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Résumé de l'article

Les Monts Cal^doniens orientaux (Nouveau-Brunswick meridional) sont constitue's surtout de roches volcaniques, s£dimeniaires et plutoniques melamorphis£es dans le fades des schistes verts (ou presque), g£n£ralement considerees comme typiques des series lardiprecambriennes de la Laniere d'Avalon de l'Orogene appalachien septentrional. A la suite d'un lever regional combing a des dtudes p^trologiques et des datations radiome'triques, on a divise" ces roches des Monts Caledoniens orientaux en deux groupes distincts. Le plus ancien groupe, qui s'echelorme vraisemblablement d'environ 600 a 630 Ma, comprend des roches a mdtatufs de composition mafique a felsique, des roches me"tas£dimentaires volcanoge^iiques a grain fin (ardoise et phyllade), des roches mctasedimentaires arkosiques ct des plutons dioritiques a granitiques. Les volcanites scmblent ctre calco alcalines. Les volcanites comme les plutonites furent engendrdes dans un contexte tectonique lie" a une subduct ion.

Par contre,]'autre groupe de roches semble dater d'environ 550 Ma et comprend des roches s^dimentaires arkosiques, des dpanchements subaeriens de basalte et de rhyolite, des siltstones lamin&, des tufs a lapilli felsiques, des poudingucs volcaniclastiques, ainsi que des plutons a composition principalcmcnt gabbro'i'que et sy^nogranitique. Ces unites sont typiqucment beaucoup moins deTormdes et me"tamorphisees que 1'est le groupe d'unites plus ancien. Les volcanites el les plutonites semblent appartenir a des lignees cogen^tiques bimodales; leurs caracteres pe"trochimiques suggerent une gtSncsc au sein d'un arc volcanique en contexte de rift.

Petrochemistry of contrasting late Precambrian volcanic and plutonic associations, Caledonian Highlands, Southern New Brunswick

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The eastern Caledonian Highlands of southern New Brunswick consist mainly of greenschist-facies or subgreenschist-facies volcanic, sedimentary, and plutonic rocks generally considered to be typical of Late Precambrian sequences in the Avalon Terrane of the northern Appalachian Orogen. As a result of regional mapping combined with petrological studies and radiometric dating, these rocks in the eastern Caledonian Highlands have been divided into two contrasting groups. The older group, apparently ranging in age from about 600 to 630 Ma, consists of metatuffaceous rocks ranging from mafic to felsic in composition, fine-grained volcanogenic metasedimentary rocks (slate and phyllite), arkosic metasedimentary rocks, and dioritic to granitic plutons. The volcanic rocks appear to be calc-alkalic, and both the volcanic and plutonic rocks were formed in a subduction-related tectonic setting.

In contrast, the other group of rocks appears to be about 550 Ma in age and consists of arkosic sedimentary rocks, subaerial rhyolite and basalt flows, laminated siltstone, felsic lapilli tuff, volcaniclastic conglomerate, and plutons of mainly gabbroic and syenogranitic composition. These units typically are much less deformed and metamorphosed than the older group of units. The volcanic and plutonic rocks appear to be cogenetic bimodal suites, with petrochemical characteristics suggesting that they formed in a rifting environment within an older volcanic arc.

Les Monts Calédoniens orientaux (Nouveau-Brunswick méridional) sont constitués surtout de roches volcaniques, sédimentaires et plutoniques métamorphisées dans le faciès des schistes verts (ou presque), généralement considérées comme typiques des séries tardiprécambriennes de la Lanière d'Avalon de l'Orogène appalachien septentrional. A la suite d'un lever régional combiné à des études pétrologiques et des datations radiométriques, on a divisé ces roches des Monts Calédoniens orientaux en deux groupes distincts. Le plus ancien groupe, qui s'échelonne vraisemblablement d'environ 600 à 630 Ma, comprend des roches à métatufs de composition mafique à felsique, des roches métasédimentaires volcanogéniques à grain fin (ardoise et phyllade), des roches métasédimentaires arkosiques et des plutons dioritiques à granitiques. Les volcanites semblent être calco-alcalines. Les volcanites comme les plutonites furent engendrées dans un contexte tectonique lié à une subduction.

Par contre, l'autre groupe de roches semble dater d'environ 550 Ma et comprend des roches sédimentaires arkosiques, des épanchements subaériens de basalte et de rhyolite, des siltstones laminés, des tufs à lapilli felsiques, des poudingues volcaniclastiques, ainsi que des plutons à composition principalement gabbroïque et syénogranitique. Ces unités sont typiquement beaucoup moins déformées et métamorphisées que l'est le groupe d'unités plus ancien. Les volcanites et les plutonites semblent appartenir à des lignées cogénétiques bimodales; leurs caractères pétrochimiques suggèrent une génèse au sein d'un arc volcanique en contexte de rift.

[Traduit par le journal]

INTRODUCTION

The eastern Caledonian Highlands of southern New Brunswick (Fig. 1) consist mainly of metavolcanic and metasedimentary rocks which have been generally considered correlative with the Coldbrook Group of the Saint John area (Kindle, 1962; Ruitenberg *et al.*, 1977, 1979; Giles and Ruitenberg, 1977). These rocks are interpreted to be Late Precambrian in age and comparable to rocks of similar age in southeastern Cape Breton Island, eastern Newfoundland, and elsewhere in the Avalon Terrane of the Appalachian Orogen (e.g., Williams, 1979; Williams and Hatcher, 1982; Nance, 1986). They have been intruded by plutonic units which range from gabbroic to granitic in composition (e.g., Ruitenberg *et al.*, 1979).

Although these rocks have been previously mapped on a reconnaissance scale, and locally on a more detailed scale (e.g., McLeod, 1986, 1987; Currie, 1986, 1987a), few detailed petrological studies have been done. The purpose of this paper is to provide an overview of the petrochemistry of volcanic and plutonic units in the eastern Caledonian Highlands (Fig. 1) and to use these data to infer preliminary interpretations of the tectonic setting in which these rocks formed. The data were obtained as

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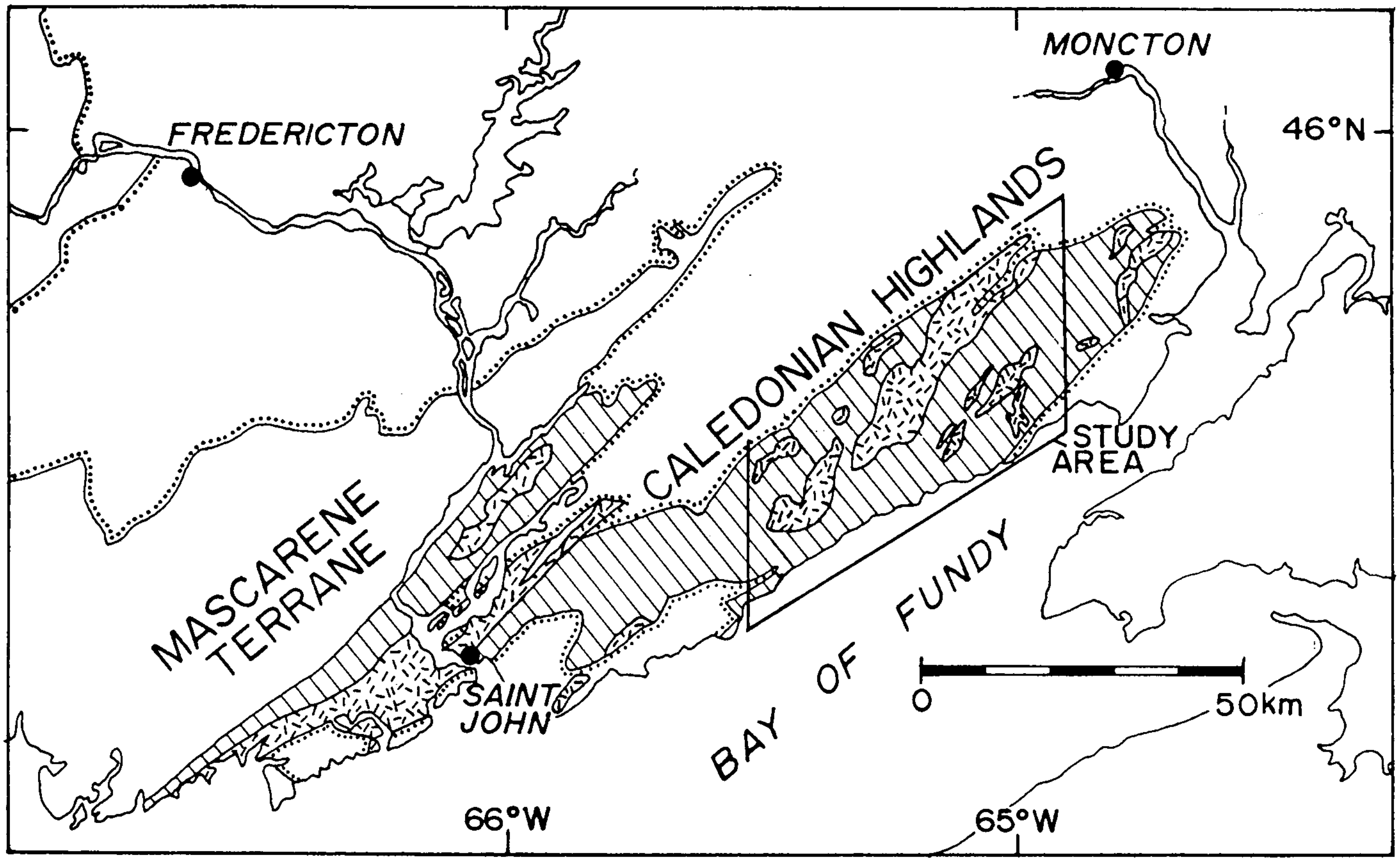

Fig. 1. Location of the study area in the Caledonian Highlands (striped) of southern New Brunswick. Dash pattern indicates plutonic rocks.

part of an on-going mapping project, begun in 1985, which is documenting field relations and map units in the eastern Caledonian Highlands (Barr, 1987; Barr and White, 1988a, b, c).

GEOLOGICAL SETTING AND PREVIOUS WORK

The inferred stratigraphy in the Avalon Terrane in the Saint John area of southern New Brunswick has been recently summarized by Nance (1987) and Currie (1987b). A tonalitic gneissic basement (the Brookville Gneiss) of possible pre-Helikian age is overlain by a carbonate-quartzite platformal sequence (the Green Head Group) of Helikian(?) age, a local carbonate breccia and turbidite unit, and volcanic, volcaniclastic, and sedimentary rocks of the Coldbrook Group (which typically have been metamorphosed to subgreenschist or greenschist facies). These units have been intruded by various dioritic to granitic plutons, and are separated from the Mascarene Terrane (Fyffe and Fricker, 1987) to the northwest by a major mylonite zone and a mafic-felsic dyke complex. Eocambrian sedimentary and volcanic rocks, Cambro-Ordovician sedimentary rocks (Saint John Group) and dominantly sedimentary Carboniferous and Triassic sequences unconformably overlie the older rock units.

Volcanic and sedimentary rocks within the study area, located east of Saint John in the Caledonian Highlands (Fig. 1), have been previously inferred to be mainly correlative with the Coldbrook Group (Kindle, 1962; Ruitenberg *et al.*, 1979). They were subdivided into two belts termed the central and eastern volcanic belts by Giles and Ruitenberg (1977) and Ruitenberg *et al.* (1979). McLeod (1986, 1987) subdivided the volcanic and sedimentary rocks in the western part of the eastern volcanic belt (the south-central part of the present map area) into a dominantly subaerial succession to the northwest and a dominantly marine succession in the southeast, separated by a major thrust. Areas of Cambrian and younger rocks were also mapped by McLeod (1986, 1987), mainly along the Bay of Fundy coast.

Most of the major plutonic units in the study area were delineated and named by Ruitenberg *et al.* (1979), who considered them to range in age from late Precambrian to Ordovician and/or Devonian. Minor intrusions (sills, dykes, and small plutons) ranging in composition from mafic to felsic are also abundant in the map area, but are not described in this paper.

VOLCANIC AND SEDIMENTARY ROCKS

Introduction

Based on field mapping and petrological studies, combined with U-Pb (zircon) dating (M.L. Bevier, personal communication, 1988; Bevier, 1988), the volcanic and sedimentary rocks in the study area are divided into older and younger sequences, informally termed A and B, respectively (Fig. 2). In addition to these extensive sequences, small areas of schist, gneiss, and marble assigned to the Helikian(?) Green Head Group and/or Brookville gneiss occur adjacent to the northwestern margin of

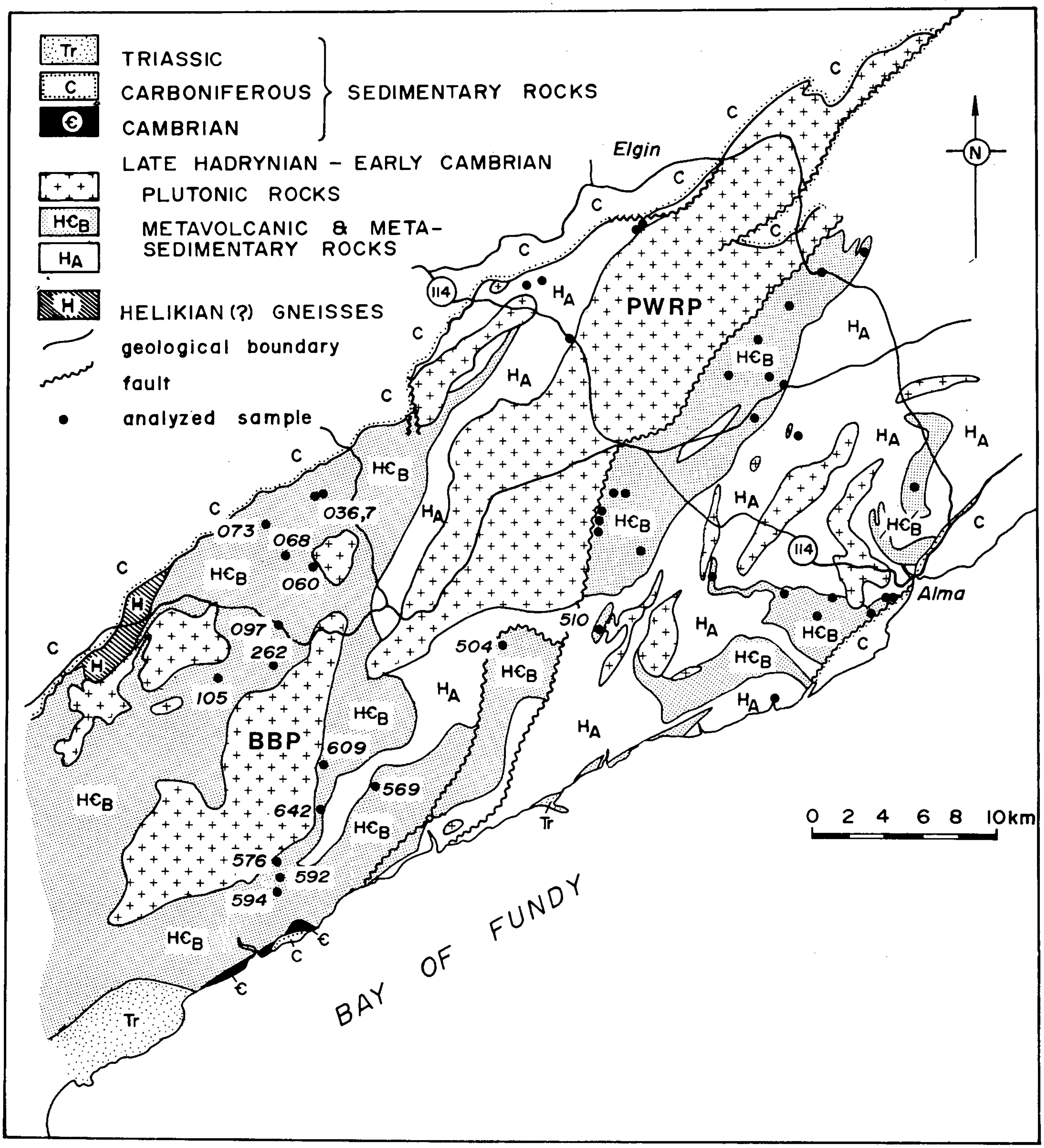

Fig. 2. Simplified geological map of the study area (after Barr, 1987; Barr and White, 1988a, b). The locations of analyzed volcanic samples are shown; numbered analyses are listed in Table 1 (first digit, 4, is omitted from sample numbers on the map to conserve space). Roads are shown as heavy solid lines. Details of plutonic units are shown on Figure 7; PWRP = Point Wolfe River Pluton; BBP = Bonnell Brook Pluton.

the map area, and inferred Cambrian, Carboniferous, and Triassic rocks are present locally near the Bay of Fundy coast (Fig. 2).

Volcanic-sedimentary sequence A corresponds approximately in distribution to the eastern volcanic belt of Giles and Ruitenberg (1977) and Ruitenberg *et al.* (1979), and the younger sequence B to their central volcanic belt. However, sequence B, which is interpreted to unconformably overlie sequence A, is not confined to the central volcanic belt and is widely distributed throughout the map area (Fig. 2). A major fault system, in part correlative with the Cradle Brook Thrust of McLeod (1986, 1987), extends across the map area, juxtaposing the Point Wolfe River Pluton against sequence B units in the northeast, and offsetting both sequence A and sequence B units in the south-central part of the map area. Hence sequence B rocks correspond in large part to the dominantly subaerial units located northwest of the Cradle Brook Fault as described by McLeod (1986, 1987), and sequence A rocks to the marine units southeast of the fault. However, the results of the present study indicate that the rocks of sequence B are younger than those of sequence A, the converse of the interpretation made by McLeod (1986, 1987).

Sequence A

Lithologies

Volcanic and sedimentary map units assigned to sequence A (Fig. 2) are characterized by an abundance of crystal tuff and lithic-crystal tuff, ranging in composition from mafic to felsic, and fine-grained tuffaceous and arkosic sedimentary rocks. Most of these rocks were previously assigned to map units 1, 2, 3, 7, and 8 in Barr and White (1988a) and H1, H2, H3, H7 and H8 in Barr and White (1988b), and were described in some detail in those publications.

All of these rocks generally have mineral assemblages indicative of lower greenschist facies metamorphism. Mafic rocks contain abundant chlorite, albite, and epidote, and are strongly cleaved mafic phyllites and chlorite schists. Intermediate to felsic lithologies are characterized by abundant quartz, albite, and sericite, and are crystal and lithic-crystal metatuffs. Fine-grained metasedimentary and metatuffaceous units are typically slates and phyllites, but arkosic metasandstone and metaconglomerate units are less cleaved and more massive. Clasts in the metaconglomerates are mainly of quartzitic and felsic volcanic composition. Locally pyrite-rich massive grey felsite layers are present, and mafic and felsic sills and dykes are common.

U-Pb dating has indicated that tuffaceous units in sequence A have a minimum range in age from about 600 Ma to 630 Ma (M.L. Bevier, personal communication, 1988), and hence the sequence probably does not represent a single continuous stratigraphic succession. However, it has not yet been possible to determine the stratigraphy with certainty because the rocks are complexly folded and faulted, and in many areas highly cataclased.

Geochemistry

Few of the rocks in sequence A are suitable for chemical analysis because they are mainly tuffs and volcanogenic sedimentary rocks, and hence only nine samples have been analysed. The sample locations and chemical data were published previously (Barr, 1987; Barr and White, 1988a).

These nine analyzed samples are mainly intermediate to felsic in composition, with silica contents (recalculated, volatile-free) ranging from about 55 to 76% (Fig. 3a). However, the most felsic samples have probably been affected by silicic alteration because minor and trace element compositions indicate a more restricted compositional range from andesite to dacite or rhyodacite (Fig. 4a). The suite is subalkalic (Fig. 4a) and probably calc-alkalic because the samples show no positive correlation between FeOT/MgO ratio and silica content or between V and Cr (Figs. 3a, 5a). However, the small number of analyzed samples and their tuffaceous nature preclude a definitive assessment of chemical characteristics.

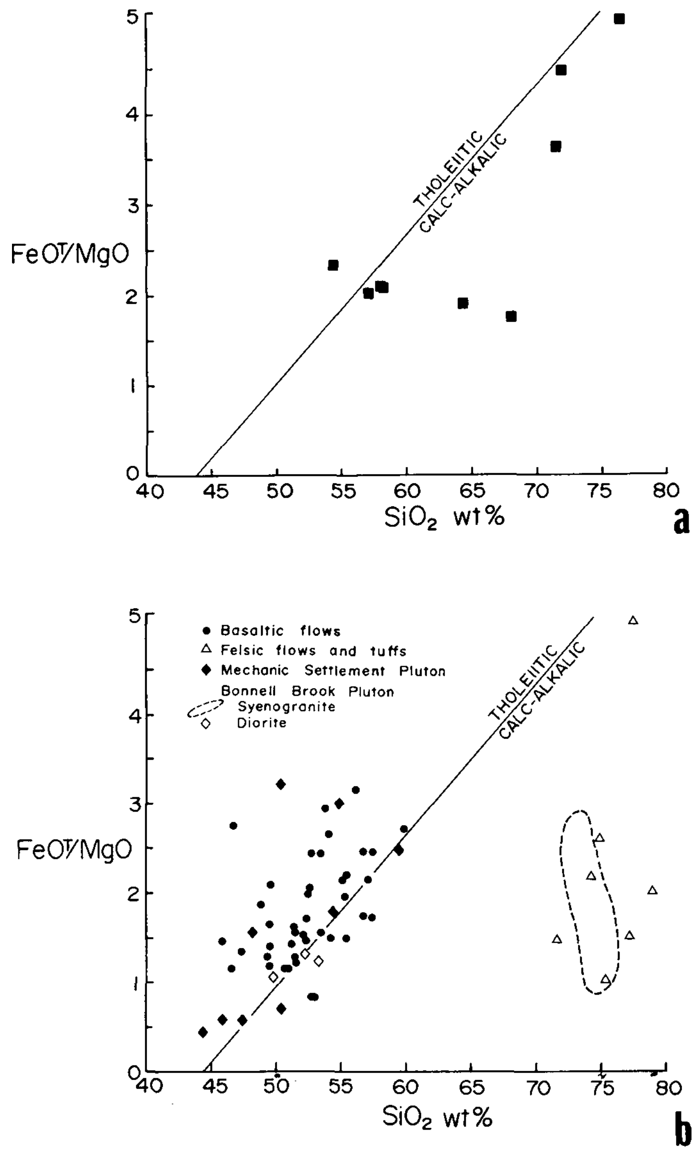

Fig. 3. Plots of FeOT/MgO against silica for (a) metatuffaceous samples from volcanic-sedimentary sequence A and (b) basaltic flows and felsic flows and tuffs from volcanic-sedimentary sequence B and samples from Bonnell Brook and Mechanic Settlement plutons. Data from Tables 1, 4 and 6, Barr and White (1988a), and Barr (1987), recalculated to 100%, volatile-free. FeOT = total iron expressed as FeO. Tholeiitic/calc-alkalic dividing line from Miyashiro (1974).

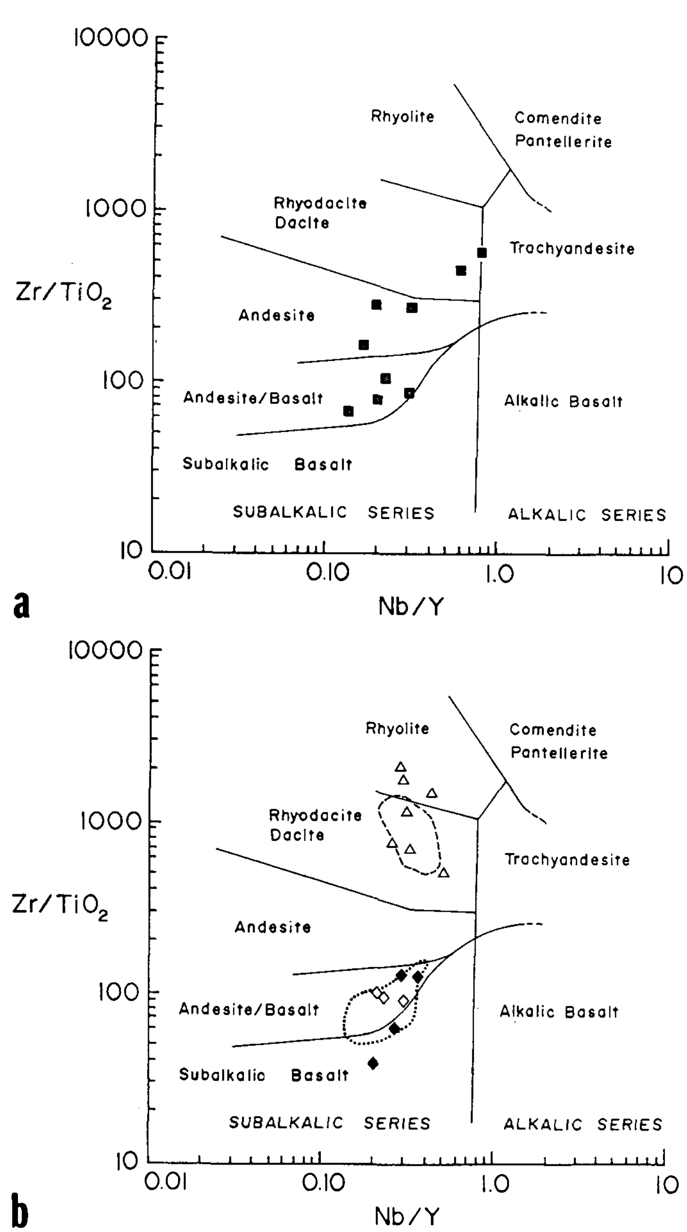

Fig. 4. Plots of Zr/TiO_2 against Nb/Y for (a) metatuffaceous samples from sequence A and (b) volcanic rocks from sequence B and Bonnell Brook and Mechanic Settlement plutons. Symbols as in Figure 3 except dotted field encloses 42 basaltic to andesitic samples from sequence B. Named fields are from Winchester and Floyd (1977).

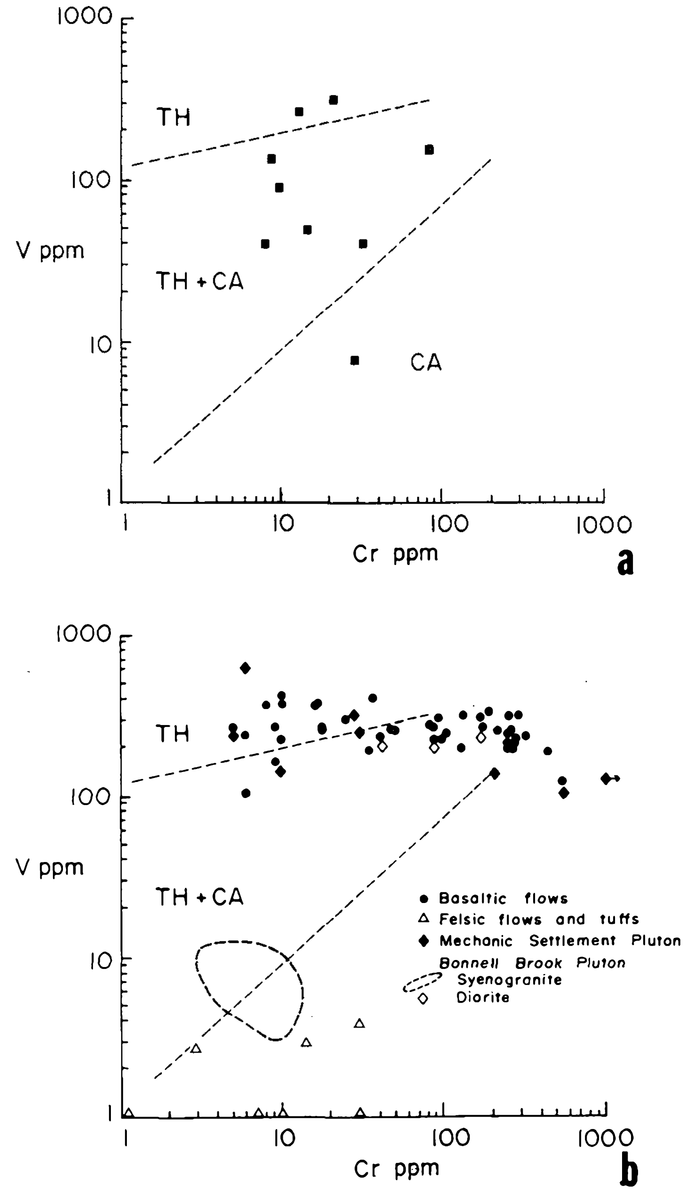

Fig. 5. Plots of V against Cr for (a) metatuffaceous samples from sequence A and (b) volcanic samples from sequence B and gabbros from Mechanic Settlement Pluton and diorite and syenogranite from Bonnell Brook Pluton. Tholeiitic (Th) and calc-alkalic (CA) fields from Miyashiro and Shido (1975).

Sequence B

Lithologies

Map units assigned to sequence B are inferred to be closely similar in age, based on U-Pb (zircon) ages of 548±1 Ma from rhyolite within the sequence and 550±1 Ma from syenogranite of the Bonnell Brook Pluton which intruded the sequence (Bevier, 1988). A stratigraphic succession can be inferred, on the basis of consistent younging direction indicators such as graded bedding and cross-bedding in sedimentary units. These rocks were previously described and assigned to units 4, 5, and 6 in Barr and White (1988a) and H4, H5, H6, H9, H10, H11, and H12 in Barr and White (1988b).

The lowermost unit consists of grey slate (with lenses of muscovite-bearing quartzite), red to maroon slate, metasiltstone, metasandstone, and metaconglomerate, as well as minor tuffaceous layers. These dominantly sedimentary rocks are overlain by rhyolitic rocks, ranging from pink to grey in colour and from massive to strongly cleaved. Massive aphanitic varieties appear welded and ignimbritic, and locally display contorted flow banding. Some horizons contain fragments of feldspar and quartz crystals and pumice, and are clearly tuffaceous. Laminated siliceous siltstone and basaltic tuff/flow layers occur locally within the rhyolitic unit. The rhyolitic unit is overlain by a unit of basaltic flows which vary from massive to amygdaloidal (near tops). Pillowed horizons were observed in only two areas. Amygdales are typically large (up to 2 cm or more in maximum diameter) and filled with chlorite and/or epidote and calcite. Overlying the basaltic unit and forming most of the northwestern part of the map area around the Bonnell Brook Pluton and satellite bodies are units consisting mainly of fine-grained laminated siliceous siltstone, volcanic breccia or lapilli tuff of generally dacitic to rhyodacitic composition, and volcanogenic breccia/ conglomerate. Blocks and bombs in the volcanic breccia range up to 1 m or more in length. Most consist of lapilli tuff, some with large flattened pumice fragments; rare lapilli of siltstone like those in the underlying sedimentary unit are also present. The overlying breccia/conglomerate unit is typically massive with small subangular to subrounded volcanic clasts of dacitic and rhyolitic composition in a feldspar-rich matrix. Clasts are poorly sorted and rarely more than 1 cm in size.

In general, rocks of sequence B are less cleaved than those of sequence A; this is particularly true in the northeastern part of the map area where the rocks are mainly unfoliated, and metamorphic grade is sub-greenschist facies.

These rocks appear to be a dominantly subaerial sedimentary and bimodal volcanic sequence. Rare pillowed basalt and laminated siltstone units may represent localized subaqueous conditions (lakes?).

Geochemistry

Analytical work has concentrated on the metabasaltic flows, from which a total of 42 samples have been analyzed. In addition, seven samples from rhyolitic flows and lapilli tuffs have been analyzed. Many of the data were previously published (Barr, 1987; Barr and White, 1988a), and only new unpublished analyses are included here (Table 1). Sample locations are shown on Figure 2.

Most of the basaltic samples display relatively high loss-on-ignition values. This is consistent with the presence of mineral assemblages of greenschist to sub-greenschist facies metamorphism; no relict pyroxene is present and plagioclase is albitic in composition. Hence mobile elements such as Na_2O, K_2O, Rb, and Sr are unlikely to have retained original magmatic values, and assessment of chemical character is based mainly on the more immobile elements.

The analyzed basaltic samples show a wide range in silica content from about 45% to 60% (recalculated volatile-free) (Fig. 3b). Minor and trace elements ratios show a range from subalkalic basalt to andesite (Fig. 5b). In thin section, the basaltic andesites and andesites have higher proportions of plagioclase (now albite) and fewer mafic minerals (now mainly chlorite) than the basalts. The analyzed samples display a trend of increasing FeOT/MgO ratio with increasing silica content (Fig. 3b), characteristic of tholeiitic suites (e.g., Miyashiro, 1974), and this is also indicated by a range of Cr values at approximately constant V values (Fig. 4b), another characteristic of tholeiitic suites (Miyashiro and Shido, 1975). Variation from basalt samples with high Cr to andesite samples with lower Cr implies that fractionation of pyroxene may have played a major role in magma evolution (e.g., Miyashiro and Shido, 1975).

Discrimination diagrams for basaltic samples indicate that the rocks formed in a volcanic arc setting (Fig. 6a, b).

The analyzed samples from felsic units all have silica contents over 70% (Fig. 3b). They range from dacite to rhyolite (Fig. 5b), and appear to be calc-alkalic (Fig. 4b). Together with the basaltic units, with which they are locally interlayered, they form a bimodal association.

PLUTONIC UNITS

Introduction

Plutonic rocks in the map area are divided into six major plutons (Fig. 7) and also occur in numerous minor (unnamed) bodies (Barr and White, 1988b), most of which cannot be shown on the scale of Figure 7. Petrologic data for these minor intrusions are not included in this paper.

Field evidence provided little constraint on relative ages of plutons and units within plutons because of general scarcity of exposed contacts, cross-cutting relations, or plutonic xenoliths. However, U-Pb (zircon) ages (Bevier, 1988) and less reliable Rb-Sr (Barr, 1987; Barr and White, 1988b) and K-Ar age data (Table 2) indicate that the plutons can be divided into two distinct age groups. Older plutons (Goose Creek Leucotonalite, Alma Pluton, Fortyfive River Pluton, and Point Wolfe River Pluton) have known or inferred ages more than about 600 Ma, and younger plutons (Bonnell Brook and satellite plutons and the Mechanic Settlement Pluton) are about 550 Ma in age.

The older plutons commonly exhibit strong shearing and cataclasis and, locally, protomylonite is developed. Where shearing is less intense in these plutons the rocks lack foliation. This observation, combined with the apparent cross-cutting form of most plutons, suggests that they are post-tectonic with relation to the major deformational event in the host rocks (see Discussion). Moderate to intense alteration/ metamorphism, including replacement of plagioclase by saussurite, sericite, and albite, and mafic minerals by chlorite, sphene, epidote, and other secondary minerals, is also characteristic of the older granitoid plutons, whereas the younger plutons are much less altered, and are typically unsheared.

Chemical data were published previously for the Goose Creek, Alma, and Fortyfive River intrusions, and for the northeastern half of the Point Wolfe River Pluton (Barr, 1987; Barr and White, 1988a). New data are presented here (Tables 3, 4, 5) from the southeastern part of the Point Wolfe River Pluton (the Old Shepody Road granite), the Bonnell Brook Pluton, and the Mechanic Settlement Pluton, as well as for an additional sample from the previously unmapped southwestern body of the Fortyfive River Pluton. Locations for all analyzed samples are shown on Figure 7, and chemical plots include data in Tables 3, 4, and 5, combined with previously published data.

Thorough discussion of petrochemical variations within and petrogenesis of each unit is beyond the scope of this paper, which is intended only to document the characteristic petrological features of each intrusion.

Table 1. Chemical data* for volcanic rocks from Sequence B** from the east-central Caledonian Highlands.

Sample	4036	4037A	4060A	4068	4073	4097	4105	4262	4504	4510	4569	4576	4592	4594	4609	4642
SiO_2	53.25	50.82	55.78	55.16	74.70	70.17	73.09	56.28	49.49	45.05	52.10	51.25	75.46	49.26	51.63	53.71
TiO_2	1.08	0.90	1.24	1.61	0.15	0.43	0.25	1.18	0.91	3.10	1.65	1.15	0.12	1.45	0.87	1.10
Al_2O_3	16.10	14.30	15.22	15.78	12.48	12.90	13.05	15.24	16.07	13.18	14.89	17.58	12.30	16.07	14.27	15.81
Fe_2O_3	9.75	9.23	9.86	12.22	2.09	3.26	2.25	8.88	9.85	16.85	13.44	9.94	1.52	10.93	7.45	10.71
MnO	0.17	0.15	0.19	0.17	0.09	0.12	0.07	0.17	0.16	0.33	0.18	0.14	0.04	0.18	0.16	0.22
MgO	5.80	10.01	4.13	4.32	1.76	1.91	0.75	4.49	6.84	5.51	4.54	5.75	0.88	7.99	7.81	4.89
CaO	6.48	6.37	6.77	2.02	0.44	1.26	0.54	7.47	9.14	8.44	4.40	5.99	0.04	6.04	12.02	7.96
Na_2O	4.99	2.82	2.91	5.68	4.09	4.91	5.69	3.33	2.71	2.06	4.68	3.82	4.09	3.26	3.20	2.19
K_2O	0.35	1.08	1.39	0.09	3.21	2.91	1.95	0.98	0.85	0.95	0.21	0.02	3.37	0.05	0.33	0.30
LOI	2.60	4.00	1.90	3.10	0.40	0.60	0.70	1.50	2.90	2.00	2.90	4.30	0.80	4.30	1.00	1.20
P_2O_5	0.17	0.15	0.17	0.21	0.02	0.06	0.03	0.27	0.20	0.94	0.27	0.23	0.02	0.24	0.10	0.23
Total	100.74	99.83	99.56	100.36	99.43	98.53	98.37	99.79	99.12	98.41	99.26	100.17	98.64	99.77	98.84	98.32
Ba	129	441	289	32	597	536	528	319	216	440	128	36	697	45	91	120
Rb	nd	42	55	nd	102	96	49	29	23	15	3	nd	103	nd	9	8
Sr	206	232	203	55	44	74	59	180	388	252	99	266	24	351	242	180
Y	25	23	28	29	67	61	54	34	19	41	29	23	57	37	18	27
Zr	111	118	131	142	346	363	320	158	77	175	133	119	224	141	115	162
Nb	7	5	7	8	18	15	16	8	5	7	5	7	16	6	5	8
Cu	112	38	76	12	1	nd	6	28	30	55	65	78	5	130	21	35
Pb	nd	nd	73	nd	24	10	nd	2	nd	nd	nd	nd	4	nd	17	nd
Zn	102	102	252	184	87	88	45	112	105	197	124	86	30	110	182	103
Ni	17	217	8	17	7	4	3	20	130	58	51	78	4	94	278	94
Cr	9	433	6	9	7	3	10	34	331	17	25	260	nd	265	548	248
V	287	201	263	180	nd	3	1	213	254	405	321	215	1	278	134	213
Ga	15	17	19	15	17	14	14	17	16	23	18	14	18	17	16	17
Th	nd	nd	2	nd	16	8	8	nd	nd	nd	4	nd	12	nd	nd	nd

*Major and trace element analyses by X-ray fluorescence using fused disks and pressed powder pelletts, respectively, at the Regional XRF Centre, St. Mary's University, Halifax (Chief Analysist, K. Cameron). Fe_2O_3 is total iron expressed as Fe_2O_3. LOI is % weight loss after heating at 1000°C for one hour. nd is below detection limit.

**Sample locations numbered on Figure 2.

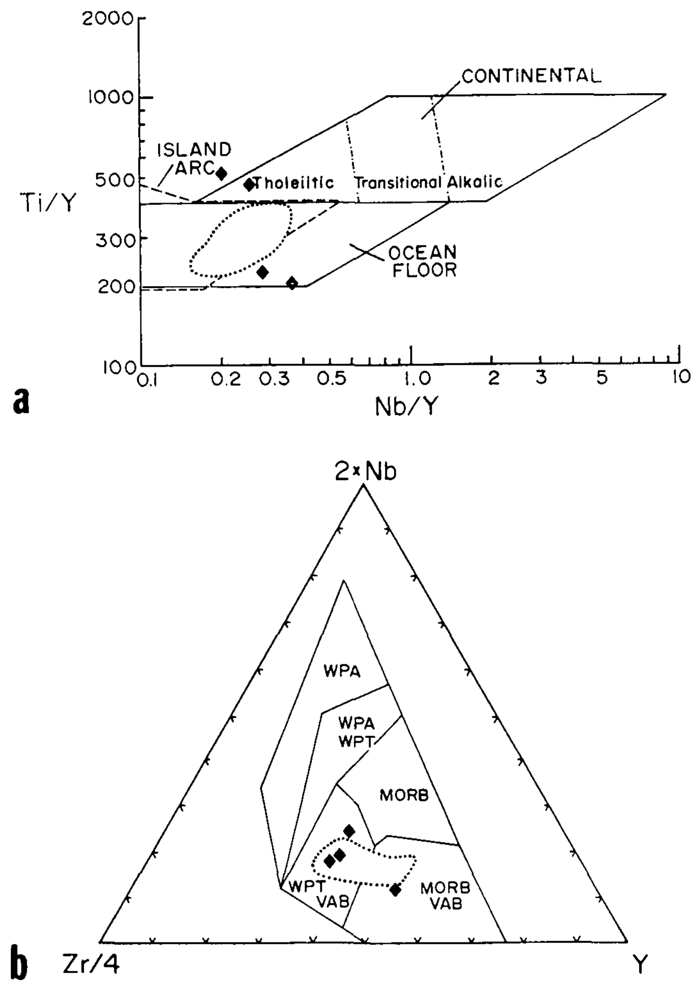

Fig. 6. (a) Plot of Ti/Y against Nb/Y for basaltic (dotted field) and gabbroic (diamonds) samples. Fields from Pearce (1982). (b) Basaltic (dotted field) and gabbroic (diamonds) samples plotted on the ternary Nb-Zr-Y diagram of Meschede (1986). Fields WPA = within-plate alkalic basalt; WPT = within-plate tholeiitic basalt; MORB = mid-ocean ridge basalt; VAB = volcanic arc basalt.

Goose Creek Leucotonalite

The Goose Creek Leucotonalite forms several small intrusions within volcanic-sedimentary sequence A. The leucotonalite is grey, leucocratic, and medium-grained, and consists mainly of quartz and plagioclase (now albite, based on unpublished electron microprobe analyses), typically in granophyric intergrowth, and abundant secondary epidote. No primary mafic mineral is preserved.

Analyses of the leucotonalite show that it is characterized by high silica contents (71 to 75%) and low abundances of most major and trace elements (especially K_2O and Rb), with the notable exception of Na_2O (Barr, 1987). It plots in the tonalite field on the normative mineralogy diagram of Streckeisen and Le Maitre (1979) (Fig. 8a), and forms a distinctive MgO-depleted cluster on the AFM diagram (Fig. 9a). It plots with more mafic rocks on the Rb vs. Nb+Y diagram (Fig. 10a) because of low Rb content.

Alma Pluton

The Alma Pluton, located northwest and west of the village of Alma, consists mainly of quartz diorite but varies from diorite to quartz diorite, tonalite, and granodiorite. Locally the rocks display well developed layering and banding of probable cumulate origin but this feature has not yet been examined in detail. The major minerals are medium-grained plagioclase and amphibole, with variable amounts of quartz and secondary minerals.

Silica contents in 11 samples from the Alma Pluton range from 45 to 67%. The range in silica content is consistent with the range in modal composition of the samples from diorite to granodiorite, as also demonstrated on the normative mineralogy plot (Fig. 8a). Most elements display good to moderate correlation with silica (Barr, 1987), and a typical calc-alkalic trend is present on the AFM diagram (Fig. 9a). Y+Nb values vary little through a wide range of Rb values (Fig. 10a).

Fortyfive River Pluton

The Fortyfive River Pluton consists of three separate small elongate bodies, all of which are composed of medium-grained pink to green (altered) granodiorite, locally gradational to monzogranite. Texture is subporphyritic, with subhedral plagioclase in a groundmass of quartz, potassium feldspar, and amphibole (now mainly replaced by chlorite, epidote, actinolite, and other secondary minerals).

Silica contents in fourteen samples from the Fortyfive River Pluton range from 61 to 69%. Most elements show moderate to good correlation with silica content (Barr, 1987), and a normative mineralogy plot shows a trend from quartz monzodiorite through to monzogranite, with most samples plotting in the granodiorite field (Fig. 8a). The samples follow the same trend as those from the Alma Pluton on the AFM diagram (Fig. 9a), but tend to have slightly higher Y+Nb values and higher Rb (Fig. 10a).

Point Wolfe River Pluton

The Point Wolfe River Pluton is divided into six separate mappable units (Fig. 7). An intrusive sequence from more mafic to more felsic is inferred, although contact relations were rarely observed. U-Pb dating of zircons from the Pollett River granodiorite and Old Shepody Road granite (Fig. 7) gave ages of 625±5 Ma and 615±1 Ma, respectively (Bevier, 1988); this significant difference in age suggests that the various lithologies in the Point Wolfe River Pluton are not comagmatic, in spite of their close spatial association. None of the lithological units is identical to those in the Fortyfive River, Alma, and Goose Creek intrusions.

Small bodies of quartz diorite/tonalite are a minor component of the pluton. They are characterized by 15 to 30% mafic minerals (amphibole or amphibole plus biotite) and only minor amounts of alkali feldspar. Modal compositions range from quartz diorite to tonalite and granodiorite (Barr and White, 1988a). Texture ranges from subporphyritic (with prominent subhedral plagioclase) to equigranular, and grain size from fine to medium. Nine analyzed samples from locations indicated on Figure 7 have silica contents ranging from 52 to 62%, with most

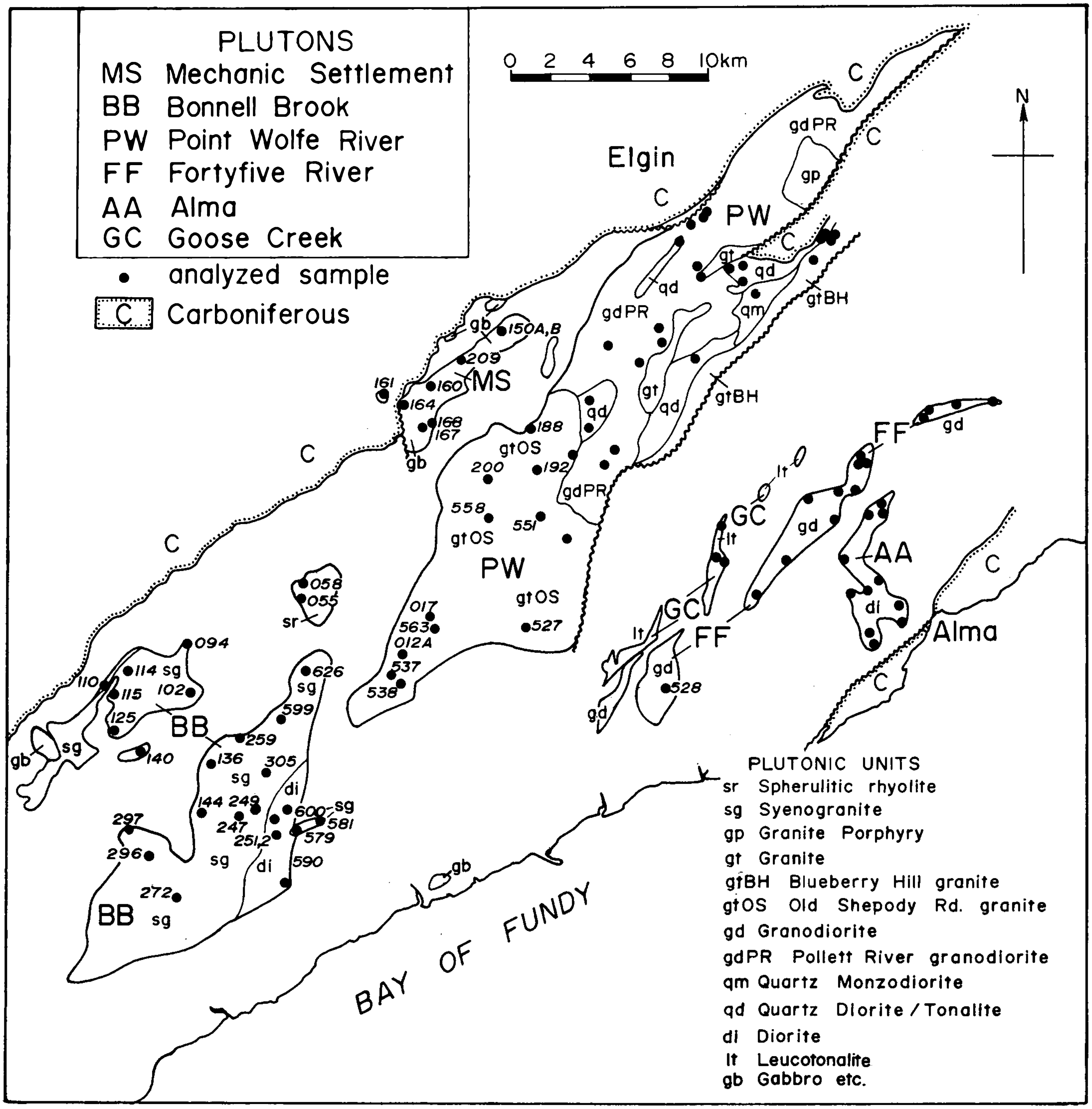

Fig. 7. Distribution of plutonic units in the study area. Locations of analyzed samples are shown; numbered sample locations are those for which data are presented in Tables 3, 4, and 6. First digit 4 is omitted from sample numbers on map for clarity. Data for unnumbered analyzed samples are given in Barr (1987) and Barr and White (1988a).

samples containing about 60% SiO_2 (Barr and White, 1988a). Hence overall these rocks are less mafic than those of the Alma Pluton, as illustrated on Figures 8a to 10a.

Quartz monzodiorite/tonalite occurs only in one area near the northeastern end of the pluton. It is coarse-grained, and contains about 20% amphibole, with less abundant, finer grained biotite. The most abundant mineral is plagioclase; quartz and microcline are interstitial. One analyzed sample from this minor unit contains about 60% SiO_2 and is chemically similar to samples with similar silica contents from the quartz diorite/tonalite unit (Figs. 8a, 9a, 10a).

The Pollett River granodiorite is the main unit of the Point Wolfe River Pluton in the northeastern part of the map area. It consists of medium-grained granodiorite, containing amphibole, biotite, and subporphyritic subhedral plagioclase, with interstitial quartz and microcline and accessory magnetite, apatite, allanite, and sphene. In its northeastern part, the granodiorite is mixed with abundant mafic material, apparently mafic metavol-

Table 2. K-Ar data** for samples from the Bonnell Brook (4590B) and Mechanic Settlement (4167B) diorites.

	K(%)	^{40}K(ppm)	^{40}Ar*(ppm)	^{40}Ar*/^{40}Ar	^{40}Ar*/^{40}K	Age (Ma)
4590B	0.280	0.334	0.01244	0.680	0.03724	548±37
4167B	0.392	0.467	0.01630	0.615	0.03490	518±40

*Radiogenic ^{40}Ar

**Analyses done on hornblende concentrates, -80/+200 mesh, treated with dilute HF and HNO_3 to remove alteration. Separations and analyses by Krueger Enterprises, Inc., Geochron Laboratories Division, Cambridge, Massachusetts. Constants used: $\lambda\beta = 4.962 \times 10^{-10}$/year; $\lambda e + \lambda \acute{e} = 0.581 \times 10^{-10}$/year; $^{40}K/K = 1.193 \times 10^{-4}$ g/g. Errors reported are 2σ.

canic rocks, and both are highly altered and sheared. Elsewhere, xenolithic material is less abundant. Twelve analyzed samples from the Pollett River granodiorite show a range in SiO_2 content from about 61 to 70%. They are similar in range of normative (as well as modal) mineralogies to the Fortyfive River granodiorite (Fig. 8a), and overlap with the Fortyfive River samples on the AFM plot (Fig. 9a). They also are similar in Rb content but show a broader range in Nb+Y content compared to the Fortyfive River samples (Fig. 10a).

The Old Shepody Road granite forms most of the southwestern portion of the Point Wolfe River Pluton, as well as small intrusions (gt on Figure 7) within the Pollett River granodiorite to the northeast. It is characterized by large (up to 2 cm) ovoid phenocrysts of quartz, which survive as augen in the more highly sheared samples. Plagioclase is subhedral and subporphyritic, and microperthitic microcline is interstitial. Biotite is the main mafic mineral, with minor amphibole in some samples. Allanite is an abundant accessory mineral. Silica contents in thirteen analyzed samples (Table 2 and Barr and White, 1988a) range from 70 to 74%, and normative mineralogies overlap with some samples from the Pollett River granodiorite (Fig. 8a). On the AFM diagram (Fig. 9a), the samples form a close grouping, again overlapping with the Pollett River granodiorite (Fig. 10b). They are also similar to the granodiorite in range of Rb and Nb+Y contents (Fig. 10b).

The Blueberry Hill granite extends along the southeastern margin of the Point Wolfe River Pluton. In many areas it is intensively sheared and reduced to a fine-grained, banded protomylonite, but locally the original texture is partially preserved. In those places the rock is coarse-grained and consists of approximately equal amounts of quartz, plagioclase, and alkali feldspar with less than 10% mafic minerals. The felsic minerals form augen in a more granulated matrix, but the original texture appears to have been equigranular. Three samples from the Blueberry Hill granite contain 71-72% silica, and they are chemically similar to the Old Shepody Road granite (Figs. 8a, 9a, 10a). It is possible that the Blueberry Hill granite is closely related to the Old Shepody Road granite.

A large body of granite porphyry occurs within the Pollett River granodiorite in the northeastern part of the map area (Fig. 7). Most exposures of this unit are intensely deformed and altered, and mafic (metavolcanic?) xenoliths are abundant. The porphyry consists of euhedral plagioclase phenocrysts (up to 0.5 cm in length), less abundant ovoid quartz phenocrysts, and very rare mafic phenocrysts in a fine-grained equigranular groundmass of anhedral quartz and alkali feldspar. The granite porphyry appears to have intruded the granodiorite and is probably the youngest (and highest level) unit of the pluton. No samples suitable for chemical analysis were obtained.

Near the margins of the Old Shepody Road granite there occur small areas of fine grained diorite, granodiorite, and rarely granite. Poor exposure in these areas precluded mapping of these as separate lithologies. Dykes and irregular bodies of fine grained pink syenogranite also occur locally in the Old Shepody Road granite. These appear to be petrologically similar to granite of the Bonnell Brook Pluton described below, and if so, support that U-Pb zircon data (Bevier, 1988) which show that the Bonnell Brook Pluton is younger. One analyzed sample (4537; Table 4) contains more than 75% SiO_2, and is compositionally similar to the Bonnell Brook samples.

Bonnell Brook Pluton

The Bonnell Brook Pluton occurs in several separate bodies in the southwestern part of the map area. It consists mainly of relatively homogeneous syenogranite containing less than 3% biotite, amphibole, sphene, and allanite. Texture varies from medium-grained equigranular to fine-grained microporphyritic, the latter consisting of mainly plagioclase microphenocrysts in a granophyric groundmass. This granophyric granite occurs along the northern margins of the pluton. Especially where granophyric or fine-grained equigranular, the syenogranite contains numerous miarolitic cavities. The Bonnell Brook Pluton is interpreted to be a high-level intrusion, with shallower parts exposed towards the northern part of the map area.

A dome-like body of spherulitic rhyolite located north of the largest body of the pluton (Fig. 7) is interpreted to be the highest level (sub-volcanic) part of the pluton. It is texturally very similar to the granophyric unit of the pluton, except it contains subhedral plagioclase microphenocrysts rimmed by spherulites instead of granophyre.

Table 3. Chemical analyses* and CIPW normative mineralogies** for samples from the Fortyfive River Pluton (4528) and the Old Shepody Road granite unit of the Point Wolfe River Pluton***.

	Fortyfive River	Old Shepody Road Granite									
Sample	4528	4012A	4017	4188	4192	4200	4527	4538	4551	4558	4563
SiO_2	65.65	74.75	72.24	71.47	69.06	72.06	74.01	70.30	70.23	71.62	70.56
TiO_2	0.53	0.25	0.28	0.30	0.36	0.26	0.29	0.32	0.36	0.33	0.35
Al_2O_3	16.10	12.70	14.35	14.65	15.12	14.24	13.38	14.15	14.71	14.31	14.82
Fe_2O_3	4.32	1.77	2.07	2.15	3.03	1.83	1.86	2.31	2.71	2.41	2.57
MnO	0.08	0.06	0.07	0.07	0.07	0.06	0.08	0.08	0.09	0.08	0.05
MgO	2.20	1.19	1.37	1.27	1.47	1.16	1.42	1.43	1.60	1.40	1.59
CaO	2.32	0.90	1.38	1.83	2.68	1.66	0.45	1.61	1.73	2.06	1.66
Na_2O	4.39	4.02	3.72	4.12	3.71	4.16	4.22	4.25	4.13	4.23	4.07
K_2O	2.90	3.95	3.16	3.07	2.69	3.26	3.68	2.87	2.65	2.99	3.19
LOI	1.30	0.90	0.80	0.70	1.70	0.70	0.60	1.20	0.90	0.90	1.00
P_2O_5	0.17	0.06	0.08	0.09	0.09	0.07	0.07	0.08	0.10	0.09	0.10
Total	99.96	100.55	99.52	99.72	99.98	99.46	100.06	98.60	99.21	100.42	99.96
Q	20.61	32.47	33.74	30.05	29.37	30.30	32.30	29.53	30.20	28.97	28.83
C	1.96	0.32	2.53	1.45	1.48	1.03	1.82	1.35	2.18	0.59	1.92
Or	17.41	23.45	18.94	18.34	16.20	19.53	21.89	17.44	15.95	17.78	19.08
Ab	37.75	34.17	31.92	35.25	32.00	35.68	35.94	36.97	35.60	36.01	34.85
An	10.56	4.09	6.41	8.59	12.95	7.88	1.79	7.67	8.08	9.69	7.67
Hy	7.73	3.85	4.51	4.27	5.30	3.83	4.47	4.84	5.45	4.71	5.24
Mt	2.55	1.03	1.22	1.26	1.79	1.08	1.09	1.38	1.60	1.41	1.51
Il	1.02	0.48	0.54	0.58	0.70	0.50	0.55	0.63	0.70	0.63	0.67
Ap	0.40	0.14	0.19	0.21	0.21	0.16	0.16	0.19	0.24	0.21	0.23
Total	99.99	100.00	100.00	99.99	100.00	100.00	100.00	100.00	99.99	100.00	100.00
Ba	834	664	602	694	679	669	743	658	656	662	647
Rb	72	125	88	87	82	100	82	87	60	98	99
Sr	220	125	215	229	300	215	95	226	253	243	263
Y	24	20	21	18	16	22	24	15	23	16	16
Zr	143	117	134	142	127	136	152	137	130	136	143
Nb	9	11	11	10	7	9	17	7	11	9	8
Cu	9	1	2	3	nd	3	88	6	2	2	4
Pb	nd	nd	1	nd	nd	11	nd	6	nd	13	1
Zn	47	25	28	39	44	31	56	47	42	35	34
Ni	3	3	7	6	6	2	5	2	3	8	5
Cr	7	8	7	7	14	9	1	5	9	6	8
V	74	23	29	29	21	25	26	38	43	35	44
Ga	13	14	11	15	12	13	13	12	13	13	14
Th	4	19	18	5	nd	16	15	10	6	19	12

*Analytical methods as in Table 1.
**Calculated with FeO/FeO(total) set at 0.6.
***Sample locations shown on Figure 7.

Table 4. Chemical analyses* and CIPW normative mineralogies** for samples from the Bonnell Brook Pluton, the spherulitic rhyolite dome (4055, 4058), and a dyke in the Old Shepody Road granite (4537)***.

	Diorite			Syenogranite										
Sample	4251	4252	4590B	4094	4102	4110	4114	4115	4125	4136	4140	4144	4247	4249
SiO_2	52.23	53.18	49.90	74.59	74.30	73.44	73.98	75.93	74.23	75.99	75.33	75.99	74.48	73.92
TiO_2	0.88	0.83	0.77	0.24	0.24	0.27	0.28	0.23	0.24	0.15	0.20	0.17	0.24	0.31
Al_2O_3	15.95	16.45	16.96	13.10	13.38	13.23	13.19	13.18	12.98	12.55	12.80	12.58	13.17	13.50
Fe_2O_3	8.83	8.34	8.84	1.79	1.95	2.64	2.01	1.71	1.75	1.29	1.62	1.35	1.84	2.09
MnO	0.15	0.14	0.16	0.04	0.04	0.08	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.05
MgO	6.05	6.09	7.44	0.85	0.90	0.93	0.92	0.96	0.95	0.85	0.85	0.84	1.04	0.93
CaO	9.55	8.54	9.44	0.75	0.66	0.45	0.64	0.44	0.80	0.33	0.39	0.44	0.74	1.07
Na_2O	3.06	2.88	2.73	3.78	4.24	4.98	4.82	4.23	4.16	4.08	4.56	4.57	4.28	4.16
K_2O	0.82	1.05	1.12	3.68	3.60	3.02	3.15	3.57	3.70	3.91	3.69	3.44	3.54	3.41
LOI	1.70	1.60	1.70	0.40	0.70	0.30	0.90	0.40	0.40	0.10	0.50	0.30	0.50	0.70
P_2O_5	0.16	0.18	0.14	0.04	0.04	0.05	0.04	0.03	0.05	0.14	0.04	0.03	0.04	0.06
Total	99.38	99.28	99.20	99.26	100.05	99.39	99.98	100.73	99.30	99.43	100.02	99.75	99.91	100.20
Q	4.36	6.38		35.82	33.03	30.38	31.15	34.91	32.90	35.68	32.52	34.04	32.84	32.93
C				1.65	1.42	1.08	0.79	1.63	0.81	1.35	0.70	0.62	1.06	1.17
Or	4.99	6.38	6.83	22.02	21.44	18.04	18.81	21.05	22.13	23.28	21.93	20.46	21.06	20.28
Ab	26.65	25.07	23.82	32.39	36.15	42.59	41.21	35.71	35.63	34.78	38.81	38.91	36.47	35.42
An	28.17	29.69	31.67	3.50	3.04	1.93	2.94	1.98	3.69	0.73	1.68	2.00	3.43	4.95
Di	15.62	10.14	12.50											
Hy	12.84	15.30	17.75	3.02	3.23	3.81	3.28	3.23	3.24	2.82	2.95	2.80	3.51	3.30
Ol			0.31											
Mt	5.27	4.98	5.29	1.05	1.14	1.55	1.18	0.99	1.03	0.75	0.95	0.79	1.08	1.22
Il	1.72	1.62	1.51	0.46	0.46	0.52	0.54	0.44	0.46	0.29	0.38	0.33	0.46	0.59
Ap	0.38	0.43	0.34	0.09	0.09	0.12	0.09	0.07	0.12	0.33	0.09	0.07	0.09	0.14
Total	100.00	100.00	100.00	100.01	100.00	100.01	100.00	100.00	100.00	100.01	100.01	100.00	100.00	100.00
Ba	168	208	201	506	504	544	643	570	483	498	485	565	531	430
Rb	24	35	45	142	133	100	97	111	134	143	131	82	127	124
Sr	232	251	255	46	51	66	59	46	48	22	36	53	48	74
Y	28	27	22	58	53	81	46	44	51	39	54	40	43	34
Zr	90	80	75	211	207	336	252	201	195	156	205	177	206	192
Nb	6	8	5	17	17	18	15	14	15	17	17	13	16	10
Cu	87	76	59	6	3	5	nd	1	10	5	5	5	5	16
Pb	5	nd	5	nd	10	nd	3	8	27	10	29	10	2	5
Zn	102	98	102	34	43	63	41	43	67	25	46	27	30	55
Ni	69	98	154	4	7	6	3	4	4	5	5	5	4	3
Cr	166	41	85	4	12	8	10	9	8	5	5	5	9	4
V	242	210	211	5	8	nd	8	4	11	5	5	5	3	8
Ga	17	15	19	15	12	16	15	13	14	16	15	13	15	12
Th	2	nd	nd	15	11	9	5	12	20	10	13	17	11	14

Table 4. Chemical analyses* and CIPW normative mineralogies** for samples from the Bonnell Brook Pluton, the spherulitic rhyolite dome (4055, 4058), and a dyke in the Old Shepody Road granite (4537)***

	Syenogranite (Continued)										Rhyolite Dome		Dyke
Sample	4259T	4272	4296	4297	4305	4579	4581T	4599T	4600T	4626	4055	4058	4537
SiO_2	74.26	74.38	74.77	73.28	74.73	75.97	72.52	72.81	75.28	73.93	72.71	73.56	74.34
TiO_2	0.22	0.25	0.22	0.24	0.25	0.18	0.31	0.26	0.24	0.19	0.28	0.28	0.20
Al_2O_3	12.94	13.04	13.14	13.25	13.08	13.00	14.03	13.37	13.14	12.87	12.96	12.97	13.40
Fe_2O_3	1.68	1.80	1.70	2.52	1.33	1.68	2.84	2.11	1.79	1.71	2.45	2.69	1.24
MnO	0.04	0.05	0.04	0.09	0.03	0.05	0.11	0.05	0.04	0.07	0.08	0.10	0.07
MgO	0.84	0.91	1.00	0.83	0.86	0.82	1.08	0.92	0.92	0.82	0.81	0.87	1.02
CaO	0.63	0.78	0.41	0.73	0.91	0.57	1.19	0.79	0.78	0.69	0.93	0.68	0.37
Na_2O	4.41	4.57	4.71	5.22	3.96	4.53	4.93	4.39	4.33	4.34	4.86	4.73	4.01
K_2O	3.59	3.55	3.61	3.16	3.84	3.58	2.75	3.17	3.39	3.51	2.83	2.82	3.95
LOI	0.40	0.60	0.40	0.20	0.50	0.30	0.50	1.00	0.40	0.70	0.50	0.60	0.70
P_2O_5	0.04	0.04	0.03	0.04	0.04	0.03	0.06	0.05	0.04	0.04	0.04	0.04	0.05
Total	99.05	99.97	100.03	99.56	99.53	100.71	100.32	98.92	100.35	98.87	98.45	99.34	99.35
Q	32.48	31.13	31.04	27.70	34.00	33.05	28.72	32.46	33.86	32.87	30.61	32.39	33.93
C	0.76	0.36	0.82	0.01	0.86	0.71	0.93	1.43	1.03	0.79	0.31	1.01	2.00
Or	21.52	21.13	21.43	18.82	22.93	21.09	16.31	19.15	20.06	21.15	17.10	16.90	23.68
Ab	37.86	38.95	40.04	44.52	33.86	38.21	41.86	37.98	36.69	37.44	42.04	40.60	34.42
An	2.91	3.64	1.85	3.39	4.30	2.62	5.53	3.67	3.61	3.22	4.45	3.16	1.53
Hy	2.96	3.16	3.34	3.53	2.69	2.94	4.27	3.43	3.16	3.05	3.40	3.72	3.21
Mt	0.99	1.05	0.99	1.47	0.78	0.97	1.65	1.25	1.04	1.01	1.45	1.58	0.73
Il	0.42	0.48	0.42	0.46	0.48	0.34	0.59	0.51	0.46	0.37	0.54	0.54	0.39
Ap	0.09	0.09	0.07	0.09	0.09	0.07	0.14	0.12	0.09	0.10	0.10	0.09	0.12
Total	99.99	99.99	99.99	100.00	99.99	100.00	100.01	99.99	100.00	99.99	100.00	99.99	100.00
Ba	477	477	458	599	484	484	476	506	455	509	526	525	585
Rb	128	116	135	81	143	123	99	111	99	116	90	92	135
Sr	41	45	41	62	60	40	80	50	52	48	57	46	114
Y	51	42	41	60	30	57	47	76	50	57	65	70	21
Zr	227	203	204	342	162	201	307	234	209	211	354	349	129
Nb	18	13	15	17	10	18	15	19	15	14	17	18	10
Cu	3	5	5	5	3	4	5	5	6	2	1	nd	6
Pb	3	12	10	10	5	27	21	4	7	8	nd	12	12
Zn	43	41	46	73	24	52	69	50	49	39	39	84	30
Ni	2	5	5	8	2	5	5	8	6	10	7	2	6
Cr	5	6	7	5	3	6	13	3	11	11	4	5	7
V	5	8	5	5	11	4	6	9	6	4	nd	nd	10
Ga	15	15	15	18	12	13	16	16	13	14	17	17	11
Th	10	12	10	10	18	12	7	16	12	14	6	17	19

*Analytical methods as in Table 1.

**Calculated with FeO/FeO(total) set at 0.6.

***Sample locations shown on Figure 7.

Table 5. Average syenogranite* from the Bonnell Brook Pluton compared with average evolved I-type and S-type granites and average A-type granite from Whalen *et al.* (1987).

	I-Type	S-Type	A-Type	BONNELL
SiO_2	73.39	73.39	73.81	74.36
TiO_2	0.26	0.28	0.26	0.24
Al_2O_3	13.43	13.45	12.40	13.12
Fe_2O_3	2.05	2.26	2.97	1.90
MnO	0.05	0.04	0.06	0.06
MgO	0.55	0.58	0.20	0.91
CaO	1.71	1.28	0.75	0.67
Na_2O	3.33	2.81	4.07	4.45
K_2O	4.13	4.56	4.65	3.44
P_2O_5	0.07	0.14	0.04	0.05
Ba	510	388	352	513
Rb	194	277	169	116
Sr	143	81	48	54
Y	34	33	75	50
Zr	144	136	528	228
Nb	12	13	37	15
Cu	4	4	2	5
Pb	23	28	24	11
Zn	35	44	120	46
Ni	2	4	1	5
V	22	23	6	6
Ga	16	17	25	15
Th	22	18	23	13

*Calculated from data in Table 4.

Along the southeastern margin of the pluton an extensive area of diorite to quartz diorite is present. These rocks consist mainly of plagioclase and hornblende, with minor interstitial quartz and relict clinopyroxene in the cores of hornblendes. Grain size varies from medium to coarse. The diorite body is cut by abundant dykes of the syenogranite, as well as minor fine-grained granodiorite. A K-Ar date from hornblende in the diorite (Table 2) indicates that it may be similar in age to the syenogranite (about 550 Ma).

A small body of gabbro occurs adjacent to the Bonnell Brook Pluton near the northwestern margin of the map area. It has not yet been studied in detail but may be similar to the Mechanic Settlement Pluton described below.

Analyzed samples from the Bonnell Brook granite (Table 4) range in composition from monzogranite to alkali feldspar granite but most are syenogranites (Fig. 8b). The two analyzed samples from the spherulitic rhyolite dome fall in the trend of the Bonnell Brook samples. On the AFM diagram, all these samples form an elongate cluster (Fig. 9b). On the Rb-Nb+Y diagram (Fig. 10b), they form a cluster spanning the volcanic arc/within-plate field boundary. Although a detailed discussion of the petrogenesis of these granites is beyond the scope of the present paper, it is of interest to note that they do not display the high average Zr, Y, Nb, Ga, and Zn contents typical of A-type granitoid suites, although Na_2O, CaO, and Sr values are more like those of A-types than evolved I-types (Table 5). However, high Ba and moderate Rb, as well as high Na_2O, suggest I-type rather than S-type affinities (Table 5).

The dioritic rocks of the Bonnell Brook Pluton contrast markedly with the adjacent syenogranite. They are quartz gabbros and quartz diorites (Fig. 8b) which are more MgO-rich and lower in FeO than diorites of the Alma or Point Wolfe River plutons (Fig. 8b). Their chemical similarities (Figs. 9b, 10b) to the Mechanic Settlement suite (see below) suggest that they may be related, or have a similar origin.

Mechanic Settlement Pluton

The Mechanic Settlement Pluton occurs near the northern margin of the Caledonian Highlands in the vicinity of the community of Mechanic Settlement. It is mainly of gabbroic composition, but grades to diorite and granodiorite. It appears to be a small layered intrusion, although mapping and sampling are not yet detailed enough to determine the pattern of layering. Ultramafic layers contain abundant relict olivine and orthopyroxene. The host rock units display hornfelsing and development of biotite adjacent to the pluton.

Eight samples from the pluton (Table 6) range in silica content from 44 to 59% and from gabbro to quartz diorite in normative rock name (Fig. 8a). The AFM diagram (Fig. 9a) shows a scattered "iron-enrichment" trend characteristic of tholeiitic suites (see Discussion).

DISCUSSION

Relations between Volcanic and Plutonic Units

The Bonnell Brook syenogranite and associated rhyolite dome appear to be part of a high-level to subvolcanic intrusion. The U-Pb (zircon) age of 550±1 Ma for the syenogranite is essentially identical to the age of 548±1 Ma for a rhyolite sample from sequence B south of the Point Wolfe River Pluton (Bevier, 1988). Hence it seems probable that these felsic intrusive and extrusive rocks are comagmatic. The chemical data are consistent with this interpretation, as the syenogranite is broadly similar to analyzed dacitic to rhyolitic volcanic samples (Figs. 3b, 4b, 5b).

These felsic rocks, both volcanic and plutonic, are spatially in close association with the mafic volcanic and plutonic rocks and are probably of similar age. The main basaltic unit occurs adjacent to and locally interlayered with rhyolite across much of the map area, and basaltic flows are also interlayered with the dacitic to rhyolitic lapilli tuff and overlying volcaniclastic conglomerate, suggesting close association in time. The age of the Mechanic Settlement Pluton is not yet known, but a K-Ar (amphibole) date of 518±37 Ma (Table 2) may be an approximate age for the pluton. Hence it may be similar in age to the rhyolitic and basaltic volcanic rocks and the Bonnell Brook syenogranite and diorite. This is supported by the chemical similarity between the Mechanic Settlement Pluton and the basaltic rocks. Both are

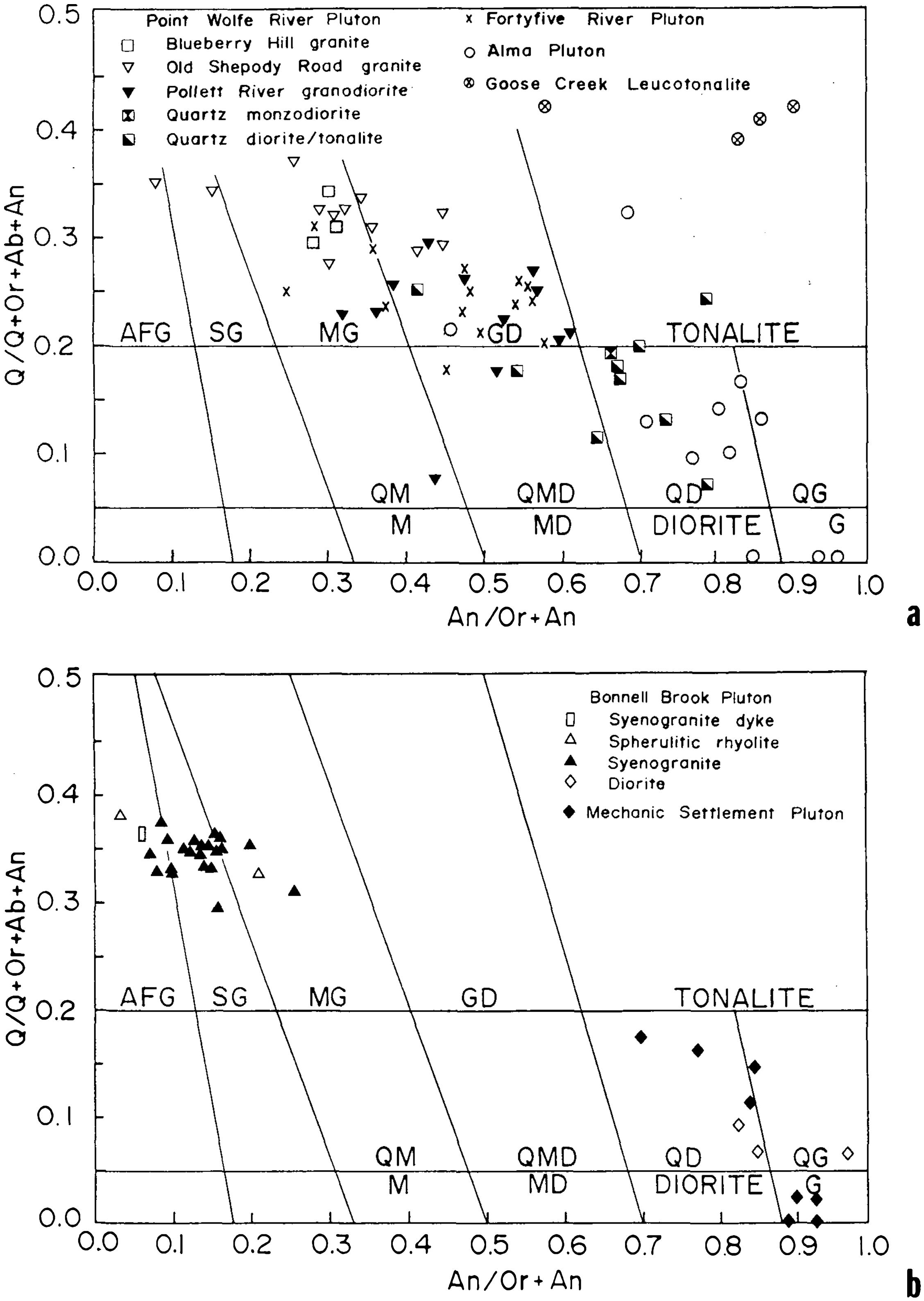

Fig. 8. Plots of CIPW normative Quartz/Quartz+Orthoclase+Albite+Anorthite against Anorthite/Orthoclase+Anorthite for plutonic rocks of the study area. Data are from Tables 3, 4, and 6, Barr (1987), and Barr and White (1988a). Fields are from Streckeisen and Le Maitre (1979); AFG = alkali feldspar granite, SG = syenogranite, MG = monzogranite, GD = granodiorite, QM = quartz monzonite, M = monzonite, QMD = quartz monzodiorite, MD = monzodiorite, QD = quartz diorite, QG = quartz gabbro, G = gabbro. (a) Older group of plutons: Goose Creek leucotonalite (n = 4), Alma Pluton (n = 11), Fortyfive River Pluton (n = 14), and Point Wolfe River Pluton: quartz diorite/tonalite (n = 9), quartz monzodiorite (n = 1), Pollett River granodiorite (n = 12), Old Shepody Road granite (n = 13), Blueberry Hill granite (n = 3). (b) younger group of plutons: Mechanic Settlement Pluton (n = 8), Bonnell Brook Pluton: syenogranite (n = 22), diorite (n = 3) spherulitic rhyolite dome (n = 2).

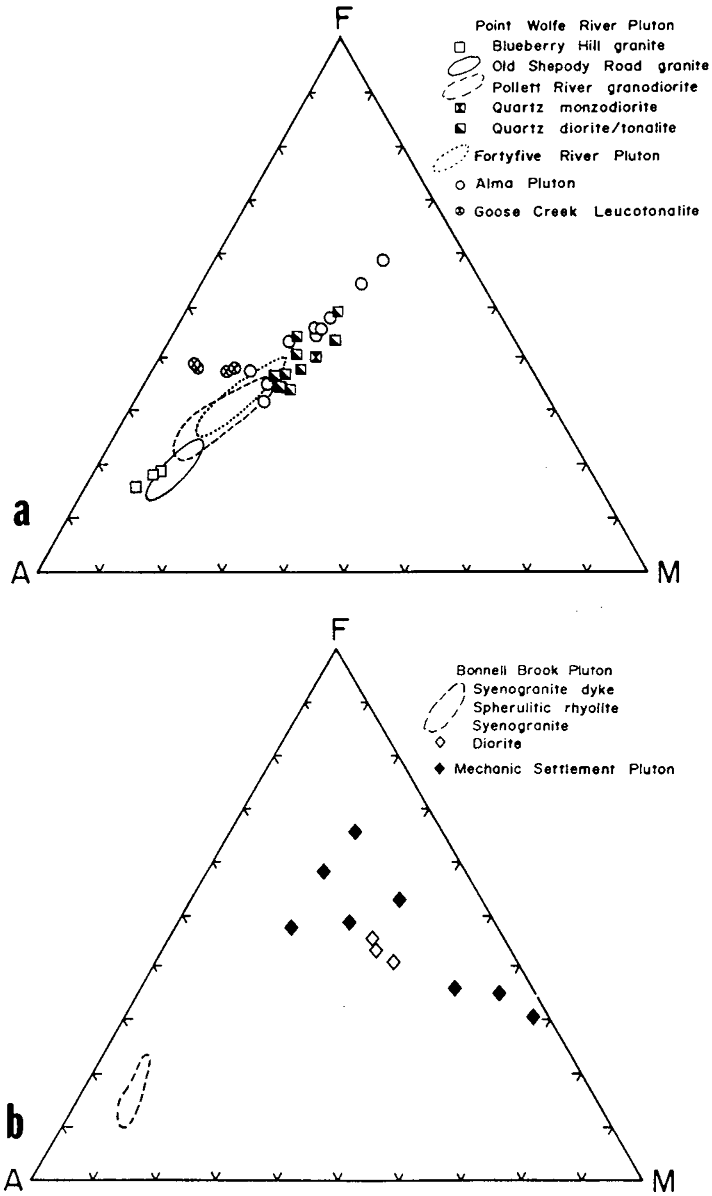

Fig. 9. A(Na_2O+K_2O) - F(FeO total) - M(MgO) diagrams for plutonic rocks of the study area. (a) older plutons and (b) younger plutons, as in Figure 8.

tholeiitic, and display a similar range of compositions (Figs. 3b, 4b, 5b).

Hence, the mafic and felsic volcanic and plutonic rocks are interpreted to be similar in age (about 550 Ma) and to represent a bimodal temporal and spatial association. Such associations typically form in extensional environments, but the discrimination diagrams for the mafic rocks suggest a strong volcanic arc influence (Fig. 6a, b). This is corroborated by the nature of the Bonnell Brook syenogranite, which is not a typical A-type granitoid suite such as characteristically form in within-plate anorogenic extensional settings (White and Chappell, 1983; Whalen *et al.*, 1987; Pitcher, 1982). Hence it is suggested that these rocks formed during a relatively short-lived intra-arc extensional event. Volcanism was dominantly subaerial (as evidenced by the characteristics of the volcanic rocks), and sedimentation fluvial and lacustrine (N.A. Van Wagoner, personal communication, 1988).

The other major plutons in the map area, as well as volcanic-sedimentary sequence A, have characteristics which contrast markedly with those described above. Age data suggest that these rocks are all older than about 600 Ma: U-Pb (zircon) ages of 625±5 Ma and 615±1 Ma have been obtained from the Pollett River granodiorite and the Old Shepody Road granite, respectively, and Barr (1987) reported a Rb-Sr whole-rock isochron age of 597±18 Ma for the Fortyfive River granodiorite and a K-Ar (hornblende) age of 598±27 Ma for diorite from the Alma Pluton. U-Pb (zircon) ages between about 600 and 630 Ma have been obtained from tuffs in volcanic-sedimentary sequence A (M.L. Bevier, personal communication, 1988). The chemistry of the volcanic rocks in sequence A, although data are limited, suggests that they are calc-alkaline. The plutons, although they are probably not all the same age and hence not part of a single comagmatic suite, form a typical "compositionally expanded I-type" series, characteristic of plutonic rocks formed in association with subduction at continental margins (Pitcher, 1982). They may be broadly co-genetic with the volcanic rocks, although they show less obvious effects of regional deformation. Intense alteration within these intrusions appears to be related to zones of major shearing, and does not require regional metamorphism and deformation (D1) which pervasively affected sequence A volcanic and sedimentary rocks.

The Bonnell Brook and Mechanic Settlement plutons are essentially undeformed and were clearly post-tectonic with respect to the D1 deformational and metamorphic event in the area. They are also located north of the main zone of later shearing which affected the other intrusions, as well as their host rocks (approximately the Fundy Cataclastic Zone of Ruitenberg *et al.*, 1973).

Regional Implications

U-Pb zircon ages of about 625 Ma and 565-555 Ma recently reported from granitoid units in the Saint John area (Watters, 1987; Currie, 1987a, 1988a, 1988b) indicate that older and younger plutons corresponding to those in the eastern Caledonian Highlands are also present in that area. The older plutons have been considered part of the Golden Grove Suite (Currie *et al.*, 1981; Currie, 1987a, 1987b), and cogenetic with volcanic rocks of the Coldbrook Group (e.g., Nance, 1987). The older group of plutons in the eastern Caledonian Highlands (Point Wolfe River, Alma, Fortyfive River, and Goose Creek) appear to be related to this Late Precambrian igneous activity.

In the Saint John area, Eocambrian sedimentary and volcanic rocks unconformably overlie the Coldbrook Group and Golden Grove Suite (Nance, 1987; Currie, 1987b). Volcanic and sedimentary rocks of sequence B are probably correlative with these Eocambrian units. However, major plutonic activity also accompanied volcanism in the study area, as was also suggested by Currie (1988b), and that there may have been a hiatus in igneous activity (in the eastern Caledonian Highlands at least) between about 600 Ma and 550 Ma. The older igneous activity was related to subduction, whereas the younger event was exten-

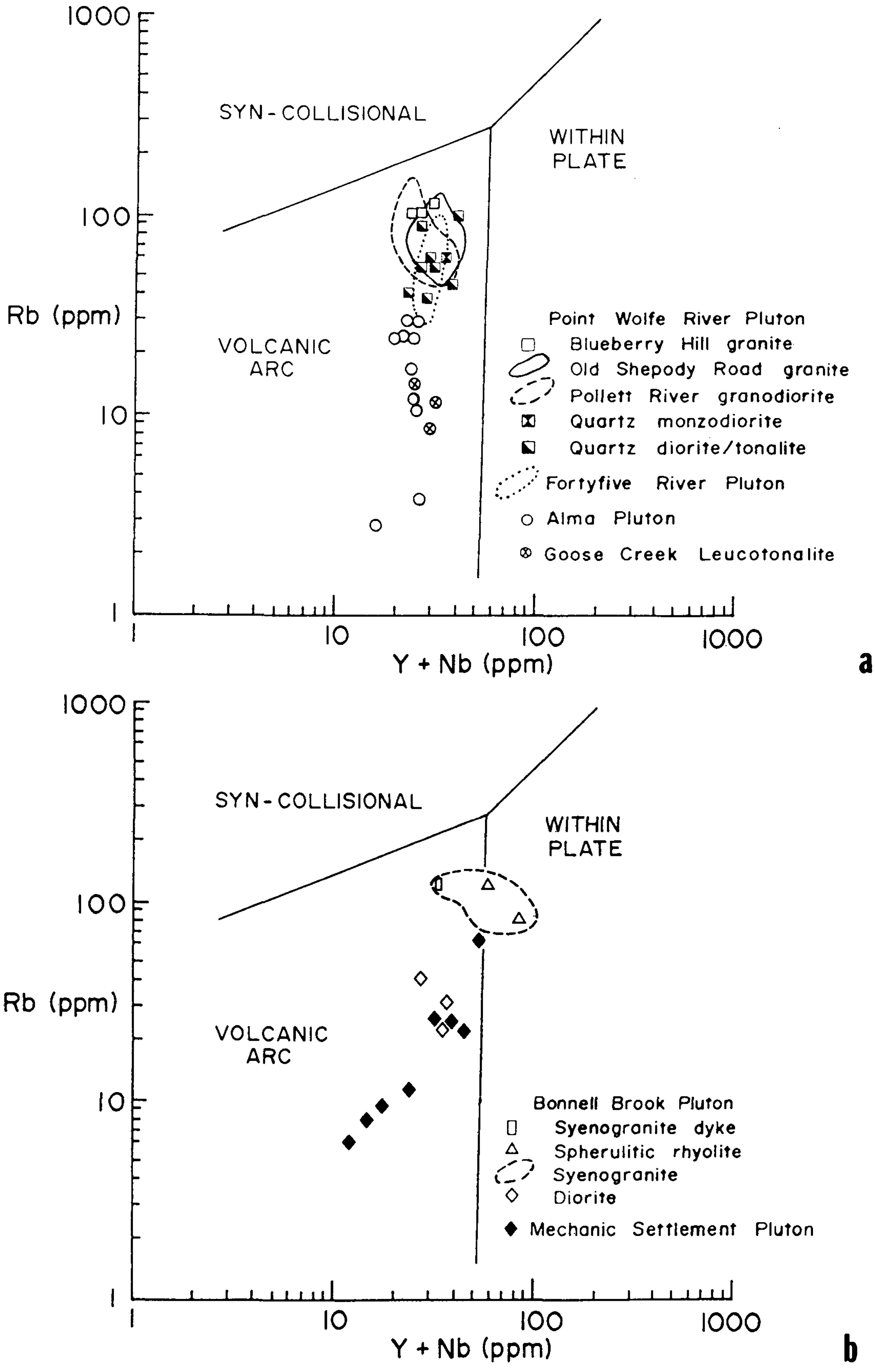

Fig. 10. Plots of Rb against Y+NB. (a) older plutons and (b) younger plutons, as in Figure 8. Fields are from Pearce *et al.* (1984).

Table 6. Chemical analyses* and CIPW normative mineralogies** of samples from the Mechanic Settlement Pluton***.

Sample	4150A	4150B	4160	4161	4164	4167B	4168	4209
SiO_2	49.11	41.41	53.42	46.50	58.41	48.60	53.78	45.35
TiO_2	0.52	0.36	1.25	1.75	1.17	2.13	1.83	0.36
Al_2O_3	16.77	4.99	16.40	16.01	16.07	14.71	14.39	11.26
Fe_2O_3	6.61	14.11	9.40	11.39	8.51	15.42	12.30	11.08
MnO	0.12	0.21	0.15	0.16	0.23	0.20	0.29	0.17
MgO	8.41	27.78	4.76	6.56	3.07	4.29	3.69	16.76
CaO	13.49	3.22	8.52	11.33	4.76	7.98	6.74	8.72
Na_2O	1.62	0.77	3.09	2.01	3.93	2.14	3.43	1.31
K_2O	0.43	0.19	0.91	0.57	1.57	0.86	1.04	0.33
LOI	1.80	6.10	0.40	2.50	1.20	1.80	0.90	3.60
P_2O_5	0.08	0.05	0.19	0.15	0.22	0.20	0.48	0.05
Total	98.96	99.19	98.49	98.93	99.14	98.33	98.87	98.99
Q	1.48		8.11	1.62	14.01	9.36	11.05	
Or	2.63	1.22	5.51	3.52	9.52	5.32	6.32	2.06
Ab	14.17	7.06	26.81	17.76	34.13	18.94	29.85	11.70
An	38.46	10.41	28.91	34.44	22.14	29.28	21.39	25.20
Di	23.88	5.17	10.57	18.58	0.50	8.79	7.96	15.92
Hy	14.21	27.28	11.62	13.34	11.83	14.25	11.38	21.52
Ol		39.13						15.97
Mt	3.96	8.87	5.59	6.90	5.07	9.35	7.34	6.78
Il	1.02	0.74	2.43	3.47	2.28	4.23	3.58	0.72
Ap	0.19	0.13	0.45	0.36	0.52	0.49	1.14	0.12
Total	100.00	100.01	100.01	100.00	100.01	100.00	100.01	100.00
Ba	140	47	232	185	391	304	331	82
Rb	9	6	24	11	58	25	21	8
Sr	178	55	239	358	273	293	303	157
Y	14	8	30	20	44	26	40	11
Zr	70	35	126	71	157	141	122	50
Nb	4	4	10	4	11	7	5	4
Cu	40	33	41	610	8	67	13	58
Pb	nd	nd	nd	nd	6	nd	nd	nd
Zn	61	89	88	87	117	115	140	80
Ni	97	858	27	44	15	8	3	433
Cr	207	1577	30	28	10	6	5	552
V	143	108	263	339	144	642	253	109
Ga	13	7	21	20	19	19	19	11

*Analytical methods as in Table 1.
**Calculated with FeO/FeO(total) set at 0.6.
***Sample locations shown on Figure 7.

sional. Volcanic, plutonic, and sedimentary rocks related to this extensional event are much more extensive in the eastern Caledonian Highlands than those related to the older subduction activity.

The older sequence A and coeval plutonic rocks are comparable to Harbour Main and equivalent volcanic sequences in the Avalon Terrane of eastern Newfoundland. A similar range of U-Pb (zircon) ages, between about 608 and 632 Ma, have been reported from volcanic rocks in Newfoundland, and the Holyrood Granite, closely associated and probably comagmatic with at least some of the volcanic rocks, yielded an age of about 620 Ma (Krogh *et al.*, 1988). These rocks are overlain by Late Precambrian sedimentary rocks, which are separated from Cambro-Ordovician sedimentary units by a local unconformity considered to represent the Avalonian Orogeny. Volcanic-sedimentary sequence B in the eastern Caledonian Highlands may be correlative with these strata. The petrochemical data for volcanic rocks in sequence B and associated plutons are consistent with the interpretation that the Avalonian event was extensional. However, in contrast to the interpretation of Krogh *et al.* (1988), the Late Precambrian history of the Avalon Terrane in southern New Brunswick appears to have been a two-stage event, not a continuum between about 630 Ma and 550 Ma.

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