

AGPAITIC AND MIASKITIC NEPHELINE SYENITES OF THE MCGERRIGLE PLUTONIC COMPLEX, GASPÉ, QUEBEC: AN UNUSUAL PETROLOGICAL ASSOCIATION*

GRAEME M. WALLACE

Department of Geological Sciences, McGill University, 3450 University Street, Montreal, Quebec H3A 2A7

JOSEPH B. WHALEN

Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

ROBERT F. MARTIN

*Department of Geological Sciences and Mineral Exploration Research Institute, McGill University,
3450 University Street, Montreal, Quebec H3A 2A7*

ABSTRACT

The dominantly granitic Early Devonian McGerrigle plutonic complex, in the Gaspé region of Quebec, contains minor volumes of 1) miaskitic and 2) sodalite - aenigmatite - astrophyllite - arfvedsonite-bearing agpaitic nepheline syenites. Significant mineralogical variations in these rocks principally reflect the agpaitic index and $f(\text{O}_2)$ of the magma. These geochemically highly evolved undersaturated rocks probably represent the products of fractionation of mildly alkaline mafic magma(s). Isotopic data imply that batches of juvenile syenitic magma were variably contaminated by minor volumes of crustal material. Fractionation of mafic magmas in a crustal reservoir could have supplied heat to partially melt the protolith of the granitic rocks. This proposal accounts for the contemporaneous supply of silica-undersaturated and silica-oversaturated rock-types in the McGerrigle plutonic complex. Our proposal is consistent with a very stable magma chamber, as would be expected in a tensional environment, possibly associated with rifting or strike-slip faulting.

Keywords: nepheline syenite, miaskitic, agpaitic, granite, crustal contamination, McGerrigle complex, Gaspé, Quebec.

SOMMAIRE

Le complexe plutonique de McGerrigle, situé en Gaspésie (Québec), d'âge dévonien précoce et à caractère surtout granitique, contient de petites quantités de syénites néphéliniques miaskitiques et agpaïtiques (association de sodalite + aenigmatite + astrophyllite + arfvedsonite). Les variations minéralogiques importantes dans ces roches reflètent surtout l'indice d'agpaïté et la fugacité d'oxygène du magma. Ces roches sous-saturées fortement évoluées résulteraient du fractionnement de magma(s) mafique(s) légèrement alcalin(s). Les données isotopiques témoignent aussi d'une contamination locale du magma syénitique juvénile par la croûte. Le fractionnement de magma(s) mafique(s)

dans un réservoir crustal pourrait avoir fourni le flux de chaleur requis pour une fusion partielle du protolithe des roches granitiques. Cette hypothèse explique la mise en place de magmas contemporains sous-saturé et sursaturé en silice dans le massif de McGerrigle. Ce schéma requiert une chambre magmatique très stable, donc un milieu en extension le long d'un rift ou d'une faille transformante.

Mots-clés: syénite néphélinique, miaskitique, agpaïtique, granite, contamination crustale, complexe de McGerrigle, Gaspésie, Québec.

INTRODUCTION

The nepheline syenites of the generally granitic McGerrigle plutonic complex, Gaspé Peninsula, Québec (Fig. 1; Whalen 1987) constitute the only known example of silica-undersaturated felsic magmatism of Devonian age in the Canadian Appalachians (Currie 1976, Woolley 1987). The association in the McGerrigle complex of small volumes of both agpaitic and miaskitic nepheline syenite with large volumes of granite and lesser volumes of gabbro (Whalen 1987) is petrologically highly unusual. In this paper, we present new mineralogical and geochemical data bearing on the nature and petrogenesis of these rocks. Where used without a qualifier, "nepheline syenite" will refer to both agpaitic and miaskitic varieties of nepheline syenite.

GENERAL GEOLOGY AND PETROGRAPHY

The McGerrigle plutonic complex, which intrudes the Cambro-Ordovician Shickshock and Quebec groups (de Römer 1977), has been subdivided into two suites, a predominantly northern *hybrid suite* (Fig. 1), with which the undersaturated rocks are associated, and a *granitic suite* in the southern part (Whalen 1985, 1987). The hybrid suite exhibits a het-

*Geological Survey of Canada Contribution Number 34789. Mineral Exploration Research Institute contribution number A9031.

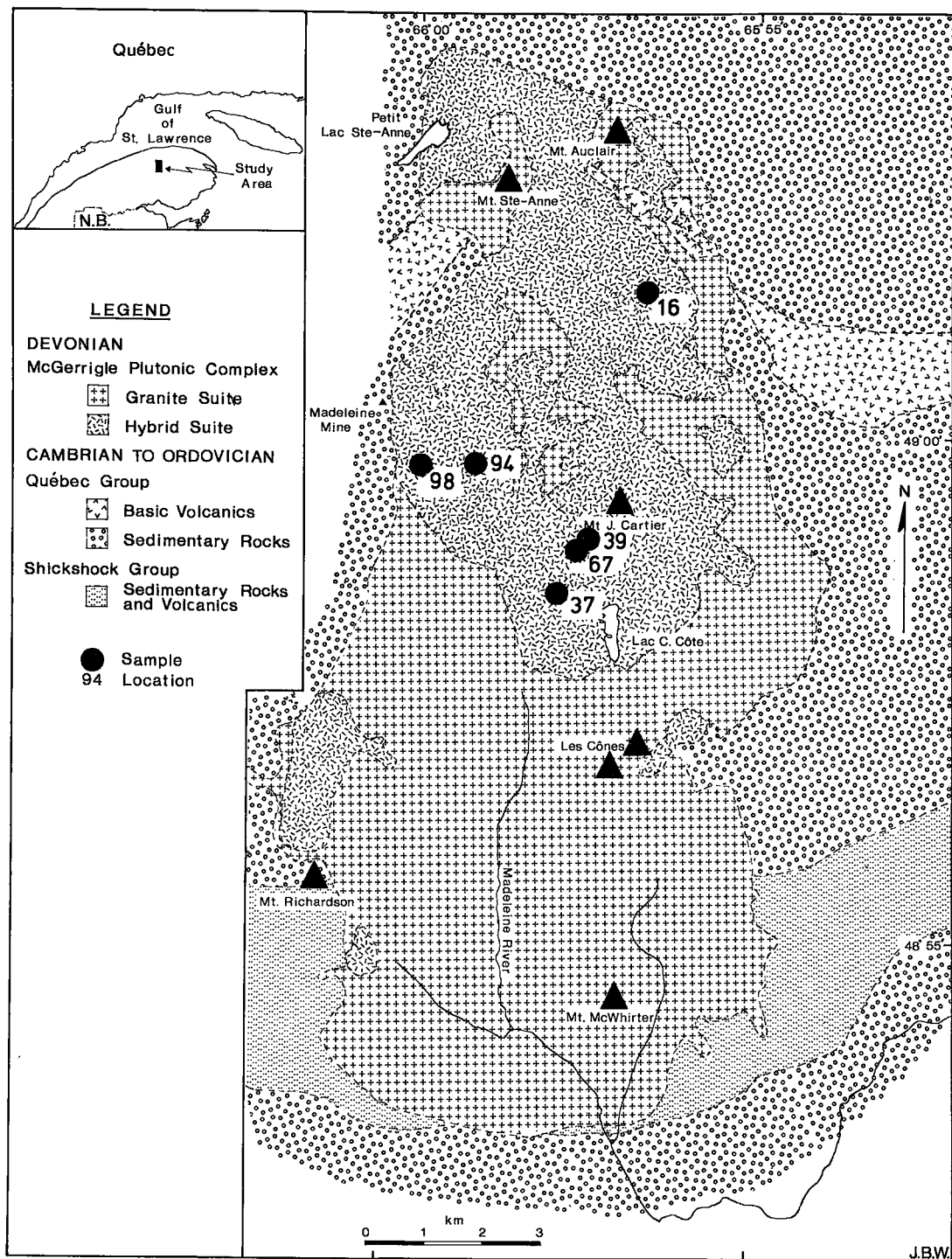


FIG. 1. Location of the McGerrigle Plutonic Complex, Gaspé Peninsula, and a generalized geological map of the area giving locations of the nepheline syenite samples studied in detail (closed circles). Sample 16 (WXMG16) consists of miaskitic nepheline syenite, whereas the others consist of agpaïtic nepheline syenite, exposed as dykes or sills. The triangles correspond to the main peaks in the McGerrigle Mountains.

erogeneous appearance on both the outcrop and regional scale; xenoliths of gabbro, diorite, nepheline syenite, metavolcanic rocks and hornfels are found in quartz-bearing monzodiorite, monzonite and syenite (Whalen & Gariépy 1986). Felsic inclusions are rare. Remarkable features suggestive of complex interaction and hybridization of the mafic and felsic magmas led Whalen (1985) and Whalen & Gariépy (1986) to propose a magma-mixing model for the origin of the hybrid suite. On the other hand, the granitic suite does exhibit textural variations, but in general it corresponds mineralogically and compositionally to a homogeneous subsolvus biotite-amphibole granite *sensu stricto*. Mafic inclusions are rare.

Radiometric data indicate that the complex is Devonian in age (de Römer 1974, La Rocque 1986, Whalen & Roddick 1987). A K-Ar age of 377 ± 9 Ma, determined on biotite from a sample of miaskitic nepheline syenite (WXMG16), falls within the range of ages exhibited by the silica-oversaturated rock types in the pluton (Whalen & Roddick 1987). U-Pb ages from the same sample of nepheline syenite, a sample of gabbro and one of granite all overlap at about 390 Ma, which suggests that all components of the pluton are contemporaneous (J.B. Whalen and J. Mortenson, unpubl. data).

Equilibrium assemblages of minerals in a 1.5- to 3-km contact aureole of the complex indicate a confining pressure of less than 2 kbars (de Römer 1977, Van Bosse & Williams-Jones 1988). The aureole has a much broader extent than 3 km, as revealed by regional contact-related gradients in illite crystallinity and reflectance of organic matter in the enclosing Cambro-Ordovician flysch sequence (Islam *et al.* 1982). The extent of the aureole suggests that the pluton flares out at a shallow depth.

The agpaitic nepheline syenite is exposed in dykes and sills up to 3 m thick that cut syenite and other rocks of the hybrid suite in the northern half of the complex (Fig. 1). The dyke rocks are fine grained, grey to dark green, and porphyritic. A chilled margin commonly is observed, with little or no evidence of metasomatism of the host rock at the contact. The miaskitic nepheline syenite, texturally similar to the agpaitic variants, appears as grey pods or ovoid bodies about 100 by 20 m that cut syenite of the hybrid suite northeast of Mont Jacques-Cartier (Fig. 1). Leucocratic aplitic veins commonly cross-cut or are associated with the miaskitic nepheline syenite, and the host rocks may exhibit local evidence of alkali metasomatism (*cf.* Wallace 1988). Modal and mineralogical data for the nepheline syenite are summarized in Table 1. Owing to the sporadic nature of the outcrop, the fields of felsenmeer, and the similarity between the weathered nepheline syenite and other members of the hybrid suite, the actual volume of nepheline syenite probably exceeds the abundance

TABLE 1. MINERALOGY AND MODAL COMPOSITION OF SAMPLES OF NEPHELINE SYENITE FROM THE MCGERRIGLE PLUTON

Rock Type Sample	1 MIAS MG16	2 AGPA MG37	3 AGPA MG39	4 AGPA MG67	5 AGPA MG94	6 AGPA MG98	7 CINC MG98
K-feldspar	78.3	61.8	X	X	X	X	X
Albite	tr	tr	X	X	X	X	X
Nepheline	9.2	19.3	X	X	X	X	*
Sodalite	-	2.8	X	-	?	X	X
Pyroxene	3.0	11.9	X	X	X	X	X
Ambibole	Agt	Ae	Ae	-	Agt	-	Ae
	-	3.5	-	X	-	X	X
		Arf					
Biotite	4.6	0.2	X	X	X	X	X
	Bt	Lep	MgBt		Lep		Lep
Magnetite	0.8	-	X	X	X	-	X
Ilmenite	-	-	-	-	X	-	-
Aenigmatite	-	0.6	-	-	-	-	-
Titanite	1.9	-	-	-	-	X	**
Zircon	2.2	-	X	-	X	-	X
Apatite	tr	tr	X	-	X	X	X
Astrophyllite	-	tr	-	-	-	-	X
Fluorite	-	tr	X	X	-	-	X
Pectolite	-	tr	X	-	-	-	?
Wöhlerite	-	-	-	-	X	-	-
Pyrochlore	-	-	-	-	X	-	-
Eudialyte	-	tr	-	-	-	-	-
Rosenbuschite	-	-	-	-	-	-	-
-gützenite	-	-	-	-	?	-	-

Mineralogy and modal composition of selected samples of nepheline syenite (Whalen & Gariépy 1986). Abbreviations of rock types: MIAS miaskitic nepheline syenite, AGPA agpaitic nepheline syenite, CINC leucocratic cognate inclusion in WXMG98 (column 6). Symbols: Ae aegirine (MG37, MG39 also contain titanian aegirine), Agt aegirine-augite, Arf arfvedsonite, Bt biotite, MgBt Mg-rich biotite, Lep lepidomelane; X present, tr trace amounts, - absent, * altered to secondary minerals, ** possibly secondary. The full sample number contains the prefix WX.

indicated by mapping.

Gabbro, which occurs as inclusions up to 1500 m in length or as thin dykes (Whalen 1987) in the hybrid suite, is the only other silica-undersaturated rock type in the complex. The gabbros contain up to 6 wt.% normative nepheline and exhibit a chemistry and mineralogy (*e.g.*, presence of titaniferous diopside and kaersutite) consistent with an alkaline character (Whalen & Gariépy 1986, Wallace 1986).

Inclusions are present in the nepheline syenite. Some are mafic to intermediate, angular to irregularly shaped, metasomatized xenoliths up to 10 cm across. The more strongly agpaitic samples (*e.g.*, WXMG37, WXMG39) contain rare polyminerale clots (Figs. 2a, b) that may represent pseudomorphs after, or remnants of, xenocrysts that were possibly derived from such xenoliths. Also present are ovoid, equigranular to porphyritic cognate inclusions up to 10 cm across that have a mineralogy similar to that of their host rock. The larger cognate inclusions may exhibit disaggregation features.

MINERALOGY OF THE NEPHELINE SYENITES

Feldspars and feldspathoids

K-feldspar, the dominant mineral in the nepheline syenite, occurs as anhedral to euhedral, pristine to strongly turbid laths or phenocrysts of perthite that commonly exhibit a trachytic texture. Minor

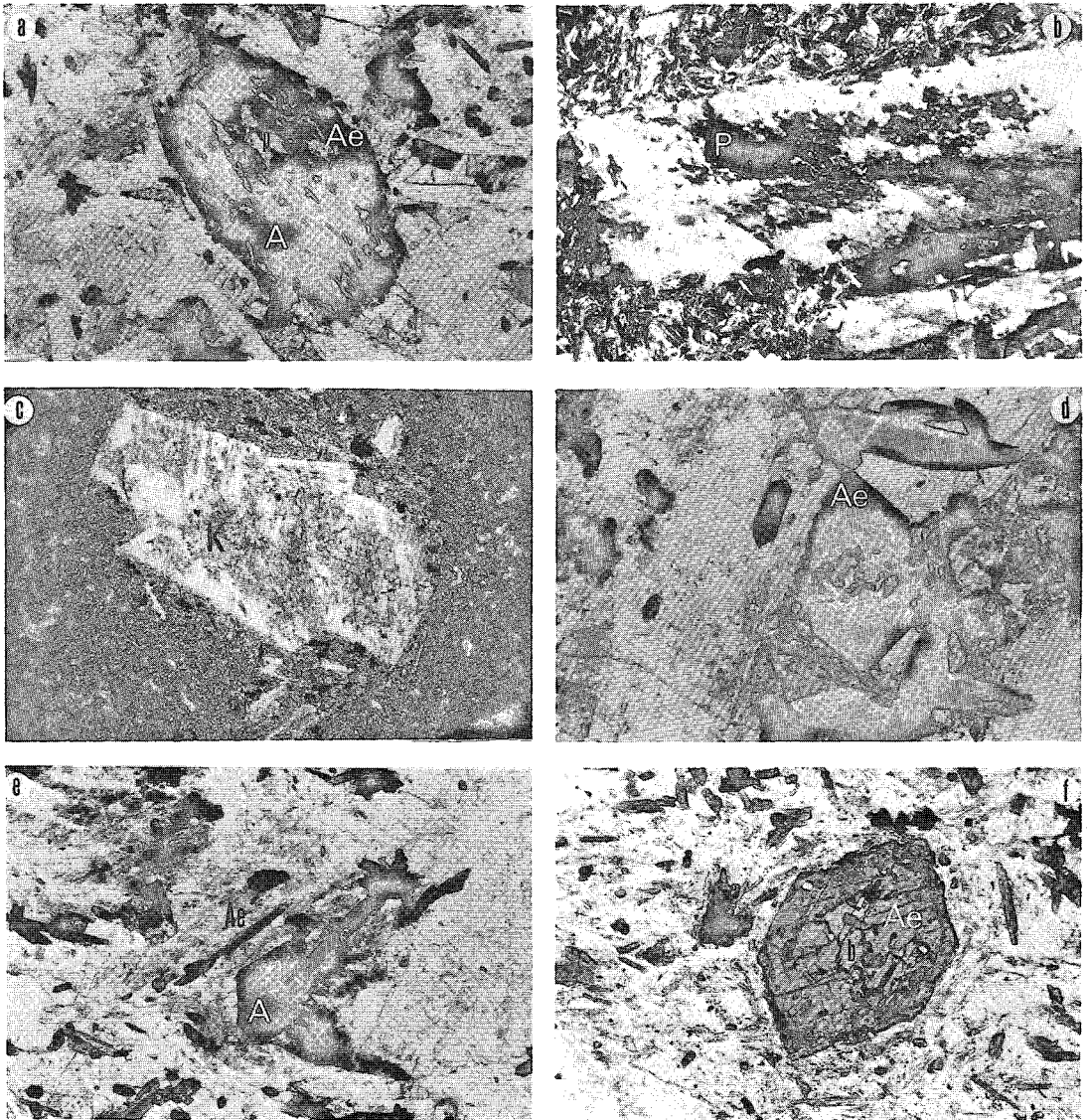


FIG. 2. a. Pseudomorph after an amphibole (xenocryst?) consisting of arfvedsonite (A), aegirine (Ae), pectolite (p) and minor fluorite. Long dimension of pseudomorph: 1.1 mm. Agpaitic nepheline syenite sample WXM37. b. Recrystallized remnants (P) of feldspar (xenocrystic plagioclase?) at the core of a perthitic K-feldspar phenocryst. Crossed polars. Width of field of view: 2.6 mm. Agpaitic nepheline syenite sample WXM39. c. A phenocryst of turbid perthitic K-feldspar (K) has been albited, principally along its margin. The phenocryst is characterized by a very patchy extinction. Width of field of view: 8 mm. Agpaitic nepheline syenite sample 84-105. d. Euhedral zoned aegirine crystal (Ae) containing a grass-green core and a blue-green titanian rim. Grain is cross-cut by fluorite. Long dimension of zoned crystal: 0.3 mm. Agpaitic nepheline syenite sample WXM37. e. Euhedral phenocryst of arfvedsonite (A) coexisting with a phenocryst of aegirine (Ae). Width of field of view: 2 mm. Agpaitic nepheline syenite sample WXM37. f. Remnants of Mg-rich biotite (b) at the core of an aegirine phenocryst (Ae). The phenocryst is 0.3 mm across. Agpaitic nepheline syenite sample WXM39.

amounts of discrete grains of anhedral to subhedral albite are found in the groundmass. Nepheline is anhedral, and predominantly interstitial. Sodalite is

common in strongly agpaitic samples (e.g., WXM37), in which it forms interstitial grains or anhedral to subhedral phenocrysts.

All K-feldspar samples are monoclinic to X rays, but a small volume of microcline also is present, according to the powder-diffraction pattern (Table 2; Guinier-Hägg camera, $\text{CuK}\alpha_1$ radiation). The K-feldspar in the miaskitic nepheline syenite consists of orthoclase ($2t_1 = 0.89$; nomenclature of Ribbe 1983), whereas the agpaite nepheline syenite contains low sanidine to orthoclase ($0.72 < 2t_1 < 0.79$) (Wallace 1988). In agpaite sample WXM94, the phenocrystic orthoclase is less well ordered than the matrix orthoclase, an illustration of the grain-size effect on degree of Al-Si order (Martin 1973). The greater degree of disorder of the K-feldspar in the agpaite nepheline syenite is consistent with more rapid cooling of the narrow dykes and sills than of the larger bodies of miaskitic nepheline syenite.

The K-feldspar in the perthite ranges from Or_{94} to Or_{100} ; such a K-rich composition indicates that subsolidus equilibration continued to low temperatures, in the range $300 - <200^\circ\text{C}$, via the exsolution of albite. There is a high proportion of diffraction lines in the powder pattern that is assigned unambiguously to the albite component of the perthite. Petrographic evidence (e.g., Fig. 2c) suggests that this enrichment in sodium may in part reflect postexsolution Na-metasomatism (e.g., White & Martin 1980). Such interaction with a fluid medium must have occurred above the stability field of microcline ($>400^\circ\text{C}$), as the conversion of orthoclase to microcline is incipient only in these samples. The conversion probably involved deuteric fluids generated during crystallization of the nepheline syenite.

The nepheline in these assemblages (Wallace 1988, Table A5.4) contains low concentrations of Ca (0–0.24 wt.% CaO) and Fe (0.19–0.72 wt.% Fe_2O_3). Its average bulk composition approaches $\text{Ne}_{74}\text{Ks}_{22}\text{Qtz}_4$, which is typical for plutonic nepheline (Edgar 1984).

Clinopyroxene

Clinopyroxene occurs as green pleochroic anhedral grains or phenocrysts of aegirine-augite or aegirine (Table 1). Zoning is rare, but in some samples of agpaite nepheline syenite, grains have a blue-green rim of titanite aegirine (Fig. 2d, Table 3, no. 3). Pyroxene compositions (Table 3) resemble those in nepheline syenite from other alkaline complexes (e.g., Gomes *et al.* 1970, Larsen 1976, Brooks *et al.* 1982, Brousse & Rançon 1984).

In the agpaite nepheline syenite, the sodic pyroxene is essentially silica-saturated, with the greatest proportion of the jadeite component, 10.1 mol.%, occurring in pale brown, late-stage (possibly post-magmatic) overgrowth of aegirine (Table 3, no. 4).

Both Ti and Zr are concentrated in the blue-green titanite aegirine of the agpaite nepheline syenites, even though both cations compete for the M1 site

TABLE 2. COMPOSITION AND DEGREE OF Al-Si ORDER IN ORTHOCLASE IN THE NEPHELINE SYENITE

Sample	Rock Type	N_{or}	$t_1\text{O}+t_2\text{m}$	$t_1\text{O}-t_2\text{m}$	$t_1\text{O}$
WXM616	MIAS	1.014	0.893	0	0.45
WXM937	AGPA	0.956	0.739	0	0.37
WXM94	AGPA				
	phenocryst	0.960	0.724	0	0.36
	matrix	0.938	0.789	0	0.40

Composition N_{or} is expressed in mol % Or, and is calculated using the equation of Kroll & Ribbe (1983) that relates the unit-cell volume to composition in a partly disordered K-rich feldspar. Degree of Al-Si order, expressed by $t_1\text{O}$, is calculated using the cell parameters (reported in Wallace 1988) and the equations of Blasi (1977). The error in N_{or} and $t_1\text{O}$ is estimated to be ± 0.015 . The rock types are described in Table 1.

TABLE 3. COMPOSITIONS OF CLINOPYROXENE IN THE NEPHELINE SYENITE

Rock Type	1 MIAS Av(10)	2 AGPA Av(4)	3 AGPA Av(1)	4 AGPA Av(1)	5 AGPA Av(1)	6 AGPA Av(1)	7 AGPA Av(1)	8 AGPA Av(2)
SiO_2	51.08	52.72	52.39	53.31	52.17	52.41	52.88	50.31
Al_2O_3	1.54	1.36	1.12	2.28	1.22	1.32	1.02	1.29
FeO_3	11.54	26.47	21.25	21.00	22.34	25.59	23.07	14.42
TiO_2	0.48	1.70	3.54	1.07	3.44	0.64	1.54	0.42
MgO^{\dagger}	6.50	0.27	0.37	2.33	0.29	0.41	0.44	2.43
FeO^{\ddagger}	6.39	2.75	5.52	2.96	4.06	4.43	4.95	9.18
FeO^{\ddagger}	16.77	26.57	24.64	21.86	24.16	27.45	25.71	22.16
MnO	1.60	0.39	0.57	1.74	0.65	0.55	0.80	2.34
ZrO	0.29*	0.02	1.83	0.12	n.d.	0.14	n.d.	0.70
CaO	16.64	1.58	0.98	4.80	2.54	2.77	3.13	12.19
Na ₂ O	4.44	12.71	12.70	10.73	12.29	11.66	11.66	6.35
Total	100.60	99.97	100.27	100.34	99.00	99.91	99.49	99.63
Si	1.945	2.010	2.004	2.011	2.008	2.013	2.033	1.973
Al	0.055	0.000	0.000	0.000	0.000	0.000	0.000	0.027
Al^{IV}	0.014	0.061	0.050	0.101	0.055	0.060	0.046	0.033
Fe^{IV}	0.331	0.760	0.612	0.596	0.647	0.740	0.668	0.426
Ti	0.014	0.049	0.102	0.030	0.100	0.018	0.045	0.012
Fe^{IV}	0.375	0.015	0.021	0.131	0.017	0.023	0.025	0.142
Fe^{IV}	0.203	0.098	0.176	0.093	0.131	0.142	0.159	0.301
Mn	0.052	0.013	0.018	0.056	0.021	0.018	0.026	0.078
Zr	0.005	0.000	0.034	0.002	0.000	0.003	0.000	0.013
Ca	0.679	0.065	0.040	0.194	0.105	0.114	0.129	0.512
Na	0.328	0.940	0.942	0.785	0.917	0.868	0.869	0.483
Mg \ddagger	0.413	0.017	0.026	0.160	0.021	0.025	0.029	0.163
Mg/(Mg+Fe \ddagger)	0.648	0.149	0.107	0.584	0.113	0.142	0.137	0.320
Fe \ddagger /Fe \ddagger	0.620	0.896	0.777	0.865	0.832	0.839	0.808	0.586

Compositions were obtained using a Cameca Camebax electron microprobe equipped with four wavelength-dispersion sequential spectrometers. Accelerating voltage: 15 kV, beam current: 7 nA. Wallace (1988) listed counting times and standards used. The proportion of the total Fe that is FeO_3 and the structural formula were calculated by normalizing to 4 cations and then by adjusting the Fe^{IV} content so that the total number of oxygen atoms equals six, following the recommendations of Robinson (1980). Nomenclature after Morimoto (1989). Rock types are defined in Table 1. Av(n): average result of n analyses; †: total Fe; ‡: average of four determinations; Mg \ddagger = Mg/(Mg + Fe \ddagger); n.d.: not determined. Samples: 1 aegirine-augite, WXM616, 2 aegirine (core), WXM937-1a, 3 titanite aegirine (rim of the same grain as 2), 4 aegirine (late-stage pale brown rim), WXM937, 5 titanite aegirine, WXM939, 6 aegirine (core of phenocryst), WXM939-2a, 7 aegirine (rim of the same phenocryst as 6), 8 aegirine-augite, WXM94-2a.

(Larsen 1976). The lowest concentrations of Zr (<0.1 wt.% ZrO_2) are found in the core of both groundmass and phenocrystic aegirine. Owing to the high solubility of Zr in peralkaline melts (Watson 1979), enrichment in Zr is only observed where a sodic pyroxene crystallizes from a late-stage Zr-enriched residual liquid.

A plot of Na-Mg-($\text{Fe}^{2+} + \text{Mn}$) (Fig. 3) does not display a single continuous trend, the existence of which usually is interpreted in terms of consanguinity of batches of alkaline magma in a fractionating sequence (e.g., Stephenson 1972, Nielsen 1979). Lack

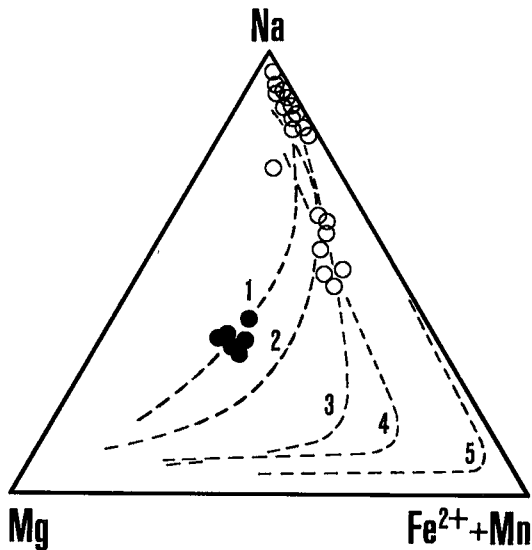


FIG. 3. Selected pyroxene compositions plotted in terms of Na-Mg-Fe²⁺+Mn (molar). Filled circle: miaskitic nepheline syenite, open circle: agpaitic nepheline syenite. Compositional trends of pyroxene from other silica-undersaturated alkaline suites: 1) Itapirapuã: Gomes *et al.* (1970), 2) Uganda: Tyler & King (1967), 3) South Qôroq: Stephenson (1972), 4) Coldwell nepheline syenites: Mitchell & Platt (1982), 5) Ilímaussaq: Larsen (1976).

TABLE 4. COMPOSITION OF AMPHIBOLE IN AGPAITIC NEPHELINE SYENITE WXM37

	I	P			
	Av(6)	Av(5)			
SiO ₂ wt. %	50.57	50.96	Si	8.011	8.121
Al ₂ O ₃	1.29	0.96	Al	0.241	0.180
TiO ₂	0.98	0.91	Ti	0.117	0.109
FeO	29.57	27.97	Fe ³⁺	3.803	3.438
FeO	28.7	25.8	Fe ²⁺	0.114	0.289
Fe ₂ O ₃	1.0	2.4	Mn	0.421	0.359
MnO	3.14	2.66	Mg	0.293	0.504
MgO	1.24	2.12	Ca	0.251	0.140
CaO	1.48	0.82	Na _{tot}	1.749	1.860
Na ₂ O	7.84	7.71	Na _a	0.659	0.522
K ₂ O	2.48	3.20	K	0.501	0.650
F	0.89	1.06			
Cl	0.02	0.01	F	0.446	0.534
			Cl	0.005	0.003
O#F, Cl	0.38	0.45			
Total	99.25	98.16	Mg/(Mg+Fe ²⁺)	0.071	0.128
			Fe ³⁺ /(Fe ³⁺ +Mg)	0.930	0.881
			Fe ³⁺ /Fe ²⁺	0.029	0.078

Concentration of Fe₂O₃ calculated by the method of Laird & Albee (1981), using a computer program written by A.J. Hynes. Formula based on 23 anions. Av(*n*): average result of *n* analyses. ⁺: total iron, expressed as Fe or as FeO. I: manganese potassium arfvedsonite (interstitially), P: manganese potassium arfvedsonite (phenocrysts). Nomenclature after Leake (1978). Proportion of F and Cl in a formula unit are calculated assuming a stoichiometry of (OH + F + Cl) = 2.

of a smooth trend may indicate that processes or factors other than closed-system fractionation (*e.g.*, variations in intrinsic $f(O_2)$ and in alkali content; *cf.* Woolley & Platt 1988) are partly responsible for the

observed variation among pyroxene compositions in the McGerrigle nepheline syenites.

Amphibole

Amphibole, which occurs only in some samples of agpaitic nepheline syenite (Table 1), forms interstitial or poikilitic, unzoned grains or phenocrysts that exhibit a yellow-brown or brownish green to black or deep blue-green pleochroism. Whereas amphibole and pyroxene appear to be at equilibrium in some samples (Fig. 2e), a replacement relationship is observed in others. Sample WXM37 contains manganese potassium arfvedsonite (Table 4) which, relative to the arfvedsonite in nepheline syenites from other complexes (*e.g.*, Larsen 1976, Ferguson 1978, Brooks *et al.* 1982), is characterized by high Mn (2.5–3.4 wt. % MnO) and K (2.1–3.3 wt. % K₂O), and low Al (0.9–1.5 wt. % Al₂O₃), Mg (1.1–2.4 wt. % MgO) and Ca (0.7–1.7 wt. % CaO). Arfvedsonite is characteristic of the most highly evolved peralkaline rocks of undersaturated suites (Mitchell & Platt 1982).

Biotite

Biotite, the dominant mafic mineral in the miaskitic nepheline syenite, occurs as anhedral or poikilitic flakes. It ranges in composition from manganese titaniferous biotite in miaskitic nepheline syenite to manganese titaniferous lepidomelane or Mg-rich biotite in the agpaitic nepheline syenite (Table 5). Biotite in the nepheline syenites of the McGerrigle complex is characterized by high Mn (1.6–4.8 wt. % MnO), moderate Ti (1.4–4.0 wt. % TiO₂) and low Na (0.03–0.18 wt. % Na₂O) relative to compositions reported from other suites of nepheline syenite (*e.g.*, Rock 1978, Mitchell & Platt 1982, Brooks *et al.* 1982).

Aenigmatite and oxide minerals

The aenigmatite in aegirine-bearing nepheline syenite approaches the end-member composition (Na₂Fe₃²⁺TiSi₆O₂₀; Table 6). However, its extreme enrichment in Mn (4.6–5.9 wt. % MnO) exceeds the 4.4 wt. % MnO reported by Marsh (1975). Fe³⁺-poor aenigmatite is typical of an association with arfvedsonite and aegirine, whereas Ca- and Al-poor aenigmatite may reflect a relatively low temperature of primary crystallization (Larsen 1977). The observed absence of a coexisting Fe-Ti oxide mineral is consistent with the existence of a no-oxide field in which sodic pyroxene and aenigmatite coexist (Marsh 1975).

Magnetite is the only primary oxide observed in the miaskitic nepheline syenite. Aegirine-bearing nepheline syenite WXM39 contains magnetite

TABLE 5. SELECTED COMPOSITIONS OF BIOTITE IN THE NEPHELINE SYENITE

Rock Type Sample	1 MIAS MG16 Av(5)	2 AGPA MG37-4 Av(4)	3 AGPA MG39-8* Av(4)	4 AGPA MG94 Av(4)	5 CINC MG98-1 Av(3)
SiO ₂	37.39	37.35	41.88	35.67	37.77
Al ₂ O ₃	12.82	10.61	12.58	11.50	10.35
TiO ₂	2.71	2.06	2.56	3.74	3.42
FeO ⁸	22.28	30.10	9.10	30.37	26.79
FeO	16.34	23.98	9.10	24.16	21.30
Fe ₂ O ₃	6.6	6.8	0.0	6.9	6.1
MnO	1.77	3.17	4.20	3.07	4.45
MgO	9.46	2.50	14.90	2.50	3.30
CaO	0.01	0.0	0.01	0.0	0.01
Na ₂ O	0.13	0.06	0.16	0.10	0.08
K ₂ O	9.18	9.62	9.34	9.75	10.17
F	1.25	0.16	3.17	0.13	0.23
Cl	0.02	0.02	0.01	0.02	0.0
O=F,Cl	0.53	0.07	1.34	0.06	0.10
Total	97.15	96.26	96.57	97.48	97.08
Si	2.852	3.001	3.085	2.845	2.990
Al	1.148	0.999	0.915	1.081	0.966
Fe ²⁺	0.0	0.0	0.0	0.074	0.044
Al	0.004	0.006	0.177	0.0	0.0
Ti	0.155	0.124	0.142	0.224	0.204
Fe ³⁺	0.379	0.411	0.0	0.340	0.319
Y1	0.538	0.341	0.319	0.554	0.523
Mg	1.075	0.299	1.636	0.237	0.389
Fe	1.042	1.612	0.561	1.611	1.410
Mn	0.114	0.216	0.0	0.207	0.298
Na	0.0	0.0	0.0	0.007	0.012
Y2	2.231	2.127	2.459	2.122	2.109
K	0.893	0.986	0.878	0.992	1.027
Na	0.019	0.009	0.023	0.008	0.0
Ca	0.001	0.0	0.001	0.0	0.001
X	0.913	0.995	0.902	1.000	1.028
F	0.302	0.041	0.738	0.033	0.058
Cl	0.003	0.003	0.001	0.003	0.0
Fe ²⁺ /(Fe ²⁺ +Mg)	0.569	0.871	0.255	0.872	0.820
Fe ³⁺ /Fe ²⁺	0.267	0.203	-	0.204	0.205
Mg/(Mg+Fe ²⁺)	0.508	0.157	0.745	0.156	0.216

* All Fe treated as FeO. For other compositions, Fe₂O₃ was obtained by titration (Wallace 1988). Formula based on 11 atoms of oxygen. Proportions of F and Cl in a formula unit assume a stoichiometry of (OH + F + Cl) = 2. Rock types defined in Table 1. Av(n): average results of n analyses. ²: total iron, expressed as Fe or FeO. 1 manganiferous titaniferous biotite (nomenclature after Rock (1982), 2 manganiferous titaniferous lepidomelane, 3 manganiferous Mg-rich biotite (inclusion in aegirine; Fig. 2f), 4 manganiferous titaniferous lepidomelane, 5 manganiferous titaniferous lepidomelane (inclusion in aegirine phenocryst).⁸ The full sample number contains the prefix WX.

instead of aenigmatite, and both primary ilmenite and magnetite occur in aegirine-augite-bearing nepheline syenite WXMG94. As is the case in other felsic undersaturated complexes (Neumann 1974, Brooks *et al.* 1982), the oxide minerals are characterized by high Mn contents (Table 7). A low concentration of the ulvöspinel component and the presence of pyrophanite lamellae in the magnetite indicate that "oxidation-exsolution" (Buddington & Lindsley 1964) has occurred. The pyrophanite lamellae in magnetite reflect the preference of Mn for the rhombohedral over the spinel phase under conditions of subsolidus "oxidation-exsolution" (*e.g.*, Haggerty 1976). Only magnetite in an aegirine-bearing nepheline syenite (WXMG39) lacks visible lamellae of

TABLE 6. COMPOSITIONS OF ACCESSORY MINERALS IN THE AGPAITIC NEPHELINE SYENITE

Sample	1 MG37a Av(4)	2 MG37b Av(5)	3 MG37c Av(2)	4 MG37d Av(3)	5 MG94a Av(2)	6 MG94b Av(2)	7 MG94c Av(2)
SiO ₂	42.49	35.87	56.75	52.91	0.0	30.41	31.21
Al ₂ O ₃	0.34	1.19	0.08	0.01	0.0	0.01	0.0
TiO ₂	9.17	11.05	0.51	0.01	8.22	1.12	7.19
ZrO ₂	0.0	0.34	12.69	0.0	0.34	13.96	7.89
Nb ₂ O ₅	0.23	1.23	1.03	0.0	43.54	11.19	1.36
MgO	0.29	0.60	0.01	0.01	0.01	0.07	0.0
FeO	34.34	26.42	5.57	1.14	0.19	0.39	0.14
MnO	5.23	7.97	2.50	4.29	0.09	1.24	0.76
CaO	0.05	1.89	12.20	26.19	16.94	26.12	28.92
Na ₂ O	7.63	2.04	2.94	8.71	4.98	7.94	8.35
K ₂ O	0.0	6.64	0.31	0.04	0.04	0.04	0.03
Li ₂ O	n.d.	n.d.	n.d.	0.02	0.66	0.06	0.36
Ce ₂ O ₃	n.d.	n.d.	n.d.	0.06	1.55	0.22	0.87
F ₂ O ₃	n.d.	n.d.	n.d.	0.01	0.09	0.12	0.15
Cl	0.01	1.47	0.22	n.d.	n.d.	n.d.	n.d.
O=F,Cl	0.03	0.62	0.26	-	-	-	-
total	99.85	96.11	95.31	93.40	76.65	92.89	87.23
Si	6.050	7.749	6.982	3.095	0.0	2.068	2.090
Al	0.057	0.303	0.012	0.001	0.0	0.0	0.0
Fe ³⁺	0.0	-	-	-	-	-	-
Ti	0.982	1.795	0.047	0.0	0.449	0.057	0.362
Zr	0.0	0.036	0.761	0.0	0.012	0.463	0.257
Nb	0.015	0.120	0.057	0.0	1.431	0.344	0.041
Mg	0.062	0.193	0.001	0.001	0.001	0.007	0.0
Fe ²⁺	-	4.773	0.573	0.056	0.011	0.022	0.008
Fe ³⁺	-	4.089	-	-	-	-	-
Mn	0.631	1.459	0.260	0.212	0.006	0.071	0.043
Ca	0.008	0.436	1.608	1.641	1.319	1.904	2.074
Na	2.105	0.856	0.700	0.988	0.702	1.047	1.084
K	0.0	1.830	0.049	0.003	0.004	0.003	0.003
La	-	-	-	0.001	0.018	0.002	0.009
Ce	-	-	-	0.001	0.041	0.005	0.021
F	-	-	-	0.0	0.006	0.007	0.008
F	0.005	1.002	0.086	-	-	-	-
Cl	0.024	0.008	0.158	-	-	-	-

Rock types defined in Table 1. Av(n): average composition based on n analyses; n.d. not determined. 1 aenigmatite (basis of the recalculation: 14 cations and 20 atoms of oxygen), 2 astrophyllite (28 atoms of oxygen), 3 eudialyte (18.5 atoms of oxygen), 4 pectolite (6 cations), 5 pyrochlore (4 cations), 6 whlerite (6 cations), 7 rosenbuschite-götschelite(?) (6 cations). The full sample number contains the prefix WX. As the analyses were carried out using wavelength dispersion, there is no information available on the concentration of minor elements like Ta, Sn, Bi, Pb, etc., which are expected in some of these minerals (and hence the low analytical totals).

pyrophanite. It is, however, also Ti-depleted (0.06-0.16 wt.% TiO₂) and anomalously Mn-enriched (8.3-9.3 wt.% MnO), which suggests that the magnetite was initially highly Ti-depleted (*cf.* Wallace 1988).

Other accessory minerals

Several accessory minerals have been identified in the nepheline syenites (Tables 1, 6). In aegirine-bearing nepheline syenite WXMG37, a Na-Zr silicate, interpreted to be a member of the eudialyte group Na₄(Ca,REE)₂(Fe²⁺,Mn,Y)(Zr,Ti)(Si₈O₂₂)(OH,Cl)₂ (Table 6, no. 3) occurs as interstitial, colorless to pale pink-brown, low-birefringence grains. The presence of zircon in WXMG39 rather than the Na-Zr silicate of WXMG37 may appear anomalous since both samples are characterized by the same agpaite index (1.09) and near-identical whole-rock compositions (Table 8). The formation of Na-Zr minerals depends on an excess of alkalis at the stage of their crystallization (Currie 1976) and on the Fe³⁺/Fe²⁺ value of the melt (Watson 1979). The presence of zircon in WXMG39 is probably

TABLE 7. COMPOSITIONS OF OXIDE PHASES IN THE NEPHELINE SYENITE

Rock Type Sample	1 MIAS MG16 Av(8)	2 MIAS MG16-2 Av(3)	3 AGPA MG39 Av(5)	4 AGPA MG39 Av(1)	5 AGPA MG94 Av(3)	6 AGPA MG94 Av(3)
Al ₂ O ₃ wt. %	0.11	0.50	0.05	0.0	0.06	0.0
TiO ₂	0.29	49.86	0.11	52.65	0.74	50.78
FeO (total)	91.36	5.23	83.38	3.40	90.94	32.28
MnO	1.23	41.48	8.71	41.53	0.72	14.45
MgO	0.01	0.01	0.05	0.10	0.01	0.03
NiO	0.05	0.02	0.0	0.0	0.03	0.02
V ₂ O ₅	0.20	0.34	0.08	0.0	0.02	0.34
Cr ₂ O ₃	0.02	0.0	0.0	0.0	0.0	0.0
Fe ₂ O ₃	68.15	2.72	68.18	0.0	66.93	1.47
FeO	30.04	2.79	22.03	3.40	30.72	30.95
Total	100.10	97.72	99.21	97.68	99.23	98.04
Al	0.005	0.015	0.002	0.0	0.003	0.0
Ti	0.008	0.963	0.003	1.012	0.022	0.983
Fe ³⁺	1.973	0.053	1.989	0.0	1.954	0.029
Fe ²⁺	0.966	0.060	0.714	0.073	0.956	0.666
Mn	0.040	0.903	0.286	0.899	0.024	0.315
Mg	0.001	0.0	0.003	0.004	0.001	0.001
Ni	0.002	0.0	0.0	0.0	0.001	0.0
V	0.005	0.006	0.002	0.0	0.0	0.006
Cr	0.001	0.0	0.0	0.0	0.0	0.0
Fe ₂ TiO ₄ wt. %	0.0	-	0.0	-	0.86	-
Fe ₃ O ₄	96.27	-	70.78	-	97.04	-
Mn ₂ TiO ₄	0.70	-	0.17	-	1.13	-
MnFe ₂ O ₄	2.54	-	27.97	-	0.0	-
FeTiO ₃	-	5.88	-	10.78	-	65.38
MnTiO ₃	-	88.20	-	88.31	-	30.73
MgTiO ₃	-	0.03	-	0.30	-	0.09

Fe₂O₃ was calculated for both ilmenite and magnetite using the procedure of Carmichael (1967). Formulae are based on 4 atoms of oxygen for magnetite, and 3 for ilmenite. The rock types defined in Table 1. Av(1): average result of 3 analyses. 1 magnetite, 2 pyrophanite lamellae in magnetite, 3 Mn-rich magnetite, 4 secondary pyrophanite, 5 magnetite, 6 Mn-rich ilmenite. The full sample number contains the prefix WX.

related to the higher Fe³⁺/Fe²⁺ of the relevant magma.

In the zircon-bearing agpaite nepheline syenite WXM94, wöhlerite NaCa₂(Zr,Nb)Si₂O₇(O,OH,F)₂ occurs as colorless to yellow pleochroic interstitial grains, some of which exhibit complex polysynthetic twinning. In the same sample, colorless, low-birefringence interstitial grains (Table 6, no. 7) may be a member of the rosenbuschite-götzenite (Ca,Na)₃(Zr,Ti)Si₂O₈F - (Ca,Na)₃(Ti,Al)Si₂O₇(F,OH)₂ series.

The occurrence of pyrochlore in WXM94 as rare pale yellow-green cubes reflects the absence of significant amounts of Ti- or Na-Zr-bearing accessory phases into which Nb and Ta could have substituted (Gerasimovsky 1974). The astrophyllite from the aegirine-bearing nepheline syenites is compositionally similar to that reported from other undersaturated suites (Macdonald & Saunders 1973). The absence of primary titanite in magnetite-bearing (but ilmenite-free) agpaite nepheline syenite probably reflects the low *a*_{CaO} of the magma. Absence or scarcity of fluorite and sodalite in the least alkaline nepheline syenites (e.g., WXM16, WXM94) implies that only in the agpaite magmas was the activity of fluorine and chlorine sufficient to stabilize these minerals (cf. Wallace 1988).

TABLE 8. BULK COMPOSITION OF SELECTED SAMPLES OF NEPHELINE SYENITE FROM THE MCGERRIGLE COMPLEX

Rock type Sample	MIAS MG16	AGPA MG37	AGPA MG39	AGPA MG67	AGPA MG94	AGPA MG98
SiO ₂ wt. %	60.80	59.20	59.50	58.90	59.90	59.10
TiO ₂	0.69	0.31	0.31	0.31	0.33	0.32
Al ₂ O ₃	19.30	19.60	19.60	19.60	20.00	19.60
Fe ₂ O ₃	1.65	2.71	3.38	3.00	2.31	2.67
FeO	1.39	0.89	0.40	0.69	1.40	1.09
MnO	0.17	0.28	0.28	0.28	0.26	0.27
MgO	0.54	0.14	0.13	0.25	0.12	0.12
CaO	1.30	0.90	0.78	0.96	0.81	0.93
Na ₂ O	7.48	9.61	9.62	8.49	9.21	9.21
K ₂ O	5.67	5.10	5.20	5.07	5.09	5.06
P ₂ O ₅	0.14	0.03	0.04	0.04	0.04	0.04
H ₂ O	0.63	0.74	0.50	1.30	0.29	1.03
CO ₂	0.10	0.08	0.09	0.07	0.03	0.04
F	0.04	0.05	0.05	0.06	0.03	0.07
Cl	0.01	0.19	0.15	0.10	0.01	0.10
Trace elements	0.24	0.36	0.34	0.36	0.28	0.31
Total	100.15	100.19	100.37	99.48	100.11	99.96
Li ppm	78	84	58	140	29	27
Ba	311	46	28	45	61	38
Rb	152	188	175	187	168	166
Sr	300	23	65	149	7	48
Zr	32	62	57	64	49	59
Y	845	1979	1917	2009	1474	1811
Nb	202	362	335	396	306	320
Pb	15	31	30	-	22	-
V	38	8	7	-	<1	-
Ni	8	7	8	8	7	8
Cu	4	3	4	5	4	3
Zn	61	134	95	137	85	115
Ga	24	32	34	34	31	30
Sc	1.6	0.8	0.7	-	0.8	-
Cr	2.0	5.0	5.0	<1	2.0	<1
Cs	2.5	2.0	1.3	-	1.5	-
Hf	14.6	34.6	32.8	-	26.6	-
Ta	10.8	17.9	19.2	-	16.2	-
Th	17.5	59.4	53.3	-	35.2	-
U	4.6	14.0	14.7	-	13.0	-
La	93.5	155.1	156.4	140	149.4	140
Ce	155.2	248.5	241.0	230	233.7	220
Nd	34.5	54.0	49.6	61	50.3	59
Sm	6.5	9.4	9.5	8.7	8.5	8.5
Eu	1.1	0.6	0.6	0.7	0.5	0.6
Gd	-	-	-	7.3	-	7.2
Tb	0.9	1.4	1.2	-	1.2	-
Dy	-	-	-	9.1	-	8.9
Ho	1.3	2.2	-	-	4.0	-
Tm	-	-	-	-	0.3	-
Yb	3.8	7.3	7.5	8.5	5.9	8.2
Lu	0.7	1.2	1.7	-	1.0	-
AlI	0.96	1.09	1.09	0.99	1.03	1.05
DI	90.8	95.0	96.0	92.4	94.1	94.6

Major-element analyses performed at the Geological Survey of Canada by X-ray fluorescence; FeO was determined by titration, F by selective ion-electrode analysis, and Cl, by colorimetric analysis. The determination of trace-element concentrations was carried out by a combination of X-ray fluorescence and neutron activation. AlI agpaite index, (Na+K)/Al; DI differentiation index, the sum of normative Ab, Or, Ne and Ac (wt. %); - not determined. The full sample number contains the prefix WX.

BULK COMPOSITION OF THE ROCKS

Whole-rock compositions of six representative samples of nepheline syenite from the McGerrigle complex are given in Table 8. The five peralkaline samples, collected from separate bodies (Fig. 1), are almost chemically indistinguishable. Except for sample WXM67, which differs only in having less Na (about 0.7 wt. % Na₂O lower), these five samples contain between 2.99 and 8.40% normative Ac. Five of the six bulk compositions of the nepheline syenites plot in the thermal trough on the liquidus in the

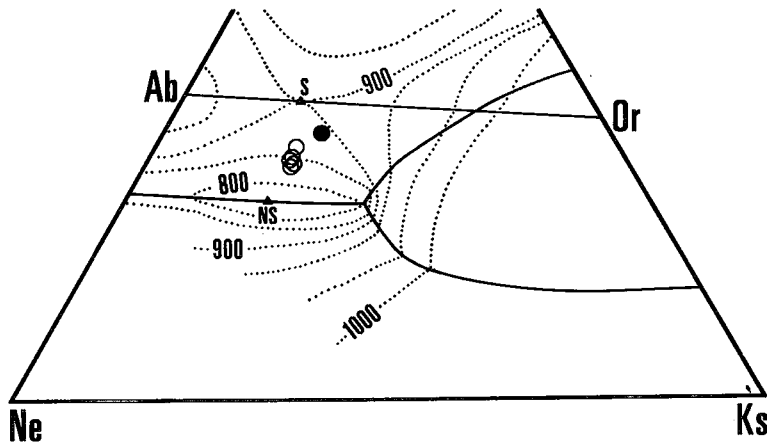


FIG. 4. Liquidus phase relations for the system Ne-Ks-Qtz-H₂O at 1 kbar $P(H_2O)$. S and NS are the syenite and nepheline syenite minima, respectively. After Fudali (1963) and Hamilton & MacKenzie (1965). Filled circle: miaskitic nepheline syenite WXMG16, open circles: agpaitic nepheline syenite.

quaternary system $NaAlSi_3O_8 - KAlSi_3O_8 - SiO_2 - H_2O$ at $P(H_2O) = 1$ kbar (Fig. 4). This trough, which links the "syenite" and "nepheline syenite" minima, is followed by silica-undersaturated felsic liquids that fractionate compositionally intermediate sanidine. The nepheline syenite compositions thus seem to have been controlled by crystal-liquid equilibria imposed on a somewhat more mafic, less strongly undersaturated parental magma.

TRACE-ELEMENT AND ISOTOPIC GEOCHEMISTRY

Relative to the peralkaline samples, the miaskitic nepheline syenite has lower *REE* contents and a less pronounced negative Eu anomaly (Fig. 5A). Similar variations in *REE* content and Eu anomalies exist among various other components of the hybrid suite, and all chondrite-normalized *REE* patterns in this suite are very similar [see Fig. 30.6 of Whalen & Gariépy (1986)]. For purposes of comparison, data of Eby (1985) for a tinguaita (37P12) and two pulaskites (BR15 and SH5) from Montereian suites and the average within-plate alkali olivine basalt of Pearce (1982) are plotted in Figure 5B. Overall patterns for these rocks are generally similar, except that the McGerrigle samples, especially the peralkaline nepheline syenites, are much more fractionated, as indicated by depletion in Eu, Sr, Ba, P and Ti, and enrichment in Th, Nb, *REE* and Zr.

Values of the lead isotope ratios in K-feldspar from three samples of nepheline syenite vary as follows: $18.263 < {}^{206}Pb/{}^{204}Pb < 18.863$, $15.538 < {}^{207}Pb/{}^{204}Pb < 15.616$, $38.084 < {}^{208}Pb/{}^{204}Pb < 39.095$ (Robert *et al.* 1988; C. Gariépy, pers. comm. 1986). Agpaitic nepheline syenite WXMG37 and

miaskitic nepheline syenite WXMG16 exhibit the highest and lowest values, respectively. Values of ϵ_{Nd} from the same three samples range from +4.2 to +5.2 (J.B. Whalen, unpubl. data). Values of $\delta^{18}O/^{16}O$ (Wallace 1988) range from 6.6‰ (miaskitic nepheline syenite WXMG16, aegirine-augite-bearing nepheline syenite WXMG94) to 7.7‰ (SMOW) for agpaitic nepheline syenite WXMG37. La Rocque (1986) obtained a high initial ${}^{87}Sr/{}^{86}Sr$ value (>0.71) for a sample of agpaitic nepheline syenite from the same locality as WXMG39. The initial ${}^{87}Sr/{}^{86}Sr$ value of the magma may be this high; considered more likely, however, since the Sr content of the rock is low (65 ppm), is the possibility of selective contamination by wall-rock material. A major feature of the available Pb, Sr, Nd and O isotopic data is that the nepheline syenites are not isotopically distinguishable from other intrusive phases of the McGerrigle complex.

INFERENCES CONCERNING CONDITIONS OF CRYSTALLIZATION

Miaskitic nepheline syenite WXMG16 appears to have crystallized under relatively oxidizing conditions, above the value of $f(O_2)$ defined by the quartz-fayalite-magnetite (QFM) buffer, as indicated by the Mg-rich composition of the biotite and clinopyroxene (*e.g.*, Czamanske & Wones 1973), and the presence of early-formed titanite that coexists with magnetite (Carmichael & Nicholls 1967, Hagerter 1976). The $f(O_2)$ can be qualitatively estimated from average compositions of biotite plotted in terms of Fe^{3+} , Fe^{2+} and Mg (Fig. 6; Wones & Eugster 1965, Speer 1984). The biotite in miaskitic

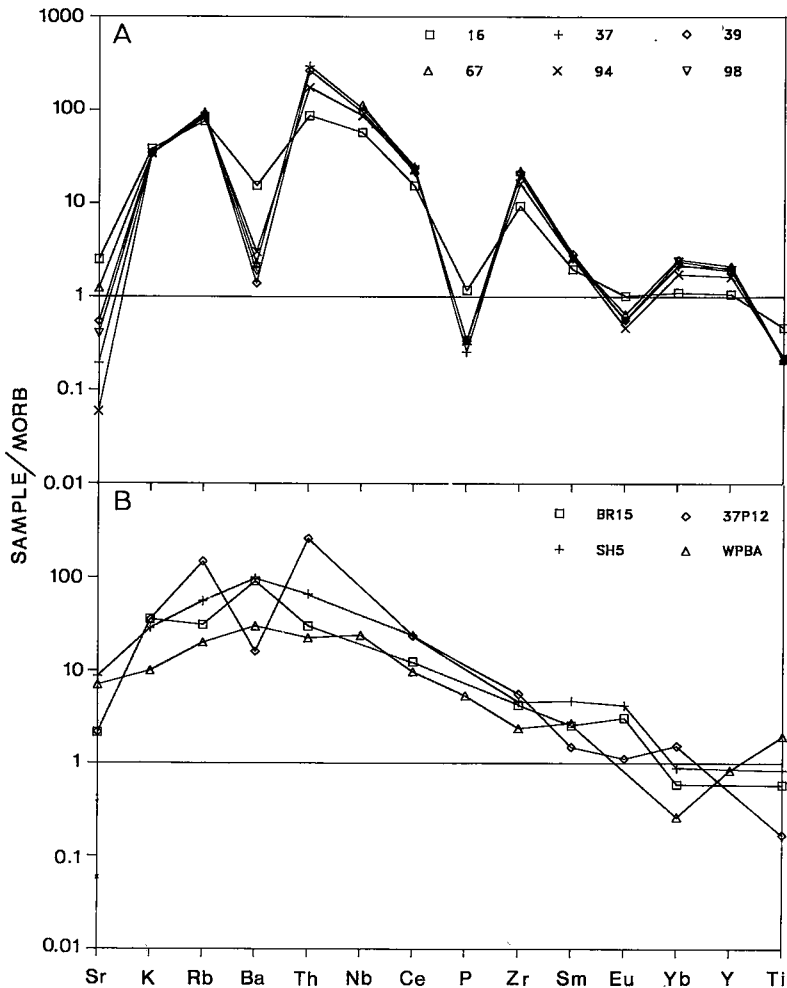


FIG. 5. Incompatible-element-abundance plots, normalized to normal mid-ocean ridge basalt (MORB; Pearce *et al.* 1981), for: (A) nepheline syenite from the McGerigle complex, (B) Monteregian pulaskites (BR15 and SH5) and a tinguaita (37P12) from Eby (1985), and average alkaline within-plate basalt (WPBA) from Pearce (1982).

nepheline syenite WXMG16 indicates conditions above the magnetite-hematite buffer; however, the presence of magnetite implies that the estimate is higher than the actual value, possibly because of subsolidus oxidation due to interaction with a deuteritic fluid (*e.g.*, Barrière & Cotten 1979). The presence of abundant early-formed biotite and the occurrence of late-stage veins and aplite are consistent with a relatively high initial $P(\text{H}_2\text{O})$ in the magma and the generation of such a fluid through H_2O saturation.

The association aenigmatite + arfvedsonite, *e.g.*, in aegirine-bearing nepheline syenite WXMG37, places the tightest constraints on the conditions of crystallization. On the basis of experimental data,

Bailey (1969) concluded that the presence of arfvedsonite indicates a maximum temperature of 700°C and an $f(\text{O}_2)$ in the range defined by the magnetite-wüstite and QFM buffers. Curtis & Currie (1981) concluded that peralkaline magmas that coprecipitate sodic pyroxene and arfvedsonitic amphibole crystallize at temperatures not much above 650°C and at $f(\text{O}_2)$ conditions well below the QFM buffer. Furthermore, the maximum stability of aenigmatite is probably limited to $f(\text{O}_2)$ values at most 1 log unit above the QFM buffer (D. H. Lindsay, pers. comm. 1987).

The significant Mg-enrichment of the biotite, lack of arfvedsonite, presence of ulvöspinel-depleted Mn-

rich magnetite rather than aenigmatite, lack of astrophyllite and Na-Zr silicates and occurrence of zircon, as well as the high whole-rock $X(\text{Fe}^{3+})$, indicate that aegirine-bearing nepheline syenite WXMG39 crystallized under more oxidizing conditions (>QFM buffer?) than the nearly identical WXMG37. This condition probably is reflected in the breakdown of the aegirine-arfvedsonite buffer (Larsen 1977, Curtis & Currie 1981), which may have controlled the $f(\text{O}_2)$ in WXMG37. If the $f(\text{O}_2)$ of WXMG39 was internally buffered (Carmichael & Nicholls 1967), equilibria among magnetite, biotite and aegirine would have been involved. Possible buffering reactions would be:

- 1) $2\text{Fe}_3\text{O}_4 + 3\text{Na}_2\text{Si}_2\text{O}_5(\text{liquid}) + 6\text{SiO}_2(\text{liquid}) + \frac{1}{2}\text{O}_2 = 6\text{NaFeSi}_2\text{O}_6$,
- 2) $2\text{KAlFe}_3\text{Si}_3\text{O}_{10}(\text{OH})_2 + 3\text{Na}_2\text{Si}_2\text{O}_5(\text{liquid}) + 6\text{SiO}_2(\text{liquid}) + 1\frac{1}{2}\text{O}_2 = 6\text{NaFeSi}_2\text{O}_6 + 2\text{KAlSi}_3\text{O}_8 + 2\text{H}_2\text{O}$.

or a combination of the two. There is textural evidence for the second reaction, with aegirine rimming and replacing biotite (Fig. 2f). No field, chemical or textural evidence is found for saturation with respect to a volatile phase. Rather, the presence of abundant fluorite-lined microfractures in WXMG39 suggests that the volatiles remained in solution until the very late stages of crystallization, an inference consistent with the high solubility of volatiles in alkaline magmas (Kogarko 1974, Burnham 1979). There is no direct evidence that the $f(\text{O}_2)$ was externally controlled by the exsolution of a fluid phase (e.g., Larsen 1977). If the breakdown of the aegirine-arfvedsonite buffer is due to an increase in $f(\text{O}_2)$, such a breakdown could reflect a slightly higher volatile content of the magma that gave WXMG39 (Haggerty 1976), loss of H_2 from the thin dyke or sill (less than 2 m wide), presumably by diffusion, or interaction with oxygenated crustal material.

A relatively low $f(\text{O}_2)$ is consistent with the coexistence of ilmenite and magnetite, the late crystallization of biotite and magnetite, and the Fe-rich nature of the mafic silicates in aegirine-augite-bearing nepheline syenite WXMG94. Unfortunately, the magnetite has undergone subolidus "oxidation-exsolution", and the Fe-rich nature of the biotite means that an estimate of $f(\text{O}_2)$ based on its $X(\text{Fe}^{3+})$ (Fig. 6) is likely to be grossly exaggerated (Hewitt & Wones 1984). The presence of aegirine-augite rather than aegirine in WXMG94 probably reflects both the low $f(\text{O}_2)$ and the lower agpaitic index of the magma.

The felsic minerals in the nepheline syenites represent a case of arrested subsolidus reactions. The assemblage low microcline + low albite + nepheline_{ss} is expected below 450°C, and commonly is encountered in mesozonal bodies of nepheline

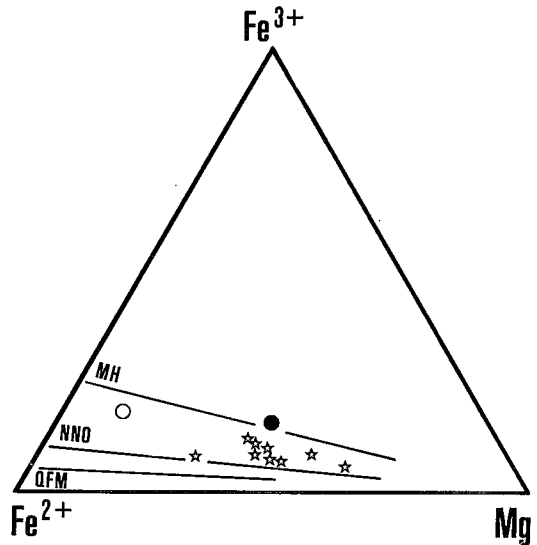


FIG. 6. The composition of biotite in terms of Fe^{2+} - Fe^{3+} -Mg. Lines representing oxygen fugacity buffers are from Wones & Eugster (1965). MH: magnetite - hematite, NNO: nickel - nickel oxide, QFM: quartz - fayalite - magnetite. Filled circle: miaskitic nepheline syenite WXMG16, open circle: agpaitic nepheline syenite WXMG94, stars: other data from pluton.

syenite. At McGerrigle, the nepheline - orthoclase pair continued to re-equilibrate structurally down to 500°C at least, but the recrystallization step required to convert the orthoclase to low microcline was largely inhibited owing to kinetic factors. In terms of Na-K exchange, the composition of the orthoclase indicates successful re-equilibration down to less than 200°C in the case of WXMG16, and closer to 300°C in WXMG37 and WXMG94.

In summary, the McGerrigle nepheline syenites exhibit a wide range of different mineral assemblages (Table 1), even when geochemically indistinguishable samples (e.g., WXMG37, WXMG39; Table 8) are compared. The miaskitic nepheline syenite and at least some samples of agpaitic nepheline syenite (e.g., WXMG94) exhibit mineral assemblages [*i.e.*, aegirine-augite - biotite - magnetite - ilmenite (titanite) - zircon] typical of nepheline syenites that are miaskitic and intermediate in terms of alkalinity (Sørensen 1974). The rest of the nepheline syenites, especially those exhibiting the assemblage sodalite - aenigmatite - astrophyllite - arfvedsonite, exhibit mineralogical characteristics of true agpaitic nepheline syenites. This variability reflects differences in magma chemistry, principally in terms of agpaitic index, as well as the differing conditions of crystallization, especially in terms of $f(\text{O}_2)$, that characterized different batches of magma.

PETROGENESIS

The occurrence of silica-undersaturated residual melts, admittedly present in small volumes, in a dominantly granitic complex, clearly is unusual, though not unique (*e.g.*, Foland & Friedman 1977, Fletcher & Beddoe-Stephens 1987, Bonin & Bardintzeff 1989). The association can be considered completely fortuitous, in which case the petrogenesis of the magmas that define the two lineages can be considered in isolation. However, the weight of the available evidence invalidates such a simple explanation. For example, the distribution of the nepheline syenites is restricted to the McGerrigle pluton. No such dykes or other intrusive bodies have been recognized in the country rocks near the pluton. Also, the radiometric ages of Whalen & Roddick (1987) and Whalen (unpubl. data) support the field evidence (Whalen 1985), which indicates that the spectrum of compositions in the McGerrigle complex are all approximately contemporaneous. Furthermore, the state of Al - Si disorder of the K-feldspar, the only rock-forming mineral common to the silica-undersaturated and silica-oversaturated suites, is virtually constant across the McGerrigle system (Wallace 1988). A regional reheating of the older suite of intrusive rocks by a younger intrusive pulse could have been expected to result in local recrystallization of orthoclase in the wall rocks to give low microcline, *i.e.*, a removal of the metastable assemblage of feldspars that is typical of the felsic rocks at McGerrigle. Finally, all components of the McGerrigle com-

plex are found to possess a similar range in Pb, Nd and O isotopic values and a distinctive enrichment in Nb. For example, concentrations for the granite samples exceed those considered typical of I- and A-type granites (Fig. 7), including those of Gaspé and New Brunswick (Whalen 1988, unpubl. data). Enrichment in Nb is characteristic of felsic undersaturated rocks (Table 8, Fig. 5).

As in the case of nepheline syenites from the Monteregian Hills (Eby 1985), those in the McGerrigle complex likely represent the products of fractionation of a mildly alkaline mafic magma(s) derived through a small degree of partial melting of incompatible-element-enriched mantle. Several lines of evidence are consistent with this hypothesis:

(1) The presence of alkaline mafic rocks (up to 6 wt. % normative nepheline) of similar age (Whalen & Roddick 1987) within the pluton confirms that such magmas were contemporaneous with the silica-undersaturated felsic magmas.

(2) The observed depletion of Ca, Sr and Ba, and the well-developed negative Eu anomaly (Fig. 5) of the nepheline syenites are consistent with fractionation of feldspar(s). Depletion of Cr, Ni, Sc and Mg (Table 8) indicates that fractionation of mafic minerals likely also has occurred.

(3) The observed enrichment in incompatible elements (*e.g.*, Rb, Zr, Nb, Th, U, *etc.*), especially in the peralkaline samples (Fig. 5), is consistent with their formation from a highly fractionated residual liquid.

(4) The closeness of compositions to the "nepheline

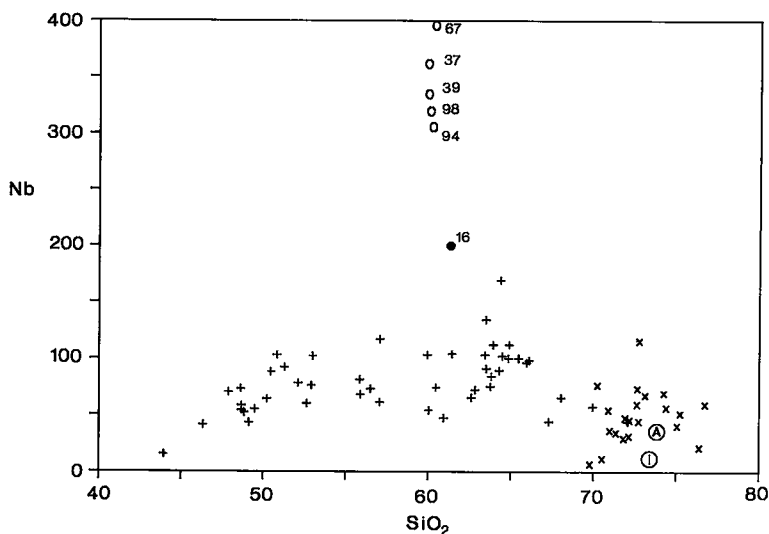


FIG. 7. Plot of silica content (wt.%) versus Nb (ppm) for intrusive rocks of the McGerrigle complex. Symbols: + hybrid suite, x: granite suite, closed circle: miaskitic nepheline syenite WXMG16, open circles: agpaitic nepheline syenite samples WXMG37, 39, 67, 94 and 98. Also plotted are the average I- and A-type granites (circled I and A symbols, respectively) taken from Whalen *et al.* (1987).

syenite" minimum (Fig. 4) and the limited volumes of nepheline syenite are consistent with the final stages of a crystal-fractionation process.

(5) The ϵ_{Nd} values exhibited by the nepheline syenites are typical of juvenile or "mantle-like" material (Whalen *et al.* 1989).

However, the lack of intermediate compositions and data on other isotopic systems complicate this simple model. Observed variations in Pb, O and Sr systems could be explained by varying degrees of crustal interaction. As such a possibility is not reflected in the Nd isotopic data, either the volumes of assimilated crustal material were small, or the process involved volatile transfer or metasomatism of the crustal component in such a way that these isotopic systems were affected but Nd was not. The existence of stronger evidence for a crustal component in the agpaite nepheline syenites (*e.g.*, WXMG37; C. Gariépy, pers. comm. 1989, Wallace 1988) may reflect their comparatively F- and Cl-rich compositions relative to the less alkaline ones (*e.g.*, WXMG16, 94).

Other nepheline syenite occurrences also show evidence of a crustal component. Blaxland *et al.* (1978) attributed the ^{87}Sr enrichment of agpaite syenites from the Ilímaussaq complex to the preferential leaching of ^{87}Sr from the walls and roof of the magma chamber by highly reactive volatile-rich agpaite magmas. Crustal contamination also is indicated in some batches of nepheline syenite of the Red Hill complex, New Hampshire, alluded to earlier, and was documented using isotopic evidence (Foland & Friedman 1977). The juvenile SiO_2 -undersaturated felsic magma may have become mixed with a similar magma derived from wallrocks that had undergone a fenitization-type of metasomatism by an alkali- and rare-element-carrying volatile phase emanating from the mantle (Bailey 1974, Martin & Morogan 1988).

The presence of extremely fractionated felsic undersaturated magmas suggests that fractionation of the alkaline basaltic parent occurred in a very stable magma chamber(s), because of a lack of periodic replenishment by basaltic magma or the very efficient fractionation in an environment where amphibole was undergoing resorption (Bonin & Bardintzeff 1989). Such stability in the magma reservoir is consistent with a tensional environment, possibly associated with rifting or strike-slip faulting in the area (*e.g.*, Bédard 1986). Based on Nd isotopic evidence, Whalen *et al.* (1989, in prep.) concluded that the granites from the Gaspé Peninsula were derived from tectonically buried and accreted Ordovician arc-type rocks or metasomatized Ordovician mantle. Partial melting of such protoliths may have been induced by the introduction of high-temperature mantle-derived mafic magma (*e.g.*, Barker *et al.* 1975, Collerson 1982).

To explain the petrogenetic evolution of the McGerrigle complex as a whole, Whalen & Gariépy (1986) concluded that magma mixing or hybridization has played a major role. They suggested that the interacting magmas included at least one felsic SiO_2 -undersaturated magma, its mildly alkaline parental basic magma, as well as a felsic SiO_2 -oversaturated magma. The "Nb signature" of the McGerrigle suite as a whole can be interpreted as evidence that the large-scale hybridization process involved a felsic silica-undersaturated magma or magmas. As an alternative, the "Nb signature" may be a shared characteristic of the source area, possibly imprinted by metasomatism prior to partial melting.

In conclusion, the mineral assemblages and bulk compositions of the SiO_2 -undersaturated felsic rocks at McGerrigle are complex expressions of superimposed processes, possibly including: metasomatism prior to melting, in the upper mantle as well as the crust, crystal fractionation in batches of alkaline basic magma held in crustal reservoirs, partial melting of crustal rocks, selective contamination from the wall rocks, and large-scale mixing of "incompatible" magmas, of unlike parentage, containing both crustal and mantle components.

ACKNOWLEDGEMENTS

Research costs were covered in part by a Natural Sciences and Engineering Research Council grant to RFM. Field and part of the research costs were covered by the "Plan de développement économique Canada/Gaspésie et Bas Saint-Laurent" projet. We acknowledge the constructive comments of Dr. Clément Gariépy, of the Université du Québec à Montréal; Dr. Gariépy allowed us to quote the ranges of lead-isotope values determined by Francine Robert (M.Sc. candidate at UQAM) and by him. Drs. M.J.K. Flohr, T.J. Armbrustmacher and E.E. Foord provided critical reviews and helpful suggestions.

REFERENCES

- BAILEY, D.K. (1969): The stability of acmite in the presence of H_2O . *Am. J. Sci.* **267A**, 1-16.
- (1974): Melting in the deep crust. *In* The Alkaline Rocks (H. Sørensen, ed.). John Wiley & Sons, New York (436-442).
- BARKER, F., WONES, D.R., SHARP, W.N. & DESBOROUGH, G.A. (1975): The Pikes Peak batholith, Colorado Front Range, and a model for the origin of the gabbro - anorthosite - syenite - potassic granite suite. *Precambrian Res.* **2**, 97-160.
- BARRIÈRE, M. & COTTEN, J. (1979): Biotites and associated minerals as markers of magmatic fractionation and deuterium equilibration in granites. *Contrib. Mineral. Petrol.* **70**, 183-192.

- BÉDARD, J.H. (1986): Pre-Acadian magmatic suites of the southeastern Gaspé Peninsula. *Geol. Soc. Am. Bull.* **97**, 1177-1191.
- BLASI, A. (1977): Calculation of T-site occupancies in alkali feldspar from refined lattice constants. *Mineral. Mag.* **41**, 525-526.
- BLAXLAND, A.B., VAN BREEMEN, O., EMELEUS, C.H. & ANDERSON, J.G. (1978): Age and origin of the major syenite centers in the Gardar province of south Greenland: Rb-Sr studies. *Geol. Soc. Am. Bull.* **89**, 231-244.
- BONIN, B. & BARDINTZEFF, J.-M. (1989): Plutonic rocks from Tahiti-Nui caldera (French Polynesia). II. Evolution of thermodynamical parameters during magma differentiation and emplacement. Applications to other alkaline magmatic provinces. *Bull. Soc. géol. France, sér. 8*, V, 1091-1099.
- BROOKS, C.K., ENGELL, J., LARSEN, L. M. & PEDERSEN, A.K. (1982): Mineralogy of the Werner Bjerge alkaline complex, East Greenland. *Meddr. Grønland Geosci.* **7**.
- BROUSSE, R. & RANÇON, J.P. (1984): Crystallization trends of pyroxenes from agpaitic phonolites (Cantal, France). *Mineral. Mag.* **48**, 39-45.
- BUDDINGTON, A. F. & LINDSLEY, D.H. (1964): Iron-titanium oxide minerals and synthetic equivalents. *J. Petrol.* **5**, 310-357.
- BURNHAM, C.W. (1979): The importance of volatile constituents. In *The Evolution of the Igneous Rocks: Fiftieth Anniversary Perspectives* (H.S. Yoder, Jr., ed.). Princeton University Press, Princeton, New Jersey (439-482).
- CARMICHAEL, I.S.E. (1967): The iron-titanium oxides of salic volcanic rocks and their associated ferromagnesian silicates. *Contrib. Mineral. Petrol.* **14**, 36-64.
- & NICHOLLS, J. (1967): Iron-titanium oxides and oxygen fugacities in volcanic rocks. *J. Geophys. Res.* **72**, 4665-4687.
- COLLIERSON, K.D. (1982): Geochemistry and Rb-Sr geochronology of associated Proterozoic peralkaline and subalkaline anorogenic granites from Labrador. *Contrib. Mineral. Petrol.* **81**, 126-147.
- CURRIE, K.L. (1976): The alkaline rocks of Canada. *Geol. Surv. Can. Bull.* **239**.
- CURTIS, L.W. & CURRIE, K.L. (1981): Geology and petrology of the Red Wine alkaline complex, central Labrador. *Geol. Surv. Can. Bull.* **294**.
- CZAMANSKE, G.K. & WONES, D.R. (1973): Oxidation during magmatic differentiation, Finnmarka complex, Oslo area, Norway. 2. The mafic silicates. *J. Petrol.* **14**, 349-380.
- DE RÖMER, H.S. (1974): Geology and age of some plutons in north-central Gaspé, Canada. *Can. J. Earth Sci.* **11**, 570-582.
- (1977): Région des Monts McGerrigle. *Ministère des Richesses Naturelles, Québec, Rapport géol.* **174**.
- EBY, G.N. (1985): Monteregean Hills. II. Petrology, major and trace element geochemistry, and strontium isotopic chemistry of the eastern intrusions: Mounts Shefford, Brome and Megantic. *J. Petrol.* **26**, 418-448.
- EDGAR, A.D. (1984): Chemistry, occurrence and paragenesis of feldspathoids: a review. In *Feldspars and Feldspathoids - Structures, Properties and Occurrences*. D. Reidel, Dordrecht, Holland (501-532).
- FERGUSON, A.K. (1978): The crystallization of pyroxenes and amphiboles in some alkaline rocks and the presence of a pyroxene compositional gap. *Contrib. Mineral. Petrol.* **67**, 11-15.
- FLETCHER, C.J.N. & BEDDOE-STEPHENS, B. (1987): The petrology, chemistry and crystallization history of the Velasco alkaline province, eastern Bolivia. In *Alkaline Igneous Rocks* (J.G. Fitton & B.G.J. Upton, eds.). *Geol. Soc. London, Spec. Publ.* **30**, 403-413.
- FOLAND, K.A. & FRIEDMAN, I. (1977): Application of Sr and O isotope relations to the petrogenesis of the alkaline rocks of the Red Hill complex, New Hampshire, USA. *Contrib. Mineral. Petrol.* **65**, 213-225.
- FUDALI, R.F. (1963): Experimental studies bearing on the origin of pseudoleucite and associated problems of alkali rock systems. *Geol. Soc. Am. Bull.* **74**, 1101-1126.
- GERASIMOVSKY, V.I. (1974): Trace elements in selected groups of alkaline rocks. In *The Alkaline Rocks* (H. Sørensen, ed.). John Wiley & Sons, New York (402-412).
- GOMES, C. DE B., MORO, S.L. & DUTRA, C.V. (1970): Pyroxenes from the alkaline rocks of Itapirapua, São Paulo, Brazil. *Am. Mineral.* **55**, 224-230.
- HAGGERTY, S.E. (1976): Opaque mineral oxides in terrestrial igneous rocks. In *Oxide Minerals* (D. Rumble III, ed.). *Rev. Mineral.* **3**, Hg101-300.
- HAMILTON, D.L. & MACKENZIE, W.S. (1965): Phase equilibrium in the system NaAlSi₃O₈-KAlSi₃O₈-SiO₂-H₂O. *Mineral. Mag.* **34**, 214-231.
- HEWITT, D.A. & WONES, D.R. (1984): Experimental phase relations of the micas. In *Micas* (S. W. Bailey, ed.). *Rev. Mineral.* **13**, 201-256.
- ISLAM, S., HESSE, R. & CHAGNON, A. (1982): Zonation of diagenesis and low-grade metamorphism in Cambro-Ordovician flysch of Gaspé Peninsula, Quebec Appalachians. *Can. Mineral.* **20**, 155-167.

- KOGARKO, L.N. (1974): Role of volatiles. In *The Alkaline Rocks* (H. Sørensen, ed.). John Wiley & Sons, New York (474-487).
- KROLL, H. & RIBBE, P.H. (1983): Lattice parameters, composition and Al, Si order in alkali feldspars. In *Feldspar Mineralogy* (P.H. Ribbe, ed., 2nd edition). *Rev. Mineral.* **2**, 57-99.
- LAIRD, J. & ALBEE, A.L. (1981): High-pressure metamorphism in mafic schist from northern Vermont. *Am. J. Sci.* **281**, 97-126.
- LA ROCQUE, C. (1986): *Geochronology and Petrology of North-Central Gaspé Igneous Rocks, Québec*. M.Sc. thesis, McGill Univ., Montreal, Quebec.
- LARSEN, L.M. (1976): Clinopyroxenes and coexisting mafic minerals from the alkaline Ilímaussaq intrusion, south Greenland. *J. Petrol.* **17**, 258-290.
- (1977): Aenigmatites from the Ilímaussaq intrusion, south Greenland: chemistry and petrological implications. *Lithos* **10**, 257-270.
- LEAKE, B.E. (1978): Nomenclature of amphiboles. *Can. Mineral.* **16**, 501-520.
- MACDONALD, R. & SAUNDERS, M.J. (1973): Chemical variation in minerals of the astrophyllite group. *Mineral. Mag.* **39**, 97-111.
- MARSH, J.S. (1975): Aenigmatite stability in silica-undersaturated rocks. *Contrib. Mineral. Petrol.* **50**, 135-144.
- MARTIN, R.F. (1973): Controls on ordering and sub-solidus phase relations in the alkali feldspars. *Proc. NATO Advanced Study Institute on Feldspars* (W.S. MacKenzie & J. Zussman, eds.). Manchester Univ. Press, Manchester, England.
- & MOROGAN, V. (1988): Partial melting of fenitized crustal xenoliths in the Oldoinyo Lengai carbonatitic volcano, Tanzania: reply. *Am. Mineral.* **73**, 1468-1471.
- MITCHELL, R.H. & PLATT, R.G. (1982): Mineralogy and petrology of nepheline syenites from the Coldwell alkaline complex, Ontario, Canada. *J. Petrol.* **23**, 186-214.
- MORIMOTO, N. (1989): Nomenclature of pyroxenes. *Can. Mineral.* **27**, 143-156.
- NEUMANN, E.-R. (1974): The distribution of Mn²⁺ and Fe²⁺ between ilmenites and magnetites in igneous rocks. *Am. J. Sci.* **274**, 1074-1088.
- NIELSEN, T.F.D. (1979): The occurrence and formation of Ti-aegirines in peralkaline syenites. An example from the Tertiary ultramafic alkaline Gardiner Complex, East Greenland. *Contrib. Mineral. Petrol.* **69**, 235-244.
- PEARCE, J.A. (1982): Trace element characteristics of lavas from destructive plate boundaries. In *Andesites* (R.S. Thorpe, ed.). John Wiley & Sons, New York (525-548).
- , ALABASTER, T., SHELTON, A.W. & SEARLE, M.P. (1981): The Oman ophiolite as a Cretaceous arc-basin complex: evidence and implications. *Phil. Trans. R. Soc. London, Ser. A*, **300**, 299-317.
- RIBBE, P.H. (1983): Chemistry, structure and nomenclature of feldspars. In *Feldspar Mineralogy* (P. H. Ribbe, ed., 2nd edition). *Rev. Mineral.* **2**, 1-19.
- ROBERT, F., GARIEPY, C. & WHALEN, J.B. (1988): Pb-isotopic geochemistry of the Topsails, Mt. McGerrigle and Eastern Townships granitoid intrusives. *Geol. Assoc. Can. - Mineral. Assoc. Can. Program Abstr.* **13**, A104.
- ROBINSON, P. (1980): The composition space of terrestrial pyroxenes - internal and external limits. In *Pyroxenes* (C.T. Prewitt, ed.). *Rev. Mineral.* **7**, 419-494.
- ROCK, N.M.S. (1978): Petrology and petrogenesis of the Monchique alkaline complex, southern Portugal. *J. Petrol.* **19**, 171-214.
- (1982): Chemical mineralogy of the Monchique alkaline complex, southern Portugal. *Contrib. Mineral. Petrol.* **81**, 64-78.
- SØRENSEN, H. (1974): Alkali syenites, feldspathoidal syenites and related lavas. In *The Alkaline Rocks* (H. Sørensen, ed.). John Wiley & Sons, New York (22-52).
- SPEER, J.A. (1984): Micas in igneous rocks. In *Micas* (S.W. Bailey, ed.). *Rev. Mineral.* **13**, 299-356.
- STEPHENSON, D. (1972): Alkali clinopyroxenes from nepheline syenites of the South Qôroq centre, south Greenland. *Lithos* **5**, 187-201.
- TYLER, R.C. & KING, B.C. (1967): The pyroxenes of the alkaline igneous complexes of eastern Uganda. *Mineral. Mag.* **36**, 5-21.
- VAN BOSSE, J.Y. & WILLIAMS-JONES, A.E. (1988): Chemographic relationships of biotite and cordierite in the McGerrigle thermal aureole, Gaspé, Quebec. *J. Metamorph. Geol.* **6**, 65-75.
- WALLACE, G.M. (1986): The mineralogy of the McGerrigle plutonic complex, Gaspé, Quebec. *Geol. Surv. Can., Pap.* **86-1A**, 507-514.
- (1988): *Petrogenesis of the McGerrigle Plutonic Complex, Gaspé, Quebec*. M.Sc. thesis, McGill University, Montreal, Quebec.
- WATSON, E.B. (1979): Zircon saturation in felsic liquids: experimental results and applications to trace element geochemistry. *Contrib. Mineral. Petrol.* **70**, 407-419.

- WHALEN, J.B. (1985): The McGerrigle plutonic complex, Gaspé, Québec: evidence of magma mixing and hybridization. *Geol. Surv. Can., Pap.* **85-1A**, 795-800.
- _____ (1987): Geology of the McGerrigle Mountains plutonic complex, Gaspésie Peninsula, Quebec. *Geol. Surv. Can. Map* **1665A**.
- _____ (1988): Granitic rocks of New Brunswick and Gaspé, Quebec: a transect across the southern Canadian Appalachians. *Geol. Assoc. Can. - Mineral. Assoc. Can. Program Abstr.* **13**, A133.
- _____, CURRIE, K.L. & CHAPPELL, B.W. (1987): A-type granites: geochemical characteristics, discrimination, and petrogenesis. *Contrib. Mineral. Petrol.* **95**, 407-419.
- _____ & GARIÉPY, C. (1986): Petrogenesis of the McGerrigle plutonic complex, Gaspé, Québec: a preliminary report. *Geol. Surv. Can., Pap.* **86-1A**, 265-274.
- _____, HEGNER, E. & JENNER, G. (1989): Nature of Canadian Appalachian basement terranes as inferred from a Nd isotopic transect. *Geol. Soc. Am., Abstr. Program* **21(6)**, A201.
- _____ & RODDICK, J.C.M. (1987): K-Ar geochronology of the McGerrigle plutonic complex, Gaspésie Peninsula, Québec. *Geol. Surv. Can., Pap.* **87-1A**, 375-380.
- WHITE, M.V.W. & MARTIN, R.F. (1980): The metasomatic changes that accompany uranium mineralization in the nonorogenic rhyolites of the Upper Aillik Group, Labrador. *Can. Mineral.* **18**, 459-479.
- WONES, D.R. & EUGSTER, H.P. (1965): Stability of biotite: experiment, theory, and application. *Am. Mineral.* **50**, 1228-1272.
- WOOLLEY, A.R. (1987): *Alkaline Rocks and Carbonatites of the World. 1. North and South America*. University of Texas Press, Austin, Texas.
- _____ & PLATT, R.G. (1988): The peralkaline nepheline syenites of the Junguni intrusion, Chilwa province, Malawi. *Mineral. Mag.* **52**, 425-433.

Received September 6, 1989, revised manuscript accepted March 5, 1990.