Ordovician volcanic and hypabyssal rocks in the central and southern Miramichi Highlands: their tectonic setting and relationship to contemporary volcanic rocks in northern New Brunswick

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New analyses of mafic igneous rocks from the central Miramichi Highlands have led us to modify the interpretation of its tectonic setting. New samples have been obtained from the Bamford Brook and Trousers Lake areas of New Brunswick, and the Danforth area in Maine. All subalkalic mafic rocks, including the Trousers Lake striped amphibolites, are associated with a thick sequence of metasedimentary rocks and all are continental tholeiites, analogous to tholeiitic suites in the Tetagouche Group of the northern Miramichi Highlands. The presence of alkalic basalt and comendite in this area supports this correlation. In the southern Miramichi Highlands of Maine, silicic and intermediate volcanic rocks form part of the Woodstock-Meductic arc-related volcanic suite.

De nouvelles analyses de roches ignées mafiques provenant du centre des hautes-terres de la Miramichi nous ont conduit à modifier l'interprétation de leur environnement tectonique. De nouveaux échantillons ont été recueillis dans les régions du ruisseau Bamford et du lac Trousers au Nouveau-Brunswick, et dans la région de Danforth au Maine. Toutes les roches mafiques subalcalines, incluant les amphibolites rubannées du lac Trousers, sont associées avec une séquence épaisse de roches métasédimentaires et sont toutes des tholéiites continentales, similaires aux suites tholéiitiques appartenant au Groupe de Tétagouche du nord des hautes-terres de la Miramichi. La présence de basaltes alcalins et de comendites dans cette région appuie cette corrélation. Dans le sud des hautes-terres de la Miramichi au Maine, les volcanites siliceuses et intermédiaires constituent une partie de la suite volcanique d'arc de Woodstock-Meductic.

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Introduction and Geological Setting

In a recent study Fyffe *et al.* (1988) described striped and unstriped amphibolites from the Trousers Lake area of the central Miramichi Highlands of New Brunswick (Fig. 1). The distinction between striped and unstriped amphibolite was originally based on their different field appearance: striped amphibolites possess a characteristic compositional banding, whereas the unstriped amphibolites tend to be internally homogeneous. Analysis revealed that the two suites of amphibolite were compositionally distinct. Both amphibolite suites correlate chemically with some of the low-grade basalts of the Middle Ordovician Tetagouche Group exposed elsewhere in the Miramichi Highlands, although the striped amphibolites, which were previously considered to form part of a Precambrian basement inlier (Rast *et al.*, 1976; Fyffe and Pronk, 1985), were thought in part to show arc affinities.

This paper reports the results of analyses of additional samples of amphibolites from the Trousers Lake area, as well as samples of volcanic rocks collected in the Bamford Brook and Sevogle areas in the central Miramichi Highlands and the Danforth area of Maine (Fig. 1). These analyses are compared with the previous results of Fyffe *et al.* (1988), arc-type volcanic rocks from the Woodstock-Meductic suite in the southern Miramichi Highlands (Dostal, 1990), and volcanic rocks from the Tetagouche Group in the Bathurst area in the northern Miramichi Highlands (van Staal *et al.*, 1991). The comparisons show that metabasalts in the central Miramichi Highlands can be correlated with those of the northern Miramichi Highlands (Table 1) and that, although arc tholeiites are probably not present in the central Miramichi Highlands, the arc affinities of the Woodstock-Meductic volcanic suite are confirmed.

The geology of the areas sampled was described by Fyffe *et al.* (1988) and Irrinki (1980). The sedimentary rocks, comprising lithic wackes and grey and red cherty slates

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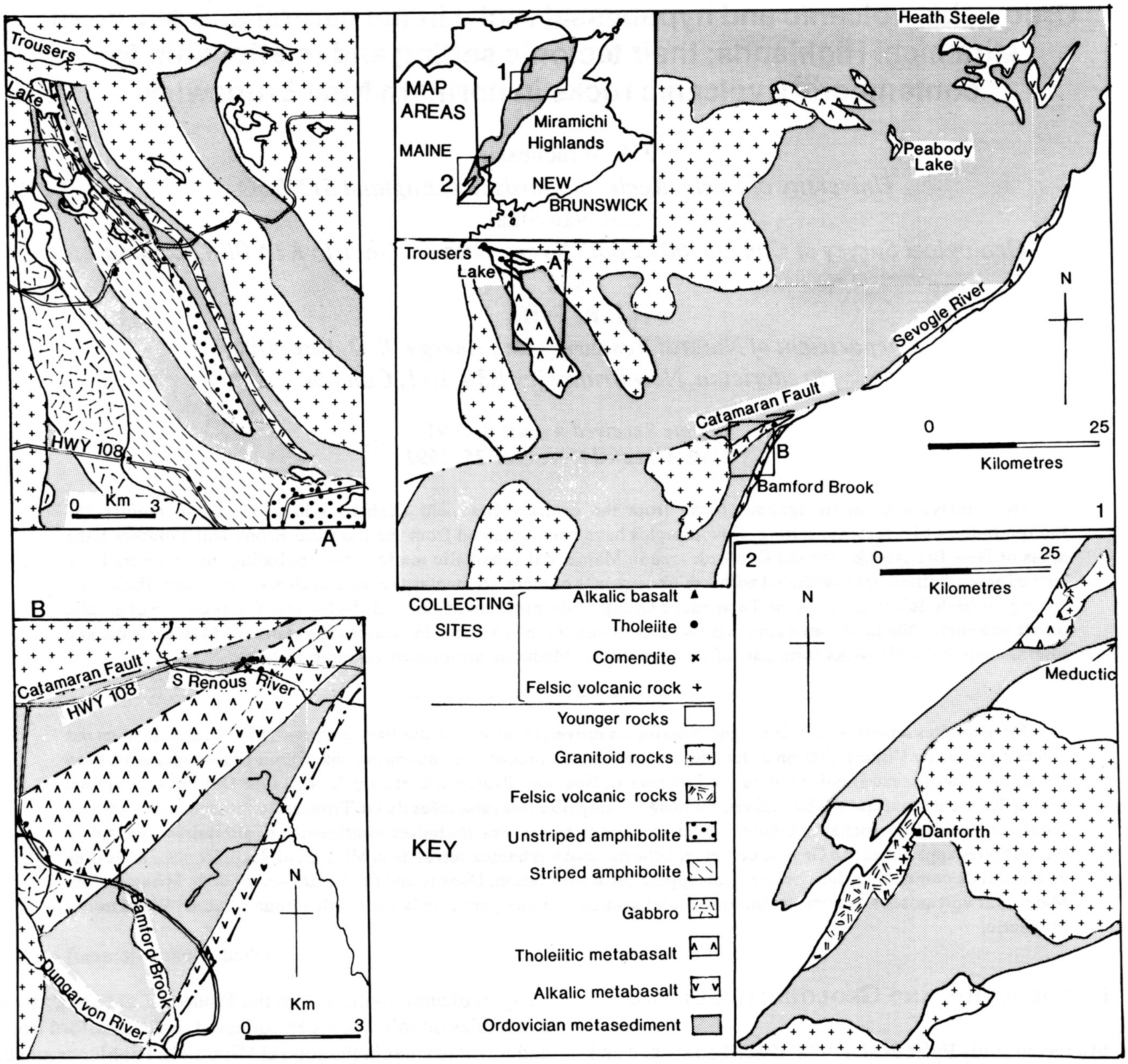

Fig. 1. Location map showing the areas of outcrop of (1) the metavolcanic suites in the CMH, and (2) the southwestern extremity of the Miramichi Highlands in Maine, covering the area where felsic volcanic rocks were collected south of Danforth. Detailed geological maps depicting the Trousers Lake area (A) and the Bamford Brook area (B) are adapted from Fyffe *et al.* (1988).

associated with the low-grade metavolcanic rocks in the Bamford Brook area of the eastern central Miramichi Highlands, are typical of the Tetagouche Group (Fyffe, 1982). By contrast, the amphibolite-facies psammites and pelites of the western central Miramichi Highlands were included in the Trousers Lake metamorphic suite by Fyffe *et al.* (1988), as their relationship to the Tetagouche Group was not known.

Geochemical Characteristics of the Volcanic Rocks

New analyses of rocks from the Trousers Lake and Bamford Brook areas are comparable with those previously obtained in the same areas by Fyffe *et al.* (1988), thus revealing no significant differences between analyses performed at the different laboratories. Because metamorphism in the Miramichi Highlands ranges from greenschist to amphibolite facies, some chemical change in the various rock suites is probable, particularly with respect to light ion lithophile elements (LILE). We have therefore tended to rely preferentially on the relatively immobile high field strength elements (HFSE) in both classification and tectonic setting determination. Zr/Y and Nb/Y ratios tend to change little during high-level mafic differentiation and have mainly been used to distinguish the various basaltic suites (Fig. 2a,b).

In the Bamford Brook area new analyses of mafic vol-

Table 1. New analyses from the central Miramichi Highlands.

Sample No.	WS636	WS643	WS648	WS649	WS637	WS638	WS639	WS640	WS641	WS642	WS644	WS645	WS646	WS647	WS672	WS673	WS675	WS669	WS670	WS671	WS674
	Bamford Brook alkalic basalt				Bamford Brook tholeiite									Comendite	Clearwater Brook gabbro		Trousers Lake amphibolite unstriped			striped	
%																					
SiO_2	48.19	49.98	45.06	46.55	52.17	47.85	49.28	47.30	48.27	46.76	47.37	48.80	49.23	80.30	50.89	55.01	55.42	55.11	49.00	47.96	49.87
TiO_2	3.62	2.91	2.62	2.80	1.10	2.13	2.06	2.73	2.43	1.50	1.47	1.57	2.08	0.23	1.66	1.56	1.35	1.72	1.54	1.71	1.06
Al_2O_3	14.15	12.41	16.70	16.55	15.60	15.25	14.67	15.01	14.50	15.13	16.15	16.08	14.75	9.20	16.38	16.14	16.59	16.21	15.95	14.15	15.77
Fe_2O_3	2.19	3.19	2.85	2.47	1.61	1.92	1.99	5.59	7.23	2.31	2.71	2.47	2.91	0.55	1.96	1.90	1.65	1.86	1.79	4.66	3.30
FeO	9.72	7.95	8.37	8.18	8.53	8.28	8.08	5.06	3.61	6.51	6.41	6.63	7.11	2.14	6.22	6.17	8.93	6.27	8.14	7.53	1.02
MnO	0.31	0.44	0.21	0.20	0.33	0.18	0.36	0.22	0.18	1.12	0.39	0.21	0.18	0.04	0.15	0.14	0.16	0.14	0.17	0.18	0.17
MgO	5.33	5.85	5.88	5.92	7.58	8.81	8.18	5.85	3.92	8.11	8.45	6.66	7.14	0.23	6.32	5.36	5.98	4.60	7.76	8.46	8.52
CaO	9.91	6.33	10.17	8.90	7.63	10.74	9.16	5.75	7.36	9.59	8.55	8.78	7.17	0.96	9.82	8.29	0.42	7.71	10.23	11.27	10.96
Na_2O	4.53	3.48	2.90	3.10	4.37	2.60	3.52	6.06	6.64	1.99	3.12	4.50	4.71	3.53	4.10	3.34	4.68	3.58	2.42	2.78	2.90
K_2O	0.37	0.29	1.27	1.55	0.07	0.43	0.64	0.24	0.43	2.09	1.21	0.32	0.65	1.82	0.77	0.84	0.02	1.41	1.10	0.33	0.10
P_2O_5	0.57	1.37	0.31	0.35	0.10	0.27	0.26	0.34	0.27	0.17	0.16	0.16	0.27	0.04	0.32	0.28	0.14	0.32	0.21	0.15	0.09
H_2O	0.15	5.07	4.04	3.24	0.36	0.36	0.88	4.98	5.91	3.99	4.53	3.61	3.65	1.29	1.16	1.73	4.62	1.11	1.62	1.28	1.53
S	0.03	0.04	0.07	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.03	0.02	0.03
Total	99.07	99.31	100.45	99.84	99.46	98.84	99.09	99.14	100.76	99.28	100.53	99.81	99.86	100.39	99.76	100.77	99.97	100.06	99.96	100.48	100.32
Fe_2O_3(tot)	12.99	12.03	12.15	11.56	11.09	11.12	10.97	11.21	11.24	9.54	9.83	10.04	10.81	2.92	8.87	8.76	11.57	8.83	10.83	13.02	9.99
ppm																					
Ba	61	258	122	127	26	183	193	166	340	1190	742	613	178	692	133	215	45	280	133	39	13
Cl	187	148	137	119	163	85	154	135	123	106	121	141	117	149	316	207	122	313	160	119	106
Cr	13	0	40	64	291	481	272	506	494	882	637	398	406	20	145	127	0	104	328	390	358
Cu	22	22	43	46	70	62	61	37	52	62	55	60	36	0	16	18	92	41	40	68	75
Ga	22	21	23	22	12	20	17	15	17	17	16	16	14	32	18	19	15	19	20	19	15
Nb	27	49	23	22	5	19	23	18	17	13	13	11	15	371	11	10	10	22	12	6	4
Ni	29	14	27	32	87	184	79	179	189	338	231	154	135	9	40	34	54	23	58	135	105
Pb	13	9	11	8	9	9	9	11	13	7	10	7	9	25	7	6	1	6	6	7	4
Rb	4	5	10	15	2	13	32	5	6	60	31	5	18	40	27	24	4	42	39	4	3
Sr	316	331	361	403	194	210	242	78	201	117	167	242	197	41	429	379	19	321	261	95	97
Th	1	3	1	0	0	1	0	4	1	1	0	0	1	66	5	7	11	8	1	1	2
V	411	246	345	346	243	329	375	420	381	278	298	326	335	9	255	226	364	237	258	341	257
Y	43	46	29	32	24	40	42	50	45	29	28	34	42	292	34	31	32	30	26	43	26
Zn	110	108	88	93	54	92	82	99	88	81	88	86	97	86	58	63	115	75	81	87	78
Zr	282	277	218	215	68	155	135	199	187	77	78	81	153	2851	164	158	164	111	111	102	65
Rare-Earth Elements																					
La	15	41	9	6	0	2	4	1	4	2	0	0	2	278	10	10	10	18	5	0	0
Ce	63	132	47	53	25	12	26	60	21	12	8	8	25	733	41	68	48	53	29	0	2
Nd	30	66	31	26	28	19	21	44	16	14	21	11	17	265	21	33	25	33	24	13	8

Analyses were performed at Keele University, using an ARL 8420 X-ray fluorescence spectrometer.

Ferrous iron was determined using potassium dichromate as titrant and diphenylamine sulphonate as indicator.

canic rocks include both tholeiitic and alkalic basalts (Table 1). The HFSE and Cr contents of the analysed basalts vary significantly (Table 1). The tholeiitic basalts are characteristically Cr-rich and chemically resemble the three Forty Mile Brook tholeiites in the southernmost part of the northern Miramichi Highlands east of Heath Steele Mines (Fig. 1, Tables 1, 2, 3). They fall within the subalkalic basalt field on a Zr/TiO_2-Nb/Y diagram (Fig. 2a; Winchester and Floyd, 1977) and are confined to the western belt of mafic volcanic rocks in the area (Fig. 1). The alkalic basalts are Cr-poor and

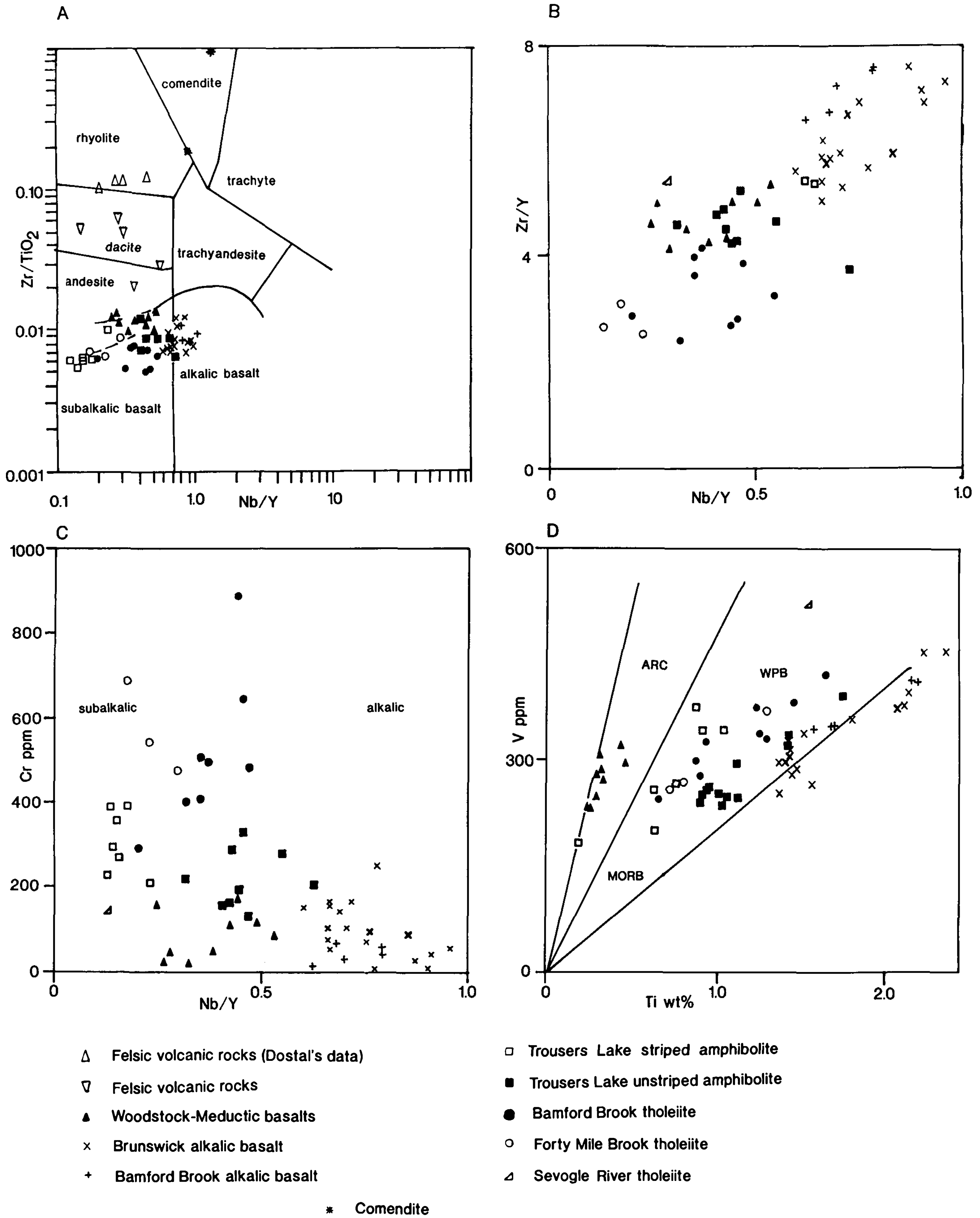

Fig. 2. Discriminant diagrams highlighting chemical characteristics of the different volcanic suites in the CHM and SMH. (A) Zr/TiO_2-Nb/Y, after Winchester and Floyd (1977). The felsic volcanics plotted include data from the CMH, from south of Danforth, Maine, and data cited in Dostal (1990). (B) Zr/Y-Nb/Y diagram, plotting basic rocks only. (C) Cr-Nb/Y diagram. (D) Ti-V diagram, after Shervais (1982). WPB - Within-Plate Basalt; MORB - Mid-Ocean Ridge Basalt.

have Nb/Y averaging 0.8 (Table 1), thus chemically resembling the Brunswick alkalic basalt suite in the northern Miramichi Highlands (van Staal *et al.*, 1991). They are compared here with Brunswick alkalic basalts sampled near Peabody Lake and in areas E and SE of Heath Steele Mines (Tables 2, 3, Figs. 1, 2c). They are confined to the eastern belt of mafic rocks and the eastern margin of the western belt (Fig. 1). Felsic rocks analysed by Fyffe *et al.* (1988) are chemically similar to those previously sampled (van Staal *et al.*, 1991) in the northern Miramichi Highlands, ranging from dacite to rhyolite in composition. However, one sample (WS 647, Table 1), collected near the South Renous River in the

Table 2. New analyses from east and south of Heath Steele Mines.

Sample No.	WS198	WS476	WS477	WS215	WS216	WS196	WS197	WS210	WS211	WS212	WS471	WS472	WS473	WS474	WS475	WS479	WS480	WS481	WS483	WS484	WS485	WS482
	Forty Mile Brook tholeiite					Brunswick alkalic basalt																Comendite
	Heath Steele area			Peabody Lake		Heath Steele area																
%																						
SiO_2	44.46	47.76	45.14	44.04	47.87	47.60	52.19	50.08	51.43	48.03	46.19	48.09	46.12	45.65	48.35	48.82	45.11	42.91	48.42	47.44	42.25	65.31
TiO_2	1.35	1.22	2.15	2.60	2.29	2.36	2.45	2.23	2.12	3.60	2.28	3.89	2.36	2.51	2.98	2.40	3.69	3.52	3.49	6.00	4.18	0.70
Al_2O_3	15.69	16.73	16.67	15.80	14.84	14.04	14.27	14.91	14.99	16.10	15.24	12.99	15.69	16.38	14.92	14.26	14.64	16.13	13.19	17.59	13.11	14.26
Fe_2O_3	3.68	2.51	3.76	6.83	8.10	5.28	3.88	1.47	1.77	6.63	5.59	6.24	3.24	3.41	3.81	4.66	5.30	5.09	3.89	3.76	5.07	3.82
FeO	5.65	5.90	6.27	5.82	5.09	6.26	5.55	8.78	7.78	6.40	6.87	9.16	8.00	8.10	7.41	6.58	10.09	8.37	8.74	8.90	8.96	3.62
MnO	0.34	0.17	0.16	0.16	0.24	0.18	0.16	0.13	0.13	0.12	0.17	0.44	0.18	0.28	0.18	0.18	0.20	0.16	0.22	0.37	0.35	0.12
MgO	7.27	10.63	8.58	4.44	4.83	3.51	3.34	7.45	6.42	4.14	5.65	7.51	7.84	7.86	6.72	6.61	5.58	6.70	5.85	1.11	5.10	1.75
CaO	12.19	5.22	9.85	10.37	6.69	8.06	6.78	4.69	5.08	6.10	8.20	2.50	8.65	5.94	6.13	5.29	7.60	8.17	7.83	2.57	8.17	1.54
Na_2O	1.14	3.08	2.68	3.59	4.17	4.02	3.06	3.25	3.68	4.53	3.55	2.38	2.70	3.87	2.60	4.03	1.52	1.99	4.00	1.00	3.55	5.74
K_2O	0.02	1.36	0.18	0.25	0.40	1.20	1.81	0.05	0.21	1.14	1.00	0.37	0.66	0.51	0.46	1.01	0.45	0.47	0.90	5.43	1.21	0.64
P_2O_5	0.13	0.12	0.21	0.31	0.25	0.50	0.41	0.27	0.27	0.53	0.29	0.59	0.29	0.30	0.39	0.30	0.48	0.38	0.40	0.78	0.53	0.12
H_2O	8.07	5.21	3.94	5.90	5.51	6.88	6.16	6.70	5.81	2.87	4.69	5.65	3.64	4.31	5.04	6.07	5.35	5.79	2.66	4.27	6.80	1.57
S	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.03	0.05	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.03	0.01	0.02	0.03	0.01	0.01
Total	99.90	99.92	99.60	100.12	100.29	99.91	100.07	100.04	99.74	100.20	99.73	99.82	99.40	99.14	99.00	100.22	100.04	99.69	99.61	99.25	99.29	99.20
Fe_2O_3(tot)	9.97	9.07	10.73	13.30	13.76	12.24	10.05	11.23	10.42	13.75	13.22	16.42	12.13	12.76	12.04	11.98	16.51	14.39	13.61	13.65	15.03	7.84
ppm																						
Ba	15	341	80	60	118	201	170	6	87	189	201	263	539	391	55	494	129	166	288	889	244	183
Cl	0	53	93	0	0	0	0	0	0	0	115	96	57	38	100	74	110	73	72	50	73	92
Cr	543	475	682	153	149	165	166	107	105	96	73	0	139	101	251	52	3	38	24	70	51	0
Cu	46	14	57	39	55	40	37	30	31	34	49	29	55	53	42	44	33	62	57	43	40	8
Ga	13	17	20	30	25	21	15	24	20	18	22	27	18	21	26	21	23	21	25	38	26	27
Nb	8	6	9	22	17	30	28	31	31	39	20	38	20	22	32	24	38	32	28	50	35	57
Ni	178	120	237	87	60	71	66	65	50	37	60	25	90	81	119	41	30	49	24	48	45	6
Pb	11	18	33	10	17	14	12	28	17	16	15	18	15	11	13	14	15	14	13	68	16	14
Rb	2	41	9	7	13	34	58	2	2	29	22	20	17	14	19	24	14	14	21	129	32	22
Sr	225	168	237	259	285	132	176	144	231	266	182	159	337	352	221	98	303	404	168	63	260	135
Th	0	0	4	6	2	3	2	5	8	4	7	7	3	5	3	3	7	2	6	8	12	20
V	269	259	370	267	252	322	286	300	297	352	294	451	315	356	357	278	452	396	376	661	452	6
Y	34	20	49	33	28	45	39	46	40	46	30	49	29	31	41	25	42	35	32	66	52	95
Zn	81	71	83	103	92	92	90	101	132	115	107	158	105	113	110	82	150	121	126	197	149	143
Zr	86	108	152	178	157	226	207	265	273	271	176	410	169	184	233	182	299	241	241	455	321	1106
Rare-Earth elements																						
La	0	0	0	7	35	11	18	34	9	18	8	29	9	0	11	8	9	15	20	27	19	50
Ce	5	36	18	16	77	19	31	114	71	41	30	68	22	32	58	29	54	69	38	77	60	171
Nd	15	5	9	33	43	29	38	36	44	24	26	50	18	29	43	21	48	46	37	57	40	73

Table 3. Selected metavolcanic suites in the Miramichi Highlands, New Brunswick and Maine

	Bamford Brook tholeiite		Forty Mile Brook tholeiite		Trousers Lake amphibolite (striped)		Trousers Lake amphibolite (unstriped)		Clearwater Brook gabbro		Otter Brook tholeiite	
	x	s	x	s	x	s	x	s	x	s	x	s
%												
SiO_2	48.56	1.62	45.79	1.74	49.75	2.34	51.28	3.06	52.95	2.91	49.27	3.46
TiO_2	1.90	0.52	1.57	0.50	1.20	0.46	1.80	0.43	1.61	0.07	2.43	0.78
Al_2O_3	15.24	0.60	16.36	0.58	15.32	1.04	15.58	0.63	16.27	0.17	14.40	1.12
Fe_2O_3	3.19	1.91	3.32	0.70	1.97	1.34	1.53	0.20	1.93	0.04	4.19	2.32
FeO	6.69	1.59	5.94	0.31	8.55	1.51	8.58	1.13	6.20	0.04	7.67	2.01
MnO	0.35	0.30	0.24	0.14	0.20	0.03	0.19	0.04	0.15	0.01	0.21	0.06
MgO	7.19	1.54	8.83	1.69	7.66	2.14	6.69	1.06	5.84	0.68	5.78	1.33
CaO	8.30	1.49	9.08	3.55	11.28	1.75	8.77	2.80	9.06	1.08	6.12	2.32
Na_2O	4.17	1.54	2.30	1.02	2.60	0.50	2.63	0.95	3.72	0.54	4.19	1.13
K_2O	0.68	0.62	0.52	0.73	0.36	0.36	1.17	0.63	0.81	0.05	0.74	0.75
P_2O_5	0.22	0.08	0.15	0.05	0.10	0.05	0.24	0.08	0.30	0.03	0.32	0.12
H_2O	3.14	2.08	5.74	2.12	0.96	0.41	1.62	0.98	1.45	0.40	4.55	1.79
S	0.01	0.004	0.01	0.00	0.03	0.01	0.02	0.01	0.01	0	0.02	0.02
Fe_2O_3(tot)	10.65	0.66	9.92	0.83	11.25	1.88	11.07	1.29	8.82	0.08	12.71	2.03
ppm												
Ba	403	375	145	173	68	103	149	63	174	58	194	143
Cl	127	24	49	47	113	9	198	101	262	77	35	52
Cr	485	186	567	106	305	76	185	90	136	13	72	63
Cu	55	12	39	22	53	14	40	24	17	1	35	24
Ga	16	2	17	4	19	3	22	3	19	1	20	5
Nb	15	5	8	2	5	2	16	4	11	1	19	7
Ni	175	78	178	59	77	33	56	17	37	4	29	20
Pb	9	2	21	11	9	3	11	5	7	1	13	6
Rb	19	19	17	21	9	13	60	56	26	2	22	24
Sr	161	81	210	37	124	61	239	126	404	35	169	68
Th	1.6	1.3	1.4	2.2	1.7	0.8	5.0	3.6	6.0	1.4	4	3
V	332	55	299	61	280	74	282	52	241	21	353	72
Y	37	9	34	15	31	10	33	6	33	2	44	12
Zn	85	13	78	6	87	14	89	15	61	4	111	18
Zr	126	51	115	34	78	30	158	36	161	4	221	67
Rare-earth elements												
La	3	1	0	0	0	0	11	7	10	0	17	4
Ce	22	16	20	16	0	0	35	13	55	19	42	10
Nd	21	9	10	5	11	4	27	5	27	8	25	7
n=	9		3		7		12		2			

	Bamford Brook alkalic basalt		Brunswick alkalic basalt		Sevogle River basalt	Woodstock Meductic basalt		Woodstock Meductic felsics		Danforth félsic volcanics	
	x	s	x	s	x	x	s	x	s	x	s
%											
SiO_2	47.40	1.67	47.25	2.66	44.98	50.22	1.64	75.21	3.16	70.34	7.01
TiO_2	3.05	0.43	3.06	0.99	2.57	0.57	0.12	0.12	0.02	0.61	0.36
Al_2O_3	14.88	1.71	14.95	1.22	14.63	17.51	1.12	13.36	1.59	13.94	3.11
Fe_2O_3	2.68	0.44	4.67	1.71	7.75	-	-	-	-	1.62	-
FeO	8.56	0.80	7.60	1.42	6.59	-	-	-	-	3.43	1.76
MnO	0.29	0.09	0.21	0.09	0.23	0.16	0.02	0.27	0.02	0.14	0.08
MgO	5.89	0.38	5.59	1.81	6.80	5.98	0.82	2.16	0.63	1.03	0.41
CaO	8.61	1.51	6.60	2.06	5.60	9.05	2.15	0.12	0.07	0.91	0.69
Na_2O	3.47	0.57	3.19	0.98	3.65	3.03	1.28	3.54	1.41	1.58	1.38
K_2O	1.08	0.64	0.97	1.20	0.19	1.31	0.83	1.81	1.08	3.02	0.90
P_2O_5	0.59	0.40	0.40	0.14	0.21	0.16	0.04	0.05	0.01	0.12	0.05
H_2O	2.72	2.00	5.25	1.25	7.10	3.30	0.65	1.85	0.67	3.23	0.68
S	0.04	0.02	0.02	0.01	0.01	-	-	-	-	0.02	0.02
Fe_2O_3(tot)	12.24	1.03	13.14	1.78	15.08	8.82	0.70	2.15	0.71	5.42	3.08
ppm											
Ba	183	110	249	215	61	284	228	599	388	1702	991
Cl	148	29	48	43	1	-	-	-	-	95	7
Cr	34	24	97	66	144	90	56	4	1	29	27
Cu	32	15	43	10	31	72	33	6	7	10	7
Ga	25	5	23	5	19	20	3	19	4	16	6
Nb	29	10	30	8	8	6	2	12	1	12	7
Ni	24	6	60	25	57	17	6	20	8	19	17
Pb	8	4	18	13	20	7	7	-	-	15	8
Rb	13	8	26	29	7	34	25	54	33	113	44
Sr	399	104	224	92	188	370	129	114	50	84	40
Th	1.7	1.2	5.2	2.7	0.1	3.6	0.7	8.0	1.4	9.8	3.6
V	351	61	358	99	522	270	31	7	2	68	69
Y	37	8	39	10	57	15	3	43	11	34	5
Zn	104	13	119	29	156	78	9	64	15	68	18
Zr	251	38	249	82	153	68	15	128	14	209	61
Rare-earth elements											
La	18	16	16	10	5	11	3	38	12	23	12
Ce	74	39	50	26	17	25	6	74	19	60	29
Nd	38	19	37	11	17	13	3	35	11	29	6
n=	6		18		1	9		4		5	

Notes: x - mean; s - standard deviation; n - number of samples

Bamford Brook area, but associated with bimodal felsic and tholeiitic mafic volcanic rocks, is a comendite similar to those associated with the Brunswick alkalic basalt suite in the northern Miramichi Highlands.

In the Trousers Lake area, Fyffe *et al.* (1988) divided the mafic rocks into two distinct groups (striped and unstriped amphibolites) on the basis of their field appearance. They also found that the Zr/Y, Nb/Y and HFSE of the striped amphibolites is characteristically lower than in the unstriped amphibolites, which probably represent more evolved basalts (Fig. 2a,b,c). Seven additional samples were analysed from the Trousers Lake area for this study (Fig. 1, Table 1), including two samples from the Clearwater Brook gabbro, which had not been previously analysed. The amphibolite results are comparable with those obtained by Fyffe *et al.* (1988), and the Clearwater Brook gabbro is shown to be chemically akin to unstriped amphibolites. Comparison with the northern Miramichi Highlands shows that the unstriped amphibolites chemically resemble the Otter Brook tholeiites (Tables 1, 3).

The chemistry of the Trousers Lake amphibolites may be compared with that of metabasalts in the Bamford Brook area and the area east of Heath Steele Mines. Compared to the Trousers Lake amphibolites, the Bamford Brook tholeiites are more primitive and contain generally lower Zr/Y and higher Cr and Ni with Cr ranging up to 882 ppm. (Fig. 2c). A single, extensively altered and weathered specimen of tholeiitic metabasalt from the Sevogle area (Fig. 1, Table 3) consistently plots away from the other metabasalts (Fig. 2b,c,d), but this chemical distinction may not be genuine, as in such an altered sample compositional change affecting even the less mobile elements may have occurred. All these suites plot in the Within-Plate Basalt field on a Ti-V diagram (Shervais, 1982), in contrast to the Woodstock-Meductic basalts (Dostal, 1990) which are characterised by lower TiO_2 contents and plot separately in the arc field (Fig. 2d).

When plotted on a multi-element spider diagram (Pearce, 1983) all the tholeiitic basalt suites emerge as relatively enriched (Fig. 3), with profiles comparable to those of basaltic suites in the Tetagouche Group of the northern Miramichi Highlands. Although the Trousers Lake striped amphibolites have somewhat lower HFSE than the other mafic suites, the differences are not large. These differences and relative enrichment of LILE may owe more to metasomatic changes than original composition and are not considered significant.

Discussion

The reappraisal of the striped amphibolites of the Trousers Lake area superficially suggests that they are chemically similar to the Forty Mile Brook tholeiites in the northern Miramichi Highlands, but they differ in having consistently lower HFSE and thus have no exact equivalent in the latter area. The unstriped amphibolites are more comparable with the Otter Brook tholeiites of the northern Miramichi Highlands, suggesting that all the metavolcanic rocks in the central Miramichi Highlands are equivalent to those seen structurally below the blueschist belt in the northern Miramichi Highlands. The Bamford Brook tholeiites resemble the Forty Mile Brook tholeiites of the northern Miramichi Highlands, which also occur SE of Heath Steele Mines. The Bamford Brook alkalic basalts in the eastern central Miramichi Highlands are chemically akin to the Brunswick alkalic basalts of the northern Miramichi Highlands which also crop out southeast of Heath Steele Mines and near Peabody Lake.

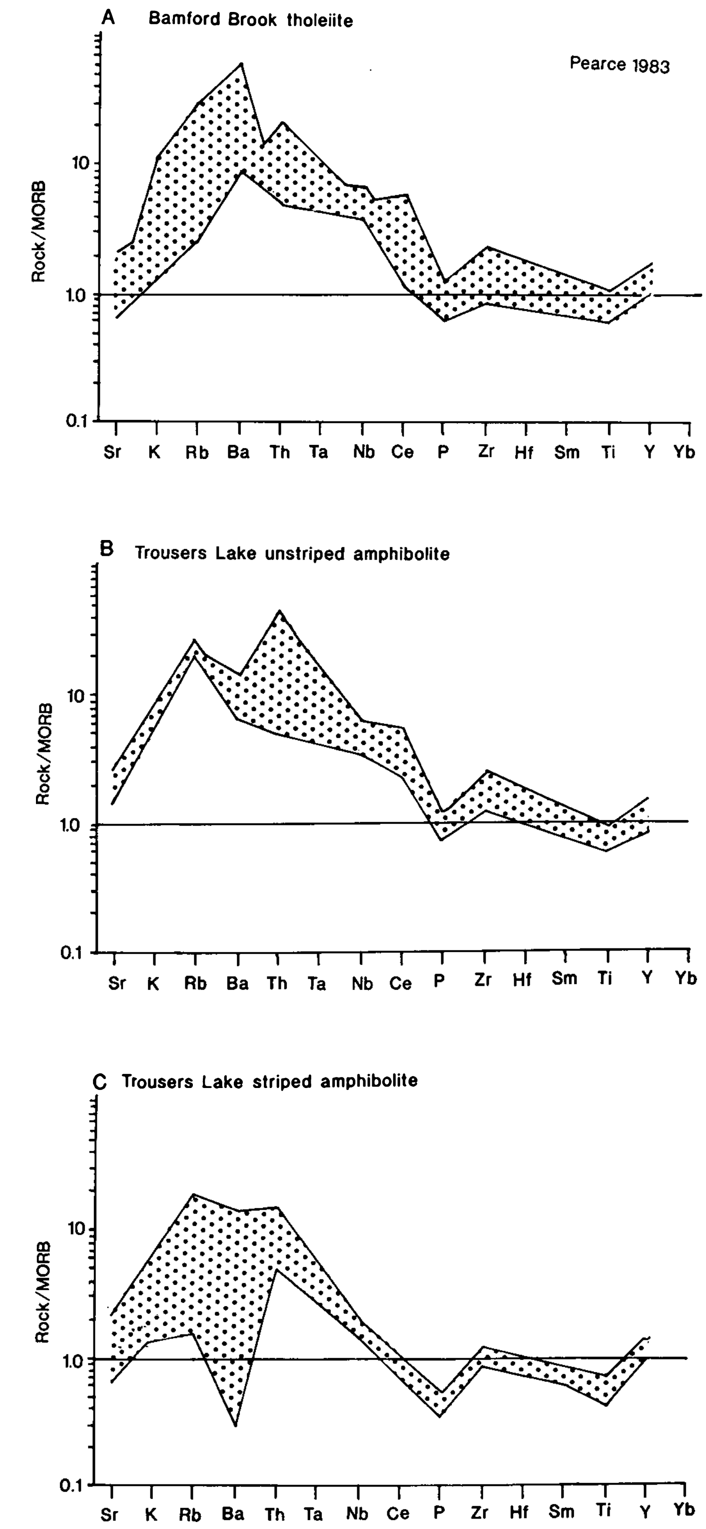

Fig. 3. Multielement spiderdiagrams. Normalization factors (MORB) after Pearce, 1983. (A) Bamford Brook tholeiite. (B) Trousers Lake unstriped amphibolite. (C) Trousers Lake striped amphibolite.

Both the Forty Mile Brook and Brunswick basalt suites, described in the northern Miramichi Highlands by van Staal *et al.* (1991) therefore probably also extend across much of the central Miramichi Highlands. In the former area the structural model proposed by van Staal *et al.* (1991) shows these volcanic rocks to have been erupted in a thinned Korean-type continental margin setting. HFSE depletion in these rocks, in the absence of supporting field evidence, does not justify the arc setting proposed by Fyffe *et al.* (1988) and may result instead from crustal contamination.

The occurrence of felsic orthogneisses (Fyffe *et al.*, 1988) and the discovery in 1989 of a comendite among the felsic rocks along the South Renous River in the Bamford Brook area, strengthens links with volcanic rocks in the Tetagouche Group in the northern Miramichi Highlands. There is no chemical indication that the felsic volcanic rocks were erupted in an arc setting.

In contrast, the basaltic and felsic volcanic rocks of the Meductic-Woodstock area in the southern Miramichi Highlands exhibit calc-alkalic affinities (Dostal, 1990) and record arc volcanicity. Their different chemistry and tectonic setting is evident on a Ti-V plot (Fig. 2d). Five calc-alkalic felsic volcanic rocks independently sampled by us in 1989 from the southwestern extremity of the Miramichi Highlands near Danforth in Maine (Fig. 1, Table 4) dominantly comprise variably silicified dacitic rocks (Fig. 2a), which are best linked with the rhyolites of the Meductic-Woodstock suite and support the presence of a remnant volcanic arc in the southern Miramichi Highlands.

Hence, although arc-related volcanics are present in the southern Miramichi Highlands, they do not seem to extend into the central Miramichi Highlands where the tectonic setting of magmatic emplacement was, like that of the northern Miramichi Highlands, a thinned continental margin. These data also support the incorporation of the central Miramichi Highlands rocks into the Tetagouche Group (e.g., Fyffe, 1982). Initial lavas may have acquired higher Zr/Y by means of crustal contamination; later magmas (i.e., the Bamford Brook tholeiites), emplaced when the magma pathways were established, tend to be more primitive and have higher Cr and lower Zr/Y, thus presenting a more MORB-like character. The amphibolites of the central Miramichi Highlands, therefore, support the model of van Staal *et al.* (1991) which proposed that during the Middle Ordovician, continental magmatism associated with an extensional regime which split a Lower Ordovician ensialic arc was associated with the formation of a large back-arc basin.

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Table 4. Felsic volcanics from Danforth, Maine.

	WS631	WS632	WS633	WS634	WS635
%					
SiO_2	76.27	61.23	77.10	72.19	64.93
TiO_2	0.29	1.07	0.27	0.88	0.53
Al_2O_3	11.39	17.39	12.06	11.59	17.28
Fe_2O_3	1.34	3.51	1.03	1.26	0.89
FeO	1.27	6.12	2.14	4.70	2.91
MnO	0.08	0.28	0.10	0.14	0.08
MgO	0.53	1.51	0.69	1.08	1.32
CaO	1.79	0.09	0.37	1.00	1.31
Na_2O	0.70	0.09	2.29	1.23	3.59
K_2O	3.04	4.38	2.17	2.25	3.24
P_2O_5	0.06	0.11	0.09	0.14	0.19
H_2O	3.25	4.28	1.99	3.45	3.25
S	0.01	0.01	0.02	0.06	0.02
Total	100.02	99.07	100.32	99.97	99.54
Fe_2O_3(tot)	2.75	10.31	3.40	6.49	4.13
ppm					
Ba	1138	1643	1961	566	3201
Cl	106	88	95	89	95
Cr	8	73	19	38	8
Cu	1	18	7	16	9
Ga	12	24	11	12	19
Nb	5	24	9	11	11
Ni	6	47	9	22	10
Pb	4	16	23	11	20
Rb	96	189	80	88	113
Sr	91	38	69	78	146
Th	5	13	11	7	13
V	5	172	21	102	42
Y	32	42	31	29	35
Zn	66	99	53	57	65
Zr	155	295	164	182	250
Rare-earth elements					
La	6	37	20	19	33
Ce	23	104	51	66	56
Nd	20	33	32	34	26

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APPENDIX 1: Co-ordinates of sampling localities.

Sample	Latitude (°north)	Longitude (°west)
WS631	45°33'00"	67°53'00"
WS632	45°32'00"	67°54'00"
WS633	45°32'00"	67°54'00"
WS634	45°30'00"	67°54'00"
WS635	45°30'00"	67°54'00"
WS636	46°44'25"	66°30'45"
WS637	46°44'40"	66°31'30"
WS638	46°45'10"	66°31'50"
WS639	46°45'10"	66°31'50"
WS640	46°47'30"	66°27'20"
WS641	46°47'30"	66°27'20"
WS642	46°47'30"	66°26'30"
WS643	46°47'25"	66°26'25"
WS644	46°47'25"	66°26'40"
WS645	46°47'25"	66°26'25"
WS646	46°47'20"	66°27'05"
WS647	46°47'25"	66°27'20"
WS648	46°43'20"	66°28'15"
WS649	46°43'20"	66°28'15"
WS669	46°51'40"	66°48'20"
WS670	46°51'35"	66°48'40"
WS671	46°51'45"	66°51'40"
WS672	46°52'20"	66°54'00"
WS673	46°52'20"	66°54'00"
WS674	46°56'00"	66°54'00"
WS675	46°56'00"	66°54'00"