An Update on the Acid-generating Potential of Rocks in Southwestern Nova Scotia, with Emphasis on the Metropolitan Halifax Regional Municipality

C. E. White, L. L. Trudell[1] and R. Hamblin[2]

Introduction

The effects of acid rock drainage (ARD) continue to be a problem in parts of southwestern Nova Scotia, especially around areas where slate-rich units contain abundant sulphide-bearing minerals, such as the Cunard Formation of the Halifax Group. This situation is especially true in metropolitan Halifax Regional Municipality (HRM) where the rocks of Cunard Formation are continually being disturbed (e.g. construction sites, new subdivisions, transportation corridors, etc.). This ground disturbance is an on-going source of environmental contamination, mostly in the form of ARD with the transfer of large amounts of acidity and potential dissolved metals (Fe, Al, Mn, Cu, Zn, Cd, Pb, and As) into the surface and groundwater systems.

In addition to the degradation of water quality, ARD causes excessive premature corrosion of concrete and metal infrastructure. For instance, in May 2013, Nova Scotia Power confirmed that some of the steel anchors on the transmission towers are being "eaten by rust" related to pyritic slate, costing millions of dollars to repair (CBC News, 2013).

As a derivation of the Nova Scotia Meguma terrane mapping program (e.g. White *et al*., 2008; White, 2010a; White, 2012), the Nova Scotia Department of Natural Resources is attempting to identify geological units in southern Nova Scotia, particularly in HRM, that have potential acid-generating hazards and to produce a series of ARD risk maps (e.g. Trudell and White, 2013) that can be utilized by various government, environmental and other interest groups. This paper summarizes the results to date obtained from the ARD study in southwestern Nova Scotia, with emphasis on the metropolitan HRM area including details in the Bayers Lake-First Chain Lake area and the Bridgewater area.

Methodology and Analytical Techniques

Field Sampling

Detailed 1:10 000-scale bedrock mapping was done during several seasons from 1998 to 2013 in southwestern Nova Scotia (Fig. 1), and thousands of representative rock samples were collected from a variety of lithologies (White, 2010a, 2012; White and Barr, 2010). In metropolitan HRM alone (Fig. 2), 260 samples were collected and analyzed for ARD potential and other elements (White and Goodwin, 2011). As a follow-up study, a more detailed mapping and rock-sampling project (64 samples) was conducted in the Bayers Lake-First Chain Lake area (Figs. 2, 3a, and 3b) as part of a student (R. Hamblin) senior project through the Nova Scotia Community College. In this local study, rocks of the Cunard Formation and adjacent granitoid rocks of the South Mountain Batholith were targeted. In conjunction with these rock samples, the project involved water sampling to monitor the pH in Bayers Lake and First Chain Lake, as well as several smaller unnamed bodies of

[1]Geographic Information Systems, British Columbia Institute of Technology, 3700 Willingdon Ave., Burnaby, BC V5G 3H2
[2]Pinchin LeBlanc Environmental Limited, 42 Dorey Avenue, Dartmouth, Nova Scotia B3B 0B1

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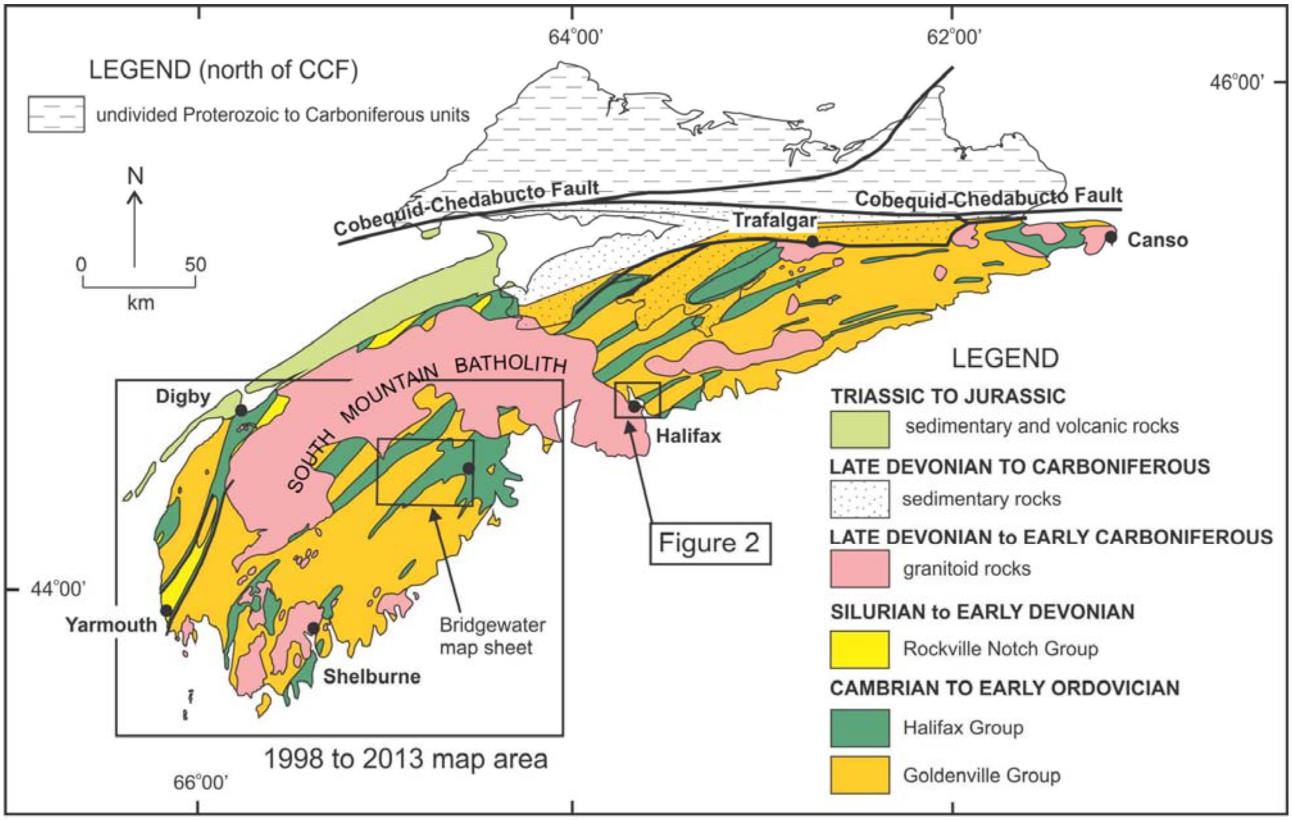

Figure 1. Simplified geology map of the Meguma terrane of southern Nova Scotia, showing the distribution of the Goldenville, Halifax and Rockville Notch groups, and other major units.

water. Samples from running water entering the lakes were also collected to monitor pH and compared to the standing water and local geology. Locations (UTM NAD 1983) of all rock and water samples were documented using a portable hand-held GPS.

Magnetic susceptibility data were collected on each sample using a handheld KT-9 Kappameter (Appendices A and B). The maximum sensitivity of the KT-9 is 1 ´ 10^{-5} SI units (see White and Goodwin, 2011, for details related to data collection protocols). In this study, all measurements were recorded in 1 ´ 10^{-3} SI units. These measurements were taken to investigate if there is a correlation between magnetic susceptibility and ARD.

Laboratory Analyses

Because sampling was done in February 2012, holes had to be opened in the ice surface to sample the water. Fifty water samples were collected using sterile plastic sampling containers. The samples were returned to the laboratory at Nova Scotia Community College (Waterfront Campus) and within 24 hours, and at room temperature, were analyzed using a hand-held pH meter. The pH meter was recalibrated every five samples.

All rock samples collected were analyzed for total sulphur and calcium, among other elements, using a portable X-5000 XRF machine manufactured by Innov-X. In Nova Scotia, however, the Sulphide Bearing Material Disposal Regulations (Province of Nova Scotia, 1995) require that all samples submitted for ARD analysis should use the static British Columbia Research Initial Test (BC-RIT). White and Goodwin (2011), using the same rock samples, conducted several experiments comparing data acquired from the BC-RIT method and those from Acme Analytical Laboratories (Vancouver) Ltd. and the portable XRF. All results are comparable and hence the portable XRF results can be used with a significant degree

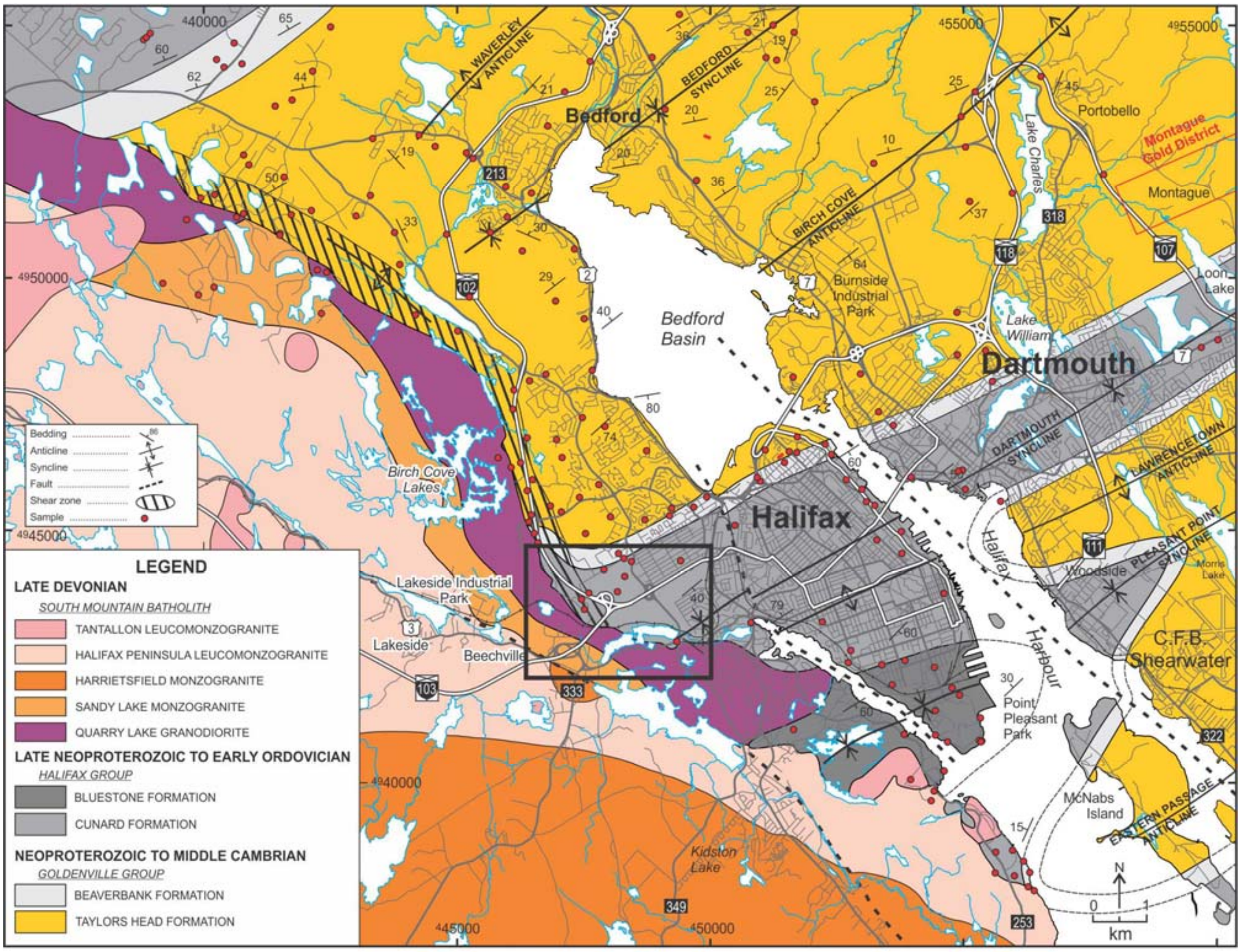

Figure 2. Simplified geology map of the metropolitan Halifax Regional Municipality (modified after White *et al.,* 2008 and White and Goodwin, 2011). Black box shows location of Figure 3. See White and Goodwin (2011) for UTM coordinates for sample locations.

of confidence in establishing a cost-effective way to provide an early warning of possible ARD problems (White and Goodwin, 2011).

Geological Framework

The recent 1:10 000-scale mapping undertaken in southwestern Nova Scotia (Fig. 1), including HRM (Fig. 2), by White *et al.* (2008) and White (2012) provided the perfect framework for an ARD study. Because of the new mapping and the complimentary study of thousands of samples, new rock units were recognized, which include the Cambrian to Ordovician Goldenville and Halifax groups, and Silurian to Early Devonian Rockville Notch Group (White 2012; White *et al.*, 2012). The oldest unit recognized, the Goldenville Group, is divided into several formations (Fig. 4). In the Digby to Yarmouth area they include the Church Point Formation, High Head member, and overlying Bloomfield Formation, whereas in the Yarmouth to Chester area they are the Moses Lake and Green Harbour formations, Lake Rossignol member, and the upper Moshers Island Formation. In the Halifax to Canso area the Goldenville Group consists of the Moose River, Tangier, Taylors Head and Beaverbank formations (Horne and Pelley, 2007; White *et al*., 2008; White, 2010a, b).

The lower formations and members in the Goldenville Group consist of mainly grey, thickly bedded and weakly cleaved metasandstone, interbedded with minor green to grey, cleaved metasiltstone, and rare black to rusty slate.

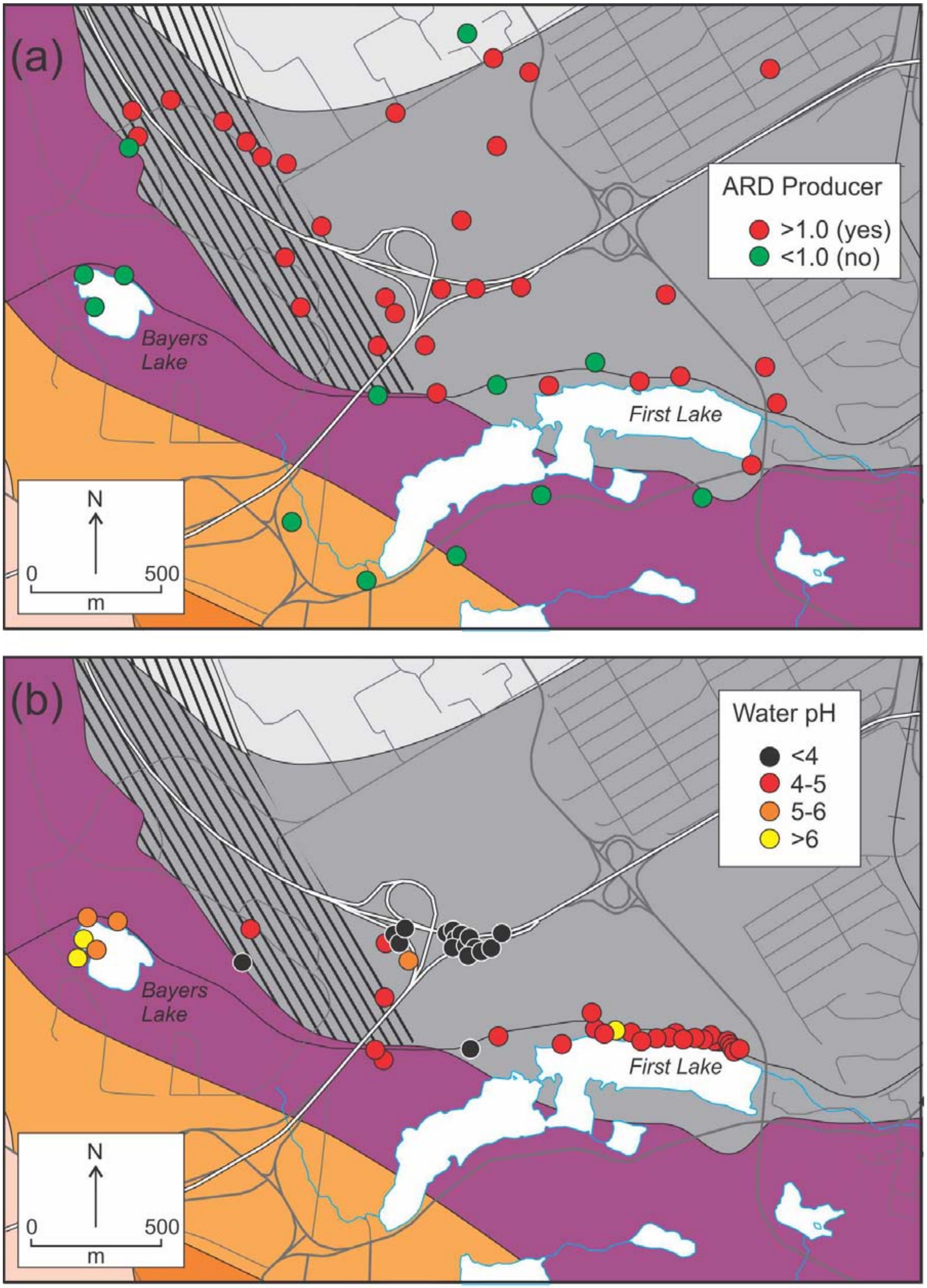

Figure 3. (a) Simplified geology map of the Bayers Lake-First Chain Lake area showing distribution of bedrock samples. UTM coordinates for sample locations are in Appendices A and B. (b) Simplified geology map of the Bayers Lake-First Chain Lake area showing distribution of water samples. UTM coordinates for sample locations are in Appendix C.

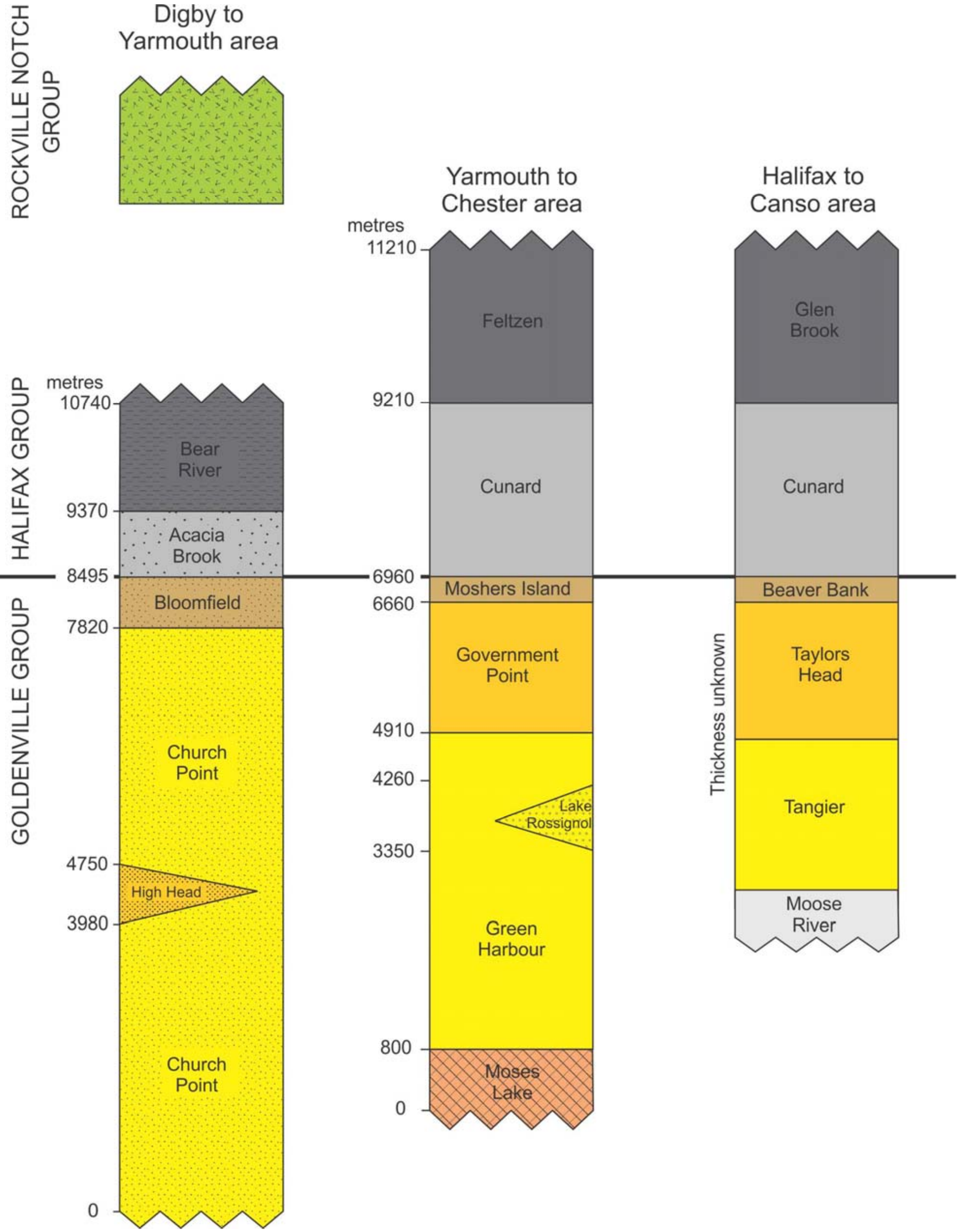

Figure 4. Schematic stratigraphic column displaying the various units in the Meguma terrane mentioned in the text. Summary of geological events in the Meguma terrane after White (2010b) and White *et al.* (2012).

Calc-silicate nodules and pyrite cubes are locally common. The upper units (Beaverbank, Moshers Island, and Bloomfield formations) are conformable and marked by a decrease in thickly bedded metasandstone over tens of metres. These units consist of grey to black, cleaved metasiltstone interbedded with minor thin, light grey metasandstone and black graphitic slate. Thin brown to black manganese-rich limestone beds and nodules are common in the Beaverbank and Moshers Island formations. Close to the contact with granite of the South Mountain Batholith these manganese-rich limestone beds and nodules become garnet (spessartine)-rich coticules.

The overlying Halifax Group in the Digby to Yarmouth area is divided into the lower Acacia Brook Formation and the overlying Bear River Formation, and in the Yarmouth to Chester area the group consists of the lower Cunard Formation and overlying Feltzen Formation. From Halifax to Canso the Halifax Group consists of the lower Cunard and overlying Bluestone and laterally equivalent Glen Brook formations (Fig. 4). The Acacia Brook and Cunard formations are characterized by black, commonly rusty on weathered surfaces, graphitic slate and metasiltstone interbedded with 10 to 30 cm thick, cross-laminated fine-grained metasandstone. This formation typically contains abundant pyrrhotite and pyrite, with lesser amounts of chalcopyrite, galena, sphalerite and arsenopyrite (e.g. Fox *et al*., 1997; Haysom *et al*., 1997; Betts-Robertson, 1998; Clarke *et al*., 2009; White and Goodwin, 2011). The overlying formations of the Halifax Group are lithologically similar but lack the abundant sulphide minerals. The Rockville Notch Group only occurs in the Digby to Yarmouth area and consists of mafic to felsic metavolcanic rocks and related clastic (green to black slate and metasiltstone) and carbonate metasedimentary rocks.

Except for a few areas northeast of HRM, the Goldenville and Halifax groups have not been mapped in detail in the northeastern part of the terrane; until the entire area is mapped and a representative suite of rock samples collected, an ARD study cannot be attempted.

The ca. 380–373 Ma peraluminous South Mountain Batholith (SMB) intruded the Goldenville, Halifax, and Rockville Notch groups (Fig. 1 and 2) and produced a narrow (up to 2 km wide), well developed contact metamorphic aureole that is superimposed on regional greenschist-facies mineral assemblages and textures (Jamieson *et al*., 2005a, b, 2011; White *et al*., 2008).

Results

Halifax Regional Municipality

Rocks having sulphide sulphur contents equal to or greater than 0.4 wt. % are considered as hazardous ARD material (Sulphide Bearing Material Disposal Regulations, 1995). However, the portable XRF results, like the results from Acme Analytical Laboratories, report only total wt. % sulphur, which for most units in the Goldenville and Halifax groups in HRM is about 17% higher than total sulphide sulphur recorded by the BC-RIT method (White and Goodwin, 2011). Hence, White and Goodwin (2011) suggested using a total sulphur content equal to or greater than 0.47 as the hazardous threshold. However, White and Goodwin (2011, Fig. 3) showed that samples from the Cunard Formation have sulphide sulphur versus total sulphur ratios of almost 1:1.

The potential for acid generation is dependent on the ratio of acid-producing potential (APP) to acid-consuming ability (ACA). The British Columbia Research Initial Test uses a 1:1 ratio (acid/base) and assumes that samples below this ratio are net acid consumers. However, Lawrence and Scheske (1997) noted that carbonate minerals react faster than feldspar minerals and hence the control on neutralization varies with mineralogy; therefore, they defined a zone of uncertainty between the 1:1 and 1:2 gradient lines, which was adopted by White and Goodwin (2011). Following the work of Downing and Madeisky (1997), White and Goodwin (2011) considered total S wt. % versus CaO wt. % can be considered broadly equivalent to APP/ACA. Hence, a plot of total S wt. % versus CaO wt. % for data collected from the portable XRF can be used to estimate acid generating potential of the rock (Fig. 5a, b).

A detailed ARD study was conducted in HRM by White and Goodwin (2011), and their results are briefly summarized in this section. Figure 5 shows

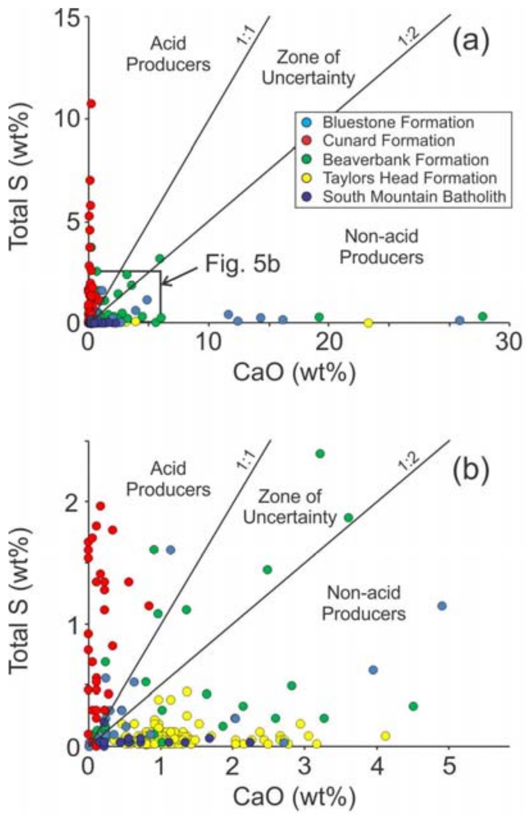

Figure 5. (a) Plot of total S against CaO using results from the portable XRF on samples from HRM (modified from White and Goodwin, 2011). (b) Close-up of data in box shown at origin in Fig. 5a.

a wide distribution of sample populations, which indicates that three units within HRM are potentially acid producers (Bluestone, Cunard and Beaverbank formations) and two units are non-acid producing (Taylors Head Formation and South Mountain Batholith). White and Goodwin (2011) showed that about 97% of the samples collected from the Cunard Formation are potential acid producers with a high median total sulphur content of 4.87 wt. %, with some of the highest levels up to 20.67 wt. %. In comparison, 26% of the samples in the stratigraphically higher Bluestone Formation and 24% of the samples from the underlying Beaverbank Formation are potential acid producers with average total sulphur of 0.44 wt. % and 0.74 wt. %, respectively. However, about half (50–55%) of the samples from these two formations lie in the zone of uncertainty and hence can be acid producers under the right conditions. About 99% of the samples from the Taylors Head Formation are non-acid producing (Fig. 5a, b) and have a low total sulphur content (median = 0.04 wt. %). About 95% of the granitoid samples from the South Mountain Batholith are non-acid producing (Fig. 5a, b) and have the lowest average total sulphur content (0.02 wt. %) of all the units sampled (White and Goodwin, 2011).

White and Goodwin (2011) showed that the most important acid neutralizing minerals in the Goldenville group are carbonate minerals, along with the abundant plagioclase grains and alteration products. In comparison, the granitoid rocks of the South Mountain Batholith have total sulphur less than 0.20 wt. % and pose no apparent ARD risk, likely due to negligible sulphide mineral content and high plagioclase content.

Bayers Lake and First Chain Lake

The results of the bedrock samples taken from the Bayers Lake and First Chain Lake area (Fig. 3a) showed that 84% of the samples from the Cunard Formation can be classified as acid producing (Fig. 3a, 6; Appendix A) with median total sulphur content of 0.99 wt. %. However, 8% of the samples are not acid producing due to low amounts of sulphide-bearing minerals and another 8% plotted in the “uncertain” field (Fig. 6). Although the number of samples are small from the South Mountain Batholith (Appendix A), 79% show no signs of being acid producing, which would be expected due to the elevated amount of calcium plagioclase found in granite bedrock (e.g. Fox *et al.*, 1997). However, 14% were acid producing and these samples are from late-stage sulphide-bearing aplitic dykes.

Water samples from along the northern shore of First Chain Lake (Fig. 3b) have pH ranges between 4 and 5 (Fig. 3b; Appendix C), which indicate the presence of ARD (U.S. Environmental Protection Agency, 1994). Water samples with pH less than 4 are strongly acidic and all are associated with nearby recent ground disturbance in the Cunard Formation where very sulphide-rich slate was exposed. In these low pH areas many of the ponds and streams were noted to have thin brown iron(?) coatings along the bottom. Water samples taken from Bayers Lake, located on coarse-grained granodiorite of the South Mountain Batholith, has a

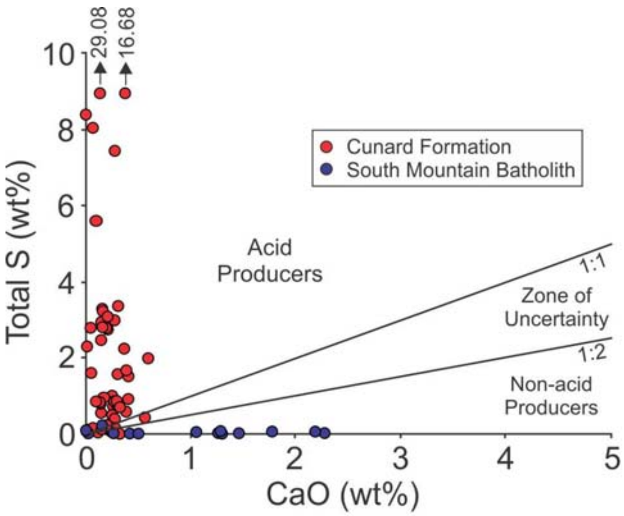

Figure 6. Plot of total S against CaO using results from the portable XRF on samples from the Bayer Lake-First Chain Lake area.

higher pH than the water samples related to the Cunard Formation. Here the pH levels range between 6 and 7, which are relatively neutral. Samples from streams with running water over the Cunard Formation also display neutral pH (Fig. 3b). Our observations and data show that pH in water can be directly related to the type of bedrock in the area. Higher pH levels are recorded in water that is sitting on or originates from granitoid rocks of the South Mountain Batholith and do not indicate the presence of ARD. The pH of water associated with the slate-rich rocks of the Cunard Formation indicates the presence of ARD and ranges between 4 and 5. The most acidic water conditions are associated with recent ground disturbances in slate-rich rocks of the Cunard Formation.

Bridgewater

Another ARD study (White *et al.*, 2012) was undertaken in rocks on the Bridgewater map area (Fig. 1) in 2012. Most of these data are preliminary and unpublished, but the major results will be presented here. Like the HRM dataset, the Bridgewater data show a wide distribution of sample populations, which indicate that the Cunard Formation is the most acidic (Fig. 7a, b). About 84% of the samples collected are potential acid producers with a high median total sulphur content of 0.43 wt. %, much lower than the levels from the Cunard Formation in HRM; however, the highest levels are similar, up to 26 wt. % . In comparison, 40% of the samples in the stratigraphically lower Moshers Island Formation are potential acid producers, with 23% in the zone of uncertainty, and hence can be acid producers under the right conditions. When compared to the equivalent Beaverbank Formation in HRM the Moshers Island Formation is significantly higher in its potential for acid production. About 52% of the samples from the underlying Government Point Formation are non-acid producing, whereas the remainder have a low acid-generating potential. Although these samples have low total sulphur levels, the noticeable lack of calcium as a neutralizing agent results in higher acid production values. Like the Taylors Head Formation in HRM, most samples (84%) from the Green Harbour Formation are non-acid producing (Fig. 7a, b) with a low total sulphur content (median = 0.09 wt. %).

Magnetic Susceptibility Measurements

A useful application of susceptibility measurements is to determine the presence of ferromagnetic and paramagnetic minerals (e.g. King, 1997; Howells and Fox, 1998; Fitzgerald and Goodwin, 2005), which may relate to ARD-producing minerals in outcrop. The study by White and Goodwin (2011) showed that there is no strong correlation between high magnetic-susceptibility measurements and the production of ARD, a result corroborated in the present study (Fig. 8). However, there is a slight positive correlation with Fe content in the rock with lower magnetic-susceptibility measurements in Fe-poor rocks (Appendices A and B).

Acid Rock Drainage Risk Maps

Based on bedrock mapping in southwestern Nova Scotia (White, 2012) combined with lithogeochemistry (White, 2010b; White and Barr, 2010; White and Goodwin, 2011; unpublished data) it has been shown that some bedrock formations contain abundant pyrite, pyrrhotite, and other sulphide minerals and have the potential to generate ARD. The main acid producers are sulphide-bearing slate, metasiltstone and

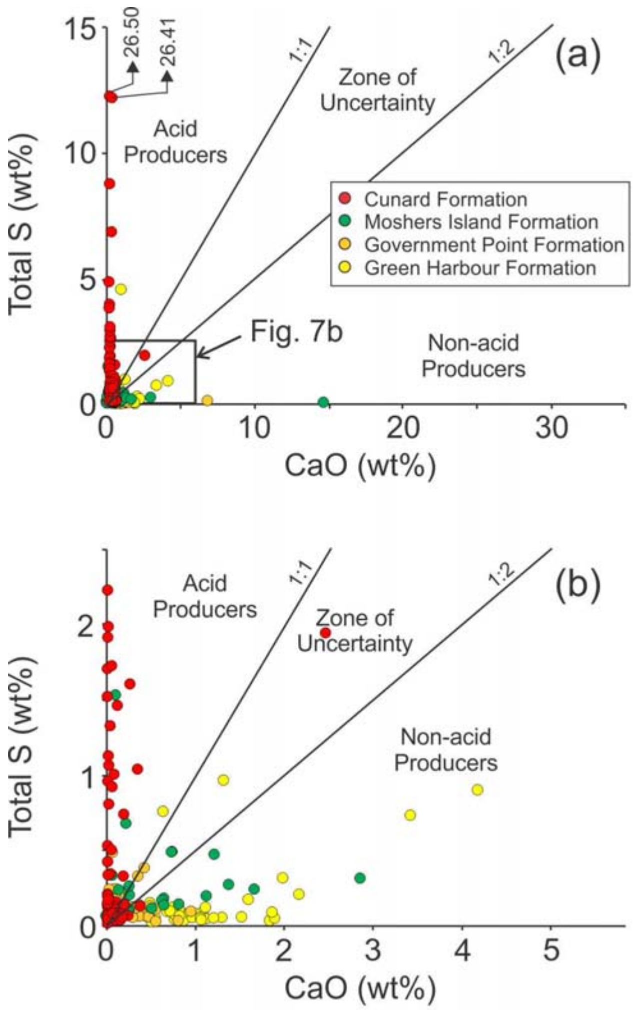

Figure 7. (a) Plot of total S against CaO using results from the portable XRF on samples from the Bridgewater map area. (b) Close-up of data in box shown at origin in Figure 7a.

metasandstone of the Beaverbank, Moshers Island, Bluestone, Bear River and Government Point formations. Although no data are presented in this paper, preliminary results indicate that most of the upper part of the Rockville Notch Group has acid generating potential. The units with the highest acid-producing potential in southwestern Nova Scotia are the Cunard Formation and the laterally equivalent Acacia Brook Formation.

Based on these observations, a series of 26, 1:50 000 scale maps (Open File Maps ME 2013-002 to 2013-027) showing the bedrock acid

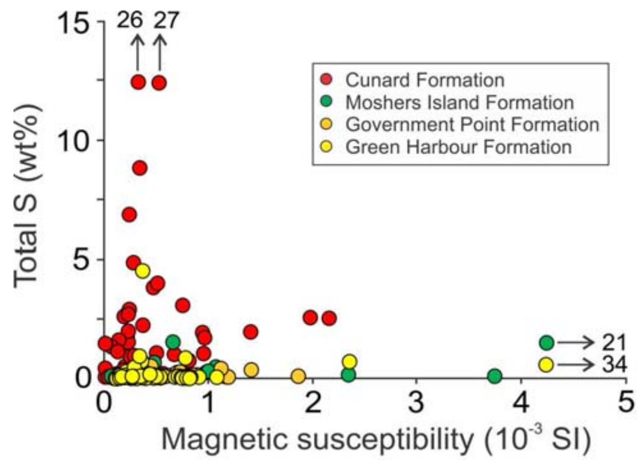

Figure 8. Plot of magnetic susceptibility against total S from unpublished whole-rock data from the Bridgewater map area.

rock drainage potential of southwestern Nova Scotia have been produced (Trudell and White, 2013) and can be accessed at http://novascotia.ca/natr/meb/download/mg/ofm/htm/ofm_2013-002.asp. Six additional 1:20 000 scale ARD-risk maps for metropolitan HRM are currently in production. On these maps, formations have been classified as high, moderate or low in terms of their ARD-producing potential. It is hoped that these maps can be used as an additional tool during the planning stages of development and construction to broadly determine if sulphide-bearing bedrock is present in order to mitigate negative environmental and human health effects caused by ARD, as well as to reduce costly remediation efforts.

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Appendix A. Whole-rock chemical analyses of samples from the Cunard Formation in the Bayers Lake - First Chain Lake area by the portable XRF.

sample	UTM nad 83*		lithology	Mag	major oxides (wt%)					total S (wt%)	trace elements (ppm)											ARD Problem
	Easting	Northing			CaO	K_2O	TiO_2	MnO	$Fe_2O_3^T$		As	Ba	Cu	Nb	Pb	Rb	Sr	V	Y	Zn	Zr	
BL12-R103	449071	4943180	dark spotted hornfels	0.96	0.38	2.72	0.63	0.08	6.19	0.60	4	530	23	14	5	131	96	67	12	109	184	YES
BL12-R103	449071	4943180	light spotted hornfels	1.02	0.41	3.00	0.63	0.07	6.01	0.92	4	664	17	15	9	151	123	77	12	99	225	YES
BL12-R103	449071	4943180	light spotted hornfels	1.57	0.32	2.99	0.63	0.06	6.21	1.57	4	602	25	16	9	137	100	72	10	91	297	YES
BL12-R104	448879	4943151	dark spotted hornfels	0.50	0.07	3.54	0.84	0.10	5.80	0.16	7	644	10	21	18	165	139	86	24	105	107	YES
BL12-R104	448879	4943151	light spotted hornfels	0.60	0.18	4.67	0.83	0.05	5.74	2.80	3	923	42	23	25	188	172	119	18	93	224	YES
BL12-R105	448666	4943224	dark spotted hornfels	0.23	0.32	2.41	0.80	0.06	4.09	0.01	4	352	6	19	0	95	153	85	20	65	85	NO
BL12-R105	448666	4943224	light spotted hornfels	0.28	0.24	2.03	0.76	0.08	4.66	0.07	2	329	4	19	0	87	135	75	18	70	81	NO
BL12-R106	448552	4943126	dark spotted hornfels	0.55	0.03	2.37	0.73	0.10	5.31	0.12	0	299	7	15	0	123	49	56	14	82	85	YES
BL12-R106	448552	4943126	light spotted hornfels	0.86	0.10	5.20	0.52	0.06	10.84	5.60	0	821	39	15	31	201	190	87	7	108	102	YES
BL12-R107	448295	4943150	spotted hornfels	0.26	0.12	2.62	1.09	0.11	3.85	0.06	3	357	7	26	0	100	59	91	22	66	104	NO
BL12-R108	448074	4943102	spotted hornfels	0.81	0.11	0.92	0.80	0.30	12.46	0.86	3	282	29	20	0	43	19	53	31	133	175	YES
BL12-R109	447846	4943107	spotted hornfels	0.24	0.24	7.28	0.99	0.12	4.29	0.10	2	1454	8	22	29	254	187	155	35	63	119	NO
BL12-R110	447850	4943311	light andalusite hornfels	0.26	0.16	4.50	0.98	0.11	8.20	3.28	10	909	56	20	5	165	215	111	41	81	654	YES
BL12-R110	447850	4943311	dark andalusite hornfels	0.38	0.28	5.08	0.91	0.14	6.32	0.40	8	974	18	23	18	171	250	133	32	80	130	YES
BL12-R111	447940	4943505	dark andalusite hornfels	0.28	0.18	3.07	0.91	0.06	4.03	0.96	2	764	17	19	18	133	203	92	15	90	105	YES
BL12-R111	447940	4943505	light andalusite hornfels	0.33	0.15	4.70	0.91	0.07	5.16	0.82	3	784	19	16	18	181	154	107	13	101	112	YES
BL12-R112	447949	4943460	light spotted hornfels	0.58	0.17	3.48	0.69	0.05	7.07	3.23	6	571	29	15	0	142	67	79	9	89	165	YES
BL12-R112	447949	4943460	dark spotted hornfels Fe-spot	0.71	0.07	2.49	0.57	0.08	9.95	8.05	9	534	50	15	0	127	51	60	8	124	109	YES
BL12-R112	447949	4943460	dark spotted hornfels	0.72	0.28	3.17	0.61	0.09	6.49	0.87	5	527	19	12	0	128	88	81	7	116	95	YES
BL12-R112	447949	4943460	ht hornfels with sulphide miner	0.83	0.16	2.99	0.57	0.05	30.16	16.68	6	760	203	21	52	169	155	65	5	218	229	YES
BL12-R113	448097	4943500	light spotted hornfels	0.68	0.57	3.26	0.93	0.09	5.28	0.44	1	614	14	20	15	130	182	107	19	108	142	MAYBE
BL12-R113	448097	4943500	dark spotted hornfels	0.69	0.60	3.23	0.87	0.05	5.28	2.00	2	578	21	20	11	125	196	109	20	80	106	YES
BL12-R114	448098	4943515	dark spotted hornfels	1.65	0.28	5.32	0.83	0.05	5.28	0.75	3	626	17	18	8	224	87	111	15	113	118	YES
BL12-R114	448098	4943515	light spotted hornfels	1.87	0.14	6.06	0.87	0.03	4.54	0.84	7	1012	37	18	5	217	93	144	10	84	157	YES
BL12-R115	448437	4943577	dark spotted hornfels	5.21	0.26	5.07	0.86	0.04	4.17	1.02	3	786	18	18	13	197	159	123	27	74	153	YES
BL12-R116A	446842	4944102	andalusite hornfels	0.29	0.24	4.52	1.07	0.03	5.23	3.00	11	1020	36	23	18	174	163	156	36	79	119	YES
BL12-R116A	446842	4944102	ndalusite and cordierite hornfel	0.32	0.31	4.51	0.96	0.04	5.68	3.36	12	1104	42	20	12	186	165	171	21	74	122	YES
BL12-R116B	446839	4944086	dark cordierite hornfels	0.47	0.31	2.65	0.84	0.03	6.61	29.08	31	474	37	9	5	106	84	47	13	103	126	YES
BL12-R116B	446839	4944086	pale cordierite hornfels	0.47	0.30	3.72	0.57	0.02	4.07	0.77	4	806	20	13	26	112	173	84	12	59	95	YES
BL12-R117A	449034	4943522	andalusite hornfels	0.22	0.16	4.36	0.92	0.05	3.06	0.12	14	831	6	20	32	171	189	117	14	72	118	MAYBE
BL12-R117B	449034	4943522	andalusite hornfels	0.25	0.29	3.40	0.99	0.08	3.96	0.16	3	632	9	20	19	123	223	126	15	95	108	MAYBE
BL12-R117B	449034	4943522	fine-grained metasandstone	0.33	0.18	2.98	0.59	0.08	5.85	2.82	7	682	119	17	8	129	100	70	7	117	170	YES
BL12-R117B	449034	4943522	cordierite hornfels	0.47	0.21	3.38	0.88	0.10	10.93	3.09	1	874	63	17	11	123	72	118	10	165	147	YES
BL12-R123	447954	4943304	andalusite hornfels	1.02	0.22	3.97	1.09	0.04	3.73	0.21	16	808	4	22	7	151	159	172	25	129	118	MAYBE
BL12-R123	447954	4943304	cord hornfels	3.23	0.05	4.93	0.65	0.06	12.30	2.80	7	516	96	15	0	216	80	127	8	253	56	YES
BL12-R124	449408	4943112	andalusite hornfels	0.37	0.26	5.68	0.96	0.05	3.48	0.51	10	638	9	21	76	194	283	100	14	65	107	YES
BL12-R124	449408	4943112	cord hornfels	1.87	0.00	4.05	0.69	0.04	12.12	8.39	8	1099	27	16	15	194	92	109	5	116	228	YES
BL12-R125A	449356	4943213	andalusite-cordierite hornfels	0.20	0.39	2.16	0.73	0.03	1.87	1.66	4	355	16	10	15	86	156	88	39	59	70	YES
BL12-R125B	449356	4943213	cord hornfels	1.11	0.15	6.07	0.83	0.07	9.30	2.94	5	1240	38	15	0	243	101	126	15	132	134	YES
BL12-R126A	447453	4944030	andalusite hornfels	0.65	0.21	4.38	1.03	0.05	3.12	0.25	7	1144	15	30	14	286	294	144	27	99	124	YES
BL12-R126B	447453	4944030	fine-grained metasandstone	0.25	0.30	1.12	0.57	0.09	6.36	0.87	1	412	21	8	0	58	81	58	22	134	103	YES
BL12-R126B	447453	4944030	cordierite hornfels	0.25	0.37	3.17	0.50	0.03	4.95	2.25	6	621	20	9	23	123	157	65	6	72	109	YES
BL12-R127A	446835	4944250	cordierite hornfels	8.98	0.01	2.78	1.34	0.05	5.92	2.31	15	455	21	23	0	98	42	64	11	35	991	YES
BL12-R128A	447008	4944265	andalusite hornfels	1.05	0.06	4.14	1.13	0.04	3.95	1.61	12	507	46	16	0	159	91	125	16	27	155	YES
BL12-R128B	447008	4944265	metasiltstone	0.12	0.33	2.88	0.59	0.05	3.27	0.71	6	667	21	10	0	113	116	66	9	70	192	YES
BL12-R128B	447008	4944265	cordierite hornfels	0.14	0.41	3.40	0.94	0.05	4.10	1.53	5	780	15	12	0	138	94	112	107	80	148	YES
BL12-R129	447119	4944239	andalusite hornfels	0.13	0.15	3.99	0.84	0.08	4.22	2.48	10	712	47	12	0	168	132	157	17	112	103	YES
BL12-R130	447190	4944190	andalusite hornfels	0.98	0.16	4.77	0.93	0.07	4.26	0.56	8	1034	12	11	1	170	181	152	40	96	113	YES
BL12-R130	447190	4944190	andalusite hornfels	1.31	0.28	2.39	0.56	0.04	11.34	7.46	15	732	63	15	57	158	266	109	18	79	172	YES
BL12-R131	447302	4944103	andalusite hornfels	1.13	0.46	3.71	0.75	0.04	3.45	2.82	1	881	21	13	35	139	187	106	13	43	98	YES

Notes: * Zone 20.

Appendix B. Whole-rock chemical analyses of samples from the South Mountain Batholith in the Bayers Lake - First Chain Lake area by the portable XRF.

sample	UTM nad 83*		lithology	Mag	major oxides (wt%)					total S	trace elements (ppm)											ARD Problem
	Easting	Northing			CaO	K_2O	TiO_2	MnO	$Fe_2O_3^T$	(wt%)	As	Ba	Cu	Nb	Pb	Rb	Sr	V	Y	Zn	Zr	
BL12-R100	446654	4943601	c.g., bt. monzogranite	0.17	1.26	3.90	0.30	0.04	1.54	0.01	1	633	4	6	17	144	239	60	17	25	101	NO
BL12-R101	446783	4943579	aplite	0.01	0.02	7.46	0.03	0.00	0.17	0.01	3	93	1	2	26	269	13	6	4	0	1	MAYBE
BL12-R101	446783	4943579	f.g., bt. monzogranite	0.06	0.50	3.75	0.01	0.03	0.40	0.01	2	79	2	0	15	142	16	4	7	2	14	NO
BL12-R101	446783	4943579	c.g., bt. monzogranite	0.15	0.27	6.61	0.04	0.03	0.52	0.01	4	56	1	5	22	232	17	5	9	3	ND	NO
BL12-R102	446689	4943466	c.g., bt. monzogranite	0.20	1.28	2.04	0.25	0.03	1.33	0.01	2	498	2	6	8	60	102	28	21	13	96	NO
BL12-R116B	446839	4944086	aplite sill	0.20	0.17	2.50	0.08	0.01	0.98	0.26	1	627	14	2	24	71	146	38	9	7	11	YES
BL12-R116C	446830	4944065	m.g., bt. monzogranite	0.14	1.46	3.71	0.10	0.02	0.65	0.02	1	432	2	3	23	125	159	28	16	9	62	NO
BL12-R118	449139	4942701	m.g., bt. monzogranite	0.18	2.26	3.89	0.70	0.07	3.71	0.03	7	516	6	11	13	114	221	69	24	34	115	NO
BL12-R119	448476	4942689	m.g., bt. monzogranite	0.20	1.05	4.51	0.50	0.04	2.44	0.05	1	1046	9	8	13	116	127	90	17	31	84	NO
BL12-R120	448136	4942533	m.g., bt. monzogranite	0.17	1.78	5.56	0.73	0.07	3.76	0.07	6	758	9	12	17	165	223	88	16	36	139	NO
BL12-R121	447798	4942444	porphyritic bt-monzo	0.08	0.43	5.27	0.27	0.04	1.98	0.02	3	147	3	8	16	200	49	21	26	28	67	NO
BL12-R122	447451	4942601	m.g., bt. monzogranite	0.20	1.26	4.26	0.28	0.03	1.27	0.02	3	710	2	4	21	111	147	62	18	10	53	NO
BL12-R127A	446835	4944250	f.g. mu-bt. granite	0.15	0.01	0.31	0.01	0.00	0.35	0.05	2	15	3	0	0	12	14	2	0	0	51	YES
BL12-R127B	446835	4944250	m.g., bt. monzogranite	0.23	2.20	3.54	0.54	0.04	2.74	0.07	8	599	7	7	13	117	190	59	25	41	149	NO

Notes: Abbrevations: c.g. = coarse-grained; m.g. = medium-grained; f.g. = fine-grained; mu = muscovite; bt = biotite; * Zone 20.

Appendix C. Water pH data from the Bayers Lake - First Chain Lake area.

water sample	UTM nad 83*		water pH	water information	geological information
	Easting	Northing			
BL12-001	446633	4943441	6.43	Bayers Lake (standing water)	c.g. biotite monzogranite with minor aplite and pegmatite dykes (SMB)
BL12-002	446644	4943491	6.35	Bayers Lake (standing water)	c.g. biotite monzogranite with minor aplite and pegmatite dykes (SMB)
BL12-003	446654	4943601	5.75	Bayers Lake (standing water)	c.g. biotite monzogranite with minor aplite and pegmatite dykes (SMB)
BL12-004	446783	4943579	5.69	Bayers Lake (standing water)	c.g. biotite monzogranite with minor aplite and pegmatite dykes (SMB)
BL12-005	446689	4943466	5.80	Bayers Lake (standing water)	c.g. biotite monzogranite with minor aplite and pegmatite dykes (SMB)
BL12-006	449008	4943142	4.71	First Chain Lake (standing water)	contact between (CF) hornfels (north) and (SMB) c.g. monzogranite (south)
BL12-007	448892	4943123	4.69	First Chain Lake (standing water)	contact between (CF) hornfels (north) and (SMB) c.g. monzogranite (south)
BL12-008	448733	4943153	4.56	First Chain Lake (standing water)	contact between (CF) hornfels (north) and (SMB) c.g. monzogranite (south)
BL12-009	448695	4943168	4.29	First Chain Lake (standing water)	contact between (CF) hornfels (north) and (SMB) c.g. monzogranite (south)
BL12-010	448680	4943224	4.29	First Chain Lake (standing water)	contact between (CF) hornfels (north) and (SMB) c.g. monzogranite (south)
BL12-011	448561	4943104	4.67	First Chain Lake (standing water)	contact between (CF) hornfels (north) and (SMB) c.g. monzogranite (south)
BL12-012	448261	4943150	4.00	small flowing stream	sits on rusty hornfels (CF)
BL12-013	448154	4943105	3.81	flowing stream	sits on rusty hornfels (CF)
BL12-014	447852	4943068	4.41	pooled water body from run off	sits on rusty hornfels (CF)
BL12-015	447819	4943104	4.76	pooled water body from run off	sits on rusty hornfels (CF)
BL12-016	447323	4943555	4.61	pooled water body from run off	contact between (CF) hornfels (east) and (SMB) c.g. monzogranite (west)
BL12-017	447293	4943431	3.85	pooled water body from run off	sits on coarse grained biotite monzogranite (SMB)
BL12-018	447850	4943311	4.30	pooled water body from run off	sits on rusty hornfels (CF)
BL12-019	447949	4943460	5.80	pooled water on bedrock	sits on rusty hornfels (CF)
BL12-020	447883	4943522	4.40	standing water in small pond	sits on rusty hornfels (CF)
BL12-021	447888	4943528	3.80	standing water in small pond	sits on rusty hornfels (CF)
BL12-022	447901	4943530	3.99	standing water in small pond	sits on rusty hornfels (CF)
BL12-023	447919	4943546	3.81	standing water in small pond	sits on rusty hornfels (CF)
BL12-024	448143	4943515	3.99	standing water in small pond	sits on rusty hornfels (CF)
BL12-025	448133	4943510	3.67	standing water in small pond	sits on rusty hornfels (CF)
BL12-026	448113	4943526	3.69	standing water in small pond	sits on rusty hornfels (CF)
BL12-027	448092	4943534	3.76	standing water in small pond	sits on rusty hornfels (CF)
BL12-028	448072	494517	3.79	standing water in small pond	sits on rusty hornfels (CF)
BL12-029	448097	4943500	3.96	standing water in small pond	sits on rusty hornfels (CF)
BL12-030	448089	4943480	3.78	standing water in small pond	sits on rusty hornfels (CF)
BL12-031	448234	4943471	3.85	standing water in swamp	sits on rusty hornfels (CF)
BL12-032	448198	4943464	3.62	standing water in swamp	sits on rusty hornfels (CF)
BL12-033	448166	4943482	3.47	standing water in swamp	sits on rusty hornfels (CF)
BL12-034	448155	4943457	3.60	standing water in swamp	sits on rusty hornfels (CF)
BL12-035	448280	4943524	3.56	standing water in ditch	sits on rusty hornfels (CF)
BL12-036	448779	4943159	7.48	fast running water	sits on rusty hornfels (CF)
BL12-037	448837	4943148	4.72	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-038	448938	4943137	4.63	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-039	449022	4943152	4.64	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-040	449056	4943140	4.68	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-041	449100	4943133	4.65	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-042	449135	4943132	4.64	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-043	449165	4943145	4.29	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-044	449181	4943129	4.54	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-045	449203	4943126	4.58	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-046	449224	4943122	4.59	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-047	449239	4943119	4.63	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-048	449242	4943114	4.61	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-049	449246	4943107	4.78	First Chain Lake (standing water)	next to rusty hornfels (CF)
BL12-050	449251	4943104	4.83	First Chain Lake (standing water)	next to rusty hornfels (CF)

Notes: Abbrevations: c.g. = coarse-grained; CF = Cunard Formation; SMB = South Mountain Batholith; * Zone 20.