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ACID DRAINAGE AND THE ACIDIFICATION
OF NOVA SCOTIA WATERS

by

MARK KING

for

Water Planning and Management Branch
Inland Waters Directorate (Atlantic)
Environment Canada

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Summary by Allen
Mudrock

EC

Subject: Acid Drainage in Nova Scotia

(Report by Mark King to IWD, Water Planning and
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Acid drainage from sulphide bearing bedrock could have a similar effect as acid precipitation on a large scale water systems. Considerably important areas for acid drainage are those underlain by sulphide bearing bedrock which has been exposed to oxidation by excavation, blasting or any activity causing fresh fractures within the rock, or areas that receive sulphide bearing rock in the form of road surfacing gravel, fill material, etc.

A potential for this type of acid drainage exists in Nova Scotia at areas underlain by the Halifax Formation containing different sulphide minerals. The Report gives a background information on the acidification by LRTAP, and a detail information on bedrock geology and occurrence of sulphides in Nova Scotia, in particular the Halifax and Lunenburg Counties. Poor health of fish and fish kills in the Shubenacadie River and Salmon River watersheds were related to the acid drainage from Halifax slates disturbed during the construction activities in the Halifax airport complex. pH values (as low as 3.6) well below those expected from atmospheric deposition reported in some lakes in the Halifax County watershed were related to subsequent exposure of pyritic slate bedrock.

The Report describes the method of collection of water and rock samples at 27 quarries in parts of Lunenburg and Halifax Counties, measuring the pH and concentrations of major ions and selected metals in the water (using the Water Quality Branch, IWD, analytical methods, published in 1979). Rocks were analysed for sulphur content, acid producing potential and acid consuming ability.

Results showed all quarry water samples exhibited low pH (range 2.6 to 4.9), and elevated sulphate (4 to 970 mg/l), aluminium (0.5 to 47 mg/l), iron (0.24 to 120 mg/l) and manganese (0.12 to 4.5 mg/l). All collected rock samples were identified as potentially acid drainage producing.

The recommendations derived from the study were:

- a) an evaluation and future development of the sampling methods to establish a standard for the determination of acid generation from the rocks;
- b) quantification of metal loadings from slate quarries and monitoring the hydrological budget in conjunction with water quality data;
- c) compilation and inventory of slate pits and quarries within the Halifax Formation;
- d) geological mapping of sulphide content in the Halifax Formation.

The results of the investigation and previous reports on the fish kill etc. indicate that the acid drainage from the regional bedrock should be considered in the assessment of the effects of the LRTAP on the aquatic ecosystem in Nova Scotia.

ABSTRACT

Acid drainage in Nova Scotia is examined for indications that, in some areas, it is a significant contributor of mineral acid warranting consideration in studies of the effect of LRTAP on Nova Scotian waters. A brief review is given of LRTAP, the processes involved in acid drainage, and the water quality aspects of acidification. The geology of the Halifax Formation is reviewed since the widespread nature of pyritiferous mineralization in this rock type make it important as a potential source of acid drainage when exposed.

Reconnaissance visits to 27 rock quarries within the Halifax Formation in Lunenburg and Halifax Counties showed all of them to exhibit a high degree of pyritiferous mineralization. Of 26 drainage water samples from 11 of these, all but one yielded a pH below 3.6. Rock samples from 10 quarries all showed values for acid producing potential in excess of acid consuming ability. In all but one, excess acid producing potential was greater than 24 lbs/ton.

These results as well as three other cases of acid drainage in Nova Scotia, most notably at the Halifax International Airport, indicate that acid drainage could be a significant cause of acidification in watersheds where mineralized rock of the Halifax Formation is exposed. This suggests that, in LRTAP studies of such watersheds, acid drainage should be considered in interpreting water quality data.

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1.0 INTRODUCTION

The purpose of this report is to explore the possibility that, in some areas of Nova Scotia, water quality impairment from acidification is significantly influenced by acid drainage from mineralized rock. In studies of acidified systems, bedrock is often referred to as having influence on acidification with respect to its capacity to serve as a buffer to acidic precipitation. However, its role as an actual source of acid is often overlooked. Where bedrock is mineralized, the presence of isolated and/or on-going acid drainage events may have implications with regard to the interpretation of water quality data.

Inherent in the above stated purpose is examination of the connection between the acid drainage phenomenon in Nova Scotia and LRTAP studies. When viewed regionally as an on-going problem controlled by the coincidence of sulphide bearing bedrock and man-made perturbations, it is argued that acid drainage could have an effect on large-scale water systems similar to that of acidic precipitation. Where acid drainage may contribute to acidification, it should receive attention in studies of acidified systems.

Areas in which this premise can be considered are those underlain by sulphide-bearing bedrock which has been exposed to oxidation by excavation, blasting or any activity causing fresh fractures within the rock. Other potential sources of acid drainage include areas that receive sulphide-bearing rock in the form of road surfacing gravel, fill material, etc. In Nova Scotia, the Halifax Formation is notable in terms of acid drainage in that it contains widespread occurrences of sulphide minerals. This formation underlies much of the southern half of Nova Scotia and is widely used as a source of aggregate. The potential for

widespread occurrences of acid drainage resulting from activities involving rock of the Halifax Formation is great. In a given area, acid input from this source depends on the amount of rock used or exposed, the degree and type of sulphide mineralization present, and the amount of surface area exposed by fracturing or crushing.

2.0 BACKGROUND INFORMATION

2.1 LRTAP and Acidification

Acidic deposition has only been perceived as a problem in North America since 1972. Prior to this, it was believed that atmospheric dilution provided an effective means for the disposal of gaseous industrial wastes (U.S.-Canada MOI, 1983).

Pristine rainfall has a pH of approximately 5.6 due to an equilibrium reaction with CO_2 that yields carbonic acid. Precipitation also contains a wide variety of other natural chemical constituents derived from such sources as sea spray, dust particles and natural cycling of certain elements. Gaseous wastes are generally rich in carbon, nitrogen and sulphur and therefore increase the atmospheric load of compounds containing these elements. Oxidation of some portion of these compounds takes place after emission, resulting in the formation of airborne nitric and sulphuric acid and lowering of the pH of precipitation.

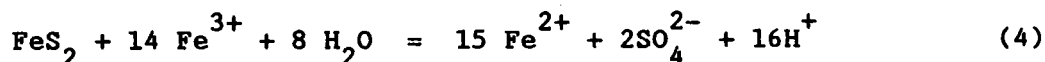
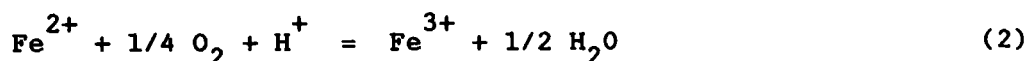
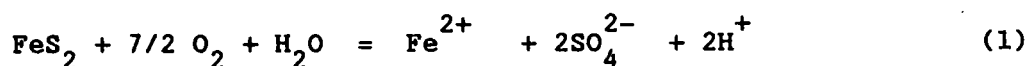
Impact on aquatic environments from acid rain is based on the hydrogen ion concentration - a key factor in controlling the rate of most chemical reactions. Solubilization and corrosion of minerals, and the resultant mobilization of metals, are pH-dependent and are accelerated by increased acid concentration in water (U.S.-Canada MOI, 1983). Therefore, a decrease in pH of an aquatic system is often associated with elevated concentrations of aluminum and heavy metals leached from lake sediments or soil and bedrock profiles.

Further water quality impairment may arise from the mobilization of metals from plumbing systems drawing water from an acidified source (U.S.A.-Canada MOI, 1983).

2.2 Acid Drainage

Acid drainage results when sulphuric acid, released by the oxidation of metallic sulphide minerals, gains access to groundwater or surface waterways. The term "acid mine drainage" is often used to describe this phenomenon because of its early identification with coal and sulphide mining activity. In coal seams, as well as in the Halifax Formation of Nova Scotia, the predominant sulphide is the iron sulphide, pyrite (FeS_2).

The oxidation of pyrite is characterized by the following overall reactions (Stumm and Morgan, 1970):



In (1), the sulphide portion of the mineral is oxidized to sulphate while dissolved ferrous iron and acidity (2H^+) are released. Soluble ferrous iron is oxidized to ferric iron (2) and subsequently hydrolyzed to insoluble ferric hydroxide (3). In (3), more acidity is released with the production of ferric hydroxide which will tend to adhere to rock surfaces and stream beds giving a rusty appearance. Ferric iron may also be reduced by pyrite (4) thus oxidizing the sulphide portion of the mineral and releasing acidity and ferrous iron.

From the above reactions, it can be seen that oxidation of 1 mole of pyrite has the potential to release four equivalents of acidity -

two from oxidation of the sulphide portion and two from the oxidation and subsequent hydrolyses of the iron portion (Stumm and Morgan, 1970).

These reactions will proceed abiotically in the presence of oxygen, but the rate of reaction is greatly increased by the bacteria *Thiobacillus ferrooxidans* (Duncan 1967). *T. Ferrooxidans* is ubiquitous with the ability to utilize the energy released from the oxidation of sulphide minerals. It has adapted to an environment of extreme acidity (pH 1.5 - 3.0) and of very high metal concentrations (Hawley 1972). Besides low pH, a suitable environment for the breakdown of sulphides by *T. ferrooxidans* must also include oxygen, carbon dioxide, water and certain essential nutrients.

Sulphide mineral surface area, thus available reaction sites, is the main control on rate of acid production (Ohio State 1970). Bedrock fractured by blasting will present a larger surface area for sulphide oxidation as will crushed rock. Also, where the sulphide mineral composition and volume per unit volume of bedrock are equal, disseminated mineralization will promote a more accelerated rate of acid production than for large blocky crystals.

2.3 Geology of the Halifax Formation

The Halifax Formation is of particular interest in regard to acid drainage due to the widespread presence of pyrite and other sulphides. The Halifax Formation lies conformably on top of the Goldenville Formation, and together they comprise the Meguma Group. These are marine-laid, regionally metamorphosed sediments of Cambro-Ordovician age.

The Meguma Group is centered in two large areas in the southeast and northeast of mainland Nova Scotia (see Figure 1). Separating the two areas is a tongue of the main granite batholith in the province. Northwest of the batholith are small, isolated areas of Meguma rocks (Taylor and Schiller 1966).

The main folding of the Meguma occurred during the Acadian Orogeny and is manifest in upright, low-plunging folds trending northeast to east. These can be up to one hundred miles in length and are closely paralleled by a steep axial plane cleavage, well-defined in the finer-grained lithologies of the Group (Fyson, 1966). A major fracture system trends northwest across the main folds with some of the fractures passing into faults (Fyson 1966). The Meguma Group is regionally metamorphosed to the greenschist facies with contact metamorphism near granitic intrusions.

The Goldenville formation is composed of thin to thick-bedded greywacke and quartzite with lesser amounts of interbedded slates. Rock colours range from green to grey (Taylor and Schiller 1966).

Towards the Goldenville-Halifax contact, the slate content of the rock increases. Schenk (1970) suggested that a quartz wacke to slate ratio of unity be used as the division between the two formations.

This transitional zone is currently under investigation because of its proven potential for high metallic, potentially valuable mineral concentrations (Zentilli et al, in progress). Most of the gold, tungsten, antimony and arsenic mined in Nova Scotia has come from beds in this zone. Although current investigations focus on the Eastville area of the northeastern Meguma block (See Figure 1), finely laminated mangiferous beds, locally rich in sulphides and other minerals, have been found in other parts of the transition zone (Zentilli et al., in progress).

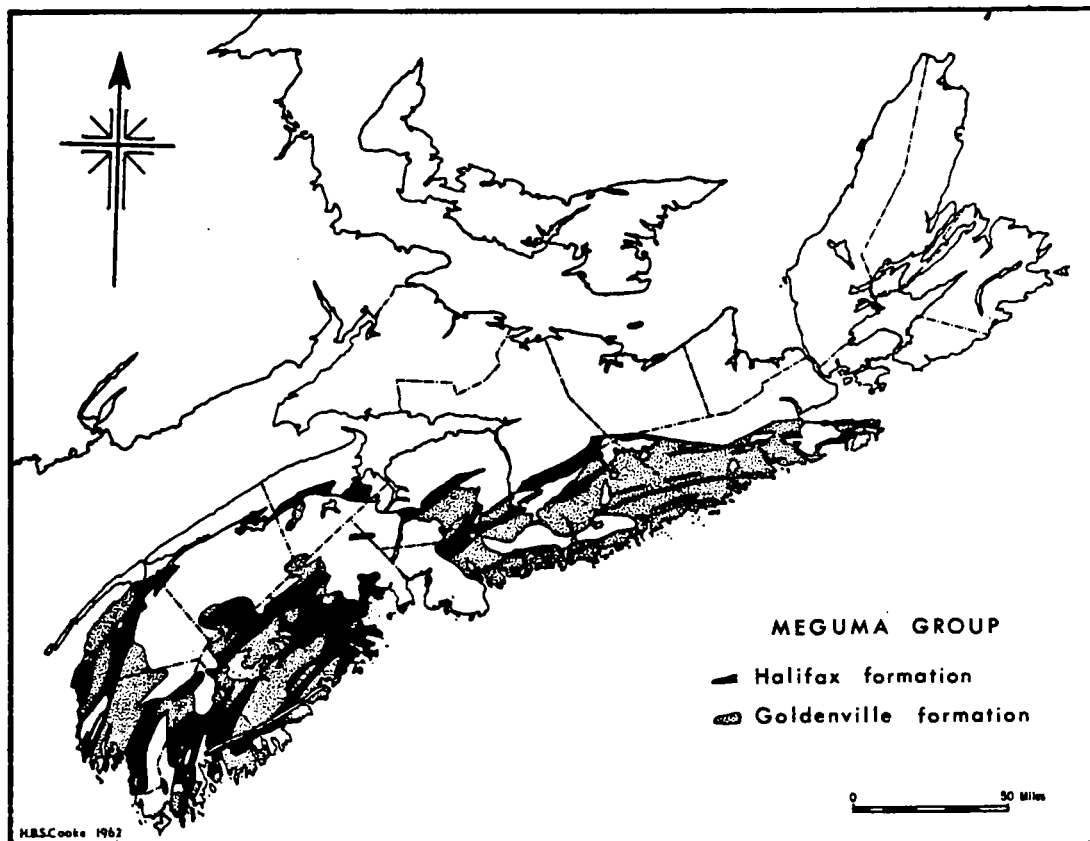


Figure 1. The Meguma Group in Nova Scotia

Upward from the transition zone, the slates of the Halifax Formation become the dominant lithology. The Halifax Formation is composed of thinly bedded slates, siltstones and argillites with lesser amounts of interbedded quartzite (Taylor and Schiller 1966). Cleavage is often so closely spaced that bedding is difficult to discern in the absence of a quartzitic marker bed (Hall 1981). Halifax slates range from grey in the Upper Halifax to black with abundant sulphides towards the base of the formation. Pyrite is the most common sulphide and occurs in massive veins, aggregates or disseminated crystals. Other sulphides commonly present include pyrrhotite, marcasite, chalcopyrite and arsenopyrite. Mineralized sections usually trend parallel to bedding (Brian O'Brien, personal communication), although in some cases, mineralization has been reported to follow cleavage planes in the form of boudinage (Lund 1985).

Work by the Nova Scotia Research Foundation (1985, NSRF), near the Halifax International Airport, illustrates the variability in sulphide content both vertically and horizontally within a small area of the formation (See Table 1). NSRF has had some success in delineating high sulphide zones using geophysical methods.

Keppie (1983) reported that, in the Halifax and Country Harbour area, visible pyrite and pyrrhotite in Halifax Formation slates coincide with enrichment in iron and manganese. Slates of lesser sulphide mineralization are aluminous. He noted this variation could be traced on the vertical gradient magnetic anomaly maps (Anonymous 1982) as could the lower boundary of the Halifax Formation in the Isaac's Harbour area where the magnetic mineral pyrrhotite is abundant.

TABLE 1
RESULTS OF CHEMICAL ANALYSIS OF ROCK SAMPLES (FROM NSEF, 1985)

Lab Desc. No.	% wt. Total Sulfur	±5% Error	% Weight Pyritic Sulfur		Error ±0.1	Non Pyritic Sulfides		% Wt. Fe+2	Error ±0.1	% Weight Graphitic Carbon	Error ±0.02	Lbs/Ton Acid Pro Potential	
			% weight	PPH		% weight	PPH					Potential	Acid consum
Aero grid													
1	2+50 Top	0.034	.002	0.032	0.07	<0.005	<5	1.98	1.88	0.18	0.16	2.1	78
2	Mid	0.17	.009	0.179	0.030	0.0028	28	1.55	1.65	0.92	0.94	10.4	86
3	Bot	0.074	.004	0.074	0.013	<0.0005	<5	0.76	0.86	1.36	1.34	4.3	84
15	1+00Top-1	2.00	.100	1.90-	1.76	0.0052	52	4.15	4.05	0.28	0.26-	122	235
4	Top-2	0.85	0.43	0.893	0.69	0.0048	48	2.69	2.79	0.25	0.23-	52	39
5	Mid	2.05	.103	2.153	1.80	<0.0005	<5	1.40	1.27	1.27	1.29	125	86
6	Bot	1.11	.056	1.166	0.47	0.426	4260	2.45	2.55	0.60	0.58-	68	68
Wine Grid													
12	6+50 Top	1.00	.050	1.05	0.50	0.0149	149	3.12	3.02-	0.39	0.37	61	74
13	Mid	2.17	.109	2.279	1.92	0.0308	308	5.82	5.92	0.18	0.16-	133	67
9	3+25 Top	0.06	.003	0.063	0.02	0.0012	12	4.06	3.96-	0.42	0.40-	3.7	127
	Mid	2.19	.110	2.30	1.66	0.0010	10	2.60	2.70	0.64	0.62-	134	137
11	Bot	2.79	.140	2.93	1.69	0.0174	174	1.82	1.92	0.67	0.65-	171	70
14	1+75 Top	0.23	.012	0.242	0.13	0.0237	237	3.19	3.29	0.12	0.10-	14	112
7	0+25 Top	0.57	.029	0.599	0.43	<0.005	<5	2.70	2.80	1.11	1.09	35	144
16	Top	1.86	.093	1.953	1.66	0.0040	40	2.96	3.06	0.30	0.28-	114	204
8	Mid	1.60	.080	1.68	0.80	0.2865	2865	4.70	4.80	0.53	0.51-	90	163

In the coastal Lunenburg County area, the Halifax Formation has been divided further into informal members that have been successfully mapped (Hall 1981; O'Brien 1985; O'Brien, in progress). The unit above the zone of transition from the Goldenville to the Halifax Formations has been designated the Cunard Slate. This unit, which forms the base of the Halifax Formation (Hall 1981), is made up of black slates interbedded with pyritiferous, grey, rippled and cross-stratified sandstone beds approximately 20-50 cm in thickness (O'Brien 1985). O'Brien (personal communication) contends that the majority of the pyrite in this unit occurs in the sandstones as opposed to the slates. The rationale for this field observation is that the coarser grained sediments were permeable and thus provided a better medium for migrating mineral rich fluids even though the source of the mineralization was likely the slates. He adds that the two lithologies are sometimes confused because of the well-defined cleavage often found in the finer-grained sandstones.

The Feltzen member is above the Cunard and comprises the rest of the Halifax Formation found within the map area (O'Brien 1985). The Feltzen is characterized as less pyritiferous than the Cunard, and therefore is probably less troublesome in terms of acid drainage. The slates of this unit are light grey, dark grey and blue-grey, and are rhythmically interbedded with thinly bedded grey sandstones (5-10 cm thick near the base, 1-2 cm higher in the sequence (O'Brien 1985).

Work by Lambert and Muecke (in progress) will add to the scant geochemical information available on the Halifax Formation. Whole rock and trace metal analyses will be performed on 55 black slate samples from coastal Lunenburg County. The authors report that chemistratigraphic correlation of the formation will be possible with the resultant data.

2.4 Acid Drainage in Nova Scotia

A severe case of acid drainage from bedrock of the Halifax Formation at the Halifax International Airport has been well documented (e.g. Lund 1985; Porter-Dillon 1985; Thompson 1978). As early as 1961, Scott attributed a major fish kill in the neighbouring Shubenacadie River to acid drainage from Halifax slates. EPS (1976) has subsequently linked numerous fish kills in the river to construction activities at the airport complex (See Table 2).

Porter Dillon (1985) suggests that the poor health of fish in parts of the Salmon River watershed is directly related to acid drainage originating at the Halifax Airport. In the McDowell, McKay and Williams systems in particular, aluminum and sulphate concentrations are considered to be above background levels, while pH is lower than background values. These values are attributed to acid drainage originating at the Airport from sulphide minerals in the bedrock exposed during construction activities.

Other Nova Scotian waters have also been impacted by acid drainage. Kerekes et al (1984), in a study of the effects of high nutrient loadings on an acidified lake, reported pH values well below those expected from atmospheric deposition. The study lakes, Little Springfield Lake (mean pH 3.6) and Drain Lake (mean pH 4.0), are located in the same watershed in Halifax County. Kerekes et al attributed the high acidification to construction within the watershed and subsequent exposure of pyritic slate bedrock. A large slate quarry is located approximately 400 m from Little Springfield Lake and a stream originating within the quarry empties into the east end of the lake. Physical and chemical characteristics of the lakes are shown in Table 3.

Acid drainage from crushed mineralized slate used to resurface the Union Square Road in Lunenburg County is believed to be responsible

TABLE 2

FISH KILL HISTORY IN THE SHUBENACADIE RIVER

(From EPS, 1976)

<u>MAJOR CONSTRUCTION</u>		<u>MAJOR FISH KILLS</u>
Terminal and Runways	1957-1960	September, 1960
Imperial Oil	1959-1960	
IMP Hangar (large)	1959	
IMP Hangar (small)	1961	
Air Canada Hangar	1961	
Air Halifax Hangar	1961	October 1961
Highways slate needs	1965	October, 1965
Avis Service Station	1966	September, 1966
Highways slate needs	1968	November 1968
Halifax Flying Club	1970	
Mobil Oil Hangar	1972	
Highway Overpass	1974	August 1974
Aircon Tank Farm	1975	October 1975
EPA Hangar	1976	September 1976

TABLE 3

MEAN PHYSICAL AND CHEMICAL CHARACTERISTICS OF DRAIN LAKE
AND LITTLE SPRINGFIELD LAKE (FROM KEREKES, ET AL., 1984)

	Drain Lake	Little Springfield Lake
Location	44°47'50"N 63°45'20"W	44°48'00"N 63°44'50"W
Area (hectares)	16.3	13.7
Mean Depth (m)	0.61	4.0
Maximum depth	3.0	7.0
Mid-summer secchi depth (m)	1.0	3.4
Colour (Hazen units)	10	5
Turbidity (N.T.U.)	1.3	1.0
Conductivity (umhos/cm)	260	270
pH	4.0	3.6
Alkalinity (mg/l)	0.0	0.0
Total phosphorous (mg/m ³)	27	9
Total dissolved phosphorus (mg/l)	11	5
Soluble reactive phosphorus (mg/l)	4	1
Ca (mg/l)	6.1	6.3
Mg	1.9	2.8
K	1.2	0.9
Na	33	35
SO ₄	29	53
Cl	54	58
Al	0.9	3.9
Fe	0.5	0.8
Mn	0.2	0.3

for a major fish kill in Patten and Biscuit Brooks in August 1977 (Pettipas 1979; Thompson 1978). Runoff from the road became highly acidified before entering the two tributary streams of the North LaHave River (See Figure 2). Among the results of analysis of a water sample collected by Pettipas (1979) from a roadside ditch flowing into Biscuit Brook were the following: Al 123 mg/l, Fe 68 mg/l, Mn 150 mg/l, As 2.2 mg/l, Co 2.6 mg/l, Cu 2.5 mg/l, Zn 2.5 mg/l, pH 3.

The Northfield quarry (also known as Pinehill Quarry), from which the material to resurface the Union Square Road was obtained, has been shown to yield highly mineralized slate. Standing water from the quarry sampled on May 23, 1978, yielded the following concentrations when analyzed (EPS Memo 4100-4, 1978): Al 250 ppm, Fe 232 ppm, Mn 193 ppm, As 2.2 ppm, Co 5.8 ppm, Cu 7.69 pp, and pH 2.8 (measured in the field).

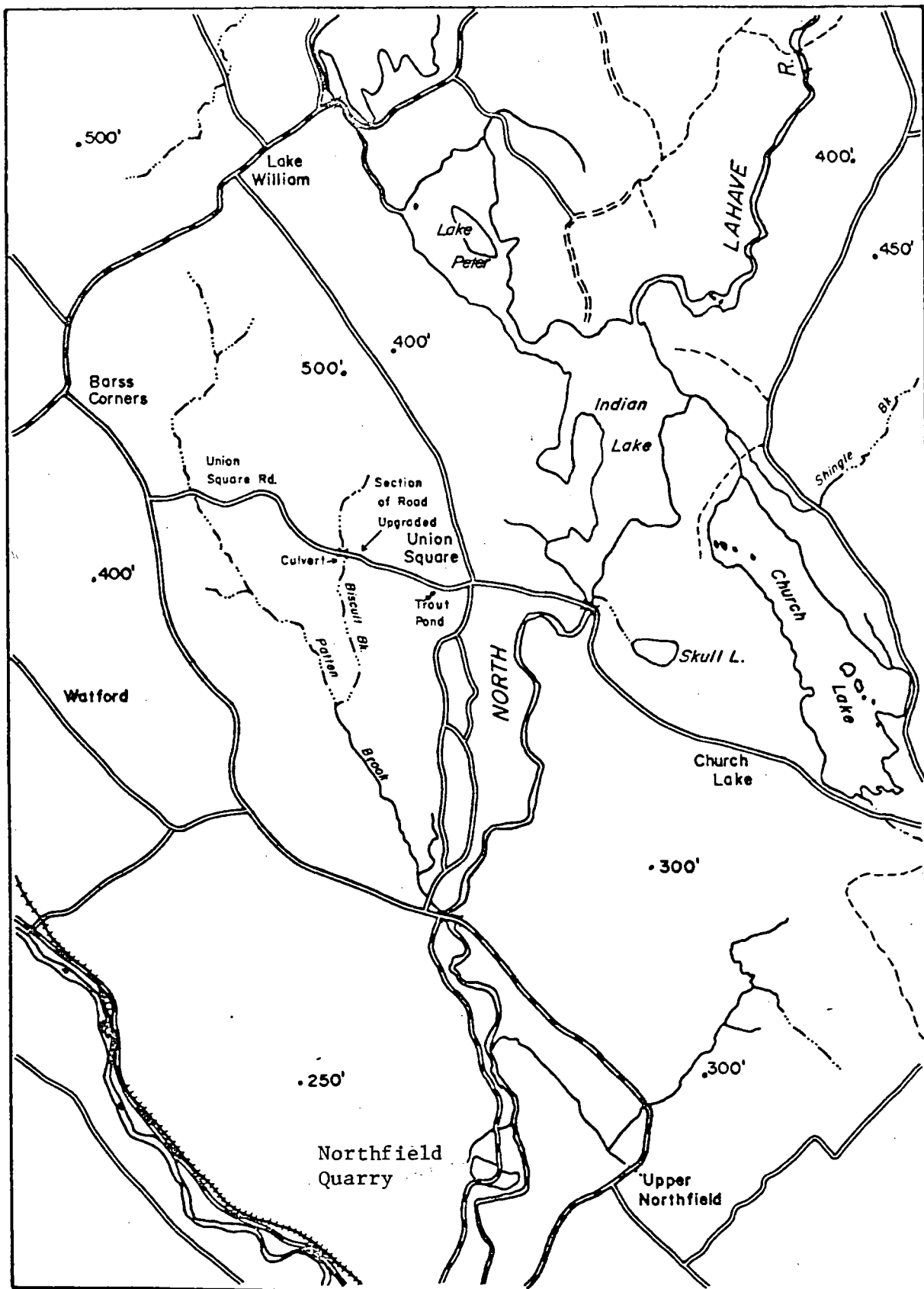


Figure 1. Location Map of Pattern Brook Fish Kill

3.0 METHODS

Reconnaissance trips were made to 27 rock quarries within the Halifax formation in Lunenburg and Halifax counties. Water samples were taken of standing water in quarries, water leaving quarries via drainage ditches and nearby natural water bodies. Ten quarries in Lunenburg County and one in Halifax County were sampled in this way. Two rounds of water sampling were conducted - one after several days of dry weather and one during a rainfall event. All samples were analyzed for pH using a Radiometer PHM82 pH meter at the Centre for Water Resources Studies at the Technical University of Nova Scotia. Portions of twenty-three of the samples collected were sent to the Water Quality Branch of Inland Waters Directorate for additional analysis, including major ions and selected trace metals.

Rock samples were taken in ten quarries with four samples at two different locations. A channel sampling technique was chosen as the most practical and effective way of obtaining a representative sample of the large and compositionally variable bedrock exposures (John Fowler, personal communication). A uniform channel is hammered out of the rock in a direction perpendicular to bedding planes and the chips collected. In this way, stratigraphically controlled compositional differences are weighted proportionally in the sample. In some cases, where piles of crushed rock were present, samples were taken from these as it is assumed they represent a fairly homogeneous sample of large sections of the quarry.

Rock samples were analyzed for acid producing potential and acid consuming ability. As set out by Duncan (1972), the sample is pulverized and assayed for total sulphur. The sulphur assay is then expressed as pounds of sulphuric acid per ton of sample. This value is the acid

producing potential. To find acid consuming ability, a 10 gram portion of the pulverized sample is suspended in 100 ml of distilled or de-ionized water and titrated to pH 3.5 with sulphuric acid. The total volume of acid added is expressed as pounds per ton of sample and is the acid consuming ability of the sample.

TABLE 4

SELECTED PARAMETERS OF WATER SAMPLES FROM 13 SITES IN LUNenburg AND HALIFAX COUNTIES

Sample #	Watershed	Quarry Site #	Sampling Site Description	pH	Cond ysie/cm	SO ₄ mg/l	Al mg/l	Fe mg/l	Mn mg/l	Cu mg/l	Colour (App) rel. units	Remarks
1d*	1EJ-4D	1	A Spring fed brook	2.8 (2.70)	1600	480	22	31	1.7	0.014	<5	
1w*			originating in quarry	2.6 (2.72)	1940	865	47	120	1.4	0.38	10	
2d	1EJ-4D	B	Little Springfield Lake	3.6 (3.43)	398	68	2.1	0.79	0.33	0.005	<5	
2w				3.5 (3.45)	399	68	3	0.86	0.32	0.004	<5	
3d	1EE-1H	1	C Ditch draining south end of quarry	3.1 (3.15)	1019	360	37	11	4.5	0.14	5	
3w				3.1 (3.06)	1293	970	45	8.2	4.5	0.17	5	
4d	1EE-1H	2	F Large standing pool at centre of quarry	3.2 (3.23)	433	100	6	2.7	0.90	0.026	<5	
4w				3.2 (3.17)	477	126	9.4	2.8	1.3	0.030	<5	
5d	1EE-1H	2	G Ditch draining east end of quarry	2.9 (2.81)	979	280	38	11	4.5	0.14	<5	
5w				2.7 (2.66)	1420	492	32	16	4.0	0.28	<5	
6d	1EE-1H	3	H Pond in centre of quarry	3.5 (3.46)	244	60	2.2	3.1	1.4	0.008	<5	
6w				3.2 (3.26)	401	110	7.5	0.30	3.0	0.02	10	
7d	1EE-1H	3	I Small pool of standing water at north end of quarry	3.5 (3.42)	269	93	8	0.47	1.2	0.014	<5	No sample
8d	1EE-1H	3	J Drainage ditch at south end of quarry	3.2 (3.23)	445	128	7.4	3.0	3.0	0.020	<5	No sample (pool dry)
9d	1EE-1H	K	Wildcat Brook below quarry #3	4.3 (4.39)	45	4	0.75	2.2	0.12	<0.002	260	
9w				4.5 (4.44)	53	11	0.70	2.9	0.31	<0.002	300	
10d	1EE-2M	11	L Ditch draining large central pond	3.7 (3.58)	171	22	1.1	0.34	0.23	0.006	<5	
10w				4.2 (4.17)	101	20	1.1	0.24	0.26	0.007	<5	
11d	1EF-2EE	4	M Ditch draining central pond	3.1 (3.10)	727	280	25	3.4	2.0	0.18	<5	No sample (ditch dry)
12d	1EF-2GG	1	O Road side ditch east of quarry	2.8 (3.11)	1420	602	9.4	47	1.9	0.015		Interference with colour determination
12w				2.9 (3.05)	1400	755	19	48	3.0	0.10		
13d	1EF-2G25	1	S Above outlet of small brook below quarry to N. Lahave River.	4.6 (4.44)	68	16	0.98	0.40	1.7	0.005	10	
13w				4.9 (6.70)	46	11	0.56	0.86	1.5	0.003	40	

* d - dry conditions

* w - wet (rainy) conditions

TABLE 5
ACID PRODUCING POTENTIAL AND ACID CONSUMING ABILITY OF SAMPLES

Map No.	Watershed No.	Quarry No.	Sample Site	lbs/ton		Comments
				Acid Producing Potential	Acid Consuming Ability	
11D/13	IEJ-4D	1	AA	178	7.0	3 ft. channel sample from SE part of quarry
11D/13	IEJ-4D	1	BB	73.4	10.8	10 ft. channel sample taken from a "rip" in the NW part of quarry
21A/7	IEE-1H	1	CC	85.7	6.6	3 ft. channel sample from central part of quarry
21A/7	IEE-1H	1	DD	67.3	3.9	grab sample from pile of finely crushed rock at SE end of quarry
21A/7	IEE-1H	2	EE	245	7.8	3 ft. channel sample from central part of quarry
21A/7	IEE-1H	2	FF	355	8.3	5 ft. channel sample from a "rip" in central part of quarry
21A/7	IEE-1H	3	GG	220	7.5	composite sample of chips from central slate pile
21A/7	IEE-2H	11	HH	30.6	10.3	3 ft. channel sample from E end of quarry
21A/17	IEF-2DD	2	II	91/8	3.0	5 ft. channel sample taken from "rip" at N end of quarry
21A/7	IEF-2GG	1	JJ	147	8.1	3 ft. channel sample 20 ft. back from central working face
21A/7	IEF-2GG	1	KK	245	54.9	3 ft. channel sample from working face
21A/10	IEF-2G25	1	LL	337	12.3	5 ft. channel sample from central part of quarry
21A/10	IEF-2L		MM	91.8	2.94	grab sample from pile of pebble-sized crushed material
21A/10	IEF-2L	2	NN	195.2	5.88	3 ft. channel sample from N end of quarry

4.0 RESULTS

Quarry locations are shown on maps included as Appendix B. Results of analyses of water samples from 13 sites in 11 quarries are shown in Table 4. Several sites were not sampled during the dry periods due to lack of runoff at these times. Three sampling gaps exist in the wet period data either because the site was not visited at this time (V and W), or because the water body was no longer present (I).

Acid producing potential and consuming ability of 14 rock samples from 10 quarries are shown in Table 5. Appendix A contains photos of selected quarries that were visited during the project. Rock pit locations are shown on the maps in appendix B and were obtained from working copies of quarry and borrow pit maps compiled by the Nova Scotia Department of Mines. Sand and gravel pits were the main target of this mapping, therefore some slate pits may not be shown. Additional pits were located during field trips. It was not possible to confirm the locations of all pits in the time available for the study. The 27 confirmed pits are identified by corresponding area estimates given on the maps.

5.0 DISCUSSION

In North America, one of the areas displaying the most marked symptoms of surface water acidification is southwestern Nova Scotia. A significant portion of this area is underlain by bedrock of the Halifax Formation (See Figure 1). The Halifax Formation is noted for broad occurrences of pyritiferous mineralization. Due to well-defined cleavage planes, slates of the Halifax Formation are easily excavated with heavy equipment. The excavated material is slab-like and therefore makes a good base for surfacing gravel roads. Slate quarries and borrow pits are prolific in this formation and many of the unpaved roads in Lunenburg County, where the majority of the reconnaissance was done, are surfaced with the material. Information on locations of roads surfaced with slate in Lunenburg County, and the source of the material, was requested from the Department of Transportation office in Bridgewater, but was not received in time to be included in this report.

As is evident by the maps, pits and quarries are plentiful in the parts of the Halifax Formation shown. Many are active on a daily basis, others are active on demand, while some appear to have been inactive for some time.

Virtually all of the 27 quarries and borrow pits within the Halifax Formation, visited in the duration of this study, showed a high degree of visible sulphide mineralization. In some of the pits (1EJ-4D/1, 1EF-2L/1, 1EF-2GG/1), a thick red sludge coated drainage ditches suggesting the hydrolysis and subsequent precipitation of ferric iron released through the oxidation of iron sulphides. Melanterite ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) was commonly present as a white powdery coating on rock surfaces. This is a by-product of the oxidation of the mineral

marcasite (FeS_2) and other iron sulphides. Limonite, a general term for iron hydroxide minerals, is another by-product of acid drainage, and was ubiquitous in all the quarries, present as rust-coloured staining.

Except for site L, all quarry water samples were generally characteristic of acid drainage (Table 4), exhibiting low pH, elevated sulphate, aluminum, iron and manganese. Samples 9 and 13, not from quarries, exhibit little of any of these qualities, although iron is somewhat elevated in Wildcat Brook (sample 9).

Samples collected during the dry period were expected to exhibit less severe indications of acid drainage than those collected during rainfall. Some studies have reported a decrease in pH of runoff from exposed slates during rainfall due to acid washed from rock surfaces (EPS 1976; Pettipas 1979). From the limited number of samples taken, though, there appears to be little correlation between precipitation and acid drainage impact. Correlation may have been more apparent had the sampling been done nearer the beginning of the precipitation event and more frequently. It should be noted, however, that even if the pH of drainage waters remains the same during a precipitation event, the resultant increase in volume of drainage water may still serve to increase acid loadings from a quarry.

The brook that runs below part of quarry 1EF-2G25/1 (Table 4) had a much higher pH during the wet sampling period (pH 6.21) than the dry (pH 4.44.). This may have been due to a large input of water upstream, unaffected by the quarry, that tended to dilute any quarry runoff reaching the stream.

Samples, taken from the shore of Little Springfield Lake, in Middle Sackville during this study, indicate extreme lake acidification (pH 3.43 and pH 3.45). This is consistent with the findings of Kerekes

et al (1984) (See Table 3). A brook originates in quarry 1EJ-4D/1 and enters this lake approximately 400 m away. Water samples from the brook where it leaves the quarry were also collected for this report and indicate that at least part of the lake acidification is attributable to oxidation of sulphide minerals within the quarry. The samples exhibited pH readings of 2.70 and pH 2.72 respectively (Table 4).

The suggestion that the quarries are the source of the acid in the waters draining from them is consistent with the results of the rock sample analysis shown in Table 5. Standard interpretation suggests that the ratio of acid producing potential to acid consuming ability should be less than one for a sample to be considered non-acid. Acid consuming ability should be less than one for a sample to be considered non-acid producing (Duncan 1972). In Nova Scotia, the 1:1 ratio is commonly considered the upper limit of safety when projects involving exposure of slate are evaluated for potential environmental hazards. Every sample analyzed surpassed this ratio. The acid producing potential in excess of acid consuming ability of the samples ranged from 1.3 to 182.9 lbs/ton. The quarry yielding the lowest excess acid producing potential (1DD-2M/11) also had the highest drainage water pH (sample L, pH 3.48 and 4.17).

It should be noted that sulphide mineral content and thus acid producing potential and acid consuming ability are extremely variable in the Halifax Formation. Even though an attempt was made to take mineralogically representative samples of bedrock sections or homogeneous crushed material, some sections of individual pits may yield an acceptable acid producing to consuming ratio. However, the results of analyses of quarry drainage samples indicate that enough sulphides are present in every quarry sampled to cause acid drainage to some degree.

In order to define the extent of acid drainage from the pits, water quality data would have to be collected over time, in conjunction with hydrologic information.

The relevance of acid drainage in Nova Scotia to LRTAP studies depends on the areal extent, persistence and degree of resultant acidification. Practical considerations, such as the location of the past, present and future surface water sampling sites for LRTAP studies in relation to acid drainage occurrences are also important.

A small isolated acid drainage event may temporarily impair water quality within its sphere of influence by depressing pH and causing abnormally high metal concentrations, and may even be responsible for a fish kill. However, the confined boundaries of such an event in space and time may make it relatively insignificant in interpreting water quality data for LRTAP studies. On the other hand, the cumulative effects of several small intermittent and/or on-going acid drainage events within the same geographical area could produce a significant addition to the acidification of a large aquatic system over a prolonged period of time.

The Halifax Formation is areally extensive in Lunenburg and Halifax Counties. Quarries and slate pits are numerous in this formation and a high degree of sulphide mineralization is common. Rock samples taken from a cross-section of the pits indicate that all those sampled are potentially acid producing. All but two of the ten pits sampled are active on a regular basis. Pit 1EF-2G25/1 (Northfield Quarry) has been inactive for several years, and 1EE-1H/3d is intermittently active. Analysis of water samples taken from pit drainage waters showed pH to be consistently low. Material from these quarries is used to surface many

roads in and around the study area. If the material continues to acidify runoff after emplacement, the occurrence of acid drainage may be areally extended.

Studies of the acid drainage problem at the Halifax International Airport (e.g. Porter Dillon 1985; Lund 1985; EPS 1976; Thompson 1978) show that the degree of acidification by acid drainage arising from mineralized sections of the Halifax Formation can even exceed that associated with LRTAP. Porter Dillon (1985) identified a trend of decreasing metals concentrations downstream of the Halifax Airport and linked it to acid drainage originating at the airport. As far as approximately 9 km downstream in the Williams Lake system, water quality was still considered to be toxic to fish. The pit drainage samples analyzed for the current study show that, before dilution, these waters contain H^+ concentrations considerably higher than those expected from LRTAP.

The persistence of the acid drainage phenomenon in Nova Scotia can be illustrated in several ways. Acid drainage from the Halifax International Airport was first documented by Scott in 1961 and has continued, at least episodically, to the present. Continuation in this case is linked to on-going construction within the airport complex (e.g. EPS 1976) leading to fresh exposures of pyritiferous bedrock. Also significant here is the indefinite duration from initial exposure to eventual consumption of sulphides through oxidation to the point that significant amounts of acid are no longer generated.

Kerekes et al (1984) linked low pH and high metals in Little Springfield Lake to oxidation of sulphide minerals in the lake's watershed. Rock samples from the only slate pit in the watershed

(1EJ-4D/1) reinforce this suggestion. Water samples from this lake show that it continues to be very acidic (pH 3.45 and 3.43) to the present.

Standing water in the Northfield Quarry (1EF-2G25/1) was analyzed in 1978, shortly before use of the quarry was discontinued. These samples were found to exhibit low pH (field pH 2.8, laboratory pH 3.0) and high metals concentrations (See Section 2.4). Samples taken for the current study show pH of standing quarry water is still depressed (sample T, pH 2.64; sample U, pH 2.49).

The examples above illustrate that, in areas underlain by the Halifax Formation or receiving crushed rock from this formation, the possibility exists for a significant input over an indefinite time period to acidification of fresh water systems by acid drainage. This becomes especially relevant when interpreting water quality data to assess the impact of LRTAP on these systems.

6.0 SUMMARY AND CONCLUSIONS

Reconnaissance was done in parts of Lunenburg and Halifax Counties underlain by the Halifax Formation to sample quarry rock and drainage waters. Observations were also made of any indications that acid drainage may be taking place in these areas. This was done with a view to assessing the possibility that, in areas underlain by the Halifax Formation, acid drainage might be a significant source of acidity to aquatic environments and, as such, should receive attention in LRTAP related studies.

The large number of pits and quarries in the Halifax Formation, and the widespread use of crushed rock from them, indicate extensive areal distribution and likely exposure of the aquatic system to highly mineralized bedrock associated with this formation. Sulphide mineralization within quarries in the Halifax Formation were observed to be the rule rather than the exception.

Water samples were taken at 13 sites in and around 11 pits and quarries after several days of no precipitation and again during a precipitation event. Results of analyses indicate that these quarries are generating acid drainage. Two water bodies, Springfield Lake (sample site kB, H 3.43 and 3.45) and Wildcat brook (sample site K, pH 4.39 and 4.44), located near quarries, showed low pH but background values are not known. A brook below quarry 1EF-2G25/1 produced low pH water during dry sampling with a much higher pH during rainfall (sample site S, pH 4.44 and 6.70). This is believed to be caused by a large input of unaffected water upstream of the quarry that diluted quarry drainage reaching the brook.

Rock analyses indicate that the 14 samples collected from 10 different quarries are all potentially acid producing with all but one yielding an acid producing potential of 24 lb/ton in excess of acid

consuming ability. Eight of these quarries are active on a regular basis. In three instances (samples DD, GG, MM) samples were taken from stockpiles which were destined for use as road construction material.

The persistence that acid drainage from rock of the Halifax Formation can attain is best illustrated by the case of the Halifax International Airport. Acid drainage from the airport was first identified in 1961 and has continued to be a problem ever since. This study has shown that the pH of water in Springfield Lake is still depressed to at least the level indicated by Kerekes et al. in 1984 (pH 3.6), and that, in part, the acidity source is likely the nearby quarry (1EJ-fD/1. Excess acid producing potential of samples AA and BB from this quarry are 97.7 and 43.1 lbs/ton respectively.

The 1978 data from Northfield Quarry (1EF2G25/1), a source of slate linked to the 1977 fish kill in Patten Brook, show, among other things, a quarry standing water laboratory pH of 3 and a field pH of 2.8. Northrhfield quarry was abandoned in 1978, and there has presumably been no fresh rock surfaces exposed since then. Two samples of standing water taken from the quarry during rainfall indicate that enough acid is still being generated within the quarry to acidify runoff (pH 2.64 and 2.49).

Past work and results of analyses done for this study show there exists in Nova Scotia the potential for significant contribution to the acidification of water systems by acid drainage. The geology of some areas of Nova Scotia dictates this potential and should therefore be considered in LRTAP studies.

7.0 RECOMMENDATIONS

1. Evaluate possible slate pit and excavation sampling methods with a view to establishing a realistic standard for the determination of acid generation. Such an investigation would include experimental work with both rock and quarry drainage sampling techniques.
2. Inherent in the above recommendation is the need to better understand the relationship between acid producing potential and acid consuming ability. This would involve testing of the widely accepted method of interpreting these parameters which suggests that a one to one ratio is the upper limit of acceptability below which any acid produced will be neutralized. Of interest is whether acid consuming ability of a given rock can become available at a rate equal to acid generation.
3. Building on these two recommendations, it is further recommended that acid and metal loadings from one or more slate quarries be quantified. This should be done after the acid generation potential of the quarry is fully characterized and could be used as a check and a calibration for the findings of the previous recommendations. A hydrologic budget should be kept over a period of time in conjunction with water quality data. If carried on over an extended duration, it may also be possible to draw conclusions about the persistence of acid drainage from exposed slates with this data.

4. It is also recommended that the inventory of slate pits and quarries within the Halifax Formation started here be continued. These should be mapped at a suitable scale and assigned a level of activity, e.g. active on a regular basis, active on demand, or inactive. Additional information, such as pH of drainage waters, acid producing potential of quarry rock, area of exposure and proximity to water supplies could also be compiled.

5. Work to delineate which areas of the Halifax Formation in Nova Scotia are most prone to acid generation is recommended. Sulphide content of this unit seems to be stratigraphically controlled and so this work may take the form of geological mapping. The use of reconnaissance by geophysical and geochemical methods for this purpose should also be investigated.

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APPENDIX A



Photo 1. Quarry 1EF-2DD/2



Photo 2. Quarry 1EJ-4D/1



Photo 3. Quarry 1EE-1H/1



Photo 4. Quarry 1EF-2L/1 in foreground with 1EF-2L/2 in background



Photo 5. Quarry 1EF-2L/2



Photo 6. Quarry 1EF-2G25/1 (Northfield Quarry)



Photo 7. Quarry 1EE-1H/3



Photo 8. Quarry 1EK-1RR/1 (Dollar Lake Quarry)



Photo 9. Quarry 1EE-1H/2



Photo 10. Pyritic mineralization in bedrock section of Quarry 1EE-1H/2

ACID DRAINAGE MAP

CANADA

NOVA SCOTIA
WATERSHED AREAS

LEGEND

DRAINAGE INDEX DIVISION

- 1 DE Primary Division Number, Boundary
- 1 DE-1 Secondary Division Number, Boundary
- 1 DE-1A Tertiary Division Number, Boundary
- SD Shoreline Direct Inflow to Salt Water

- control structure
- Water Supply Area
- Gauging Stations
- Flow Direction

NOTE: All measurements are in hectares and are for this map sheet only. Refer to adjacent map sheets or printed tabulation for complete watershed area.
- Areas unnamed are land
- Areas named are water

Conversion factor (1 hectare = 2.471 Acres)

Watershed information compiled and drawn by Maritime Resource Management Service, Amherst, N.S., 1980.

Base map supplied by Surveys and Mapping Branch, Department of Energy Mines and Resources.

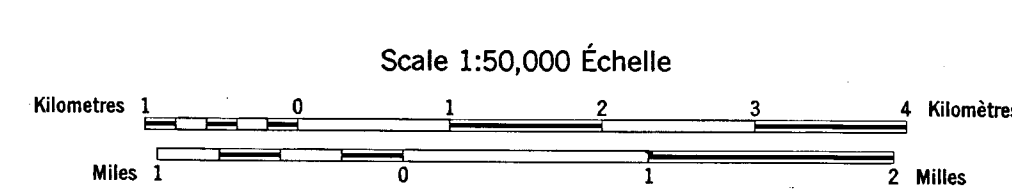
- Government of Canada
- Government of Nova Scotia
- Regional Economic Expansion
- Provincial Economic Expansion

WATERSHED NUMBER	LAND USE DATA (HECTARES)	WATERSHED NUMBER	LAND USE DATA (HECTARES)
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2	2000	200	2000
3	3000	300	3000
4	4000	400	4000
5	5000	500	5000
6	6000	600	6000
7	7000	700	7000
8	8000	800	8000
9	9000	900	9000
10	10000	1000	10000
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97	97000	9700	97000
98	98000	9800	98000
99	99000	9900	99000
100	100000	10000	100000

Note: The watershed boundaries and the digitized watershed areas were delineated by HRMS based on up-to-date topographic maps. If there are any discrepancies with actual drainage boundaries, please notify: N.S. Department of the Environment, P.O. Box 2107, Halifax, Nova Scotia B3J 3B7

- Geological Boundary
- Fault
- Quarry Location and Identification Number
- Approximate quarry area (acres)
- NAQUADAT Station
- Hydrometric Station

BRIDGEWATER
NOVA SCOTIA

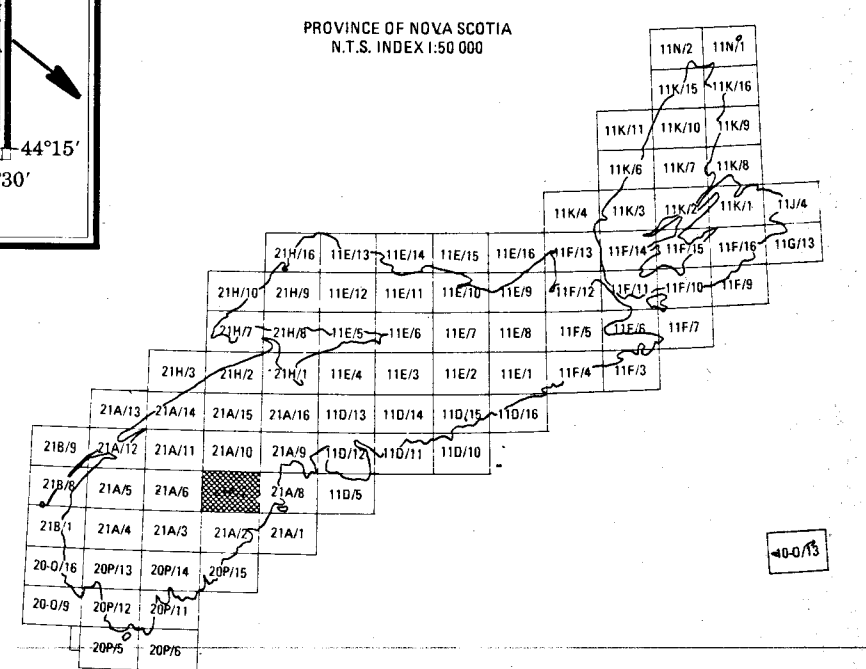


Bedrock Geology

- Carboniferous
- ECw Undivided Windsor Group
- ECw C-E subzone
- ECw B subzone
- ECw A subzone
- Devonian-Carboniferous
- DGt Granitoid
- DGng Monzo-granite

Bedrock Geology

- Devonian
- Dgt Granitoid
- Cambrian-Ordovician
- Meguma Group
- Halifax Formation
- Goldenville Formation



ACID DRAINAGE MAP

21 A/8

1:50,000

CANADA

EDITION 2

21 A/8

NOVA SCOTIA WATERSHED AREAS

LEGEND

DRAINAGE INDEX DIVISION

- 1DE Primary Division Number, Boundary
- 1DE-1 Secondary Division Number, Boundary
- 1DE-1A Tertiary Division Number, Boundary
- SD Shoreline Direct Inflow to Salt Water



NOTE: All measurements are in hectares and are for this map sheet only. Refer to adjacent map sheets or printed tabulation for complete watershed area.

Areas unmarked are land

Areas named are water

Conversion factor (1 hectare = 2.471 Acres)

Watershed information compiled and drawn by Maritime Resource Management Service, Amherst, N.S., 1980.

Base map supplied by Surveys and Mapping Branch, Department of Energy Mines and Resources.



WATERSHED	AREA	WATER
100-01	1	100-01
100-02	2	100-02
100-03	3	100-03
100-04	4	100-04
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100-06	6	100-06
100-07	7	100-07
100-08	8	100-08
100-09	9	100-09
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100-11	11	100-11
100-12	12	100-12
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100-66	66	100-66
100-67	67	100-67
100-68	68	100-68
100-69	69	100-69
100-70	70	100-70
100-71	71	100-71
100-72	72	100-72
100-73	73	100-73
100-74	74	100-74
100-75	75	100-75
100-76	76	100-76
100-77	77	100-77
100-78	78	100-78
100-79	79	100-79
100-80	80	100-80
100-81	81	100-81
100-82	82	100-82
100-83	83	100-83
100-84	84	100-84
100-85	85	100-85
100-86	86	100-86
100-87	87	100-87
100-88	88	100-88
100-89	89	100-89
100-90	90	100-90
100-91	91	100-91
100-92	92	100-92
100-93	93	100-93
100-94	94	100-94
100-95	95	100-95
100-96	96	100-96
100-97	97	100-97
100-98	98	100-98
100-99	99	100-99
100-100	100	100-100

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- Legend**
- Geological Boundary
 - Fault
 - Quarry Location and Identification Number
 - (3) Approximate quarry area (acres)
 - NAQUADAT Station
 - Hydrometric Station

LUNenburg
NOVA SCOTIA

Scale 1:50,000 Échelle

Kilometres 1 0 1 2 3 4 Kilometres

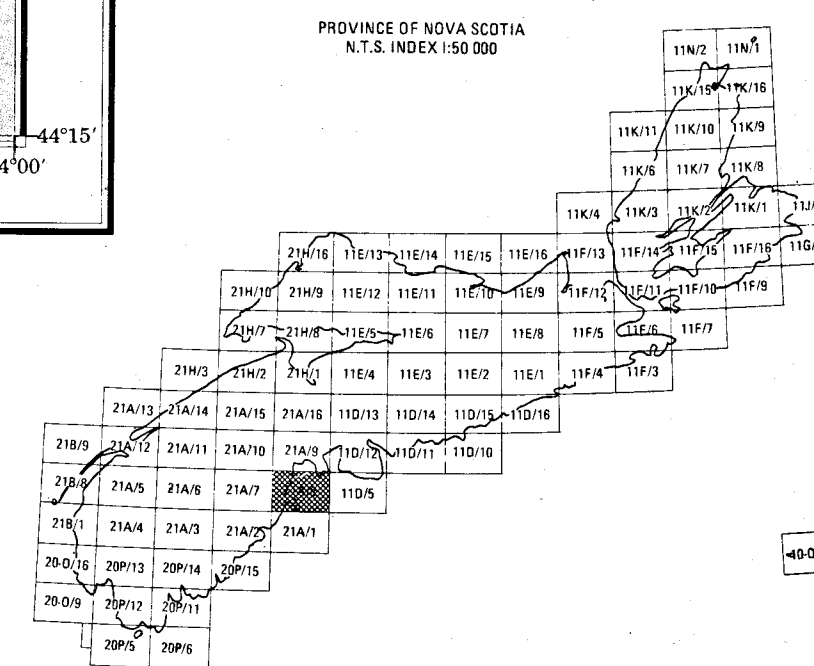
Miles 1 0 1 2 Miles

Bedrock Geology

- Carboniferous
- ECW Undivided Windsor Group
- ECWc C-E subzone
- ECWb B subzone
- ECWa A subzone
- Devonian-Carboniferous
- DCgt Granitoid
- DCmg Monzo-granite

Bedrock Geology

- Devonian
- Dgt Granitoid
- Cambrian-Ordovician
- Meguma Group
- COu Halifax Formation
- COg Goldenville Formation



PROVINCE OF NOVA SCOTIA
N.T.S. INDEX 1:50,000

48°45'
63°30'

Map sheets shown include: 2162, 2161, 2160, 2159, 2158, 2157, 2156, 2155, 2154, 2153, 2152, 2151, 2150, 2149, 2148, 2147, 2146, 2145, 2144, 2143, 2142, 2141, 2140, 2139, 2138, 2137, 2136, 2135, 2134, 2133, 2132, 2131, 2130, 2129, 2128, 2127, 2126, 2125, 2124, 2123, 2122, 2121, 2120, 2119, 2118, 2117, 2116, 2115, 2114, 2113, 2112, 2111, 2110, 2109, 2108, 2107, 2106, 2105, 2104, 2103, 2102, 2101, 2100, 2099, 2098, 2097, 2096, 2095, 2094, 2093, 2092, 2091, 2090, 2089, 2088, 2087, 2086, 2085, 2084, 2083, 2082, 2081, 2080, 2079, 2078, 2077, 2076, 2075, 2074, 2073, 2072, 2071, 2070, 2069, 2068, 2067, 2066, 2065, 2064, 2063, 2062, 2061, 2060, 2059, 2058, 2057, 2056, 2055, 2054, 2053, 2052, 2051, 2050, 2049, 2048, 2047, 2046, 2045, 2044, 2043, 2042, 2041, 2040, 2039, 2038, 2037, 2036, 2035, 2034, 2033, 2032, 2031, 2030, 2029, 2028, 2027, 2026, 2025, 2024, 2023, 2022, 2021, 2020, 2019, 2018, 2017, 2016, 2015, 2014, 2013, 2012, 2011, 2010, 2009, 2008, 2007, 2006, 2005, 2004, 2003, 2002, 2001, 2000, 1999, 1998, 1997, 1996, 1995, 1994, 1993, 1992, 1991, 1990, 1989, 1988, 1987, 1986, 1985, 1984, 1983, 1982, 1981, 1980, 1979, 1978, 1977, 1976, 1975, 1974, 1973, 1972, 1971, 1970, 1969, 1968, 1967, 1966, 1965, 1964, 1963, 1962, 1961, 1960, 1959, 1958, 1957, 1956, 1955, 1954, 1953, 1952, 1951, 1950, 1949, 1948, 1947, 1946, 1945, 1944, 1943, 1942, 1941, 1940, 1939, 1938, 1937, 1936, 1935, 1934, 1933, 1932, 1931, 1930, 1929, 1928, 1927, 1926, 1925, 1924, 1923, 1922, 1921, 1920, 1919, 1918, 1917, 1916, 1915, 1914, 1913, 1912, 1911, 1910, 1909, 1908, 1907, 1906, 1905, 1904, 1903, 1902, 1901, 1900, 1899, 1898, 1897, 1896, 1895, 1894, 1893, 1892, 1891, 1890, 1889, 1888, 1887, 1886, 1885, 1884, 1883, 1882, 1881, 1880, 1879, 1878, 1877, 1876, 1875, 1874, 1873, 1872, 1871, 1870, 1869, 1868, 1867, 1866, 1865, 1864, 1863, 1862, 1861, 1860, 1859, 1858, 1857, 1856, 1855, 1854, 1853, 1852, 1851, 1850, 1849, 1848, 1847, 1846, 1845, 1844, 1843, 1842, 1841, 1840, 1839, 1838, 1837, 1836, 1835, 1834, 1833, 1832, 1831, 1830, 1829, 1828, 1827, 1826, 1825, 1824, 1823, 1822, 1821, 1820, 1819, 1818, 1817, 1816, 1815, 1814, 1813, 1812, 1811, 1810, 1809, 1808, 1807, 1806, 1805, 1804, 1803, 1802, 1801, 1800, 1799, 1798, 1797, 1796, 1795, 1794, 1793, 1792, 1791, 1790, 1789, 1788, 1787, 1786, 1785, 1784, 1783, 1782, 1781, 1780, 1779, 1778, 1777, 1776, 1775, 1774, 1773, 1772, 1771, 1770, 1769, 1768, 1767, 1766, 1765, 1764, 1763, 1762, 1761, 1760, 1759, 1758, 1757, 1756, 1755, 1754, 1753, 1752, 1751, 1750, 1749, 1748, 1747, 1746, 1745, 1744, 1743, 1742, 1741, 1740, 1739, 1738, 1737, 1736, 1735, 1734, 1733, 1732, 1731, 1730, 1729, 1728, 1727, 1726, 1725, 1724, 1723, 1722, 1721, 1720, 1719, 1718, 1717, 1716, 1715, 1714, 1713, 1712, 1711, 1710, 1709, 1708, 1707, 1706, 1705, 1704, 1703, 1702, 1701, 1700, 1699, 1698, 1697, 1696, 1695, 1694, 1693, 1692, 1691, 1690, 1689, 1688, 1687, 1686, 1685, 1684, 1683, 1682, 1681, 1680, 1679, 1678, 1677, 1676, 1675, 1674, 1673, 1672, 1671, 1670, 1669, 1668, 1667, 1666, 1665, 1664, 1663, 1662, 1661, 1660, 1659, 1658, 1657, 1656, 1655, 1654, 1653, 1652, 1651, 1650, 1649, 1648, 1647, 1646, 1645, 1644, 1643, 1642, 1641, 1640, 1639, 1638, 1637, 1636, 1635, 1634, 1633, 1632, 1631, 1630, 1629, 1628, 1627, 1626, 1625, 1624, 1623, 1622, 1621, 1620, 1619, 1618, 1617, 1616, 1615, 1614, 1613, 1612, 1611, 1610, 1609, 1608, 1607, 1606, 1605, 1604, 1603, 1602, 1601, 1600, 1599, 1598, 1597, 1596, 1595, 1594, 1593, 1592, 1591, 1590, 1589, 1588, 1587, 1586, 1585, 1584, 1583, 1582, 1581, 1580, 1579, 1578, 1577, 1576, 1575, 1574, 1573, 1572, 1571, 1570, 1569, 1568, 1567, 1566, 1565, 1564, 1563, 1562, 1561, 1560, 1559, 1558, 1557, 1556, 1555, 1554, 1553, 1552, 1551, 1550, 1549, 1548, 1547, 1546, 1545, 1544, 1543, 1542, 1541, 1540, 1539, 1538, 1537, 1536, 1535, 1534, 1533, 1532, 1531, 1530, 1529, 1528, 1527, 1526, 1525, 1524, 1523, 1522, 1521, 1520, 1519, 1518, 1517, 1516, 1515, 1514, 1513, 1512, 1511,

ACID DRAINAGE MAP
CANADA

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EDITION 3

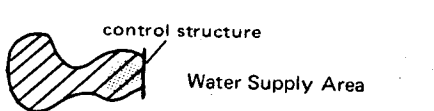
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NOVA SCOTIA
WATERSHED AREAS

LEGEND

DRAINAGE INDEX DIVISION

- 1 DE Primary Division Number, Boundary
1 DE-1 Secondary Division Number, Boundary
1 DE-1A Tertiary Division Number, Boundary
SD Shoreline Direct Inflow to Salt Water



NOTE: All measurements are in hectares and are for this map sheet only. Refer to adjacent map sheets or printed tabulation for complete watershed area.

Areas named are "Lead" Areas named are water

Conversion factor (1 hectare = 2.471 Acres)

Watershed information compiled and drawn by Maritime Resource Management Service, Amherst, N.S., 1980.

Base map supplied by Survey and Mapping Branch, Department of Energy Mines and Resources.

Government of Canada
Provincial Government
Provincial Government

PROVINCE OF NOVA SCOTIA

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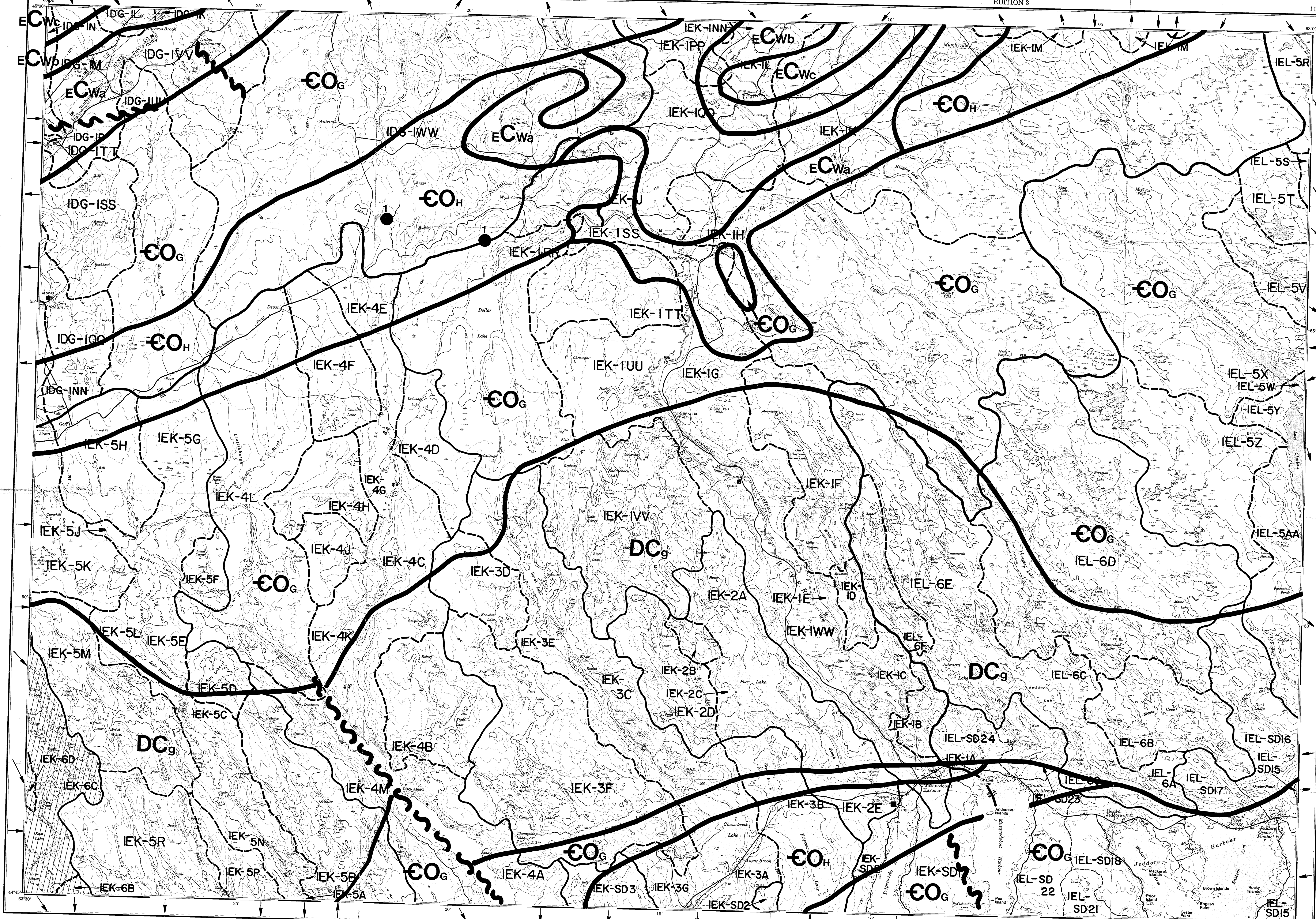
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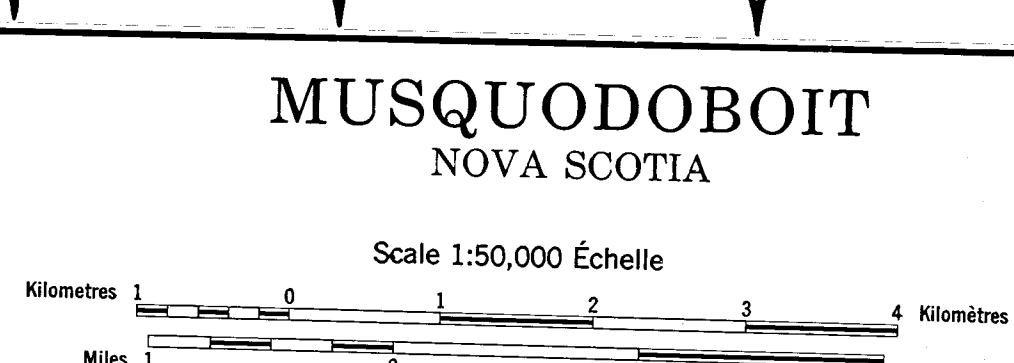
NOVA SCOTIA

NOVA SCOTIA



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