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Résumé de l'article

De petites intrusions ignées gabbroïques et de faibles quantités de roches volcano-mafiques sont présentes dans la région de St. Peters, dans le sud-ouest de l'île du Cap-Breton. Une datation au U-Pb à partir de zircon et de baddeleyite révèle que le gabbro est âgé de 339 ± 2 Ma et qu'il remonte donc au Carbonifère inférieur, similairement aux unités sédimentaires des groupes de Horton et de Windsor. Les gabbros ont atteint une faible profondeur, conformément à leur association avec les roches volcano-mafiques. Des études pétrologiques permettent de supposer que l'évolution des gabbros a comporté un fractionnement d'olivine et de pyroxène riches en Mg, mais pas de fractionnement de plagioclase important. Les caractéristiques chimiques de la série ont été partiellement modifiées par altération, comme le démontrent l'albitisation du plagioclase et les zones d'altération du carbonate, mais elles révèlent généralement une compaction tectonique intra-plaque continentale et une affinité tholéitique. Le magma parental a pu être appauvri d'éléments lourds des terres rares et il provient probablement d'une source mantellique grenatifère. Les gabbros et les basaltes de St. Peters font partie de l'activité ignée générée du milieu du Devonien au Carbonifère dans les provinces de l'Atlantique, laquelle est apparemment liée à l'extension survenue pendant le développement du bassin des Maritimes.

Early Carboniferous gabbro and basalt in the St. Peters area, southern Cape Breton Island, Nova Scotia

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Small gabbroic plutons and minor mafic volcanic rocks occur in the St. Peters area of southwestern Cape Breton Island. U-Pb dating of zircon and baddeleyite show that the gabbro has an Early Carboniferous age of 339 ± 2 Ma, similar to the age of the surrounding sedimentary units of the Horton and Windsor groups. The gabbros were intruded at shallow depth, consistent with their association with minor mafic volcanic rocks. Petrological studies suggest that evolution of the gabbros involved fractionation of Mg-rich olivine and pyroxene, but not significant plagioclase. The chemical characteristics of the suite have been partly modified by alteration, evidenced in albitization of plagioclase and zones of carbonate alteration, but generally indicate a continental within-plate tectonic setting and tholeiitic affinity. The parent magma may have been depleted in heavy rare-earth elements, and was possibly derived from a garnet-bearing mantle source. The St. Peters gabbros and basalts are part of widespread mid-Devonian to Carboniferous igneous activity in Atlantic Canada, apparently related to extension during the development of the Maritimes Basin.

De petites intrusions ignées gabbroïques et de faibles quantités de roches volcano-mafiques sont présentes dans la région de St. Peters, dans le sud-ouest de l'île du Cap-Breton. Une datation au U-Pb à partir de zircon et de baddeleyite révèle que le gabbro est âgé de 339 ± 2 Ma et qu'il remonte donc au Carbonifère inférieur, similairement aux unités sédimentaires des groupes de Horton et de Windsor. Les gabbros ont été pénétrés à une faible profondeur, conformément à leur association avec les roches volcano-mafiques. Des études pétrologiques permettent de supposer que l'évolution des gabbros a comporté un fractionnement d'olivine et de pyroxène riches en Mg, mais pas de fractionnement de plagioclase important. Les caractéristiques chimiques de la série ont été partiellement modifiées par altération, comme le démontrent l'albitisation du plagioclase et les zones d'altération du carbonate, mais elles révèlent généralement une compaction tectonique intra-plaque continentale et une affinité tholéiitique. Le magma parental a pu être appauvri d'éléments lourds des terres rares et il provient possiblement d'une source mantélique grenatifère. Les gabbros et les basaltes de St. Peters font partie de l'activité ignée générale du milieu du Dévonien au Carbonifère dans les provinces de l'Atlantique, laquelle est apparemment reliée à l'extension survenue pendant le développement du bassin des Maritimes.

[Traduit par la rédaction]

INTRODUCTION

Small gabbroic plutons and minor mafic volcanic rocks occur in association with Late Devonian(?) and Lower Carboniferous sedimentary rocks in the St. Peters area of southern Cape Breton Island (Figs. 1, 2). They have been an intriguing problem in Nova Scotian geology because of uncertainty about their age and hence about their geological significance. Weeks (1954, 1964) considered them to be of Early Carboniferous age, but other workers assumed ages ranging from Late Precambrian (Keppie and Smith, 1978) to Mesozoic (Durocher, 1974). A Late Precambrian - Cambrian age has been accepted in most recent publications (e.g., Keppie, 1979; Donohoe and Grantham, 1989), although a K-Ar date of 347 ± 36 Ma was determined for biotite from one of the gabbros by Wanless *et al.* (1979), and Rb-Sr whole rock and biotite analyses yielded a two-point isochron indicating an age of 298 Ma (R.F. Cormier, personal communication cited by Keppie and Smith, 1978). Keppie and Smith

(1978) considered these dates to be unreliable, suggesting that they are either cooling ages or a reflection of reheating during the Acadian Orogeny and/or Maritime Disturbance. In addition to uncertainty about the age, the petrological characteristics of the gabbros and associated volcanic rocks were not well known. Previous studies were limited in scope and consisted mainly of major element geochemistry (Davis, 1972; Durocher, 1974; Keppie and Smith, 1978); they did not lead to a definitive interpretation of either chemical character or tectonic setting.

We report here the results of a study of the St. Peters gabbros and associated volcanic rocks, which included mapping, petrological work, and U-Pb dating of zircon and baddeleyite. Our data confirm the interpretation of Weeks (1954, 1964) that the rocks are of Early Carboniferous age, and also suggest that they are tholeiites formed in a continental within-plate extensional setting.

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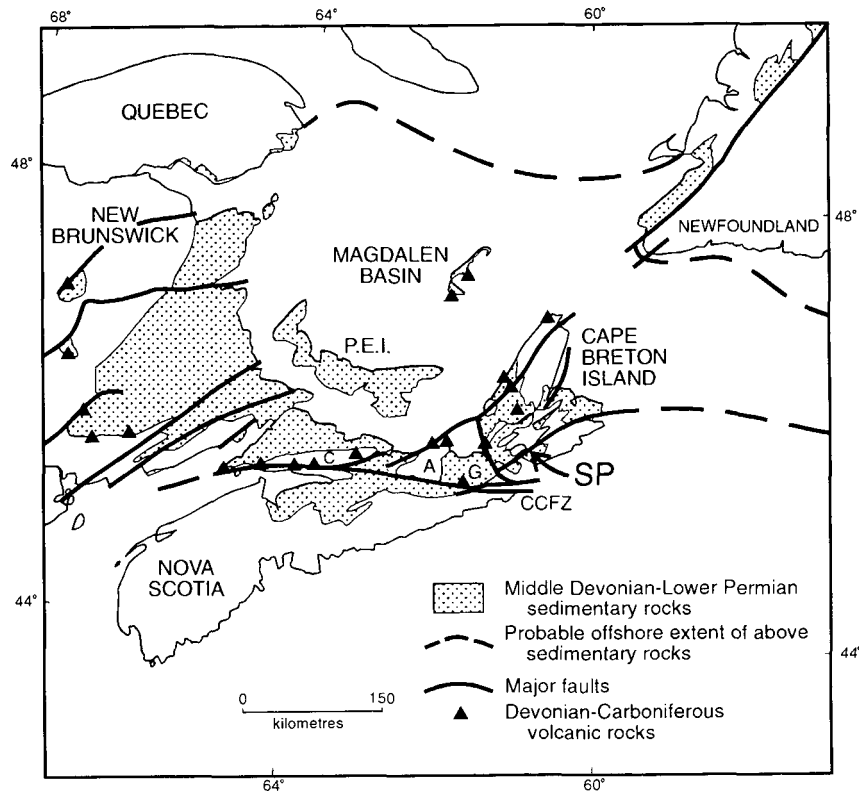


Fig. 1. Outline map of the Maritime provinces showing the location of the St. Peters area gabbros (arrow labelled SP). The area underlain by Middle Devonian - Lower Permian sedimentary rocks is the Maritimes Basin. Triangles represent approximate locations of Devonian - Carboniferous volcanic rocks mentioned in the text: Fisset Brook Formation and correlative units in Cape Breton Island, Guysborough area (G), Fountain Lake Group and associated plutonic units in the Cobequid Highlands, the Magdalen Islands, and various areas in New Brunswick (after Fyffe and Barr, 1986). Map is modified after Piper *et al.* (1993) and Jansa *et al.* (1993). Abbreviations: SP = St. Peters area, G = Guysborough area, CCFZ = Cobequid - Chedabucto fault zone, PEI = Prince Edward Island.

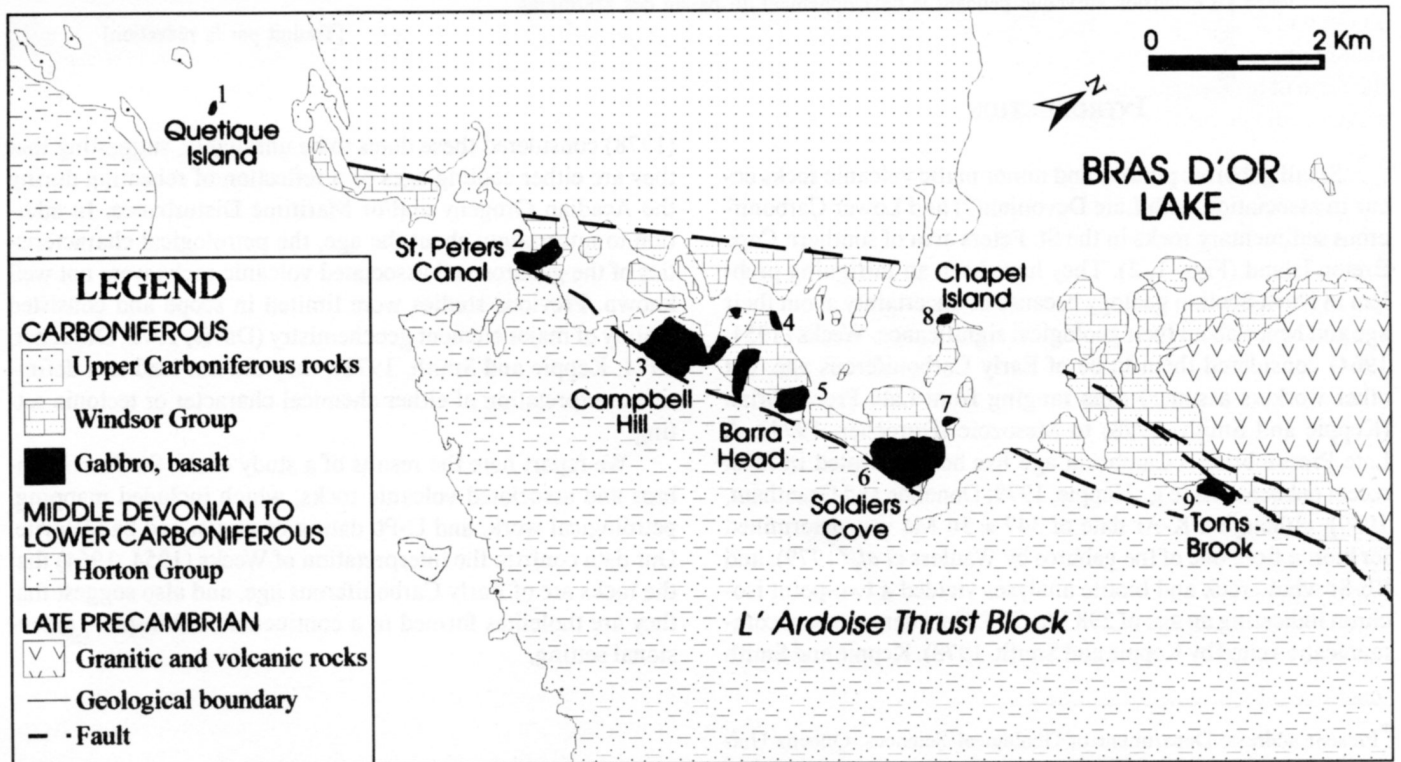


Fig. 2. Geological map showing distribution of gabbroic plutons and volcanic rocks in the St. Peters area. 1, Quetique island gabbro; 2, St. Peters Canal gabbro; 3, Campbell Hill gabbro; 4, Macleans Point basalt; 5, Barra Head gabbro (two bodies); 6, Soldiers Cove West gabbro; 7, Alick Island gabbro; 8, Chapel island basalt; 9, Toms Brook gabbro. Map is modified after Weeks (1964) and Keppie and Smith (1978).

GEOLOGICAL SETTING

The gabbroic bodies occur in a fault-bounded linear belt (Figs. 1, 2), called the Lennox Passage - St. Peters lineament (Keppie and Smith, 1978), at the margin of the L'Ardoise thrust block of Weeks (1954, 1964). They are surrounded by sedimentary rocks, mainly of the Lower Carboniferous Windsor Group. The underlying Upper Devonian to Lower Carboniferous Horton Group occurs mainly south of the plutons in the L'Ardoise thrust block (Fig. 2). The plutons have been assigned informal names based on appropriate geographic locations (Appendix A; Fig. 2).

The shapes of the plutons and the presence of fine-grained to glassy rocks that appear to represent chilled margins suggest an intrusive relationship with the surrounding sedimentary rocks, but no evidence of contact metamorphism was observed around any of the intrusions. Weeks (1954) reported that the gabbros intruded strata of both the Horton Group and the lower part of the Windsor Group, but did not describe the evidence for this intrusive relationship. In contrast, Keppie and Smith (1978) suggested that the contacts with the Carboniferous rocks are entirely faulted or unconformable, in support of their interpretation that the gabbros are Precambrian in age.

Our observations confirm that, where exposed, contacts appear to be either faults or unconformities. On Quetique Island (Fig. 2), a faulted contact is exposed between the Quetique Island gabbro and folded limestone of the Windsor Group, with fault breccia developed in both units. At the southern contact of the St. Peters Canal gabbro (#2, Fig. 2), a gap in exposure of about 1 m separates brecciated gabbro from siltstone, also suggesting the presence of a fault. Along the coast north of the Campbell Hill gabbro (#3, Fig. 2), a layer of gabbro, about 5 to 7 m in width, occurs between sandstone outcrops. Although the gabbro appears to be conformable with the sandstone and has the form of a small sill, the sandstone, which exhibits well preserved sedimentary lamination, shows no evidence of contact metamorphism. The Toms Brook gabbro (#9, Fig. 2) is unconformably overlain by a conglomerate containing pebbles and cobbles of gabbro, as well as granite, sandstone, and shale. On the basis of miospores and acritarchs recovered from sedimentary samples from nearby locations by Utting (1977), Keppie and Smith (1978) suggested that the conglomerate is part of the Horton Group and of Middle Devonian to Early Carboniferous age. However, based on the U-Pb age for the St. Peters Canal gabbro reported below, the fossiliferous samples may not be from the same unit as the conglomerate.

In places, the plutons contain features such as interstitial granophyric intergrowths, pegmatoid patches, and miarolitic cavities which indicate that they are high-level intrusions. In several areas they are autobrecciated and display intense carbonate alteration. Small areas of mafic volcanic rocks are associated with the gabbros, although exposure is poor and interlayering of volcanic and sedimentary rocks cannot be demonstrated. On Chapel Island (#8, Fig. 2), the basalt is amygdaloidal and occurs with minor basaltic tuff; similar basalt also occurs near MacLean Point (#4, Fig. 2). Glassy basaltic rocks are present locally in the Soldiers Cove West pluton (#6, Fig.

2), and areas of fine-grained rocks of possible extrusive origin also were found in several other plutons.

On Alick Island (#7, Fig. 2), fine-grained gabbro forms thin layers that appear to be the result of multiple injection of magma in sheeted dykes.

The only felsic igneous rocks observed in the St. Peters area are two pink felsic dykes, one about 20 cm in width parallel to a prominent joint plane in the St. Peters Canal gabbro, and the other of similar size in the Campbell Hill gabbro. These felsic dykes appear very altered, with abundant epidote and manganese minerals. Due to their small size and intense alteration, no chemical studies were done on these dykes.

PETROGRAPHY

The most abundant rock type in the plutons is medium- to coarse-grained gabbro, dominated by plagioclase and clinopyroxene with minor amphibole, biotite, opaque minerals, and other accessory phases, including apatite, zircon, and baddeleyite. Relict olivine was observed only in the Quetique Island gabbro, but olivine pseudomorphs are present in some samples from the St. Peters Canal gabbro, and olivine has also been reported in the Toms Brook gabbro (Douglas and Goodman, 1940), although it is not present in our samples. Textures are mainly intergranular to ophitic or sub-ophitic. Rare pegmatoid patches contain coarse plagioclase and interstitial amphibole and biotite. Fine-grained gabbro, generally found near margins of the plutons, is more varied in texture than the medium- to coarse-grained gabbro, and also more altered. Some varieties are porphyritic with plagioclase phenocrysts, and groundmass plagioclase displays alignment as a result of flow. Interstitial glass is present in several of the fine-grained samples. The amygdaloidal basaltic flows on Chapel Island and at MacLeans Point contain sparse plagioclase phenocrysts, and amygdales contain carbonate and chlorite. The basalts show intense alteration to saussurite, chlorite, epidote, and carbonate.

Plagioclase forms 50 to 60% of most gabbro samples and shows moderate to intense alteration to sericite, albite, carbonate minerals, and epidote. Compositions determined optically and by electron microprobe are about An₆₀ in the least altered grains. Clinopyroxene and its alteration products (chlorite, epidote, uralite, biotite, carbonate minerals, and iron oxides) comprise between 30 and 40% of the gabbro. Analyses of several grains in six samples indicate that clinopyroxene is of salite composition (average Ca:Mg:Fe = 45:43:12), but with variable amounts of minor components Cr, Ni, Ti, and Na (Grammatikopoulos, 1992). Relict olivine in the Quetique Island gabbro ranges in composition from Fo₈₀ to Fo₇₇, with NiO content of 0.31 to 0.15 wt. % (Grammatikopoulos, 1992). The high proportion (65%) of olivine and pyroxene in this sample suggests that it is a cumulate.

Amphibole and mica occur around the rims of clinopyroxene grains, as well as interstitially, in the medium- to coarse-grained gabbro samples. The amphibole exhibits dark brown to green pleochroism, and electron microprobe analyses of amphibole in olivine gabbro sample #1 from Quetique Island indicated pargasitic composition. The mica is pleochroic in

Table 1. Major and trace element analyses from the St. Peters gabbros.

	1	2	3	4	5	6	7	8	9	10	11	12
SiO ₂	39.25	49.10	47.65	48.64	43.20	47.63	49.01	50.46	48.76	50.78	48.41	51.23
TiO ₂	1.04	2.09	3.54	2.14	4.09	2.94	2.60	2.98	2.32	2.81	3.03	2.13
Al ₂ O ₃	8.12	16.65	15.64	16.53	12.97	16.18	16.41	13.51	14.12	14.52	14.63	17.14
Fe ₂ O ₃	14.47	9.11	12.64	10.06	18.47	12.83	10.68	13.62	13.11	11.34	12.94	6.65
MnO	0.38	0.16	0.23	0.13	0.17	0.15	0.09	0.17	0.06	0.15	0.46	0.09
MgO	20.75	5.22	5.18	5.01	6.03	4.16	5.03	4.99	4.67	5.27	5.01	5.53
CaO	4.36	8.97	6.89	9.20	9.85	7.61	6.46	6.34	5.34	5.90	6.27	7.85
Na ₂ O	0.91	4.51	4.20	4.26	3.03	4.37	4.62	5.31	5.07	5.69	4.52	5.15
K ₂ O	0.49	1.09	1.10	0.82	0.73	1.47	0.37	0.48	0.13	0.62	0.50	0.55
P ₂ O ₅	0.17	0.27	0.26	0.26	0.18	0.27	0.35	0.28	0.20	0.41	0.33	0.02
LOI	9.40	2.10	1.40	2.00	0.60	1.50	3.20	1.80	6.30	2.00	3.20	3.00
Total	99.34	99.27	98.73	99.05	99.32	99.11	98.82	99.94	100.08	99.49	99.30	99.34
Ba	175	410	425	301	309	376	282	189	34	229	362	248
Rb	7	10	12	7	8	19	3	5	5	7	7	6
Sr	462	1129	944	929	825	1113	771	725	232	1112	669	590
Y	7	14	12	15	15	16	16	22	17	23	25	17
Zr	58	101	99	83	84	144	113	135	92	183	131	100
Nb	9	14	15	13	12	16	18	10	9	19	19	13
Cu	103	67	93	63	155	156	70	134	33	39	91	8
Pb	767	--	314	10	10	19	--	44	10	10	345	10
Zn	1624	179	779	62	158	159	68	286	31	72	796	53
Ni	861	86	45	55	63	43	70	56	77	51	61	27
Cr	826	209	43	131	11	26	136	136	187	145	127	93
V	89	172	359	193	638	360	217	279	195	258	245	133
Ga	11	21	22	21	29	25	20	26	23	25	26	21

¹Analyses by X-ray fluorescence at the Nova Scotia Regional Geochemical Centre, St. Mary's University, Halifax. Precision is about 5% for major elements and 3 to 10% for trace elements, based on replicate analyses of internal standards. Total iron is reported as Fe₂O₃. LOI is loss-on-ignition (% weight loss after heating for one hour at 1000°C).

²Sample locations and descriptions are listed in Appendix A.

shades of dark to pale brown and ranges in composition from titaniferous phlogopite (in olivine gabbro sample #1) to biotite.

Opaque phases are a major component in some samples, forming up to 10% in sample #5 from the St. Peters Canal gabbro. Titaniferous magnetite and ilmenite are the dominant opaque phases. The gabbro body in Toms Brook has been investigated as a possible source of magnetite (Shaw, 1988).

GEOCHEMISTRY

Twenty-four samples were analyzed (Table 1; Appendix A), representing nine plutons and flows in the St. Peters area, and including the textural varieties described above. Loss-on-ignition values show wide variation, generally consistent with the degree of alteration in the samples. The highest value is 9.4% in the Quetique Island olivine gabbro (sample 1), consistent with the abundance of serpentinized olivine in the sample. Because of the variation in loss-on-ignition values, the major ele-

ment oxides were recalculated to total 100% on a volatile-free basis before plotting on the diagrams discussed below.

Silica contents in all except two of the gabbro samples have a limited range in recalculated values between about 49 and 53% (Fig. 3a). The two exceptions are cumulate olivine gabbro sample #1 from Quetique Island and opaque mineral-rich St. Peters Canal gabbro sample #5; both are ultramafic in terms of their SiO₂ contents. Because of the limited variation in silica in the sample suite as a whole, the FeO^t/MgO ratio is used as the x-axis on variation diagrams (Figs. 3, 4, 5). This ratio ranges from 0.6 to 2.8, and hence is better than SiO₂ for revealing chemical trends among the samples.

Excluding the anomalous gabbro samples 1 and 5 noted above, Al₂O₃, MgO, Ni, and Cr show negative correlation with FeO^t/MgO ratio (Figs. 3, 4), whereas TiO₂, FeO^t, V (Fig. 5), and Cu (not shown) show positive correlation. The trend in Ni tends to flatten in samples with FeO^t/MgO more than about 2. Na₂O (Fig. 5), as well as CaO, K₂O, Sr, Ba, and Rb (plots not

Table 1 continued.

	13	14	15	16	17	18	19	20	21	22	23	24
SiO ₂	49.37	49.95	47.53	49.49	47.34	47.26	48.72	49.36	50.90	47.85	48.61	47.48
TiO ₂	2.73	2.35	2.68	2.42	2.28	2.24	1.98	2.20	2.28	1.87	2.23	2.28
Al ₂ O ₃	14.91	15.50	14.86	15.15	14.80	15.02	16.92	15.71	16.09	16.72	14.48	15.74
Fe ₂ O ₃	12.61	10.80	11.31	11.10	10.73	10.97	9.92	10.77	8.22	11.28	11.88	11.20
MnO	0.20	0.15	0.48	0.16	0.15	0.19	0.12	0.15	0.11	0.18	0.09	0.19
MgO	5.78	6.30	4.75	5.98	6.42	6.66	6.26	6.60	6.91	7.22	5.46	5.41
CaO	6.51	6.77	7.60	6.57	7.49	7.54	6.62	6.86	6.66	5.57	6.62	8.21
Na ₂ O	4.24	4.32	5.49	4.73	4.57	3.67	3.78	4.07	4.62	3.02	5.49	4.08
K ₂ O	0.72	1.02	0.28	0.78	0.31	0.34	1.04	0.42	0.31	2.20	0.57	0.75
P ₂ O ₅	0.30	0.27	0.32	0.32	0.29	0.28	0.28	0.21	0.17	0.92	0.39	0.34
LOI	1.80	2.00	4.00	2.60	5.20	4.90	2.70	2.00	2.00	4.10	4.70	2.80
Total	99.17	99.43	99.32	99.30	99.07	99.07	98.34	98.35	98.27	100.93	100.52	98.48
Ba	240	290	249	280	206	220	282	130	56	1378	180	240
Rb	10	15	3	7	5	5	20	7	5	35	10	9
Sr	828	773	675	642	655	710	735	709	665	1179	372	797
Y	21	16	16	15	18	17	18	18	19	30	21	17
Zr	108	106	126	118	124	99	125	125	108	323	137	127
Nb	17	14	16	14	14	12	12	9	12	30	18	14
Cu	70	57	46	138	6	34	53	43	12	16	63	60
Pb	75	--	623	--	10	10	47	10	10	13	6	23
Zn	268	113	2069	112	105	84	177	107	107	289	132	145
Ni	60	81	62	146	157	172	144	124	87	185	44	92
Cr	110	165	139	281	260	261	221	223	184	185	159	176
V	233	199	242	209	204	193	161	200	181	169	149	190
Ga	23	21	19	19	23	19	21	22	20	22	20	23

shown), do not show any significant correlation with FeO^t/MgO, and their scatter may partly reflect the alteration apparent in thin section. P₂O₅ shows a peak at about FeO^t/MgO = 2, and then decreases, probably reflecting apatite fractionation (Fig. 4). In general, no consistent chemical differences are apparent among plutons or textural varieties, other than a tendency for fine-grained samples to have lower K₂O, Rb, and Ba than medium- to coarse-grained samples, perhaps a result of more intense alteration (Fig. 6a). The chemical trends in the gabbroic suite are consistent with a major role for Mg-rich olivine and pyroxene fractionation. The increase in FeO^t, V and TiO₂ with FeO^t/MgO ratio shows that minerals such as magnetite and ilmenite were not being removed by fractionation processes.

Olivine gabbro sample #1, in addition to having low SiO₂ content, also has the lowest FeO^t/MgO and TiO₂, Al₂O₃, CaO, Na₂O, V, Zr, and Y contents, and the highest MgO, FeO^t, Ni, Cr, and Zn (Fig. 6b), and is also relatively high in MnO and Cu. Its low FeO^t/MgO and correspondingly high Mg# (Mg/Mg+Fe = 74), as well as high Ni and Cr contents, are consistent with its interpretation as a cumulate, and hence not representative of a magmatic composition; primary mantle-derived melts have Mg# about 66, and Cr and Ni about 300 ppm (Basaltic Volcanism Study Project, 1981).

Basalt sample #11 from MacLeans Point is chemically simi-

lar to the gabbros (Fig. 6b). However, basalt sample #22 from Chapel Island shows some large chemical differences compared to the gabbros, in particular high K₂O, P₂O₅, Rb, Ba, Y, Zr, and Nb contents (Fig. 6b). More sampling is required in order to test investigate the significance of these differences.

Relatively high Na₂O contents in the St. Peters gabbros led previous workers to suggest that the suite is alkalic (Davis, 1972; Durocher, 1974; Keppie and Smith, 1978). However, the extent of albitization in the plagioclase evident in microprobe analyses (Grammatikopoulos, 1992) suggests that the rocks may have experienced sodic metasomatism, and hence that alkali elements are not likely to be reliable indicators of chemical affinity. Multi-element variation diagrams (Fig. 6a) show scatter in the more mobile incompatible elements, but much less variation in the typically less mobile elements Nb, P₂O₅, Zr, and TiO₂. As discussed above, the variations in Cr and Ni can be attributed to fractional crystallization processes within the gabbroic magmas. The average abundances for Nb, P₂O₅, Zr, and TiO₂ are similar to those in the average within-plate tholeiite of Pearce (1982), and lower than those in the average alkalic basalt. However, V contents of the gabbros are more similar to those in the average alkalic basalt, as are their V/Ti values of more than 50 (Shervais, 1977). Low Y values are also characteristic of the samples, averaging 17 ppm, compared to values

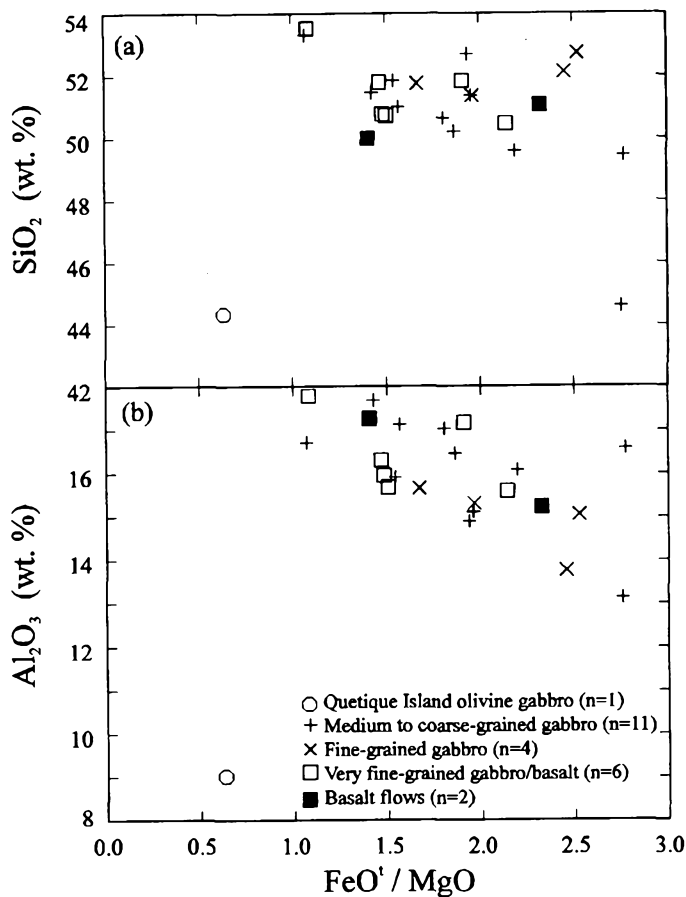


Fig. 3. Plots of SiO_2 and Al_2O_3 against FeO^t/MgO .

of 26 and 25 cited by Pearce (1982) for within-plate tholeiitic and within-plate alkalic basalts, respectively.

On the Ti-Zr-Y diagram (Fig. 7a), the St. Peters samples plot mainly in the within-plate field, with a spread toward higher Ti values; their position also reflects the low Y contents in most samples. On the Nb-Zr-Y diagram (Fig. 7b), they plot almost entirely in the field for both within-plate tholeiitic and within-plate alkalic basalts.

Four samples analyzed for rare-earth elements (Table 2) show relative enrichment in light REE compared to the heavy REE, with light REE about 20 to 30 times chondritic values, and heavy REE 2 to 5 times chondritic values (Fig. 8). Olivine gabbro sample 1 has the lowest absolute REE abundances (Table 2). The other three samples (3, 5 and 4) have almost identical chondrite-normalized patterns and all of the samples show a slight positive Eu anomaly, consistent with other chemical data discussed above which indicate that plagioclase was not an important fractionating phase. The degree of light REE enrichment is similar to that for continental within-plate tholeiitic suites such as Columbia Plateau, and less than that for typical within-plate alkalic suites such as that of the Gregory Rift in East Africa (Fig. 8). The Ta and Hf values in these four samples (average 2.0 and 0.84 ppm, respectively; Table 2) are also more similar to the values for within-plate tholeiitic basalts (average 3.44 and 0.73 ppm, respectively; Pearce, 1982) than those for within-plate alkalic basalts (average 6.36 and 5.9 ppm, respectively; Pearce, 1982). Overall, tholeiitic affinity seems more likely than alkalic on the basis of these elements.

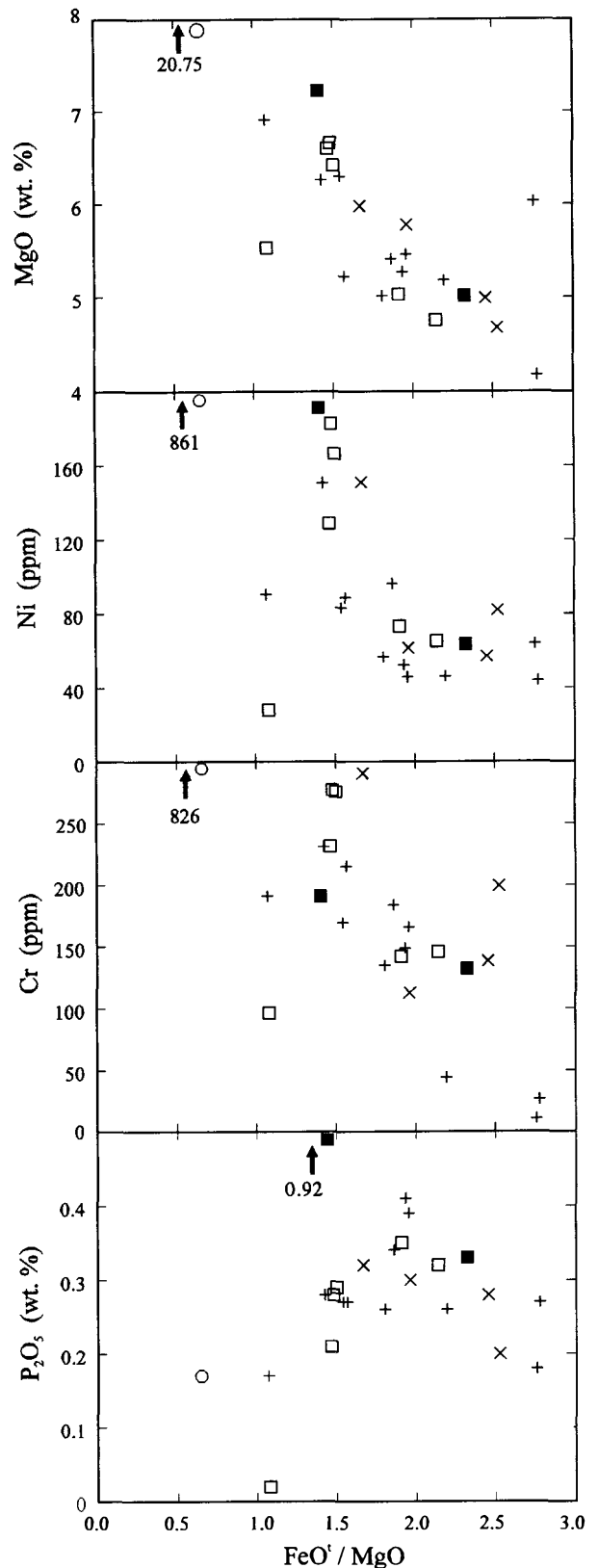


Fig. 4. Plots of MgO , Ni , Cr , and P_2O_5 against FeO^t/MgO .

However, the St. Peters gabbros differ from both continental tholeiitic and alkalic suites in their low abundance of heavy REE (Fig. 8). One possible explanation for this relative depletion in heavy REE may be the presence of garnet, which has very large mineral/melt distribution coefficient values for heavy

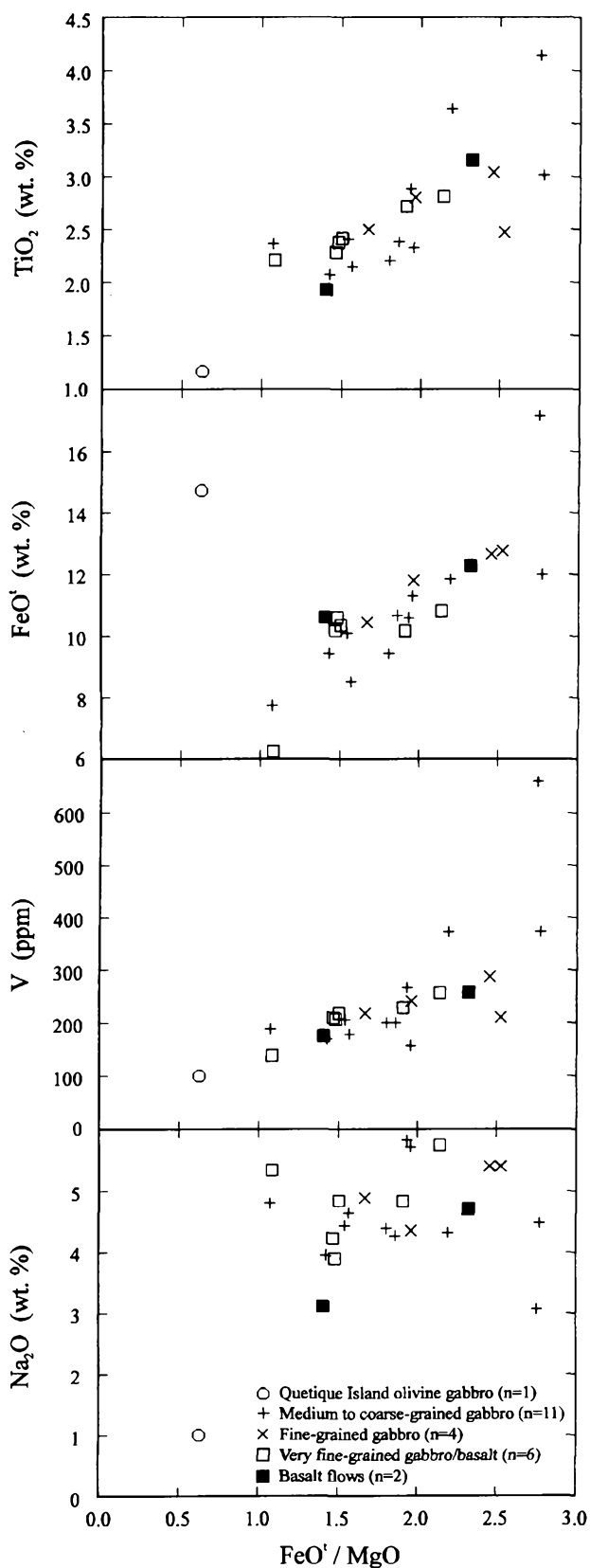


Fig. 5. Plots of TiO_2 , FeO^t , V, and Na_2O against FeO^t/MgO .

REE (Hanson, 1980), in the residue left by partial melting. Hence, it is suggested that the source for the gabbro magmas may have been garnet peridotite, rather than spinel peridotite which is the source of many mafic magmas.

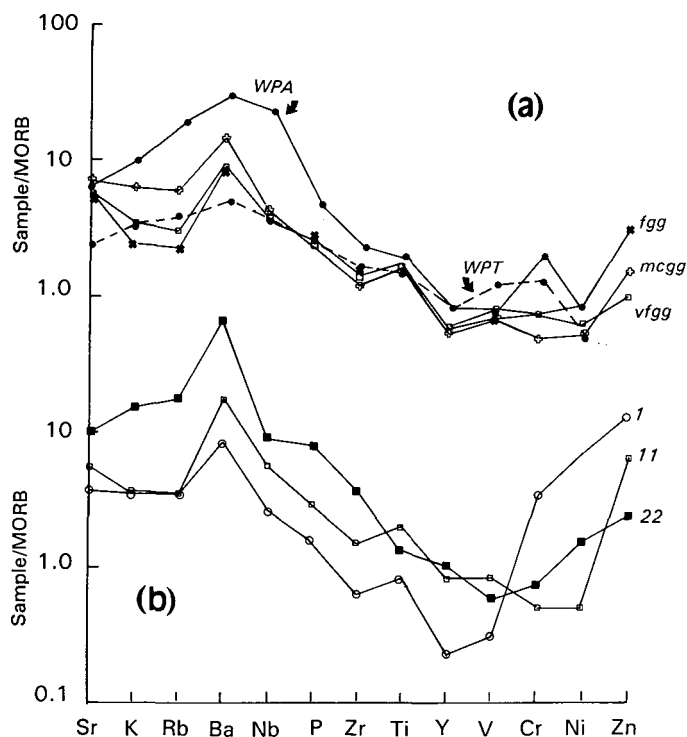


Fig. 6. (a) Multi-element variation diagrams for average medium- to coarse-grained gabbro (mcgg), fine-grained gabbro (fgg), and very fine-grained gabbro/basalt (Vfgg) from the St. Peter's samples, compared to average within-plate tholeiitic (WPT) and alkalic (WPA) basalts from Pearce (1982). Data are normalized against average mid-ocean ridge basalt from Pearce (1982). (b) Similar diagram for other samples 1 (olivine gabbro), 11 (MacLean Point basalt), and 22 (Chapel Island basalt).

In summary, the petrochemical data combined with geological setting indicate that the gabbros formed in a continental within-plate environment. Although their characterization as tholeiitic or alkalic is not definitive, most data suggest tholeiitic affinity.

U-Pb DATING

The sample for U-Pb dating was collected from a more felsic pegmatoid area in the St. Peter's Canal gabbro near its faulted southern contact with sedimentary rocks of the Horton Group. The sample is very coarse-grained and consists of a network of large saussuritized plagioclase crystals up to 2 cm in length, with interstitial green-brown amphibole and biotite. Accessory apatite, titanite, and ilmenite are abundant.

Zircon and baddeleyite were obtained from the bulk crushed rock sample using a Wilfley table and further concentrated using a combination of heavy liquids and magnetic separation. Mineral separates were hand-picked under a microscope to obtain high quality, morphologically similar grains. Zircon fractions were abraded using the technique of Krogh (1982). Analytical methods were as described by Dunning *et al.* (1990). Regression lines were calculated using the program of Davis (1982), and uncertainties on the ages are reported at the 95% confidence level.

Three zircon and three baddeleyite fractions were analyzed (Table 3; Fig. 9). All exhibit slight Pb loss; a line (12.6% prob-

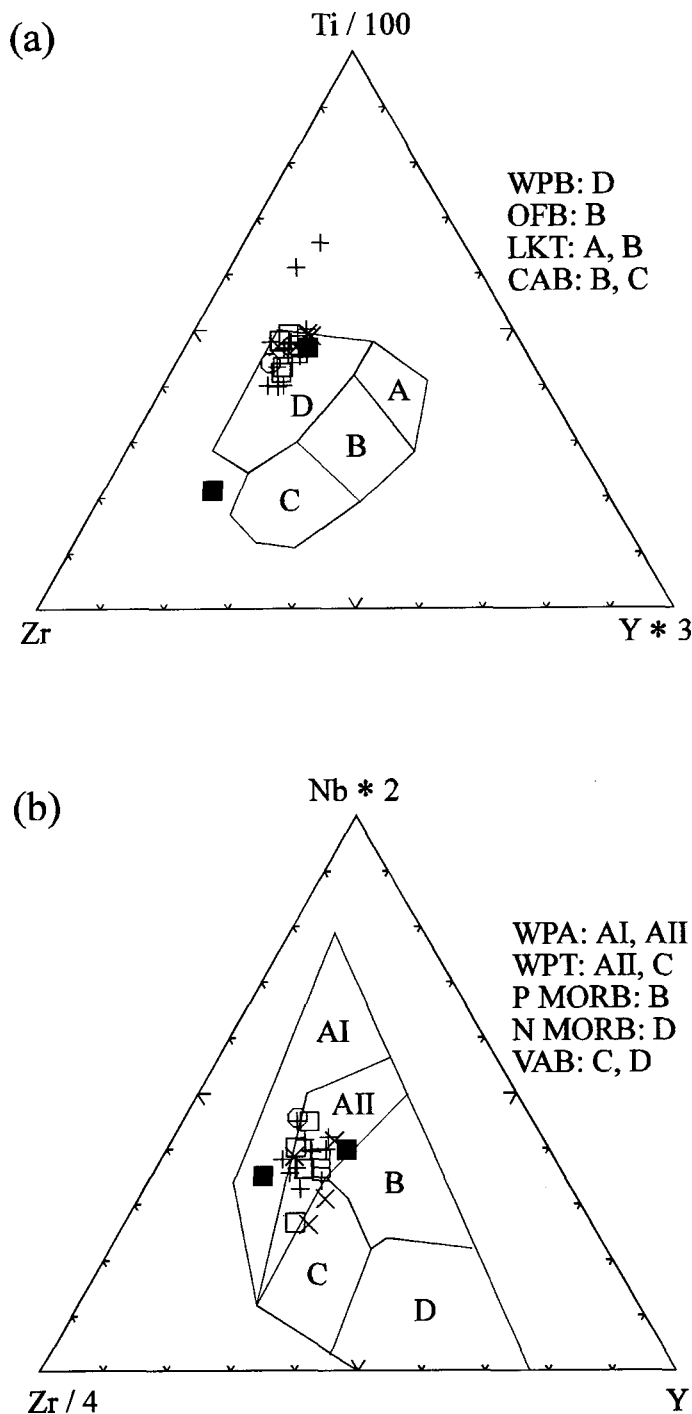


Fig. 7. Ternary plots of (a) Ti-Zr-Y (fields from Pearce and Cann, 1973) and (b) Nb-Zr-Y (fields from Meschede, 1986) for samples from the St. Peters area. Abbreviations: WPB = within-plate basalt, OFB = ocean floor basalt, LKT = low-potassium tholeiite, CAB = calc-alkalic basalt, WPA = within-plate alkalic basalt, WPT = within-plate tholeiitic basalt, P-MORB = primitive mid-ocean ridge basalt, N-MORB = normal mid-ocean ridge basalt, VAB = volcanic-arc basalt.

ability of fit) through all 6 fractions indicates an age of $341 \pm 3/-2$ Ma. The three zircon fractions define a line (97% probability of fit) with an upper intercept age of 339 ± 2 Ma. The latter age is considered to be more reliable because of the apparent tendency for baddeleyite to give ages marginally older than zircon ages. The age of 339 ± 2 Ma is within the error range of the K-Ar (biotite) age of 347 ± 36 Ma reported by Wanless *et al.* (1979).

Table 2. Rare-earth element and Hf, Ta, and Sc data for four samples from the St. Peters gabbros.

Element	1	3	5	14
La	7.67	10.04	8.38	9.96
Ce	17.25	22.68	19.98	23.19
Pr	2.26	3.27	2.85	3.37
Nd	10.36	15.62	14.10	16.29
Sm	2.33	4.04	3.85	4.36
Eu	0.87	1.56	1.49	1.66
Gd	2.22	3.86	3.86	4.22
Tb	0.27	0.53	0.48	0.64
Dy	1.55	2.73	2.71	3.33
Ho	0.26	0.47	0.46	0.58
Er	0.66	1.18	1.19	1.48
Tm	0.09	0.15	0.14	0.15
Yb	0.56	0.88	0.89	1.18
Lu	0.07	0.12	0.12	0.16
Hf	1.30	2.09	2.08	2.51
Ta	0.68	0.71	1.10	0.85
Sc	12.91	21.82	37.37	17.62

¹Analyses by ICP-MS, Department of Earth Sciences, Memorial University.

DISCUSSION

The location of the St. Peters gabbros along the Lennox Passage - St. Peters lineament suggests that their origin can be broadly related to the development of the Maritimes Basin. The lineament has been traced to the northeast and offshore (Jansa *et al.*, 1993), but postulated mergence with other major faults to the southwest (Fig. 1) is not yet confirmed.

Based on the U-Pb age presented above, the St. Peters gabbros are younger than volcanic rocks of the Fisset Brook Formation in central and northern Cape Breton Island (Fig. 1), for which a mid- to Late Devonian age is generally accepted, based on fossil evidence from associated sedimentary units (Smith and Macdonald, 1981; Dostal *et al.*, 1983; Blanchard *et al.*, 1984), and recent U-Pb dating (Barr *et al.*, in press; D.J.W. Piper, personal communication, 1995). However, an Early Carboniferous age has also been suggested for the Fisset Brook Formation, based on Rb-Sr dates (e.g., Cormier and Kelley, 1964; Kelley and Mackasey, 1965; Huard, 1984). Mafic dykes are known to have intruded sedimentary rocks assigned to the Horton Group overlying the Fisset Brook Formation in the southern Creignish Hills (MacDougall, 1994), and these gabbroic dykes could be similar in age to the St. Peters gabbros. Like the St. Peters gabbros, the mafic volcanic rocks of the Fisset Brook Formation, as well as the younger mafic dykes in the southern Creignish Hills, appear to be mainly within-plate tholeiites (Dostal *et al.*, 1983; Blanchard *et al.*, 1984; MacDougall, 1994; Arnott, 1994). They have been interpreted to represent localized extension and basin development associated with the opening of the Magdalen Basin (e.g., Bradley, 1982).

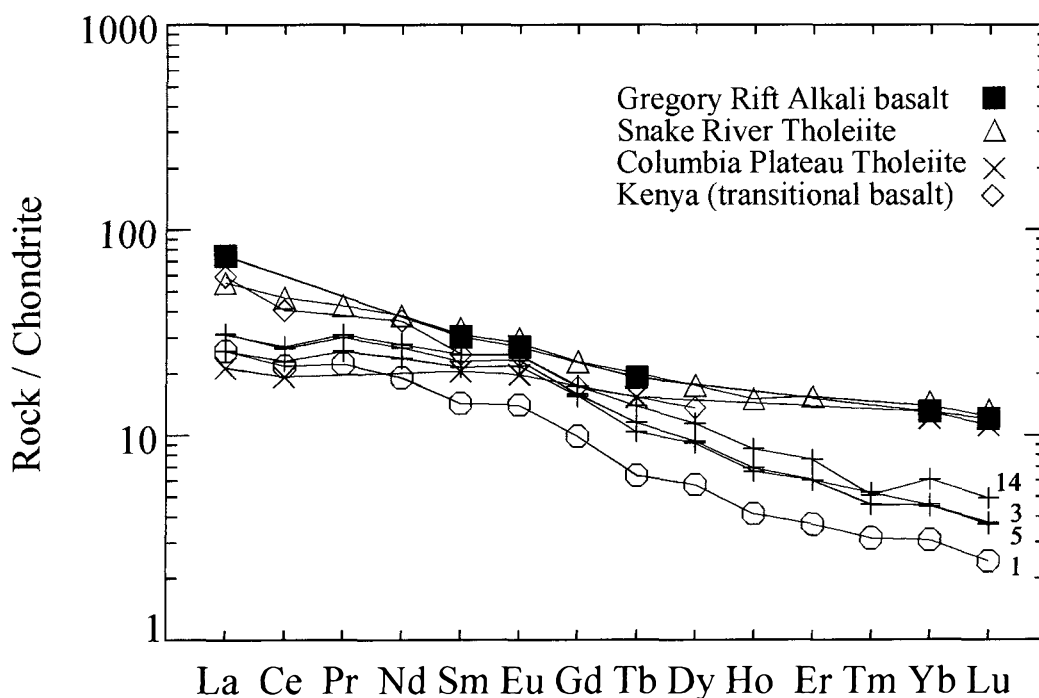


Fig. 8. Chondrite-normalized rare-earth element plot for coarse-grained gabbro samples 3, 5, and 14 and olivine gabbro sample 1. Patterns for within-plate continental tholeiitic basalt from the Columbia Plateau in the USA and alkalic basalt from the Gregory rift in East Africa (data from Wilson, 1989) are shown for comparison. Chondrite normalizing values are from Evensen *et al.* (1978).

Previous workers have inferred a correlation between the St. Peters gabbros and gabbroic rocks in the Guysborough area of northern mainland Nova Scotia (e.g., Geological Map of Nova Scotia, 1965; Durocher, 1974). Cormier (1994) showed that many of these “gabbroic plutons” on older maps are volcanic, and include both basalt and rhyolite flows and tuffs. One of the rhyolite units yielded a U-Pb (zircon) age of *ca.* 389 Ma (G. Dunning, unpublished data, 1994), and hence the volcanic rocks in the Guysborough area appear to be significantly older than the gabbroic plutons of the St. Peters area. However, it is possible that some small gabbroic plutons in the Guysborough area are not the same age as the volcanic rocks in the area (Cormier, 1994); dating is in progress to determine the age of one of the Guysborough gabbros to see if it might be the same age as the St. Peters gabbros.

Farther west in the Cobequid Highlands, granitic plutons closely associated with gabbroic plutons appear to be about 20 Ma older than the St. Peters gabbros, based on U-Pb data which indicate ages of *ca.* 360 Ma or more (Doig *et al.*, 1991; Piper *et al.*, 1993), and preliminary U-Pb data from volcanic rocks of the spatially associated Fountain Lake Group appear to be of similar *ca.* 360 Ma age (D.J.W. Piper, personal communication, 1995). Parts of the Fountain Lake Group has been interpreted previously to be of similar age to the St. Peters gabbros, based on Rb-Sr dating (Piper *et al.*, 1993), but the validity of these *ca.* 340 Ma Rb-Sr “isochron ages” is uncertain. Similar Rb-Sr “ages” also have been obtained from rhyolite and basalt in the Guysborough area (R.F. Cormier, cited by Cormier, 1994), and in the Fisset Brook Formation (Huard, 1984), but do not appear to represent the crystallization ages of the rocks. On the basis of current data, it seems that none of these other plutonic and volcanic units are as young as the St. Peters gabbros.

In New Brunswick, minor mafic volcanic rocks of Early Carboniferous age have been reported from several areas, with ages reasonably well constrained by stratigraphic evidence but not yet by radiometric dating (Fyffe and Barr, 1986). Like the St. Peters gabbros, these volcanic rocks appear to be mainly tholeiitic in composition (Fyffe and Barr, 1986). In contrast, younger mafic volcanic rocks at scattered locations in New Brunswick, as well as in the Magdalen Islands, appear to be mainly alkalic (Barr *et al.*, 1985; Fyffe and Barr, 1986). Fyffe and Barr (1986) attributed these variations to a decrease in the rate of extension in the Maritimes Basin between the Viséan and Namurian.

In conclusion, the data presented here confirm an Early Carboniferous (Viséan) age for the St. Peters gabbros and show that they formed in a within-plate (extensional) tectonic setting. More detailed tectonic interpretations and comparison of the St. Peters gabbros with other igneous rocks of similar age in the region awaits more detailed information about the overall age distribution of mid-Devonian to Carboniferous igneous activity in the Maritimes Basin.

ACKNOWLEDGEMENTS

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Table 3. U-Pb data for a pegmatoid gabbro sample from the St. Peters Canal gabbro.

Fraction	Concentration		Measured		Corrected Atomic Ratios *				Age [Ma]					
	Weight [mg]	U [ppm]	Pb rad	total common [pg]	208Pb	206Pb	207Pb	206Pb	207Pb	208Pb	206Pb	207Pb	206Pb	207Pb
SP-93-1 ST. PETER'S GABBRO														
Z1 clr angular frag abr	0.178	1414	114.0	10	81097	0.7215	0.05266	0.3865	14	0.05323	4	331	332	339
Z2 clr frags abr	0.258	909	73.3	10	78949	0.7424	0.05212	0.3825	12	0.05324	4	328	329	339
Z3 clr pale brn abr	0.153	601	40.6	6	46932	0.5176	0.04989	0.3661	12	0.05322	4	314	317	338
B1 euh plates	0.059	790	38.2	42	3718	0.0074	0.05297	0.3895	14	0.05333	8	333	334	343
B2 equant prisms/frags	0.057	986	47.7	1171	177	0.0097	0.05293	0.3892	28	0.05334	30	332	334	343
B3 fine frags + plates	0.048	842	40.9	7	17911	0.0126	0.05298	0.3897	14	0.05334	10	333	334	343

Notes: *Corrected for fractionation, spike, laboratory blank of 2 to 10 pg of common lead and initial common lead at the age of the sample calculated from the model of Stacey and Kramers (1975) and 1 pg U blank. Two sigma uncertainties are reported after the ratios and refer to the final digits.

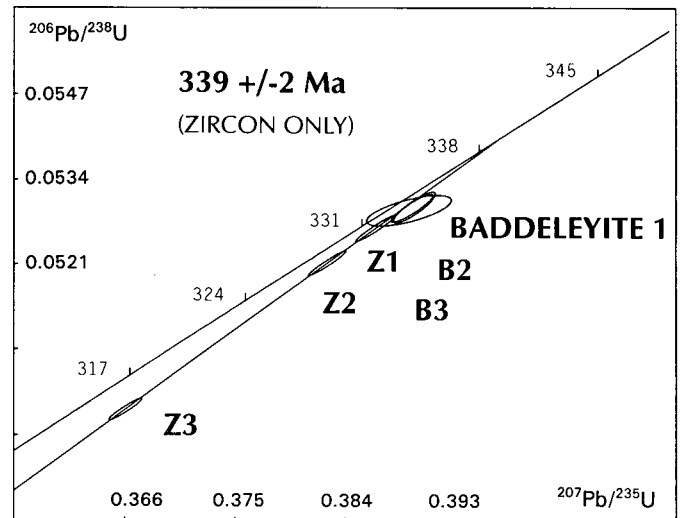


Fig. 9. Concordia plot for data in Table 3.

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Editorial responsibility : G.L. Williams

Appendix A: Sample locations (UTM Coordinates: E, N on NTS 11F/10) and descriptions (original sample number from Grammatikopoulos (1992) in brackets)

- | | | | |
|---|---|----|--|
| 1 | Quetique Island (659225, 52495). C.g. olivine gabbro (SP86). | 8 | Campbell Hill (669800, 58600). F.g. gabbro (SP20). |
| 2 | St. Peters Canal (665750, 56900). M.g. - c.g. gabbro (SPG5). | 9 | Campbell Hill (69450, 58500). F.g. gabbro, plagioclase phenocrysts (SP22). |
| 3 | St. Peters Canal (665650, 56998). M.g. - c.g. gabbro (SPG6). | 10 | Campbell Hill (669755, 59900). F.g. gabbro, flow-aligned plagioclase laths (SP95). |
| 4 | St. Peters Canal (665649, 57000). M.g. - c.g. gabbro (SP31). | 11 | MacLeans Point (670000, 61400). Porphyritic basalt with plagioclase phenocrysts (SP30). |
| 5 | St. Peters Canal (665650, 57005). M.g. - c.g. gabbro (SP32). | 12 | Barra Head (670900, 59800). C.g. ophitic gabbro (SP16). |
| 6 | St. Peters Canal (666005, 57750). M.g. - c.g. gabbro (SP51). | 13 | Barra Head (671700, 60680). C.g. to m.g. gabbro (SP01). |
| 7 | St. Peters Canal (666010, 57850). Very f.g. porphyritic gabbro/basalt (SPG7). | 14 | Barra Head (671697, 60650). C.g. gabbro (SPG3). |
| | | 15 | Soldiers Cove West (674850, 62950). Very f.g. to glassy gabbro/basalt, plagioclase phenocrysts (SPG8). |
| | | 16 | Soldiers Cove West (674850, 62952). F.g. gabbro with abundant plagioclase (SPG9). |

Appendix A Continued.

- | | | | |
|----|--|----|---|
| 17 | Soldiers Cove West (674850, 62955). Very f.g. gabbro/basalt (SP59). | 22 | Chapel Island (671750, 65000). Basalt with sparse plagioclase phenocrysts (SP73). |
| 18 | Soldiers Cove West (674850, 62955). Very f.g. gabbro/basalt with plagioclase phenocrysts (SP60). | 23 | Toms Brook (678600, 68600). C.g. ophitic gabbro (EB223A). |
| 19 | Soldiers Cove West (674650, 62750). M.g. gabbro (SP63). | 24 | Toms Brook (678200, 67800). C.g. ophitic gabbro (SP105). |
| 20 | Alick island (673900, 64100). Very f.g. gabbro/basalt (SP75). | | |
| 21 | Alick Island (674150, 64150). Very f.g. gabbro/basalt (SP82). | | |