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GEOCHEMISTRY OF VOLCANIC ROCKS IN THE MORETON'S HARBOUR–TWILLINGATE AREA, NOTRE DAME BAY

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ABSTRACT

Geological and geochemical data are applied to a long-standing controversy concerning the distribution of the Sleepy Cove Formation and the Moretons Harbour Group in eastern Notre Dame Bay. The Sleepy Cove Formation, in its type area, comprises strongly deformed, pervasively chloritized pillow lavas having no associated epiclastic sediments or felsic volcanic rocks. Mafic volcanic rocks include island-arc tholeiites and other depleted-arc rocks as well as rocks of boninitic affinity. The Moretons Harbour Group, in its type area, comprises relatively undeformed, unaltered pillow lavas that are locally porphyritic or strongly amygdaloidal; they are locally interbedded with epiclastic turbidites, and intruded by swarms of hornblende-bearing mafic intrusions and high level, subvolcanic rhyolitic dykes. The oldest rocks in the sequence are non-arc tholeiites of E-MORB or OIB affinity, which are intruded and overlain by mafic LREE-enriched tholeiites and rhyolites.

Geochemical data clearly support the interpretation that the Sleepy Cove Formation should be considered to include volcanic rocks on the Twillingate Islands, Black Island, the Trump Islands and in the immediate vicinity of Tizzard's Harbour. These data further support the correlation of this unit with the Lushs Bight Group to the west. The Moretons Harbour Group is considered to underlie the remainder of the Moreton's Harbour peninsula. It may be correlative with parts of the Western Arm and Cutwell groups, although additional work is required to test this hypothesis.

INTRODUCTION

The Notre Dame Subzone of the Dunnage Zone in central Newfoundland (Figure 1; Williams *et al.,* 1988) is widely considered to record Cambrian to Early Ordovician events in a series of island-arcs and back-arc basins that fringed the Laurentian continent (Colman-Sadd *et al.*, 1992; Swinden *et al., in press*). Detailed geochemical studies in the western part of the Notre Dame Subzone have shown that arc-related volcanism was active over an extended time period in various tectonic environments including intra-oceanic island-arcs, juvenile to mature back-arc basins, and island-arcs built upon continental lithosphere (Szybinski, 1995; Swinden *et al., in press*). Many of the tectonic environments in the Notre Dame Subzone contain volcanogenic massive sulphide (VMS) deposits, the character of which varies according to the tectonic environments in which they occur (Swinden, 1991).

Although geological relationships among the various volcanic units in the Notre Dame Subzone are now relatively well understood, there are still unresolved problems of timing and correlation in some areas. One of these problem areas, the Moreton's Harbour–Twillingate area, encompassing the Twillingate Islands, the Moreton's Harbour peninsula and adjacent islands to the east and north of the Chanceport Fault (Figures 1 and 2), is critical, as it is the location of the northeastern termination of the Notre Dame Subzone. Geological relationships between the two volcanic units in this area, the Sleepy Cove Formation and Moretons Harbour Group, have been a matter of debate. The crux of the controversy is the relative ages of the two units and the location and nature of the boundary between them. Strong and Payne (1973), Dean (1978) and Kean *et al.* (1981) considered the Sleepy Cove Formation to be restricted to the Twillingate Islands. They assigned volcanic rocks immediately south and southeast of the Twillingate Islands, including those on the Trump Islands and Black Island (Figure 2) to the Moretons Harbour Group, which was defined on the adjacent Moreton's Harbour peninsula to the west (Strong and Payne, 1973). This interpretation requires a Cambrian age for the Moretons Harbour Group because the volcanic rocks on the Trump

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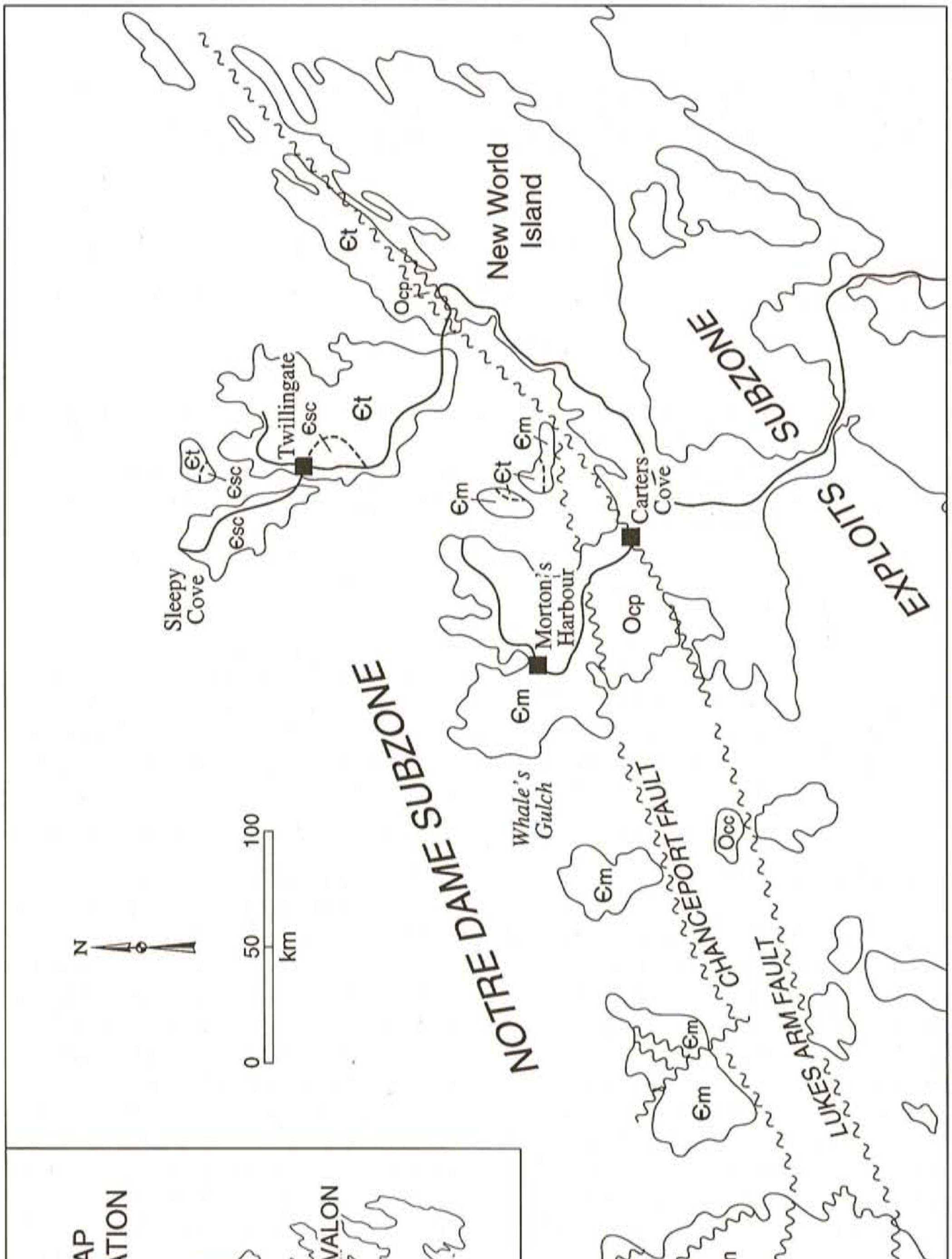


Figure 1. *General geology of the eastern part of Notre Dame Bay. Inset shows the zonal subdivision of Newfoundland. LB/WA–location of Lushs Bight, Western Arm and Cutwell groups referred to in text. Єt–Twillingate granite; Єsc–Sleepy Cove Group; Єm–Moretons Harbour Group; Occ–Cottrells Cove Group; Ocp–Chanceport Group.*

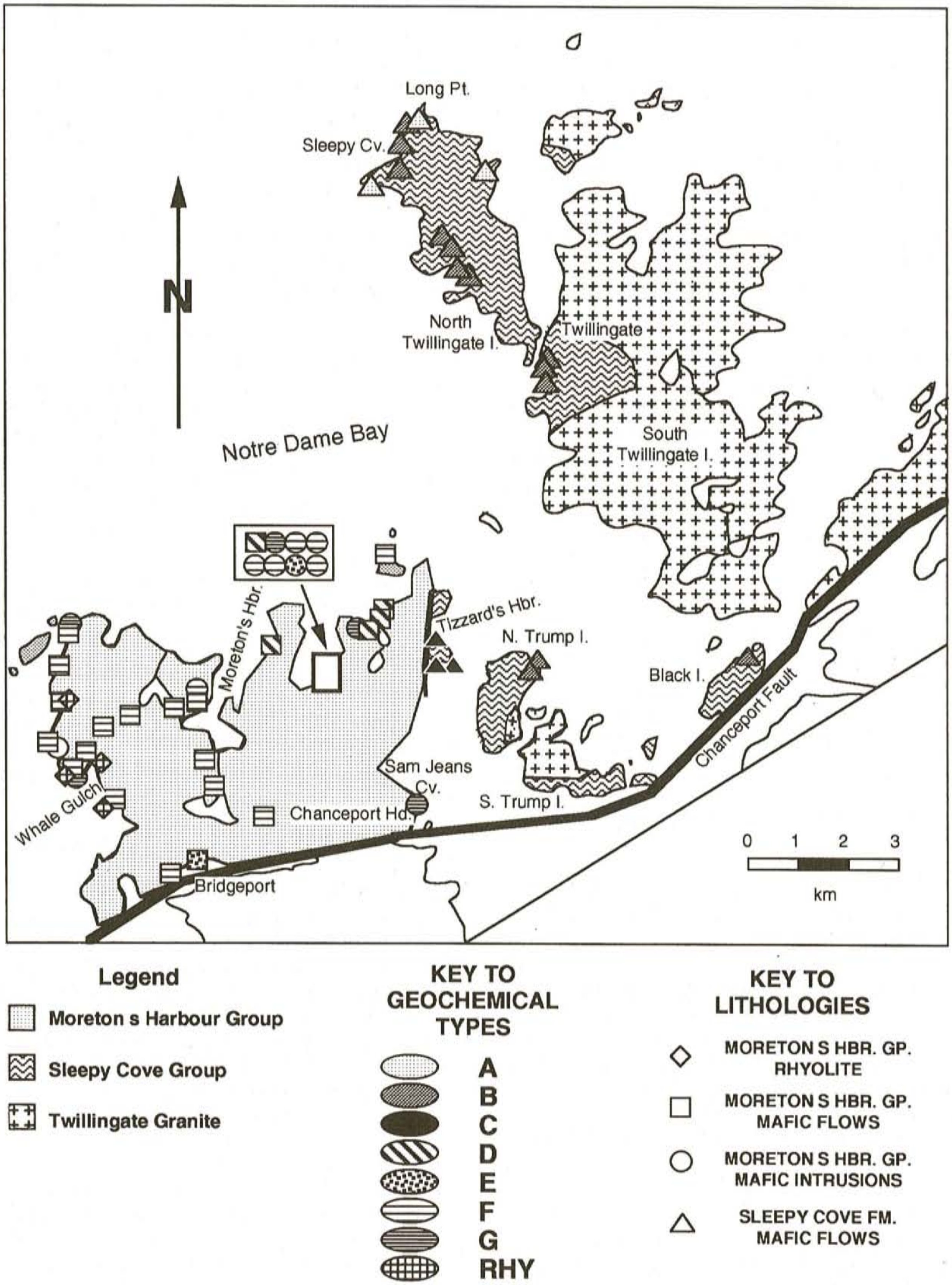


Figure 2. *General geology of the Moreton's Harbour–Twillingate area. Symbols show sample locations, rock types and geochemical affinities.*

Islands are intruded by the Twillingate granite (507^{+3}_{-2} Ma; Elliot *et al.*, 1991). However, Williams and Payne (1975) and Williams *et al.* (1976) considered all rocks intruded by the Twillingate granite (including those on the Trump Islands) to belong to the Sleepy Cove Formation. Noting that volcanic rocks on the Moreton's Harbour peninsula immediately north of the Chanceport Fault are similarly deformed and metamorphosed to the Sleepy Cove Formation at Twillingate, they suggested that these rocks also should be assigned to the Sleepy Cove Formation. In this interpretation, the Moretons Harbour Group is considered to be younger than the Sleepy Cove Formation (because it is less deformed and metamorphosed) and separated from it by a fault, the trace of which crosses the eastern and southern part of the Moreton's Harbour peninsula (Figure 2).

The present study addressed this problem through a geochemical study of the volcanic rocks in the two units. Approximately 50 samples were collected from mafic volcanic and high-level mafic and felsic intrusive rocks on the Moreton's Harbour peninsula, the Twillingate Islands, North Trump, Mouse and Black islands (Figure 2). The objectives were:

1) to characterize the samples geochemically;

2) to determine whether an empirical subdivision between volcanic rocks from the two groups can be achieved and use this to evaluate the contrasting interpretations of their distribution;

3) to interpret the tectonic setting(s) in which the rocks formed; and

4) to provide geochemical constraints on the regional correlation with volcanic rocks elsewhere in the Notre Dame Subzone.

The approach to interpreting the distribution of the two groups from the geochemical data was to characterize the rocks in the type areas of the two units (i.e., Twillingate Islands for the Sleepy Cove Formation; Moreton's Harbour peninsula west of Tizzard's Harbour for the Moretons Harbour Group) and then compare these geochemical signatures with rocks in the controversial areas (i.e., Tizzard's Harbour area, Trump Islands and Black Island).

This study may provide new constraints on the tectonic history of the Laurentian Margin in the Cambrian to Early Ordovician; it also allows for the refinement of metallogenic models through correlation with other volcanic sequences in central Newfoundland for which similar geochemical data are already available.

REGIONAL GEOLOGY

The Notre Dame Subzone in eastern Notre Dame Bay is bounded to the south by the Lukes Arm Fault (Figure 1), a steep structure that separates Cambrian and Early Ordovician volcanic and intrusive rocks to the north (Notre Dame Subzone) from Early Ordovician volcanic rocks, Ordovician – Silurian shales and turbidites, and Silurian redbeds to the south (Exploits Subzone). The latest movement on the Lukes Arm Fault postdates much of the folding history of the area (Karlstrom *et al.*, 1982).

The most southerly rocks in the Notre Dame Subzone are assigned to the Chanceport Group, a sequence of mafic pillow lavas, lesser pillow breccias and minor turbidites that Dean (1978) correlated with the Roberts Arm Group to the west. Dec and Swinden (1994) showed that these rocks, like the main body of the Roberts Arm Group to the west, are bipartite and include both calc-alkalic basalt–andesites and island-arc tholeiitic basalts. The Chanceport Group becomes progressively attenuated east of the Moreton's Harbour peninsula as it is tectonically thinned between the converging Lukes Arm and Chanceport faults and is pinched out where these faults merge on the northeastern part of New World Island (Figure 1).

The Moretons Harbour Group, Sleepy Cove Formation and Twillingate granite are structurally juxtaposed with the Chanceport Group across the Chanceport Fault. The Twillingate granite intrudes the Sleepy Cove Formation and consists mainly of medium- to coarse-grained trondhjemite, dated as 507^{+3}_{-2} Ma (Elliot *et al.*, 1991).

GEOLOGY OF THE MORTONS HARBOUR GROUP

The Moretons Harbour Group, a thick, west-facing, succession of mafic pillow lavas, mafic to felsic subvolcanic rocks, and epiclastic rocks, was first defined by Strong and Payne (1973) who recognized and described five formations of mafic volcanic rocks, sheeted dykes, and mixed volcanic–epiclastic rocks. Kay and Strong (1983) subsequently redefined the boundaries of some formations and defined an additional unit, the Haywards Cove formation, considered to comprise rhyolite flows outcropping along the western shore of the Moreton's Harbour peninsula.

The base of the Moretons Harbour Group comprises dominantly mafic pillow lavas. Strong and Payne (1973) assigned these to two formations, based on contrasts in field characteristics. The easternmost Tizzards Harbour Formation, comprising dominantly strongly deformed, highly chloritized pillow lavas, was considered to be in stratigraphic contact to the west with the Webber Bight Formation, comprising dominantly undeformed, locally strongly plagioclase porphyritic pillow lavas and abundant diabasic and gabbroic intrusive rocks. Geochemical data presented here suggest that the rocks assigned to the Tizzards Harbour Formation are, in fact, properly part of the Sleepy Cove Formation.

The Webber Bight Formation is overlain by the Wild Cove Formation (Kay and Strong, 1983), comprising swarms of medium- to coarse-grained mafic dykes, which locally preserve screens of pillow lava between them. The dykes are commonly hornblende-bearing, and locally include hornblendite. The lower contact with the Webber Bight Formation is gradational.

The Little Harbour Formation, which overlies the Wild Cove Formation, is comprised of a mixed assemblage of mafic pillow lava and pillow breccia, aquagene tuff and epiclastic sedimentary rocks. Pillow lavas and related breccia contain undeformed pillows, locally with abundant large calcite-filled amygdules. In contrast to the Webber Bight Formation, they are not commonly porphyritic. The Little Harbour Formation is intruded by abundant mafic to silicic dykes. The former are dominantly hornblende-bearing diabase and gabbro similar to those in the Wild Cove Formation. Silicic dykes range from aphanitic pink rhyolitic rocks to medium-grained pink granite. Although widespread in the Moretons Harbour Group, they are most abundant in the uppermost areas along the west coast of the Moreton's Harbour peninsula between Whale's Gulch and Western Head. In this area, rhyolitic fragments are present in pillow breccias, confirming the high-level subvolcanic nature of the intrusions. Kay and Strong (1983) considered these felsic rocks to be flows and assigned them to the Haywards Cove formation. However, the present mapping clearly shows them to be intrusive and they are not herein considered to constitute a mappable lithostratigraphic unit.

GEOLOGY OF THE SLEEPY COVE FORMATION

The Sleepy Cove Formation was first informally defined by Payne (1974). However, the name has not been used consistently since that time and workers have variously applied the term Sleepy Cove "Formation", "Group", or "volcanics".

The Sleepy Cove Formation in the Twillingate area consists of mafic volcanic rocks and minor mafic dykes. Volcanic rocks comprise dominantly pillow lavas and local pillow breccias and massive flows. The pillows tend to be relatively small (i.e., 30 to 50 cm), and the rocks have been metamorphosed in the greenschist facies and now comprise an assemblage of chlorite, albite and sphene with minor secondary amphibole and magnetite and local concentrations of epidote. Pervasive and ubiquitous chloritic alteration give the rocks a distinctive dark green to black colour. The volcanic rocks are variably sheared and deformed and locally rich in chlorite- and/or calcite-filled amygdules. There are few if any felsic volcanic rocks or sedimentary rocks.

The sequence is cut by abundant northeast-trending faults with strong topographic expressions and rocks adjacent to the faults are locally strongly carbonatized. Because of the lithological monotony of the rocks, no basis for defining internal fault offsets or folds has been recognized; accordingly, the exposed section may contain repetition or excision of stratigraphy and no meaningful estimate of original thickness is possible.

GEOLOGICAL OBSERVATIONS IN THE TIZZARD'S HARBOUR–TRUMP ISLANDS, BLACK ISLAND AREA

Volcanic rocks in the Trump and Black islands and pillow lavas in the immediate vicinity of Tizzard's Harbour are lithologically similar to the Sleepy Cove Formation, as previously noted by Williams and Payne (1975). All are pervasively chloritized with a distinctive dark green to black colour in outcrops, strongly sheared and locally disposed in high strain zones that apparently mark major fault zones. The pillows are typically strongly extended with aspect ratios greater than 5:1. The rocks are non-porphyritic, at least at hand-specimen scale, and contain no clear examples of either epiclastic sedimentary or felsic volcanic rocks.

ANALYTICAL METHODS

A geographically and stratigraphically representative suite of samples was collected from outcrop for geochemical analysis. Samples were taken from the crystalline interior of pillows and high-level intrusions; samples showing excessive alteration, veining, vesiculation or weathering in hand specimen were discarded.

For samples prefaced "86SS" in Table 1, major elements and a standard suite of trace elements were analyzed by X-ray fluorescence at X-Ray Assay Laboratories Limited. Rare-earth elements (REE) and the trace elements Sc, Th, Nb, and Y were analyzed by Inductively-Coupled-Plasma–Mass-Spectrometry (ICP-MS) at Memorial University of Newfoundland (see Jenner *et al.*, 1990). The precision for Th and the REE (excluding Eu and Lu) is better than 3 percent RSD, for Eu and Lu it is 4 percent and for Nb 7 percent. Accuracy (as percentage difference compared to recommended values for USGS standards) is; better than 3 percent for La–Nd, Gd–Tb, Er and Y; 3 to 7 percent for Sm, Eu, Dy, Lu and Nb; and 7 to 10 percent for Th and Ho. All other trace elements were analyzed by X-ray fluorescence at Memorial University of Newfoundland.

For samples 2141541 to 2141591, major elements and the trace elements Ba, Zr and Cr were determined by lithium

Table 1. Geochemical analyses of rocks from the Moreton's Harbour–Twillingate area

Sample	2141541	2141542	2141543	2141544	2141545	2141546	2141547	2141548
SiO_2	78.09	46.13	43.05	48.57	44.77	52.60	48.49	57.90
Al_2O_3	13.24	13.86	16.30	14.49	17.94	14.98	14.55	13.42
Fe_2O_3	0.65	9.60	7.32	9.46	13.72	7.51	7.40	7.65
MgO	0.11	2.97	5.14	4.81	5.21	3.10	4.52	6.99
CaO	0.63	10.17	11.47	8.21	6.77	8.10	12.66	5.91
Na_2O	3.03	4.84	4.55	3.19	3.14	6.16	4.90	6.39
K_2O	2.44	0.47	0.47	0.54	0.82	0.10	0.39	0.06
TiO_2	0.06	2.02	0.91	1.34	1.96	1.22	1.38	0.11
MnO	0.02	0.18	0.16	0.16	0.17	0.14	0.16	0.13
P_2O_5	0.02	0.39	0.20	0.48	0.42	0.28	0.16	0.01
LOI	1.61	8.44	10.86	8.60	5.97	6.95	6.24	1.80
Total	99.90	99.07	100.42	99.86	100.88	101.14	100.84	100.37
Cr	10	17	96	178	20	30	74	451
Ni	5	19	39	88	39	45	29	82
Co	0	33	27	40	45	39	39	37
Cu	1	68	24	17	129	14	3	75
Zn	10	79	66	95	113	75	46	72
Pb	4	2	0	4	4	2	0	0
Ga	19	17	14	15	25	16	11	11
V	2	338	174	267	386	287	205	252
Sc	3	29	28	36	34	30	29	40
Li	17	8	10	14	10	12	3	1
Rb	73.5	6.1	7.2	9.8	10.5	1.0	5.8	0.5
Sr	59	228	415	163	231	245	359	129
Ba	178	158	186	129	143	72	98	19
Th	6.17	3.67	1.94	4.47	5.11	2.55	0.59	0.29
Ta	0.89	0.87	0.34	1.06	0.92	0.45	0.32	0.06
Nb	10.5	16.5	5.8	21.4	17.0	7.1	4.7	0.7
Zr	53	171	70	123	186	94	94	13
Hf	2.46	3.95	1.89	3.27	4.64	2.44	1.80	0.47
Y	16	29	15	22	31	22	16	4
La	9.42	28.80	12.62	25.68	25.51	20.69	6.95	0.88
Ce	21.80	62.45	27.44	54.38	60.90	42.83	18.60	1.91
Pr	2.51	7.60	3.36	6.77	7.29	5.24	2.64	0.23
Nd	8.91	32.56	14.92	27.97	30.99	21.73	12.04	0.87
Sm	2.43	7.04	3.26	6.14	6.95	5.01	3.23	0.26
Eu	0.37	2.25	1.04	1.68	1.66	1.56	1.21	0.08
Gd	2.33	6.67	3.27	6.05	6.95	4.93	3.40	0.31
Tb	0.42	0.99	0.50	0.85	1.05	0.74	0.52	0.07
Dy	2.64	5.86	3.14	4.85	6.44	4.49	3.22	0.59
Ho	0.56	1.17	0.64	0.91	1.29	0.88	0.67	0.15
Er	1.66	3.26	1.77	2.42	3.89	2.66	1.75	0.56
Tm	0.31	0.45	0.25	0.32	0.54	0.35	0.26	0.10
Yb	1.75	2.78	1.65	2.09	3.54	2.22	1.56	0.67
Lu	0.25	0.42	0.24	0.30	0.51	0.35	0.22	0.12

Table 1. *Continued*

Sample	2141549	2141551	2141552	2141553	2141554	2141555	2141556	2141557
SiO_2	47.56	46.00	44.51	55.46	46.46	47.98	48.97	49.01
Al_2O_3	13.95	15.85	14.89	13.39	15.85	17.40	15.99	16.85
Fe_2O_3	7.97	9.36	7.65	10.65	12.57	9.96	11.12	9.83
MgO	3.75	4.77	9.02	3.79	8.02	6.56	5.54	6.43
CaO	11.66	10.68	12.99	6.76	10.27	10.62	10.52	10.82
Na_2O	5.11	3.99	2.36	4.70	2.40	2.53	3.37	2.81
K_2O	0.11	0.69	1.73	0.04	0.78	1.23	0.65	1.01
TiO_2	1.49	1.22	0.45	1.94	1.20	0.84	1.50	1.49
MnO	0.12	0.13	0.17	0.16	0.15	0.13	0.14	0.19
P_2O_5	0.33	0.40	0.06	0.36	0.15	0.17	0.22	0.29
LOI	8.27	7.83	6.79	4.04	3.06	3.34	2.93	2.40
Total	100.35	100.92	100.63	101.28	100.94	100.76	100.94	101.11
Ni	18	39	174	7	66	58	34	57
Co	34	36	51	44	32	35	32	31
Cu	58	48	104	47	10	99	37	47
Zn	61	68	62	97	43	29	31	40
Pb	0	5	0	0	0	0	0	0
Ga	16	16	13	18	20	19	19	19
V	268	290	224	293	217	226	307	273
Sc	28	33	37	25	32	30	36	31
Li	4	15	14	6	4	3	3	4
Rb	0.8	12.0	38.6	0.4	21.8	28.6	13.1	20.3
Sr	277	294	265	233	274	387	397	406
Ba	42	253	179	28	121	251	151	217
Th	2.36	3.60	0.62	3.07	0.42	3.03	2.37	2.66
Ta	0.62	0.62	0.13	0.91	0.24	0.32	0.48	0.66
Nb	10.9	13.2	2.0	15.4	3.9	6.2	8.7	13.2
Zr	120	115	18	177	83	71	111	113
Hf	3.17	3.13	0.84	4.09	1.39	1.97	2.55	2.90
Y	24	25	12	29	17	16	26	23
La	18.11	27.31	3.67	25.67	5.18	28.34	17.12	20.11
Ce	41.87	60.59	8.10	57.03	14.98	52.28	41.65	43.94
Pr	5.39	7.54	1.04	7.23	2.15	5.45	5.61	5.38
Nd	23.77	31.61	4.73	30.76	10.16	20.92	24.94	22.55
Sm	5.33	6.41	1.33	6.66	2.89	3.88	5.67	4.97
Eu	1.82	1.86	0.46	2.07	0.98	1.20	2.23	1.60
Gd	5.19	5.59	1.79	6.47	3.33	3.76	5.70	4.85
Tb	0.81	0.83	0.31	1.01	0.55	0.57	0.89	0.78
Dy	4.76	4.75	2.25	6.01	3.38	3.29	5.42	4.75
Ho	0.94	0.98	0.49	1.16	0.67	0.65	1.09	0.94
Er	2.62	2.72	1.42	3.28	1.88	1.80	3.08	2.75
Tm	0.37	0.38	0.21	0.44	0.26	0.26	0.45	0.39
Yb	2.43	2.52	1.43	2.75	1.65	1.68	2.82	2.52
Lu	0.36	0.41	0.22	0.37	0.23	0.26	0.41	0.36

Table 1. *Continued*

Sample	2141558	2141559	2141561	2141562	2141563	2141564	2141565	2141566
SiO_2	49.47	52.58	46.87	47.48	46.98	52.24	46.60	46.16
Al_2O_3	15.17	16.79	12.44	16.90	15.91	14.80	18.55	15.82
Fe_2O_3	11.61	9.36	10.44	11.21	11.03	11.84	12.87	12.47
MgO	5.83	5.38	13.64	6.91	8.26	3.99	3.92	5.53
CaO	10.38	8.09	10.80	9.46	10.53	9.12	9.06	12.46
Na_2O	3.77	3.28	1.14	2.39	2.28	4.82	3.63	2.53
K_2O	0.45	1.18	0.99	1.64	1.08	0.35	0.90	0.66
TiO_2	1.67	0.89	0.49	0.84	0.91	2.31	1.53	2.16
MnO	0.13	0.13	0.18	0.14	0.18	0.14	0.15	0.17
P_2O_5	0.27	0.17	0.04	0.16	0.15	0.32	0.18	0.29
LOI	2.45	2.71	3.38	3.85	4.12	2.09	3.35	2.11
Total	101.21	100.57	100.40	100.98	101.44	102.03	100.72	100.35
Cr	53	90	771	148	241	33	46	169
Ni	34	31	223	62	92	15	26	53
Co	34	32	53	37	45	36	36	44
Cu	31	28	7	23	34	96	3	2
Zn	28	28	38	35	62	37	43	48
Pb	0	0	0	0	0	0	0	0
Ga	21	20	14	18	17	22	23	22
V	327	254	235	231	222	325	273	274
Sc	35	30	40	34	36	33	31	31
Li	2	3	4	6	3	2	6	4
Rb	7.3	30.2	27.2	48.1	12.0	3.0	10.3	7.2
Sr	345	309	77	357	108	336	350	355
Ba	127	233	165	406	179	79	164	160
Th	2.89	2.47	0.58	2.44	2.37	1.87	0.39	1.28
Ta	0.75	0.36	0.09	0.29	0.17	0.79	0.43	0.73
Nb	13.4	7.1	1.5	5.6	3.0	13.2	6.8	10.7
Zr	132	81	21	65	64	187	111	157
Hf	3.10	2.39	0.91	1.86	1.13	3.69	2.20	3.07
Y	32	18	11	14	9	32	16	20
La	14.59	12.97	2.54	13.54	17.92	15.79	1.51	15.19
Ce	37.55	27.45	6.67	29.46	31.54	38.48	7.35	35.94
Pr	5.60	3.21	0.95	3.71	3.47	5.03	1.46	4.76
Nd	26.94	13.40	4.71	15.25	13.41	23.22	8.41	20.53
Sm	7.22	3.04	1.38	3.38	2.68	6.05	2.71	4.88
Eu	2.78	0.99	0.52	1.15	0.74	2.05	0.92	1.63
Gd	7.46	3.19	1.79	3.25	2.38	6.51	3.23	4.98
Tb	1.17	0.54	0.30	0.50	0.36	1.10	0.54	0.77
Dy	7.25	3.52	2.12	3.03	2.08	6.76	3.30	4.47
Ho	1.43	0.74	0.44	0.60	0.41	1.36	0.69	0.84
Er	4.15	2.14	1.35	1.64	1.06	3.82	1.86	2.24
Tm	0.56	0.32	0.19	0.24	0.15	0.51	0.25	0.30
Yb	3.57	2.16	1.30	1.58	0.97	3.17	1.59	1.78
Lu	0.50	0.33	0.20	0.22	0.14	0.47	0.20	0.24

Table 1. *Continued*

Sample	2141567	2141568	2141569	2141571	2141572	2141573	2141574	2141575
SiO_2	50.38	53.32	51.83	50.08	54.06	57.23	74.67	54.11
Al_2O_3	14.35	15.95	20.43	15.92	10.38	14.92	13.24	12.56
Fe_2O_3	10.49	6.50	6.44	11.17	9.60	12.41	1.24	8.69
MgO	8.58	7.34	3.72	4.79	10.28	3.41	0.30	8.92
CaO	7.22	10.57	9.83	10.49	10.11	1.54	0.99	9.67
Na_2O	4.51	3.89	4.92	3.62	3.02	3.93	3.80	1.72
K_2O	0.34	0.25	0.29	0.04	0.13	0.55	3.69	1.23
TiO_2	0.30	0.35	0.37	0.87	0.10	1.01	0.17	0.14
MnO	0.24	0.16	0.10	0.19	0.16	0.15	0.04	0.16
P_2O_5	0.02	0.05	0.03	0.21	0.00	0.26	0.03	0.02
LOI	3.69	1.81	1.74	3.18	2.59	5.33	2.14	2.46
Total	100.12	100.19	99.70	100.55	100.42	100.73	100.31	99.68
Cr	587	547	839	59	803	14	6	447
Ni	131	197	219	25	167	12	3	81
Co	44	45	35	29	51	23	2	48
Cu	51	4	184	5	3	229	1	41
Zn	91	80	35	51	71	40	16	68
Pb	0	0	0	0	0	0	14	0
Ga	16	15	20	22	9	20	16	16
V	217	218	218	322	222	211	14	272
Sc	31	37	40	33	37	21	4	40
Li	16	5	6	3	2	10	3	2
Rb	5.7	4.6	4.6	0.3	1.2	7.6	85.0	23.4
Sr	108	267	272	494	88	101	97	191
Ba	68	62	32	20	116	696	435	33
Th	0.28	0.12	0.13	2.96	0.35	5.01	11.23	0.49
Ta	0.02	0.03	0.02	0.11	0.06	0.74	0.85	0.10
Nb	0.3	0.3	0.3	2.2	0.7	13.6	8.7	1.1
Zr	19	20	27	55	13	161	80	17
Hf	0.59	0.45	0.66	1.58	0.43	4.16	2.56	0.52
Y	11	10	8	16	4	19	11	5
La	1.61	1.21	1.15	15.40	1.09	27.40	23.13	0.96
Ce	4.06	3.72	3.65	33.78	2.31	56.74	45.65	2.48
Pr	0.57	0.60	0.59	4.22	0.25	6.65	4.67	0.31
Nd	2.93	3.20	3.12	17.43	1.12	26.46	15.24	1.29
Sm	0.97	1.09	1.17	3.61	0.24	5.47	2.80	0.37
Eu	0.31	0.45	0.47	1.16	0.09	1.43	0.40	0.15
Gd	1.43	1.49	1.50	3.39	0.35	4.63	2.23	0.51
Tb	0.25	0.28	0.26	0.53	0.07	0.64	0.36	0.10
Dy	1.74	2.00	1.62	3.07	0.66	3.79	2.08	0.86
Ho	0.41	0.43	0.36	0.62	0.18	0.79	0.42	0.21
Er	1.27	1.36	1.00	1.76	0.60	2.37	1.21	0.65
Tm	0.18	0.19	0.15	0.25	0.10	0.38	0.21	0.12
Yb	1.26	1.28	1.00	1.62	0.85	2.58	1.25	0.89
Lu	0.21	0.20	0.13	0.24	0.14	0.43	0.21	0.14

Table 1. *Continued*

Sample	2141576	2141577	2141578	2141579	2141581	2141582	2141583	2141584
SiO_2	49.28	46.62	76.93	47.89	58.77	55.71	46.26	46.36
Al_2O_3	16.26	13.74	11.53	15.18	15.41	11.20	15.85	14.87
Fe_2O_3	10.90	11.94	0.38	13.88	5.57	6.97	12.04	11.88
MgO	4.28	4.88	0.03	6.27	2.62	2.30	5.36	4.76
CaO	8.80	7.72	1.01	3.84	4.29	8.12	4.90	6.22
Na_2O	4.43	4.91	5.18	2.68	5.04	3.97	5.51	5.93
K_2O	0.14	0.20	2.04	1.69	1.60	0.99	0.55	0.32
TiO_2	1.14	2.16	0.14	1.18	0.81	1.34	1.98	1.97
MnO	0.13	0.23	0.02	0.14	0.09	0.17	0.15	0.17
P_2O_5	0.31	0.90	0.02	0.53	0.24	0.50	0.67	0.59
LOI	4.61	7.23	1.84	7.30	5.85	8.20	7.05	7.40
Total	100.27	100.53	99.10	100.58	100.30	99.47	100.33	100.47
Cr	16	19	10	17	43	16	20	15
Ni	17	10	5	12	19	9	11	12
Co	37	30	3	38	18	18	28	32
Cu	135	18	4	87	17	11	20	30
Zn	47	141	4	119	69	101	115	106
Pb	0	4	2	2	1	0	0	0
Ga	24	18	8	23	18	12	23	20
V	273	321	5	353	104	200	283	362
Sc	24	25	2	34	13	18	25	30
Li	5	11	1	27	11	11	16	18
Rb	1.9	3.0	26.4	33.2	33.5	15.1	8.5	2.9
Sr	176	271	247	178	253	143	173	220
Ba	92	5357	302	372	850	176	72	165
Th	3.81	3.09	12.16	9.30	4.68	3.10	4.51	3.24
Ta	0.59	0.34	1.96	0.93	0.59	0.66	0.92	0.42
Nb	11.4	7.7	35.2	25.4	9.1	12.1	18.1	7.7
Zr	133	109	351	114	163	126	183	113
Hf	2.64	2.80	9.98	3.00	4.30	3.03	4.61	3.01
Y	21	25	29	25	18	22	32	26
La	25.55	29.50	60.31	60.43	22.42	28.90	36.93	24.27
Ce	55.35	66.33	119.71	116.26	47.04	59.33	83.40	54.64
Pr	6.47	8.27	12.83	12.25	5.32	7.13	10.16	6.90
Nd	26.32	35.14	44.23	44.02	20.53	29.18	42.98	28.98
Sm	5.25	7.19	7.31	7.27	4.13	5.86	8.67	6.29
Eu	1.56	2.68	1.51	1.95	1.24	2.14	3.33	2.07
Gd	4.88	6.76	5.87	5.95	3.94	5.28	7.93	6.44
Tb	0.71	0.96	0.92	0.82	0.60	0.77	1.19	0.93
Dy	4.17	5.52	5.43	4.88	3.52	4.68	6.74	5.58
Ho	0.83	1.11	1.14	1.02	0.72	0.92	1.31	1.11
Er	2.31	2.92	3.25	3.11	2.01	2.55	3.64	3.27
Tm	0.32	0.38	0.48	0.44	0.29	0.35	0.51	0.45
Yb	1.99	2.38	3.03	2.88	1.83	2.23	3.18	2.88
Lu	0.28	0.36	0.44	0.41	0.27	0.33	0.49	0.45

Table 1. *Continued*

Sample	2141585	2141586	2141587	2141588	2141589	2141591	86SS-023	86SS-023
SiO_2	47.38	45.54	75.75	49.04	48.42	64.29	40.60	45.50
Al_2O_3	14.63	15.44	13.26	15.23	14.52	15.36	11.50	13.80
Fe_2O_3	11.88	8.21	0.56	10.40	10.26	3.85	7.07	6.34
MgO	4.40	3.66	0.10	5.19	5.07	1.79	7.52	6.27
CaO	8.31	12.94	0.38	7.83	8.50	3.14	14.10	11.60
Na_2O	4.70	5.13	3.38	5.66	5.38	4.94	3.21	4.54
K_2O	0.21	0.05	4.30	0.11	0.35	1.81	0.07	0.05
TiO_2	1.38	1.17	0.06	1.42	1.72	0.57	0.39	0.57
MnO	0.16	0.11	0.03	0.17	0.15	0.06	0.22	0.18
P_2O_5	0.29	0.24	0.01	0.24	0.28	0.19	0.06	0.07
LOI	7.42	7.71	1.29	5.01	5.53	3.78	15.50	11.40
Total	100.76	100.21	99.12	100.32	100.16	99.79	100.24	100.32
Cr	11	18	9	42	18	36	868	369
Ni	16	17	5	19	25	16	206	266
Co	39	31	0	34	41	11	37	40
Cu	128	54	1	47	89	17	56	100
Zn	87	61	33	87	83	58	51	41
Pb	0	0	20	0	0	3	5	2
Ga	21	19	19	20	16	22	0	0
V	334	296	2	328	289	69	281	297
Sc	29	30	3	32	34	9	34	41
Li	17	9	5	9	8	10	8	7
Rb	3.4	0.4	118.1	0.9	3.3	43.7	17.8	5.7
Sr	191	160	51	161	153	317	136	140
Ba	469	703	43	107	300	321	10	12
Th	4.80	2.84	6.62	2.82	1.90	6.28	0.15	0.20
Ta	0.58	0.45	0.97	0.47	0.56	0.50	0.00	0.00
Nb	10.7	8.1	10.7	8.4	9.7	7.3	0.4	0.3
Zr	123	95	53	114	134	169	30	35
Hf	3.27	2.51	2.59	3.10	3.56	4.76	0.59	1.09
Y	23	19	16	22	23	13	11	9
La	25.47	19.08	11.00	18.38	14.64	24.72	1.38	2.42
Ce	56.62	41.63	25.62	41.25	35.97	51.38	3.50	6.00
Pr	6.80	5.14	2.97	5.18	4.70	5.57	0.63	0.96
Nd	28.06	21.46	10.51	22.52	21.53	21.10	2.89	4.90
Sm	5.90	4.79	2.60	4.80	5.11	4.07	1.08	1.41
Eu	1.77	1.49	0.41	1.65	1.59	1.00	0.45	0.59
Gd	5.57	4.30	2.56	5.06	5.20	3.22	1.51	1.72
Tb	0.83	0.68	0.45	0.76	0.82	0.47	0.28	0.25
Dy	4.84	4.19	2.90	4.59	4.83	2.62	1.81	1.70
Ho	0.95	0.83	0.59	0.92	0.98	0.51	0.42	0.40
Er	2.61	2.32	1.87	2.63	2.77	1.53	1.17	0.99
Tm	0.38	0.34	0.28	0.37	0.40	0.20	0.16	0.17
Yb	2.30	1.99	1.72	2.29	2.50	1.15	1.16	1.30
Lu	0.38	0.31	0.27	0.37	0.37	0.18	0.17	0.21

Table 1. *Concluded*

Sample	86SS-023	86SS-023	86SS-024	86SS-024	86SS-024	86SS-024	86SS-025	86SS-025
SiO_2	45.30	39.30	50.10	43.10	49.20	48.30	52.00	47.80
Al_2O_3	13.10	12.80	14.00	12.50	16.00	15.00	13.10	13.30
Fe_2O_3	7.70	6.80	9.13	9.53	8.14	11.30	7.77	11.60
MgO	7.58	5.91	6.60	10.30	6.74	8.04	10.10	11.50
CaO	11.70	16.00	11.20	10.80	6.83	9.00	8.32	8.97
Na_2O	4.68	3.94	4.15	3.36	5.87	3.00	4.15	2.56
K_2O	0.08	0.05	0.06	0.08	0.09	0.24	0.07	0.08
TiO_2	0.43	0.43	0.73	0.39	0.97	1.31	0.28	0.40
MnO	0.14	0.18	0.16	0.16	0.14	0.17	0.24	0.32
P_2O_5	0.06	0.07	0.07	0.05	0.11	0.10	0.04	0.06
LOI	9.08	14.80	3.77	9.70	6.16	3.39	3.62	3.47
Total	99.85	100.28	99.97	99.97	100.25	99.85	99.69	100.06
Cr	611	600	411	1263	284	231	351	537
Ni	154	189	181	415	113	109	93	228
Co	42	35	42	48	40	38	39	63
Cu	63	33	0	10	25	37	0	3
Zn	38	41	38	56	49	62	199	72
Pb	2	2	2	0	0	2	2	2
V	291	288	250	308	283	333	223	266
Sc	38	47	36	39	41	30	38	41
Li	4	5	2	18	12	5	6	5
Rb	24.4	18.9	5.2	19.0	12.9	11.5	16.8	10.5
Sr	115	156	177	58	97	205	94	158
Ba	22	8	14	9	21	23	7	6
Th	0.18	0.19	0.13	0.13	0.14	0.07	0.11	0.13
Nb	0.7	0.4	0.4	0.5	0.7	0.4	2.5	0.4
Zr	29	30	42	30	59	51	22	23
Hf	0.68	0.95	0.98	0.77	1.38	0.75	0.49	0.50
Y	13	9	19	11	21	21	9	13
La	1.51	1.97	1.54	1.02	1.85	1.31	1.02	1.06
Ce	3.80	4.75	4.60	2.68	6.15	4.51	2.43	2.41
Pr	0.65	0.82	0.89	0.50	1.11	0.83	0.42	0.49
Nd	3.29	3.70	4.68	2.51	6.01	4.74	2.01	2.18
Sm	1.16	1.19	1.75	0.94	2.30	1.78	0.72	0.95
Eu	0.45	0.46	0.74	0.30	0.62	0.84	0.24	0.40
Gd	1.65	1.33	2.51	1.34	3.16	2.74	1.03	1.38
Tb	0.30	0.24	0.51	0.26	0.61	0.48	0.21	0.30
Dy	2.15	1.58	3.37	1.86	3.85	3.30	1.49	2.06
Ho	0.49	0.37	0.81	0.41	0.84	0.72	0.34	0.47
Er	1.24	1.08	2.08	1.06	2.35	1.92	0.93	1.39
Tm	0.19	0.16	0.30	0.15	0.29	0.24	0.13	0.19
Yb	1.28	1.29	1.96	1.02	1.90	1.65	0.91	1.31
Lu	0.18	0.24	0.30	0.15	0.26	0.23	0.13	0.20

metaborate fusion followed by inductively-coupled-plasma–optical-emission-spectrophotometry (ICP-OES) and Ni, V, Rb, Sr, Cu, Pb and Zn by total multi-acid digestion and ICP-OES determination, both at the Newfoundland Department of Natural Resources analytical laboratory. The REE and the trace elements Sc, Th, Nb, and Y were analyzed at Memorial University by ICP-MS, as described above.

RESULTS

The geochemical data reveal a considerable diversity in the geochemical signatures of volcanic and high level intrusive rocks in the Moreton's Harbour–Twillingate area. Seven distinct types of mafic rocks can be recognized, herein referred to as types A to G, respectively. The geochemical signatures of these rocks are displayed on a series of magmatic and tectonic discrimination diagrams in Figure 3 and on primitive mantle-normalized trace-element plots in Figures 4 and 5.

Type A rocks comprise LREE depleted (La/Sm_n=0.47 to 0.56) subalkalic basalts with small but distinct negative Nb anomalies and a positive Th inflection with respect to Nb. These rocks have Mg# between 59 and 62 and so are only moderately fractionated. Although there are not enough samples to define a fractionation trend, they are geochemically similar to arc-tholeiites and plot with arc-tholeiites on tectonic discrimination diagrams.

Type B rocks are also subalkalic basalts having slightly LREE-depleted to slightly LREE-enriched mantle-normalized trace-element patterns ((La/Sm_n=0.68 to 1.08) and prominent negative Nb and positive Th anomalies. These rocks have very low TiO_2 concentrations (generally <0.5 percent) and plot in arc fields on geochemical discrimination. These rocks have Mg# between 62 and 72 and are only slightly fractionated; they do not exhibit a sufficient fractionation trend to define the magma series.

Type C rocks are subalkalic andesites, which are highly impoverished in incompatible trace elements such that they plot outside the fields of normal mafic rocks on discrimination diagrams, and have a distinctive concave upward mantle-normalized trace-element pattern with a distinct positive Zr anomaly. These rocks exhibit most of the geochemical characteristics of boninites.

Type D rocks are LREE-enriched (La/Sm_n=1.13 to 1.65) subalkalic tholeiites with relatively smooth mantle-normalized trace-element patterns and no Nb or Th anomalies. They plot in OFB fields on tectonic discrimination diagrams and have Mg# between 40 and 56 indicating that they are moderately fractionated. These characteristics are typical of enriched mid-ocean-ridge basalts (E-MORB) or ocean-island basalts (OIB).

Type E rocks are slightly LREE-enriched ((La/Sm_n=1.17 to 1.75) subalkalic tholeiites. They plot in island-arc fields on most discrimination diagrams, are only slightly fractionated with Mg# between 70 and 72, and have very low TiO_2 concentrations (~0.5 percent). They do not exhibit a clear fractionation trend and plot very close to *Type B* rocks on tectonic-discrimination diagrams.

Type F rocks are the most abundant in the area. They are characteristically LREE-enriched (La/Sm_n=1.28 to 3.17), with distinct negative Nb and positive Th anomalies and slight negative Zr anomalies on mantle-normalized trace-element plots. Most are subalkalic basalts or andesites although at least two samples may be slightly alkalic. Most samples exhibit a trend of TiO_2 enrichment with fractionation, suggesting that these rocks are probably high-K tholeiites (cf. Gill, 1981; Swinden, 1987). However, there is considerable scatter and the possibility remains that two or more fractionation series are presented here. They plot in OFB or other non-arc fields in most tectonic discrimination diagrams, despite the negative Nb anomalies. They are extensively fractionated with Mg# ranging from 38 to 58.

Type G rocks are very similar to *Type F,* being distinguished by either stronger LREE-enrichment (La/Sm_n=2.7 to 5.79) and/or stronger negative Nd anomalies. These rocks also show moderate to weak TiO_2 enrichment with fractionation and some plot along what may be calc-alkalic rather than tholeiitic trends.

Rhyolites exhibit considerable geochemical diversity. They are moderately to strongly LREE-enriched with prominent negative Ti anomalies (indicating substantial iron-oxide fractionation) and negative Nb anomalies that are nonetheless rather weak compared to similar rhyolites elsewhere in the Notre Dame Subzone (Swinden *et al., in press*). This weak Nb anomaly results in relatively high Nb/Y ratios, characteristic of alkalic rather than subalkalic rocks.

GEOGRAPHICAL DISTRIBUTION OF SAMPLE TYPES

There is a clear geographical distribution of sample types in the Moreton's Harbour–Twillingate area that corresponds to geological features recognized in the field and leads to new interpretations of the stratigraphic relationships among the various geochemical types in the area, illustrated schematically in Figure 6.

Type A and most of the *Type B* rocks are found in the Sleepy Cove Formation in its type area on the Twillingate Islands. *Type A* rocks have only been recognized in the Sleepy Cove–Long Point area of North Twillingate Island. *Type B* volcanic rocks are found throughout the Twillingate Islands and also on Black and North Trump islands.

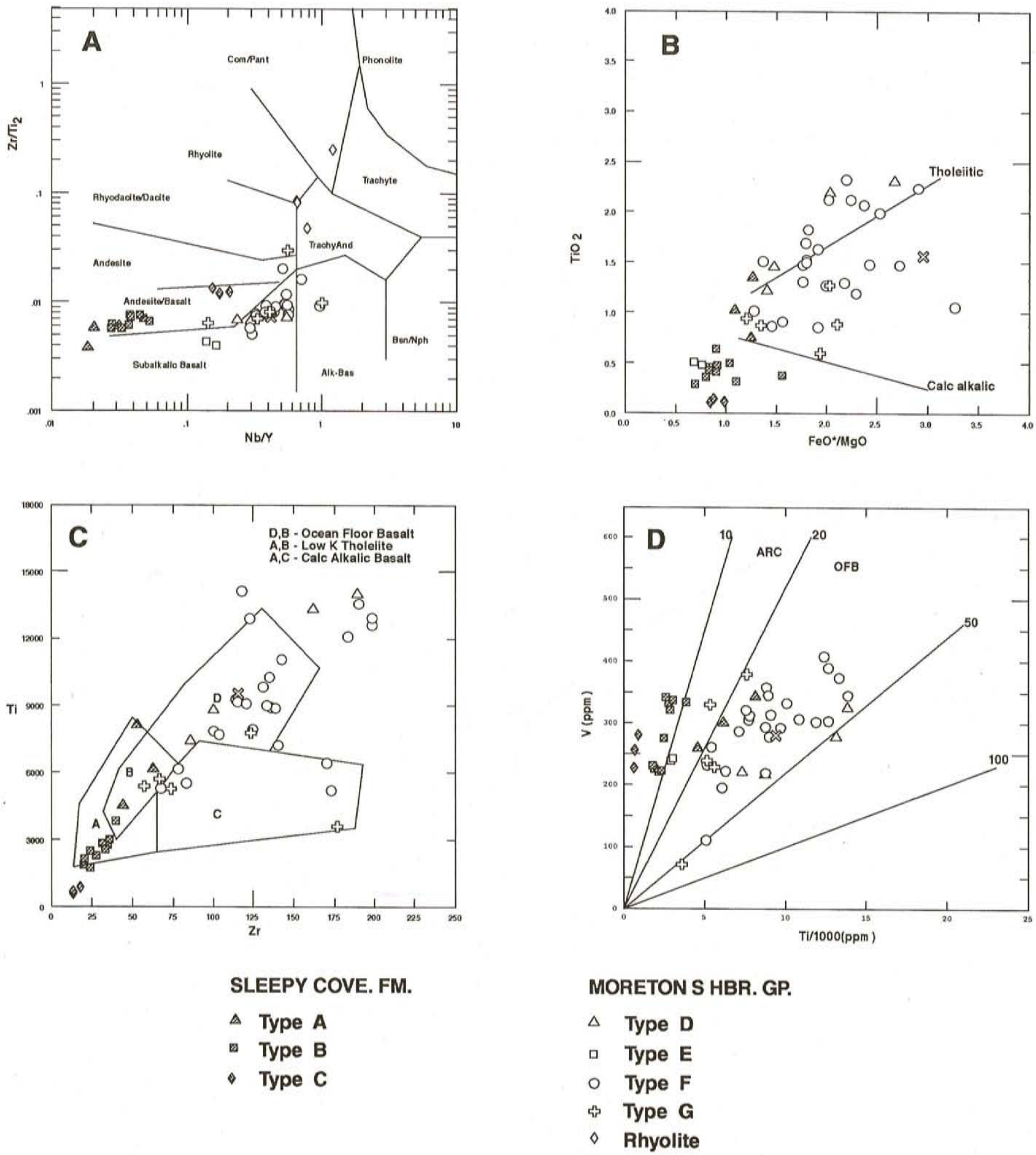
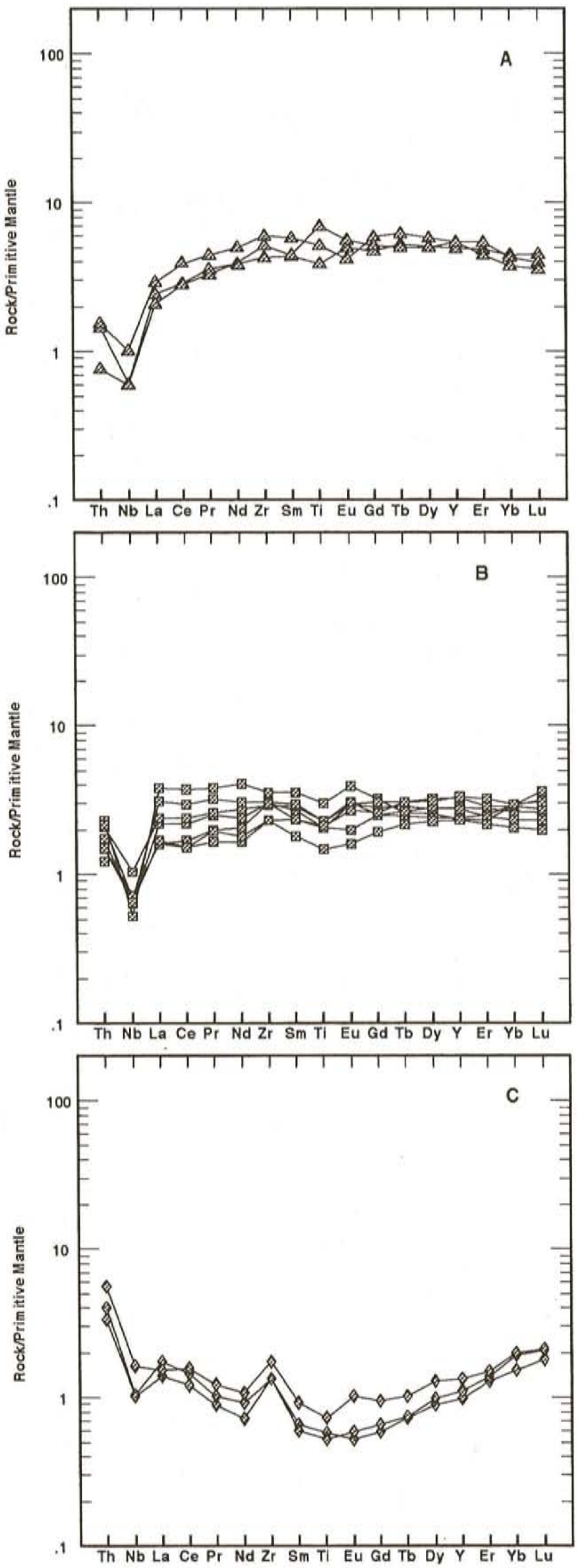


Figure 3. *Geochemical discrimination diagrams for volcanic and subvolcanic rocks. A–discrimination of alkalic and subalkalic rocks after Winchester and Floyd (1977); B–discrimination of tholeiitic and calc-alkalic magma series, after Miyashiro and Shido (1975); C–tectonic discrimination diagram after Pearce and Cann (1973); D–tectonic discrimination diagram after Shervais (1982); OFB–ocean-floor basalt.*



Type C rocks (boninites) have been recognized only in outcrops in the immediate vicinity of Tizzard's Harbour and seem to be characteristic of Strong and Payne's (1973) Tizzards Harbour Formation.

Type D rocks have been recognized only in shoreline outcrops west of Tizzard's Harbour and east of Moreton's Harbour. The marked lithological contrast between these relatively unaltered, undeformed, commonly highly porphyritic lavas and the highly deformed chloritized boninitic lavas of the Tizzards Harbour Formation is also reflected in the strongly contrasting geochemical signatures. *Type D* rocks most commonly form large outcrops dominated by pillow lava and have previously been assigned to the Webber Bight Formation and the basal part of the Little Harbour Formation. However, they also occur as screens among high-level mafic intrusive rocks of *Types E, F,* and *G* in the Wild Cove Formation, a fact that provides important constraints on the stratigraphic relationships of the different geochemical types in the Moretons Harbour Group (see below).

Type E rocks are represented by only two samples, one taken from a diabase sill in Wild Bight and the other from a roadside pillow lava outcrop in Bridgeport.

Types F and *G* occur as pillow lavas and diabase dykes throughout the western part of the Moreton's Harbour peninsula (the middle and upper parts of the Little Harbour Formation) and also as hornblende-bearing dykes in the Wild Cove and Webber Bight formations east of Moreton's Harbour.

Rhyolitic rocks are most common in the Whale's Gulch area on the west coast of the Moreton's Harbour peninsula. Their abundance diminishes markedly to the east but isolated examples of felsic dykes were noted as far east as the area east of Moreton's Harbour.

The geographic distribution of these rocks, considered in the context of geological relationships in the area, provides new evidence for the location and nature of the boundary between the Moretons Harbour Group and the Sleepy Cove Formation. Geological observations, which link the Sleepy Cove Formation with similar rocks on Black Island, the Trump Islands and in Tizzard's Harbour, are apparently supported by the geochemical data. The *Type B* rocks on

Figure 4. *Mantle-normalized trace-element plots for the Sleepy Cove Formation. Symbols match Figure 3.*

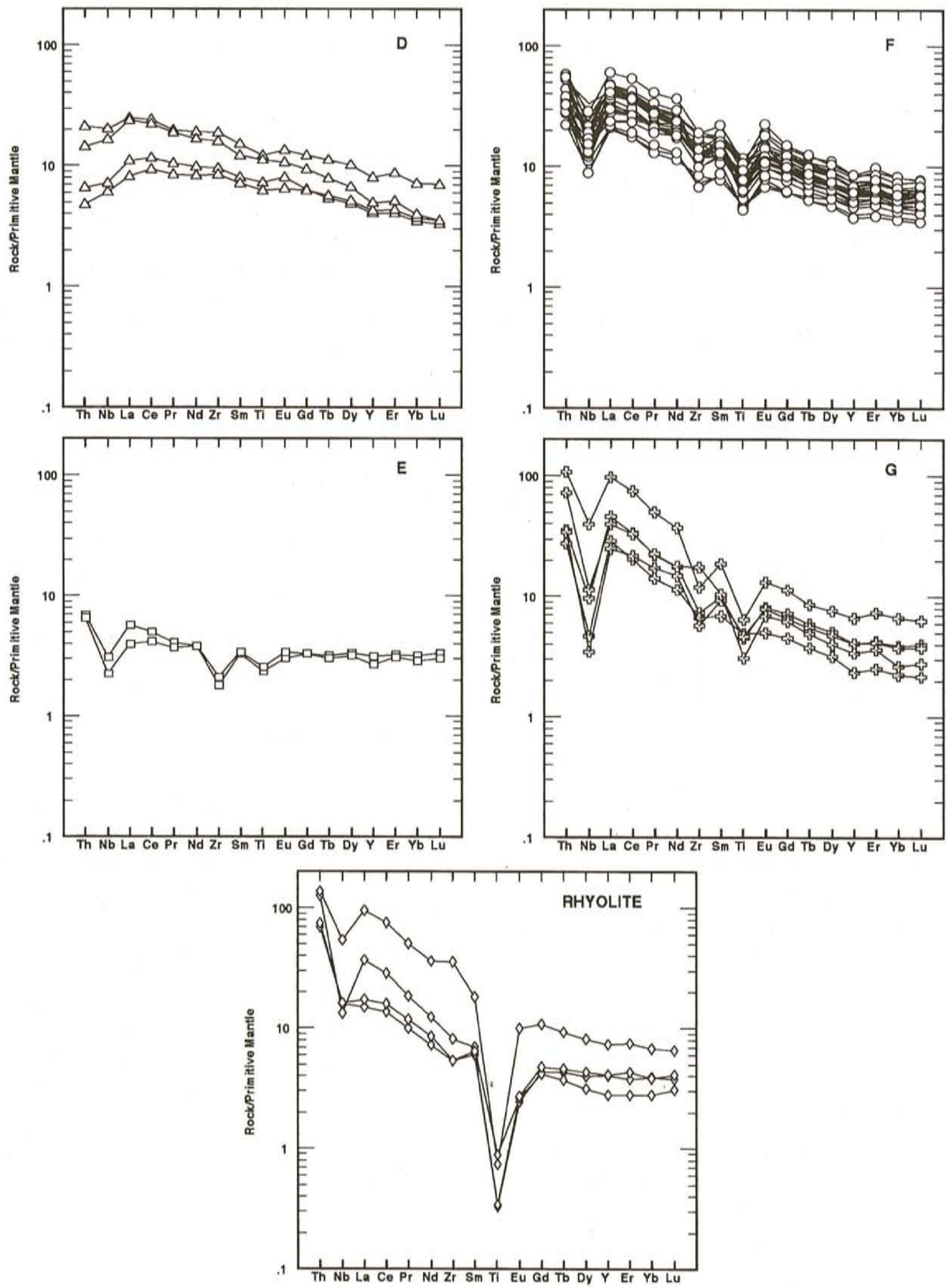


Figure 5. *Mantle-normalized trace-element plots for the Moretons Harbour Group. Symbols match Figure 3.*

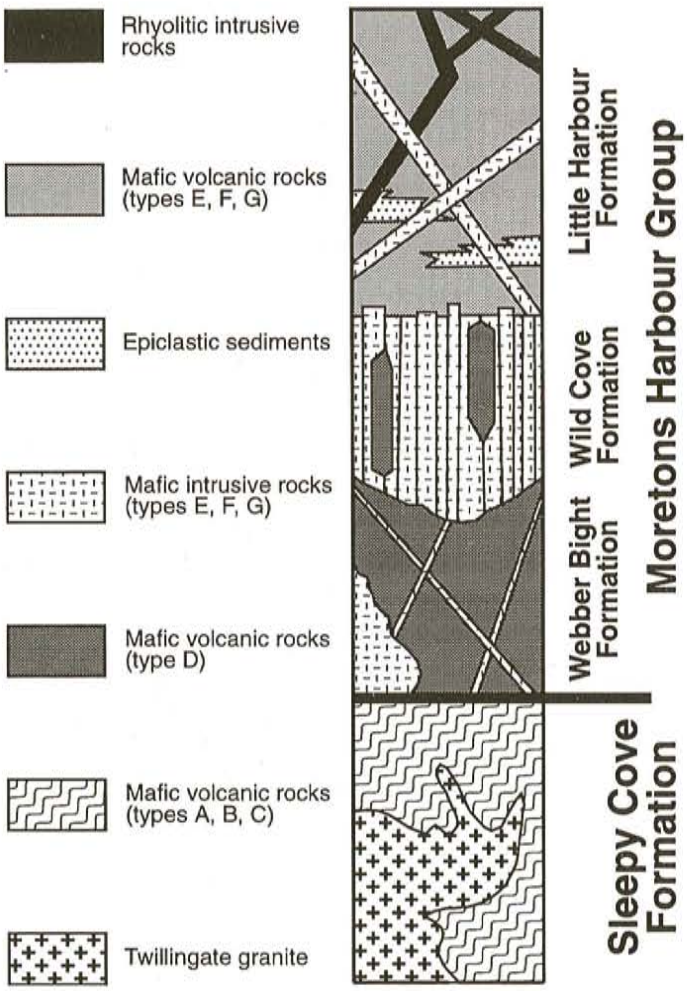


Figure 6. *Schematic illustration of the stratigraphic relationships in the Moreton's Harbour–Twillingate area, interpreted from field and geochemical relationships. Vertical axis is not to scale.*

North Trump and Black islands are readily interpreted as correlative with similar rocks on the Twillingate Islands. The association of *Types A* and *B* rocks with rocks of boninitic affinity (*Type C*) is well documented elsewhere in Notre Dame Bay (e.g., Lushs Bight Group; Kean *et al.*, 1995). The best interpretation would seem to be that these rocks collectively define an assemblage that should be assigned to the Sleepy Cove Formation.

The field evidence for a significant geological boundary between mafic volcanic rocks in Tizzard's Harbour and the Webber Bight Formation to the west, is strongly supported by the geochemical evidence. The boundary between these rocks marks a significant geochemical discontinuity. The geochemical assemblage in the Moretons Harbour Group is more complex than in the Sleepy Cove Formation, but is nonetheless readily interpreted because of a number of key geological relationships. The geochemical similarity between the lavas west of Moreton's Harbour and the mafic intrusive rocks throughout the Moretons Harbour Group leaves little doubt that the latter are high-level coeval subvolcanic equivalents of the former. This being the case, the non-arc *Type D* lavas must be the oldest rocks in this assemblage as they occur as screens within the subvolcanic dykes in Wild Bight. The felsic rocks appear to be generally relatively young as they apparently are most abundant in the westernmost parts of the group. However, the fact that these rocks occur as clasts in pillow breccias shows that the mafic and felsic volcanism were essentially coeval.

A problem still remains as to the affinity of rocks in the area of Chanceport Head immediately north of the Chanceport Fault. Williams and Payne (1975) and Williams (1994) suggested that the fault separating the Sleepy Cove Formation from the Moretons Harbour Group trends southward from Tizzard's Harbour to Sam Jeans Cove and then southwestward to the area of Bridgeport (Figure 2). This implies that there is a wedge of Sleepy Cove Formation rocks in the southeastern part of the Moreton's Harbour peninsula. Coastal exposures in this area are not clearly identifiable as intrusive or extrusive. However, one sample from this area yielded a *Type G* geochemical signature. Experience along the north coast of the peninsula suggests that such rocks do not intrude the Sleepy Cove Formation. The preliminary interpretation is that these rocks are in fact part of the Moretons Harbour Group and the boundary between them and the Sleepy Cove Formation must lie to the east, under the water between Chanceport Head and the Trump Islands.

REGIONAL CORRELATIONS AND TECTONIC SETTINGS

Previous workers have proposed a correlation between the Sleepy Cove Formation and the Lushs Bight Group in western Notre Dame Bay, on the basis of lithological similarity and sparse geochemical data (Dean, 1978; Kean *et al.*, 1981). More recently, the recognition that the Lushs Bight Group, like the Sleepy Cove Formation, is older than 500 Ma has strengthened this interpretation (Szybinski, 1995; Swinden *et al.*, *in press*). The geochemical data presented herein provide additional support for this correlation. The Lushs Bight Group has been shown to comprise an assemblage of pillow lavas and sheeted dykes that consist dominantly of tholeiites of arc and transitional-arc affinity having a significant component of boninitic rocks (Kean *et* *al.*, 1995), an assemblage very similar to that seen in the Sleepy Cove Formation. The Lushs Bight Group is generally interpreted to have formed in a supra-subduction zone setting (Kean *et al.*, 1995; Swinden *et al., in press*) and such a setting is consistent with the geochemical signatures in the Sleepy Cove Formation. The simplest interpretation would seem to be that the two form isolated remnants of a Late Cambrian arc and/or back-arc sequence.

Regional analogues for the Moretons Harbour Group are less easily identified. The non-arc tholeiites are readily interpreted as mantle-derived rocks, the sources of which were not contaminated by subduction. Similar rocks are present elsewhere in the Notre Dame Subzone (Swinden *et al., in press*), for example, in the Snooks Arm Group on the Baie Verte Peninsula (Jenner and Fryer, 1980) and in the Western Arm Group in western Notre Dame Bay (Szybinski, 1995). The association of LREE-enriched rocks (having arc signatures) and rhyolitic rocks is also common elsewhere in the Notre Dame Subzone. Most of these rocks in the Moretons Harbour Group have rather weak, negative Nb anomalies and a tholeiitic affinity, in contrast to the generally calc-alkalic affinity of similar rocks in the Roberts Arm and Buchans groups (Swinden *et al., in press*). However, similar rocks occur in the upper part of the Western Arm Group and in the Cutwell Group (Szybinski, 1995). Such a correlation would be compatible with regional relationships, as the Western Arm–Cutwell assemblage is structurally juxtaposed with the Lushs Bight Group in western Notre Dame Bay. Regionally, in the Notre Dame Subzone, LREE-enriched rocks having arc signatures are calc-alkalic with strong arc signatures and isotopic systematics suggesting the involvement of continental lithosphere in their petrogenesis; such rocks are readily interpreted as representing an island-arc built upon continental lithosphere (Swinden *et al., in press*). However, the LREE-enriched rocks in the Moretons Harbour Group are high-Ti rocks that appear to be tholeiitic, and have relatively weak arc signatures. Likewise, there is a substantial diversity in the geochemical character of the felsic rocks, and the arc signature is not strongly developed. The LREE-enriched rocks in particular do not have any clear analogues in the well-documented calc-alkalic arc sequences of the Roberts Arm and Buchans groups to the west (Swinden *et al., in press*). The relatively small Nb anomalies, the tholeiitic nature of the magmas, and the high Ti concentrations suggest that these may be best interpreted as melts derived from uncontaminated mantle but modified by interaction with continental lithosphere. This being the case, they may represent some form of back-arc rifting rather than an active-arc sequence. Isotopic data are needed to more fully constrain the petrogenesis of these rocks.

IMPLICATIONS FOR METALLOGENY

The Lushs Bight Group is one of the most prolific hosts to VMS deposits in Notre Dame Bay with three post-confederation producers (Whalesback, Little Bay, and Little Deer) and a host of smaller deposits and occurrences (Kean *et al.*, 1995). Volcanogenic massive sulphide deposits in the Lushs Bight Group tend to be spatially associated with boninitic rocks (Swinden *et al.*, 1989a and b) have postulated that there may be a genetic link between boninitic volcanism and VMS formation in this environment. The identification of boninitic rocks in the Sleepy Cove Formation clearly pinpoints this unit as a favourable target for VMS exploration and suggests that mineralization previously reported in this unit (the Sleepy Cove mine, Wild Cove occurrence) may provide targets equivalent to those in the Lushs Bight Group. In addition, the correlation of the Sleepy Cove Formation and the Lushs Bight Group implies a similar structural history and it is reasonable to expect that syn-accretion gold occurrences such as those in the Lushs Bight Group might be expected in the Sleepy Cove Formation as well.

The geochemical data do not provide specific new information about the potential of the Moretons Harbour Group, although by analogy with other parts of central Newfoundland, the volcanic rocks with arc-like geochemical signatures and abundant syn-volcanic felsic intrusion might be expected to provide a favourable target for VMS exploration. More work is required to test whether these rocks may be correlated with the highly prospective calc-alkalic arc sequences of the Buchans and Roberts Arm groups. It has been suggested that the antimony occurrences in Moreton's Harbour form part of a widespread Au–Sb mineralizing event that extended from Notre Dame Bay to Bay d'Espoir (Evans, *in press*) and minor Au values have been reported from this area.

CONCLUSIONS

Geological and geochemical data provide additional constraints on a long-standing controversy concerning the relative extent of the Moretons Harbour Group and the Sleepy Cove Formation in eastern Notre Dame Bay. Volcanic rocks in the Moreton's Harbour–Twillingate area are readily separated into two distinct assemblages on the basis of field observations and geochemical signatures. The Sleepy Cove Formation in its type area on the Twillingate Islands comprises an assemblage of pillow lavas and related mafic volcanic rocks that exhibit island-arc-tholeiite geochemical signatures. Geologically similar rocks on Black and North Trump islands have identical geochemical signatures and in Tizzard's Harbour, geologically similar rocks have geochemical signatures characteristic of boninites. These rocks are herein interpreted to comprise the Sleepy Cove Formation, the minimum age of which is constrained to ca. 506 Ma by the age of the intruding Twillingate granite.

The Moretons Harbour Group is herein restricted to rocks west of Tizzard's Harbour. It comprises a basement of non-arc tholeiites of oceanic island affinity, intruded through and overlain by a sequence of LREE-enriched tholeiites having mixed arc to non-arc geochemical signatures, epiclastic turbidites and high level felsic and mafic intrusive rocks. The age of the Moretons Harbour Group is unconstrained.

The Sleepy Cove Formation has good potential for VMS deposits similar to those in the Lushs Bight Group. A potential for VMS mineralization is also suggested for the Moretons Harbour Group but is not as yet supported by solid comparisons with analogues elsewhere in central Newfoundland. Both sequences have a good potential for mesothermal gold deposits.

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