.15	4.61
H <sub>2</sub> O <sup>+</sup> .....	7.50	—	0.87	0.12	0.18	1.24	0.35	—	1.24	0.36	0.59
P <sub>2</sub> O <sub>5</sub> .....	—	—	—	0.02	0.08	—	0.24	—	—	0.04	0.07
S.....	—	—	—	0.01	0.11	—	0.04	—	—	0.05	0.04
SiO <sub>2</sub> .....	—	—	—	0.83	0.10	0.08	0.42	—	—	0.15	0.17
Al <sub>2</sub> O <sub>3</sub> .....	—	—	—	0.00	0.00	—	0.00	—	—	0.00	0.00
PbO.....	0.10	—	0.06	—	—	—	—	—	0.08	—	—
L on lg.....	—	1.54	—	—	—	—	—	0.91	—	—	—
O—F.....	100.30	98.82	99.90	101.05	100.62	97.37	100.54	99.97	99.21	100.35	100.79
	0.90	1.65	1.00	1.60	1.65	1.55	1.00	0.92	1.55	0.91	1.94
	99.40	97.17	98.90	99.45	98.97	95.82	99.54	99.05	97.66	99.44	98.85
SG.....	—	—	4.33	—	4.38	—	—	—	—	—	—
a°A.....	10.36	—	10.38	10.43	10.393	—	10.428	—	—	10.395	10.4195

1. Thorian pyrochlore, Manny Zone, (Hogarth, 1961: sample No. H7. Ce<sub>2</sub>O<sub>3</sub> = Σ cerium earths, Y<sub>2</sub>O<sub>3</sub> = Σ yttrium earths).
2. Deep red pyrochlore (type 1), from St. Lawrence Columbian and Metals Corporation property. (G. Joncas, University of Sherbrooke, Quebec. Personal communication, 1962).
3. Reddish-brown pyrochlore (type 1), from Bond Zone. (Hogarth, 1961: sample No. H8a. Ce<sub>2</sub>O<sub>3</sub> = Σ cerium earths, Y<sub>2</sub>O<sub>3</sub> = Σ yttrium earths).
4. Deep-red pyrochlore (type 1) in ijolite, from pit A2, St. Lawrence Columbian and Metals Corporation property. (G. Perrault, Ecole Polytechnique, Montreal. Personal communication, 1964).
5. Chocolate-brown, cerian pyrochlore (type 2) from soda pyroxene-calcite rock, pit A1, St. Lawrence Columbian and Metals Corporation property. (Perrault, 1964, and personal communication).
6. Red pyrochlore (type 3), from St. Lawrence Columbian and Metals Corporation property. (Perrault, 1961).
7. Very fine grained brownish-red pyrochlore (type 3) from biotitized ijolite, between pits A1 and A2, St. Lawrence Columbian and Metals Corporation property. (Perrault, 1964, and personal communication).
8. Red pyrochlore, (type 3) from St. Lawrence Columbian and Metals Corporation property. (G. Joncas, University of Sherbrooke, Quebec. Personal communication, 1962).
9. Red pyrochlore (type 3). Average chemical composition of mill concentrate. St. Lawrence Columbian and Metals Corporation. (*Engineering and Mining Jour.*, Oct, 1961).
10. Black zirconium pyrochlore (type 4), from biotite-monticellite calcite rock, footwall of pit A2, St. Lawrence Columbian and Metals Corporation property. (Perrault, 1964, and personal communication).
11. Buff pyrochlore (type 5) from coarse-grained calcite rock, from pit A2, St. Lawrence Columbian and Metals Corporation property. (Perrault, 1964, and personal communication).

Table 10—Pyrochlore Associations

Type	Assays	Association	Phase	Colour	% Nb <sub>2</sub> O <sub>5</sub> Content
Thorian Pyrochlore	1	Biotitized zones, (late hydrothermal activity)	Deuteric	Deep red	40
1	2, 3, 4	Pyrochlore associated with ijolite	Deuteric	Red-brown, deep red	47 — 49
2	5	Soda pyroxene carbonatite	Primary	Chocolate brown to red	55
3	6, 7, 8, 9	Pyroxene or monticellite or tremolite carbonatite	Primary	Brown red to red	56 — 58
4	10	Biotite-monticellite-perovskite magnetite carbonatite	Primary	Dark brown to black	47
5	11	High carbonatite (85%)	Primary	Beige to buff	65

- 1) Carbonate rocks (sövites) of various types and intrusive phases, that are distinguished on economic, temporal, mineralogical, and textural grounds as:

a) Niobium-poor sövites (Early Stage)

	% CaCO <sub>3</sub>	% Nb <sub>2</sub> O <sub>5</sub>
Pyroxene-biotite	70-73	0.05-0.10
Monticellite-magnetite	70-80	0.05-0.08
Coarse-grained calcite	90-100	0.03-0.08

b) Niobium-rich sövites (Middle Stage)

Pyroxene-apatite-pyrochlore	90-94	0.50-0.90
Pyroxene-biotite-magnetite-pyrochlore	74-80	0.30-0.80
Monticellite-magnetite-pyrochlore and/or perovskite	78-80	0.20-0.60
Richterite-biotite-pyrochlore	82-88	0.40-0.60

c) Rare Earth sövites (Late Stage)

Rare earth carbonates, pyrite, galena	85-98	0.02-0.05

A 2 m thick dyke in stope 5060-108, strikes N50°E and dips 50°NW, and contains abundant synchisite and about 37% of acid soluble carbonates.

The dark accessory minerals impart a banded appearance to the rock, and clusters of the minor minerals occur locally.

Pyroxene-magnetite-pyrochlore sövite, monticellite-magnetite sövite, and apatite-biotite-pyroxene-magnetite sövite are the most common carbonate rocks exposed.

- 2) Ijolitic rocks of different ages occur in the mine area. The main mass exhibits a general concordant attitude with the sövites, but in detail there are many discontinuities and much evidence for rupturing. The smaller dykes transgress the sövites, and in places, are boudinaged within it.
- 3) The okaite suite (melilite-bearing) is represented in the mine by some thin dykes, and a thick mass of nepheline okaite on the east face of pit A-1.
- 4) Replacement rocks (glimmerites) due to alteration by hydrothermal solutions occur in discontinuous zones. Biotite and chlorite are the common alteration minerals.

- 5) Alnöite and other lamprophyre dykes were intersected in some drill holes.
- 6) Apatite fission track ages from soda pyroxene-pyrochlore sövite range from 112 (Gold) to 126 Ma (Eby, Table 6).

Mineralization. The salient facts concerning niobium mineralization are summarized below:

1. The economic niobium mineralization in the A ore zone occurs in pyrochlore disseminated in specific types of sövite. Of these, the biotite-pyroxene and monticellite sövites are the most important, though locally the richterite sövite, and the monticellite-perovskite sövite are ore grade. Though the perovskite (latrappite) may contain up to 39% Nb<sub>2</sub>O<sub>5</sub>, it is not an ore mineral.
2. The pyrochlore content varies from layer to layer, and within individual layers.
3. The niobium content of the pyrochlore varies with rock type (see Table 9 and 10).
4. Pyrochlore mineralization associated with zones of hydrothermal alteration is erratic in grade and distribution near the surface, but improves with depth.

STOP 2-1: THE MONCHIQUE SILL AT STE. DOROTHEE

Leader: G. N. Eby

The village of Ste. Dorothée lies along Rte. 148, approximately half way between the Mount 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. 9). Although individual sills intrude successively higher strata (in the Beekmantown Group) eastward, their compositional similarity led Clark (1962) 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).

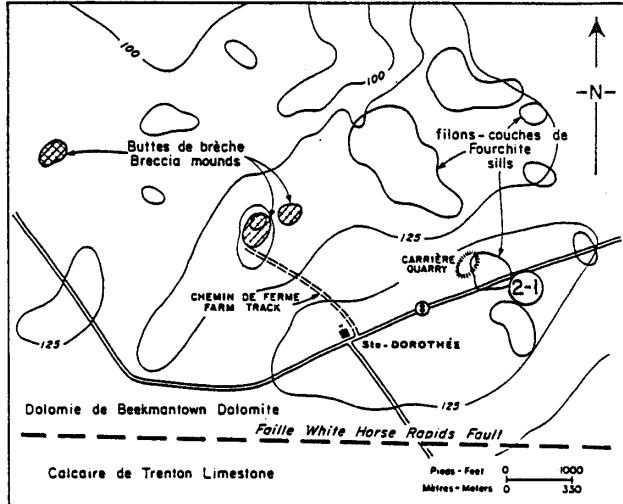


Figure 9: Geological map of the sills (Stop 2-1) and breccia pipes around Ste. Dorothee. From Clark (1952).

These phenomena are well displayed in the road-cuts through two scarplets on Rte. 148, about 0.8 km east of the church, and in the quarry (now covered) about 60 m north of the westernmost scarp.

Philpotts and Hodgson (1968) described in some detail the petrographic features of the sill as seen in the small quarry (Fig. 10). 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, sphene, 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

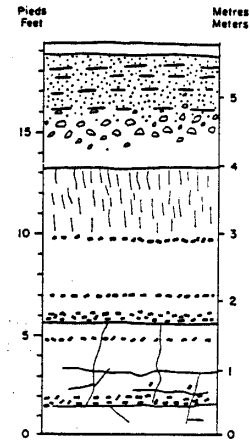


Figure 10: Vertical section through the Ste. Dorothee sill (Stop 2-1). Dots, lenses and irregular lines represent ocelli of analcite syenite; open polygons represent inclusions, and the subhorizontal laths represent phenocrysts. The shaded zone represents a darker, weathered layer. From Philpotts and Hodgson (1968).

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, 1972), 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 which 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, sphene, 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 quite 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 which 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 which produced immiscible liquids. Philpotts (1972) subsequently calculated the density, interfacial tension with respect to the monchiquitic magma, and viscosity of the fluid which 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, 1983) 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 which 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 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 will be

observable. 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 which in places is evidenced by the alignment of the acicular amphiboles.

Sphene separated from the monchiquite yielded a fission track age of  $119 \pm 4$  Ma (Eby, 1985), which is consistent with an approximately 120 Ma paleo-pole position obtained by Foster and Symons (1979).

#### STOP 2-2: NATURE CENTRE--THE "SOUTHERN RING"

##### STRUCTURE

Leaders: D.P. Gold and Marcel Vallée

The Southern Ring is about 1830 by 2440 m and consists of lithostructural units of sövite and ijolite that dip outward with increasingly steeper dips toward the margin (Fig. 11). The overall structure is interpreted as the upper part of a ring-dyke pluton. Ijolites and melteigites are the dominant silicate rocks exposed and they differ from those of the Northern Ring in their coarser grain size, abundance of melanite garnet and the presence of wollastonite in some units. Fenites are exposed in places near the margin, and mobilized metasomatic rocks, urtite and juvite occur as local detached masses within the sövite (Fig. 11; Stop 2-2d). Although the melanite- and wollastonite-bearing ijolites/melteigites of the Southern Ring have chemical counterparts (Table 5) in the okaite rocks of the Northern Ring, their dissimilar mineralogy as well as the coarser textures, and domal structural setting of the sövites suggest a different emplacement and crystallization history. Fission track ages for apatites from the Southern Ring indicate a general cooling age of 121 to 126 Ma (Table 6).

Silicate rocks predominate in the Southern Ring; however, their distribution is not uniform, and broad zones of potentially exploitable pyrochlore-bearing sövite have been delimited by drilling. The sövites are similar to those of the Northern Ring except for a tabular body, about 300 m thick, of very coarse-grained (pegmatitic) richter-

ite sövite (see analysis No. 11, Table 5) exposed behind the Nature Centre (Stop 2-2e). Euhedral calcite crystals up to 5 cm across dominate in a rock that contains accessory magnetite, pyrochlore, and fine acicular richterite. Much of the monticellite in the monticellite sövites is altered to a blue mixture of quartz, dolomite, and amphibole.

Melilite is absent from this part of the Complex, but the melanite and wollastonite-bearing rocks with ijolitic affinities give a uniqueness to the Southern Ring. Melanite garnets locally are well developed, both in the ijolites and adjacent sövites, and may be as much as 2 cm across (Stop 2-2a). They commonly are intergrown with sodian augite; most are zoned and some contain up to 3.7%  $ZrO_2$ . Wollastonite occurs as silky green platy

crystals up to 10 cm long, and differs from "normal" wollastonite in its higher MnO content and lower optic axial angle ( $2V_x = 40^\circ$ ).

Perhaps the most interesting silicate rocks are the metasomatized gneisses (Stop 2-2c) that exhibit different degrees of chemical and textural transformation (fenites and ultra-fenites). Although some of these are transformed compositionally into ijolite, juvite, foyaite and malignite, they commonly retain textures such as relict vein networks or clusters of partially replaced feldspar crystals that serve to identify them as replacement rather than melt rocks. Also, the grain boundaries in the fenites tend to be diffuse, or ghost crystals of uniform background extinction appear through an imposed poikilitic texture. Structural re-orientation of the inherited gneissic fabric is

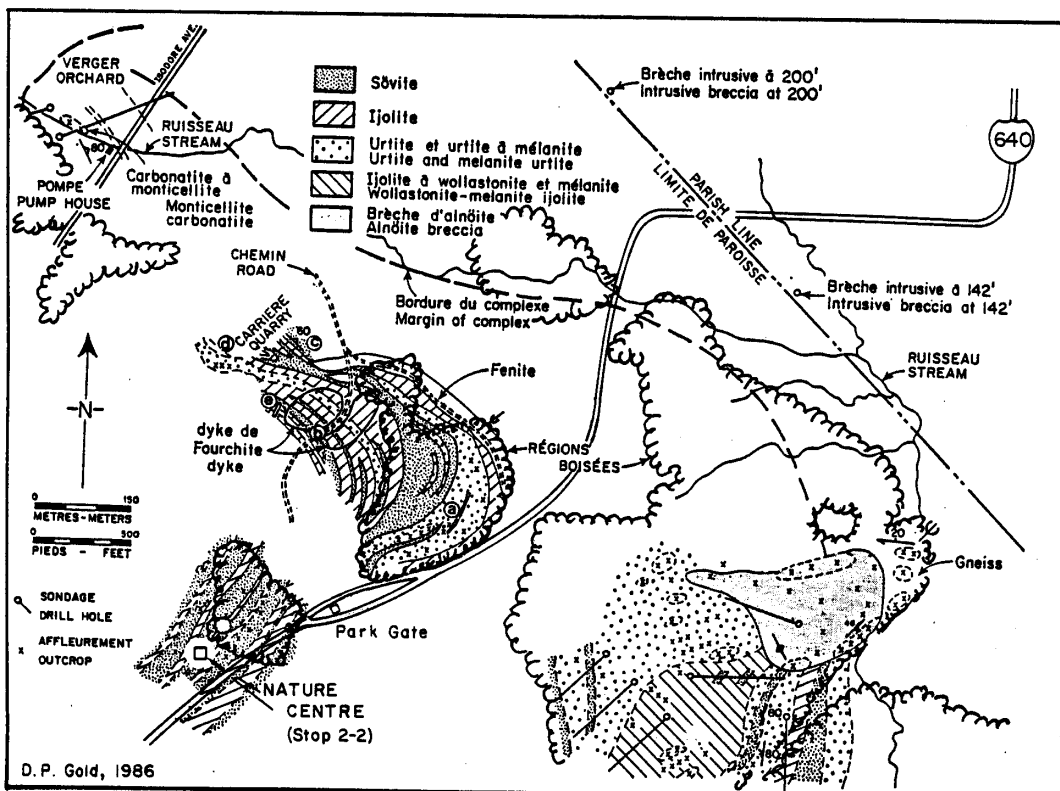
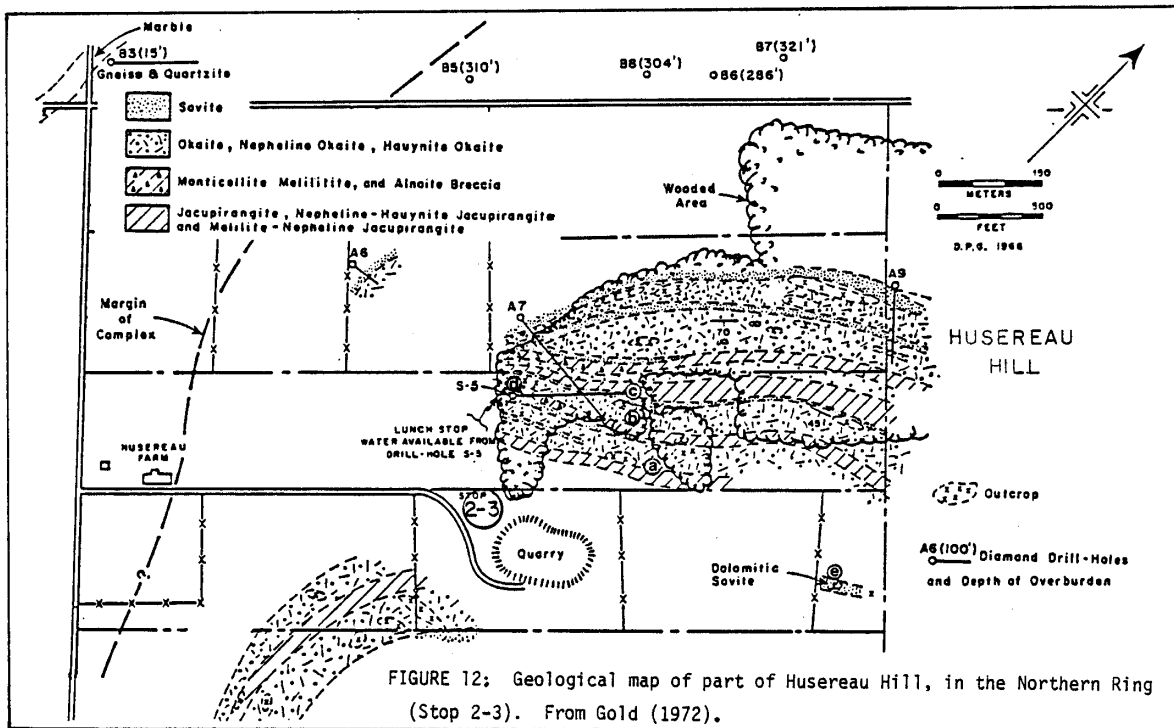


Figure 11: Geological map of portion of the Southern Ring structure near the Nature Centre (Stop 2-2). From Gold (1972).

apparent close to the Complex, where it parallels the margin of the Complex. The fenitization process is essentially one of desilicification and soda metasomatism with the development of aegirine and nepheline-rich rocks. Although the chemical balance locally is complicated (especially in the vein replacements) by late introduction of biotite and calcite and the hydrothermal alterations of some pyroxenes to uraltite (and chlorite) and magnetite, generally the depletion of  $\text{SiO}_2$  is matched mainly by an increase in  $\text{Na}_2\text{O}$ ,  $\text{CaO}$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{CO}_2$  and  $\text{H}_2\text{O}$ . In a road-cut near the top of the small hill about 200 m northeast of the Nature Centre (Stop 2-2b), a subhorizontal sill(?) of fourchite (Table 5, #31, sample A-478) is exposed cutting steeply-dipping ijolite and melanite ijolite units. This gently undulating "sill" is approximately 25 cm thick, exhibits well developed chilled margins, and locally is amygdaloidal; this habit suggests a nearer surface emplacement than the other rocks in the Oka Complex. It may represent a much later event.

STOP 2-3: HUSEREAU HILL--ARCuate OKAITE-  
JACUPIRANGITE DIKES OF THE "NORTHERN RING"  
STRUCTURE  
 Leader: D.P. Gold

General Geology. Husereau Hill is a crescentic-shaped hill, 1.2 km long by 400 m wide, in the northern part of the Oka Complex, and was described as a "circular mass of camptonite with a border facies of nepheline aplite" by Howard (1922), and "an intrusive plug of melilite-rich rocks" by Stansfield (1923). The ultrabasic rocks, composed of melilite, hauynite, biotite, with accessory magnetite, apatite, perovskite, calcite, and pyrite, Stansfield named okaite, or nepheline okaite for the nepheline-bearing varieties. From drill-hole data and detailed mapping (Gold, 1963), the hill is shown to be underlain by rocks of the okaite-jacupirangite suite, and locally by lamprophyric breccia dykes rich in monticellite and melilite (Fig. 12). The



former rocks are interpreted as a swarm of arcuate dykes, which vary from melilite-magnetite rocks, through melilite (okaite), melilite-nepheline, melilite-nepheline-hauynite, melilite-nepheline-titanaugite, titanaugite-nepheline, to titanaugite-magnetite rocks (jacupirangite). They represent some of the most ultrabasic silicate rocks yet analysed (see Table 5, analyses 16 to 22), and while they are akin to ouachites, turjaites, uncomphgrites, and vibetoides, they are sufficiently different to retain separate and simplified mineralogical names. Between Husereau Hill and the centre of the Northern Ring, there are 7 separate arcuate dykes of okaite.

Fine- and coarse-grained varieties of these rocks are exposed: all exhibit automorphic to hypautomorphic granular textures and contain accessory apatite, perovskite, calcite, magnetite, and biotite. These rocks are blue-grey to dark grey in colour, and exhibit a glassy appearance in a fresh surface which tarnishes to a waxy lustre. Melilite occurs in euhedral blades and usually contains a number of fine inclusions, mostly of calcite, less commonly of apatite and biotite. Perovskite is disseminated in fine irregular grains, and in places encloses magnetite grains. Rounded grains of magnetite and green hercynite form aggregates and clusters within the interstitial calcite and biotite. Hauynite is rare and occurs as rounded grains that are finely cross-hatched with iron sulphides. Augites in the jacupirangite are unusual in their low silica and high alumina content, their anomalous extinction colours in dark brown and blue, and in their well-developed hour-glass extinction.

Biotite-rich zones are common adjacent to carbonate filled fractures and veins and represent reaction zones with the carbonate melt. Late hydrothermal activity has altered the okaite locally to a mottled cream coloured rock. Nepheline alters most readily, and in the advanced stages of alteration appears as a very fine-grained, radiating, fibrous and sheath-like aggregate of zeolite minerals, which include natrolite, thompsonite, cancrinite, and carbonate. Incipient alteration of melilite to fibrous vesuvianite occurs around carbonate inclusions and along cleavages. The advanced alteration products are a very

fine-grained brownish aggregate, fibrous in places, of cebollite, vesuvianite, and dolomite. Wairakite, the Ca analogue of analcite, has been identified in some of the cream-coloured zeolite aggregates.

The melilite in the okaites conforms closest to a soda-akermanite ( $\text{NaM}_{35}\text{Ge}_{11}\text{Ak}_{54}$ ). It is unzoned, has a pinkish tint, a length slow orientation and a uniaxial negative sign. This melilite and melilites from other rock types in the Oka Complex are of interest because of their uniformity in composition (Gold, 1966) and their similarity to those from other carbonatite complexes (Yoder, 1964). Apparently this is the stable melilite for "carbonatite" environments and its composition is probably conditioned by the partial pressure of carbon dioxide and the partitioning of soda with a nepheline phase. The stability of gehlenite to pressures as high as 35 kb in the synthetic system  $\text{CaO-Al}_2\text{O}_3\text{-SiO}_2\text{-H}_2\text{O}$  (Boettcher, 1970), suggests that these natural melilites may exist in the mantle.

Specific Localities. An apatite fission track age of  $118 \pm 6$  Ma (Gold, unpub.) was obtained from a very coarse-grained "pegmatitic" apatite okaite at Stop 2-3c. This is a good outcrop for collecting large crystals (1 cm and greater) of magnetite, melilite, and apatite. The magnetite commonly exhibits trapezohedral faces; melilite occurs as tabular crystals with perfect basal pinacoids; apatite is in a radiating acicular habit, and perovskite occurs locally as small black cubes. A nepheline okaite dyke, farther down the hill to the north, yielded an apatite fission track age of 118 Ma (Eby, Table 6).

The alnöite dykes at Stop 2-3d differ from others in the Oka area in their paucity of large inclusions, and presence of lapilli in a matrix rich in melilite and monticellite.

Most of the fragments are rounded; many occur as lapilli of a very fine-grained mosaic of phlogopite, magnetite, calcite, and melilite, surrounding partially resorbed phenocrysts of augite, olivine, monticellite, biotite, and in places, hornblende. Titanaugite phenocrysts commonly are rimmed by melilite; olivine by either monticellite, or calcite and melilite; biotite by a light brown phlogopite and melilite. These globular fragments are set in a fine-grained trachytic-

textured matrix consisting mainly of melilite and lesser amounts of monticellite, phlogopite, calcite, apatite and perovskite. The melilite differs from those in the surrounding okaite rocks in its fine grain size, zoning, and anomalous blue interference colours. The lapilli are interpreted as an early generation alnöite, preserved in a late monticellite-melilitite matrix.

The rare dolomitic sövite from the southeast flank of Husereau Hill has been shown by Treiman and Essene (1984) to contain the eutectic mineral assemblage calcite-dolomite-periclase-apatite-forsterite-magnesioferrite-pyrrhotite-alabandite that was in equilibrium with water-rich H<sub>2</sub>O-CO<sub>2</sub> fluid, and an oxygen fugacity near the QFM buffer ( $\log f_{O_2} = -18.6$ ). For the chemical composition, mode, and norm, see Table 5, # 15.

The largest niobium ore zone of potential economic interest in the Oka Complex occurs in the well-layered sovites and ijolitic rocks that underlie the ridge along the west-central side of the Complex. This zone is known as the Bond Zone (Fig. 13), and has been explored by drill holes to a depth of 550 m. The combined ore reserves to 154 m (500 feet) from two adjacent properties, Quebec Columbian Limited to the north and Columbian Mining Products to the south, are estimated to be 60 million tons of 0.5% Nb<sub>2</sub>O<sub>5</sub>. Besides the economic potential this zone is of interest as the type locality for niocalite and latrappite, for the well-exposed ijolite boudins in foliated sövites, and for fresh outcrops of magmatic phase alnöite. Boulder-clay and beach-terrace deposits containing recent fossil shells (*Hiatella* and *Macoma*) can be seen overlying glaciated surfaces in some of the trenches.

Although different lithologies are portrayed as continuous bands on the map (Fig. 13), only the

**STOP 2-4: EXPLORATION TRENCHES IN THE BOND ZONE**

Leaders: D.P. Gold and Marcel Vallée

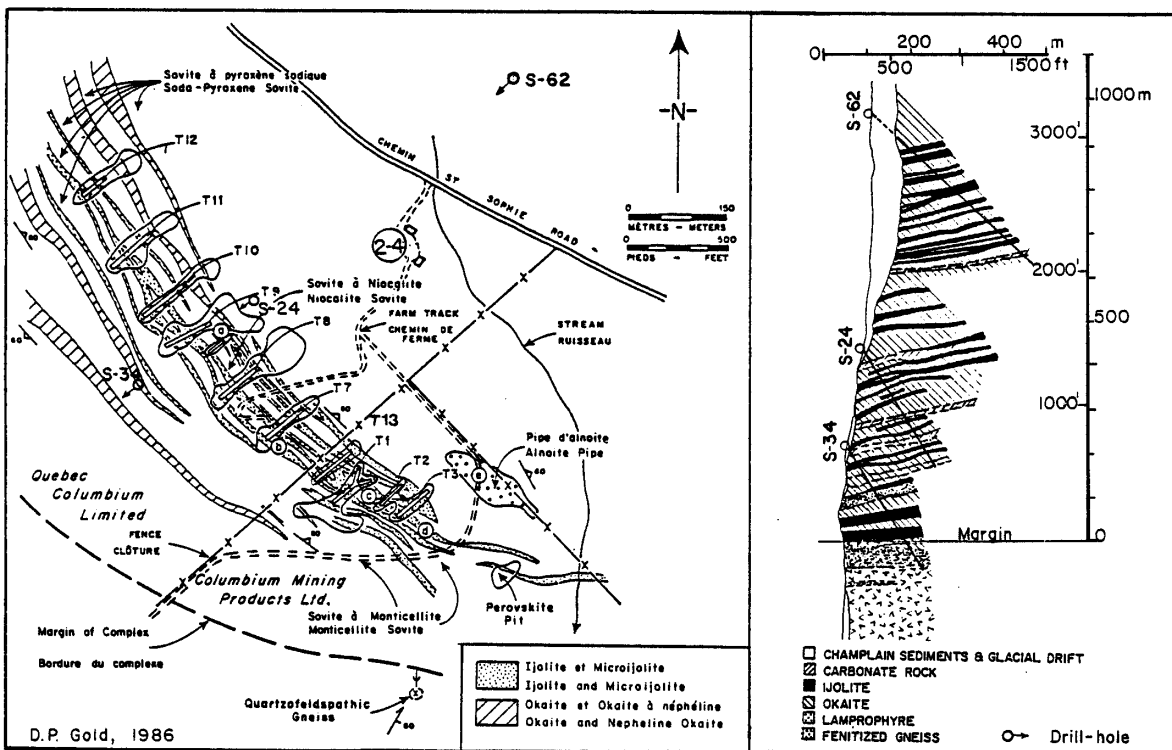


Figure 13: Geological map and cross-section of the Bond Zone (Stop 2-4). From Gold (1972).

okaites have a continuous dyke-like habit. The ijolitic rocks occur in discontinuous layers, as rafted blocks and boudins and define a zone that is generally parallel to the foliation in the enclosing sövites. Flow-layering in the sövites is well-developed around these ijolitic bodies and also into carbonate-filled tension cracks. Biotite-rich rims surround the ijolite boudins, and are developed to a lesser degree adjacent to the carbonate veins within the boudins. Different degrees of biotite replacement can be seen: the end product, glimmerite, is a decussate-textured rock consisting of biotite, calcite, and zeolite. In places, relict "islands" of ijolite are preserved in glimmerite to produce replacement breccias.

A foliation, similar to the compositional layering in gneisses, is defined by the concentration of silicate and oxide minerals into layers 1-2 cm thick and separated from predominantly carbonate layers 2-10 cm thick. The silicate mineral assemblages vary with location, and give rise to the soda-pyroxene sövite, monticellite sövite, and niocalite-melilite sövite. The latter rock is rare and is exposed only in a layer about 18 m thick in trenches 4, 7, 8, and 9: trench 4 (Stop 2-4a in Fig. 13) is the type locality of niocalite, a niobium silicate  $(Ca,Nb)_{16}Si_6(O,OH,F)_{36}$  of the woehlerite group (Nickel, 1956; Nickel et al., 1968). Other minor and accessory minerals in the sövites are: forsterite, monticellite, melilite, apatite, pyrochlore, perovskite (latrappite), magnetite, biotite, and sodian augite. The perovskite pit (Fig. 13) on the Columbian Mining Products property is the type locality of latrappite (niobium perovskite) where it occurs in the monticellite sövite.

Sulphide-bearing veins with a general northeasterly strike (along the trenches) are exposed in and parallel to the trenches. They rarely exceed 6 mm thickness and consist primarily of pyrite, pyrrhotite, and chalcopyrite. Apatite fission track ages for the niocalite sövite range from 109 (D.P.G) to 125 Ma (G.N.E.; Table 6). The monticellite-perovskite sövite yielded an age of 130 Ma (G.N.E.; Table 6). More data are needed to resolve these differences.

Adjacent to the road below the trenches (location 2-4e) are a number of outcrops of massive

alnöite. Exploration drill holes have delimited an oblong plug 30 m across and 160 m long. It is a dense, blue-grey, porphyritic rock with phenocrysts of olivine, titanite, phlogopitic biotite and rare hornblende in an aphanitic and glassy matrix containing disseminated magnetite grains in a diffuse background of melilite, calcite, melanite, and apatite. A chemical analysis is given in Table 5, # 34 (sample A-368).

#### STOP 2-5: LALANDE QUARRY

Leader: D.P. Gold

The St. André Hills are located about 12 km up the Ottawa Valley from the Oka Complex, between Lalande Siding in the east and the village of St. André-Est, 8 km to the west (Fig. 15). This cluster of hills represents a similar setting to Oka, as an inlier of Precambrian rocks in the St. Lawrence Lowlands, with a central depression underlain by a carbonatite. The Lalande Quarry is located on the northeastern flank of the St. André Hills, 25 m south of the Canadian National Railway line and 1 km west of Lalande siding. This quarry (Fig. 14) has been abandoned for at least 30 years.

The Lalande Quarry was developed in a foliated quartz monzonite of late Precambrian age (Doig, 1968), probably only a meter or two beneath the Potsdam Sandstone unconformity. This location is of interest for the diabase, lamprophyre, and carbonate dykes, sills(?), and veins (Fig. 14), exposed in the stripped area around the quarry and in the quarry wall. These are probably related to the St. André Carbonatite only 2 km to the west.

The quartz monzonite is a medium- to coarse-grained pink, leucocratic gneiss, consisting mainly of euhedral plagioclase ( $An_{10}$ ) with lesser amounts of subhedral to anhedral microcline and interstitial quartz in a granular texture. A compositional layering is defined by the crude segregation of biotite and/or hornblende. Accessory minerals include euhedral apatite and magnetite. Muscovite and chlorite appear to be deuteric alteration products. Apart from local kaolinization and sericitization of the feldspars, these rocks are remarkably fresh. Fine- and coarse-grained diabbases intrude the monzonite as steeply dipping dykes up to

a couple of meters thick.

Thin, khaki-coloured lamprophyre dikes, of varying but mainly shallow dip, are exposed in many of the outcrops. There has been very little reaction with the country rock, and thin slivers of monzonite are preserved within the chill margins of these dykes. Late veins, 0.1 to 0.5 mm thick, of carbonate and cryptocrystalline quartz are ubiquitous. A typical dyke (Site 4) is composed of phenocrysts (up to 2 mm long) of phlogopite, kaersutite, olivine, and magnetite in an aphanitic matrix of carbonate, serpentine, magnetite and

altered melilite(?). Another dyke at Site 13 consists of phlogopite, olivine, and augite phenocrysts up to 1 cm across, in a fine-grained matrix of chlorite, serpentine and carbonate. Opaque minerals occur in sieve-like grains up to 2 mm across, and as finely disseminated "dust" in the matrix.

Composite dykes, with centimeter-scale layers, and a well-developed flow fabric were found at Sites 1 and 31. Thin, flow-texture lamprophyres, consisting of titanite, altered olivine, magnetite and phlogopite phenocrysts in an aphanitic

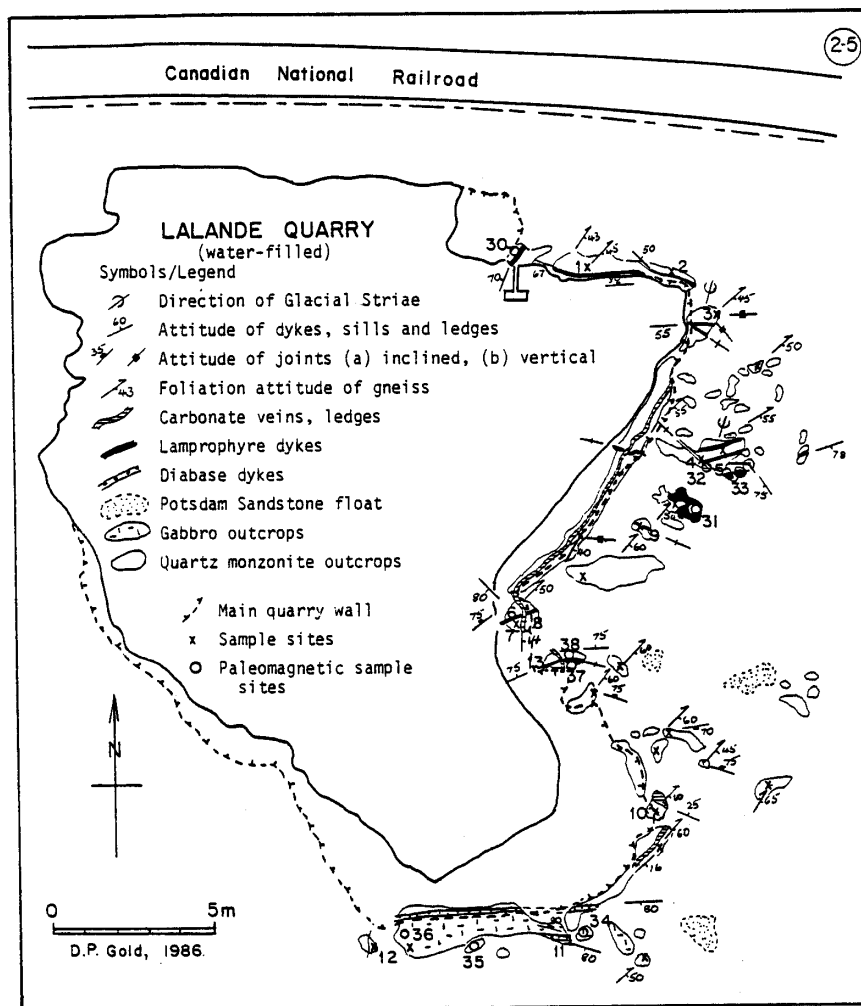


Figure 14: Map of Lalande Quarry (Stop 2-5), showing the distribution of diabase (D), lamprophyre (L), and carbonate (C) dykes and tufa(?) deposits.

matrix of carbonate, titanite and phlogopite, are juxtaposed with a coarser grained aragonite(?) - rich rock that contains subordinate amounts of olivine, augite and hornblende. The aragonite(?) occurs as elongate grains, generally about 0.5 mm long, but locally as parallel blades oriented perpendicularly to the lamprophyre.

A late, white, vuggy carbonate occurs as either a vein(?) or sill(?), up to 120 cm thick, in the east quarry wall. It consists of mosaic or fine (0.01 to 0.05 mm) calcite grains, with coarser grained patches (0.1 to 0.3 mm) marginal to the vugs. Some vugs are filled with cryptocrystalline quartz. In places there is a relict spinifex texture of bladed grains up to 1 mm long. A crude wavy layering, subparallel to the contact, is preserved locally, along with "cabbage-head"

structures 1 to 2 cm across. Some of these textures are similar to those found in hot spring deposits.

Very little is known about the quartz monzonite country rock, except that it is considered to be part of the Rigaud Syenite Complex of Late Precambrian age. Phlogopite from the lamprophyre dyke at Site 13, and hornblende phenocrysts from another dyke, yielded K/Ar ages respectively of  $123 \pm 4$  Ma, and  $128 \pm 6$  Ma (J.O. Wheeler, Geol. Surv. Canada, pers. comm., 1973). These emplacement(?) ages are a little older than the approximately  $120 \pm 4$  Ma paleopole position for ten lamprophyre sample sites (Foster and Symons, 1979). It is concluded that these carbonate-rich lamprophyre dykes are products of the Montereian igneous event.

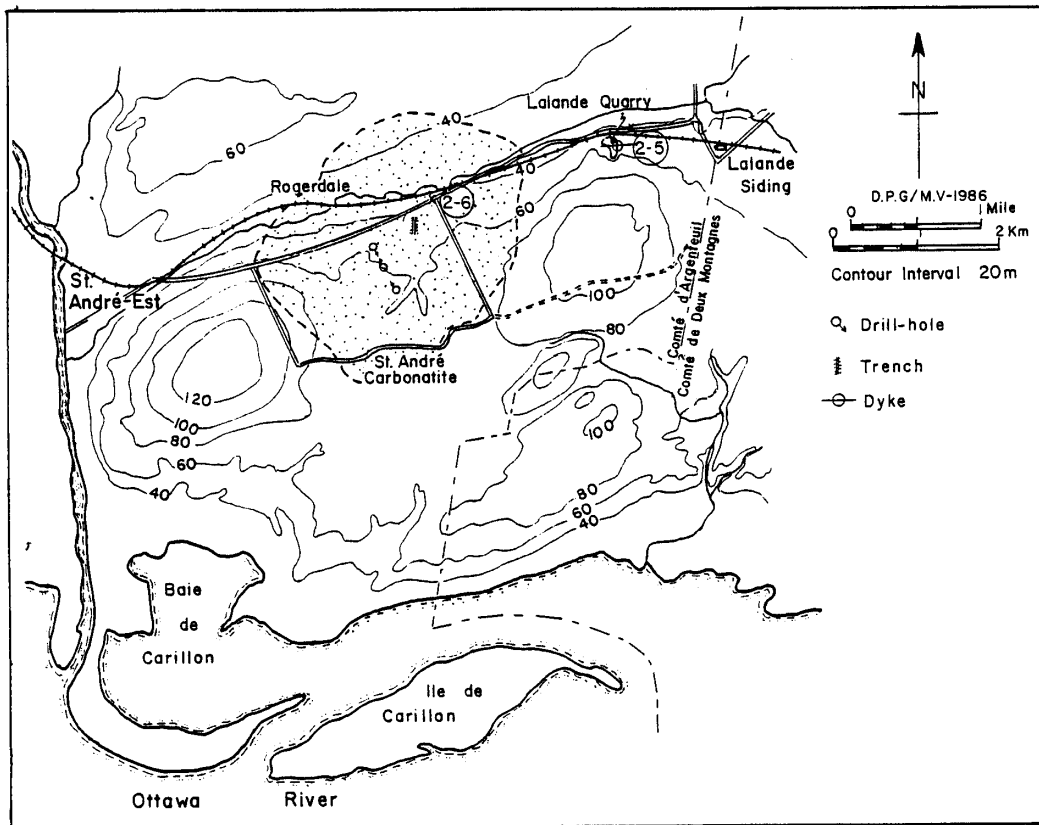


Figure 15: Topographic map of the St. André Hills, showing the locations of the St. André Carbonatite Complex, and the Lalande Quarry.



**STOP 2-6: THE ST. ANDRE CARBONATITE COMPLEX**

Leader: Marcel Vallée and James McCann

**Introduction.** The St. André carbonatite is located in the St. André Parish, Argenteuil County, approximately 60 km west of Montreal. Its setting as a poorly exposed, roughly elliptical intrusion (Fig. 15) in an inlier of Precambrian rocks in the St. Lawrence Lowlands is similar to that for the Oka Complex, 18 km to the east. It is located within the Ottawa-Bonnechère graben, about 15 km south of the border fault between the Paleozoic sediments and

Grenville gneisses of the Canadian Shield. Monzonite, monzonite gneiss, and syenite, presumably of the Rigaud Syenite Complex, surround the carbonatite body, much of which is overlain by a thick cover of Pleistocene glacial tills and Recent marine clays.

An airborne radiometric anomaly led to the discovery of the St. André Complex late in 1967. Fortunately, a ridge in the center of the Complex rises to within a meter of the surface, and fairly fresh "carbonatite" rock fragments are present in the field and along the fence-rows. The only natural outcrop is located in the creek near the road to St. André-Est.

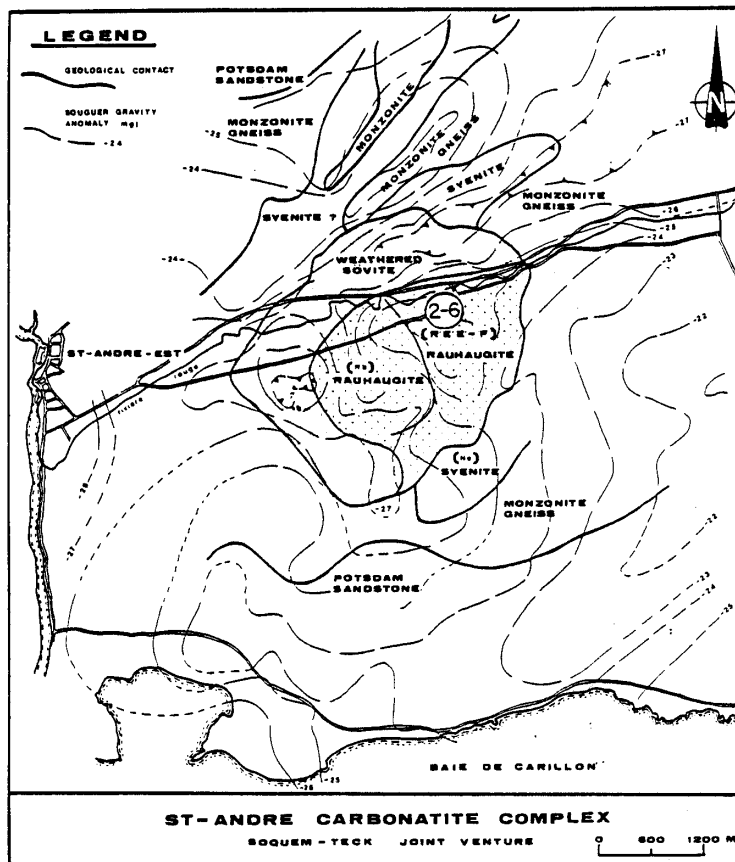


Figure 16: Geological map showing the distribution of rock types, and the Bouguer gravity anomalies over part of the St. André Hills.

**Lithology and Structure.** The shape and size of the carbonatite body (Fig. 16) have been inferred, from drill hole and magnetometer data, as approximately 3 km by 2.5 km. The main rock types intersected in the drill cores are rauhaugite (dolomitic carbonatite) and lesser amounts of sövite. The carbonates generally are brecciated, but both massive and foliated varieties are present. The sövites appear to be more weathered than the rauhaugites. From the limited and unevenly distributed drill-hole sampling it would appear that a rauhaugite core with some pyrochlore-rich zones is partially encircled by highly-weathered sövites to the north and west, and a rare earth-bearing fluor-rauhaugite to the south and east. Syenite dykes, exhibiting local potash metasomatism, apparently intrude the core. A N70°E trend to the layering and foliation is inferred for the drill hole locality from radiometric and topographic alignments. Core angles indicate a near vertical

dip. The overall structure of the massive rauhaugites in the eastern sector is unknown. Little remains of the outer sövites except a sandy residuum, impregnated with variable amounts of limonite and goethite. Weathering is apparent to at least 15 m in the rauhaugites, and much deeper near fracture zones. Alteration of the silicate minerals to chlorite is widespread.

**Geophysics.** Ground-based geophysical surveys were conducted after the initial discovery of the Complex. A radiometric anomaly was detected over the core, and some east-west trends were defined. No magnetic anomaly nor trends are apparent over the Complex, but some syenite bodies near the margin were delineated. A positive gravimetric anomaly was found over the central part of the Complex, as well as over the syenite bodies (see Fig. 16).

**Mineralization.** During the initial investigation, pyrochlore was identified in float

TABLE 11 - Average Chemical Composition of Pyrochlore from the St. André Carbonatite

Lot Number # of grains/ analyses	2 52/54	4 59/62	6 35/35	8 30/35	17 33/35	19 62/69	20 29/30
Na <sub>2</sub> O	4.03	6.56	7.60	5.56	7.06	6.07	6.55
CaO	11.04	13.99	14.64	12.83	13.76	13.86	13.17
FeO	0.10	0.35	0.01	0.25	0.03	0.25	0.03
SrO*	4.20	1.75	0.39	1.76	0.91	1.81	1.76
BaO*	1.95	0.84	0.06	0.87	0.34	0.73	0.66
Ce <sub>2</sub> O <sub>3</sub>	0.85	-	0.04	-	0.03	-	-
UO <sub>2</sub> /ThO <sub>2</sub>	0.47/tr	0.92/-	0.43/0.07	0.02/0.62	0.43/tr	0.37/tr	0.28/tr
TiO <sub>2</sub>	1.86	2.21	2.29	1.88	1.81	2.17	2.04
Nb <sub>2</sub> O <sub>5</sub>	69.91	69.69	70.26	68.20	69.09	70.03	68.63
Ta <sub>2</sub> O <sub>5</sub>	<u>0.73</u>	<u>0.86</u>	<u>0.37</u>	<u>0.79</u>	<u>0.64</u>	<u>0.08</u>	<u>0.60</u>
Total	95.14	97.17	96.16	92.78	94.10	95.37	93.72
Proportions of grains by type of pyrochlore:							
A - conventional	22%	73%	91%	84%	88%	74%	87%
B - strontian	39%	18%	9%	0%	3%	9%	3%
C - strontio	19%	10%	0%	16%	0%	17%	10%
D - cerian	20%	0%	0%	0%	0%	0%	0%

Analyses by J. McCann, 1981, using an Energy Dispersive System on an Electron Microprobe Analyser.

\* Analytical precision approximately 10%.

Trace amounts = tr; Not detected = (-).

TABLE 12 - Average Chemical Composition of Rutile from the St. André Carbonatite

Lot Number	2	4	6	8	17	19	20
# of analyses	11	6	4	4	6	8	4
Na <sub>2</sub> O							
CaO							
FeO	3.74	3.67	3.37	2.70	4.04	3.18	3.81
SrO							
BaO							
UO <sub>2</sub> /ThO <sub>2</sub>							
TiO <sub>2</sub>	77.41	76.94	77.26	77.58	77.53	78.71	75.14
Nb <sub>2</sub> O <sub>5</sub>	10.16	10.48	10.09	7.76	8.78	8.09	7.82
Ta <sub>2</sub> O <sub>5</sub>	—	—	—	—	—	—	—
Total	91.31	91.09	90.72	88.05	90.35	89.98	86.77

Analyses by J. McCann, 1981, using an Energy Dispersive System on an Electron Microprobe Analyser.

fragments. Exploration holes drilled between 1968 and 1978 located several zones, 3 to 20 m thick, that assayed from 0.3% to 0.7% Nb<sub>2</sub>O<sub>5</sub>. These values were not competitive at the time with either the St. Lawrence Columbian and Metals Corporation mine at Oka, nor the newly developed Niobec mine at St. Honoré (Vallée and Dubuc, 1970; Gagnon, 1979).

The pyrochlore (Table 11) at St. André averages more than 68.0% Nb<sub>2</sub>O<sub>5</sub> (McCann, 1981). Four varieties have been recognized: a conventional pyrochlore (type A), a strontian pyrochlore (type B), a strontio-pyrochlore (type C), and a cerian pyrochlore (type D). Some of the type C pyrochlore shows a complete coupled substitution of Sr + Ba for Ca + Na, as well as anomalous concentrations of Fe, U, Ta, and Th (McCann, 1981). Other accessory minerals include barite, zircon, and a niobium rutile containing from 3 to 27% Nb<sub>2</sub>O<sub>5</sub>. Analyses of batches of niobium rutile (Table 12) indicate an average Nb<sub>2</sub>O<sub>5</sub> content of approximately 9%. Potash feldspar, probably metasomatic, locally constitutes up to 25% of the rauhaugite. High background values of strontium (0.65% SrO), manganese (1.3% MnO), and iron (5.4% FeO) occur in the dolomitic groundmass.

Five drill holes in the east-central and southern parts of the Complex intersected rare earth and fluorine-rich rauhaugites. Assay values of La<sub>2</sub>O<sub>3</sub>, locally as high as 1.06%, averaged 0.58% over 48.2 m. In this same zone, fluorine content ranged from 0.3 to 2.0%, niobium from 0.05 to 0.30% Nb<sub>2</sub>O<sub>5</sub>, and zinc from 0.05 to 0.17%. Barite occurs locally in association with late dolomitic veins. The host rauhaugite consists mainly of a breccia of angular to rounded fragments of dolomite, 0.5 mm to 1.5 cm across, in a finer grained carbonate matrix in an aphanitic grey to brown cement. Accessory sphalerite, feldspar, zircon(?), apatite, quartz(?), opaque minerals, and euhedral fluorite grains 2 to 5 mm across occur in the matrix. The rare earth values are associated with the aphanitic (amorphous?) cement.

Exploration Perspectives. More exploration is warranted not only for the unusually high tenor pyrochlore, but also for its potential in fluorine and rare earth elements. A detailed study of the St. André Hills should be initiated to establish the age and geochemical relationships of these unusual rocks while the drill cores still are available.

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#### NOTES