Field relationships and petrology of the Late Devonian Fisset Brook Formation in the Cheticamp area, western Cape Breton Island, Nova Scotia

Sandra M. Barr and Kevin C.A. Peterson
Department of Geology, Acadia University, Wolfville, Nova Scotia B0P 1X0, Canada

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The Fisset Brook Formation in the Cheticamp area forms two elongate belts, a western belt which includes the type section of the formation in Fisset Brook and a separate eastern belt. In the western belt, the Fisset Brook Formation consists of (1) a lower, mainly sedimentary unit dominated by a basal conglomerate that overlies Proterozoic to Silurian metamorphic and igneous rocks, (2) a dominant middle part that consists of basaltic flows interlayered with minor red clastic sedimentary rocks, and (3) an upper part that consists mainly of rhyolite flows and tuffs. In the eastern belt, the basal sedimentary unit appears to be absent due to faulting, and the upper felsic unit is thicker than in the western belt. Mafic dykes in overlying sedimentary strata of the Creignish Formation (Horton Group) are petrochemically similar to basalt in the Fisset Brook Formation, and may represent the waning stages of igneous activity in the area, or a separate minor Late Devonian to Early Carboniferous igneous event.

Petrological studies of an extensive suite of samples support the results of earlier studies showing that the mafic volcanic rccks are continental, within-plate tholeiites. The rhyolites are similar to within-plate felsic rocks, but lack elevated values of elements such as Zr and Nb that characterize A-type granites. They are probably the extrusive equivalents of voluminous granites of similar age in the Cape Breton Highlands, suggesting that the present exposures of the Fisset Brook Formation may be remnants of more extensive sequences. The stratigraphy, lithology, age, and petrochemical characteristics of the Fisset Brook Formation in the Cheticamp area are very similar to those in the Gillanders Mountain–Lake Ainslie area.

La Formation de Fisset Brook dans la région de Chéticamp forme deux ceintures allongées, une ceinture occidentale renfermant le stratotype de la Formation dans le secteur du ruisseau Fisset et une ceinture orientale séparée. Dans la ceinture occidentale, la Formation de Fisset Brook est constituée (1) d'une unité inférieure principalement sédimentaire où prédomine un conglomérat de base qui recouvre des roches métamorphiques et ignées du Protérozoïque au Silurien, (2) une partie médiane prédominante qui est principalement volcanique et constituée de coulées basaltiques interstratifiées, de roches sédimentaires clastiques rouges en petite quantité, et (3) d'une partie supérieure constituée principalement de coulées rhyolitiques et de tufs. Dans la ceinture orientale, l'unité sédimentaire de base semble absente en raison d'une dislocation, et l'unité felsique supérieure est plus épaisse que dans la ceinture occidentale. Les dykes mafiques dans les strates sédimentaires sus-jacentes de la Formation de Creignish (groupe Horton) possèdent une structure pétrochimique semblable au basalte de la Formation de Fisset Brook et ils pourraient représenter les derniers stades de l'activité éruptive dans le secteur ou un phénomène éruptif mineur distinct qui s'est produit entre le Dévonien supérieur et le Carbonifère inférieur.

Des études pétrologiques d'une vaste série d'échantillons appuient les résultats d'études antérieures révélant que les roches volcanomafiques constituent des tholéiites intra-plaque continentaux. Les rhyolites sont similaires aux roches felsiques intra-plaque, mais elles ne présentent pas les valeurs élevées en éléments comme le Zr et le Nb qui caractérisent les granites de type A. Elles représentent probablement les équivalents extrusifs des granites volumineux d'âge analogue des hautes-terres du Cap-Breton, ce qui laisse supposer que les affleurements présents de la Formation de Fisset Brook pourraient constituer les restes de séquences plus étendues. L'âge et les caractéristiques stratigraphiques, lithologiques et pétrochimiques de la Formation de Fisset Brook dans la région de Chéticamp ressemblent infiniment à ceux de la région du mont Gillanders et du lac Ainslie.

[Traduit par la rédaction]

INTRODUCTION

The Fisset Brook Formation in the Cheticamp area of Cape Breton Island occurs in western and eastern belts separated by older metamorphic and plutonic rocks (Fig. 1). The western belt includes the type section of the formation in Fisset Brook (Kelley and Mackasey, 1965; Blanchard, 1982; Blanchard *et al.*, 1984).

The Fisset Brook Formation and probable correlative units occur at scattered locations through western Cape Breton Island (Fig. 1). Kelley and Mackasey (1965) considered the formation to be the lowermost unit of the Horton Group, but some earlier workers (e.g., Neale, 1964) and most subsequent workers (e.g., Keppie, 1979; Smith and Macdonald, 1981; Giles *et al.*, 1997a, b) considered the formation to be separate from the overlying Horton Group. The age of the Fisset Brook Formation was generally cited as broadly Late Devonian–Early Carboniferous (e.g., Williams *et al.*, 1985), because of conflicting paleontologic and radiometric evidence, and uncertainty as to whether or not all the scattered areas included in

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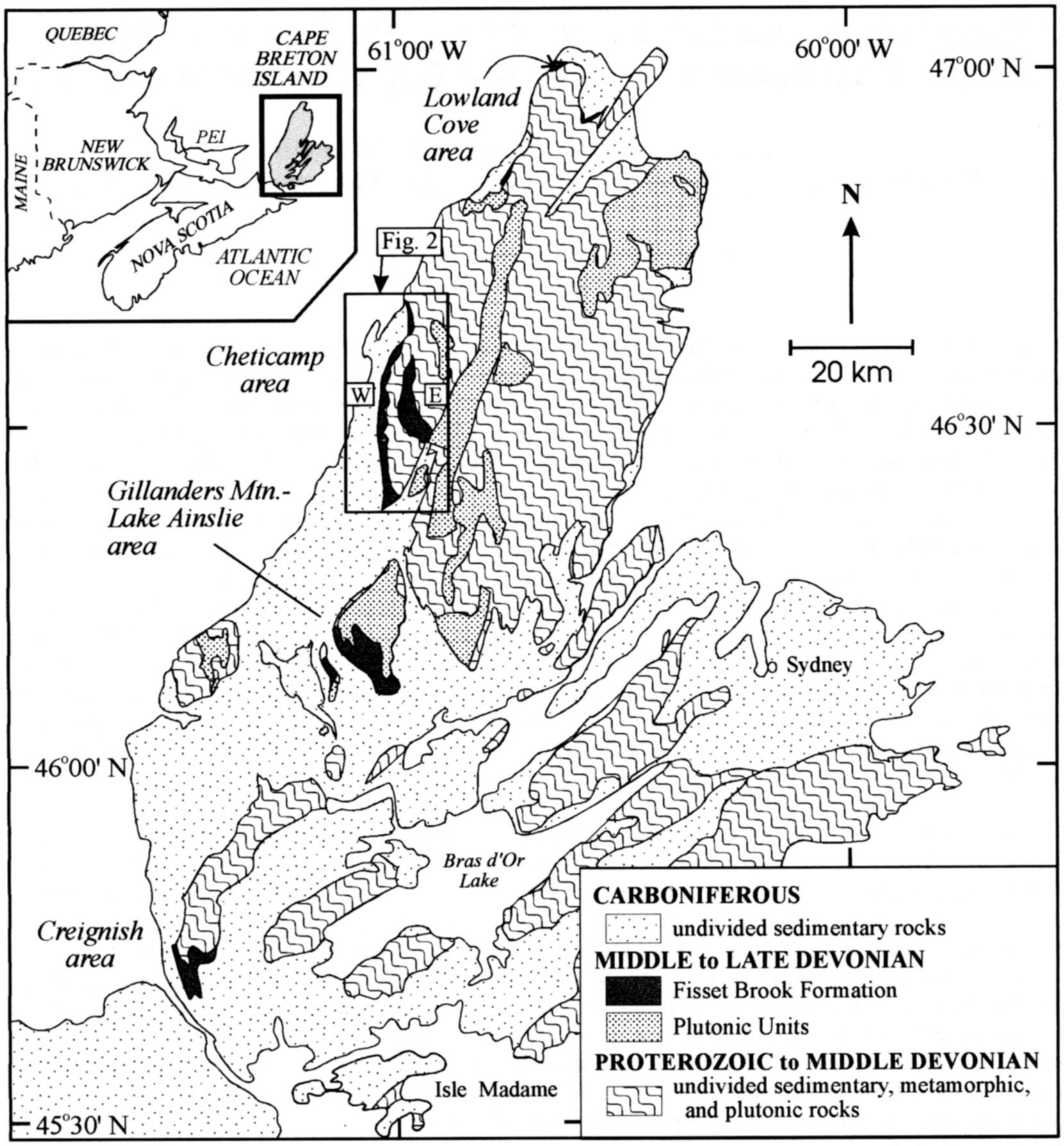

Fig. 1. Distribution of the Fisset Brook Formation in Cape Breton Island, including the western (W) and eastern (E) belts in the Cheticamp area. Map also shows the distribution of plutonic units similar in age to the Fisset Brook Formation (ca. 375 Ma).

the formation are of the same age (e.g., Blanchard *et al.*, 1984). However, recent U-Pb (zircon) dating has shown that rhyolite from the western belt near the type section and from the eastern belt (Fig. 2), as well as in the Gillanders Mountain area (Fig. 1), have identical (within error) ages of 374+6/-3 Ma, ca. 373 to 375 Ma, and 373+/-4 Ma, respectively (G.R. Dunning, written communication, 1997, 1998; Barr *et al.*, 1995). These ages, from rhyolite collected near the top of the formation, suggest that the bulk of the Fisset Brook Formation in these areas is of early Late Devonian age, following the time scale of Tucker *et al.* (1998) which places the boundary between Middle and Late Devonian at ca. 382.5 Ma. However, volcanic rocks in the Lowland Cove area (Fig. 1) appear to be slightly younger at ca. 360 Ma (G.R. Dunning, written communication, 1997); rocks assigned to the Fisset Brook Formation in the Creignish area (Fig. 1) remain undated.

Blanchard (1982) and Blanchard *et al.* (1984) described the Fisset Brook Formation as consisting generally of bimodal basalt-rhyolite suites with interlayered alluvial fan, lacustrine, and minor, fluvial sedimentary rocks. They showed that the basaltic rocks are tholeiitic and formed in an extensional tectonic regime. Based on two samples from the type section, Keppie *et al.* (1997) corroborated that the basalts have a typical, within-plate, tholeiitic chemical signature, with strongly positive epsilon Nd values. Associated rhyolites have lower epsilon Nd values, interpreted to be evidence of mixing between mantle and crustal sources (Keppie *et al.*, 1997).

The purpose of this paper is to report the results of new field and petrochemical studies of the Fisset Brook Formation in both the western and eastern Cheticamp belts, especially the southern part of the western belt which was not included in previous studies, and to compare the formation in the Cheticamp area to that in the Gillanders Mountain–Lake Ainslie area, now known to be the same age. Overall, the results confirm the earlier conclusions by Blanchard (1982), Blanchard *et al.* (1984), Dostal *et al.* (1983) and Keppie *et al.* (1997), but provide a more comprehensive data base for future regional comparisons.

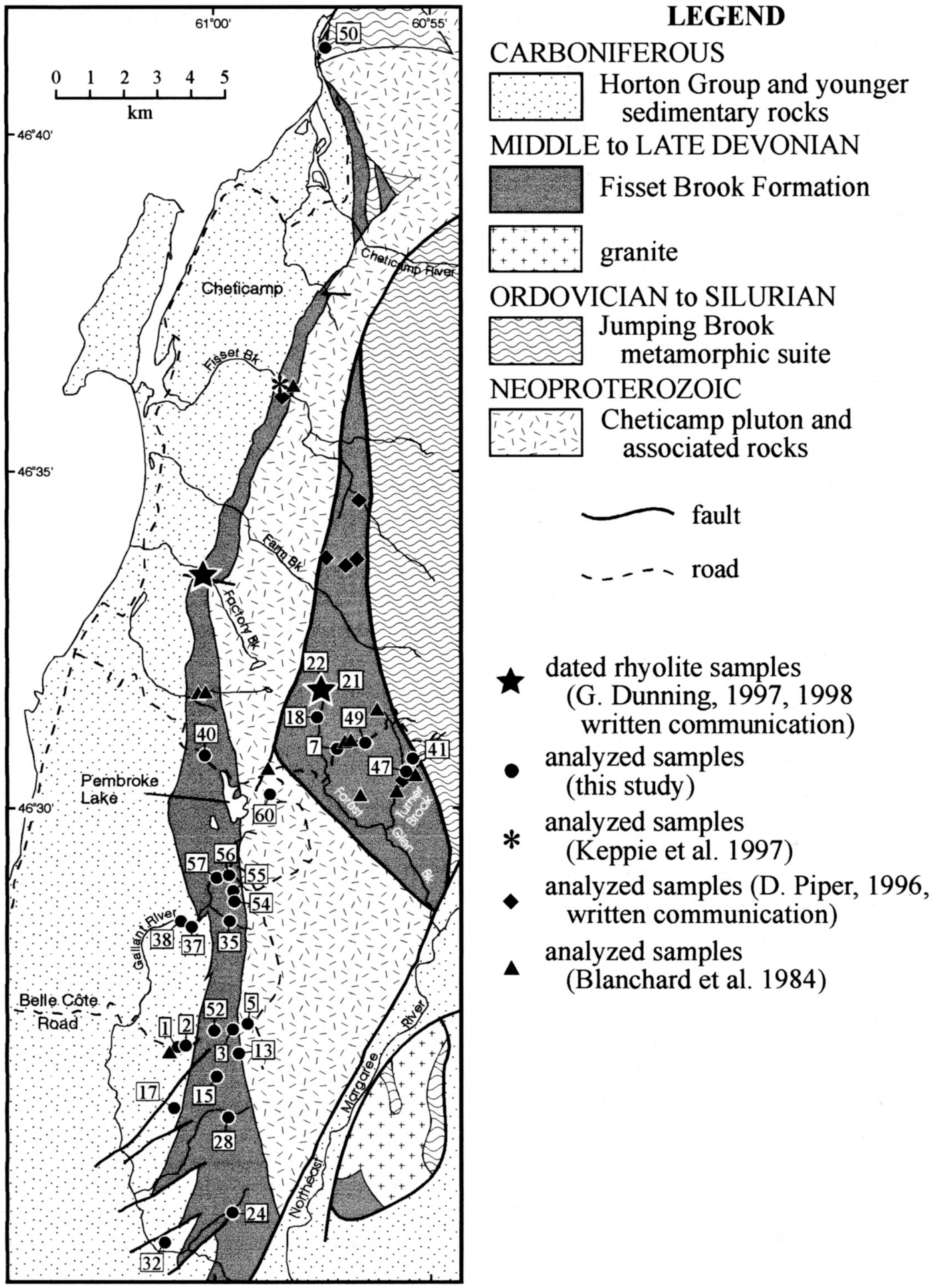

Fig. 2. Simplified geological map of the western and eastern belts of the Fisset Brook Formation in the Cheticamp area, compiled after Peterson (1996), Giles *et al.* (1997a, b), Blanchard (1982), and Barr *et al.* (1992). Locations of analysed samples listed in Table 1 are indicated by numbered circles. Locations on Fisset Brook include 4 samples from Keppie *et al.* (1997), 3 samples from D. Piper (written communication, 1996), and 3 samples from Blanchard *et al.* (1984). Stars indicate locations of dated rhyolite samples (G.R. Dunning, written communication, 1997, 1998).

FIELD RELATIONSHIPS IN THE CHETICAMP AREA

Western belt

Kelley and Mackasey (1965) described the Fisset Brook Formation in the type section in Fisset Brook (Fig. 2) as consisting of a lower, mainly sedimentary unit (polymictic conglomerate, grey siltstone, and andesite), a middle unit described as predominantly andesitic with interbeds of red siltstone, and an upper, predominantly rhyolitic, unit. In the type section, the upper unit also includes both sedimentary and andesitic rocks. Based on more detailed petrological studies, Blanchard

(1982) and Blanchard *et al.* (1984) showed that the "andesite" is mainly basalt in terms of both mineralogy and chemical composition, and that the rhyolite is a welded crystal tuff. Kelley and Mackasey (1965) reported that the three lithological units of the formation were traceable throughout the length of the western belt. During the present study, however, no rhyolite was observed along Belle Cote Road or in stream sections to the south (Fig. 2), although the apparent absence may be due to limited exposure. The southernmost exposure of rhyolite found during the present study is in the upper part of Gallant River east of sample locality 37 (Fig. 2), where porphyritic rhyolite is exposed over a distance of about 20 m, and is intruded by a gabbroic dyke like those in the overlying Creignish Formation.

Kelley and Mackasey (1965) formally placed the top of the Fisset Brook Formation at the top of the uppermost volcanic unit, a position difficult to locate in areas of limited exposure. Similarly, Giles *et al.* (1997a, b) distinguished the Fisset Brook Formation from the overlying units on the basis of the presence of volcanic rocks in the Fisset Brook Formation and their apparent absence in the Horton Group, although mafic dykes continue to occur in the lower part of the Horton Group (Creignish Formation). Observations during the present study suggest that sedimentary rocks in the upper part of the Fisset Brook Formation are lithologically similar to those of the overlying Creignish Formation, but the latter contain more granitoid debris compositionally similar to granite and granodiorite of the Cheticamp Pluton, suggesting that erosion of the pluton made a larger contribution to the Creignish Formation than to the Fisset Brook Formation.

The base of the Fisset Brook Formation in the western belt is an unconformity on the Cheticamp Pluton, marked by a granite-boulder conglomerate or, more locally (e.g., in the area of sample location 50, Fig. 2), the Jumping Brook metamorphic suite or varied unnamed metamorphic rocks (schist and gneiss) of Late Proterozoic or younger age (Barr *et al.*, 1986; Barr *et al.*, 1992). No evidence of mylonitization of the Fisset Brook Formation was observed. The basal conglomerate is well exposed in several streams, including Gallant River, and on the road near the northern tip of Pembroke Lake.

Eastern belt

Lithological units in the eastern belt of the Fisset Brook Formation appear to be very similar to those in the western belt. However, stratigraphic relationships with adjacent units are not clear, as described below, and it is likely that the eastern belt is entirely fault-bounded (Fig. 2).

In the Turner Brook area (Fig. 2), a mainly basaltic unit with interlayered red and grey siltstone forms the basal part of the formation. Lynch (1996a, b) interpreted the basal part of the Fisset Brook Formation in this area to be mylonitic, but observations by the present authors concur with earlier interpretations (e.g., Blanchard, 1982; Barr *et al.*, 1992) that the mylonitic rocks (chlorite schist and phyllite) in this area are part of the underlying Jumping Brook metamorphic suite, not the Fisset Brook Formation. This difference in interpretation is considered in more detail in the Discussion section.

No basal conglomerate units were observed in the eastern belt, and the contact with the Jumping Brook metamorphic suite appears to be a brittle fault. Based on way-up criteria, mainly cross-bedding, the rocks appear to consistently young toward the west where the Fisset Brook Formation is in faulted contact with the Cheticamp Pluton (Fig. 2). The rhyolite which forms the uppermost unit of the formation is well exposed in the upper part of Forest Glen Brook (sample locations 21, 22), and in Turner Brook near its confluence with Forest Glen Brook (Lynch, 1996a; D. Piper, personal communication, 1997). Sedimentary units exposed locally adjacent to the Cheticamp Pluton may represent the Creignish Formation of the Horton Group (Blanchard, 1982), although Giles *et al.* (1997b) included these rocks in the Fisset Brook Formation. In Fisset and Farm brooks in the northern part of the eastern belt, the rhyolitic unit appears to have been faulted out, and interbedded basalt and sedimentary rocks (dipping steeply and younging to the west) outcrop adjacent to the Cheticamp Pluton. The presence of flow-banded, quartz-feldspar porphyritic rhyolite cobbles in conglomerate horizons, however, suggests that the interbedded basalts and sedimentary rocks in this area could be interlayered with or overlie unexposed rhyolite.

PETROGRAPHY

Basaltic rocks

Basaltic flows in both the western and eastern belts are mainly fine-grained and range from intergranular to ophitic in texture. Their primary mineralogy is dominated by plagioclase and clinopyroxene, with up to 5% magnetite. Microprobe analyses (Peterson, 1996) in samples 7 and 35 from the eastern and western belts, respectively (Fig. 2), showed that the clinopyroxene is of augite composition, with varying amounts of TiO_2 (3% in the sample from the western belt but less than 1% in the eastern belt sample). Pyroxene analyses reported by Blanchard (1982) and Dostal *et al.* (1983) suggest similar variation. Much of the plagioclase in these samples is now of albitic composition. Phenocrysts of plagioclase occur in some flows, as well as rare pseudomorphs which may have been originally olivine but now consist of chlorite. Chlorite is also a major interstitial component, apparently having replaced clinopyroxene and glassy groundmass. Titanite, epidote, sericite, and hematite are other abundant secondary minerals. Amygdales are abundant in the upper parts of flows, and contain mainly carbonate minerals and/or chlorite.

Rhyolitic rocks

Rhyolite in both the eastern and western belts varies from pink to orange and is commonly porphyritic, with phenocrysts of quartz and sanidine. Quartz phenocrysts are embayed, and more abundant than sanidine. The groundmass contains quartz, K-feldspar, albite, chloritized biotite, and opaque minerals. Texture varies from spherulitic to cryptocrystalline and equigranular. In places, flow-banding is well displayed on weathered surfaces. As suggested by Blanchard *et al.* (1984), the rhyolite may be welded tuff.

A felsic, lithic tuff is exposed on the Belle Cote Road at sample locality 49 in the eastern belt (Fig. 2), in a sequence dominated otherwise by basaltic flows and interbedded siltstone. It contains abundant glass shards, plagioclase crystals, and siltstone clasts. Zircon populations from this tuff yielded ages of ca. 430 Ma (Silurian) and ca. 560 Ma (Neoproterozoic), and are apparently inherited (G.R. Dunning, written communication, 1997).

Sedimentary rocks

Sedimentary rocks in the Fisset Brook Formation are mainly red, and vary from mudstone to conglomerate, although siltstone is most abundant. They are dominated by angular to subangular quartz grains, and detrital muscovite is abundant. Red varieties contain abundant interstitial hematite. In places (e.g., in Turner Brook near locality 47, Fig. 2), the sandstone and siltstone are arkosic, and contain abundant perthitic microcline as well as quartz and muscovite.

Mafic dykes

Mafic dykes are abundant in the lower part of the Horton Group (Creignish Formation) west of the western belt of the Fisset Brook Formation. Similar dykes also occur in the Fisset Brook Formation and in the Cheticamp Pluton. The dykes vary from fine-grained, intergranular or subophitic, to coarse-grained and ophitic, but all are gabbroic and consist mainly of plagioclase and clinopyroxene (augite), with abundant interstitial chlorite that appears to have replaced olivine or orthopyroxene. Clinopyroxene compositions are similar to those in the basaltic samples (Peterson, 1996). The plagioclase is partly replaced by sericite and clay minerals and has also undergone some albitization.

Chemical characteristics of the igneous rocks

Introduction

Chemical data from the Cheticamp area obtained as part of this study are presented in Table 1. In addition, 9 unpublished analyses of mafic flows and dykes from both the western and eastern belts were provided by D. Piper (written communication, 1996), and published analyses were taken from Keppie *et al.* (1997) (4 samples from the Fisset Brook type section) and from Blanchard *et al.* (1984) (11 samples from the eastern and western belts). Locations for all of these samples, including those from Table 1, are shown on Figure 2.

Mafic samples

The mafic samples range in SiO_2 content (recalculated volatile-free) from about 44% to 55% (Fig. 3a). Loss-on-ignition values range from 1.3 to 8%, with most samples falling in the range of 3 to 4% (Table 1). Alkali element mobility is suggested by a wide range in K_2O and Na_2O values (Table 1), although most samples plot in the "igneous spectrum" of Hughes (1973) (Fig. 4). In comparison to the extrusive rocks, gabbroic dyke samples show less variation in alkali content, and overall appear less altered (Fig. 4).

No consistent chemical differences are apparent between mafic volcanic samples from the western and eastern belts (e.g., Fig. 3a, b). The chemical similarity is further illustrated by their similar patterns on multi-element variation diagrams (Fig. 5a). Typically mobile elements such as K, Rb, and Ba show much wider variation than the typically less mobile elements such as Ti, Zr, Y, and Nb (Winchester and Floyd, 1976). As previously suggested by Blanchard (1982) and Blanchard *et al.* (1984), the high alkali element content in some samples is not a primary feature, and should not be used to suggest that the rocks are alkalic. The overall compositional pattern in the typically immobile elements is more similar to that of within-plate tholeiites than within-plate alkalic basalts, especially the low Nb and P contents (Fig. 5a). Nb/Y ratios are less than 0.6, characteristic of subalkaline mafic rocks (Fig. 3b).

Mafic dyke samples are generally similar in chemical composition to the mafic flow samples (e.g., Fig. 5b compared to Fig. 5a). However, they tend to have higher TiO_2 and FeO^t/MgO values (Fig. 6), suggesting that they have somewhat more evolved compositions.

A within-plate tholeiitic affinity for the mafic flows and dykes is further supported by the Ti-Zr-Y and Nb-Zr-Y diagrams for mafic rocks, on which the samples plot mainly in the "within-plate basalt" and overlapping "within-plate tholeiite/volcanic arc" fields, respectively (Fig. 7a, b). The shift toward the MORB (mid-ocean ridge basalt) and arc fields on these diagrams seems to result from slightly elevated Y values in some samples. Slightly high Y values compared to average within-plate tholeiites are also apparent on Figure 5.

Mafic flows and gabbros from the Gillanders Mountain–Lake Ainslie area (data from Barr *et al.*, 1995), show the same chemical characteristics as those from the Cheticamp area, including an evolutionary trend toward higher TiO_2 and FeO^t/MgO values (Fig. 6). Although spatially separate, it is clear that the magmas formed from similar source rocks in the same within-plate tectonic setting (Fig. 5a, b; Fig. 7a, b).

Felsic samples

Relatively few analyses of rhyolite have been obtained because of its limited distribution in the Cheticamp area. In the 6 analyzed rhyolite samples (3 from each of the western and eastern belts), SiO_2 content ranges from 71 to 80% (Fig. 3a). A tendency to elevated potash values, particularly notable in the two samples from Keppie *et al.* (1997), as well as in one of their basalt samples (Fig. 4), suggests localized potassic alteration, a feature also apparent in the Gillanders Mountain–Lake Ainslie samples (Fig. 4; Barr *et al.*, 1995).

A multi-element variation diagram, normalized to the average A-type (anorogenic) granite of Whalen *et al.* (1987), further illustrates the chemical variability in the Cheticamp rhyolites (Fig. 8). They show similarities to the average A-

Table 1. Geochemical data[1] for samples from the Fisset Brook Formation and gabbroic dykes in the Cheticamp area.

SAMPLE	KP95-01	KP95-02	KP95-03	KP95-05	KP95-07	KP95-13	KP95-15	KP95-17	KP95-18	KP95-21	KP95-22	KP95-24	KP95-28	KP95-32
Unit	md(CF)	md(CF)	md(FBF)	md(sch)	mf east	mf west	mf west	md(CF)	mf east	ff east	ff east	mf west	md(FBF)	md(CF)
wt. %														
SiO_2	46.64	47.57	48.02	48.31	49.30	50.22	48.31	48.70	46.07	78.50	75.41	44.03	49.81	48.39
TiO_2	1.65	1.67	2.45	2.20	1.45	2.80	2.12	2.30	1.83	0.08	0.07	1.55	2.67	2.08
Al_2O_3	15.98	14.95	13.29	13.86	16.66	12.41	13.37	12.94	16.43	10.86	12.35	16.84	12.11	13.17
$Fe_2O_3^t$	12.40	11.93	14.68	14.06	10.66	15.21	14.00	14.52	13.54	1.03	1.69	14.24	15.37	13.78
MnO	0.34	0.32	0.40	0.26	0.29	0.25	0.30	0.26	0.31	0.02	0.03	0.50	0.40	0.42
MgO	7.17	7.53	5.56	6.13	6.71	5.34	5.93	5.92	7.36	0.08	0.28	9.34	5.68	6.73
CaO	7.44	7.34	8.36	9.63	3.53	5.88	8.36	10.00	2.77	0.10	0.09	2.00	7.75	7.14
Na_2O	2.94	2.62	3.33	2.99	4.75	3.61	3.26	2.82	4.83	2.63	2.94	3.89	4.22	2.22
K_2O	1.62	2.21	1.53	0.64	1.41	1.46	1.50	0.67	1.14	6.07	6.27	1.32	0.84	3.31
P_2O_3	0.19	0.20	0.30	1.33	0.31	0.34	0.27	0.26	0.34	0.02	0.01	0.29	0.30	0.24
LOI	3.00	2.80	1.10	1.80	3.60	3.40	2.00	1.70	4.80	0.50	0.90	6.60	2.00	2.60
Total	99.37	99.14	99.02	101.21	98.67	100.92	99.42	100.09	99.42	99.89	100.04	100.60	101.15	100.08
ppm														
Ba	811	1037	829	234	429	241	373	279	500	279	264	1791	250	1157
Rb	85	90	51	19	51	49	60	23	46	242	247	43	25	150
Sr	322	506	345	265	308	213	354	277	301	45	94	286	275	390
Y	29	30	42	44	34	53	37	39	33	51	46	42	45	33
Zr	122	128	189	197	172	216	171	158	142	133	157	146	191	149
Nb	8	7	12	13	8	14	9	11	7	43	44	6	13	9
Th	10	10	10	10	10	10	10	10	10	33	33	10	10	10
Pb	118	38	318	12	11	10	265	47	11	10	14	10	17	13
Ga	17	17	25	23	20	16	19	20	18	11	18	19	16	20
Zn	588	159	553	109	207	121	461	164	269	12	18	326	162	183
Cu	56	81	121	92	26	76	94	116	5	5	5	5	112	24
Ni	96	99	49	71	69	50	69	63	155	5	5	173	46	58
V	276	262	341	285	257	318	289	339	293	11	12	307	368	294
Cr	221	261	134	180	134	124	157	139	186	5	6	292	97	213

[1]Analyses by X-Ray Fluorescence at the Nova Scotia Regional Geochemical Centre, Saint Mary's University, Halifax.

Abbreviations: $Fe_2O_3^t$, total Fe as Fe_2O_3; LOI, loss-on-ignition; md, mafic dyke; mf, mafic flow; ff, felsic flow or tuff; ft, felsic tuff. East and west refer to eastern and western belts shown in Figure 2.

Host rocks for dykes are indicated in brackets: CF, Creignish Formation; FBF, Fisset Brook Formation; CP, Cheticamp Pluton; sch, older schist.

Table 1. Cont.

SAMPLE Unit	KP95-35 mf west	KP95-37 md(CF)	KP95-38 md(CF)	KP95-40 ff west	KP95-41 mf east	KP95-47 mf east	KP95-49 ft east	KP95-50 mf west	KP95-52 mf west	KP95-54 md(FBF)	KP95-55 mf west	KP95-56 mf west	KP95-57 mf west	KP95-60 md(CP)
wt. %														
SiO_2	45.76	46.55	48.77	79.76	43.88	44.04	74.01	45.39	47.03	48.31	46.44	46.00	45.38	47.58
TiO_2	1.84	3.00	2.80	0.07	2.27	2.18	0.32	2.13	1.86	2.69	1.32	1.80	3.46	2.05
Al_2O_3	17.63	12.88	12.31	10.78	16.81	17.25	11.63	16.92	15.94	13.37	16.63	17.84	13.09	13.80
$Fe_2O_3^t$	10.41	15.20	15.64	0.83	13.34	13.00	2.39	13.55	12.20	14.62	9.99	10.99	15.59	12.90
MnO	0.60	0.36	0.41	0.02	0.33	0.22	0.02	0.35	0.34	0.21	0.29	0.17	0.22	0.56
MgO	6.44	5.68	5.76	0.12	6.85	6.46	0.01	7.59	7.71	5.33	8.09	6.61	5.66	6.47
CaO	6.49	9.20	9.30	0.11	7.45	9.12	0.33	4.83	4.79	10.07	9.77	9.79	8.38	8.30
Na_2O	2.72	2.72	2.90	3.69	2.86	2.80	3.31	2.62	4.01	2.87	2.64	2.96	3.40	3.07
K_2O	2.51	1.41	0.94	3.24	0.87	0.64	5.19	2.64	0.36	0.67	0.72	0.82	1.36	1.61
P_2O_3	0.32	0.35	0.34	0.02	0.32	0.33	0.05	0.28	0.36	0.40	0.15	0.31	0.71	0.23
LOI	3.50	2.10	1.50	0.70	5.30	3.70	0.80	4.30	4.50	1.30	4.20	2.10	2.20	2.40
Total	98.22	99.45	100.67	99.34	100.28	99.74	98.06	100.60	99.10	99.84	100.24	99.39	99.45	98.97
ppm														
Ba	1108	465	278	64	519	249	543	804	137	276	211	572	1085	432
Rb	106	45	36	101	18	16	118	82	12	12	27	18	21	65
Sr	440	288	267	45	406	497	37	322	347	341	247	534	627	334
Y	31	50	49	51	35	32	29	34	35	41	27	30	43	34
Zr	179	219	204	129	184	190	272	166	153	199	98	170	241	151
Nb	10	16	14	41	8	8	14	7	10	15	5	8	22	9
Th	10	10	10	28	10	10	22	10	10	10	10	10	10	10
Pb	74	11	21	10	10	12	10	10	11	10	10	10	19	288
Ga	17	20	22	11	20	23	8	20	18	20	16	23	21	22
Zn	424	140	153	31	114	102	6	241	271	117	111	95	175	666
Cu	52	179	149	5	5	28	6	7	5	80	15	41	49	109
Ni	83	72	54	5	70	70	5	75	111	39	165	90	36	75
V	223	366	366	8	263	232	20	255	253	359	197	210	335	300
Cr	40	126	123	5	22	28	9	22	115	59	310	50	74	212

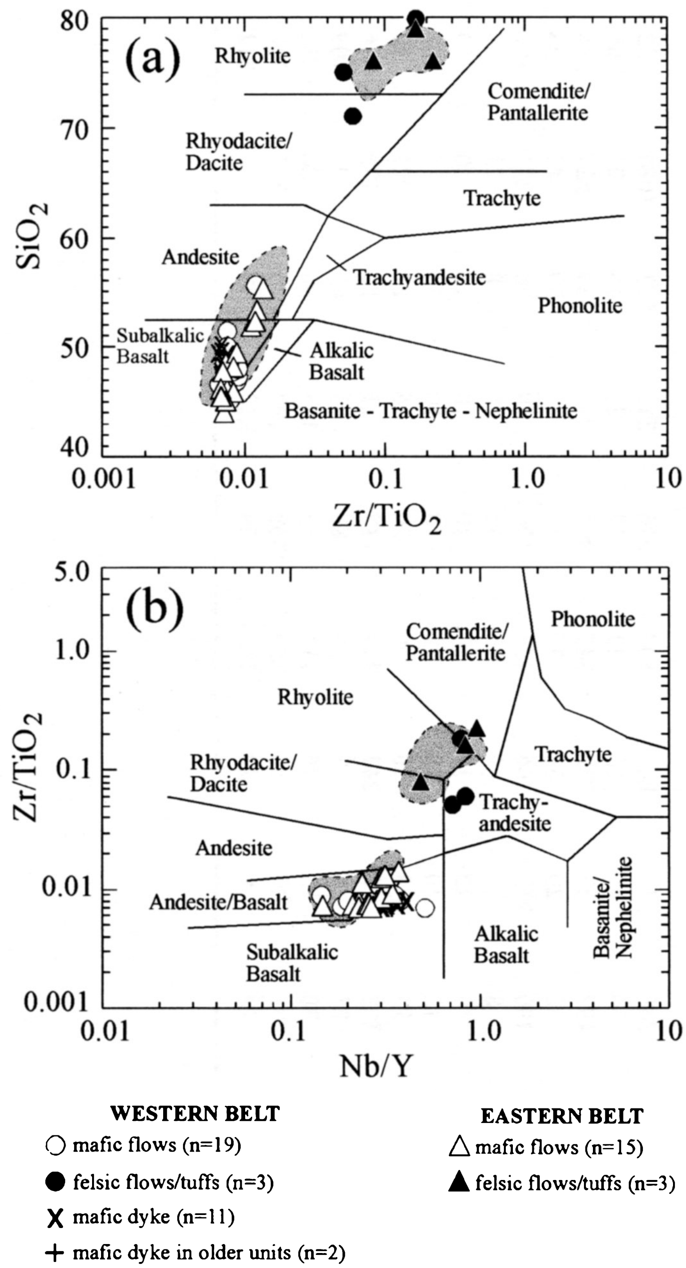

Fig. 3. Plots of (a) Zr/TiO_2 against SiO_2 and (b) Zr/TiO_2 against Nb/Y, with fields from Winchester and Floyd (1977). Data are from Table 1 and sources described in the text. Shaded fields include 38 samples from mafic flows and gabbros (lower field on each diagram) and 19 rhyolite samples (upper field on each diagram) from the Gillanders Mountain–Lake Ainslie area.

type granite, but have notably lower Zr, Ga, Y, and Zn, and higher V. The pattern is very similar to that of rhyolite samples from the Gillanders Mountain–Lake Ainslie area, also shown on Figure 8 as a shaded field. The chemical variability is also reflected on a tectonic setting discrimination diagram (Fig. 9), on which the six samples scatter around the junction between the volcanic-arc, syn-collisional, and within-plate granite fields, a distribution similar to that of rhyolite samples from the Gillanders Mountain–Lake Ainslie area.

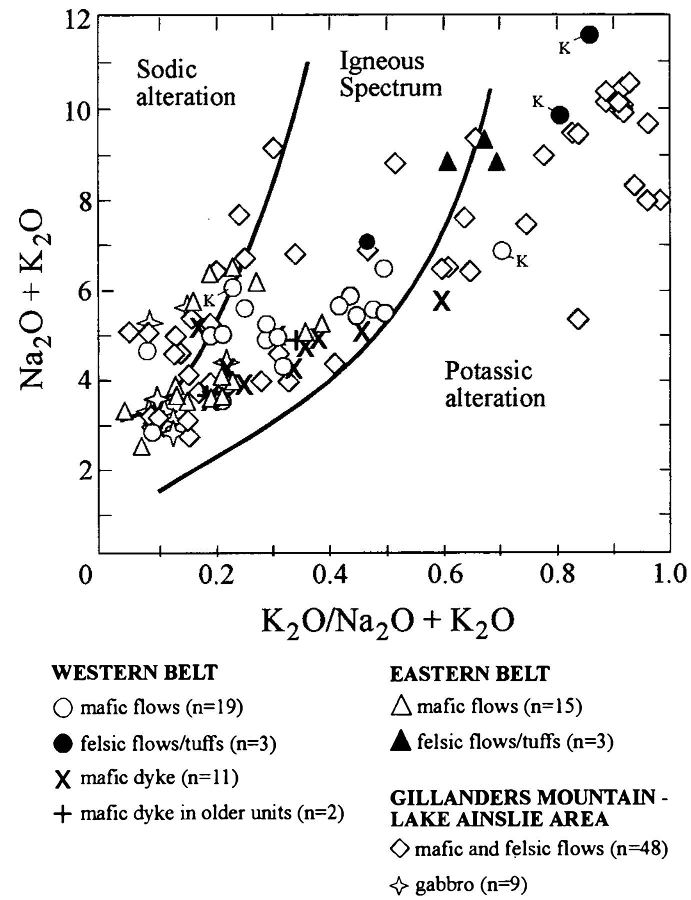

Fig. 4. Plot of Na_2O+K_2O (weight %) against K_2O/Na_2O+K_2O, for samples from the Cheticamp and Gillanders Mountain–Lake Ainslie areas, as in Figure 3. Samples indicated by K are from Keppie *et al.* (1997). Fields are after Hughes (1973).

Rare-earth element data

No rare-earth element (REE) data were obtained during the present study, but data were published by Keppie *et al.* (1997) and also provided for 3 samples by D. Piper (written communication, 1996). Chondrite-normalized plots of these data (Fig. 10) show that samples from mafic flows in both the western and eastern Cheticamp belts, and from a mafic dyke in the overlying Horton Group, are similar. They show gently sloping patterns with slight light REE enrichment and heavy REE depletion. Eu anomalies are non-existent or small, indicating that plagioclase fractionation was not a major factor in mafic magma evolution (e.g., Hanson, 1980). One mafic flow from the Gillanders Mountain area shows a very similar pattern, but a second basalt sample, as well as a gabbro sample, show more evolved compositions, and better developed negative Eu anomalies, consistent with plagioclase fractionation. The REE patterns are similar to those typical of within-plate tholeiitic basalts, and are generally interpreted to indicate melts derived from the subcontinental upper mantle (Keppie *et al.*, 1997).

Rhyolite samples show lower overall REE abundances than the mafic rocks, and large negative Eu anomalies. They

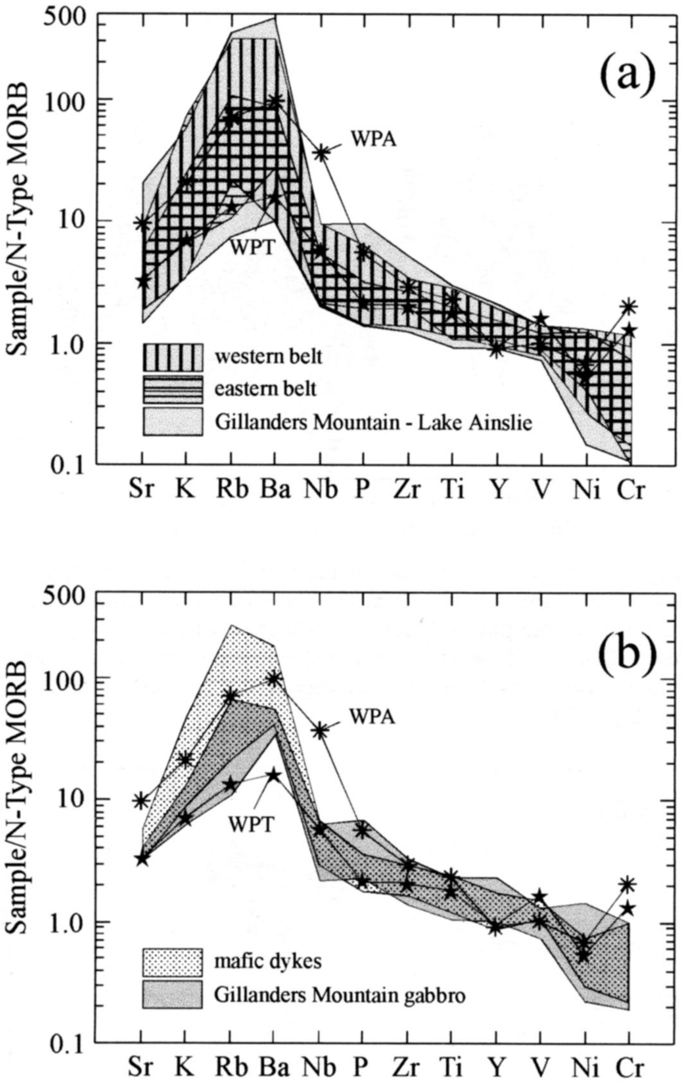

Fig. 5. Multi-element variation diagrams to illustrate chemical similarity of (a) basaltic and (b) gabbroic rocks from the study area to the average within-plate tholeiite (WPT; star symbol) from Pearce (1982). Data are normalized to average mid-ocean ridge basalt from Pearce (1982), except V value estimated from Shervais (1982). Average within-plate alkalic basalt (WPA; astericks symbol) is from Pearce (1982).

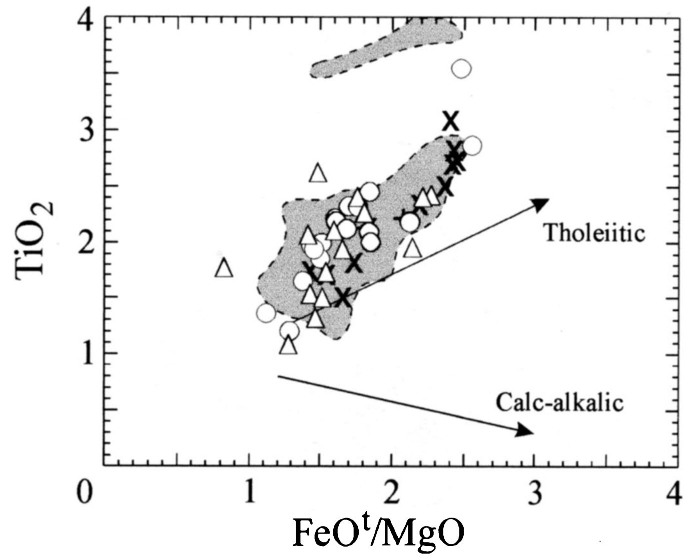

Fig. 6. Plot of TiO_2 against FeO^t/MgO, with tholeiitic and calc-alkalic trends after Miyashiro (1974), for mafic samples from the Cheticamp area (symbols as in Fig. 4) and Gillanders Mountain–Lake Ainslie area (shaded field).

are similar to a rhyolite sample from Gillanders Mountain from Barr *et al.* (1995). As noted by Barr *et al.* (1995), the REE abundances are low compared to typical within-plate continental rhyolites. Typically, rhyolite contains elevated REE contents compared to mafic rocks (e.g., Kenya Rift rhyolite; Wilson, 1989, p. 348). The low REE abundances in rhyolite samples from the Fisset Brook Formation may indicate that the magmas were highly fractionated, or that they were derived from crustal sources with a high content of residual refractory minerals with a high REE content, such as zircon (e.g., Hanson, 1980). The latter interpretation is consistent with the low Zr and Y contents in the rhyolite samples compared to other within-plate felsic magmas such as A-type granites (Fig. 8), and also with the presence of inherited older zircon populations in the previously mentioned dated felsic tuff sample from the same location as sample 49.

DISCUSSION

The petrochemical data presented here support the results of previous studies which suggested that the Fisset Brook Formation originated in a within-plate continental setting (Blanchard, 1982; Blanchard *et al.*, 1984; Dostal *et al.*, 1983; Barr *et al.*, 1995; Keppie *et al.*, 1997). Although the volcanic expression of this ca. 375 Ma igneous activity in Cape Breton Island is limited at current levels of exposure, plutonic rocks of similar age are much more voluminous (Fig. 1). In contrast to the volcanic rocks, which are dominantly mafic, the plutonic rocks are dominantly granitic (Barr, 1990). The plutonic rocks have chemical characteristics similar to those of rhyolites of the Fisset Brook Formation (e.g., Fig. 9), and it is likely that the granitic plutons are the intrusive equivalents of the rhyolites of the Fisset Brook Formation. Hence, the total volume and geographic distribution of igneous rocks formed in northwestern Cape Breton Island during the Middle to Late Devonian is large, and requires significant amounts of crustal melting.

These observations suggest that the volcanic rocks of the Fisset Brook Formation may have been more extensive than their present distribution suggests. Although it has been generally assumed that the Fisset Brook Formation was deposited in isolated separate basins (e.g., Blanchard *et al.*, 1984; Keppie *et al.*, 1997), it may be that these areas are erosional remnants of originally much more extensive volcanic units.

Petrochemical similarity between the mafic volcanic rocks of the Fisset Brook Formation and gabbroic dykes in the overlying Creignish Hills Formation suggests that the mafic dykes may represent continued but waning igneous activity into the latest Devonian and early Carboniferous. Alternatively, the dykes may represent a renewal of igneous activity after a hiatus, as ca. 360 Ma volcanic rocks have been documented in the Low-

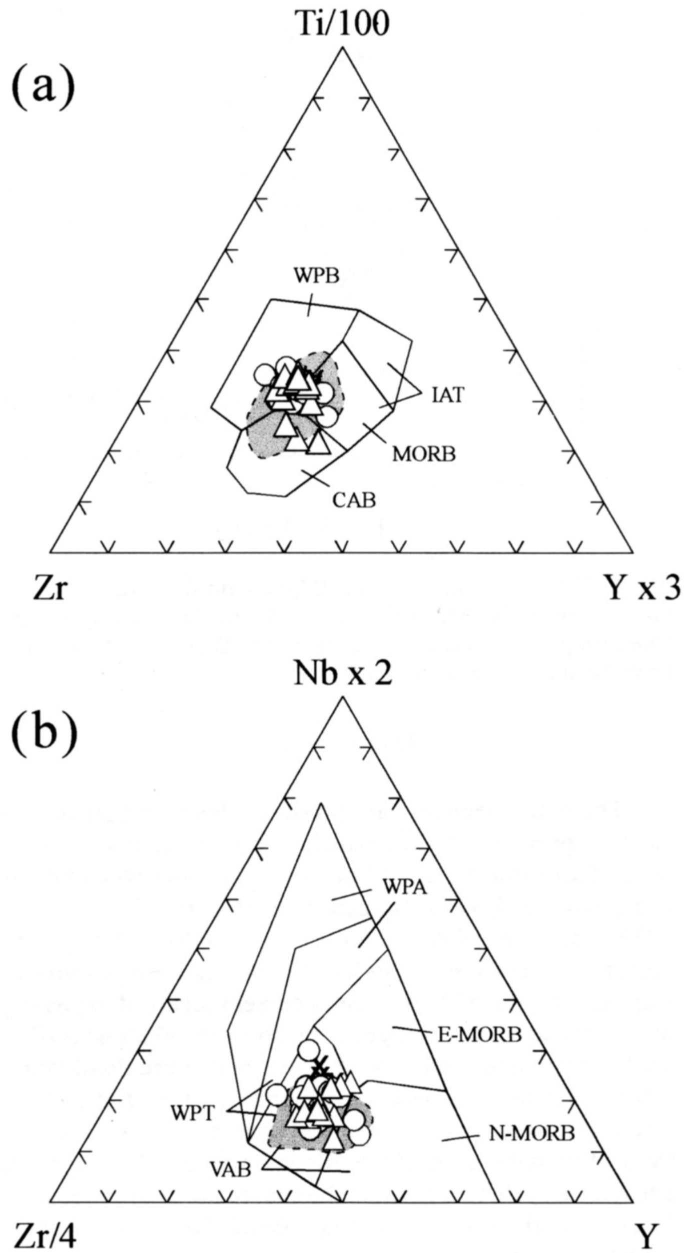

Fig. 7. Mafic samples plotted on (a) Ti-Zr-Y and (b) Nb-Zr-Y discrimination diagrams. Symbols are as for mafic samples in Figure 3. Shaded field includes 38 mafic flows and gabbros from the Gillanders Mountain–Lake Ainslie area. Fields in (a) are from Meschede (1986), and in (b) from Pearce and Cann (1973). Abbreviations: WPB, within-plate basalt; IAT, island-arc tholeiite; MORB, mid-ocean ridge basalt (E, enriched; N, normal); CAB, calc-alkalic basalt; WPA, within-plate alkalic basalt; VAB, volcanic-arc basalt; WPT, within-plate tholeiite.

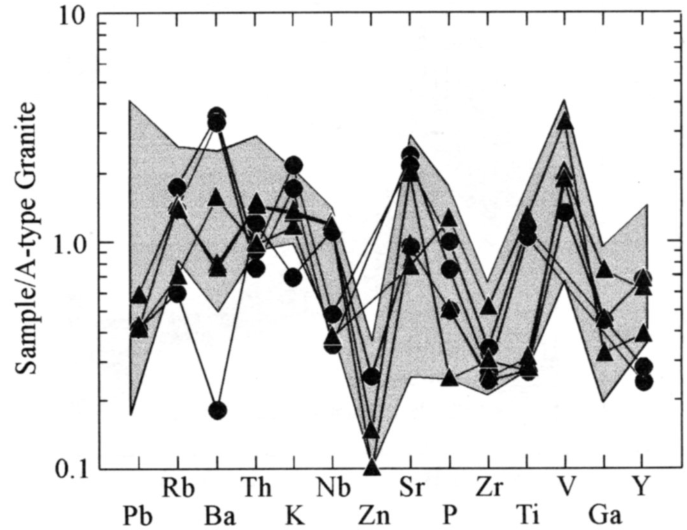

Fig. 8. Multi-element variation diagram to illustrate chemical variation in rhyolitic samples from the Cheticamp area, with symbols as for felsic samples in Figure 3. Field for rhyolitic samples from the Gillanders Mountain–Lake Ainslie area is shown for comparison. Data are normalized to the average A-type granite from Whalen *et al.* (1987).

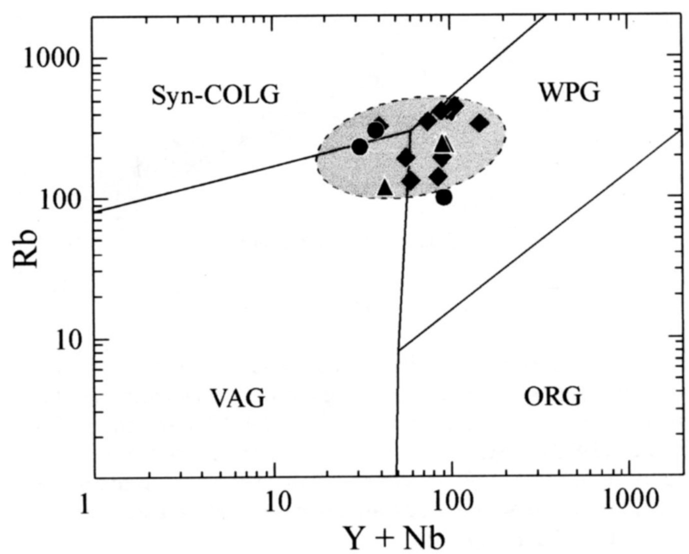

Fig. 9. Tectonic setting discrimination diagram for felsic samples from the Cheticamp and Gillanders Mountain–Lake Ainslie areas, with symbols as for felsic samples in Figure 3. Diamond symbols are felsic samples from the Gillanders Mountain–Lake Ainslie area. Shaded field includes approximately 80 analyses from ca. 375 Ma plutonic units in the Cape Breton Highlands, after Barr (1990). Granite fields are from Pearce *et al.* (1984): VAG, volcanic-arc granite; Syn-COLG, syn-collisional granite; WPG, within-plate granite; ORG, ocean-ridge granite.

land Cove area to the north (Fig. 1) (G.R. Dunning, written communication, 1997).

Bradley (1982) suggested that the Magdalen Basin northwest of Cape Breton Island developed as a pull-apart basin between dextral strike-slip faults in Newfoundland and New Brunswick. He proposed that during the rift stage of basin development, the Fisset Brook Formation and equivalent units were deposited in fault-bounded, isolated depocentres located along the regional fault zones. Langdon and Hall (1994) suggested that the early rift stage was more likely controlled by post-tectonic extension, and that the subsequent thermal subsidence stage was dominated by regional strike-slip movements. This model is more compatible with recent proposals for widespread post-orogenic (post-Acadian) extension in Cape Breton Island (e.g., Hamblin, 1992; Lynch and Tremblay, 1992, 1994; Lynch *et al.*, 1993; Lynch, 1996b). This model also seems more

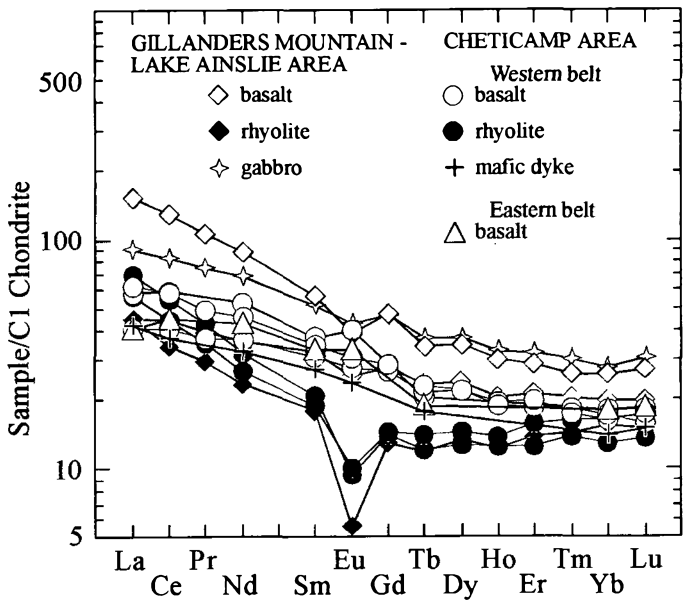

Fig. 10. Plots of chondrite-normalized REE data from basalt, rhyolite, and mafic dyke samples from the Cheticamp area (data from Keppie *et al.*, 1997, and D. Piper, written communication, 1996) compared to basalt, gabbro, and rhyolite samples from the Gillanders Mountain area (data from Barr *et al.*, 1995). Chondrite-normalizing values are from Sun and McDonough (1989).

compatible with the evidence noted above for a large volume of Middle to Late Devonian magmatism in the Cape Breton Highlands than the pull-apart basin model of Bradley (1982). The present distribution of the Fisset Brook Formation may be the result of preservation in fault-bounded basins produced in a regional strike-slip regime in the Carboniferous.

Widespread crustal melting could also be the result of asthenospheric up-welling associated with a Mantle plume, but chemical data from the Fisset Brook Formation and equivalent units do not appear to show evidence for a plume component (Keppie *et al.*, 1997).

Lynch and Tremblay (1994) and Lynch (1996a) proposed that part of the Fisset Brook Formation was deposited during and after extensional collapse of the orogen, and hence that basalts formed after extension are fresh and overlie chloritized and foliated basalt which grades down into chloritic mylonite. A discontinuous belt of mylonite and associated detachment faults extending south from Cheticamp to Gillanders Mountain and termed the Margaree Shear Zone, was interpreted to mark the extensional locus between the Fisset Brook Formation and its crystalline infrastructure (Lynch and Tremblay, 1994). Our mapping in the Cheticamp area during this study showed no evidence of mylonitization of the Fisset Brook Formation, although mylonitic zones are common in the older metamorphic units which unconformably underlie or are in brittle faulted contact with the Fisset Brook Formation. Lynch (1996a) used chemical data to support his argument that the basalt of the Fisset Brook Formation is the protolith of mylonitic rocks in the Turner Brook area. He showed that his mylonitic mafic samples are chemically more similar to basalts of the Fisset Brook Formation, using data from Blanchard *et al.* (1984), than to metabasalts of the Faribault Brook unit of the Jumping Brook metamorphic suite, using data from Connors (1986). A detailed investigation of this conclusion is beyond the scope of the present study; however, it is pointed out that the Faribault Brook metabasalts are chemically very different from other metavolcanic units in the Aspy terrane (e.g., Barr and Jamieson, 1991), and may be significantly older than other metavolcanic units of the Aspy terrane (Lin *et al.*, 1997). Comparison of the mylonitic samples to Silurian metavolcanic units such as the Sarach Brook metamorphic suite or the Money Point Group would be more appropriate.

Conclusions

The Fisset Brook Formation in the type area near Cheticamp, in the nearby but separate eastern belt, and in the Gillanders Mountain–Lake Ainslie area shows stratigraphic, lithological, and petrochemical similarities, and are of the same age (ca. 373-375 Ma). Volcanic rocks in the formation constitute a bimodal basalt-rhyolite suite. The basalts are within-plate tholeiites formed in a continental rift setting, and the rhyolitic rocks are likely to be contemporaneous crustal melts. The widespread occurrence of plutonic rocks of the same age as the Fisset Brook Formation throughout the Cape Breton Highlands suggests that the original distribution of the volcanic rocks may have been more extensive than its present distribution; the latter may reflect preservation in basins generated during Carboniferous strike-slip movements.

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