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Ontario Geological Survey MAP 80 756 **GEOCHEMICAL SERIES** 

## Preliminary Studies of Lake Sediment Geochemistry in an Area Northeast of Sudbury

Sudbury and Temiskaming Districts NTS References: 41 I/15; 41 P/2,7,10 DDM-GSC Aeromagnetic Maps: 284G, 1512G, 1513G, 1514G ODM-OGS Geological Compilation Maps: 2221, 2419

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demic Press. 1983.

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#### "Much information on the distribution of chemical elements in rocks and their redistribution in the surface environment has been obtained as a result of progress in geochemistry, particularly during the ast decade. Nevertheless, levels of trace elements and to a lesser extent those of major elements cannot be predicted reliably using geological maps." J.A. Plant and R. Raiswell, Applied Environmental eochemistry, p.36, edited by lan Thornton, Aca-

## INTRODUCTION

During the late 1970s the Ontario Geological Survey and the Geological Survey of Canada jointly completed a series of reconnaissance geochemical maps based on lake sediments and waters in the area along the northern shore of Lake Superior and urther west. These maps (GSC-OGS 1978a, 1978b, 1979a, 1979b) included information on the pH of waters of some 4600 lakes.

In 1980 the Ontario Geological Survey comenced a research program aimed at the study of effects of "acid rain" on lakes to the north and east of Lake Superior with the general objective of relating the geochemical stratigraphy of deep basin lake ediments to the acid rain problem. This work was carried out by a team including a limnologist (M. Dickman, Professor, Brock University), a palynologisi Terasmae, Professor, Brock University) and geochemical staff of the Ontario Geological Survey Fortescue et al. 1981, 1984). Briefly, by 1983 a nethod had been developed for the description of the pH history of lakes, which is based on detailed studies of the abundance of diatoms in the top

25 cm of lake sediment (Dickman and Fortescue Prior to 1983, all of the studies by the team had been concerned with lakes located to the north and east of Lake Superior, especially around Wawa Fortescue et al. 1981, 1984). In 1983 it was decided o test the methods that were developed around Nawa in a new area where different limnological nd geochemical conditions were to be expected. The 1983 study was completed northeast of Sudbury

where lakes known to have been affected by acid rain from the Sudbury smelters occur. The team completed the field work during a 0-day period in late July and early August, 1983 Chemical analysis of the waters and lake sedimen aterial were completed during the Winter of 1983/84. This broadsheet was compiled in the Sum-

### OBJECTIVES

mer of 1985.

The project had the following objectives: to complete a limnological/geochemical study of 40 lakes located in a 100 by 10 km sampling strip extending northward from Lake Wanapitei across the area affected by the fallout of chemicals from the plume from the Sudbury

- smelters in order to establish a working curve for future diatom-inferred pH measurements i the area and to establish the effects of the Sudbury smelter fallout on the geochemistry of surface midbasin lake sediments to intensively study a 10 by 10 km area located within the sampling strip to establish a technique for regional geochemical sampling of lake
- sediments in the area affected by smelter fallout of trace elements to draw conclusions from the limnological and geochemical studies concerning planning of future regional geochemical mapping in the area

### METHODOLOGY . CHOICE OF STUDY AREA

The 10 km wide sampling strip extends 100 km north rom the shore of Lake Wanapitei (Figure 1) and includes Frederick Lake, Solace Lake, Smoothwater ake and across Highway 560 to Longpoint Lake Figure 2). The area was located using the overprined U.T.M. arid on 1:50 000 National Topographic Series maps and was subdivided into 10 by 10 km quares (i.e. micromodules, see Fortescue 1983) hese were further subdivided into 5 by 5 km squares (micromodule quarters, see Fortescue 984); within each micromodule quarter 1 lake was dentified for study. The lakes are referred to by the code letters which are plotted on Figure 2. Within he sampling strip a 10 by 10 km area was desgnated for intensive sampling (Figure 3). This area cludes sample Lakes R3, R4, Q1, and Q2 (Figur ). The intensive sampling area was divided into 16 2.5 km squares. Two lakes or ponds were designated for sampling within each of these squares.



Figure 1, Location of the area sampled. The extensive sampling area is highlighted.

Almost all of the sampling strip is underlain by ne Gowganda Formation or the Lorrain Formation oth belonging to the Huronian Supergroup of Middle Precambrian age. The Gowganda Formation is a heterogeneous sequence of conglomerate, arkose, and wacke. The Lorrain Formation is a sandstone with local siltstone and quartz-pebble paraconglomerate beds (Dressler 1982). In general, the bedrock's contribution of elements to the lake sediments in the area was expected to be low. Con-

sequently, if calcareous drift is absent in the area. then lakes that are low in nutrients (i.e. oligotrophic lakes) are likely to be common. The area that was chosen for the intensive study is also within the Sudbury smelter plume. This should result in a lower pH of lakes due to acid rain fallout and which would also provide abnormal amounts of nickel and copper in the topmost lake sediment (i.e. Post-Ambrosia) material.

. SAMPLING PROCEDURE Similar limnological and geochemical sampling methods were applied to the sampling strip as a

whole and to the lakes included in the area selected



Figure 2.Location of the lakes included in the extensive phase of the study.

#### work was completed using a crew of 3 in a Bell 206 helicopter fitted with floats. Under favourable con ditions, the team was able to sample up to 30 lakes per day.

for detailed study. Within the sampling strip, field

At each lake sample point, the limnologist described the setting of the lake and the general nature of its waters. Observations of the pH, temperature, conductivity, and dissolved oxygen in the water column were made at 1 m intervals to the bottom of the lake using a special probe (Hydroprobe). Secchi disc depths were also taken. Sampling of the water was carried out using an integrating sampler to a depth of 5 m in deep lake and from the surface in shallow lakes. One litre samples of water were collected from each lak Lake sediment material was collected using an Ekman dredge to sample surface sediment. The same procedure was used for the collection of samples and information from the area where detailed sampling was completed except that, instead of an Ekman sampler, a gravity sampler

(developed by the Ontario Geological Survey) was used to obtain short cores (i.e. 30 to 50 cm long). The pH of the water samples together with alkalinity was determined within 24 hours of collection in a laboratory set up at the base camp. After the intensive area sampling was completed, 2 long (about 50 cm) sediment cores were obtained from selected lakes for detailed diatom-inferred pH study. SAMPLE PREPARATION

The remainder of the water sample was kept cool in refrigerator and transported to the Geoscience aboratories, Ontario Geological Survey, Toronto,

where pH, sulphate, conductivity, calcium, and magnesium determinations were carried out. The Ekman dredge sediment samples were divided into 2 parts one for diatom measurements and the other for deochemical analysis. The short core from the intersively studied area were kept cool and transported to Toronto for extrusion and sampling. In Toronto, the core was divided into a Pre-Ambrosia subsample (collected from a depth greater than 25 cm) and a Post-Ambrosia subsample (collected from a depth of 0 to 12 cm). The subsamples for chemical analysis were freeze-dried prior to being sent to the Geoscience Laboratories and other contracted laboratories.

#### 4. CHEMICAL ANALYSIS The Ekman samples were submitted to the Geosci

ence Laboratories, Ontario Geological Survey, 1 ronto, for trace element analysis for elements likely to be included in fallout from the smelters at Sudbury (i.e. nickel and copper) and other elements whose content in the sediment was expected to be normal (e.g. zirconium and niobium). The samples from the intensive study were sent for multielement analysis under contract by Barringer Magenta Limit ed, Toronto. In each case a reference standard mixture was prepared for quality control purposes. Su samples of the mixture were submitted for analysis randomized within the batches of unknown samples and the data obtained from them tabulated to pro vide information on the performance of the analytical methods.

## 5. DATA PROCESSING

The results from the study of the diatoms in the Ekman samples were used by M. Dickman and his coworkers to prepare a working curve for the interpretation of diatom data. The curve was then used to interpret data from the 2 sediment cores from the area of detailed sampling. The chemical data was tabulated. For compara tive purposes relating to fallout from the smelter,

nickel, copper, zirconium, and niobium data sets were transformed into Clarke Index-I units by a method described in detail elsewhere (Fortescue, in preparation). Briefly, the Clarke Index-I relates the content of an element in sediment to an estimate for the level of that element in the earth's crust as a whole. When geochemical data that is transformed in this way is plotted using a uniform format from element to element, geochemical comparisons can be made between element patterns based on the use of the Clarke Index-I as a datum. The use of the Clarke Index is of particular interest in geochemical mapping because it provides a datum for comparisons of patterns of elements (i.e. in lake sediments). 6. INTERPRETATION OF THE PATTERNS

#### The data obtained from limnology and geochemistr during the project are tabulated in full on this sheet reference purposes. The results of the project that are pertinent to acid rain and geochemistry are written up under 2 headings; Limnology, and Geochemistry. At the end of this broadsheet some general conclusions are drawn regarding the planning of future regional geochemical surveys in the Sudbury



Figure 3. Location of the lakes and ponds included in the intensive phase of the study.

#### LIMNOLOGY DIATOM-INFERRED pH

Section prepared by M. Dickman bration curve must be constructed. In order to con- carpet on the lake's bottom. struct the Sudbury lakes calibration curve, 39 lakes (Q1 to Z3) were sampled. The pH of their surface water (using a 0 to 5 m integrated sample) was measured, and the surface sediments of each lake were sampled using an Ekman dredge. The ratio of acid to alkaline indicator diatoms in these surface sediments was calculated according to the following formula to give log alpha  $(\log_{\alpha})$ :

 $(R^2 = -0.87, P = 0.01, m = 39)$ . This relationship is described by the equation "Y = 5.86 - 1.25 log alpha" where "Y" is the observed pH.

Log alpha =

et al. 1981; Del Prete and Schofield 1981; Fortescue et al. 1984; Merilainen 1967; Norton et al. 1981; 4) it is evident that the Sudbury lakes are unique. of a rather different group of diatoms than those studied previously (Fortescue et al. 1984). This is evident from the large percentage of alkalophilous indicator (diatom) species in the acid lakes near Sudbury. In the "W" lakes (where pH ranged from 5.1 to 5.7 and alkalinity ranged from -0.84 to +0.5 nicroequivalents/I) up to 59% of the diatom taxa were alkalophilous forms (Table 2). Similarly, in the 'S" lakes where pH ranged from 4.9 to 7.0, and alkalinity from -1 to 11.9 microequivalents/l, the per-

75% (Lake S1, Table 3). Thus the Sudbury lakes are unique in their high percentage of alkalophilous Notwithstanding the above, it is still possible to use the calibration curve (Figure 4) to estimate the paleo-pH of a lake from its downcore diatom log alpha. This was attempted for only 2 of the study lakes, Lake KN4 (Figure 5) and Lake KH4 (Figure 6). The Ambrosia rise in Lake KN4 (Figure 5) occurs at 15 cm. It occurs at 16 cm (Figure 6) in Lake KH4. roughly the same for both of these lakes. Lake KH4 s moderate in depth (21 m) and well oxygenated at the bottom. Its Secchi transparency (15.4 m) and its deep blue colour indicate that the lake is og lake with humic rust-orange coloured water (Secchi depth of 0.7 m). The temperature-corrected conductivity of both

KH4, and 29 to 41 microequivalents/I for Lake KN4). Their pH range is also similar (4.8 to 5.0 for Lake able, particularly within the topmost 5 m of the wa-KH4, and 4.5 to 5.7 for Lake KN4). The profundal waters of the bog lake (KN4), however, are nearly



DIATOM-INFERRED pH Figure 5. Downcore diatom-interred pH for bog Lake



% acidophilic diatoms + % acidobiontic diatoms X 5 % alkalophilic diatoms + % alkalobiontic diatoms X 5 Log alpha ranges from a high of 1.65 to a low of

centage of alkalophilous diatoms ranged as high as

Before it is possible to infer the pH of a lake based anaerobic while those of the oligotrophic lake (KH4) on its sediment diatom species composition, a cali- are supersaturated with oxygen due to the moss During the past 30 years (0 to 5 cm assuming a average sedimentation rate of 1.6 mm/year) the diatom-inferred pH of the bog lake (KN4) has fluctuated between 4.3 and 4.7 with a mean pH of 4.5 (Figure 5). Thus there is no indication that this lake has been acidifying during the last 30 years. By contrast, the diatom-inferred pH of Lake KH4 has dropped from 5.8 at 4 cm to 5.3 in its surface sediments, roughly half a pH unit in the last 20 years.

Furthermore, the observed pH of this lake (4.8) is a full pH unit lower than its average pH (Figure 6). -1.07 (Table 1). When log alpha is regressed against observed pH, a highly significant relationship results rapid acidification. DESCRIPTION OF SELECTED LAKES

The regression equations for observed pH (Y) In order to provide information on the variety of vs. log alpha for each of 6 published studies (Davis lakes encountered along the sampling strip (Figure 2); field data for 10 lakes (one in each micro module) have been listed on Table 4. The data Nygaard 1956) as well as the Sudbury study are evidences the variation which occurs within the provided in Figure 4. From this comparison (Figure lakes of the area. For example, the range in depth of centre basins is from 4 m (Lake Q2) to 30 m (Lake Their regression equation is significantly different W3). Similarly, the Secchi depth varies from 2.9 m from all of the other published studies. The reason (Lake Z1) to 12.5 m (Lake W3). The notes below for this is likely due to the high heavy metal content each lake's description in Table 4 indicate the variin the Sudbury lakes. This has resulted in the growth ability of the conditions within the lake basins and lakes themselves. The tabulated data for the 4 parameters measured within the water column by the probe evi-

dences more uniform conditions, particularly in the topmost 5 m of the water (Table 4). The range of surface water temperature was 21.7° to 24.7°C with the lowest surface temperature being in the deepest lake (W3). The pH measured by the probe indicated generally stable acidity conditions in the top 5 m of the water column. An exception is in Lake S1 where the pH was found to range from 7.0 to 8.2 in the top 5 m of water. Although the conductivity, water temperature, and dissolved oxygen data obtained from the probe are considered reliable as a first approximation, the data from the pH meter is less so. This is because the field water hydroprobe pH data was found to read consistently low compared with the laboratory results obtained within a few hours of collection. Consequently the pH data on Table 4 should be used to indicate pH trends with depth only and not absolute values. The laboratory pH hus sedimentation rates over the last century were data on Table 5 should be used for comparative purposes. The dissolved oxygen at the lake surface is usually about 8.8 ppm and ranges from 7.9 ppm to 8.9 ppm. In general the conductivity is low (i.e. below 40 µmhos/cm) except in Lake Z1 near the oligotrophic. In contrast, Lake KN4 is a shallow (4 m) Walsh Mine (Miller Lake) where it is 61 to 80  $\mu$ mhos/cm, associated with a pH of 7.4 to 7.7. In summary, within the 10 lakes selected for discussion, the setting and nature of the lakes varlakes is similar (34 to 42 microequivalents/I for Lake ies considerably. However, the physiochemical conditions within the lake water columns are less vari-

ou ip.	OH	DH	loc		
Lake	pn (observed)	pn (informed)	log		
	(observed)	(Interred)	atpria		
KW1	7.94	6.39	-0.42		
KW2	4.10	4.59	1.02		
KW3	6.10	6.10	-0.19		
KW4	4.20	3.80	1.65		
KS1	7.00	7.20	-1.07		
KS2	5.70	5.45	0.33		
KS3	4.54	5.16	0.56		
KS4	7.18	6.30	-0.35		
KR1	4.03	5.59	0.22		
KR2	4.59	4.64	0.98		
KR3	4.20	4.76	0.88		
KR4	4.27	5.39	0.38		
KX1	5.01	6.14	-0.22		
KX2	4.40	3.96	1.52		
кхз	5.30	5.63	0.19		
KX4	3.90	3.56	1.84		
KV1	4.00	5.14	0.58		
KV2	4.40	5.05	0.65		
KV3	5.25	5.80	0.05		
KV4	4.20	4.33	1.22		
KZ1	6.50	5.82	0.03		
KZ2	6.40	5.77	0.07		
KZ3	6.80	5.52	0.27		
KZ4	7.08	7.55	-1.35		
KU1	5.20	4.97	0.71		
KU2	5.80	6.22	-0.29		
KU3	4.12	5.64	0.18		
KU4	5.94	5.54	-0.26		
K01	5.30	4.69	0,94		
K02	4.32	5.15	0.57		
K03	5.20	4.32	1.23		
K04	5.56	5.72	0.11		
KY1	8,20	7,15	-1.03		
KY2	8,60	7.72	-1.49		
KY3	6.50	5,81	-0.04		
KYA	3.80	3 60	1 74		
KT1	7 40	7 50	-1 21		
KT2	5.30	A 17	1 25		
	5.50	4.1/	1.35		

ble 3. List of diaton	n taxa =acido	identifi	ed in t	he surf ndiffer	ace sed	liment =pH in	s of Lakes KS1, dicator status un	KS2, K	S3, a	nd K
	uorai	K21	852	823	rsa	1	truncatum Ehr.	interest	(alo)	1
anther Bary		K51	K32	K33	K34	-	Melosica Ao		(arp)	1
ffinis Grun	(a1n)						distans (Fhr.) Kutz		(aco)	9
levi Grun.	(alp)	,					granulate (Ehr.) Ral	lfs	(alp)	3
xigua Grun.	(alp)				5		Meridion circulare (Gr	reg)Ag.	(alp)	
lexella (Kutz.) Brun.	(ind)	2	3				Navicula Bory			
anceolate (Breb.) Grun.	(alp)	1			15		bacillum Ehr.		(alp)	1
inearis (W.Sm.) Grun.	(alp)	2	3		4		elginensis var. rost	trata		
arginulata Grun.	(acp)						(A. Mayer) Patr.		(-)	
inutisima Kutz.	(cir)	2	7		7		minima Grun.		(aip)	2
axonica Krasske	( - )			1			Skv. & Mayer		(cir)	1
inella Lewis							pupula Kutz.		(cir)	
unctata Lewis	(acb)						pupula var. rectange (Greg) Grun.	ularis	(cir)	1
hora Ehr. ex Kutz.							radiosa var.parva W	allace	(rir)	3
valis Kutz.	(alp)		7	1			radiosa Kutz.		(cir)	
meoneis Pfitz.				-			radiosa var. tenella	a		
ollis (Ehr.) Cl.	(cir)		3				(Breb. ex Kutz.) G	run.	(cir)	
erians var. brachysira (Breb. ex Kutz.) Hust.	(acp)	2	32	13	2		scaloides		(-)	
erians (Breb.ex Kutz.)cl.	(acb)		2	2			subtillissima cl.		(100)	1
itrea (Grun.) Ross.	(alp)		7		3		Medium Dfitz		(ma)	
erionella Hass.							affine (Fhr.) Pifit	7.	(ind)	
ormosa Hass	(ind)	50	4	393	20		hitchcockii (Ehr.)	c1.	(acp)	
oneis Cl.							iridis var. amphigo	mohus		
entricosa (Ehr.) Meist.	(alp)	1					(Ehr.) A. Mayer		(ind)	1
entricosa var alpina	(alp)		3				iridis (Ehr.) Cl.		(cir)	1
lotella Kutz.							Nitzschia Hass.			
comta (Ehr.) Kutz.	(cir)	15	1	5	102		fonticola Grun.		(alp)	2
cellata Pant.	(ind)	72		1			kutzingiana Hilse		(alp)	
telligura (Cl.&Grun)V.H.	(alp)	292	38	14	129		linearis W. Sm.		(alp)	
bella Ag.							palea (Kutz.) W. Sm		(CIF)	
ngustata (W.Sm.) Cl.	(alp)	1	3				abaujensis (Pant.)	Ross	(ind)	
esatii (Rabh)Grun.dx A.S.	(cir)	2	11				abaujensis var. lin	earis	(	
istula (Enr.) Kirchn.	(alp)		,				(Hust.) Patr.		(ind)	
uspidata kutz.	(aip)		16	,	2		abaujensis var. ros (Patr.) Patr.	trata	(acp)	1
upata W Sm	(cic)	,	8				biceps Greg.		(acp)	1
vicrocephala Grun.	(cir)	2	8	1	1		divergens W. Sm.		(acp)	
ninuta Hilse ex Rabh.	(cir)		2		2		formica (Ehr.) Patr		(-)	
loneis Ehr.							gibba		( )	
'innica (Ehr.) Cl.	(cir)		1		1996 a		maior (Kutz.) Rabh.		(ind)	1
marginestriata Hust.	(alp)	1					mesolepta (Ehr.) W.	Sm.	(acp)	
temia Breb.							microstauron (Ehr.)	C1.	(acp)	1
iorex Kutz.	(alp)				1		Semiorbis Patr.			
notia Ehr.							Hemicyclus (Ehr.) P	atr.	(acb)	
ingusta (Grun.) A.Bg.	(acp)			1			Stauroneis Ehr.			
bactriana Ehr.	(acb)						anceps Ehr.		(cir)	1
oldentula W. Sm.	(acp)	1			1		livingstonii Reim.		(-)	
curvata (Kutz.) Lager.	(acp)	1	2	1			phoenicenteron (Nit	z.)Ehr.	(cir)	1
elegans Oster.	(acp)		1	2			Stenopterobia Lewis			
exigua (Breb.ex Kutz)Rabh.	(acb)	1	19				intermedia Lewis		(acp)	1
flexuosa Breb. ex Kutz.	(acp)	1	/	1	1		Surirella Turpin		(4-4)	Ι.
hexaglyphis Ehr.	(acp)		1	1			delicatissima Lewis		(1nd)	1
incisa W. Sm. ex Greg.	(acp)		2	2	1		(Ehr.) Grun.	ricta	(ind)	
naegelli Migula.	(acp)						linearis W. Sm.		(ind)	
pectinalis var. minor (Kutz.) Rabh.	(acp)		9	8	1		Synedra Ehr.			
Dectinalis (0. Mull) Rabh.	(acp)		1	3			acus Kutz.		(cir)	
pectinalis var.	(						delicatissima W. Sm		(cir)	
ventricosa Grun.	(acp)		3	1			parasitica (W. Sm.)	Hust.	(alp)	
praerupta Ehr.	(acp)	1			1		radians Kutz.		(alp)	
serra Ehr.	(acp)	1		1			ulna (Nitz.) Ehr.		(alp)	1
vanheurckii Patr.	(acp)		1	1	2		Tabellaria Ehr.		(ach)	
agilaria Lyngb.	(-1-)	. ·					fenestests (lungh	1. Kutz	(aco)	,
previstriata Grun.	(alp)		2	6	1		flocculose (Poth)	(utz.	(acp)	25
constructa Enr.	(acp)						Total	UCL.	(ucp)	829
binodis (Ehr.) Grun.	(ind)	1	1				Alp-I	No.		618
construens (Ehr.) Grun.	(alp)				3		-1	6		74.
venter (Ehr.) Grun.	(alp)				1		Cir-I	No.		31
crotonensis Kitton.	(alp)	300		3	25		-1			3.
leptostauron var.							Acp-I	No.		48
dubia. (Grun.) Hust.	(alp)			1			-1	L		5.
pinnata Ehr.	(alp)	3	29	2	13		Acb-	No.		1
virescens Ralf.	(cir)		118	2			-1	1		0.
ustulia Rabh.	here t						. Ind-I	No.		131
rnompoldes (thr.) Del.	(acp)	1	10	3	2		-1	1		15.
vulgaris (Inw.) Del.	(100)		1		1		Index	x Alpha		0.
acuminatum Fhr	(alo)						Log	Alpha		-1.
angustatum Fhr	(alo)	1	1	1	2		Lake	ph		7.
anguasasum cort.	(a.b)	1	1	1	1		Alka	linity		





Diploneis Ehr.

Epithemia Breb.

construens var. binodis (Ehr.) Grun.



① Y = 6.97 - 0.46 log a Nygaard 1956 - Denmark

(3) Y = 6.76 - 0.74 loga Fortescue et al. 1984

2) Y = 6.62 - 0.65 log a Davis et al. 1981 - Norway

							~ .	~
Figure	4.Calibration	curves	for	the	7	equ	ation	s liste

		KW1	KW2	KW3	KW4	pinnata Ehr.	(alp)	3	2	1	1
Achnanthes Bory					vaucheriae (Kutz.) Peter.	(alp)	2				
exigua Grun.	(alp)		1			virescens Ralf.	(cir)	11	6	15	1
flexella (Kutz.) Brun.	(ind)	4			1	Frustulia Rabh.	()				
lanceolata (Breb.) Grun.	(-) (alp)		5	7	2	rundaris (Thw.) Det.	(acp)	2/	15	9	58
linearis (W.Sm.) Grun.	(alp)	20	°	33		Gomphonema Ehr.	(alp)		1		23
marginulata Grun.	(acp)	7	2	2	5	Melosira Ag.	(0.0)		1		1
minutissima Kutz.	(cir)	2		12		distans (Ehr.) Kutz.	(acp)	18	395	120	4
Actinella Lewis						granulata (Ehr.) Ralfs	(alp)	200		4	
punctata Lewis	(acb)				1	Navicula Bory					
mphora Ehr. ex Kutz.						minima Grun.	(alp)	90	12	11	
ovalis Kutz.	(alp)	7	2			pupula var. rectangularis (Greg) Grun.	(cir)		2	1	
nomeoneis Pfitz.						radiosa var.parva Wallace	(cir)	19	5	2	
follis (Ehr.) Cl.	(cir)		2	1	1	scaloides	(-)			2	
(Breb. ex Kutz.) Hust.	(acp)	25	63	22	500	subtillissima Cl.	(1nd)	20	14	2	77
serians (Breb. ex Kutz.)cl.	(acb)	1		1	4	viridula (Kutz.) Kutz.					
vitrea (Grun.) Ross.	(alp)	8	3	2	8	emend. V.H.	(alp)	2			
sterionella Hass.				1		affine (Fhr. ) Differ	(ind)				
formosa Hass	(ind)		27	5	1	iridis var. amphicomphus	, (110)	1 ·	1		
aloneis Cl.						(Ehr.) A. Mayer	(ind)		1		1
ventricosa (Ehr.) Meist.	(alp)	2	1			iridis (Ehr.) Cl.	(cir)	3	4	1	1
yclotella Kutz.	(-(-)					Nitzschia Hass.					
comta (Enr.) Kutz.	(110)	10		51	3	amphibia Grun.	(a1p)		1		
ocellata Pant	(ind)	10		117		fonticola Grun.	(alp)	9	1	12	3
stelligera (Cl.&Grun)V.H.	(alp)	113	35	285	1	nales (Kutz ) M Sm	(aip)		1		
vmbella Aq.	(0.6)			200		Pippularia Ebr	(CIF)		1	2	
angustata (W.Sm.) Cl.	(alp)		1	6		abaujensis (Pant.) Ross	(ind)		1.1		
cesatii (Rabh)Grun.dx A.S.	(cir)	4	4	2	5	abaujensis var. rostrata	(		1		1
cuspidata Kutz.	(alp)	2				(Patr.) Patr.	(acp)	2		2	2
hebridica Kutz.	(ind)	7	5	6	4	biceps Greg.	(acp)	8	2	3	
lunata W. Sm.	(cir)	13	5		1	maior (Kutz.) Rabh.	(ind)				
microcephala Grun.	(cir)	22	9	14	3	microstauron (Ehr.) Cl.	(acp)				1
minuta Hilse ex Rabh.	(cir)	4	4	11	2	Semicyclus (Ebr.) Patr	(ach)				
iatoma anceps (Ehr.) Kirch.	(alp)	1				Stauroneis Ehr.	(aco)				5
iploneis Ehr.						anceps Ehr.	(cir)	12	7	<b>,</b>	
smithi (Breb.ex.W.Sm.)Cl.	(cir)	2				livingstonii Reim.	(-)	2	2		
pithemia Breb.						phoenicenteron (Nitz.) Ehr.	(cir)		2	1	1
argus var alpestris Grun.	(alp)			1		Stenopterobia Lewis					
angusta (Grup ) A Ro	(1000)			Ι.		intermedia Lewis	(acp)	4		2	1
bactriana Ebr.	(acb)		2	1	1	Surirella Turpin					
bidentula W. Sm.	(aco)	2	1		1	delicatissima Lewis	(ind)	8	7	1	
bigibba Kutz.	(acp)					linearis var. constricta (Ehr.) Grun.	(ind)		2		
curvata (Kutz.) Lager.	(acp)	2	1		1	linearis W. Sm.	(ind)	2	1		
elegans Oster.	(acp)				2	capronii var. obtusa Hust.	( - )	3			
exigua (Breb.ex Kutz)Rabh.	(acb)	3	4	5	9	Tabellaria Ehr.					
flexuosa Breb. ex Kutz.	(acp)			2		binalis (Ehr.) Grun.	(acb)		7		12
gibbosa Grun.	(acp)					fenestrata (Lyngb.) Kutz.	(acp)	30	23	12	5
hexaglyphis Ehr.	(acp)					flocculosa (Roth) Kutz.	(acp)	16	5	22	6
incisa W. Sm. ex Greg.	(acp)	1	8		2	Total		798	787	796	811
monodon Ehr.	(acp)	2				A1p-No		469	66	361	18
naegerii Migula.	(acp)					-1		58.77	8.39	45.35	2.22
pectinalis var. minor	(ach)					CIFC-NO		12 52	52	93	17
(Kutz.) Rabh.	(acp)	4	17	6	11	-5		12.53	5.01	202	2.10
ectinalis (O. Mull) Rabh.	(acp)	6	1		2	-5		19.92	73.92	26 20	79.10
ventricosa Grun.	(acp)					Acb-No		4	22	6	34
perpusilla Ehr.	(acp)				3	-1		0,50	2.80	0.75	4.19
praerupta Ehr.	(acp)		2	2	2	Ind-No		61	64	132	108
septentrionalis Ostr.	(acp)					-I		7.64	8.13	16.58	13.32
serra Ehr.	(acp)					Index Alpha		0.38	10.47	0.64	44,65
triodon Ehr.	(acp)				16	Log Alpha		-0.42	1.02	-0.19	1.65
valida Hust.	(acp)				1	Lake pH		5.1	5.1	5.7	5.2
vanheurckii Patr.	(acp)	2	20		10	Alkalinity			-0.84	0.5	
agilaria Lyngb.						Secchi		.10.5	7.5	12.5	21
previstriata Grun.	(alp)		1			Colour		blue-	green	blue-	blue
CONSCRICTA ENF.	(acp)		24		1 3	1	1	green		green	
								FUI	PHO	PUS	Mar 4



LAKE SEDIMENTS

is considered to be material laid down in Post-Ambrosia time and, as a consequence, includes the natural level of elements plus material derived from tailed study area data have been set up using these atmospheric fallout from smelters. For this reason criteria (Figure 12). the multielement chemical analysis package chosen for these samples included elements such as copper to atmospheric fallout as well as other elements (eg. zirconium, niobium, lanthanum, and yttrium) which ered "signal elements" and the latter "control ele-The performance of the analytical method used for the Ekman samples is summarized in Table 6 where data for 20 elements are listed. Because there is considerable noise in these data, it is be-

lieved that the mixture was inhomogeneous. For this reason these data should be considered as a first erally low in most elements. An examination of the approximation only for the performance of the ana- geochemical patterns on Figure 12 confirms that the nickel and copper to a significant extent, particularly lytical methods employed. Note that the data for yttrium, niobium, and lanthanum in the mixture are ments are low and exhibit a random nature to many which were unaffected by the fallout. The second relatively precise compared with other elements list- of their patterns. This distribution of elements would experiment was concerned with geochemical pat-The data for the 20 elements in the Ekman samples taken from the sampling strip (Figure 2) are marked contrast to geochemical patterns observed general lack of calcareous drift in the area there are listed in full in Table 7. Data for selected elements

(i.e. Ni, Cu, Nb, and Zr) are plotted on Figure 10 using the Clarke Index-I transform. Averaged pH rock lithology and chemical composition of the sur- tified and discussed. data for the lakes of interest are also included in the The aim of Figure 10 is to focus attention on the

enhancement of nickel and copper in the lake sediment collected relatively close to the Sudbury smelters compared with the level of these elements in normal sediment collected further north. The plot of the curves for the elements niobium and zirconium is used as a control. It is concluded that both nickel and copper decrease with increasing distance from the smelters, this effect being most marked in the first 35 km from the margin of Lake Wanapitei (Figure 10). Unlike nickel and copper, niobium and tirconium are relatively uniform in concentration in the lake sediment along the whole sampling strip. The pH curve for lake waters indicates no direct relationship between water pH and nickel and copper in the sediment although there is a pH high in the area of Lake Y2 associated with calcium in surficial material as discussed above. The full element data listing for the Ekman samples appear in Table 7 and are not further discussed here. It is desirable to remove the effects of fallout of trace elements from the atmosphere from data collected for regional geochemical surveys. In order to accomplish this it is necessary to separate the 'Pre-" (i.e. uncontaminated) Ambrosia sediment from the "Post-" (contaminated) Ambrosia sediment material. This is accomplished simply by using a sediment core sampler and extruding the cores obtained to a different depth for each sample type. Consequently, the sediment cores which were collected from the intensive study area were inverted and extruded in 2 stages. The first stage removed all material obtained deeper than 20 cm (i.e. Pre-Ambrosiamaterial) and the second all material from 0 to 12 cm in depth (i.e. Post-Ambrosia material). The transitional material was combined and used for the quality control reference samples as described above. Samples of Pre- and Post-Ambrosia material.

analyzed under contract by Barringer Magenta Limitment special care was taken to mix the reference standard material well prior to sampling. Data for the quality control samples are listed in Table 8 and The first experiment on the intensive study g chemical data was to determine if the Pre- and Post-Ambrosia data for nickel and copper was sim lar, or different, from that for elements not considered to be present in the atmospheric fallout (i.e zirconium and titanium). Data for the Pre- and Post-Ambrosia levels in the samples collected during th intensive survey are plotted on Figure 11. If the

same content of an element is present in the Pre Ambrosia material as in the and Post-Ambrosia material, then the pattern for the elements would be like that for zirconium and titanium with the points clustered along the 45° slope line. In the case of nickel and copper there is a cluster of points at the upper left side of the graph which indicates that many samples are enriched in these elements in Post-Ambrosia material. It should be noted that 4 copper and 2 nickel values are both high and present in the Pre- and Post-Ambrosia material. This may be due to a denuine deochemical anomaly in the lakes from which these samples were collected However, this is unlikely; the high values probably reflect mixing of sediment during inversion of the core prior to subsampling, particularly when the sampled material is very liquid.

The second experiment on the intensive study ochemical data was aimed at an examination of he element patterns in lake sediments. This information is of particular interest where the lakes are acid and the geology is such (i.e. very siliceous rocks) that the abundance of the elements of interest in the lake sediment are likely to be extremely low. In order to make this comparison we are concerned with the uncontaminated Pre-Ambrosia material only. These data are displayed in Table S where samples with high levels of nickel and copper suspected of being contaminated by Post-Ambrosia material) are marked with an asterisk. These are deleted from the following discussion. This leaves a total of 20 samples from the 10 by 10 km square intensive study area (Figure 3). Previous work has demonstrated that if the Clarke index-I transform is used on lake sediment geochemical data collected from 2.5 km squares,

then a factor of 2 between map panel frames on a

1200 70 35 170

Al Ba Be Ca Co Cr Cu Fe La Mg Mn No Ni P Sr Ti V Y Zn

levels

![](_page_2_Figure_79.jpeg)

Figure 13. Conceptual models for 6 common regional geochemical patterns based on the concepts of landscape geochemistry.

Geological Map

Forma

20 - 391. .. 0.5 - 0.910 . . . 0 0.2.000 0000 • 0 0 25 - 0.490 0 0 tob ole lob el 0..... 0.125 - 0.24 K 00 0 0 0 0 0 .... . . . . . . . BELOW 0.0312 K Figure 12.Scan sheet showing the patterns for 13 elements in Pre-Ambrosia lake sediment taken from lakes indicated in Figure 3.

the deochemical patterns to advantage for compara- in lake sediment data. tive purposes. Consequently the plots for the de-

The intensive study area (Figure 3) is underlain

The lake sediment collected with the Ekman dredge scan sheet (Fortescue 1970, in preparation) displays ficial cover give rise to strong geochemical patterns A close inspection of Figure 12 reveals some

apparent development of geochemical gradients (Figure 13) for some elements. For example, magne-The scan sheet (Figure 12) provides detailed sium increases from southwest to northeast and this information on the distribution and concentration of trend may also be seen for titanium, zirconium, and and nickel likely to be enhanced in the samples due 13 elements in 20 samples of Pre-Ambrosia lake chromium. The strontium pattern suggests that this sediment taken from the area selected for detailed element is relatively low around the western and study. The data are presented on a series of small southern margins of the area compared with the are present in significant amounts in the lake sedi-squares, each representing the area, arranged in central portion. The copper pattern is interpreted to ment but not expected to increase significantly due rows and columns. By reading across a row, one indicate that higher values occur in the southwest to smelter fallout. The former group can be consid- can see the distribution patterns for elements within than in the northeast of the area. The patterns for the same range of Clarke Index-I values. By reading other elements (including calcium, lead, nickel, mandown a column, one can see the distribution pat-ganese, zinc, cobalt, and iron) are generally random terns for the same element at different concentration over the whole area. In summary, two experiments were completed on

the geochemical data from the area where the intenlargely by rocks of the Gowganda and Lorrain Formations, which are known to be siliceous and gen- lished that atmospheric fallout had, in fact, affected many of the lake sediment geochemical results for Clarke Index-I levels of most elements in the sedi- when compared with zirconium and titanium levels be expected in lake sediments in an area of uniform terns in the Pre-Ambrosia geochemical data. Owing bedrock geology with little surficial cover. This is in to the uniformity of the bedrock conditions and the in lake sediments obtained in other areas (see For- few recognizable patterns in data sets for individual tescue, in preparation) where variations in the bed-elements although a few weak patterns are idenGENERAL SUMMARY AND CONCLUSIONS

The two studies described on this broadsheet together provide information which is essential during he planning of future regional geochemical surveys in the Sudbury area. The study of the 100 km sampling strip focused attention on the different lake types found in the area and demonstrated that a special working curve is required for the establishment of diatom-inferred pH curves for lakes in the Sudbury area. In particular, the Sudbury diatominferred pH working curve has a different curve slope from that for the curve developed previously in the Wawa area (see Fortescue et al. 1984). Both of the diatom-inferred sediment core curves obtained from the Sudbury area were of particular interest. One curve (for Lake KN4) provides an excellent example of the pH history of the Pre- and Post-Ambrosia time at a steady rate. The second curve (for Lake KH4) provides information on the pH history of a lake which was naturally nearly acid prior to 1962 when it commenced to acidify quite rapidly, probably due to acid rain. The curve for the pH of lakewaters collected from the sampling strip was also of interest because of the relationship between geology and reaction of lake waters. Because the bedrock which underlies the sampling strip is largely metasedimentary which is low in calcium (i.e. quartzites and sandstones etc.) variations in pH of lake water towards the more basic condition found in the sampling strip are thought to be due to local accumulations of calcium carbonate in glacial drift. In the small area which was studied intensively, the effect of such calcium carbonate was considered minimal, resulting in lakewaters with a consistantly low pH. The study of lake bottom sediments collected from lakes studied in the sampling strip revealed two kinds of geochemical patterns in their data. One kind, typified by niobium and zirconium, shows a relatively uniform content along the length of the sampling strip and may be considered as a control, The other kind of pattern, typified by nickel and

NICKEL -----COPPER -----NIOBIUM ------ZIRCONIUM ----pH 1983 \_\_\_\_ R<sub>1</sub> S<sub>3</sub> S<sub>1</sub> T<sub>3</sub> T<sub>1</sub> U<sub>3</sub> U<sub>1</sub> V<sub>3</sub> V<sub>1</sub> W<sub>3</sub> W<sub>1</sub> X<sub>3</sub> X<sub>2</sub> Y<sub>3</sub> Y<sub>4</sub> Y<sub>2</sub> Z<sub>3</sub> Z<sub>1</sub>  $\mathbb{Q}_2 \ \mathbb{R}_4 \ \mathbb{R}_2 \ \mathbb{S}_4 \ \mathbb{S}_2 \ \mathbb{T}_4 \ \mathbb{T}_2 \ \mathbb{U}_4 \ \mathbb{U}_2 \ \mathbb{V}_4 \ \mathbb{V}_2 \ \mathbb{W}_4 \ \mathbb{W}_2 \ \mathbb{X}_4 \qquad \mathbb{Y}_1 \quad \mathbb{Z}_4 \ \mathbb{Z}_2$ 

25km 50km 75km 100km Distance from Lake Wanapitei

Figure 10.Graph of the level of 4 elements in Ekman (Post-Ambrosia) lake sediment collected from selected lakes along the sampling strip (see Figure

ble 8. Iment	The co rando	ntent o mized	of 13 ele in the b	ements atch of	in 8 su unkno	ibsam	ples of a from the	a com e deta	posite i iled stu	nixtu dy ai	rea (i	f lake n ppn	n).
icate nber	Ca	Mg	Fe	Mn	Ti	Zr	Sr	N1	Cu	Pb	Cr	Co	Zn
1	9090	2430	14700	211	800	44	73.9	39	50.1	13	39	14	94
2	9310	2620	14000	223	920	49	66.1	38	49.5	10	37	14	86
3	9910	2740	14400	223	918	49	82.3	38	49.5	13	63	21	91
4	9400	2640	13800	213	911	48	74.8	35	47.6	12	36	14	97
5	9390	2670	14100	220	889	48	83.1	34	49.4	11	38	18	95
6	8820	2550	13500	215	884	46	69.4	38	48.6	13	36	11	90
7	8930	2650	13800	216	933	48	67.4	40	47.8	11	40	25	87
8	8890	2550	13200	215	890	46	79.0	37	47.8	11	37	21	79

Table that sa withou	Table 9. Data for 13 elements in samples from the intensive study area (in ppm). Note that samples preceded by a "P" (eg. PKA1) indicate Pre-Ambrosia material, while those without the P (eg. KA1) are Post-Ambrosia material.													
LAKE	Ca	Mg	Fe	Mn	Ti	Zr	Sr	Ni	Cu	Pb	Cr	Co	Zn	
KA1	2170	948	2180	30.9	530	26	35.3	22	20.3	5	26	7	71	
KA4	4290	1950	8760	174.0	911	53	62.4	15	21.2	4	37	12	43	
KB1	7470	1980	11400	169.0	685	40	60.1	14	20.5	1	30	7	65	
KB4	4260	2740	52600	281.0	1050	51	64.9	232	235	48	53	35	229	
KC1	3830	1440	7470	122.0	699	40	41.6	14	38.1	3	42	9	58	
KC4	4220	1270	8960	145.0	715	34	59.3	13	29.0	5	41	6	36	
KD1	4440	1470	9880	144.0	750	36	54.4	14	28.1	5	41	5	60	
KE1	5160	1040	8060	76.0	495	21	45.8	13	55.9	2	28	. 2	69	
KE4	3230	1210	4600	126.0	622	37	53.8	15	24.3	6	24	12	27	
KF1	6270	3550	17900	157.0	1380	88	124.0	59	62.0	30	42	37	49	
KF4	4690	2080	19300	248.0	996	63	65.5	25	35.4	2	46	14	90	
KG1	5230	3110	38400	430.0	1320	79	92.2	66	71.9	29	57	24	127	
KG4	5240	2200	17200	186.0	1040	67	90.0	36	31.1	7	51	13	74	
KH1	4860	3450	18000	197.0	1160	81	109.0	15	11.5	5	34	42	41	
KH4	6340	4040	26700	388.0	1610	96	119.0	17	14.4	2	53	19	55	
KI1	1520	629	1890	22.6	395	16	25.9	15	49.0	2	22	4	11	
K14	5280	1140	13800	84.7	405	13	33.0	10	39.4	<1	16	2	220	
K.14	5230	1040	11000	157.0	607	27	54.7	18	40.5	4	38	8	121	
KK1	4430	1340	5650	96.1	597	21	54.3	12	35.1	1	18	6	98	
KKA	2110	1070	8220	50.4	531	25	36.2	127	113.0	30	23	28	61	
KI 1	3400	1300	8050	99.9	629	29	52 1	273	225 0	72	23	22	113	
KL I	1010	1030	5930	47 1	EEE	24	34 7	172	177.0	50	20	10	204	
KL4	5150	630	2100	47.1 54.2	104	24	34.7	26	26.1	50	15	19	204	
KM1	5150	2220	22400	224.0	194	9	34.U	20	30.1	51	15	72	174	
KM4	2000	5250	1520	44.0	1430	10	90.0	219	215.0	2	51	14	52	
KAI	2000	742	102000	44.1	270	18	23.0	10	30.0	3	19	14	50	
K01	3110	742	2100	50.0	200	14	23.0	10	34.3	~1	37	10	27	
KOA	0190	5300	32900	267.0	1950	10	116.0	155	145.0	120	67	33	160	
KD1	3250	1350	11500	152.0	607	24	20 4	155	22.0	120	07	35	109	
KDA	1060	1210	16400	117.0	560	26	39.4 AF A	242	270.0	9	41	35	120	
DVA1	2820	0.92	3930	51 1	660	20	45.4	122	105.0	20	42	19		
PKAA	3770	1870	10300	148.0	867	10	63.2	34	25.7	50	30	17	59	
PKR1	5610	1070	8200	112 0	633	20	70.9	50	20.1	0	35	10	104	
PKC1	2220	1300	5000	75.0	757	30	26.2	104	107.0	20	21	10	104	
PK01	1400	1330	9550	167.0	602	20	62.0	104	26.6	29	00	11	117	
DVEI	1710	072	16000	107.0	612	17	25.3	125	112.0		37	,	32	
DVEA	2420	1250	6150	111 0	702	17	67 5	125	112.0	40	27	11	42	
DVEA	4160	2000	10700	204.0	075	45	65.0	40	42.0	10	25	17	42	
PKC1	5360	2000	39000	405.0	9/5	20	102.0	59	59.5	0	55	1/	120	
PKGI	4920	3130	21,800	149.0	1200	79	102.0	02	50.0	21	53	31	120	
DENI	2010	2700	19100	120.0	1080	10	101 0	92	61.9	22	50	19	110	
PKHI	7510	4520	22700	212.0	922	105	101.0	21	54.0	18	31	34	00	
DE TI	2240	4520	22100	12.0	205	105	27 4	31	42.2	10	57	13	80	
DETA	5050	1070	2310	43.8	305	11	27.4	33	43.3	12	17	0	35	
PK14	3850	1270	9040	90.6	330	12	35.4	14	44.7	<1	13	<1	134	
PKJ4	4000	1010	10900	101.0	5/1	25	55.4	26	46.0	8	36	1	60	
PKKI	40/0	933	4530	113.0	434	13	49.1	12	28.4	2	18	3	57	
PKLI	3600	1240	7280	87.6	583	26	52.7	229	185.0	69	54	17	88	
PKMI	4470	837	2360	118.0	260	10	36.8	239	207.0	67	20	12	54	
PKNI	1830	571	2000	60.8	278	18	26.7	70	70.1	12	18	13	33	
PKN4	2420	655	107000	1370.0	267	20	15.3	7	29.1	<1	32	8	55	
PK01	2600	697	3100	60.1	359	17	31.7	50	41.7	8	20	9	38	
PKP1	1930	1240	10800	81.8	671	34	36.5	155	140.0	41	40	33	131	
PKP4	3860	1190	16300	117.0	525	24	43.4	254	272.0	100	37	17	155	

LAKE Ca Mg Fe Mn Ti Zr Sr Ni Cu Pb Cr Co Zn

copper, is due to fallout of the chemicals derived from the smelter, resulting in a clearly defined geochemical gradient from south to north along the sampling strip (i.e. away from the smelters). The intensive study area is located near the southern end of the sampling strip closest to the smelters. The analysis of Pre- and Post-Ambrosia lake sediment material from the 32 lakes in this area or nickel and copper indicates the uniformity of the effects of fallout of these elements in the 10 by 10 km area studied. It also focuses attention on the need for collection and chemical analysis of both Pre- and Post-Ambrosia sediment during future regional geochemical surveys in the area in order to tinguish levels of nickel and copper which are enhanced naturally from those due to smelter activhumic pond which was accumulating acidity in both ity. A more general interpretation of all elements included in the study of lake sediments from the 10 by 10 km area indicates that the levels for most elements are low using the Clarke Index-I scale. Within the small test area there is some evidence of geochemical gradients which are not considered to be very significant.

## CONCLUSIONS

- The following general conclusions are drawn from this study The limnology of lakes in the Sudbury region i
- complex and varied due in part to the paucity of nutrient elements in the bedrock and in part to the fallout effects of the material derived from Sudbury smelters. In order to prepare diatom-inferred pH data
- curves from lake sediment cores collected in e Sudbury region it is necessary to use a different calibration curve from that used in the Vawa area There are at least two types of acid lakes in the
- Sudbury area: (a) the humic lakes which have peen increasing in acidity since Pre-Ambrosia time; and (b) lakes affected by acid rain, which have increased sharply in acidity since 1963. . The fallout of nickel and copper (and, possibly, other elements) from the atmosphere as a result
- of the Sudbury smelter activity is detectable in Post-Ambrosia lake sediment material collected from lakes situated downwind from the smelt-In any future regional geochemical surveying in
- the Sudbury area two types of geochemical map should be included. One type would show the amount and distribution of elements in sediments laid down prior to 1890 (i.e. in Pre-Ambrosiatime) and the other would show the patterns for the same elements in sediment laid down subsequent to the commencement of smelting in the area. The area to the north of Lake Wanapitei, which
- is underlain by rocks of the Gowganda and Lorrain Formations, includes many acid lakes whose sediment is very low in calcium and other elements in Pre-Ambrosia time. The conclusions which are listed above for the
- research described here are broadly similar to conclusions drawn by many workers who have studied in detail the limnology and geochemistry of lakes in the Sudbury area. A convenient starting point to this existant information is found in Pinché (1982) who discuss the effects of smelter fallout on lakes in the area and provide a list of references to earlier investigations of the problem. Space does not allow for a discussion of information provided on Sudbury area lakes by others in relation to the data on this broad-

## REFERENCES

- Davis, R.B., Norton, S.A., Brokke, D.F., Berge, F., and 1981: Atmospheric Deposition in Norway During the Last 300 Years as Recorded in S.N.S.F. Lake Sediments: Part IV, Synthesis and Comparisons with New England; p.274-295 in Proceedings of the International Conference on Ecological Impact of Acid Precipitation, Sande Fiord, Norway,
- Del Prete, A., and Schofield, C. 1981: The Utility of Diatom Analyses of Lake Sediments for Evaluating Acid Precipitation Effects on Dilute Lakes; Archiv für Hydrobiologie, Volume 91, p.33-34.
- Dickman, M., and Fortescue, J. 1984: Rates of Lake Acidification Inferred from Sediment Diatoms for 8 Lakes Located North of Sudbury; Verhandlungen Internationale
- Vereinigung fuer Theoretische und Angewandte Limnologie, Volume 22, p.1345-1356. Dressler, B.C
- 1982: Geology of the Wanapitei Lake Area, District of Sudbury; Ontario Geological Survey, Report 213, 131p. Accompanied by Maps 2450 and 2451, scale 1:31 680 or 1 inch to 1/2 mile. Fortescue, J.A.C.
- 1970: A Research Approach to the Use of Vegetation for the Location of Mineral Deposits in Canada; Taxon, Volume 19, Part 5, p.695-704. 1983: The Southwest Ontario Geochemical Survey as an Example of the Micromodule Approach to Regional Geochemical Mapping; Ontario Geological Survey, Map 80 612, Geochemical
- Series. Compiled 1983. 1984: The Southwestern Ontario Geochemical Survey as an Example of the Micromodule Quarter Approach to Regional Geochemical Map ping; Ontario Geological Survey, Map 80 715
- Geochemical Series. Compiled 1984. Prep: A Standardized Approach to the Study of the Geochemistry of Humus, Williams Property, Hemlo, Thunder Bay District; Ontario Geological Survey, Map in preparation, Geo-
- chemical Series. Fortescue, J.A.C., Dickman, M., and Terasmae, J. 1984: Multidisciplinary Followup of pH Observations in Lakes North and East of Lake Superior, District of Algoma; Ontario Geological Survey, Open File Report 5483, Part I, 232p., Part II,
- Fortescue, J.A.C., Thomson, I., Dickman, M., and lerasmae.
- 1981: Multidisciplinary Followup of Regional pH Patterns in Lakes North of Lake Superior, District of Algoma; Ontario Geological Survey, Open File Report 5342, Part I, 134p. GSC-OGS
- 1978a: Schreiber and part of Longlac Sheets, Thunder Bay District; Ontario Geological Survey, Preliminary Maps P.1805 to P.1818, Geochemical Series, scale 1:250 000.
- 1978b: Fort William and part of Nipigon Sheets, Thunder Bay District; Ontario Geological Survev. Preliminary Maps P.1819 to P.1932, Geochemical Series, scale 1:250 000. 1979a: Uranium Reconnaissance Program, Eastern
- Shore, Lake Superior (NTS 42 C, 42 F/S); Ontario Geological Survey, Maps 80 000 to 80 015, Geophysics/Geochemistry Series,
- 1979b: Uranium Reconnaissance Program, Eastern Shore, Lake Superior (NTS 41 K. 41 N): Ontario Geological Survey, Maps 80 016 to 80 031, Geophysics/Geochemistry Series, scale 1:250 000.
- Airilainen. 1967: The Diatom Flora and the Hydrogen-Ion Concentration of the Water; Annals Botonica Fenoscandia, Volume 4, p.51-58.
- Norton, S.A., Davis, R.B., and Brakke, D.F. 1981: Responses of Northern New England Lakes to Atmospheric Inputs of Acids and Heavy Mel als; Land and Water Resources Centre Project Report A-048-ME, University of Maine, Orono,

## Nygaard, (

- 1956: Ancient and Recent Flora of Diatoms and Chrysophyceae in Lake Gribso; Folia Limnologica Scandinavia, Volume 8, p.32-99. Pinché, E. (ed.) 1982: Final Limnological Report of the Sudbury Envi-
- ronmental Study; Ontario Ministry of the Environment, Water Resources Branch, Limnology Section, Report SES 009/82.

## CREDITS

- Compiled by J.A.C. Fortescue, 1985.
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