Acid Rock Drainage in the Chain Lakes Watershed, Halifax Regional Municipality, Nova Scotia

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Introduction

Acid rock drainage (ARD), because of its potential to cause both environmental and economic problems, is an ongoing issue in the Halifax Regional Municipality (HRM). In HRM the effects of ARD are directly linked to the production of acidic waters from the weathering of sulphide-bearing rocks in the Cunard Formation of the Halifax Group (e.g. Fox, 1990; Fox *et al.*, 1997; White and Goodwin, 2011; Trudell and White, 2013a, b). As a result, the Nova Scotia Department of Natural Resources (NSDNR) in conjunction with the Environmental Engineering Technology-Water Resources Program at the Nova Scotia Community College has been studying ARD risks in HRM through the use of senior student research projects. This paper is the third in a series of these projects (e.g. White *et al*., 2014a; Farmer and White, 2015) and focuses on the Chain Lakes watershed in HRM (Figs. 1, 2).

Recent commercial development in the Chain Lakes watershed area has exposed new sulphide-bearing bedrock, which is contributing to low pH of local surface water bodies (White *et al*., 2014a). In addition, Halifax Water in 2014 installed a gravity-system wastewater pipeline along the Chain of Lakes Trail that involved blasting and excavating of local bedrock (Halifax Water, 2015). The Chain Lakes watershed is used as an emergency back-up water supply by Halifax Water for the Pockwock Lake region (Halifax Regional Municipality, 2015). The effects of acid rock drainage have the potential to cause a more costly and difficult treatment process in order to make the water potable.

Effects of Acid Rock Drainage

Acid rock drainage has the potential to cause a variety of negative effects both environmentally and economically. Secondary effects also occur as a result of the decreasing pH that can cause more issues than the acidity itself (Fraser Institute, 2012). Minerals that were once precipitated out of solution will dissolve back into the water when pH is decreased. Low pH also results in the leaching of metals from surrounding rocks (White and Goodwin, 2011). These metals include zinc, arsenic, copper, lead, iron, manganese, cadmium and aluminium (White *et al*., 2014a). In high enough concentrations, some of these metals are especially hazardous to human and aquatic life.

Increasing acidity in surface water leads to uninhabitable conditions for some fish. If the pH decreases below 5, salmon will not be present (Watt *et al*., 1983). Adult brook trout are able to tolerate lower pH levels in water, but the hatchability and survival of eggs and fry dramatically decreases below pH of 5.2 (Ingersoll *et al*., 1989). Fish gills may become clogged with dissolved heavy metals from ARD leading to death by asphyxiation (Trudell and White, 2013a). A lower pH also results in iron oxide precipitation that can cover the natural sediment of stream and lake beds. This metal deposition remains for years and causes difficulties for plant and animal inhabitation (Trudell and White, 2013a, b).

The higher acidity of the water also results in a corrosive effect that can damage pipes, bridges, concrete and other infrastructure (White and Goodwin, 2011). Cadmium oxidization is significant when the pH drops below 6, and Pb has

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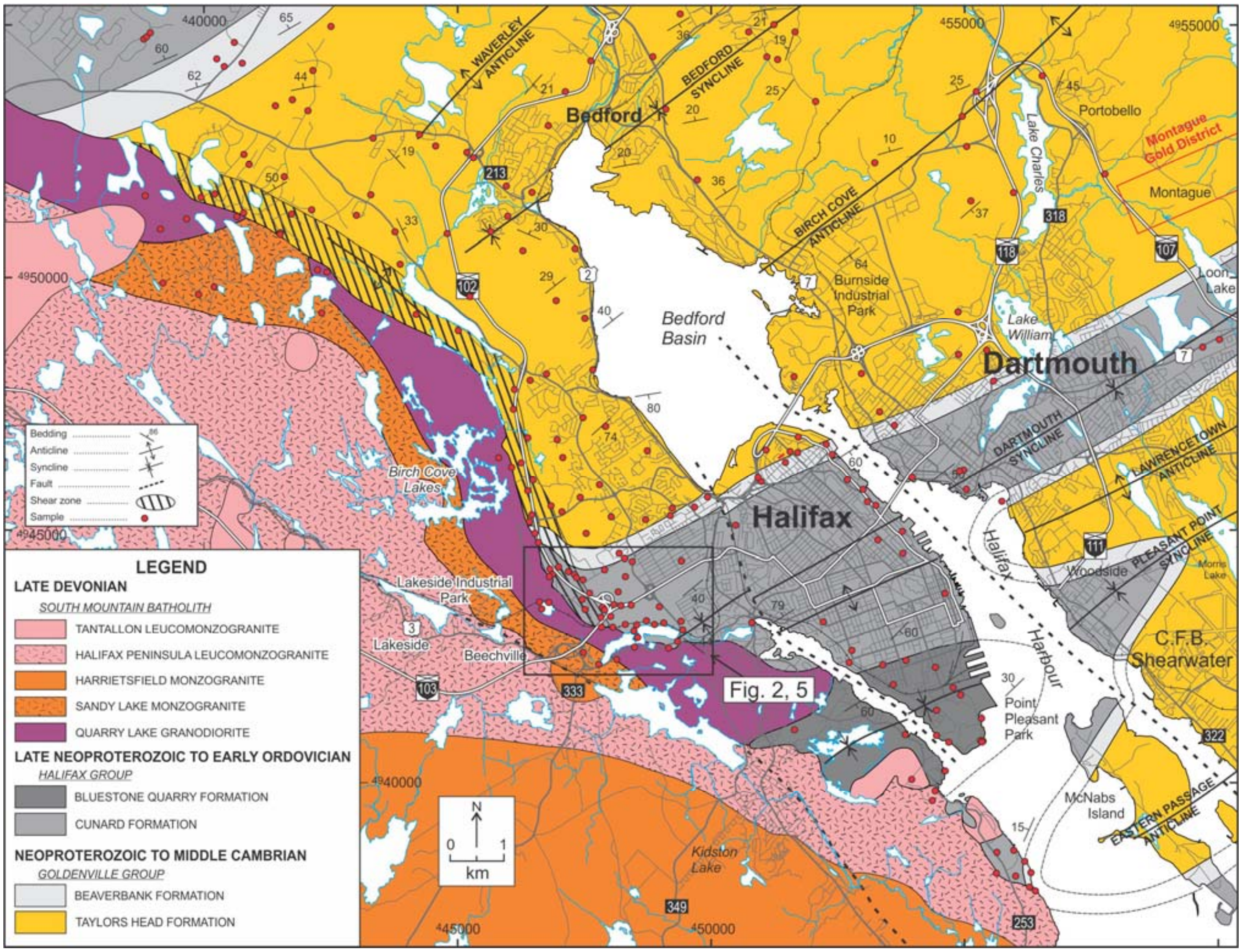

Figure 1. Simplified geology map of HRM (modified after White *et al*., 2014b) showing distribution of bedrock samples from White and Goodwin (2011), White *et al*. (2014a), Farmer and White (2015) and this study. Black box shows location of Chain Lakes area (Figs. 2, 5).

also been shown to occur in higher concentrations in low pH drinking water due to corrosion of lead plumbing (Health Canada, 2009). To avoid corrosion, water pH should be kept between 6.8 and 7.3 (Health Canada, 2009).

Drinking-water quality is also influenced by decreasing pH. Acidity causes a bitter taste and other aesthetic effects on drinking water (Trudell and White, 2013a). The high iron-content that results from sulphur oxidation can cause reddish staining of clothes, bathroom fixtures and any other water-carrying infrastructure (Trudell and White, 2013a, b). Low pH can also affect the disinfection ability of chlorine during water treatment (Health Canada, 2009). Such issues would need to be resolved before low pH water could be made potable.

Remediation of ARD-affected water is a costly and lengthy process. Paving or burying sulphide-bearing bedrock and liming acidic water are potential remediation techniques (Fraser Institute, 2012), but the most effective measure to prevent ARD from occurring is to determine potential sulphide-bearing material and avoid exposure (Trudell and White, 2013b). In order to determine where ARD may occur, extensive mapping has been done to determine areas of sulphide-bearing bedrock. Mapping of southwestern Nova Scotia in recent years by the Nova Scotia Department of Natural Resources (e.g. White 2012; Trudell and White, 2013b; White et al., 2014b) has assisted with planning for new developments in order to avoid future ARD problems (Trudell and White, 2013a, b).

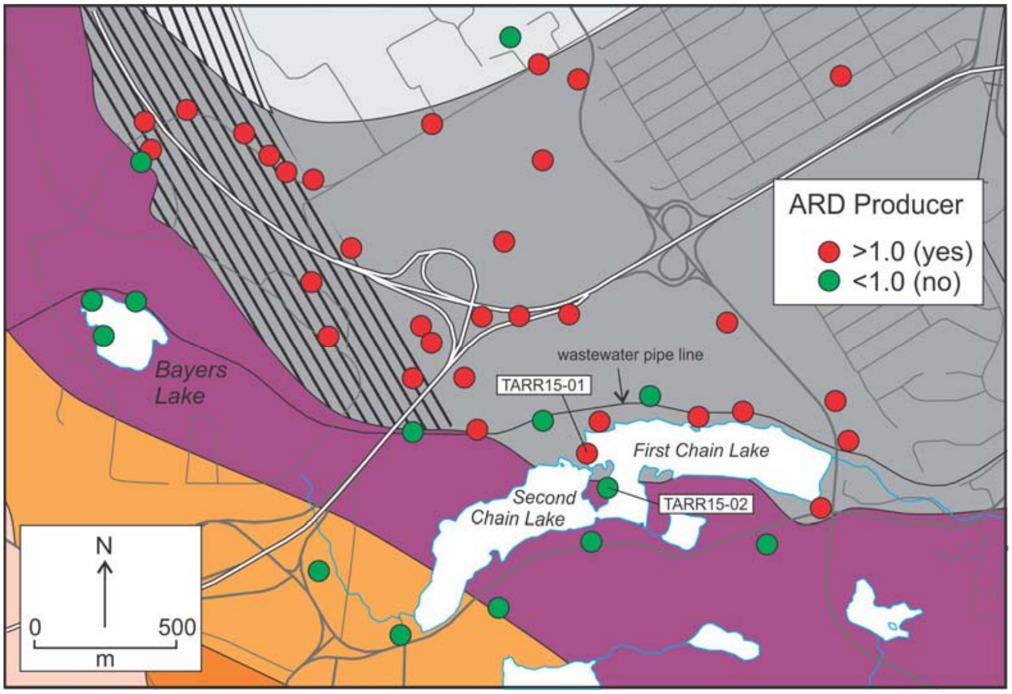

Figure 2. Simplified geology map of the Chain Lakes area showing the detailed distribution of bedrock samples from this study (TARR15-01 and 02) and previous studies (White and Goodwin, 2011; White *et al.*, 2014a). UTM co-ordinates for sample locations are in Tables 1 and 2. Legend is the same as in Figure 1.

According to the 1994-1995 *Sulphide Bearing Material Disposal Regulations* of the Nova Scotia *Environment Act*, material containing 0.4% sulphur by weight or greater is considered acid producing. However, this regulation does not consider the potential for acid neutralization. Not all sulphide-bearing bedrock will be acid producing. Acid generation can be neutralized by sufficient levels of a carbonate such as calcite in the environment or the rock itself. The acid-bearing potential is therefore an expression of the ratio between sulphide (wt%) and calcium oxide (wt%) present in the rock. A ratio greater that 1:1 indicates acid production is likely in the rock. An area of uncertainty exists between 1:1 and 1:2 where the rock may or may not have the potential to generate acid (White and Goodwin, 2011; Farmer and White, 2015).

Local Geology

The bedrock geology in the Chain Lakes watershed consists of the slate-dominated Halifax Group and the granitic South Mountain Batholith (White *et al.*, 2008; White *et al.*, 2014a, b). First Chain Lake lies entirely within the Cunard Formation of the Halifax Group, whereas Second Chain Lake is mainly within the Quarry Lake Granodiorite and to a lesser extent the Sandy Lake Monzogranite of the South Mountain Batholith (Figs. 1, 2).

The Cunard Formation consists of black to rusty brown slate and metasiltstone interbedded with pale grey, cross-laminated, fine-grained metasandstone. All these rock types contain abundant pyrite and pyrrhotite plus trace amounts of arsenopyrite. Elsewhere in the Cunard Formation chalcopyrite, galena and sphalerite occur in trace amounts (White *et al.*, 2008; White and Goodwin, 2011). The Quarry Lake Granodiorite and Sandy Lake Monzogranite are typically grey, medium- to locally coarse-grained and have large alkali feldspar and plagioclase phenocrysts (White and Goodwin, 2011; White *et al.*, 2014b). In the Chain Lakes watershed area, the Quarry Lake Granodiorite intruded into the Cunard Formation resulting in a broad contact metamorphic aureole containing abundant randomly oriented andalusite crystals set in a very hard hornfelsic matrix (White *et al.*, 2008; Jamieson *et al.*, 2012). In places the granodiorite contains abundant hornfelsic metasedimentary xenoliths, some of which are sulphide-rich (Clark *et al.*, 2009).

Methods

Field mapping and sampling was conducted on March 16, 2015, although harsh winter conditions resulted in a thick layer of snow and ice over the area (Fig. 3a). The thick snow-cover resulted in little exposed bedrock available for sampling; hence, only two bedrock samples were collected: medium-grained biotite granodiorite from the Quarry Lake Granodiorite of the South Mountain Batholith and an andalusite-bearing hornfels from the Cunard Formation. To augment the data set, rock samples collected from an earlier study in the area (e.g. White *et al*., 2014a) were re-analyzed and included in this study.

The archived and newly collected samples were slabbed at NSDNR and then analyzed on a portable X-5000 x-ray fluorescence (pXRF) machine manufactured by Innov-X. Several spots (3-5) were analyzed on each slab for 90 seconds and the average elemental composition compiled. In the previous study the archived samples were analyzed for 3 minutes. The samples from the earlier study (i.e. White *et al*., 2014a) were re-analyzed to ensure reproducibility of results over time.

Water samples were collected in the field with small (250 ml) sterile plastic bottles. After removing 20-40 cm of snow, a hatchet was used to cut through 15-30 cm of ice to reach open water (Fig. 3b). Sample bottles were filled with water from the open hole. Care was taken to ensure snow and ice stayed out of the water collected in the sample bottles to avoid diluting or contaminating the water. The samples were brought inside and raised to room temperature before testing with a handheld Hach HQ11D portable pH meter (courtesy of Nova Scotia Community College). Before use, the meter was calibrated using three standard solutions and then re-calibrated after the five samples were measured. Sampling occurred within 24 hours to minimize potential environmental changes to pH.

Results and Discussion

Upon inspection of the rock samples collected from Cunard Formation in the previous study in 2012 (i.e. White *et al*., 2014a), it was noted that many of the sulphide minerals in the cut slabs have tarnished and some produced a fine white powder. In nature, this secondary substance typically forms through the weathering of pyrrhotite and other sulphide minerals in the slate. Without XRD analyses it is impossible to ascertain what mineral it is, but it is speculated that it might be either an iron sulphate phase such as rozenite ($FeSO_4 \cdot 4H_2O$), an aluminum hydroxy-sulphate such as basaluminite ($Al_4(SO_4)(OH)_{10} \cdot 5H_2O$), or perhaps something as simple as gypsum (Fox, 1990; Jambor *et al*., 2000). It is surprising that these changes occurred within a few years in a controlled indoor and dry environment. However, in spite of this 'weathering' the results from the re-analyzed samples are very similar to the previous analyses (i.e. White *et al*., 2014a) and confirm that the Cunard Formation contains significant total sulphur concentrations up to 31.20 wt% with a median content of 2.13 wt% (Table 1).

Figure 3. (a) Photograph showing the extreme winter conditions and snow depth during sampling on Second Chain Lake. (b) Photograph of ice hole and water sampled for pH measurements.

Due to the low CaO content (0.01 to 0.65 wt%) in samples from the Cunard Formation, only 3 of the 30 samples can be classified as non-acid producing and one sample may or may not produce acid (Table 1; Figs. 2 and 4). Granitic samples from the South Mountain Batholith have very low total sulphur values (0.01 to 0.07 wt%) and higher CaO values (0.02 to 2.64 wt%) when compared with the Cunard Formation and are generally classified as non-acid producing (Table 2; Figs. 2 and 4). However, one sample is from a narrow, pyrite-bearing granitic dyke that is classified as acid producing due to its low CaO content (0.02 wt%).

Water samples from First Chain and Second Chain lakes show little difference in pH with readings ranging from 4.15 to 5.26 and a median reading of 4.66 (Table 3; Fig 5). The highest pH reading of 5.26 is from an inflow stream into Second Chain Lake from a wetland area to the north (Fig. 5). The reason for a higher pH reading is unknown as this inflow is also within the Cunard Formation and organic acids from the wetland would contribute to acidity. However, these pH levels are considerably lower compared with the results from a water survey conducted in 2000 on lakes in HRM that measured an average pH of 6.27 (Clement *et al*., 2007).

An increased level of dissolved sulphate (SO_4) is a further indicator that acid rock drainage is contributing to the acidity of surface water bodies (Kerekes *et al*., 1987). In 2000, a water quality survey of select lakes in Nova Scotia lakes recorded levels of sulphate in First Chain and Second Chain lakes at 18.3 mg/L and 20.2 mg/L, respectively, which are higher than in many lakes in the area (Clement *et al*., 2007).

Based on an earlier study of water pH in Bayers Lake (White *et al*., 2014b), it was expected that Second Chain Lake would also have similar pH levels, well above 5, because it is underlain by the same non-acid-producing granitic rocks of the South Mountain Batholith (Fig. 5). Although Second Chain Lake drains into First Chain Lake, they are both at a similar elevation above sea level

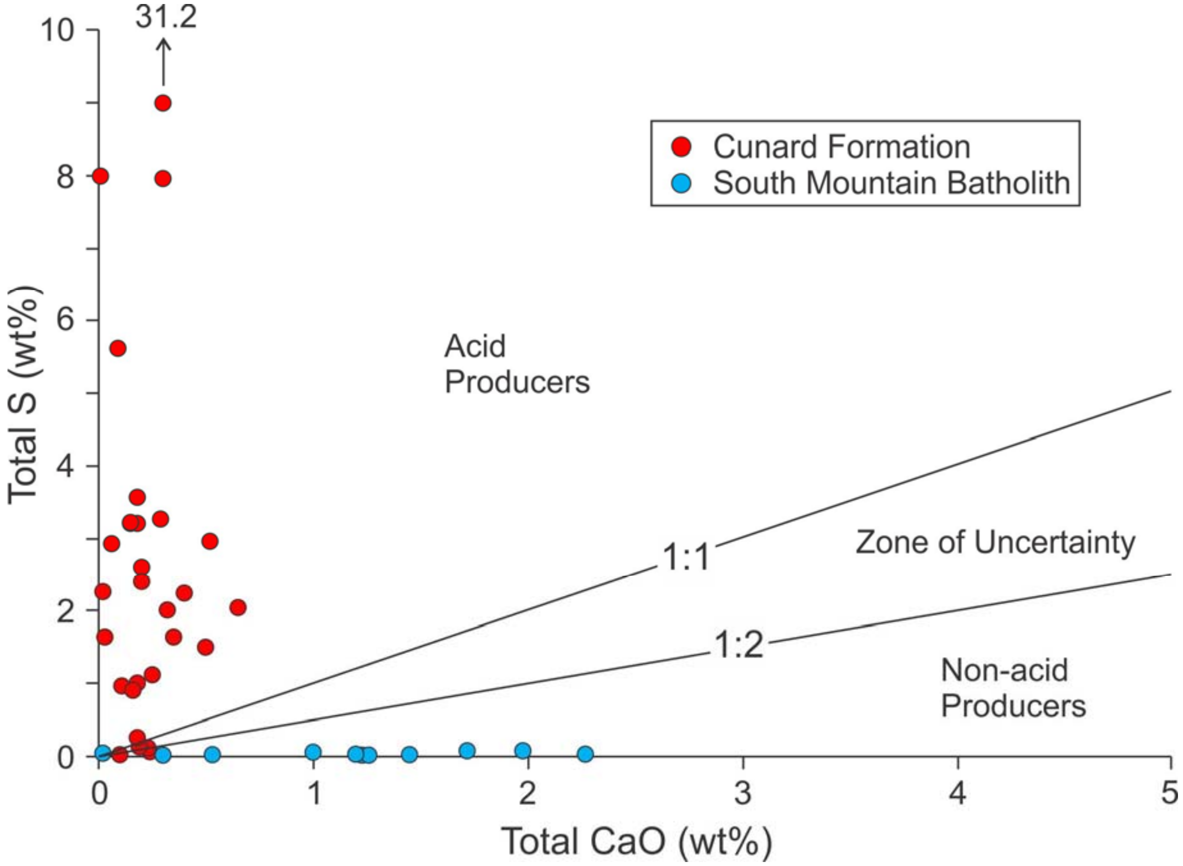

Figure 4. Plot of total S against CaO using data obtained by the portable XRF machine.

Table 1. Whole-rock chemical analyses of samples from the Cunard Formation by portable XRF.

	UTM nad 83: Zone 20			Major oxides (wt%)					Total S	Trace elements (ppm)												ARD
Sample	Easting	Northing	Rock type	CaO	K_2O	TiO_2	MnO	$Fe_2O_3^T$	(wt%)	As	Ba	Cu	Nb	Pb	Rb	Sr	V	Y	Zn	Zr	S/CaO	problem?
BL12-R103	449071	4943180	hornfels	0.35	3.12	0.70	0.05	6.33	1.63	5	623	26	15	9	140	102	69	11	95	302	4.66	YES
BL12-R104	448879	4943151	hornfels	0.20	4.56	0.80	0.03	5.88	2.59	3	903	39	22	26	187	175	109	18	95	225	12.95	YES
BL12-R105	448666	4943224	hornfels	0.24	2.00	0.71	0.09	5.23	0.06	1	330	4	19	2	88	135	75	19	69	92	0.25	NO
BL12-R106	448552	4943126	hornfels	0.09	5.14	0.49	0.09	10.52	5.60	0	852	40	15	25	199	190	85	5	112	110	62.22	YES
BL12-R107	448295	4943150	hornfels	0.10	2.78	1.20	0.09	3.78	0.02	3	302	8	25	2	104	60	95	25	60	99	0.20	NO
BL12-R108	448074	4943102	hornfels	0.11	1.00	0.96	0.30	11.50	0.96	3	291	32	21	5	445	20	48	32	132	165	8.86	YES
BL12-R109	447846	4943107	hornfels	0.23	6.98	1.23	0.11	4.59	0.11	1	1438	7	24	20	250	185	152	36	63	105	0.48	NO
BL12-R110	447850	4943311	hornfels	0.15	4.42	0.78	0.12	8.20	3.20	9	1000	62	18	2	154	214	105	39	88	699	21.33	YES
BL12-R111	447940	4943505	hornfels	0.18	3.11	0.91	0.07	4.00	1.00	3	752	18	15	32	150	200	92	18	92	96	5.56	YES
BL12-R112	447949	4943460	hornfels	0.18	3.58	0.74	0.07	6.99	3.20	6	521	28	15	2	138	62	78	9	80	165	17.78	YES
BL12-R113	448097	4943500	hornfels	0.65	2.99	0.87	0.05	5.59	2.03	3	548	19	15	15	135	195	105	15	80	120	3.12	YES
BL12-R114	448098	4943515	hornfels	0.16	6.20	0.89	0.03	5.23	0.90	7	1021	37	22	4	211	90	142	5	82	150	5.63	YES
BL12-R115	448437	4943577	hornfels	0.25	5.26	0.82	0.03	4.89	1.11	2	800	18	19	13	201	158	123	21	75	152	4.44	YES
BL12-R116A	446842	4944102	and-cord hornfels	0.29	4.26	0.90	0.02	5.50	3.26	15	1201	41	18	11	199	162	174	25	72	125	11.24	YES
BL12-R116B	446839	4944086	cord hornfels	0.29	2.50	1.00	0.02	6.23	31.20	29	463	40	12	2	100	80	48	10	100	125	107.59	YES
BL12-R117A	449034	4943522	and hornfels	0.19	4.53	1.02	0.05	3.00	0.12	15	801	5	19	35	175	192	117	10	75	125	0.65	MAYBE
BL12-R117B	449034	4943522	cord hornfels	0.18	3.40	0.90	0.11	12.23	3.56	0	869	75	15	8	123	75	120	10	160	159	19.77	YES
BL12-R123	447954	4943304	cord hornfels	0.06	5.02	0.71	0.05	11.30	2.92	6	526	101	15	0	215	78	132	9	275	39	48.67	YES
BL12-R124	449408	4943112	cord hornfels	0.01	3.98	0.61	0.03	13.30	7.98	8	999	30	16	11	192	91	102	6	120	153	798.00	YES
BL12-R125A	449356	4943213	and-cord hornfels	0.32	2.15	0.69	0.02	1.77	2.00	3	354	15	11	16	85	145	92	42	63	80	6.25	YES
BL12-R125B	449356	4943213	cord hornfels	0.15	5.99	0.90	0.04	10.30	3.21	6	1250	40	16	2	242	99	125	14	129	140	21.40	YES
BL12-R126A	447453	4944030	and hornfels	0.18	4.22	0.99	0.20	3.59	0.25	7	1123	15	35	9	278	302	144	25	106	135	1.39	YES
BL12-R126B	447453	4944030	cord hornfels	0.40	3.22	0.49	0.01	4.88	2.23	5	599	21	5	15	121	150	62	6	80	120	5.58	YES
BL12-R127A	446835	4944250	cord hornfels	0.02	2.88	1.23	0.05	6.02	2.25	15	438	20	29	0	102	38	68	10	21	1001	112.50	YES
BL12-R128A	447008	4944265	and hornfels	0.03	4.14	1.03	0.04	4.03	1.63	13	489	50	18	1	160	89	165	15	35	149	54.33	YES
BL12-R128B	447008	4944265	cord hornfels	0.50	3.33	0.95	0.60	3.96	1.49	4	723	14	14	0	132	87	100	102	89	152	2.98	YES
BL12-R129	447119	4944239	and hornfels	0.20	4.10	0.80	0.05	4.23	2.39	9	725	52	11	5	174	147	154	15	120	109	11.95	YES
BL12-R130	447190	4944190	and hornfels	0.30	2.20	0.63	0.05	12.00	7.95	12	739	65	20	62	120	277	105	18	82	175	26.50	YES
BL12-R131	447302	4944103	and hornfels	0.52	3.50	0.74	0.05	3.55	2.95	0	879	19	9	26	140	198	102	17	45	100	5.67	YES
TARR15-001	448489	4943002	and hornfels	0.19	4.40	0.90	0.12	6.07	1.01	20	890	42	21	12	168	133	116	21	31	441	5.32	YES
Average				0.22	3.83	0.85	0.09	6.49	3.29	7	748	33	18	12	171	138	107	20	91	194	14.71	YES
Standard deviation				0.15	1.30	0.19	0.11	3.10	5.54	7	290	22	6	13	70	66	32	18	46	193	142.50	
Median				0.19	3.78	0.88	0.05	5.55	2.13	6	746	29	17	9	157	140	105	16	82	138	7.56	YES

Notes: BL12 samples are from White *et al*. (2014a) and the reanalyzed results reported here; abbreviations and=andalusite, cord=cordierite.

Table 2. Whole-rock chemical analyses of samples from the South Mountain Batholith by portable XRF.

	UTM nad 83: Zone 20			Major oxides (wt%)					Total S	Trace elements (ppm)												ARD
Sample	Easting	Northing	Rock type	CaO	K_2O	TiO_2	MnO	$Fe_2O_3^T$	(wt%)	As	Ba	Cu	Nb	Pb	Rb	Sr	V	Y	Zn	Zr	S/CaO	problem?
BL12-R100	446654	4943601	c.g. bt-monzogr	1.23	4.01	0.32	0.04	1.65	0.01	1	625	3	6	20	144	141	59	17	22	99	0.01	NO
BL12-R101	446783	4943579	c.g. bt-monzogr	0.30	6.59	0.04	0.03	0.50	0.01	5	52	1	4	20	235	18	4	10	3	15	0.03	NO
BL12-R102	446689	4943466	c.g. bt-monzogr	1.26	2.02	0.24	0.03	1.29	0.01	1	500	1	7	9	62	99	28	20	14	101	0.01	NO
BL12-R116c	446830	4944065	m.g. bt-monzogr	1.45	3.74	0.09	0.01	0.66	0.02	1	431	1	3	21	131	165	27	15	10	75	0.01	NO
BL12-R118	449139	4942701	m.g. bt-monzogr	2.27	4.02	0.70	0.05	3.75	0.03	5	510	5	15	15	109	225	70	15	33	102	0.01	NO
BL12-R119	448476	4942689	m.g. bt-monzogr	1.00	4.49	0.50	0.05	2.45	0.05	2	999	10	9	13	106	163	96	17	35	85	0.05	NO
BL12-R120	448136	4942533	m.g. bt-monzogr	1.72	5.50	0.72	0.06	3.70	0.07	5	770	9	9	15	175	222	90	17	33	132	0.04	NO
BL12-R121	447798	4942444	porph bt-monzogr	0.53	5.31	0.30	0.04	2.02	0.02	2	158	2	9	15	210	39	19	22	30	60	0.03	NO
BL12-R122	447451	4942601	m.g. bt-monzogr	1.20	4.22	0.30	0.02	1.30	0.02	4	715	1	5	19	119	139	59	17	9	52	0.02	NO
BL12-R127A	446835	4944250	f.g. granite	0.02	0.41	0.01	0.01	0.31	0.04	2	14	4	1	0	10	10	3	0	0	52	2.00	YES
BL12-R127B	446835	4944250	m.g. bt-monzogr	1.98	3.60	0.55	0.05	2.75	0.07	5	610	6	9	13	109	194	52	26	38	142	0.04	NO
TARR15-002	448548	4942897	m.g. bt-monzogr	2.64	2.7	0.66	0.08	3.7	0.03	8	407	5	13	7.7	131	273	57	28	36	205	0.01	NO
Average				1.30	3.89	0.37	0.04	2.01	0.03	3	483	4	7	14	128	141	47	17	22	93.3	0.19	NO
Standard deviation				0.75	1.57	0.24	0.02	1.21	0.02	2	283	3	4	5.9	58	81	30	7	13	47.9	0.57	
Median				1.25	4.02	0.31	0.04	1.84	0.03	3	505	3.5	8	15	125	152	55	17	26	92	0.03	NO

Notes: BL12 samples are from White *et al*. (2014a) and the reanalyzed results reported here; abbreviations c.g.=coarse-grained, m.g.=medium-grained, f.g.=fine grained, porph=porphyritic, bt=biotite, monzogr=monzogranite.

Table 3. Water Ph measurements.

Sample	UTM nad 83: Zone 20		Formation under sample	Rock Types	Water Body	Sample Site Description	Ph
	Easting	Northing					
Tarr15-01	447862	4942425	South Mountain Batholith	granite	Second Chain Lake	north side of lake under 15 cm of ice and 20 cm of snow; 5 m from shore; granite boulders and outcrop nearby	4.19
Tarr15-02	447893	4942541	South Mountain Batholith	granite	Second Chain Lake	north side of lake under 20 cm of ice and 20 cm of snow; 10 m from shore; granite boulders and outcrop nearby	4.15
Tarr15-03	448057	4942842	South Mountain Batholith	granite	Second Chain Lake	north side of lake under 25 cm of ice and 5 cm of snow; 2 m from shore; granite boulders and outcrop nearby	4.17
Tarr15-04	448091	4942852	South Mountain Batholith	granite	Second Chain Lake	slow moving open water on lake shore at mouth of stream; inflow from low-land to north which is underlain by Cunard Formation; granite boulders and outcrop nearby	5.26
Tarr15-05	448263	4942974	Cunard	hornfels	Second Chain Lake	slow moving open water on lake shore at mouth of stream; inflow from low-land to north which is underlain by Cunard Formation; granite and hornfels boulders nearby	4.19
Tarr15-06	448472	4942980	Cunard	hornfels	Second Chain Lake	water in lake under 20 cm of ice and 20 cm of snow; 1 m from shore; hornfels boulders and outcrop nearby	4.82
Tarr15-07	448548	4942897	South Mountain Batholith	granite	First Chain Lake	water in lake under 25 cm of ice and 5 cm of snow; granite boulders and outcrop nearby	4.60
Tarr15-08	449738	4942855	Cunard	hornfels	First Chain Lake Stream	free-flowing water in stream; walled with hornfels (Cunard Formation); stream bed lined with rounded Cunard Formation boulders	4.81
Tarr15-09	449936	4942811	South Mountain Batholith	granite	First Chain Lake Stream	free-flowing water in stream; walled with hornfels (Cunard Formation); stream bed lined with rounded Cunard Formation boulders	4.97
Tarr15-10	449620	4942856	Cunard	hornfels	First Chain Lake Stream	free-flowing water in open stream; no walled sides; stream bed lined with rounded Cunard Formation boulders	4.72

Notes: Samples collected March 16, 2015; Weather: overcast, strong northly winds, -6°C.

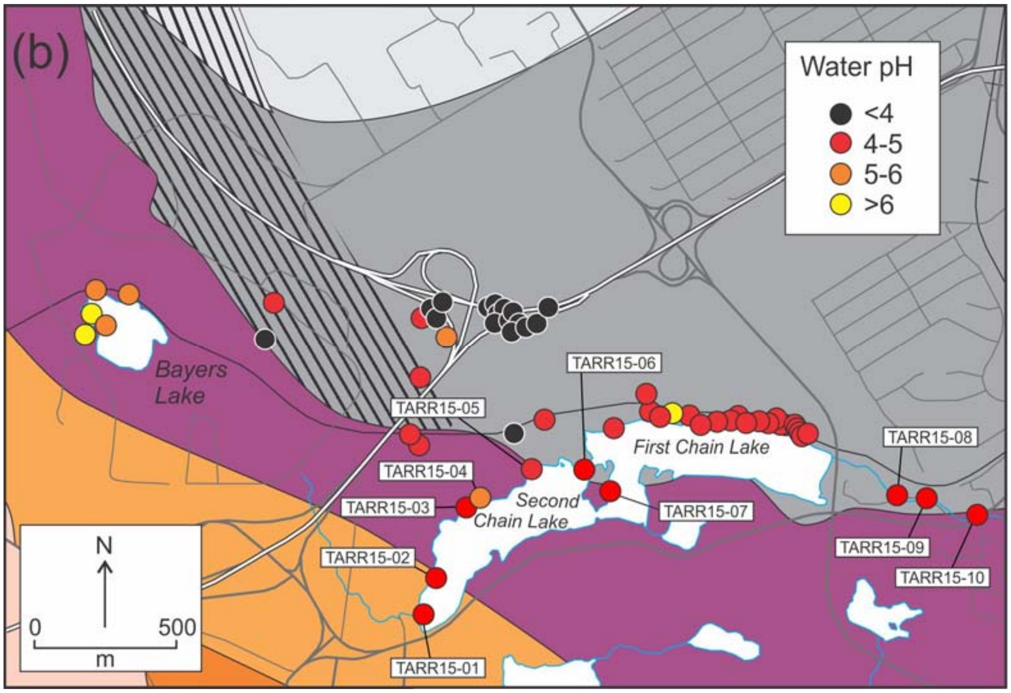

Figure 5. Simplified geology map of the Chain Lakes area showing the detailed distribution of water samples from this study (TARR15-01 to 10) and previous studies (White and Goodwin, 2011; White *et al*., 2014b). UTM co-ordinates for sample locations are in Table 3. Legend is the same as in Figure 1.

(63-64 m); hence, the connectivity between the two lakes likely has allowed ARD-affected water from First Chain Lake to influence the pH of Second Chain Lake.

The outflow stream at the east end of First Chain Lake locally has outcrops and boulders of sulphide-rich hornfels of the Cunard Formation, and this material is also used to construct walls along the stream. Although the slightly higher pH recorded in this stream may be due to dilution from melting snow, such dilution did not mask the acidity generated from such sulphide-rich rocks.

Summary

The Cunard Formation around First Chain Lake consists of strongly acid-generating rocks, and the low pH values of the water samples reflect this fact. The high levels of dissolved sulphate present in the water also support this result. Samples from the granitic rocks underlying Second Chain Lake contain very little total sulphur and as a result are not acid producing. However, due to their low CaO content, they provide little acid-buffering potential to prevent acidic water from spreading from First Chain Lake, as evidenced by the low pH values in both lakes. The outflow stream is also similar in pH , indicating that acidic water is moving throughout the area.

Overall, the results show that values are well below the acceptable pH guideline for drinking water of 6.5 to 8.5. (Health Canada, 2009); pH values of 5 and less are considered to indicate the presence of ARD (U.S. Environmental Protection Agency, 1994). Using such low pH water for an emergency water supply will likely be costly due to the need to convert the water to drinkable standards in regards to both pH and dissolved metals. Remediation and careful or reduced construction should be considered for the watershed area in order to reduce further acid rock drainage.

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