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**AN EVALUATION OF TRACE METAL SOURCES IN A SERIES OF REMOTE
LAKES IN SOUTHEASTERN ONTARIO: GEOCHEMICAL AND
PALEONTOLOGICAL EVIDENCE**

by

DEBORAH ANNE KLIZA, B.Sc. (Hon)

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Earth Sciences

Carleton University

Ottawa, Ontario

July 21, 1997

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AN EVALUATION OF TRACE ELEMENT SOURCES IN A SERIES OF REMOTE
LAKES IN SOUTHEASTERN ONTARIO: GEOCHEMICAL AND
PALEONTOLOGICAL EVIDENCE

submitted by

DEBORAH ANNE KLIZA, B.Sc. (Hon.)

in partial fulfillment of the requirements for the degree of Master of Science

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July 21, 1997

STATEMENT OF WORK

I, **Deborah Kliza**, to the best of my ability, have completed the requirements for a Master of Science degree at Carleton University. Interpretation of sonar profiles and subsequent maps were completed by me after discussion with W.W. Shilts. Also, I performed all laboratory analyses of thecamoebian research for this thesis. Interpretations of all thecamoebian, geochemical, and radiocarbon isotope data were also completed by me after discussion with supervisors. Those involved in any other work included in this study have been acknowledged within the thesis itself.

M.Sc. candidate

ABSTRACT

Natural inputs were evaluated for trace elements to three remote lakes in Precambrian units of the Central Metasedimentary Basin in the Grenville Province in southeastern Ontario using a multidisciplinary approach.

Analyses of till, soil, humus, and lake sediment showed variable trace element concentrations between catchments reflected variable concentrations found in the metalliferous marble bedrock. Natural background values for lake sediments are high as a result of local mineralization. Background variations between lakes are due to varying bedrock composition, limnological properties, and metal interactions.

Analyses of thecamoebian and diatom assemblages identified only minor disturbances in lake histories. Taxonomic separation of thecamoebian strains recognized a correlation between the eutrophic indicator, *Cucurbitella tricuspis* "achlora" and massive carbonate precipitation. Large diatom blooms dominated by *Cyclotella michiganiana* did not alter over time indicating a relatively stable environment. No persistent correlation between faunal or floral species and trace metal concentrations was observed.

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Fieldwork would not have been a success if it were not for my good friend and co-worker Stephanie Phaneuf. Much help and technical support was provided by Dr. P.W. Friske, S.J.A. Day, and M. McCurdy (Geological Survey of Canada). The sonar unit was provided by Terrain Sciences. Other equipment and transportation were supplied by Technical Field Supplies Services (TFSS), Gloucester, ON.

Geochemical lab work on all sediment types was done at Acme Laboratories Inc., Vancouver, BC. Geochemical lab work on water was done by J. Vaive, R. Beer, and J.C. Pelchat under G.E.M. Hall at the GSC Environmental Laboratories, Ottawa, ON. Special thanks go to Judy, Roxanne, and Gwendy for many pep-talks and helpful discussions about 'standard procedures'. Interpretation and discussion of diatom analysis were done by C. Prévost (GSC). Diatom identifications were done by B. Hymes at the Canadian Museum of Nature in Ottawa. Special thanks are extended to S.M. Burbidge for hours of helpful discussion over interpretation and taxonomy of thecamoebians. All data profiles for the above analyses were completed with help from P. Petelle.

More personal thank yous go to Pierre, Sue, and Rebecca who kept me sane through these few years, as well as Andrea and Paul for their friendship and generosity. Generous support and patience from superiors and co-workers at the GSC have allowed me to finally complete this thesis.

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TABLE OF CONTENTS

Title page	i
Acceptance sheet	ii
Statement of work	iii
Abstract	iv
Acknowledgements	v
Table of Contents	vi
List of Tables	ix
List of Figures	x
List of Plates	xi
List of Appendices	xii
1.0 INTRODUCTION	1
1.1 Previous investigations in study area	4
2.0 ENVIRONMENTAL SETTING	7
2.1 Bedrock geology	7
2.2 Surficial geology	13
2.3 Mineralization and exploration history	14
2.4 Lake physiography	16
2.4.1 Ardoch Lake	17
2.4.2 Little Green Lake	19
2.4.3 James Lake	19
3.0 METHODOLOGY	23
3.1 Fieldwork	23
3.1.1 Sampling	23
3.1.2 Sample preparation and storage	26
3.2 Laboratory and analytical methods	27
3.2.1 Field analyses: titration and turbidity	27
3.2.2 Geochemical analyses: water, sediments, till, soil, and rock	28
3.2.3 Thecamoebians and diatoms	30
3.2.4 ¹⁴ C dating	31
4.0 GEOCHEMISTRY	32
4.1 Results	32
4.1.1 Rock data	32
4.1.2 Till, soil, and humus data	35
4.1.3 Lake water	38
4.1.3.1 Ardoch Lake	38
4.1.3.1.1 <i>Water conditions</i>	38
4.1.3.1.2 <i>Water chemistry</i>	40
4.1.3.2 Little Green Lake	43

4.1.3.2.1	<i>Water conditions</i>	43
4.1.3.2.2	<i>Water chemistry</i>	44
4.1.3.3	James Lake	45
4.1.3.2.1	<i>Water conditions</i>	45
4.1.3.2.2	<i>Water chemistry</i>	46
4.1.4	Lake bottom sediments	47
4.1.4.1	Sediment description	47
4.1.4.1.1	<i>Ardoch Lake</i>	47
4.1.4.1.2	<i>Little Green Lake</i>	49
4.1.4.1.3	<i>James Lake</i>	49
4.1.4.2	Radioisotope dating and sedimentation rates	52
4.1.4.3	Sediment Geochemistry	53
4.1.4.3.1	<i>Comparison between mean recent and background geochemical signatures</i>	53
4.1.4.3.2	<i>Ardoch Lake</i>	55
4.1.4.3.3	<i>Little Green Lake</i>	60
4.1.4.3.4	<i>James Lake</i>	61
4.2	Discussion	63
4.2.1	Natural sources of trace metals	63
4.2.1.1	Geology	63
4.2.1.2	Surface sediments and organic matter	66
4.2.1.2.1	<i>Till</i>	66
4.2.1.2.2	<i>Soils</i>	67
4.2.1.2.3	<i>Humus</i>	68
4.2.1.3	Movement of trace elements from natural sources to a lake environment	70
4.2.2	The lake environment	71
4.2.2.1	Lake water	71
4.2.2.1.1	<i>Water properties</i>	71
4.2.2.1.2	<i>Water geochemistry</i>	74
4.2.2.2	Lake sediments	75
4.2.2.2.1	<i>Background geochemistry and trace element signatures</i>	76
4.2.2.2.2	<i>Surface sediments and enrichments</i>	79
5.0	PALEONTOLOGY	83
5.1	Results	83
5.1.1	General comments on thecamoebians	83
5.1.1.1	Taxonomic concept	85
5.1.2	Thecamoebian distributions	87
5.1.2.1	Ardoch Lake	87
5.1.2.2	Little Green Lake	90
5.1.2.3	James Lake	93
5.1.2.3.1	<i>James Lake, Basin 1</i>	93
5.1.2.3.2	<i>James Lake, Basin 2</i>	95

5.1.2 Diatoms	97
5.1.2.1 James Lake, Basin 1	98
5.1.2.2 James Lake, Basin 2	100
5.2 Discussion	102
5.2.1 Faunal distribution and lake environment	102
5.2.1.1 Ardoch Lake	102
5.2.1.2 Little Green Lake	104
5.2.1.3 James Lake	106
5.2.1.3.1 <i>Basin 1</i>	106
5.2.1.3.2 <i>Basin 2</i>	107
5.2.2 Diatoms	108
6.0 SUMMARY AND CONCLUSIONS	112
6.1 Geochemical conclusions	112
6.2 Paleontological conclusions	115
6.3 Final comments	118
REFERENCES	120
PLATES	132
APPENDIX A: National Geochemical Reconnaissance Data, 1976/77	
APPENDIX B: Geochemical Data	
APPENDIX C: Paleontological Data	

LIST OF TABLES

<u>Table</u>	<u>Description</u>	<u>Page</u>
1	Description of lakes	17
2	Types of methods used in various geochemical analyses	29
3	Selected geochemistry of rocks found around the Ardoch area	32
4	Chemical properties of till, soil, and humus from each watershed	35
5	Ardoch Lake in-situ field measurements of water properties	40
6	Chemical properties of the water surface and sediment-water interface	40
7	Little Green Lake in-situ field measurements of water properties	44
8	James Lake, basin 1 in-situ field measurements of water properties	46
9	James Lake, basin 2 in-situ field measurements of water properties	46
10	Carbon-14 analyses results	52
11	Average concentrations of variables of the sediment 'raw data' series	54
12	Summary of comparisons of background chemistry of different mediums	77
13	List of thecamoebian species and strains	86

LIST OF FIGURES

<u>Figure</u>	<u>Description</u>	<u>Page</u>
1	Location map of the study area	6
2	Geochemistry of the Ardoch area, SE Ontario	8
3	The bedrock and structural geology of the study area	9
4	Bathymetry of Ardoch Lake	18
5	Bathymetry of Little Green Lake	20
6	Bathymetry of James Lake	21
7	Sonar profile of James Lake	24
8	Temperature and dissolved oxygen profiles for lake waters	39
9	A piper diagram for waters from lakes in SE Ontario	42
10	Surface and subsurface lake bottom sediment type for Ardoch Lake	48
11	Surface and subsurface lake bottom sediment type of Little Green Lake	50
12	Surface and subsurface lake bottom sediment type for James Lake	51
13	The geochemistry of sediments from Ardoch Lake	56
14	The geochemistry of sediments from Little Green Lake	57
15	The geochemistry of sediments from James Lake, basin 1	58
16	The geochemistry of sediments from James Lake, basin 2	59
17	Thecamoebian percent abundances in Ardoch Lake	88
18	Thecamoebian percent abundances in Little Green Lake	91
19	Thecamoebian percent abundances in James Lake, basin 1	94
20	Thecamoebian percent abundances in James Lake, basin 2	96
21	Percentage profiles of diatoms in basin 1 of James Lake	99
22	Percentage profiles of diatoms in basin 2 of James Lake	101

LIST OF PLATES

<u>Plate</u>	<u>Description</u>	<u>Page</u>
1	Thecamoebians: <i>Arcella vulgaris</i> "angulosa", <i>Lesquereusia jurassica</i> , <i>Cyclopyxis kahli</i> , <i>Oopyxis</i> sp., <i>Diffugia globulus</i> 'globulosa", <i>Diffugia rotunda</i> , <i>Centropyxis aculeata</i> "ecornis".	134
2	Thecamoebians: <i>Centropyxis aculeata</i> strains. <i>Centropyxis constricta</i> strains	136
3	Thecamoebians: <i>Heleopera sphagni</i> , <i>Trinema enchelys</i> , <i>Euglypha</i> spp.	138
4	Thecamoebians: <i>Cucurbitella corona</i> , <i>Cucurbitella tricuspis</i> strains	140
5	Thecamoebians: <i>Cucurbitella tricuspis</i> "labiosa"	142
6	Thecamoebians: <i>Cucurbitella tricuspis</i> "achlora"	144
7	Thecamoebians: <i>Diffugia urceolata</i> strains	146
8	Thecamoebians: <i>Legendifflugia vas</i> , <i>Pontigulasia elisa</i> , <i>Diffugia oblonga</i> "petricola"	148
9	Thecamoebians: <i>Diffugia urceolata</i> "elongata"	150
10	Thecamoebians: <i>Diffugia oblonga</i> strains	152
11	Thecamoebians: <i>Diffugia proteiformis</i> strains. <i>Diffugia oblonga</i> strains	154
12	Diatoms: <i>Cyclotella pseudostelligera</i> , <i>Cyclotella michiganiana</i> , <i>Nitzschia</i> sp. 4	156

LIST OF APPENDICES

<u>Appx.</u>	<u>Description</u>	<u>Page</u>
A-1	1976/1977 National Geochemical Reconnaissance Survey data	1 of 1

B-1	Geochemistry of rock found around James Mine	1 of 19
B-2	Unpublished analyses of Grenville marble-hosted zinc occurrences	2
B-3	Geochemistry of till, soil, and humus samples	3
B-4	Water profiles data for each lake	4
B-5	Alkalinity and total organic carbon content of lake waters	6
B-6	Silica and sulphur in lake waters	7
B-7	Water chemistry of anions	8
B-8	All raw data for water trace element geochemistry	9
B-9	Water chemistry of each lake	11
B-10	Lake sediment geochemistry for Little Green Lake	12
B-11	Lake sediment geochemistry normalized for Al for Little Green Lake	14
B-12	Geochemistry of lake sediments from James Lake, basin 1	16
B-13	Geochemistry of lake sediments from James Lake, basin 2	18

C-1	Selected sample depths and corresponding field numbers for diatom	1 of 13
C-2	Abbreviated taxonomy for thecamoebians	2
C-3	Thecamoebian percent abundances for Ardoch Lake	3
C-4	Standard errors for thecamoebian counts of Ardoch Lake	4
C-5	Thecamoebian percentage abundances for Little Green Lake	5
C-6	Standard errors for thecamoebian counts of Little Green Lake	6
C-7	Thecamoebian percent abundances for basin 1 of James Lake	7
C-8	Standard errors of thecamoebian counts for James Lake, basin 1	8
C-9	Thecamoebian percentage abundances for basin 2 of James Lake	9

C-10	Standard errors of thecamoebian counts for James Lake, basin 2	10
C-11	Abbreviated taxonomy for diatoms	11
C-12	Diatom percent abundances for basin 1 of James Lake	12
C-13	Diatom percentage abundances for basin 2 of James Lake	13

1.0 INTRODUCTION

Work on trace element cycles in lacustrine environments has only recently begun due to increasing environmental concerns over pollution and for geochemical applications to mineral exploration. Trace elements (metals) are those elements which usually occur in water, rock or sediment at concentrations less than 1 part per million-ppm (Rose, Hawkes and Webb, 1979; Drever, 1988). Environmentalists have suggested that trace metals have been impeding ecosystems as a result of anthropogenic activities (Nriagu, 1989; Cornwell, 1986; Evans and Rigler, 1980; Davis and Norton, 1978; Kemp *et al.*, 1978). Traditionally, evidence of anthropogenic sources in Canada has been presented as universal enrichments of a wide variety of trace metals observed near the top of lake sediments (Graney *et al.*, 1995; Gobeil and Cossa, 1993; Farmer, 1991; Cornwell, 1986; Renberg, 1986; Blais and Kalff, 1983; Evans and Rigler, 1980; Cline and Upchurch, 1973). The fact remains that the elements under scrutiny, including lead, cadmium, mercury, and arsenic, occur naturally in the environment. The geological factors that control the natural distribution patterns of trace metals in bedrock, glacial and lake sediments, soil, vegetation, and atmosphere have been underestimated or not been recognized (Swain *et al.*, 1992; Evans and Rigler, 1980; Nriagu, 1989). Only recently it has been argued that these enrichments have resulted from natural inputs by surface runoff, groundwater infiltration, rock fall, as well as the mobility/remobility of metals in lake sediments and waters (Boudreau, 1996; Rasmussen, 1996; 1994; Friske, 1995; Friske and Coker, 1994; Farmer, 1991; Coker *et al.*, 1979; Garrett and Hornbrook, 1976). Many scientists agree, however, that there is a varying input from both natural and

anthropogenic sources. The critical issue remaining is the determination of the significance of each source.

Efforts by Friske (1995), Friske and Coker (1994), Farmer (1991), Cornwell (1986), Coker and Shilts (1979), and Thomas (1972) have stressed that existing global metal input models underestimate the significance of natural sources of metal loading in remote lacustrine environments of Canada, resulting in serious overestimating of anthropogenic sources. 'Remote' is a term specifically referring to small lake basins far from any direct sources of contamination such as atmospheric deposition and toxic dumping. The above listed authors conclude that natural variations in the chemistry of lacustrine environments are essentially caused by differing bedrock lithologies, mineralization, and/or glacial sediment compositions and can be used to more realistically evaluate anthropogenic effects from geochemical patterns.

In order to make an unbiased assessment of sources and effects of trace elements in a lacustrine environment, the natural background concentrations of both the study area and the individual lake have to be established. 'Background' variations are correlative with the natural chemical variations in the surrounding bedrock, mineralization, and glacial sediment compositions. Those lakes with values far above the background values are termed 'anomalous'. 'Anomalous' is used to describe high concentrations of elements in an area where natural sources, such as bedrock, would result in much lower concentrations. For example, mercury (Hg) is typically found in limestone and sandstone in concentrations averaging about 40-50 parts per billion (ppb) while in black shales it has been known to reach 500 ppb (Friske and Coker, 1994). Hence, overburden with concentrations up to 200 ppb of Hg found over limestone would be considered

anomalous, whereas over black shales, it would be considered normal (Friske and Coker, 1994). Once a lacustrine environment is determined to have anomalous values of trace elements, there remains the question of the significance of temporal and or spatial inputs. Since chemical criteria are only expedient screening tools, biological criteria also need to be examined to predict a long term influence of sources on biota.

It has been well documented that freshwater lake sediments preserve temporal and spatial records of sedimentation rates, climatic changes, and environmental change through natural and anthropogenic causes under the assumption that sediments remain undisturbed (Farmer, 1991). Micropaleontology is a useful tool for examining these records contained in lakes. Analyses of diatom populations reveal such important factors as acidity of water, nutrient availability, and biological lake activity (Barron, 1983; Prévost, 1996). Other micropaleontological tools only recently introduced into environmental studies include thecamoebian analyses. Thecamoebians are protozoa which are indicators of fresh to slightly brackish waters and are sensitive to environmental stresses (Medioli and Scott, 1988; Asioli *et al.*, 1996; Patterson *et al.*, 1996). In sediments of a known age, fluctuations in thecamoebian and diatom assemblages can be shown to correspond to temporal changes or events in the lake history.

The objectives of this study are to identify the background values of trace metal concentrations in catchments and lake bottom sediments of three remote lakes in the Ardoch area of southeastern Ontario, to identify possible sources of these metals as well as variations in these sources over the history of the lake, and to determine the significance of natural sources in the overall contribution of metal concentrations in the lake system. In order to achieve these objectives, a multidisciplinary approach is needed.

including geochemistry and paleontology, in order to decipher the physical, biological, and chemical history of the lacustrine environments. Geological and geochemical linkages will be examined to confirm that geological variations influence the chemical makeup of a lacustrine environment. To establish this link, geochemical analyses of lake sediments, waters, soil, till and humus are included. Lake histories will be reconstructed to reveal any distinct changes which would indicate anthropogenic activity causing an influx of metals and ecological change.

1.1 Previous investigations in the study area

In Canada, utilization of lake sediment and water for geochemical exploration began in the early 1970s (Painter *et al.*, 1994; Coker *et al.*, 1979; Coker and Jonasson, 1977; Shilts *et al.*, 1976). Between 1973 and present, the GSC has surveyed a significant portion of Canada using systematic stream and lake surveys under the National Geochemical Reconnaissance program (NGR) which was initiated to construct a national geochemical database. Extensive anomalies usually denote areas of mineralization and large natural sources of elements available to the environment. In the course of the more than 200 surveys, sediment and water samples were collected from more than 23000 streams and 41 000 lakes in Canada (Friske and Coker, 1994; Painter *et al.*, 1994). In 1976, NGR surveys were carried out under the auspices of the Uranium Reconnaissance Program (URP) and Provincial Geochemical Reconnaissance Surveys, collecting data mostly from southeastern Ontario, including the area around Ardoch (Hornbrook *et al.*, 1984). Sampling to NGR standards (Lynch *et al.*, 1973), the surface sediments at all sites

were purposely excluded from the study. Instead, samples consisted of lake sediments from a depth of 30 cm below the sediment-water interface to recognize the background concentrations of elements (Friske and Hornbrook, 1991). In 1977, a follow up study was done on anomalous lakes where, aside from uranium, mercury became the main focus as environmental concerns arose. Extensive geochemical data for lake sediment and water for all of southeastern Ontario, including the study area, are catalogued by Hornbrook *et al.* (1984).

In the Ardoch area of southeastern Ontario, extensive till geochemistry was performed in the 1980s by the GSC in response to concerns about direct and indirect effects of acid rain on certain terrain (Kettles and Shilts, 1994; Shilts, 1984). Detailed maps display regional compositional variations in those surficial materials (Kettles and Shilts, 1995). Maps comprised of additional data were released by Kettles and Shilts (1983), Kettles (1988), and Kettles, *et al.* (1991). Other environmental and Quaternary projects in this area were contributed by Kettles (1992; 1990). All of the above studies discuss the importance of geological variations on trace element concentrations.

Figure 1: Location map of study area.

2.0 ENVIRONMENTAL SETTING

The study area lies in the township of Clarendon in Frontenac County, northwest of Sharbot Lake and near the town of Ardoch, just east of Plevna, bounded by the coordinates 4981000; 4976000 mN and 348000; 354000 mE of NTS reference 31 C/15 (Figure 1). Because this area of southeastern Ontario was previously recognized by the NGR surveys for anomalous values of mercury, lead, zinc, arsenic, and molybdenum, it was chosen for this study (Figure 2; Appendix A, A-1). Three remote lakes, Ardoch Lake, Little Green Lake, and James Lake, were chosen for examination of their geochemical environments. The lakes were ideal for this study since James and Little Green Lakes exhibit anomalous values of trace elements while Ardoch Lake exhibits background values. Mercury concentrations in James Lake appeared in the top 5% of the highest concentrations recorded in the geochemical surveys, while Little Green Lake appeared in the top 10% (Hornbrook *et al.*, 1984).

2.1 Bedrock Geology

The geology of the Ardoch area in Frontenac County was mapped in detail in the late 1980s by the Ontario Geological Survey (Report 241). The bedrock geology is described by Pauk (1987) in Ontario Geological Survey Map 2514 (Figure 3). Units described in the text correspond to numbers in the legend of Figure 3.

The study area is underlain by structurally complex, high grade metamorphic rocks of diverse lithologies that lie within the Central Metasedimentary Belt (CMB) and form part of

Figure 2: Geochemistry of the study area showing sample sites and associated high metal concentrations.

BEDROCK GEOLOGY OF ARDOCH AREA

SYMBOLS

- Anticline, syncline, with plunge
- Highway
- River, drainage system
- H.E.P.C. power line
- Fault, observed
- Rock sample site
- Town
- Property, unsurveyed
- 2 Roeth Mine (1952)
- 9 Kibbe, C
- 12 Selco Incorporated (James Mine)
- 13 Selco Incorporated (Webber Mine)
- 15 Wilent, N

345000m. E.

350000m. E.

498000m. N.

LEGEND

PRECAMBRIAN

PROTEROZOIC

GREENVILLE SUPERGROUP

FLINTON GROUP

Ferrileigh Formation

Myer Cave Formation

Bishop Corners Formation

UNCONFORMITY

METAMORPHOSED FELSIC TO INTERMEDIATE
INTRUSIVE ROCKS

CROSS LAKE PLUTON

Trondhjemite gneiss, granodiorite gneiss

METAMORPHOSED MAFIC INTRUSIVE ROCKS

Medium- and coarse-grained gabbro and
diorite, fine-grained, foliated, biotite-bearing
gabbro-diorite phases, granodiorite and
aplite phases

INTRUSIVE CONTACT

METASEDIMENTS

7 Clastic Metasediments

6 Carbonate Metasediments

FELSIC TO MAFIC GNEISSES OF MIXED VOLCANIC
AND SEDIMENTARY ORIGIN

Interlayered Felsic & Intermediate Gneisses

MAFIC GNEISSES

MP (AVUL) CANIEN

3 Mafic Tuffs interlayered with Carbonate
Metasediments & Limestones

2 Felsic to Intermediate Metavolcanics

Mafic to intermediate Metavolcanics

Note: Numbers correspond to text when
referring to rock units

Figure 3: The bedrock and structural geology of the study area. Geology modified from Pauk (1987).

the Grenville Province of the Canadian Shield (Moore and Thompson, 1980; Kettles and Shilts, 1994). The major rock types underlying the Ardoch area are of late Precambrian (Proterozoic) age and include metavolcanics, metasediments, and plutonic bodies of trondhjemitic and granitic complexes (Moore and Thompson, 1980).

The generalized geological history of this area begins in the southeastern corner of the bedrock geology map with the northeasterly striking units (Figure 3). These rocks are the oldest units composed of metavolcanics, ranging in composition from basalt to rhyodacite (Pauk, 1987). These metavolcanics occur as outliers between Ardoch and the southeastern corner of the map. None of the belts are compositionally uniform and from north to south: the metavolcanics become progressively more felsic. Unit 1 is composed of mafic to intermediate metavolcanics, unit 2 is felsic to intermediate metavolcanics, and unit 3 is mafic tuffs interlayered with carbonate metasediments and limy mudstones (Pauk, 1987). Unit 2 borders the northeastern shores of Ardoch Lake.

A series of mafic (unit 4), intermediate and felsic (unit 5) gneisses and schists lying in the central, western, and northwestern portions of the study area are believed to have originated from sedimentary and volcanic protoliths (Pauk, 1987). These units outcrop as synforms and antiforms. Unit 5 hosts portions of both James Lake and the Deep Lake-Little Green Lake system which are areas specifically of interest in this study. The unit is composed of pink, grey to dark grey fine to medium grained quartzofeldspathic gneisses, with the prevailing mafic mineral being biotite (Pauk, 1987).

Metasedimentary rocks, comprised of clastic siliceous gneisses and carbonate metasediments (unit 6) and minor calc-silicate gneisses and schists (unit 7), may be correlative with the Mayo Group of the Grenville and underlie most of the central and

northwestern part of the map area (Pauk, 1987). Extensive outcrops of the carbonate metasediments of unit 6 occur in northeast trending zones containing large fold structures. It is these carbonate metasediments which contain the lakes of interest in this study. Unit 7 is a complex of gneisses occurring in three northeast trending belts between the carbonate metasediments of unit 6. Smaller discontinuous belts intersect Little Green Lake as well as border on the north shore of Ardoch Lake. This unit is considered to be the metamorphosed equivalent of siliceous and calcareous clastic sediments.

A metamorphosed mafic intrusive rock (unit 8) has been emplaced between units 5 (gneisses) and 6 (metasediments) as one relatively small body. This intrusive stock of gabbro-diorite composition intrudes the metasediments just south of Plevna and occupies the core of the Plevna Synform.

The Cross Lake Pluton (unit 9), at the very southeastern corner of the map, is a metamorphosed felsic to intermediate intrusive rock (Pauk, 1987). This intrusive rock varies only slightly in composition from trondjemite to granodiorite gneiss and is part of a larger intrusive body known as the Northbrook Batholith. Within the Ardoch area sequence, the Cross Lake Pluton has intruded the Hermon Group metavolcanics before the deposition of the Flinton Group. All intrusive bodies in the surrounding area, including small mafic intrusions, are considered to be post-Flinton syntectonic to late tectonic bodies.

Resting unconformably above these Precambrian units are the clastic metasediments of the Flinton Group which has been formally defined as a metaclastic succession (Moore and Thompson, 1980; 1972). It is comprised of carbonates, silicates, pelitic, mafic and conglomerate metasediments and represents a sediment facies change from a low energy to high energy depositional environment (Pauk, 1987). Three of the six formal formations of

the Flinton Group described by Moore and Thompson (1972) underlie the Ardoch area: Fernleigh (unit 12; schists), Myers Cave (unit 11; schists, marbles, and carbonate-clast metaconglomerates), and Bishop Corners (unit 10; schists and quartzite pebble, polymictic, and migmatized metaconglomerates). The most extensive and continuous exposures of the Flinton Group are confined to two narrow northeasterly striking synclinal structures, the Fernleigh and Ompah Synclines, where units lie unconformably above the older metasediments of the Grenville. In addition, northeasterly trending zones of pelitic schists, also part of the Flinton Group, are exposed along the power line northwest of Little Green Lake.

The entire study area is a series of tightly folded anticlines and synclines representing regional folding of pre-existing Precambrian rocks. The sequence outlined above was regionally metamorphosed during the late Precambrian, including both the pluton and younger metasediments of the Flinton Group. Faulting was the final post-Flinton deformation phase. The most prominent fault in the area is expressed by the 40m of vertical elevation on the northwesterly striking Plevna Fault (Pauk, 1987). Generally, the fault line runs northwest along Buckshot Creek from Ardoch. A small easterly offset is recorded within the western-most bay of Mud Lake nearest Ardoch. The Plevna fault line then continues southeast.

Among this complex geology lie the three study lakes. It is important to recognize the subtle differences in the underlying bedrock at each lake. Ardoch Lake lies in a region of carbonate metasedimentary rocks, mostly massive marble, which underlie an extensive portion of the study area. The northeastern shore of the lake lies directly on the hinge of an unnamed synform. The south and west shores of the lake border much older felsic to

intermediate metavolcanics, as well as biotite, muscovite, and garnet-bearing gneiss and schist. Drainage into the lake occurs from all three units.

Little Green Lake lies in an extensive marble unit separated from the portion which contains Ardoch Lake. For the most part, the marbles surrounding the lake are interlayered with clastic siliceous metasediments of gneiss and schist. To a lesser extent, massive dolomitic marble as well as marble and dolomitic marble with large lenses and layers of white quartzite occur. Smaller clastic metasedimentary units of lithic sandstone and or mudstone intersect the lake, while drainage into the lake flows through both gneisses and pelitic schists.

James Lake lies within a continuation of the belt of carbonate metasediments hosting Little Green Lake. Its northern shore lies just outside the limits of the biotite-plagioclase-quartz-carbonate-microcline-muscovite gneiss. The rest of the lake, including the drainage pathways both in and out of the lake, lies within an area of grey and white, laminated to massive marble, as well as tremolite, phlogopite, diopside and scapolite -bearing marble.

2.2 Surficial Geology

Quaternary sediments are lying unconformably on top of the folded and metamorphosed Precambrian rocks in the Ardoch area. A detailed surficial geology map of the Ardoch area was published by Henderson and Kettles (1992). Pleistocene deposits are represented by a variety of glacial drift. Glacial debris in the study area is of Late Wisconsinan age, and has been deposited from glaciers predominantly flowing south to southwest from Northern Quebec. Till, deposited directly from glacial ice, mantles and reflects the morphology and

structure of the underlying bedrock (Kettles and Shilts, 1994; 1989). Silty to gravelly till, grey in colour, forms a thin and discontinuous cover throughout the area. Till found around the study lakes was highly weathered and reworked. Around James and Little Green Lakes, a discontinuous till veneer lies close to their shorelines. Beyond this, bedrock is exposed, mainly forming rolling or hilly rock knob uplands which become very prominent under the powerlines (Henderson and Kettles, 1992).

As a result of glaciofluvial streams, sand and gravel deposits appear north of Plevna and Ardoch and south of Cross Lake (just east and southeast of the map). On the northeast shore of Ardoch Lake, near shore and deltaic sediments from past glacial lakes fill topographical depressions. These sediments are composed of well-sorted gravel, gravelly sand, sand, and minor clay deposits of 1 to 25 m thickness (Henderson and Kettles, 1992).

Recent deposits in the study area are composed of organic swamps and alluvial deposits occupying fault and fracture zones which run parallel to joints and strike-controlled terrane depressions (Kettles and Shilts, 1989). The majority of organic deposits follow Buckshot Creek (Plevna Fault). The most extensive swampy terrane contains both Mud Lake (Mississippi River System) and the Malcom-Ardoch Lake system.

2.3 Mineralization And Exploration History

Most metallic mineral deposits in the Central Metasedimentary Belt occur in the supracrustal and related intrusive rocks (Sangster and Bourne, 1982; Carter and Colvine, 1985). Within the Ardoch area, metallic mineralization consists of Au, As, Cu, Fe-sulphides, U, and scattered amounts of Zn, Mo, and Pb/Fe-oxides. The most prominent

occurrences appear in the Precambrian metasediments that stretch northeast from Fernleigh to Little Green Lake (Figure 3). Gold, Cu, and As-bearing quartz and quartz dolomite veins occur in the older strata that lie at or near the contacts with the Flinton Group metasediments. Small amounts of Zn and Pb are found as weak disseminations in marble and interlayered quartzofeldspathic gneisses of the older metasedimentary sequence and in the quartz-dolomite bearing veins hosted by the marbles of the Myer Cave Formation. Copper and Ni mineralization is found primarily in the mafic to intermediate metavolcanics. Small sulphide mineral occurrences of pyrite with chalcopyrite and arsenopyrite are found in many parts of the study area. Nonmetallic minerals such as mica, quartz, feldspar, tremolite and kyanite are also prevalent. Other mineralization, specifically uranium and molybdenum, occur in pegmatite dykes and veins (Pauk, 1987).

Past exploration in the Ardoch area has occurred primarily in the clastic and carbonate metasedimentary units. The area proved to contain a variety of metallic and nonmetallic deposits. Gold exploration began in the 1800s (Pauk, 1987). Gold is associated with cross-cutting quartz veins at the Boerth Mine (property #2), Selco Mining Corporation Ltd. James Mine (property #12), Selco Mining Corporation Ltd. Webber Property (property #13), and N. Wilson Property (property #15). The only significant findings ever recorded occurred at the Boerth Gold Mine, the first mine in the area. With the closing of the Boerth mine, minor surface developments of gold, arsenopyrite and galena were worked, recovering only modest amounts (Armstrong, 1976). At the James Mine, the gold-bearing mineralization is associated with quartz and chalcopyrite. James Mine, reputed to carry gold, was worked briefly in the early 1900s (Armstrong, 1976; Smith, 1958). In the 1950s, exploration reoccurred near the Boerth Mine, but no significant finds were made. In 1963, further

exploration on quartz veins near the Webber Mine revealed only minor traces of gold (Armstrong, 1976).

During the late 1950's, extensive exploration began for uranium around Cross Lake and Pine Lake, just west of the study area. In 1977, the Geochemical Reconnaissance Survey for uranium by the Geological Survey of Canada revealed anomalies of Zn, Cu, As, Mo, and Hg on property owned by Selco Mining Corporation Ltd. in the area between James Lake and Little Green Lake. In response, St. Joseph Exploration Ltd. carried out geological and geochemical surveys during the same year on all claims on the property, but only weak to moderate anomalies of Cu, Pb and Zn and the presence of gold in chalcopyrite-bearing quartz veins were reported. Weak sphalerite-pyrite mineralization was also described in the area of Little Green Lake.

Nonmetallic mineralization also proved to be economic in the Ardoch area. According to Pauk (1987), two quarries were worked for marble just east of Plevna until the 1960s. Presently, sand and gravel extractions remain the predominant resource recovery operations in the Ardoch area.

2.4 Lake physiography

Various physiographic factors affect the dispersion of trace elements in waters as well as the deposition and accumulation of these elements in lake bottom sediments. These attributes are important to recognize before examining a lake environment. The three lakes of interest in this project lie within depressions of the Canadian Shield which offers terrains

of extensive glacial overburden and low relief along with indefinite and disorganized drainage systems (Table 1) (Coker and Nichol 1975).

Table 1: Description of lakes.

Lake	Station #	NTS	Easting mE	Northing mN	Rock type	Depth m	Altitude m a.s.l.	Surface area m ²	Water colour	Observations
Ardoch Lake	031C9504	31C	353000	4976900	marble /gneiss	16	259	776249	org/br	spruce and pine; largest lake; parallel to stria; no bedrock outcrop; many cottages
Little Green Lake	031C9501	31C	351269	4980077	marble	21	259	277610	bl/gr	cedar & birch; reworked till; sandy oxidized soil; beach & cottages; steeply dipping marble sides; perpendicular to stria and geology
James Lake	031C9502 031C9503	31C	348632	4979607	marble	16	290	18700	yel/br	spruce, cedar, tamarack; till reworked; no beaches, steeply dipping marble bedrock; 2 - basins; horse shoe shaped; no cottages

2.4.1 Ardoch Lake

The largest of the three study lakes is Ardoch Lake (776249 m²), lies beside highway 501 about 2.5 km southeast of Little Green Lake at 259 m a.s.l.. The basin lies parallel to glacial stria and has a maximum depth of 16 m (Figure 4). Ardoch Lake has little bedrock outcrop around its shores and is surrounded by a sparse pine and spruce forest. Ardoch Lake is home to many permanent and seasonal homes and human activity on the lake prospers. Drainage into the lake originates in Cross Lake, the largest lake in the vicinity, while drainage out of the lake empties into Malcom Lake. This system lies parallel to and south of the Mississippi River System.

2.4.2 Little Green Lake

Little Green Lake is an elongate lake with a surface area of 277610 m² and a maximum depth of 21 m, which is of average size and depth for lakes in southeastern Ontario (Table 1, Figure 5). At 259 m a.s.l., it lies perpendicular to the glacial stria and to the structural trends of the geological units and drains southeast into the Mississippi River System. To the northwest, the lake is bordered by a steep marble cliff standing about 5 m above water surface. The elevated shoreline tapers along the sides towards a beach at the southeast end of the lake. The beach consists of fine sand and the shallow near-shore sediments are a mixture of fine sand, carbonate precipitate, and organics. A forest of mostly cedar and birch trees surrounds the lake with deciduous trees growing mostly at the southeast end. It is at this end where a few permanent cottages stand, as well as a small seasonal community of motor homes.

2.4.3 James Lake

James Lake is a small lake (41616 m²) consisting of two distinct basins. Basin 1 is ovoid with a maximum depth of 14 m while basin 2 is somewhat elongate with a maximum depth of 16 m (Figure 6). The shoreline of James Lake consists, for the most part, of steep sloping banks of marble outcrop. In shallow nearshore areas, in the bays of the lake, an accumulation of reeds and organic debris creates a swampy environment.

The lake is situated around 290 m a.s.l. and drains southwest via subterranean pathways, first into a smaller depression nearby, then to Buckshot Creek, which eventually drains into Mud Lake. Small sinkholes were found throughout the drainage basin. Past beaver activity

Figure 5: Bathymetry of Little Green Lake.

Figure 6: Bathymetry of James Lake.

at the west end of basin 2 caused another deterrent to water movement through the system. Here, remnants of a beaver dam keeps the lake water level about 30 cm above the natural level.

The lake is found along an old logging road approximately 0.5 km from the power lines and about 3 km west of Little Green Lake. Two pits, remnants of past mining operations, lie in the clearing under the power lines at the start of the road. The narrower of the two pits is about 4 m deep and flooded. The other pit is the location of the abandoned James Mine. Bedrock composed of dolomitic marble and quartz veins has recently been exposed and sampled due to recent exploration on this property. The exposures closer to the abandoned mine show patchy mineralization of chalcopyrite, malachite, and azurite.

James Lake is secluded with no homes or cottages nearby. Past logging activity is evident both in the surrounding woods and along the shallow areas nearshore by old lumbered logs and stumps up to 2 m offshore. These are estimated as having been cut at the turn of the century. The forest which now stands consists

3.0 METHODOLOGY

3.1 Field Work

3.1.1 Sampling

Field work for this project was carried out in August 1995. At each lake, a Rathyeon 1000 Sub-bottom Acoustic Profiler and Echo Sounder was used to produce a bathymetric chart and a sub-bottom (lake bottom to bedrock) profile showing sediment thickness and type. Reflecting sonar waves give a profile of the lake from the water surface to the lake bottom along a chosen transect (Figure 7a). A low frequency transducer (7 kilohertz, kHz) was responsible for vertical penetration of sound waves into the sedimentary column and a high frequency (200 kHz) transducer precisely recorded the sediment surface. Soft, clayey sediments typically had the best penetration. Wave penetration of the substrate was hindered by coarser sediment constituents reflecting or echoing the sound waves as shown in Figure 7b. 'Noise' was caused by the presence of gases in the water column or sediments (Figure 7b).

Sample sites were selected, from both sonar profiles and from a commercial depth monitor (fish finder), close to the deepest part of the lake basin because metals show a trend for increased concentrations from nearshore shallow water coarse sediments outward into the fine grained sediments found in deeper water (Thomas, 1972). Sample localities were recorded by a GPS unit. Sediment sampling was performed with a modified Kajak-Brinkhurst gravity corer (model # 2402) with tubes of 1.1 m in length. A

Map of the study area showing Basins 1 and 2. Sampling stations A, B, C, D, E, F, G, and H are marked. A scale bar indicates distances from 0 to 250 m. A north arrow is present in the top right corner.

10 cm diameter core was sampled from the lake floor for geochemical and micro-organism analyses (thecamoebian and diatom).

A total of 89 and 68 cm of sediment were recovered at Little Green and Ardoch Lakes, respectively. Both basins in James Lake were cored. Due to gases expelling from the sediment when the core was removed from the water column, it took several attempts to retrieve a 66 cm core from the first basin. Subsequently, a core of 85 cm was recovered from the second basin. Cores were subsampled within 24 hours of extraction from the lake at intervals of approximately 2 cm.

At each sample location, water colour, wave action, Secchi disc depth, as well as other physical properties were recorded. Chemical properties, including pH, Eh, dissolved organic carbon, temperature, and salinity (conductivity) were measured throughout the water column using a hydrolab; the Surveyor 3 Water Quality Logging System (serial # 1954). Using a Kemmerer Bottle sampler, lake water was sampled at the surface, thermocline, and bottom of the water column. The Kemmerer Bottle collected $3.5 \times 10^3 \text{ cm}^3$ (3.5 L) samples from which three aliquots were collected in 250 ml Nalogene™ linear polyethylene bottles, one to be analyzed for cations, one for anions, and one for turbidity and alkalinity. Temperatures of each sample were recorded from the thermometer located inside the Kemmerer Bottle. Interstitial water was also sampled at the sediment-water interface of the sediment cores by siphoning into 250 ml polyethylene bottles.

Samples of till, soil, humus, and rock were taken where available at each of the lakes. Only one sample location was chosen closest to each lake because: 1) databases already exist for the geochemistry of rock and till within study area; 2) a singular geochemical

data point will be used only as a comparison to a single data point of lake sediment geochemistry. Although till is found as a thin veneer in most places around the area, only two areas close to Little Green Lake were found to have exposed sections of fresh till and were subsequently sampled. Till found near the south beach of Ardoch Lake was extremely weathered and reworked and would not provide a reliable chemical signature. Where till samples were collected at Little Green Lake, soil and humus were also sampled. At the other two lakes, fresh soil and humus samples were easily found and sampled. Rock samples from one of the James Mine pits were taken to perform geochemical analysis for comparison with anomalous values found in the lake sediments.

Bathymetric and sediment type maps were manually reconstructed through interpretations of the sonar profiles. Lake and shore sampling sites were located on the bathymetric map (Figures 4, 5 & 6; chapter 2.4) while detailed core descriptions were included on the sediment type maps (Figures 10, 11 & 12; chapter 4.1.4).

3.1.2 Sample preparation and storage

Lake sediment cores were subsampled in the field and stored in plastic storage bags and kept cold at 4°C in a cooler/refrigerator. No preservatives were added to the samples. In the laboratory, the bagged samples were split into four aliquots, 5ml each for pollen and diatom analysis, 30 ml for thecamoebian analysis, and the remaining sediment for geochemical analysis. The samples for thecamoebian analysis were preserved with 2 ml of 30% ethanol.

The sediment, soil, till, and humus samples to be sent for geochemical analysis were air dried in greenhouses for two months. Samples were stored in standard plastic bottles for shipment. Quality control of all analytical data was maintained by inserting control reference and blind duplicate samples into each analytical block of 20 sediments to evaluate analytical accuracy and precision (Garrett and Hornbrook, 1976).

Since water is a more dynamic medium than others, several precautions were taken to preserve its *in situ* chemistry and to prepare for analysis. Of the three aliquots of water sample taken at various depths, two samples were filtered using a manual filtering apparatus with 0.45 mm filter paper. One of the filtered waters was acidified with 2 ml of 1:1 ultrapure nitric acid (HNO_3 ; $\text{pH} < 2$) to prevent metals from coming out of suspension. The other filtered sample for analysis of anions was not preserved. The non-filtered sample was tested for alkalinity (titration) and turbidity (scatter test) on the day of collection.

3.2 Laboratory And Analytical Methods

3.2.1 Field analyses of titration and turbidity

The alkalinity of the water samples from each lake was determined by successively titrating the sample with 0.01% sulphuric acid (H_2SO_4) to reach the carbonate and carbonic acid equivalent points indicated by indicator colour changes. To be more accurate, the concentration of H_2SO_4 used for these field titrations was weaker (1/10th the portion) than normally used. A phenolphthalein indicator was used to detect the

bicarbonate equivalence point and alkalinity is expressed in terms of ppm of HCO_3^- .

Turbidity of these water samples was measured within 12 hours of sampling to assess the presence of suspended material in the water. This is an optical property that causes light to be scattered or absorbed, rather than transmitted. It is measured in Nephelometric Turbidity Units (NTU).

3.2.2 Geochemistry of water, sediments, till, soil, and rock

All water analyses were done by the GSC Environmental Laboratories, Ottawa. Methodology and techniques are described in detail by Hall, Gauthier, Pelchat, Pelchat and Vaive (*in press*); Hall, Vaive and Pelchat (*in press*); and, Hall, Vaive and McConnell (1995). Precision and accuracy for chemical analyses were monitored using a variety of standard reference materials and sample duplicates and were calculated as percent errors (absolute + relative %). All errors lie within normal accepted standards and can be found included in the geochemical tables in the appendices (Appendix B: B-4 to B-9).

Analyses of lake sediments, till, rocks, soils, and humus were completed by Acme Analytical Laboratories Ltd. in Vancouver, BC (project #890043/#96-0232). Lake sediments, till, soil and humus underwent aqua regia digestion ($\text{HCl-HNO}_3\text{-H}_2\text{O}$) followed by ICP determination. Rock samples underwent a 'total' digestion, a very strong 4-acid digestion ($\text{HNO}_3\text{-HClO}_4\text{-HCl-HF}$) that effectively dissolves most minerals, followed by ICP determination. It is important to note that digestion is not complete for some Mg and Ba minerals, some oxides of Al, Mn, Sn and Zr, and massive sulphides. As, Cr, Sb, and Au are subject to loss by volatilization during HClO_4 fuming, thus the

significance of these elements are in question. Percent errors for all rock, till, soil, and humus analyses are found in Appendix B (B-1 & B-3). A summary of the types of methods used and the elements analyzed for water, lake sediments, till, soil and humus geochemistry appear on Table 2.

Table 2: Lake water and sediments, till, soil, rock, and humus were all analyzed for major and minor elements by various methods listed below. Waters were analyzed by the GSC Environmental Laboratories; sediments, rocks and humus by Acme Analytical Laboratories Ltd., BC.

LAKE WATER	
Elements	Types of Methods Used
Li, Be, Al, Ti, V, Cr, Fe, Mn, Co, Ni, Cu, Zn, As, Rb, Sr, Y, Mo, Ag, Cd, In, Sb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Tl, Pb, U, Se, Hg	ICP-MS Direct
Na, K, Ca, Mg	AA Direct (0.1% Cs-La)
NO ₂ , NO ₃ , F, Br, PO ₄ , SO ₄ , Cl	Dionex Ion Chromatography Analyzer
Total Alkalinity	Titration (to pH 4.5)
TOC	Shimadzu TOC Analyzer
Controls	
Ott-94, SLRS-2, 1643-C, NBS 1642b	
LAKE SEDIMENT, TILL, SOIL, ROCK AND HUMUS	
Elements	Types of Methods Used
Be, Al, Ti, V, Cr, Fe, Mn, Co, Ni, Cu, Zn, As, Sr, Y, Mo, Ag, Cd, Sb, Pb, U, Se, Hg	ICP-ES Direct
Na, K, Ca, Mg	ICP-ES Direct
LOI	Gravimetry
Hg	Cold Vapour AA
Controls	
.STD A (GSC), Standard C (Acme)	

3.2.3 Thecamoebians and diatoms

For thecamoebian preparation, 30 ml of lake sediment previously preserved with 2 ml of 30% ethanol were sieved in a 45 μm mesh screen to separate the fines and coarser material. For those samples extremely high in organics, residues were further split into three fractions of $>500\ \mu\text{m}$, 63-500 μm , and 45-63 μm . Residues were preserved with 2 ml of 30% ethanol and stored in a refrigerator until processed. Using the wet splitter (as described by Scott and Hermelin, 1993) processed samples were subdivided into 8 manageable aliquots for quantitative analysis. Samples were first scanned for approximate assemblages of thecamoebians and for abundances. One aliquot (1/8th of a sample) appeared sufficient to count a statistically correct fraction of approximately 300 thecamoebians. Specimens from this fraction were then identified and enumerated. Abundances are expressed as total specimens per 30 cc. of wet sample. The % error associated with each taxonomic unit was calculated using the standard error equation described by Patterson and Fishbein (1989). The percent error calculations for all species and strains are included in the appendices.

Nomenclature used for this thecamoebian analysis is similar to that described in Asioli *et al.* (1996); however, the term 'strains' replaces 'morphs'. Identification of strains of certain species according to environmental conditions was accomplished by identifying differing but reoccurring tests and aperture shapes as well as relative sizes. Identifications were verified using the JOEL 6400 scanning electron microscope (SEM) at the Carleton University Research Facility for Electron Microscopy. Plates were digitally produced

using scanning electron images on CORELPaint!™ 4.0 and outputted to a 600 dpi laser printer.

Samples chosen for diatom analysis appeared approximately every 10 cm downcore and were processed according to the standard analytical procedures of Batterbee (1986) by C. Prévost at the GSC Palynology Analytical Laboratories (Appendix C: C-1). Results were reported as part of Diatom Report # 96-06. Identification and enumeration of the diatoms was done by B. Hymes at the Canadian Museum of Nature, Ottawa, Ontario. Abundances are expressed as percents of total numbers of diatom valves counted. Scanning electron micrographs included in this Diatom Report were deposited in the Museum of Nature photograph collection. Identification of the diatom valves were based on the studies of Patrick and Reimer (1966; 1975), Foged (1981), Germain (1981), Gasse (1986), Krammer and Lange-Bertalot (1986; 1988; 1991a; 1991b), and generic revision based on Round *et al.* (1990). For synonymy and authorship, the catalogue of Van Landingham (1967-79) was consulted, along with the checklist of Hartley (1986).

3.2.4 ^{14}C dating

Samples from the bottom interval of the four cores were sent for radiocarbon age determination to Geochron Laboratories, a division of Krueger Enterprises, Inc., Cambridge, Massachusetts, USA (# GX-22185-AMS, GX-22186-AMS, GX-22187-AMS, GX-22188-AMS). Due to the size and nature of the sample, bulk analysis was done by mass spectrometry (AMS). Results were corrected for C^{13} and referenced to the year AD 1950.

4.0 GEOCHEMISTRY

4.1 Results

4.1.1 Rock data

During the 1995 field program, three samples of highly weathered rocks were collected from the top of pit 1 near James Mine and were subsequently analyzed for major and trace elements (Table 3). All analyses are shown in Table B-1 of Appendix B. The samples are assumed to be similar in composition to that of the bedrock immediately underlying James Lake despite the highly variable composition of the carbonate metasedimentary unit over small distances.

Table 3: Selected geochemistry of rocks found around the Ardoch area. CPA data were sampled strictly for this study. All LBP data are published in OGS Report 241 (Pauk 1987). SFB analytical data are unpublished from previous work by Breakwater Investments. SFB samples are boulders from glacial drift. Trace values are represented by a dash symbol. Detection limit (D.L.) and precision available only for CPA-series and is found in Appendix B, Table B-1.

ELEMENT			Au	Ag	Cu	Pb	Zn	Hg
SAMPLES	LOCATION	ROCK TYPE	ppb	ppm	ppm	ppm	ppm	ppb
95-CPA-1001	James Mine	marble	< D.L.	78.2	4379	25	366	630
95-CPA-1002	James Mine	marble	< D.L.	7.2	3211	17	108	170
95-CPA-1003	James Mine	marble	< D.L.	1.8	272	25	119	80
LBP-0430	James Mine	chalc- qtz vein	13000	102	5900	–	–	–
LBP-5194	Frog Lk	marble	40	< D.L.	157	–	–	–
LBP-4092	properties 9 & 12	marble	8	–	123	16	19	–
LBP-0414B	James Lk	marble	–	–	60	–	18	–
LBP-0417	James Lk	marble	–	–	60	–	18	–
LBP-0694	James Mine	qtz vein	10100	–	–	–	–	–
LBP-0762	Little Green Lk	marble	7	–	13	< D.L.	29	160
LBP-0760	Little Green Lk	marble	–	–	–	< D.L.	72	< D.L.
LBP-0771	Little Green Lk	marble	18	–	250	22	400	110
LBP-0786	Johnson Lk	hmn-bio gneiss	–	–	142	–	–	–
LBP-3026	Abs Lk	qtz vein	2 to 65	–	–	–	–	–
LBP-0161	Abs Lk	marble	–	–	–	–	–	–
LBP-0168	Abs Lk	qtz vein	2 to 65	–	–	–	–	–
LBP-0241	Crooked Lk	marble	–	–	–	–	–	–
SFB-86-0074	Johnson Lk	marble	7	1	36	3610	316100	29000
SFB-86-0076	Johnson Lk	marble	3	0	32	1584	270700	17000
SFB-86-0075	Johnson Lk	marble	3	1	51	7440	222800	21000
SFB-86-0072	N. of Johnson Lk	marble	22	15	60	1786	98000	117000
SFB-86-0073	N. of Johnson Lk	marble	4	20	15	689	191400	211000

Reference to the geology map (Figure 3; chapter 2.1) will be made in the rest of this section. Pauk (1987) collected several samples within the study area, especially around Little Green Lake, and performed limited analyses (Table 3). For example, a sample of marble (LBP-0771) collected 1000 m east of Little Green Lake contained 0.025% Cu, 0.04% Zn, 18 ppb Au, and 110 ppb Hg. Earlier exploration by St. Joseph Exploration Ltd. included analyzing marble samples taken from boulder trains just north of Johnson Lake, not far from Little Green Lake (Table 3). The rock source appeared to be located on private property to the north, but no further investigation occurred. These unpublished values reveal extremely high values of Pb, Zn and Hg (pers. commun., A.L. Sangster, 1995; Appendix B, B-2).

The bedrock between the Plevna Antiform and the Fernleigh Syncline, running SW-NE, consists of clastic and carbonate metasediments with many known mineral occurrences. It is within this area that the rock samples from Table 3 originated. The portion of the carbonate metasedimentary unit which hosts Frog Lake, James Lake, Little Green Lake, and Johnson Lake, shows a distinct trend in compositional changes due in part to mineral occurrences concentrated in this part of the study area.

At Frog Lake, 4.8 km southwest of James Lake, the metasedimentary unit exhibits high values of Au and Cu in tremolite, phlogopite, diopside, scapolite-bearing marble as well as marble interlayered with clastic siliceous metasediments of schist and gneiss (LBP-5194). Just south of Frog Lake, between the properties of C. Kohoe and Boerth Mine, high occurrences of Au, Cu, Pb and Zn appear within the same marble unit containing clastic silicious metasediments of schist and gneiss (LPB-5194, LPB-4092).

Bedrock around James Lake was sampled in an area of mostly massive dolomitic marble and marble with large lenses and layers of quartzite (95-CPA-1001 to 1003). These samples were all high in Ag, Cu, Pb, Zn, and Hg. Bedrock nearest to the abandoned mine had significant amounts of Cu, Zn and Hg (LBP-0430, LPB-0694). The sample from LBP-series was extremely high in Au and Cu. Just north of the lake, the tremolite, phlogopite, diopside scapolite-bearing marble was found to have some quantity of Au and a significant amount of Cu (LBP-0414B, LBP-0417). At Little Green Lake, Au, Cu, Zn, and Hg values are high mostly in marble units interlayered with clastic siliceous metasediments and marble as well as dolomitic marble with large lenses and layers of quartzite (LBP-0762, LBP-0760, LBP-0771). Near Johnson Lake, 1.5 km northeast of Little Green Lake, a sample of gneiss was found to be high in Cu (LBP-0786). Marble samples from the same area were found to have extremely high concentrations of Zn and Hg (SFB-0072 to 0076).

Rocks sampled southeast of Abs Lake came from the same carbonate metasedimentary unit (unit 6), but on the north side of the axial plane of the Plevna synform. Mostly massive, dolomitic marble bedrock near the lake (LBP-3026, 0161, 0168) was found to have only trace concentrations of the elements found in the marbles near James and Little Green Lakes. In the furthest northwestern portion of the metasedimentary unit of the map area (Figure 3), near Crooked Lake, negligible concentrations of trace elements were found (LBP-0241). No bedrock was sampled near Ardoch Lake.

4.1.2 Till, soil, and humus data

The chemical properties of till, soil, and humus samples from the catchments of each study lake are shown in Table 4. Significant amounts of Mn, Cd, Cu, Zn, Pb, Hg, Ba, La, Sr, and V occur in the media surrounding the three study lakes. Compared to media from other catchments such as Little Green and James Lakes, As appears in small concentrations around Ardoch Lake. Mo appears in large amounts only in the soils near James Lake.

Table 4: Chemical properties of till, soil, and humus from each watershed. All analyses were done at Acme Laboratories Ltd., BC. (Appendix B, B-3)

Lake	Sample Type	Mo ppm	Mn ppm	Cd ppm	Cu ppm	Zn ppm	Pb ppm	As ppm	Hg ppb	Ba ppm	La ppm	Sr ppm	V ppm
	% Error	0	23	23.7	7	2	4	n/a	19	5	7	0	1
	D.L.	1	2	0.2	1	1	3	2	10	1	1	1	1
Ardoch Lake	soil near lake	1	445	1.4	13	85	18	3	205	192	81	15	72
	humus near lake	1	641	0.8	14	86	51	< 2	150	114	14	37	28
Little Green Lake	till at road cut	2	878	1.3	103	153	23	28	70	99	116	25	113
	till near lake	2	654	0.7	97	274	37	111	220	123	24	227	86
	soil at road cut	2	100	1.2	94	148	25	32	55	96	115	27	117
	soil near lake	2	158	1.5	121	246	66	154	260	115	54	38	153
	humus near lake	1	142	2.4	34	295	147	20	290	295	11	77	38
James Lake	soil near lake	13	209	1.8	150	173	171	20	575	275	59	26	47
	humus near lake	3	223	6.1	17	261	353	10	465	306	5	48	22

According to background geochemical concentrations established for this region by Kettles and Shilts (1994), the two samples collected near Little Green Lake were found to have concentrations of Cr, Co, Fe, Mn, Mo, Ni, and U in the < 0.002 mm fraction equal to or lower than the regional background (bkgr) values (Appendix B; Table B-3). Other metals such as Cd (bkgr 0.1 ppm), Cu (bkgr 100 ppm), and Zn (bkgr 130 ppm) occur slightly above background concentrations while Pb (bkgr 12 ppm), As (bkgr 2 ppm), and Hg (bkgr 60 ppb) are many times above. Regional background concentrations

are not available for Ba, La, Sr, or V; however, these elements contribute significantly to the total trace element portion of the till. By comparison, till sampled near the southern-most beach of the lake had higher values of Hg, Sr, and Zn than in till found at the road cut.

Compared with average North American soil (ave) values documented by Rose, Hawkes, and Webb (1979), soils surrounding Little Green Lake are enriched in Cu (ave 15000 ppm), Pb (ave 35 ppm), Zn (ave 90 ppm), As (ave 6 ppm), Hg (ave 0.06 ppm), Co (ave 8 ppm), and Cd (ave 0.35 ppm) in the B-horizon (zone of illuviation). The soil chemistry of samples from the Little Green Lake area reflect the chemistry of the underlying till samples (Table 4). The majority of the trace element concentrations of the soil differ only slightly from the till values, except for Mn, Pb and Hg. Closer to Little Green Lake, Pb and Hg concentrations in the soil are significantly higher than the till values. Overall, the values of trace elements are higher in the soils nearest to the lake. The values for Zn, As, Sr, Cr, and V in the soils of the catchment of Little Green Lake are higher than any of the soils sampled in the Ardoch area.

At James Lake, soils were found to be especially high in Cu, Ba, Pb, and Hg in comparison to Little Green and Ardoch Lakes. According to average North American soil geochemistry, James Lake soils are enriched in Cu, Pb, Zn, As, Hg, Cd, Mn (ave 1000 ppm), and Mo (ave 1.2 ppm). The Pb concentrations in the soil around James Lake are 2 ½ times greater than those values found in soil nearest Little Green Lake and 9 ½ times greater than soil near Ardoch Lake. As well, Hg concentrations are 2.2 times greater than soils nearest Little Green Lake and 2.8 times greater than soils around Ardoch Lake. The soils around Ardoch Lake have the lowest overall concentrations of Cu, Pb, Zn, As, Sr,

Cr, and V. Ardoch Lake soils have Ba concentrations lower than those of James Lake but higher than any found around Little Green Lake. The concentrations of Mn are anomalous in the Ardoch Lake soil, double that of James Lake and triple that of Little Green Lake. Ardoch Lake soil is at or below average North American values, except for Mn and Hg.

Regional background values for humus geochemistry from previous studies are not available for this region. Generally, the geochemistry of humus for each of the sample sites reflects the underlying soil chemistry, except for As, Cr, V, and La (Table 4). These trace metal concentrations are very low compared to their underlying soil. Concentrations of Cu in the humus samples near Little Green and James Lakes are also significantly lower than soil values, however, humus and soil Cu concentrations at Ardoch Lake differ only by 1 ppm. All humus samples from the study area had high concentrations of Mn, Sr, and Zn with respect to the soils. Again at Ardoch Lake, humus samples for Ba were slightly lower, while Ba in humus from the other two locations were higher than corresponding soils. Unlike humus found around Little Green Lake, concentrations of Hg in humus samples are lower than soils in the area around Ardoch and James Lakes. In all humus samples, Pb is substantially enriched in the humus with respect to underlying soils.

4.1.3 Lake water

4.1.3.1 Ardoch Lake

4.1.3.1.1 *Water conditions*

In late August, at the time of sampling, the orange/brown water of Ardoch Lake was relatively clear with a Secchi depth of 3.8 m (Table 5). The Secchi depth is a measurement of the 'murkiness' of the water or roughly the limit of the photic zone. Water temperature profiles are typical of summertime stratified lakes. The surface of the water column of Ardoch Lake was a warm 23.47°C at time of sampling. Its thermocline occurs at approximately 6.0 m below the water surface at which point, temperature declines rapidly. The lake bottom waters were 8.02 °C at time of sampling (Figure 8a; Appendix B, B-4a). The pH varies from 8.54 at the surface to 7.45 at the bottom (Figure 8a). In carbonate-rich waters, total alkalinity is essentially a measure of bicarbonate alkalinity (94-132 ppm). Conductivity increases down the water column, from 228 to 266 µS/cm, measuring increasing amounts of dissolved ionic material (Figure 8a). Redox potential (E_H), a measurement of the potential for oxidation or reduction reactions, is 328 millivolts (mV) at the surface, increasing to 390 mV near the bottom, but then dropping to 361 mV at the sediment-water interface. The dissolved oxygen maximum is 15.45 ppm, and appears at 8 m depth in the water column. Dissolved oxygen drops to 0.21 ppm at the lake bottom. Turbidity (total suspended particles) of water samples from Ardoch Lake remain low throughout the column (<3.0 NTU).

Figure 8: Temperature and dissolved oxygen profiles for each lake basin. Horizontal lines indicate depth and sample number for collected water samples. Also shown is pH and conductivity values for water samples. Bottom/top ratios are shown where a value of 0% would indicate completely anoxic conditions at the lake bottom. Secchi depth describes the murkiness of the water (Appendix B: B-4a-d)

Lake	Depth	OTHER MINOR CATIONS														
		Cr	Co	Ni	Cu	Zn	As	Mo	Sr	Cd	Sb	Ba	V	Pb	U	Hg
		ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
		0.1	0.05	0.2	0.1	0.5	0.1	0.05	0.5	0.05	0.01	0.2	0.1	0.1	0.005	0.004
	D.L.	0.1	0.05	0.2	0.1	0.5	0.1	0.05	0.5	0.05	0.01	0.2	0.1	0.1	0.005	0.004
	NGR bkgr	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.02	n/a
	Error ±	21.3	11.6	0	9.4	0	20	15.3	1.3	0	7.5	1.2	16.5	0	6.3	0
Ardoch Lake	1.0	1.6	< 0.05	< 0.2	0.9	< 0.5	0.4	0.10	61.3	< 0.05	0.07	30.4	0.8	< 0.1	0.06	0.009
	9.0	2.1	0.07	0.5	0.6	< 0.5	0.3	0.10	62.5	0.20	0.06	32.9	0.5	< 0.1	0.057	< 0.004
	> 14.0	1.3	0.33	< 0.2	0.2	1.7	0.5	0.09	64.0	< 0.05	0.07	39.8	0.6	< 0.1	0.055	< 0.004
	(interface)															
Little Green Lake	1.0	1.2	0.06	< 0.2	0.6	1.0	0.9	0.47	71.7	0.07	0.17	29.9	0.5	0.3	0.153	0.011
	8.0	1.1	0.06	0.3	0.7	1.3	1.0	0.43	71.2	0.05	0.16	28.9	0.5	0.2	0.135	< 0.004
	> 21.0	2.5	0.08	0.3	1.1	4.9	9.9	3.87	76.7	< 0.05	1.29	48.1	2	0.3	0.389	< 0.004
	(interface)															
James Lake basin 1	1.0	2.2	< 0.05	0.2	0.5	0.8	1.5	0.96	83.7	< 0.05	0.29	24.6	0.8	< 0.1	0.177	0.021
	5.0	2.8	0.07	0.2	0.3	0.9	1.3	0.74	96.4	< 0.05	0.26	34.9	0.9	< 0.1	0.199	< 0.004
	> 12.0	2.7	0.31	< 0.2	0.9	1.5	11.9	1.71	114.2	< 0.05	0.84	142.3	1.7	0.6	0.274	< 0.004
	(interface)															
James Lake basin 2	1.0	1.0	0.06	< 0.2	0.4	0.6	1.4	0.95	85.6	< 0.05	0.28	24.7	0.5	< 0.1	0.187	< 0.004
	6.0	2.3	0.08	< 0.2	0.2	0.9	1.3	0.75	1.5	< 0.05	0.24	38.2	0.8	< 0.1	0.192	0.006
	> 11.0	2.4	0.13	0.8	0.5	2.3	1.5	0.65	113.5	0.20	0.28	49.5	0.4	0.1	0.191	< 0.004
	(interface)															

Water samples were analyzed for TOC, alkalinity, Si, S, Na, K, Mg, Ca, NO₂, NO₃, F, PO₄, Br, SO₄, Cl, and 42 other cations. Major anions and cations are plotted on a piper diagram (Figure 9; Appendix B, B-9). Regional (50th percentile) background values for NO₃, SO₄, Cl, Na, K, Ca, Mg, Fe, Mn, Zn, U are available from NGR surveys which include the Ardoch area. Only a few minor and trace elements (Fe, Mn, Zn, U) were analyzed in the NGR survey.

Overall, the highest concentrations of metals and trace metals occur in the hypolimnion at the bottom of the water column, usually just above the sediment-water interface. All trace element concentrations, except for Ba, lie within the ppb range, below "contamination" levels for aquatic life and drinking water standards established by the Canadian Council of Resource and Environmental Ministers (Environment Canada, 1978).

For Ardoch Lake, the most significant enrichments in the hypolimnion are Si, Ti, Mn, Co, Zn, Sr, Ba, and U. Compared to the established regional background

Figure 9: A Piper diagram for waters from lakes in SE Ontario. Chemical analyses of water represented as percentages of total equivalents per litre. Lake waters are rich in calcium, magnesium, and bicarbonates due mostly to the composition of the surrounding bedrock, marble.

concentrations of Fe, Mn, Zn, and U, the bottom waters contain anomalous values of Mn and higher values of U. Total organic carbon and alkalinity are also highest at the sediment-water interface of Ardoch Lake. Of the major constituents Mg, Ca, Cl, HCO_3 , SO_4 , Na, and K, lake water is primarily composed of Ca and HCO_3 with minor components of Mg and SO_4 (Figure 9; Appendix B-9). Concentrations of Na, K, and Cl in the water are small.

4.1.3.2 Little Green Lake

4.1.3.2.1 *Water conditions*

The blue-green water of Little Green Lake gave a Secchi depth of 4.5 m at the time of sampling. Surface waters of the lake are a few degrees warmer than Ardoch Lake (25.90°C). The thermocline begins at a shallow depth of 4 m and the lake bottom waters were 5.10°C at time of sampling (Figure 8b; Appendix B, B-4b). Its alkalinity (122-140 ppm) and turbidity (2.50-1.95 NTU) are slightly higher than Ardoch Lake (Table 7; Figure 8b). Conductivity and pH range from 268-306 $\mu\text{S}/\text{cm}$ and 8.20-7.30, respectively, down the water column. E_H increases from 325 mV at the surface to 403 mV just above the sediment-water interface, where it decreases to 243 mV. The dissolved oxygen maximum is 18.60 ppm and appears at 6 m in the water column. The interval of maximum dissolved oxygen content in the water column occurs between 5 and 13 m. At the lake bottom, dissolved oxygen levels are low: 0.3 ppm.

Table 7: Little Green Lake in-situ field and camp measurements and observations of water properties.

031C9501 LITTLE GREEN LAKE						
Easting	Northing	Surface area	Water colour	Water depth	Sample depth	Secchi depth
351269 mE	4980077 mN	290000 m ²	blue/green	21 m	18 m	4.5 m
Sample number	Water temp °C	Dissolved oxygen ppm	Conductivity µS/cm	pH	Alkalinity HCO₃⁻ ppm	Turbidity NTU
Error ±	0.10	0.10	10	0.10	10	0.10
031C9501-01.0	25.90	10.60	268	8.30	122	2.50
031C9501-08.0	12.00	17.80	275	8.30	140	2.20
031C9501-21.0	5.10	0.30	269	7.30	136	1.95

4.1.3.2.2 *Water chemistry*

Water geochemistry for Little Green Lake is given in Table 6. TOC and alkalinity in the surface waters of Little Green Lake are slightly higher than in Ardoch Lake. Values for TOC and lab-determined alkalinity for the bottom-most water sample are unavailable. Unlike Ardoch Lake, all analyzed anions were above detection limits in the hypolimnion.

For major constituents of the water geochemistry, water from Little Green Lake has lower concentrations of Na than in Ardoch Lake; however, K, Ca, and Mg concentrations are higher. Figure 9 shows Little Green Lake with a larger percentage of Mg in its water than in both Ardoch Lake and James Lake.

Of the minor or trace components, the lake water has higher concentrations of Zn, As, Mo, Sb, and V throughout the water column than either Ardoch or James Lakes, but is the lowest in Mn (Table 6). It also has relatively high concentrations of Sr and Ba at the sediment-water interface as compared to Ardoch Lake. Compared to regional background values for Fe, Mn, Zn, and U, Little Green Lake contains significantly enriched values of Mn and U, slightly enriched Zn, and Fe levels below background (Hornbrook *et al.*, 1984).

4.1.3.3 James Lake

4.1.3.3.1 *Water conditions*

The water properties for each basin are presented on Figure 8c and d and in Tables 8 and 9. The water of James Lake is yellow/brown in colour with a Secchi depth of 3.2 m. Lying in the same carbonate terrain as Little Green Lake, water chemistry is typical of its carbonate environment and similar to that of Little Green Lake. This is reflected in the alkaline waters with pH slightly greater than pH 8 in both basins declining to pH 6.49 and 7.08 at the sediment-water interface of basin 1 and basin 2, respectively.

Water temperatures throughout the water column of each basin are similar with the thermocline beginning at approximately 3 m and declining to 5.14 °C for basin 1 (at 12m depth) and 5.56°C in basin 2 (11 m depth). For other water conditions, only slight differences occur between the two basins of James Lake. The depth interval of maximum dissolved oxygen content in the water column occurs between 3 and 5 m in basin 1. In basin 2, only a very slight increase occurs between 4-5 m depth. In the hypolimnion, dissolved oxygen content decreases to a minimum of 0.61 ppm in basin 1 and 0.19 ppm in basin 2. In basin 1, maximum E_H lies 6 cm above the sediment-water interface at 374 mV, then decreases to 135 at the sediment. Similarly in basin 2, the interval is 372 to 133 mV. Conductivity and turbidity are 767 $\mu\text{S}/\text{cm}$ and 26 NTU, respectively, for basin 1 compared to 394 $\mu\text{S}/\text{cm}$ and 9.46 NTU in basin 2. The higher concentration of solutes occur primarily at the sediment-water interface of basin 1.

Table 8: James Lake basin 1 in-situ field and camp measurements and observations of water properties.

031C9502 JAMES LAKE BASIN 1						
Easting	Northing	Whole-lake surface area	Water colour	Water depth	Sample depth	Secchi depth
348632 mE	4979607 mN	41616 m ²	yellow/brown	14	13.2 m	3.47 m
Sample number	Water temp °C	Dissolved oxygen ppm	Conductivity µS/cm	pH	Alkalinity HCO ₃ ⁻ ppm	Turbidity NTU
Error ±	0.10	0.10	10	0.10	10	0.10
031C9502-01.0	24.55	10.56	275	8.14	134	0.68
031C9502-05.0	14.48	13.38	350	7.79	158	0.87
031C9502-12.0	5.14	0.33	767	6.49	n/a	26

Table 9: James Lake basin 2 in-situ field and camp measurements and observations of water properties.

031C9503 JAMES LAKE BASIN 2						
Easting	Northing	Whole-lake surface area	Water colour	Water depth	Sample depth	Secchi depth
348634 mE	4979782 mN	41616 m ²	yellow/brown	16 m	11.3 m	2.91 m
Sample number	Water temp °C	Dissolved oxygen ppm	Conductivity µS/cm	pH	Alkalinity HCO ₃ ⁻ ppm	Turbidity NTU
Error ±	0.10	0.10	10	0.10	10	0.10
031C9503-01.0	24.57	10.39	276	8.11	117	0.54
031C9503-04.0	19.60	10.61	320	7.86	134	0.70
031C9503-06.0	11.70	5.84	364	7.51	172	1.14
031C9503-11.0	5.56	0.19	394	7.08	184	9.46

4.1.3.3.2 Water chemistry

The majority of trace elements in the waters of James Lake occur in higher concentrations than in the waters of Little Green and Ardoch Lakes (Table 6). However, differences also occur between trace element concentrations of the two basins. For the anions, water at the sediment-water interface in basin 1 is especially high in NO₂, NO₃, and Si. Concentrations of Fe and Mn are high in both basins of James Lake compared to both Ardoch and Little Green Lakes; however, basin 1 has extremely high values in the hypolimnion in comparison with basin 2. Compared to regional background values for Fe and Mn, basin 1 is largely enriched in Fe and Mn at the sediment-water interface; however, basin 2 is only slightly above background values for Fe but is significantly higher in Mn compared with background and the other study lakes.

It is also important to note that there are relatively high values of As and Pb at the sediment-water interface in basin 1 compared to the low values in basin 2. Sr and Ba are elevated with respect to the rest of the water column. Concentrations of Zn and U are low with respect to Little Green Lake. As for regional background values, Zn in waters of both basins of James Lake are below that of background while U is higher than background, but remains an insignificantly small portion of the total chemistry.

4.1.4 Lake bottom sediments

4.1.4.1 Sediment description

4.1.4.1.1 *Ardoch Lake*

According to the sonar profiles of Ardoch Lake, approximately 14 m of lake sediment has accumulated in the deepest part of the basin. The majority of the basin is covered with a thick soft carbonate-rich sediment (Figure 10). Some deeper areas of the lake basin experience methane gas production. Closer to the shoreline and in the southwestern section,

Figure 10: Surface and subsurface lake bottom sediment for Ardoch Lake.

sediments are carbonate-rich sand. Shallow sand with a thin organic layer (aquatic and shore flora) border the lake. Based on core sampled from the basin, the surface sediments (~12 cm) in the deeper parts of the basin are odorous and primarily composed of blackish/brown sandy sediments rich in organic detritus (Figure 10). The underlying sediments are silts with varying degrees of carbonate material (marl).

4.1.4.1.2 *Little Green Lake*

The sonar profiles indicate that surface sediments are underlain by about 13 m of various layers of carbonate-rich silt (Figure 11). The entire basin of Little Green Lake consists of silty to sandy carbonate-rich sediment with a high degree of methane gas production in the deeper portions of the basins. The top eight centimetres of sediment are composed of black, inhomogeneous, medium- to fine-grained ooze with organic detritus (Figure 11). Below this are multiple layers of carbonate-rich silty sediment alternating with layers of marl sediments in the lower sections of the core.

4.1.4.1.3 *James Lake*

Based on interpretations made from the sonar profiles and the core samples, the lake bottom sediment consists of approximately 13 m of partially decomposed organic debris, such as leaves, pine needles, and shavings of wood mixed with silty sand (Figure 12). Bedrock is prominent along the eastern shore as well as in the narrows of this small lake. Methane gas production was observed in the sonar profiles in a section of basin 2 and was readily observed in the sample cores taken from both basins. H_2S production was also apparent.

Figure 12: Surface and subsurface lake bottom sediment type for James Lake.

Differences between basins occurred in the core samples where layers of partially decomposed woodchips were observed in great quantities in the basin 2 core. Only small amounts were observed in the basin 1 core.

4.1.4.2 Radioisotope dating and sedimentation rates

Results from radioisotope dating of the bottom 2 cm of each core show that Little Green Lake and basin 1 of James Lake have almost the same sedimentation rates while rates for basin 2 of James Lake and Ardoch Lake are comparable but different from the first two cores (Table 10). The differing sedimentation rates in the basins of James Lake result from samples taken at different depths in the basin, and a higher input of organic detritus in basin 2.

Table 10: ^{14}C results for the bottom 2 cm-interval of each core from the study lakes. All ages were corrected for ^{13}C and referenced to the year AD 1950. Sedimentation rates are based on the erroneous assumption of constant sedimentation rates.

Lake	Sample depth cm	^{14}C Age yrs	$\delta^{13}\text{C}_{\text{PDS}}$ ‰
Ardoch Lake	60	1,550±50	-32.3
Little Green Lake	72	3,720±50	-33.4
James Lake Basin 1	62	3,270±60	-29.8
James Lake Basin 2	66	1,440±60	-29.2

The estimation of sediment age by carbon-14 dating can be complicated by biological or physical mixing of sediments (Owens and Cornwell, 1993). An error exists also in the assumption that the sedimentation rates are constant. Erroneous estimates of sedimentation rates can result when compaction and the decomposition of the organic content in the sediment are not considered. Analytical ages might be too old due to the introduction of old carbon from surrounding carbonate rocks. However, correcting to the

carbonate PDB standard ^{13}C content should compensate for this error (Domineco and Schwartz, 1990). A calibration of ^{14}C values with other techniques such as pollen analysis could serve as an independent check.

4.1.4.3 Sediment Geochemistry

4.1.4.3.1 *Comparison between mean recent and background geochemical signatures*

To determine the influence of the geochemistry of terrigenous materials on lake environments, both background and recent, potential anthropogenically impacted geochemical signatures in the lake sediments are compared to each other. Furthermore, these values are observed against regional background values established by the NGR surveys for certain trace elements such as Mn, Fe, As, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sr, Zn, Ag and U (Hornbrook *et al.*, 1984). This comparison will identify anomalous concentrations in one or more lakes. The depth of this study will remain at general comparisons, eliminating detailed statistical work.

For each lake, background concentrations for each element are calculated by averaging concentrations of each element in all samples below 22 cm in the lake sediment (Friske, 1995). The thought is that concentrations of older material collected from deeper layers in the lake sediment chemically represent that which is natural and untouched by anthropogenic activities (Rasmussen, 1994). Also, these layers reflect the composition of a relatively stable zone of the lake sediment below the zone of most intense diagenetic activity (Friske, 1995). In addition, average concentrations of the top 10 cm of the sedimentary sequence, within the potentially anthropogenically-impacted and diagenetically active zone, are calculated and observed against the background

concentrations for each lake to establish enrichments or depletions in the chemical signatures. All available regional background values, plus local recent and background values, are shown in Table 11.

Table 11: Average concentrations of variables of the 'raw data' series in surface (0-10 cm) and 'background' (>22 cm) sections of the four lake sediment cores. Available regional background values ('NGR bkgr') established by the GSC NGR program are also shown for comparison purposes.

Lake	Depth	MAJOR ELEMENTS									
		LOI %	Al %	Ti %	Na %	K %	Ca %	Mg %	P %	Mn ppm	Fe %
	NGR Bkgr	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	310.00	1.20
Ardoch Lake	Surf 0-10 cm	41.66	1.04	0.07	0.05	0.21	5.90	1.02	0.11	658.20	1.99
	Bkgr 22-60 cm	43.97	0.79	0.06	0.04	0.17	10.28	0.86	0.08	501.55	1.41
Little Green Lake	Surf 0-10 cm	50.64	0.59	0.05	0.03	0.11	17.74	0.59	0.08	779.80	1.40
	Bkgr 22-72 cm	54.13	0.45	0.04	0.03	0.09	19.06	0.50	0.07	565.88	1.43
James Lake basin 1	Surf 0-10 cm	60.74	0.40	0.02	0.01	0.04	5.61	0.15	0.08	812.20	2.23
	Bkgr 22-62 cm	51.49	0.35	0.02	0.02	0.02	13.79	0.22	0.07	2940.80	3.40
James Lake basin 2	Surf 0-10 cm	65.60	0.56	0.02	0.02	0.05	7.69	0.29	0.08	826.00	1.72
	Bkgr 22-66 cm	61.75	0.36	0.01	0.02	0.03	10.62	0.19	0.06	496.33	1.50

Lake	Depth	TRACE ELEMENTS									
		As ppm	Co ppm	Cr ppm	Cu ppm	Hg ppb	Mo ppm	Ni ppm	Pb ppm	Sr ppm	Zn ppm
	NGR Bkgr	0.50	6.00	50.00	28.00	80.00	2.00	10.00	4.00	160.00	88.00
Ardoch Lake	Surf 0-10 cm	5.40	6.60	21.80	33.40	116.00	2.80	15.60	98.00	54.20	371.60
	Bkgr 22-60 cm	2.17	5.00	16.00	26.45	50.75	2.10	11.45	5.78	68.00	238.75
Little Green Lake	Surf 0-10 cm	40.60	4.00	9.20	62.00	122.00	8.80	15.00	43.80	89.00	376.60
	Bkgr 22-72 cm	68.08	3.42	7.00	68.62	86.15	13.88	16.23	6.35	87.96	390.42
James Lake basin 1	Surf 0-10 cm	34.20	4.40	4.80	72.80	560.00	13.80	17.60	86.00	47.80	589.40
	Bkgr 22-62 cm	142.90	5.40	6.30	55.60	330.50	12.90	15.10	17.00	111.80	378.70
James Lake basin 2	Surf 0-10 cm	26.80	7.80	9.80	51.40	243.00	16.20	15.60	141.20	64.20	534.60
	Bkgr 22-66 cm	26.42	3.92	5.75	92.58	261.25	22.25	20.67	7.58	90.75	637.42

Lake	Depth	OTHER TRACE ELEMENTS									
		Ag ppm	U ppm	Th ppm	Cd ppm	Sb ppm	Bi ppm	La ppm	Ba ppm	B ppm	V ppm
	NGR Bkgr	0.10	2.80	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Ardoch Lake	Surf 0-10 cm	0.33	7.00	3.00	2.02	0.00	0.00	17.20	118.00	12.80	30.40
	Bkgr 22-60 cm	0.35	9.19	2.53	0.51	2.00	0.00	13.80	110.20	12.35	24.20
Little Green Lake	Surf 0-10 cm	0.40	6.00	2.00	1.56	10.20	3.00	7.40	111.40	10.20	20.40
	Bkgr 22-72 cm	0.33	6.73	2.00	1.23	12.85	2.00	7.35	101.96	10.23	17.81
James Lake basin 1	Surf 0-10 cm	0.33	0.00	0.00	1.54	10.40	2.00	10.20	61.00	13.80	9.80
	Bkgr 22-62 cm	0.41	0.00	0.00	0.86	11.50	3.00	14.40	109.00	9.60	21.50
James Lake basin 2	Surf 0-10 cm	0.52	0.00	0.00	3.28	10.60	2.00	8.00	93.20	10.60	22.80
	Bkgr 22-66 cm	0.30	6.89	2.00	2.93	14.50	2.00	11.25	160.83	14.17	11.08

To examine bulk or "total" trace metal concentrations throughout the sediment cores, all raw data were normalized to the content of aluminum, a major constituent of clay, to reduce noise in the data and permit the comparison of background and enrichment factors

(Friske, 1995; Farmer, 1991; Horowitz, 1991; Cornwell, 1986). Aluminum is assumed to have had a uniform flux from crustal rock sources, from the time particles were eroded until they were deposited, over a long period of time. From this, compensation for changes in levels of various trace elements can be made. Any variability in the profile suggests the influence of a number of possible interacting factors in the environment, such as basin composition, climate, seasons, trophic status of the lake, sedimentation rates, and the degree of weathering of sulphide minerals and surrounding bedrock (Mudroch and MacKnight, 1991; Lindberg and Harriss, 1974). Assumptions in interpreting these lake sediment profiles includes little or no post-depositional disturbances of sediments (Farmer, 1991). The data were plotted as geochemical profiles for each lake and illustrated in Figures 13, 14, 15 and 16. The raw data can be found in Appendix B (B-16 to B-19).

4.1.4.3.2 *Ardoch Lake*

The background organic content (LOI) of the sediment in Ardoch Lake is above 40%, typical for a productive lake in late summer. Background values for the major elements Al, Ti, Na, K, and P are typically low for carbonate sediment. Consequently, Ca and Mg concentrations are high. The highest contributors of the trace elements present in Ardoch Lake sediments include Mn, Zn, Ba, Sr, and Hg, in decreasing order. Compared to regional background values, the sediments of Ardoch Lake are anomalous in Mn, As, and U. Background values of Pb, Ni, Mo, and Ag are slightly higher than regional background. Since the majority of background values for the sediments of Ardoch Lake are similar to or below the regional background values, Ardoch Lake is considered to be

Figure 13: The geochemistry of sediments from Ardoch Lake. Except for aluminum, all values are Al-normalized(ppm of element*(ppt of Al*10)).

Figure 14: The geochemistry of sediments from Little Green Lake. Except for aluminum, all values are Al-normalized (ppm of element*) (ppt of Al * 10).

Figure 15: The geochemistry of sediments from basin 1 of James Lake. Except for aluminum, all values are Al-normalized (ppm of element*(ppm of Al*10)).

Figure 16: The geochemistry of sediments from basin 2 of James Lake. Except for aluminum, all values are Al-normalized (ppm of element*(ppm of Al*10).

representative of background for the Ardoch area. Concentrations from other lake sediments, therefore, will be compared to the Ardoch Lake values.

No significant enrichment, if any, of the major components occurs in the recent (0-10 cm) sediments. Organic content decreases in the top 10 cm of the core; however, below this depth, LOI remained relatively constant. Ca concentrations are lowest in the upper sediments and Mg concentrations increase. Of the trace elements, the sediments are enriched to varying degrees for all elements, except for Ag, U, and Sb. The most significant enrichments occur in the As, Hg, and Pb concentrations. Mn, As, Cu, Hg, Mo, Ni, Pb, Zn, Ag, and U all are high compared to regional background values.

The raw geochemical data (Appendix B, B-10) were normalized to aluminum and presented as profiles of geochemical fluctuations with depth (Figure 13). Once normalized, Ardoch Lake profiles show elements such as Al, Na, K, Mg, Fe, Mn, Cu, Cr, and Co with uniform signatures throughout the sedimentary sequence. From 21 cm to surface, Hg, As, and Pb gradually increase in concentration. Zn concentrations are irregular throughout the profile. The only significant trace element fluctuations occur in the Zn, Hg, As, and Pb profiles.

4.1.4.3.3 *Little Green Lake*

The LOI content of the background sediments in Little Green Lake is >50% (Table 11). Concentrations of Al, Ti, Na, K, and P are slightly lower than the background sediments of Ardoch Lake. The Ca content of the sediment in Little Green Lake is almost twice as much as Ardoch Lake values, while Mg concentrations are much lower than Ardoch Lake values. Background Mn and Fe concentrations are similar to Ardoch Lake

concentrations and are above regional background values. For background trace element concentrations, As, Cu, Hg, Mo, Sr, Zn, and Sb are especially high or 'anomalous' compared to Ardoch Lake and regional background values. For Co, Cr, Ag, U, Ba, and B, concentration are lower than established background values.

In the surface sediments of Little Green Lake, the organic content of decreases slightly to approximately 50%. Concentrations of all major elements increase except Na which is constant, and Ca and Fe which decrease. Enrichments are apparent for all trace elements except for As, Cu, Mo, N, Zn, U, Sb, and B. Enrichments are especially high for Hg and Pb as noted for Ardoch Lake signatures.

In the geochemical profiles for Little Green Lake, the major elements tend to fluctuate from 40 cm to the bottom of the core as well as marl content in the sediments (Figure 14: 'raw values' can be found in Appendix B, Table B-11). Most profiles of both major and trace elements tend to mirror the organic content profile as well as the thick layers of marl in the sediments. Peaks occur for LOI, Na, Ca, K, Mg, P, Fe, Mn, Zn, Ni, Mo, Cu, Hg, Ba, As, and Sr between 50-60 cm and 60-68 cm, the latter being the maximum. At these depths, a depletion occurs for Cr, Co and Al concentrations. As the organic content of the upper part of the profile remains relatively constant, so does the trace metal concentrations. Only Pb is enriched at the surface.

4.1.4.3.4 *James Lake*

The background concentration for LOI is slightly above 50% in basin 1, comparable to the other study lakes (Table 11). However, the organic content of the sediments in basin 2 is above 60%, higher than in any of the other sediments including basin 1. Only

slight differences in sediment composition occur between the two basins, mostly with respect to organic detritus. Of the major components of the sediments, Al, Ti, K, Na, Mg, and P are lower than concentrations found in the other two study lakes. Ca concentrations are slightly higher than Ardoch Lake sediments, but lower than Little Green Lake sediments. For Mn values, basin 1 is anomalous with respect to regional background values. This statement holds true for Ardoch and Little Green Lakes. However, values for Mn in basin 1 are over 5 times as much as Ardoch Lake, Little Green Lake, and basin 2 of James Lake. Fe follows the same pattern, significantly higher than in the other lake basins. Most background trace element values are anomalous in basin 1 of James Lake including As, Hg, Pb, Sr, and Zn, which are significantly higher than Ardoch and Little Green Lakes, as well as basin 2 of James Lake. Trace metals, including Cu, Mo, Ni, Zn, Sb, Ba, and B, are higher than any other lake basin previously mentioned.

Both basins of James Lake have organics constituting >60% of the surface sediment chemistry. Basin 2 has the highest concentration of organic matter in both its recent and background sediments. All major element concentrations are enriched in the surface sediments, except for Ca in basin 2, as well as Ca and Mn in basin 1. The recent Mn values are similar between basins but Fe values are much higher in basin 1 compared with basin 2. A significant decrease occurs for As, Sr, and Ba in basin 1 while slight decreases occur for Co, Cr, Ag, Sb, Bi, La, and V. Of the trace elements in basin 2, Cu decreases significantly in the recent sediments while Hg, Ni, Sr, Zn, B, Ba, La, Sb, U, and Th decrease only slightly. Pb concentrations increase significantly in both basins. The largest value for Pb in the recent sediment is in basin 2, which exceeds all other lake basins.

In James Lake, the lake with the highest concentrations of organic content and most trace metals, concentrations of all components fluctuate considerably throughout the core (Figures 15 & 16). For basin 1, the general trend observed in the profiles is a correlation between organic content and the major and minor components of the sediments (Figure 15: 'raw values' in Appendix B, B-12). A large interval in the sedimentary sequence, between 35 and 10 cm, contains elevated levels of all components, except for Al and Pb. Peaks of Mn and Fe occur near the bottom of the core, between 50 and 45 cm. In Figure 16, no significant interval of universally increased concentrations of sediments are observed (Appendix B, B-13). However, concentrations do fluctuate downcore. Organic content shows a significant decrease in the surface sediments as Al, Mg, and Pb increase. A peak in organic content also occurs at 40 cm which coincides with a peak in Hg concentrations.

4.2 Discussion

4.2.1 Natural sources of trace metals

4.2.1.1 Geology

Much of the large carbonate metasedimentary unit within the study area is mineralized, generating a potential source for trace metals. The marbles between James Lake and Johnson Lake contain high concentrations of trace elements including Ag, Cu, Zn, Hg and to a lesser extent, Pb associated with metallic minerals of Au, As, Cu, Fe-sulphides, and small scattered but concentrated amounts of Mo, Zn, Ni, Pb, and Fe-oxides (Pauk, 1987). Generally, Au, Cu, and As are confined to the stratigraphic units bordering

Flinton group metasediments. Occurrences of stratigraphic-bound galena (PbS), Zn-bearing quartz-dolomite veins, small disseminations of pyrite, pyrrhotite and chalcopyrite, small clusters of chalcopyrite and patches of malachite chalco-bearing quartz are sources for other trace elements. Pb and Zn also occur as weak disseminations in marble and interlayered quartzofeldspathic gneisses.

The original source of most trace metals in the carbonate metasedimentary unit is the older rock units in the same area (volcanics) which are intercalated with or underlying the Grenville marbles (Cameron and Jonasson, 1972). It has been suggested that base metal sulphides in the marbles of the Ardoch area are related to Grenvillian volcanic intrusive events (such as unit 8; Figure 3) in which hydrothermal fluids mobilized elements contained in the volcanics (Sangster and Bourne, 1982). Regional metamorphism may also have mobilized Ag, Cu, Zn, and Pb, concentrating them in areas such as James Lake (Sangster and Bourne, 1982). For Hg, clastic metasediments (schist and mudstones) are the probable source, since concentrations in Archean metavolcanics are extremely low (Loukola-Ruskeenieme, 1990; Cameron and Jonasson, 1972). According to Sangster and Bourne (1982), Au occurs most in association with quartz vein-hosted sulphide deposits within metavolcanics, clastic metasediments, and carbonate rocks.

Large geochemical variations occur over small distances within the marble unit. In the portion contained within the Plevna synform, a variety of layers and lenses of quartz, schist, and metasedimentary materials within the marble as well as various mineral occurrences of mostly iron sulphides concentrated near James Lake control the trace element distribution in the bedrock. The highest concentrations occur in the bedrock nearest James Lake, not including the glacially derived boulders near Johnson Lake. In

the same marble unit located within the Plevna antiform, the marble type is dolomitic and is void of the interlayers and lenses of other rock types as found in the Plevna synform. These marbles contain geochemical signatures of anomalous Mo concentrations which would expect to be reflected in the catchments of near-by lakes. In lake sediments of Crooked and Abs Lakes, for example, a much different geochemical signature occurs than found in the study lakes, including anomalous Mo values. Also influencing the geochemical signatures are the large gneissic units underlying Abs Lake and surrounding Crooked Lake. In fact, each of the lakes in the Ardoch area receives differing proportions of terrigenous inputs from differing rock compositions and types resulting in unique geochemical signatures.

Trace metals contained in the bedrock surrounding Ardoch, Little Green and James Lakes become available to the environment through weathering processes. In essence, the bedrock passes on its geochemical and physical traits to soils and tills. For example, trace metals weathering out of the metalliferous marbles near James Lake will be detected as anomalous trace metal concentrations in the till and soil of the same area. In contrast, weathering marbles near Abs Lake will only result in minor trace metal concentrations within its catchment. The trace elements concentrated in the soils and tills will eventually be washed or blown into the lake and become incorporated into the lake sediments. Trace elements also enter directly into the lakes via shoreline erosion of the exposed marble and the thin overlying sediments. At James Lake, movement of metal-bearing groundwater via karst pathways allows a direct influx of trace metals into the lake.

4.2.1.2 Surficial sediments and organic matter

4.2.1.2.1 Till

The Ardoch area has been previously identified as anomalous for As, Hg, Cu, Mn, and to a lesser extent, Zn and Pb in till as well as bedrock (Kettles and Shilts, 1995; Pauk, 1987). In this study, the till found around the Little Green Lake area contains a high carbonate content, attributable to the marble terrain (Kettles *et al.*, 1991). Also, till found closest to Little Green Lake contains significant concentrations of Cu, Zn, Pb, and Hg, similar to trace element concentrations found within the marbles of the same area (see chapter 3.1.1). Many studies have shown this compositional relation between till and underlying bedrock (McMartin *et al.*, 1996; Kettles and Shilts, 1994; Kettles *et al.*, 1991; DiLabio & Rencz, 1980; Coker and Nichol, 1975). Southwest of the lake, the till found at the road cut overlies a much smaller unit of schists from the Flinton group and consequently contains a much smaller amount of Ca, but increased amount of Fe and Al. Higher concentrations of Cu, Ni, Mn, V, La, and Cr are also found in the glacial substrate than found closer to the lake. Over the short distance between the lake and the road cut, it is apparent that till compositions vary due to the influence of different bedrock sources and their varying trace elements concentrations.

In previous studies of Quaternary sediments in the Ardoch area, Kettles (1990) found As, Hg, Cu, Au to occur in anomalous concentrations in drift overlying outcrops of metasedimentary and metavolcanic rocks known to host gold mineralization. In another studies, Kettles *et al.*, (1991) found a correlation between Pb-rich drift with underlying marble, metasediments and metavolcanics; Fe and Mn with marbles and metasediments;

and, Zn and Cd over marble with sphalerite occurrences. These findings, including those from this study, are evidence that the bedrock geology in this area is a primary source of trace elements for the overlying till and in turn, becomes another source for trace elements to the surrounding environment.

4.2.1.2.2 *Soil*

Soils in the Ardoch area are another significant source of trace elements to the environment. Since soils are a product of the weathering of the surrounding and underlying bedrock and till, it is reasonable that metal concentrations in the B-horizon soils tend to reflect those variations found in the underlying till found at Little Green Lake. In most instances, geochemical values close to Little Green lake were higher in the soils than in the underlying till. At the road cut, soil values were generally the same or slightly lower than till values. For example, Hg concentrations were 220 ppb in the till nearest the lake and 260 ppb in the overlying soil. At the road cut, Hg concentrations were 70 ppb in the till and 55 ppb in soil. In this case, variations in the trace element signatures are due to the geology and changing mineralization closer to the lake. This spatial variation can also be applied to differences between geochemical compositions of soils from the catchments of the other study lakes. Temporal variations are due to factors other than the natural geochemistry of the underlying substrate (bedrock, till) including the behaviour of metals as a result of organic matter, water and clay contents of the soil contents as well as the extent of leaching into the B-horizon (McMartin *et al.*, *submitted*).

The soils of the Ardoch Lake catchment have lower trace elements concentrations than either of the other study lakes, except for Mn. Comparatively, trace metal

concentrations in the soils and bedrock around James Lake are the highest found. These general trends are also recognized in bedrock geochemistry. In comparing values of soil and bedrock geochemistry, not every element can be explained. Elements such as Zn, Cu are accountable by concentrations within bedrock for all lakes and are evidence as to the major source of trace elements. Lead concentrations are especially enriched in the soils near James Lake and cannot be accountable by the Pb concentrations within the bedrock samples near James Mine. The bedrock samples taken from around Johnson Lake, however, do contain extremely high concentrations of Pb, Cu, Zn and Hg, and are evidence that these anomalous concentrations are present in the bedrock of the study area. For Little Green Lake, Hg concentrations are higher in the soils than in the bedrock. Again, bedrock samples found within kilometres of the lake (near James Mine, Johnson Lake) contain anomalously high amounts of Hg which may influence soil chemistry around Little Green Lake.

4.2.1.2.3 *Humus*

Because the nature of metal uptake in plants is largely controlled by their chemical substrate (soil or till), the live or decaying plant tissues reflect variations in the local geochemical environment (DiLabio and Rencz, 1980). This is the case in the Ardoch area where all humus samples had anomalous concentrations of Cu, Zn, Pb, Mn, As, and Hg, as did the substrate. The Zn-Cu occurrences and the Pb-sulphide patches can account for these humus anomalies. Because of its natural ability to concentrate trace elements, humus is used for geochemical exploration (Dunn, 1989). Humus has also been regarded as a tool for mapping contamination due to anthropogenic emissions (McMartin *et al.*

submitted; Henderson *et al.*, *in press*). However, the Ardoch area lies over 350 km from any major industry. Recent studies have found that geochemical signatures in humus outside a 150 km from a point source are natural background values, unaffected by the emissions (G.F. Bonham-Carter, pers. comm., 1997; McMartin *et al.* *submitted*; Henderson *et al.*, *in press*; McMartin *et al.*, 1996). Instead, enrichments in humus and organic layers of soil and tills can be explained by natural factors through biological processes related to incorporation by living plants (McMartin *et al.*, *in press*; Brümmer, 1986).

In the biogeochemical cycling of trace elements, only a certain quantity of available trace metals are taken up by plants, and some elements have a larger affinity for organic matter than others. This is reflected in the humus around the study lakes where, although anomalous, Cu, As, Hg, La, V are similar to or lower than soil levels; while trace elements such as Mn, Zn, Cd, Ba, Sr, and especially Pb in the humus are considerably higher than the B-horizon soil concentrations. The fact that humus accumulates certain trace metals due to 1) a simple translocation of metals from subsurface horizons to organic surface layers by metals uptake of plant roots, 2) incorporation into living plants which die and accumulate in the humus layer; 3) decomposition of plants containing these elements derived from soil plant material which then become available; and, 5) strongly held by organic matter (Brümmer, 1986; Brady, 1990; Rasmussen, 1994).

Bornstein and Bolter, (1991) explained that the production of humic (fulvic) acids in the humus increases the solubility of heavy metal compounds. Consequently, metal/humic acid complexes do not precipitate or adsorb onto the soil matter. Some are easily removed from humus and washed into streams before penetration into soil while some adsorbed to

organic matter and remain concentrated in the humus. This may be an adequate explanation to explain some metal enrichments (*e.g.*, Zn, Ba, Sr, Pb) as well as indicate that the humus of the Ardoch area is a significant source of trace metals to near-by lakes. Large enrichments may be also be detecting unknown anomalies in the bedrock.

4.2.1.3 Movement of trace elements from natural sources into the lake environment

The characteristics of these terrigenous materials are transmitted to the lake during weathering and erosion by water and wind. Trace elements from the surrounding bedrock, till, soils, and humus are introduced into the lake naturally as 1) clastic particles (washed in by streams or eroded from lake margins), 2) elements adsorbed or incorporated within colloidal organic/inorganic material; and 3) dissolved material precipitating, adsorbing to suspended particles, or incorporating into living matter (Kemp *et al.*, 1978; Rose, Hawkes, and Webb, 1979). Furthermore, the soil chemistry will to some degree be influenced by input from dry and wet deposition of atmospheric particulates. Due to the remote location of these three lakes in the Ardoch area, this input should be small. However derived, the trace metals become available to the lake environment and transported to the lake via wind, erosion, surface runoff, and shoreline erosion.

4.2.2 The lake environment

4.2.2.1 Lake water

Only the physical and chemical properties observed at the time of sampling will be discussed in this section. It is understood that these properties are influenced significantly by season and to some extent by diurnal cycles, such as temperature.

Generally, the chemistry of the lake water is a result of the interactions between water and what is introduced into the lake from its surrounding environment. How a trace metal behaves in the water column depends primarily on its elemental properties (both chemical and physical), the intensity of chemical weathering, the environmental conditions, biological activity, the presence of dissolved gases, as well as the extent of stratification of the lake. These factors and how they affect the water geochemistry of Ardoch, Little Green, and James Lakes will be addressed in the following section.

4.2.2.1.1 *Water properties*

After trace metals enter the lake, many factors including temperature, oxygen content, redox potential, organic matter content and pH influence their behaviour in the water column. Since pH is near-neutral at all sample sites, it will not be discussed. Temperature is the primary factor causing the lake waters of Ardoch, Little Green, and James Lakes to be stratified and thus influences the movement and fixation of trace elements in a lake (Coker *et al.*, 1979). Each lake possesses a well defined thermocline at varying depths which begins immediately below the photic zone ends. This zone is the

lower limit of the epilimnion, occurring at 6 m for Ardoch Lake and 4 m for Little Green Lake. The thermocline is shallow for James Lake (3 m) and the water is murky where suspended and dissolved humic (fulvic) acids interrupt the transfer of light at approximately 3 m in the water column. The water temperature reaches a minimum in the hypolimnion, around 4 °C for all lakes. Most importantly, the thermocline restricts the exchange of elements between hypolimnion and epilimnion and inhibits oxygen transport to the bottom.

Variations in the dissolved oxygen content occur throughout the water column of all lakes. The dissolved oxygen distributions are controlled partially by temperature, but mostly by photosynthesis and bacterial decomposition of organic matter. The dissolved oxygen curves (Figure 8) are a result of oxygen production due to photosynthesis in the hypolimnion (reduction with depth) and an absolute oxygen maximum in the metalimnion (Wetzel, 1983). For Ardoch Lake and Little Green Lake, this event occurs in the water column at 6-9 m and 4-14 m, respectively. This zone is almost non-existent for James Lake. This indicates high seasonal biological productivity in the water column of Ardoch and Little Green Lakes compared to James Lake. The differences in maximum DO concentrations in the water columns of basin 1 and 2 may be due to the colder temperatures between 4-6 m depth in basin 2 inhibiting diatom production at time of sampling. The loss of oxygen from the hypolimnion of all study lakes results primarily from the decay of organic matter, especially at the sediment-water interface. By late summer, the bottom waters of all study lakes had become disoxic; with less than 1 ppm of dissolved oxygen. The availability of oxygen is affected by organic matter and decomposition and will affect redox reactions.

All three lakes have high amounts of organic matter, both in the water column and in the sediments. Organic substances occur both in suspension (plankton, bacteria, algae, vegetation, animal detritus) and dissolved (amino acids, fatty acids, aquatic humus) forms within natural water. Total organic carbon (TOC) was determined to be highest at the sediment-water interface of all three lakes, especially basin 1 of James Lake, due to the accumulation of dead organics during the time of low lake productivity at the end of the summer. Furthermore, the organic matter is responsible for trace metal complexing, and adsorbing such elements as Cu, Zn, Pb, and Hg. As the organic matter becomes incorporated into the sediments, so does its associated trace elements (Lindberg and Harriss, 1974; Garrett & Hornbrook, 1973; Cameron and Jonasson, 1972).

When oxygen is available, certain elements (*e.g.*, Mn, Fe) oxidize and fix other trace elements by precipitation. As the oxygen supply is depleted, these same precipitates dissolve and trace metals are remobilized. Hence, the redox potential (E_H) is an important factor affecting metal behaviour in water (and sediment). In the study lakes, E_H remains positive but decreases significantly in the hypolimnion towards the sediment-water interface. The highest potential occurs only centimetres from the sediment-water interface, typically around 350 mV in eutrophic conditions (Gobeil and Cossa, 1993; Wetzel, 1983). The redox potential can reach negative values only a few millimetres within the sediments; however, porewater redox states were not determined in this study. The maximum redox potential in the hypolimnion for Little Green Lake is 403 mV at 4 cm above the sediment and 243 mV at the sediment-water interface. The redox potential for Ardoch Lake is 390 mV at 2 cm above the sediment and 361 mV at the sediment-water interface. In basin 1 of James Lake, the maximum E_H lies 6 cm above the sediment at 374

mV, then decreases to 135 at the sediment-water interface. Similarly in basin 2, the values are 372 and 133 mV.

4.2.2.1.2 *Water chemistry*

Evidence of the effects of bedrock on the lacustrine environment are shown in the hard waters of Little Green, James, and Ardoch Lakes. All lake waters are rich in calcium, magnesium and bicarbonates, due mostly to the composition of the surrounding marble bedrock (Figure 12; Appendix B, B-9). Each of the water bodies generally have the same major geochemical components; however, Little Green Lake has higher concentrations of Mg, most likely due to the dolomitic marbles in its surrounding terrain, while James Lake has higher concentrations of Ca and SO_4 due to exposed marble and sulphide mineralization.

Generally, all trace element concentrations, except for Ba, occur in very small concentrations in the epilimnion and mesolimnion, and concentrating up to several hundreds of times more in the hypolimnion at the sediment-water interface. The major trend in these geochemical signatures is that the concentration of elements introduced in the epilimnion are enhanced in the hypolimnion due to anoxia, seasonal sedimentation, or diagenetic remobility of the elements from the sediment and pore water to the overlying hypolimnion (Boudreau, 1996; Gassama *et al.*, 1994). James Lake clearly displays this trend with the highest concentrations, due to the lowest oxygen contents, lowest redox potential, lowest pH and the highest turbidity.

In Ardoch, Little Green, and James Lakes, elements such as Al, Fe, Mn, and Pb have very short residence times compared with lake water and are rapidly lost by

sedimentation; thus only minor concentrations occur in the water column while increased concentrations are found in the lake bottom. In contrast, Ca, Cl, Mg, Na, Ba, and Sr have similar residence times to that of the lake water implying that they are lost mostly by outflow of water and for the most part are found throughout the water column in similar concentrations. Anomalous concentrations at the interface, as for Ba, may be explained by strong associations with biological cycling.

Critical inorganic anion concentrations occur at the sediment-water interface in basin 1 of James Lake and to a lesser extent, Little Green Lake for nitrite (NO_2^-) and nitrate (NO_3^-). In James Lake, an large amount of nitrite (25 560 ppb) and nitrate (311 ppb) occurs at the interface in basin 1; whereas no NO_2^- or NO_3^- were detected in basin 2. The high redox potential can explain the nitrite value being larger than the NO_3^- . The nitrates enter the lake system from organic matter and reduce to NO_2^- in the anoxic hypolimnion. Normally, such significant occurrences of nitrates in a lake are due to fertilizer or sewage inputs. The anomalous values at Little Green Lake may possibly be due to a high influx of plant debris from the steep catchment areas and community activities at the southeast end of the lake. For James Lake, however, one possible source may be bags of garden fertilizer and top soil found stored around the basin 1 shore of James Lake and dumped into the lake.

4.2.2.2 Lake sediments

The first section will discuss background trace element concentrations in the lake sediments and attempt to correlate the geochemical signatures with the geochemical

makeup of the catchments. These correlations will help establish the contribution of trace elements from natural sources. In the second section, aware of the natural sources and ‘remoteness’ of lakes, natural processes resulting in trace metal enrichments in media will be discussed.

The chemistry of lake sediments is a result of the interactions between trace element inputs, their behaviour in the water, and their behaviour within the sediments themselves. The characteristics of the sediment and the concentrations of trace elements within it are complex functions of geology, catchment size and composition, lake depth, lake water, *etc.* As discussed in the previous section, thermal stratification and redox potentials of the lake water have important impacts on the fixation of elements in lake sediments as well as the quantity of organic matter.

4.2.2.2.1 *Background geochemistry and trace element signatures*

When comparing the background trace element geochemistry in the lacustrine environments in the Ardoch area, it is clear that large sources of trace elements in the bedrock including Cu, Zn, Pb, and Hg have accumulated and incorporated into till, soil and humus in the catchments of James, Little Green and Ardoch Lakes (Table 12). In turn, these elements have been incorporated themselves into the lake sediments, creating a unique geochemical signature for each lake. Concentrations of Cu, Zn, Pb, and Hg are associated with mineral occurrences as discussed in chapter 4.2.1. Anomalous concentrations of Mo, Ba, La, Sb, and As in the lake sediments, till, soil, and humus are also associated with the same mineral occurrences as well as carbonate minerals. Geochemical signatures in the sediments of the study lakes will not mirror values

recorded from the media of their catchments due to the behaviour of each element as they interact with the environment. As previously discussed, differences in trace element concentrations in each medium are due to varying accumulations and fixation/complexing processes characteristic of each media.

Table 12: Summary of comparisons of background chemistry of different mediums. Sediments are from the lakes; humus, soil, and till are all from one sample site; and bedrock values from sample with highest values nearest to the lake. No bedrock was sampled near Ardoch Lake.

Lake	Sample medium	Cu ppm	Zn ppm	Pb ppm	Hg ppb
Little Green Lake	sediment	69	390	6	86
	humus	34	295	147	290
	soil	121	246	66	260
	till	97	274	37	220
	bedrock	250	400	22	110
James Lake (basin 1)	sediment	73	379	17	331
	humus	17	261	353	465
	soil	150	173	171	575
	bedrock	4379	366	25	630
Ardoch Lake	sediment	26	239	6	51
	humus	14	86	51	150
	soil	13	85	18	205

Once in the lake, lake sediments tend to act as a sink for trace metals. The principal mechanisms affecting trace element fixation into bottom sediments involve: 1) scavenging of metals by algal and plankton blooms; 2) sorption and co-precipitation by hydrous iron and manganese oxides, as well as other inorganic precipitates like carbonate; 3) sorption by clays and organic particles; and 4) incorporation into organic/inorganic colloidal particles (Coker *et al.*, 1979; Rose Hawkes and Webb, 1979). The occurrence of one or more of these mechanisms will depend on water properties, E_H , and organic matter content of each lake environment.

Organic content of the lake sediments appears to have a distinct but complex control over content of mobile metals in lake sediments, especially Zn, Pb, and Hg, and will

enhance trace element signatures (Garrett and Hornbrook, 1976; Lindberg and Harriss, 1974; Thomas, 1972; Cameron and Jonasson, 1972). For example, organic content/trace element associations are apparent in the profiles of James Lake, especially in basin 1. Generally, smaller lake, higher LOI and concentrations of trace metals increase with increasing organic matter in sediments, leaving very little left in the water (Coker *et al.*, 1979; Rose, Hawkes, and Webb, 1979). This is due to an increasing capacity to adsorb and chelate with increasing proportions of dissolved trace elements as more organic matter enters the lake. Decay of this organic matter will release cations into pore waters and overlying water, especially observed for basin 1 of James Lake.

Aside from geological variations, background trace element variations between the study lakes are also due to the size of the catchment affecting the amount of material entering the lakes, the size of the lake dispersing inputs over a greater/smaller area, and organic matter adsorbing and fixating certain metals. For Ardoch Lake, Zn, As, and to a small extent, Hg. No aluminum or organic fluctuations coincide with these trace metal fluctuations; therefore, no straight explanation for these variations. Background values of Au, Ag, Cu, Pb, and Hg in sediments of Little Green Lake overall were high compared to the upper portion of the sediment sequence. Due to changing inputs and sedimentation rates, large fluctuations in the geochemistry of the sediments occurred. For James Lake, higher concentrations of major and trace elements occur in basin 1 compared with basin 2. Other than frequent mineral occurrences along the catchment influence on the geochemistry of the sediments, James Lake had the highest content of organic matter in the sediments.

In the geochemical profiles for Ardoch, Little Green and James Lakes, fluctuations reflect the historical trace element deposition before the influence of European settlement (<22 cm). General patterns show variable trace element fluctuations within each lake, in the pre-industrial (background) environment. Background geochemical fluctuations can be due to natural changes in metal and organic matter loading due to weathering, flooding, and beaver activity captured in the sediment record. Also, changes in the metal influx into lake sediments from different bedrock sources will be indicated by major compositional changes in Ca and Mg, for example. Infrequent limnological factors such as carbonate precipitation events will increase precipitation and deposition of trace elements available in the water and fix them to the bottom. Finally, background trace element fluctuations can be due to atmospheric fallout from volcanic emissions, forest fires, and natural soil and rock emissions (Rasmussen, 1996; 1994; Schroeder and Lane, 1988). All of the factors mentioned above can also influence the recent, potentially anthropogenic-influenced sediments.

4.2.2.2.2 *Surface sediments and enrichments*

The normalized data of lake sediments in the study area for this project reveal enrichments only for a few elements. Geochemical data recorded enrichment trends for Pb in all lakes with a similar profile for all three lakes. In addition, Zn, As, and Hg were found to be enriched in surface sediments of Ardoch Lake while Hg enrichments were slightly enriched in lake bottom sediments of Little Green Lake. In both James Lake and Little Green Lake, Cr and Co were enriched in recent sediments. Since these enrichments

are not associated with aluminum (terrigenous) inputs, other factors are influencing these concentrations.

To explain trace metal enrichments and differences in the proportion of enrichments between Ardoch, Little Green and James Lakes, several factors can be attributed to the varying background and surface trace element concentrations in sediments. Only recently recognized and somewhat accepted, is post-depositional diagenetic remobilization of many metals and diffusion along pore-water concentration gradients (Boudreau, 1995; Farmer, 1991). The complex redistribution of many metals is created by redox processes and movement by diffusion, pore water advection and biological mixing in the sediment-water interface (Boudreau, 1995; Farmer, 1991; Cline and Upchurch, 1973). Through diagenetic mathematical modelling, Boudreau (1995) predicts surface enrichments due to redox related redistribution, not historical inputs. When sediments are reduced, the metals tend to remain in the pore water. At the time of dewatering due to compaction, the metals migrate up through the sediment (Coker and Nichol, 1975; Cline and Upchurch, 1973).

The presence and migration of gases in the sediments which may cause the remobilization of metals towards the surface. Besides oxygen, other dissolved gases present in the sediment include carbon dioxide (CO_2), methane (CH_4), and hydrogen sulphide (H_2S). They are primarily present due to the decay of organics and respiration of bacteria. In James Lake, gas was a major constituent in the cores. As any gas is taken from depth, a change of pressure will let the gas expand and rise through the sediment. The gas in the sediments of James Lake included CH_4 (since lake sediments were reducing) and smelled of H_2S (an indicator of sulphate reduction and fermentation).

In the past, enrichments have been attributed mostly to anthropogenic inputs. Since it has been determined that there is little to no direct input by human activity in the lakes, any anthropogenic trace element input comes from wet or dry, long-range atmospheric deposition (Schroeder and Lane, 1988). Proportional concentrations of an atmospherically deposited trace element would be observed in all the study lakes.

Pb shows large, continuous increases in all study lakes in the near-surface sediments. This is a globally observed trend (Graney *et al.*, 1995). Pb does slightly decrease at the surface of basin 2, whereas, any near-surface decrease in metal concentrations has been linked in the past to reductions in environmental release (Farmer, 1991). Anthropogenic sources of Pb come from combustion of leaded gasoline (Nriagu, 1989). It may be that a significant proportion of the Pb enrichment comes from anthropogenic sources; however, in all study lakes, enrichments began prior anthropogenically impacted sediments. It is possible that Pb is simply more mobile in lake sediments than previously thought. The processes responsible for Pb enrichments continue to be debated and will not be argued further in this study.

In contrast, enrichments other than Pb are not proportional in each lake. Nriagu (1989) says that Zn, Cu, Ni, Cr, and Hg in the natural environment are from coal and oil, smelting and refuse incinerators. Increases of Zn, Cu, Ni, or Cr are not present in all study lakes. For those lakes with Zn, Cu, Ni, or Cr enrichments, increases are small compared to background values indicating that inputs are negligible from concerned sources. For Hg, many examples exist in the literature illustrating bedrock as the most significant source to lake sediments over anthropogenic sources (Rasmussen, 1996; 1994; Friske and Coker, 1994). As with Pb, a large debate continues as to the significance of global and

local, natural versus anthropogenic sources of Hg and will not be discussed further in this thesis.

Estimations of anthropogenic inputs into a lacustrine environment have been calculated simply by comparing enrichments to background values (Blais and Kalff, 1993; Gobeil and Cossa, 1993; Swain *et al.*, 1993; Renberg, 1986; Evans and Rigler, 1980). It could be estimated that Hg in Little Green Lake and Ardoch Lake has an enrichment factor of 42% and 127%, respectively, due to increased emissions by human activity. In doing this, erroneous assumptions are made including: 1) background concentrations are constant not only in the same lake but over large areas with differing rock types, 2) sedimentation rates are constant and, 3) no remobilization of metals occurs due to diagenetic processes. However, once deposited, these metals and trace metals do not remain inactive. The anthropogenic portion of the enrichment, if any, can be deposited both directly and indirectly relative to that washed in from its catchment. It is possible that some portion of enrichments in the study lakes are from anthropogenic sources. From examining the evidence of natural sources, this anthropogenic load appears to be insignificant, although, the estimation of the proportion of natural and anthropogenic load on a lake is not quantifiable, at least in this study. Perhaps biological trends in the sediment would suggest anthropogenic influences on the lake, shed some light on the chemical fluctuations, or simply reveal that the lake has been unchanging for longer than the presence of man in the natural environment.

5.0 PALEONTOLOGY

In freshwater environments, organisms in sediment cores can reveal a past environmental change, ranging from major climatic trends such as the effects of glaciation to the acidification of lakes resulting from industrialization of the last 200 years (Burbidge, pers. comm., 1997; McCarthy *et al.*, 1995; Farmer, 1991; Batterbee, 1986).

Protozoa such as thecamoebians and phytoplankton such as diatoms can provide a historical record of the lake environment. Examination of the interaction between lake biota and past chemical changes may aid to explain fluctuations and trends in chemical profiles of the lake sediments and in turn, identify significant effects of the metals in the sediments.

5.1 Results

5.1.1 General comments on thecamoebians

Thecamoebians (Arcellacea) are testate rhizopoda found in a wide variety of freshwater environments. These organisms are useful for recognition of freshwater deposits, detection of environmental changes, and paleoclimatic reconstruction of lakes (*e.g.*, Kliza and Schröder-Adams, *in press*; McCarthy *et al.*, 1995; Medioli and Scott, 1988). Only recently have thecamoebians been used as environmental and pollution indicators by correlating faunal abundance, assemblage, and morphological changes with geochemistry of the lake environment (Asioli *et al.*, 1996; Reinhardt *et al.*, *in press*;

Patterson *et al.*, 1996; Schafer *et al.*, 1991). From these studies, specific arcellacean indicators have been documented for lake status, bathymetry, organic content, and sediment type. For example, *Cucurbitella tricuspis* is a well-established indicator of eutrophic conditions in lake waters (Medioli *et al.*, 1987; Medioli and Scott, 1983). In a recent study, Patterson *et al.* (1996) correlated low thecamoebian distributions to Hg and As contamination. *Diffflugia proteiformis* strain "proteiformis" was found to adapt well to environments rich in organic matter and sulphides (Asioli *et al.*, 1996). Information on ecological preferences of thecamoebians is, however, still limited. Therefore, any correlation between thecamoebian distribution and chemical variation in lake environments are important to document.

Thecamoebians are generally cosmopolitan and inhabit a wide variety of freshwater environments; although, it is unsure if certain species are particular to certain types of freshwater environments (Medioli and Scott, 1983). Initial colonization of lakes by thecamoebians is random depending on assemblages found in mosses and soils in surrounding lake environments, as well as assemblages in nearby lakes. The organisms are introduced to lakes, either alive or encysted, through transportation by various mechanisms such as wind, birds, animals, or runoff (Ogden and Hedley, 1980). The composition and successful survival of a thecamoebian assemblage depends on 1) which species are introduced to the lake; and 2) which species are adaptable to the lake environment defined by parameters such as pH, salinity, temperature, chemistry, and food sources. The identification of single pollutants in aquatic systems affecting thecamoebian distribution is therefore problematic. For example, *Centropyxis aculeata* is most abundant in the Saguenay Fjord, highly affected by local industry (Schafer *et al.*, 1991). However,

this species is one of the rare thecamoebians which are found in relatively high abundances in both brackish and freshwaters in all recorded studies. Therefore, it is difficult to conclude that *C. aculeata* is resistant to pollution in the fjord. A more accurate conclusion is that it is the taxon adaptable to the brackish conditions of the fjord. Under most conditions, as those found in the Saguenay, when changes in lake environments do occur (*e.g.*, pollution), a continuous presence of thecamoebians remains while fluctuations in species abundances occur. This could imply that they are slow to react to environmental change if their food supply has not been affected by the changes incurred, and/or hardy species thrive while others die off. In fact, it has been suggested that the distribution of thecamoebians is influenced more by the growth of food organisms (bacteria, algae, and fungi) rather than acidity, alkalinity, or other chemical variations (Ogden and Hedley, 1980; Burbidge and Schröder-Adams, *in press*). This observation may be a limiting factor in the potential for thecamoebians as indicators of trace element pollution.

5.1.1.1 Taxonomic concept

The classification of thecamoebians remains undecided by micropaleontologists. In order to relate species morphology to environmental effects, it is necessary to separate out various intraspecific morphotypical populations (Asioli *et al.*, 1996). Criteria for separation include size, shape, presence/absence of spines, presence/absence of collar, size and shape of spines or collars, testate composition, *etc.* The author identified these types as 'strains' by means of a non-italicized descriptive Latin name in quotation marks.

Table 13: List of thecamoebian species and strains. Most are present in all three lakes.

SPECIES AND STRAINS	LITTLE GREEN LAKE	JAMES LAKE		ARDOCH LAKE
		basin 1	basin 2	
<i>Arcella discoides</i>	x	x	x	x
<i>Arcella vulgaris</i> "vulgaris"	x	x	x	x
<i>Arcella vulgaris</i> "angulosa"	x	x	x	x
<i>Arcella dentata</i>		x	x	
<i>Bullinularia indica</i>		x	x	x
<i>Centropyxis aculeata</i> "aculeata"	x	x	x	x
<i>Centropyxis aculeata</i> "acrophilia"	x	x	x	x
<i>Centropyxis aculeata</i> "discoides"	x	x	x	x
<i>Centropyxis aculeata</i> "ecornis"	x	x	x	x
<i>Centropyxis constricta</i> "constricta"	x	x	x	x
<i>Centropyxis constricta</i> "cassis"	x	x	x	x
<i>Centropyxis constricta</i> "platystoma"	x	x	x	
<i>Centropyxis constricta</i> "spiniifera"	x	x	x	x
<i>Cucurbitella corona</i>	x	x	x	x
<i>Cucurbitella tricuspis</i> "gramen"		x	x	x
<i>Cucurbitella tricuspis</i> "oviformis"		x	x	
<i>Cucurbitella tricuspis</i> "achlora"	x	x	x	x
<i>Cucurbitella tricuspis</i> "tuberculata"	x	x	x	
<i>Cucurbitella tricuspis</i> "lobostoma"		x	x	
<i>Cucurbitella tricuspis</i> "labiosa"	x	x	x	x
<i>Cyclopyxis kahli</i>	x	x	x	x
<i>Diffflugia ampullula</i>				x
<i>Diffflugia globulus</i> "globulus"	x	x	x	x
<i>Diffflugia globulus</i> "globulosa"	x	x	x	x
<i>Diffflugia lanceolata</i>	x	x		
<i>Diffflugia lithophilia</i>	x	x	x	x
<i>Diffflugia oblonga</i> "bacillifera"		x		
<i>Diffflugia oblonga</i> "bryophila"	x	x	x	x
<i>Diffflugia oblonga</i> "cylindrus"		x		
<i>Diffflugia oblonga</i> "gassowskii"	x	x	x	x
<i>Diffflugia oblonga</i> "lacustris"	x	x	x	x
<i>Diffflugia oblonga</i> "petricola"	x	x	x	x
<i>Diffflugia oblonga</i> "venusta"	x	x	x	x
<i>Diffflugia proteiformis</i> "amorphalis"	x	x	x	x
<i>Diffflugia proteiformis</i> "bicornis"		x	x	x
<i>Diffflugia proteiformis</i> "elegans"	x	x	x	x
<i>Diffflugia proteiformis</i> "smilion"	x	x	x	x
<i>Diffflugia urceolata</i> "urceolata"	x	x	x	x
<i>Diffflugia urceolata</i> "elongata"	x	x	x	x
<i>Diffflugia urceolata</i> "mica"	x	x	x	x
<i>Diffflugia rotunda</i>	x	x	x	x
<i>Diffflugia viscidula</i>	x	x	x	x
<i>Euglypha acanthophora</i>		x	x	
<i>Euglypha cashii</i>		x	x	x
<i>Euglypha</i> sp. 1		x	x	
<i>Heleopera sphagni</i>	x	x	x	x
<i>Legendifflugia vas</i>				x
<i>Lesquereusia jurassica</i>	x	x		x
<i>Lesquereusia spiralis</i>			x	
<i>Nebela collaris</i>	x	x	x	
<i>Oopyxis</i> sp. 1	x	x	x	x
<i>Pontigulasia elisa</i>				x
<i>Trinema enchelys</i>		x	x	

These strains are named according to original descriptions and synonymy lists of species identified before recent recognition of intraspecific variability. An abbreviated taxonomy for species and strains found in Ardoch, Little Green and James Lakes can be found in Appendix C, Table C-2. All necessary information for each identification is included in the name, including both original references and genera for both the species and its strain. This will be critical for any later reference to the material in this study. For this study, thecamoebian species and strains found in Ardoch Lake, Little Green Lake, and James Lake are found in Table 13. These strains might have developed in response to differing environment stresses and stimuli, such as presence of chemical pollution in substrate and low O₂ levels (Reinhardt *et al.*, *in press*). These effects would otherwise be missed if the detail of strains would not have been recorded.

5.1.2 Thecamoebian distribution

5.1.2.1 Ardoch Lake

A significant number of thecamoebians exist throughout the sediment sequence of Ardoch Lake, a mean of 269 specimens per 1 cc. of wet sample (Appendix C: C-3). Percent abundance fluctuations for the past 1550 years are presented in Figure 17. Approximately 40 species and strains are identified in Ardoch Lake as indicated in Table 13; however, the majority of the species are rare. Of the dominant genus *Cucurbitella*, three strains populate the lake.

Cucurbitella tricuspis "achlora" remains the dominant thecamoebian throughout the core with fluctuations ranging from 35 to 80%. *Centropyxis aculeata* "aculeata" is the second most abundant species (5 to 20%) increasing only where abundances of *C. tricuspis* "achlora" decrease. *Diffugia oblonga* "venusta" is only significant in the lower half of the core where abundances range from 10% at the bottom of the core to <5% from 40 cm to the surface. These species fluctuations correspond to fluctuations in total specimens and changes in sediment type (*i.e.* marl content). In the lower sequence of the core, total thecamoebian populations peak at 50 cm marked by a decrease in *C. tricuspis* "achlora" and an increase in *Centropyxis aculeata* "aculeata". Total abundances decrease significantly at 40 cm where sediment type changes from clayey silt to marl. At this point, *C. aculeata* "aculeata" peaks (20%) but gradually decreases as it is replaced by *Cucurbitella tricuspis* "achlora" throughout the marl sediment interval. Thecamoebian abundances gradually decrease again until the uppermost 5 cm where a greater diversity of species occurs with the introduction of *Arcella vulgaris* "vulgaris", *Centropyxis aculeata* "aerophilia", and *Cucurbitella tricuspis* "labiosa".

Few correlations exist between fluctuations in thecamoebian assemblages and abundances and geochemical profiles in the sediments. In the uppermost 15 cm of the sediment of Ardoch Lake, fluctuating calcium concentrations of the lake sediments correspond with thecamoebian distribution changes as does the marl content of the sediment. As discussed in the previous chapter, Ba and Sr profiles mirror the calcium profile, thus the same trends can be correlated to thecamoebian fluctuations. The %LOI, which approximates the organic content of the sediment, remains relatively evenly distributed throughout the core except for a small peak at 50 cm coinciding with a small

peak in thecamoebian abundances. In the uppermost 15 cm, organic content and thecamoebian abundances gradually decrease then increases between 5 cm and the surface. Within this interval,

Cyclopyxis kahli disappears as *Centropyxis aculeata* "aerophilia". *Cucurbitella tricuspis* "labiosa" significantly increase. No continuous trend exists between the fluctuation of trace metals and thecamoebian species or total abundances; however, Pb drastically increases in the uppermost 10 cm which coincides with a decrease in *Centropyxis aculeata* "aculeata".

5.1.2.2 Little Green Lake

Little Green Lake has more significant changes in abundance and species composition in comparison of thecamoebians to Ardoch Lake (Figure 18). A major shift in the thecamoebian community occurs at 40 cm in the sedimentary sequence. The lower part of the core is characterized by high abundances ($\bar{x}=1059$) and the dominance of one strain of *Cucurbitella* whereas the upper interval shows low abundances ($\bar{x}=87$) and a high species diversity (Appendix C: C-5).

The most significant faunal trend in Little Green Lake is the change from a dominance (up to 92%) of *Cucurbitella tricuspis* "achlora" to an abundance increase in *Centropyxis aculeata* "aculeata" at 38 cm (Figure 18). The *C. tricuspis* "achlora" dominance coincides with peak total thecamoebian abundance and high marl content of the lake sediment. In the *Centropyxis aculeata* "aculeata" Assemblage, *Arcella discoides*, *Arcella vulgaris* "vulgaris", *Arcella vulgaris* "angulosa", *Centropyxis constricta* "cassis".

Figure 18: Percent abundance of thecamoebian species and geochemical concentrations (normalized to Aluminum) from Little Green Lake. All unlabelled thecamoebian axes represent a value of 10 percent.

Cucurbitella tricuspis "tuberculata", *Diffugia urceolata* "mica", *Diffugia rotunda*, and unspecified *Oopyxis* species replace *C. tricuspis* "achlora" at 38 cm. At 20 cm downcore, the assemblage changes as *Centropyxis aculeata* "ecornis" becomes the dominant thecamoebian. Also at this point in the sedimentary sequence, a total replacement of the genus *Arcella* and the partial disappearance of the genus *Centropyxis* occurs along with a decrease of *Lesquereusia jurassica* and a significant percentage of small unidentifiable thecamoebians (≤ 45 fraction). The upper 10 cm interval remains dominated by *Centropyxis aculeata* "aculeata". At the surface, however, percent abundances of *C. aculeata* "aculeata" and *Cucurbitella tricuspis* "achlora" are the same. Less common species and their strains such as *Centropyxis aculeata* ("discoides" & "ecornis"), *Centropyxis constricta* "cassis", *Diffugia lithophila*, and *Heleopera sphagni* also persist in the top interval.

The fluctuations of thecamoebian assemblages and abundances in the lower half of the core (40-72 cm) show a general correlation with increased geochemical concentrations of most minor components as indicated in Figure 18 by the increase of organic content. The geochemical content and thecamoebian distributions in the upper sequences of the core are low and somewhat invariant. However, as Pb drastically increases in the uppermost 8 cm, *Lesquereusia jurassica* abundances decrease and *Cucurbitella tricuspis* "achlora" increase.

5.1.2.3 James Lake

5.1.2.3.1 *James Lake, Basin 1*

Generally, thecamoebian abundances in James Lake are low compared to Ardoch and Little Green Lakes; however, a larger variety of species and genera exist compared to the other two lakes. In basin 1 of James Lake, the mean total thecamoebian abundance is 89 specimens per 1 cc. (Appendix C; C-7). Total thecamoebian abundance changes only slightly in the uppermost 10 cm of the core (Figures 19). The peak coincides with sediment change to an oxidized layer with no organic debris while the decrease towards the surface coincides with the reducing layer of organic-rich sediment. Below this peak, the abundances do not fluctuate and only the organic component of the sediment changes.

Centropyxis aculeata "aculeata" remains dominant throughout the core. In the near-surface sediments (between 0-5 cm), changes in the thecamoebian community occur when abundances of *C. aculeata* "aculeata" decrease. The second-most abundant thecamoebian taxon in this assemblage below 5 cm is an unidentified species of the genus *Oopyxis* which dies out after the population peak where *Arcella vulgaris* "vulgaris" to become the second most abundant species. As *Centropyxis aculeata* "aculeata" increases again towards the surface, total thecamoebian abundances decrease and *Arcella discoides* disappears. Many other thecamoebians such as the *Centropyxis constricta* strains, *Diffugia urceolata* strains, and most *C. tricusps* strains slightly increase towards the surface. However, as total species and strain diversity increases, total abundances decrease.

THECAMOEBIANS

Figure 19: Percent abundance of thecamoebian species and geochemical concentrations (normalized to Aluminum) from basin 1 of James Lake. All unlabelled axes represent a value of 10 percent.

As discussed in the previous chapter, most metal and trace metal fluctuations in basin 1 sediments are controlled by organic content. Thus, any correlation with organic content will also correlate to trace metal distributions in the sediment core. The organic content peaks in the sediment of basin 1 coincide with increases in *Centropyxis aculeata* "aculeata", *Cucurbitella tricuspis* "labiosa", and *Cucurbitella tricuspis* "tuberculata" followed by decreases in *Diffugia lithophilia* and the *Oopyxis* species. As observed in Ardoch and Little Green Lakes, Pb increases significantly towards the surface. Within the top 7 cm interval, *Arcella discoides*, *Cucurbitella tricuspis* "tuberculata", and the *Oopyxis* species disappears while *Arcella vulgaris* "vulgaris", *Centropyxis aculeata* "aculeata", and many rare species increase.

5.1.2.3.2 James Lake, Basin 2

In basin 2 of James Lake, total thecamoebian distribution fluctuates more significantly than in basin 1 and mean total abundances are reduced ($x=23$; Appendix C: C-9). In this basin, abundances peak at 5 cm (Figure 20) which most likely coincides with the peak abundance in basin 1 at 8 cm (Figure 19). The thecamoebian assemblage is diminished between 50 and 10 cm where abundances are at their lowest at 38 cm and only gradually increase up core.

General faunal trends are similar between both basins. As in basin 1, *Centropyxis aculeata* "aculeata" remains the dominant species throughout the sedimentary sequence showing a decrease at 7 cm and a subsequent increase towards the surface. Decreasing numbers coincide with a sediment interval composed mostly of woodchips. Species such as *Euglypha cashii*, *Diffugia globulus* "globulosa" and *Centropyxis aculeata* "ecornis"

Figure 20: Percent abundance of thecamoebian species and geochemical concentrations (normalized to Aluminum) in basin 2 of James Lake. All unlabelled axes represent a value of 10 percent.

temporarily disappear or die out completely as increased populations of *Centropyxis constricta* "cassis", *Cucurbitella tricuspis* strains, *Euglypha acanthophora*, and the *Oopyxis* species occur. Other common taxa are *Cucurbitella tricuspis* "labiosa" and *Arcella discoides* with slightly fluctuating numbers. It is important to note the large number of strains of the *C. tricuspis* species in both basins. Almost all morphological types of *C. tricuspis* mentioned by Medioli *et al.* (1987) are present in varying abundances in James Lake.

The sharp decrease in total abundances in basin 2 correlate to an interval of high organic matter in the sediment. The relationship holds true in the uppermost 8 cm of the core as the organic content decreases and thecamoebian abundances increase. Mercury generally follows the profile of organic content. The early increase in the Pb content of the sediment of basin 2 is not reflected in a faunal signature of any species.

5.1.2 Diatoms

Diatoms are unicellular golden-brown algae that are characterized by an external two-part skeleton (frustule) made of opaline silica. They are well-documented indicators of environmental changes in lakes due to their sensitivity to pH, nitrogen, phosphorous and silica concentrations in lakes. As a result, diatoms would be affected by anthropogenic inputs into an environment which would alter the pH of the lake water. To date, few correlations between diatom species and trace metal concentrations have been documented. For this study, James Lake in southeastern Ontario has been chosen for diatom analysis and all species found are listed in Table C-11 of Appendix C. Possible

correlations between diatom distribution and specific trace metals might shed some light on anthropogenic effects on the lake.

5.1.2.1 James Lake, Basin 1

Generally, diatoms were found in significant numbers at the surface and at each 10 cm interval thereafter. No major shifts in the diatom communities were observed (Figure 21: Appendix C; C-12). *Cyclotella michiganiana* is the dominant diatom throughout the core with an abundance of 60% increasing to 75 % at 28 cm. Subdominant diatoms include *Fragilaria tenera*, *Fragilaria nanana*, *Fragilaria crotonesis*, *Achnanthes minutissima*, and *Cyclotella pseudostelligera*. Each of the three planktonic *Fragilaria* species display abundances of 15 to 29%, but decrease when organic content increases (to 5 to 10%). *C. pseudostelligera* is more abundant in the lowest 10 cm (10%) and decreases to negligible values of 2 to 3% in the upper 40 cm of the core. Taxa encountered in low numbers, in order of decreasing overall abundances, are *Nitzschia* species, *Navicula cryptotenella*, *Stephanodiscus* cf. *hantzscii*, and *Asterionella formosa*. Abundances of each increase as total diatom abundances increase and as organic content decreases. Chrysophyte cysts experienced a marked increase in the top 8 cm of the core. An inverse pattern occurs with *Mallomonas* scales.

In basin 1, Pb increases substantially from 8 cm towards the surface. In this interval, Chrysophyte cysts increase along with *Fragilaria tenera* as *Fragilaria crotonesis* decreases. This trend, however, is not continuous.

Figure 21: Diatom assemblages from lake sediments in basin 1 of James Lake. All diatom counts are shown as percentages.

5.1.2.2 James Lake, Basin 2

As in the sedimentary sequence of basin 1, only minor shifts occurred in the diatom communities of basin 2 (Figure 22; Appendix C; C-13). At the surface, a decrease in organic content can be compared with an increase in diatom populations. The dominant diatom *Cyclotella michiganiana* shows an abundance of 45 to 50% in the lower part of the core gradually increasing to an 80% abundance in the surface sediments. As this species increases, *Cyclotella bodanica*, *Fragilaria crotonensis*, and *Fragilaria tenera* decrease. The *Fragilaria* species (*crotonensis*, *nanana*, *tenera*) display abundances of about 20% in the bottom sedimentary sequence, with a marked decrease in the top 15 cm where the abundances are negligible (less than 2 to 3%). *Cyclotella pseudostelligera* shows a steady abundance of 5% throughout the core, except for a slight decrease around 30 to 35 cm (to about 3%). *Achnanthes minutissima* remains evenly distributed throughout the sediments.

In basin 2, Pb increases from 14 cm in the core to the surface. Within this interval *Fragilaria crotonensis*, *Fragilaria tenera*, and Chrysophyte cysts decrease. No trace metal correlations were observed with diatom assemblages.

Figure 22: Diatoms in lake sediments from basin 2 of James Lake. All diatom counts are shown as percentages.

5.2 Discussion

5.2.1 Faunal distribution and lake environments

5.2.1.1 Ardoch Lake

The faunal distribution found in Ardoch lake depicts a relatively stable environment for the growth of thecamoebian communities. A strong presence of two species (*Cucurbitella tricuspis* "achlora" and *Centropyxis aculeata* "aculeata") continue throughout the sedimentary sequence of Ardoch Lake. *Cucurbitella tricuspis* is associated with eutrophic (nutrient-rich) conditions (Medioli *et al.*, 1987; Medioli and Scott, 1983). Three strains of this species (*C. tricuspis* "achlora", *C. tricuspis* "gramen", and *C. tricuspis* "labiosa") occur in Ardoch Lake indicating that the lake is eutrophic, characterized by an abundance of dissolved plant nutrients and phytoplankton in the water column. *Cucurbitella tricuspis* species has a planktonic stage in its life cycle in which it lives in association with floating algae (preferably *Spirogyra*).

Compared to the core lithology, *Cucurbitella tricuspis* "achlora" increases with increasing marl content in the sediment. Conditions in a lake environment responsible for a massive precipitation of CaCO_3 arrive when CO_2 is lost from the carbonate-water system through inorganically precipitated carbonate, photosynthesis-induced, inorganically precipitated carbonate, biogenic carbonate, and allochthonous (detrital) material derived from carbonate rocks in the drainage basin (Scolle *et al.*, 1983; Wetzel, 1983). Most of the carbonate in lake sediments is inorganic or bio-induced (Scolle *et al.*,

1983). One process which can consume available CO_2 is photosynthesis by large populations of bacteria and algae. The most important factor controlling the CO_2 budget in most moderately to highly productive hard-water lakes is the balance between CO_2 consumption by photosynthesis and CO_2 production by respiration and decay. In extreme examples, CO_2 may be depleted faster than replaced by atmosphere, and this depletion favors a prominence of phytoplankton that can utilize carbon from bicarbonate as well as from CO_2 for photosynthesis (Wetzel 1983). The increase in pH caused by photosynthetic removal of CO_2 can result in supersaturation with respect to CaCO_3 and precipitation of CaCO_3 and is the basis of bio-induced carbonate precipitation. This may be the case in Ardoch Lake during the carbonate-rich interval when *Cucurbitella tricuspis* "achlora" peaked indicating eutrophic conditions in the water column. The eutrophic conditions created an ideal environment for microbial and algal blooms as well as ample food for those thecamoebians which can adapt to such nutrient-rich conditions and outcompete other thecamoebians for the ready food source. Another factor promoting the precipitation of carbonate in waters supersaturated in HCO_3^- is low water levels during warmer and dryer periods.

Centropyxis aculeata "aculeata" is common in the sediments of Ardoch Lake. This species thrives when abundances of *Cucurbitella tricuspis* "achlora" are low. *Centropyxis aculeata* species are bacteriophages; therefore, are well suited for environments low in organic matter (McCarthy *et al.*, 1995). In Ardoch Lake, however, the organic content remains evenly distributed and relatively high (40-50%) throughout the core not signaling a response of *C. aculeata* to lack of organic matter. It is possible that due to the reducing conditions in the hypolimnion, anaerobic microbial decay

processes provide that food source for *C. aculeata* "aculeata". *C. aculeata* "aculeata" is an early colonizer and very tolerant of most conditions which may explain its presence in Ardoch Lake (McCarthy *et al.*, 1995; Medioli and Scott, 1983).

Metal concentrations of Ardoch Lake sediments are naturally high due to the trace element composition of the carbonate terrain. In examining the profiles of thecamoebian abundances with respect to geochemistry fluctuations downcore, no apparent consistent correlation was found with any of the most common trace elements. The downcore distribution trend of *Cucurbitella tricuspis* "achlora", however, appears to be mirrored by the profile of the major element Ca. This may reflect the marl events in the sedimentary sequence and its indirect effect on the thecamoebian distributions. The lead content in the sediments of Ardoch Lake is typically increasing towards the surface which parallels the reduction of *Centropyxis aculeata* "aculeata" in the upper sequence. This trend is most likely attributed to the increased abundance of the *Cucurbitella* species.

5.2.1.2 Little Green Lake

Thecamoebian distributions in Little Green Lake show two major divisions in thecamoebian populations as well as two divisions of sediment type. In the lower half of the core, high concentrations of marl coincide with large abundances of thecamoebians. As in Ardoch Lake, an overwhelming dominance of *Cucurbitella tricuspis* "achlora" occurs in this interval. Again, the dominance of *C. tricuspis* strains depicts a eutrophic lake environment (*C. tricuspis* "achlora", *C. tricuspis* "tuberculata", and *C. tricuspis* "labiosa").

As discussed in the previous section, the carbonate-rich intervals could be a result of algal photosynthetic processes or shallower stages of the carbonate-rich waters of Little Green Lake. Other factors explaining this dominance of one taxon typically include 1) the environment excludes natural predators, 2) the species has developed a unique adaptation or life cycle which is ideal for this environment, and 3) the exclusion of other species limits competition for a food source. As lake conditions changed, *C. tricuspis* "achlora" abundances dropped drastically as an increase in the populations of other genera occurred in the lake, including mesotrophic and oligotrophic indicators (*i.e.*, *Diffugia oblonga*). At this point in the lake's history, a significant ecological change produced an environment more favourable to several other species, especially *Centropyxis aculeata* strains, *Centropyxis constricta* strains, and *Lesquereusia jurassica*. The diversity of the lake increased dramatically, but at the same time, total numbers of species in the lake declined. This is most likely a result of the declining competition of *C. tricuspis* "achlora" and the developing oligotrophic conditions.

In Little Green Lake sediments, there appears to be no single continuous correlation between assemblage fluctuations and trace metal concentrations. The peak of organic content at 64 cm in the core may be reflected in the nutrient-rich status of the lake depicted by the eutrophic indicator species, *C. tricuspis*. The Pb content of the near-surface sediments exhibits the same increasing trend as observed in Ardoch Lake; however, the species possibly affected by this trend is *Lesquereusia jurassica* which decreases in abundance in the near-surface and surface sediments. Total thecamoebian abundances also decrease towards to surface. Perhaps, these are indeed effects caused by the high concentrations of Pb in the lake bottom sediment.

5.2.1.3 James Lake

James Lake has the highest concentrations of trace metals in its sediment and water and is the smallest of the three lakes. Sediments are rich in large-sized organic debris (*e.g.*, woodchips, twigs, leaves, pine needles) only partially decomposed due to the disoxic conditions on the lake floor. No obvious marl deposits are apparent. James Lake has a significantly smaller thecamoebian community than Ardoch Lake and Little Green Lake; however, this small lake exhibits a larger variety of species (see Table 13). These factors limit thecamoebian growth and do not provide a suitable substrate for test construction. Since thecamoebian populations of both basins are dominated by *Centropyxis aculeata* "aculeata" and organic content is >50%, *C. aculeata* "aculeata" is not an indicator of low organic matter. In James Lake, this thecamoebian is an opportunist and a tolerator of reducing environments. Furthermore, both basins are host to five strains of the eutrophic indicator, *Cucurbitella tricuspis* ("gramen", "oviformis", "achlora", "tuberculata", "lobostoma", and "labiosa"). Only the strain *C. tricuspis* "labiosa" is continuously present throughout both sedimentary sequences.

5.2.1.3.1 Basin 1

In basin 1, total thecamoebian distribution downcore is somewhat invariant indicating a stable environment. Little is known about the ecology and preferences for the subdominant species, *Arcella discoides* and *Oopyxis* sp.1. These thecamoebians populate basin 1 in relatively significant numbers below and above the population peak in the near-

surface sediments, only to completely disappear at 3 cm below the surface. This peak occurs within a large interval with patchy areas of oxidized sediments indicating varying times of oxygenated lake bottom sediment, required by benthic species. Above this point, the surface sediments have low thecamoebian abundance, the disappearance of most *Cucurbitella tricuspidis* strains, and more reducing conditions.

Only weak, discontinuous correlations exist between high organic content and high abundances of *Centropyxis aculeata* "aculeata" and *Cucurbitella tricuspidis* "tuberculata" and a decreased abundances of *Diffugia lithophilia*. Increasing Pb concentrations are observed to negatively affect *Oopyxis* sp.1, *Arcella discoides*, and *Lesquereusia jurassica*. The overall thecamoebian populations, however, do not seem to be directly affected by organic matter or geochemical compositions of the sediment. Consequently, other factors such as nutrient availability, food sources, and available oxygen have to be considered.

5.2.1.3.2 Basin 2

A faunal comparison between basin 1 and 2 of James Lake revealed that lower numbers of thecamoebians were encountered in basin 2 but the same diversity of species were observed as was seen in basin 1. Fluctuations are attributed to organic content of the sediments. As organic content in the sediments peaks, thecamoebian abundances decline. The organic content in basin 2 is much higher compared to basin 1 (57-81%). The fluctuations in the organic content profiles are due mostly to debris input from beaver activity. Lower concentrations of organics in the sediments may coincide with the disappearance of the beaver in James Lake which also coincides with growth of

thecamoebian communities. The subdominant species of *Cucurbitella tricuspis* "labiosa" and *Arcella discoides* fluctuate only slightly not indicating any severe changes in the lake environment.

In recent literature, low abundances of thecamoebians have been attributed to Hg and As contamination using a lake contaminated by mine tailings (Patterson *et al.*, 1996). However, thecamoebian populations in lakes with natural background levels of trace metals do not show a repeatable decrease in intervals with elevated trace metal concentrations. Results suggest that conclusions based on known anthropogenically contaminated sites do not compare to natural lake systems with high background levels of trace metals, as in the case of Hg and As. It can also be concluded that when developing correlations and examining potential trace element indicators, the entire lacustrine ecosystem should be viewed as a whole unit, not as an isolated organism affected by one or few pollutants.

5.2.2 Diatoms

Diatom communities in both basins of James Lake show significant numbers and relatively even downcore distribution, indicating a favourable environment for the diatom blooms (Figures 21 & 22). Due to the sensitivity of diatoms to pH, any changes in the pH of James Lake would have been detected through fluctuations in the diatom distribution. Since no major changes were observed in diatom abundances or assemblages, water pH has remained relatively unchanged throughout the core, most likely as a result of the buffering capacity of the hard water.

Diatom flora of both cores further suggests that oligotrophic conditions prevailed throughout both sedimentary sequences, as most taxa are characteristic of low nutrient-levels (Prévost, 1996). The dominant diatom *Cyclotella michiganiana* is clearly an indicator of such nutrient limited conditions (Davis and Norton, 1978; Weber, 1970; Smol *et al.*, 1983) since this taxon is most abundant when organic content of the sediments is largest. Also of importance is the presence of cysts and scales of siliceous algal microfossils implying both hard water and oligotrophic conditions (Smol and Glew, 1992).

There is, however, a significant component (likely 30 to 40%) of the diatom flora which is associated to more nutrient-rich conditions (mesotrophic to eutrophic). The subdominant diatoms in James Lake are mostly mesotrophic to eutrophic indicators and include *Cyclotella pseudostelligera*, *Fragilaria tenera*, *Fragilaria nanana*, *Fragilaria crotonensis* and *Achnanthes minutissima*. Straub (1984) and Gasse (1986) found that the eutrophic taxon *Cyclotella pseudostelligera* is typically present in lakes of pH 7-8.5, as in the case of James Lake.

One interpretation of the diatom data for James Lake demonstrates a seasonal succession of various species of diatoms (Prévost, 1996). This seasonal succession in the diatom-plankton is often associated with nutrient and silica depletion. A spring maximum occurs when water is relatively rich in nutrients as the winter accumulation of organic matter is mixed throughout water column due to seasonal winds or temperature changes result in mixing of stratified lakes bringing nutrients to the surface, where they can be used by planktonic diatoms. Usually, only one or several genera such as *Asterionella*, *Cyclotella*, and *Fragilaria* dominate for several weeks (Wetzel, 1983). As the lake waters

become very productive in the summer, a decrease in nutrient and silica concentration occurs (both needed for diatom production) and the initial population declines abruptly along with the seasonal fluctuations in light and temperature, grazing by zooplankton, and nutrient availability of the lake water (Wetzel, 1983). Diatom species that can tolerate this depletion will take over the initial population. In the case of James Lake, this phase would be favourable to the rapid and short growth of *Cyclotella michiganiana* (Prévost, 1996; Wetzel, 1983). Seasonal fluctuations of *C. michiganiana* were observed in Lawrence Lake (Michigan) where this species peaked for about one month in June-July and then being replaced by *Cyclotella* species (Wetzel, 1983). In Lake Michigan, *Cyclotella michiganiana* also peaked for a short period of time in August and September following peaks of mesotrophic and eutrophic diatoms such as *Fragilaria crotonensis* and *Stephanodiscus* species (Wetzel, 1983).

The algal portion of the lake environment is important to the geochemical cycling of trace elements due to uptake of nutrients and silica in the areas of light and carbon dioxide in the photic zone of the water column. It is here where dissolved oxygen is highest in the water column (usually between epilimnion and mesolimnion) due to algal respiration. But in this cycling, trace metals may not directly affect the growth of the diatom bloom (Wetzel, 1983). Overall, trace metal geochemical fluctuations in the lake sediment cores (see chapter 2.2) do not seem to have affected total diatom abundances. However, since few levels of diatoms were counted in the core compared to the levels analyzed for geochemistry, only broad interpretations can be described.

According to Holland (1969), the abundance of the principal species of diatoms encountered appeared to be correlated with the average values of nitrate and phosphorus

(nutrient) concentrations or to the lake status (eutrophic or oligotrophic). It would be safe to say that total abundances do not reflect any amount of trace metal toxicity in James Lake. Instead certain species may reflect nutrient availability as Holland (1969) indicates. Organic content in the lake sediments may reflect periods of fast sedimentation rates and reducing conditions which limits decay and the subsequent release of nutrient into the water column. It may also be that certain diatoms are unaffected by trace metal concentrations and are tolerant of the pH changes following pollution of lake waters. In James Lake, these effects are not detected and may be buffered by the carbonate-rich waters. Certain species, however, have been documented to be tolerant of pollution (*i.e.*, *Cyclotella pseudostelligera*, *Achnanthes minutissima*). In James Lake, these are rare species which may be simply tolerant of the eutrophic and alkaline conditions of the water.

In whole, no correlations exist between individual species and anomalous trace metal concentrations in James Lake. The increase in abundances of diatoms at the surface of the cores is due almost solely to the increase of the species *Cyclotella michiganiana* perhaps from longer periods of oligotrophic conditions in the spring.

6.0 SUMMARY AND CONCLUSIONS

6.1 Geochemical conclusions

The geochemical data have provided background major and trace element concentrations for the catchment areas of three remote lakes in southeastern Ontario. Generally, the composition of till, soil, humus, and lake sediments reflect the composition of the underlying and surrounding, exposed bedrock. The till consists of more than one rock type with varying concentrations of trace metals which accumulate into the clay-sized fraction of the sediment. The soil is composed of portions of till, bedrock, and vegetation, and takes on the chemical constituents of each. Humus, largely composed of remnants of varying species of plant matter, contains metals which were once available to the plants when they were living. Metals from both the underlying soil and from decaying organic matter are also strongly adsorbed to humus. The geochemical variability over short distances reflects variability of local bedrock composition. Sources of trace metals have been traced to the geochemical content of the marble/metasedimentary unit which, for the most part, contains the three study lakes. Sources for the anomalous concentrations found in Little Green Lake and in James Lake are Zn-Cu mineralization, Pb-sulphide occurrences, as well as lenses of quartzite with variable Au contents found specifically in the portion of the unit which lies outside the Plevna folds, between rock units and a gneissic limb of a synform.

The varying amount of trace elements (especially Zn, Pb, Cu, As, Cd, Cr, Hg and Ni) in each lake is due to a number of interdependent factors including size of catchments

(available material to be washed into the lake), basin size (drainage area), water status (nutrient and oxygen content), ground water inputs (geochemistry and drainage), sediment type (organic content, clay content), and proximity to mineralization.

Differences between the geochemical signatures of the lakes show that Ardoch Lake sediments contain background concentrations similar or below regional background values established by the NGR surveys of the GSC. The geochemical profiles show minimal variation in background values. Little Green Lake and James Lake have anomalous background values with respect to the regional background concentrations depicted in Ardoch Lake sediments. The sediment profile of Little Green Lake recorded a maximum peak in the background geochemical signature occurring near the bottom of the sediment core interpreted as a biochemical precipitation event, precipitating carbonate and trace metals out of the water. Background values for James Lake show anomalous background concentrations of most common and rare trace elements. Large variations in the background values are correlated with the organic content of the sediments and also possibly due to groundwater inflow via karst drainage pathways through the metalliferous terrain.

Compared to these background concentrations, surface sediments have typically been used in the past to establish enrichment factors due to the anthropogenic contribution of trace elements to the environment. The lakes chosen specifically for this study were remote from significant sources of anthropogenic activity. As a result, atmospheric deposition of long-range transported airborne particulates of trace elements would be the only pathway. Atmospheric deposition, either natural or anthropogenic, should be observed in all lakes at the same time in the sediment sequence. Only lead

shows a definite increase in the near-surface/surface sediments in all lakes, beginning prior to the industrial revolution in Europe. Although this trend has been observed in other studies, it may be that lead is not as immobile in lake sediments as traditionally thought. Recent studies have indicated that enrichments are primarily due to the influence of redox gradient, diagenesis, mobility of metal-organic complexes, organic decay, and natural metal accumulation due to plant uptake and decay.

A portion of trace element particulates entering the catchment through atmospheric deposition may also be from natural sources such as deflated soil and sediment, forest fire debris, and biogenic particles. It is agreed that some portion of the geochemical loading of the lake sediments, and its basinal components, is to some degree due to anthropogenic effects, as in dry atmospheric deposition from distal sources. This was not measured. In a mineralized area, long distance airborne pollution has a negligible overprint on the naturally generated trace metals in this area.. Finally, indirect effects of anthropogenic activity in the form of acid rain may enhance the degree of weathering of rock and the metal load to the lake.

By evaluating natural sources of trace metals in the lacustrine environments of three Shield lakes in southeastern Ontario, it is apparent that geology is a primary contributor of trace metals to the remote lakes from this area. Atmospheric contributions were not however measured but are assumed to be insignificant compared to the available natural sources of trace elements surrounding the lakes. It is impossible in this study to quantify the natural and anthropogenic components of trace metals in till, soil, humus, and lake sediments due to critical information gaps and uncertainties associated with real values collected from previous studies. Instead, the recognition and further investigation of

natural accumulation processes and behaviour of trace elements by all scientists is a necessary response to this study. It is important to recognize that the history of a lacustrine environment is very complex and cannot be reconstructed solely from geochemical data.

6.2 Paleontological conclusions

The paleontological data have provided a historical record of changes in lake water and sediment chemistry. No event caused by anthropogenic interference is reflected in assemblages from lakes in the Ardoch area. A change from clastic sedimentation to carbonate precipitation has drastically affected thecamoebian assemblages in Little Green Lake. Such fluctuations in assemblages are due to natural causes.

All study lakes are eutrophic in late summer, having low dissolved oxygen concentrations as well as high concentrations of trace elements in lake bottom waters and sediments resulting in similar thecamoebian compositions. The total numbers of thecamoebian specimens are low, suggesting a stressful environment. Low oxygen levels directly limit thecamoebian populations and indirectly limit them by reducing other organisms including bacteria, fungi, algae, and plants which would serve as food sources. Adequate oxygen levels are of paramount importance for most aquatic life. High amounts of available trace elements ingested by amoebas can harm the cell and theoretically result in deformed tests (strains). However, the maximum tolerable concentrations of trace elements which thecamoebians can withstand are unknown. It is important to note that the

strains identified in the study lakes are cosmopolitan and that a yet unknown stimulus or a combination of stimuli creates the deformation of the original species.

As previously discussed, differences between lake environments in the study area occurred in geology, morphology and sediment type, resulting in differing geochemical signatures of the lake. Some differences were observed in total abundances and strains. The constancy of sediment type and total thecamoebian abundances in Ardoch Lake suggest a stable environment. The sediment was found to be naturally high in trace elements. Unlike Ardoch Lake, thecamoebian abundances of Little Green Lake drastically changed during periods of massive carbonate precipitation to a significantly smaller population. Total trace element concentrations were anomalous compared to Ardoch Lake and reflected local bedrock geochemistry. Compared to the other study lakes, James lake is the smallest lake possessing sediments with much higher concentrations of both trace elements and organic matter. Thecamoebians in this environment appear in very low abundances but develop a higher number of strains than in the other lakes.

Distinguishing between ecotypes within each species has proven important in deciphering the differences in assemblages between these three lakes. It is believed that various strains of the same species represents response to current environmental conditions (pers. comm., F. Medioli, 1996). Strains of *Cucurbitella tricuspis*, *Centropyxis aculeata*, *Centropyxis constricta*, *Diffugia oblonga*, and *Diffugia protaeiformis* were identified. These strains have not been previously described in recent papers focusing on the high variability of morphotypical differences and environmental issues, including Patterson *et al.* (1996), Asioli *et al.* (1996), and Burbidge and Schröder-Adams (*in press*). It is essential to uncover the environmental stimuli controlling their existence. For

instance, *Cucurbitella tricuspis* proved to be morphologically variant and dominant in all study lakes. It has been well established that eutrophic conditions are the preferred environment for *Cucurbitella tricuspis*. However, eutrophism alone may not guarantee that *Cucurbitella tricuspis* and individual strains will be abundant.

In Ardoch and Little Green Lakes, one specific strain, *Cucurbitella tricuspis* "achlora" dominates the assemblages during periods of increased carbonate precipitation in the lake. This event may overprint the signal of eutrophism and thus the *C. tricuspis* strains becomes an indicator of a carbonate environment rather than just a eutrophic environment. In James Lake, however, layers of carbonate precipitate are not apparent in the sediment cores. It is in this lake where more strains of *C. tricuspis* occur, the strain "labiosa" being dominant. Compared to Ardoch Lake or Little Green Lake, the environment in James Lake is much different. The differing biological and chemical components allow *C. tricuspis* "labiosa" to dominate and limits the reproduction of *Cucurbitella tricuspis* "achlora". The stimulus for the dominance of *C. tricuspis* "labiosa" is undetermined. These observations would have been lost if the identified strains were lumped under one species as done in the past.

It has been suggested by Burbidge and Schröder-Adams (*in press*) that food sources, indirectly affected by limnological variants, are the eventual cause of fluctuating thecamoebian distributions. Hence, it may be the available food source in the carbonate environment which influences the dominance of this *C. tricuspis* "achlora". It is fair to say that thecamoebian strains are indicators of changes in productivity of the lake where nutrition and availability of certain food types are dependent on lake conditions and are the primary factors influencing thecamoebian distribution and abundances.

Whereas most thecamoebian species reflect environmental changes of lake bottom conditions, diatoms represent the upper water column. The diatom population of James Lake reflects a stable environment within the water column with only minor alterations of diatom blooms over time. The alkaline water remained chemically stable due to its buffering capacity to pH changes. In James Lake, the seasonal trophic changes were recorded throughout the sediment sequence in the diatom record by the overwhelming dominance of an oligotrophic species in an otherwise eutrophic lake. This species, *Cyclotella michiganiana*, has only been documented in a few lakes around the world.

6.3 Final comments

The net result of this multidisciplinary study is a series of vertical profiles (historic records) of metal concentrations, thecamoebian and diatom assemblages in dated sediment cores from three lakes. In essence, geochemical profiles give a true historical record due to the possibilities of the near-surface sediment being affected by bioturbation, diagenetic processes, gas movement, and metal remobilization. However, with the aid of biological indicators of changes in lake conditions, scientists are able to better understand variations in the geochemical profiles.

It is vital that increased attention be drawn to geological factors that control natural distribution patterns of trace elements in soil, atmosphere, vegetation, and sediment, especially from environmental scientists dealing with such delicate issues as mercury. It is important to consider all aspects of the environments; biological, chemical and physical, when addressing issues about anthropogenic effects. As of yet, it is not possible to

quantitatively express these influences. It may be possible to separate natural and anthropogenic inputs into a lake with further sampling of air, rain, and snow coupled with mathematical modeling. Mathematical modeling is an exceedingly important tool in clarifying processes controlling metal cycling and mass balance calculations.

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PLATES

PLATE I

- 1) *Arcella vulgaris* "angulosa", dorsal view, Little Green Lake, x520.
- 2) *A. vulgaris* "angulosa", side view, Little Green Lake, x613.
- 3) *A. vulgaris* "angulosa", dorsal view, James Lake Basin I, x500.
- 4) *Lesquereusia jurassica*, apertural view, James Lake Basin I, x600.
- 5) *L. jurassica*, close up, autogenous test of siliceous rods, James Lake Basin I, x1022.
- 6) *L. jurassica*, side view, James Lake Basin I, x500.
- 7) *Cyclopyxis kahli*, ventral view, James Lake Basin I, x602.
- 8) *C. kahli*, ventral view, James Lake Basin I, x574.
- 9) *C. kahli*, ventral view, Little Green Lake, x557.
- 10) *Oopyxis* sp., side view, James Lake Basin I, x440.
- 11) *Oopyxis* sp., ventral view, James Lake Basin I, x556.
- 12) *Diffugia globulus* "globulosa", apertural view, James Lake Basin I, x495.
- 13) *Diffugia rotunda*, side view, James Lake Basin I, x778.
- 14) *Centropyxis aculeata* "ecornis", ventral view, Little Green Lake, x381.
- 15) *C. aculeata* "ecornis", ventral view, James Lake Basin I, x325.

PLATE 2

- 1) *Centropyxis aculeata* "aerophilia", ventral view, James Lake Basin 2, x385.
- 2) *C. aculeata* "aerophilia", ventral view, Little Green Lake, x800.
- 3) *C. aculeata* "aerophilia", ventral view, Little Green Lake, x667.
- 4) *C. aculeata* "aerophilia", ventral view; James Lake Basin 1, x331.
- 5) *Centropyxis aculeata* "aculeata", dorsal view, James Lake Basin 1, x420.
- 6) *Diffugia protaeiformis* "bicornis", lateral view, Ardoch Lake, x743.
- 7) *Centropyxis constricta* "constricta", apertural view, with spines, James Lake Basin 1, x675.
- 8) *Centropyxis constricta* "spinifera", apertural view, Little Green Lake, x561.
- 9) *Centropyxis constricta* "platystoma", apertural view, James Lake Basin 2, x552.
- 10) *Centropyxis constricta* "cassis"; ventral view, James Lake Basin 1, x589.
- 11) *C. constricta* "cassis", lateral view, James Lake Basin 1, x520.
- 12) *C. constricta* "cassis", ventral view, James Lake Basin 1, x478.
- 13) *Centropyxis constricta* "constricta", ventral view, spineless, Little Green Lake, x857.
- 14) *C. constricta* "constricta", ventral view, spineless, James Lake Basin 1, x239.
- 15) *C. constricta* "constricta", ventral view, spineless, James Lake Basin 2, x700.

PLATE 3

- 1) *Heleopera sphagni*, lateral view, Little Green Lake, x560.
- 2) *H. sphagni*, apertural view, Little Green Lake, x778.
- 3) *H. sphagni*, apertural view, Ardoch Lake, x525.
- 4) *Trinema enchelys*, close up, aperture with 'teeth', James Lake Basin I, x1666.
- 5) *T. enchelys*, ventral view, autogenous test of circular plates, James Lake Basin I, x692.
- 6) *Euglypha* sp., lateral view, James Lake, x650.
- 7) *Euglypha cashii*, lateral view, broken test, James Lake Basin I, x800.
- 8) *Euglypha* sp., lateral view, James Lake Basin I, x800.
- 9) *Euglypha* sp., close up, aperture with 'teeth', James Lake Basin I, x1711.
- 10) *Euglypha acanthophora*, lateral view, James Lake Basin I, x717.
- 11) *E. acanthophora*, close up, aperture with 'teeth', James Lake Basin I, x1533.

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PLATE 4

- 1) *Cucurbitella corona*, apertural view, Little Green Lake, x400.
- 2) *C. corona*, side-apertural view, James Lake Basin 1, x350.
- 3) *Cucurbitella tricuspis* "gramen", lateral view, James Lake Basin 1, x750.
- 4) *C. tricuspis* "gramen", apertural view, James Lake Basin 1, x646.
- 5) *C. tricuspis* "gramen", apertural view, James Lake Basin 1, x600.
- 6) *C. tricuspis* "gramen", apertural view, James Lake Basin 1, x675.
- 7) *Cucurbitella tricuspis* "tuberculata", lateral view, James Lake Basin 1, x450.
- 8) *C. tricuspis* "tuberculata", apertural view, James Lake Basin 1, x573.
- 9) *C. tricuspis* "tuberculata", close up of test, James Lake Basin 1, x1108.
- 10) *C. tricuspis* "tuberculata", apertural view, James Lake Basin 1, x475.
- 11) *C. tricuspis* "tuberculata", apertural view, James Lake Basin 1, x510.
- 12) *Cucurbitella tricuspis* "oviformis", apertural view, x589.
- 13) *C. tricuspis* "oviformis", lateral view, x658.
- 14) *C. tricuspis* "oviformis", apertural view, x889.
- 15) *C. tricuspis* "oviformis", apertural view, x732.

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PLATE 5

- 1) *Cucurbitella tricuspis* "labiosa", lateral view, James Lake Basin 1, x739.
- 2) *C. tricuspis* "labiosa", apertural view, James Lake Basin 1, x650.
- 3) *C. tricuspis* "labiosa", lateral view, James Lake Basin 1, x850.
- 4) *C. tricuspis* "labiosa", apertural view, James Lake Basin 1, x635.
- 5) *C. tricuspis* "labiosa", apertural view, James Lake Basin 1, x1000.
- 6) *C. tricuspis* "labiosa", lateral view, James Lake Basin 1, x856.
- 7) *C. tricuspis* "labiosa", apertural view, James Lake Basin 1, x1161.
- 8) *C. tricuspis* "labiosa", lateral view, James Lake Basin 1, x2222.
- 9) *C. tricuspis* "labiosa", apertural view, James Lake Basin 1, x911.
- 10) *C. tricuspis* "labiosa", apertural view, James Lake Basin 1, x692.
- 11) *C. tricuspis* "labiosa", lateral view, James Lake Basin 1, x800.
- 12) *C. tricuspis* "labiosa", apertural view, Little Green Lake, x800.

PLATE 6

- 1) *Cucurbitella tricuspis* "achlora", apertural view, James Lake Basin 1, x750.
- 2) *C. tricuspis* "achlora", apertural view, James Lake Basin 1, x648.
- 3) *C. tricuspis* "achlora", apertural view, Little Green Lake, x1090.
- 4) *C. tricuspis* "achlora", apertural view, James Lake Basin 1, x650.
- 5) *Diffflugia lithophilia*, apertural view, Little Green Lake, x525.
- 6) *D. lithophilia*, lateral view, Little Green Lake, x473.
- 7) *D. lithophilia*, apertural view, Little Green Lake, x512.
- 8) *D. lithophilia*, lateral view, Little Green Lake, x500.
- 9) *Diffflugia viscidula*, apertural view, Ardoch Lake, x639.
- 10) *D. viscidula*, apertural view, Ardoch Lake, x494.
- 11) *D. viscidula*, apertural view, Ardoch Lake, x279.
- 12) *D. viscidula*, lateral view, Ardoch Lake, x550.

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PLATE 7

- 1) *Diffflugia urceolata* "urceolata", apertural view, Little Green Lake, x583.
- 2) *D. urceolata* "urceolata", lateral view, James Lake Basin 2, x248.
- 3) *D. urceolata* "urceolata", apertural view, James Lake Basin 2, x247.
- 4) *D. urceolata* "urceolata", apertural view, Ardoch Lake, x1150.
- 5) *D. urceolata* "urceolata", lateral view, x975.
- 6) *D. urceolata* "urceolata", apertural view, James Lake Basin 1, x1347.
- 7) *Diffflugia urceolata* "mica", lateral view, Little Green Lake, x978.
- 8) *D. urceolata* "mica", apertural view, Little Green Lake, x1015.
- 9) *D. urceolata* "mica", apertural view, Little Green Lake, x1250.
- 10) *D. urceolata* "mica", apertural view, Ardoch Lake, x907.
- 11) *D. urceolata* "mica", apertural view, Little Green Lake, x1344.
- 12) *D. urceolata* "mica", lateral view, Little Green Lake, x1069.

PLATE 8

- 1) *Lagendifflugia vas*, lateral view, Ardoch Lake, x667.
- 2) *Pontigulasia elisa*, lateral view, broken test, Ardoch Lake, x618.
- 3) *Diffflugia oblonga* "petricola", lateral view, Little Green Lake, x910.
- 4) *D. oblonga* "petricola", fundus view, Ardoch Lake, x650.
- 5) *D. oblonga* "petricola", apertural view, Ardoch Lake, x720.
- 6) *D. oblonga* "petricola", lateral view, Little Green Lake, x622.
- 7) *D. oblonga* "petricola", lateral view, James Lake Basin 2, x780.
- 8) *D. oblonga* "petricola", lateral view, James Lake Basin 2, x261.
- 9) *D. oblonga* "petricola", lateral view, Ardoch Lake, x659.
- 10) *D. oblonga* "petricola", lateral view, Little Green Lake, x625.
- 11) *D. oblonga* "petricola", apertural view, Ardoch Lake, x1040.

PLATE 9

- 1) *Diffugia urceolata* "elongata", apertural view, Ardoch Lake, x460.
- 2) *D. urceolata* "elongata", lateral view, Ardoch Lake, x317.
- 3) *D. urceolata* "elongata", lateral view, James Lake Basin 1, x279.
- 4) *D. urceolata* "elongata", apertural view, Ardoch Lake, x600.
- 5) *D. urceolata* "elongata", apertural view, Ardoch Lake, x750.
- 6) *D. urceolata* "elongata", lateral view, James Lake Basin 1, x513.
- 7) *D. urceolata* "elongata", lateral view, Ardoch Lake, x354.
- 8) *D. urceolata* "elongata", apertural view, Ardoch Lake, x374.
- 9) *D. urceolata* "elongata", lateral view, James Lake Basin 1, x506.
- 10) *D. urceolata* "elongata", apertural view, James Lake Basin 1, x500.
- 11) *D. urceolata* "elongata", lateral view, James Lake Basin 1, x635.
- 12) *D. urceolata* "elongata", apertural view, James Lake, Basin 1, x933.

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PLATE 10

- 1) *Diffflugia oblonga* "bacillifera". lateral view, James Lake Basin 1, x245.
- 2) *D. oblonga* "bacillifera". apertural view, James Lake Basin 1, x350.
- 3) *Diffflugia oblonga* "gassowskii". lateral view, James Lake Basin 1, x367.
- 4) *D. oblonga* "gassowskii". lateral view, James Lake Basin 1, x287.
- 5) *D. oblonga* "gassowskii". lateral view, Ardoch Lake, x202.
- 6) *D. oblonga* "gassowskii". lateral view, Ardoch Lake, x157.
- 7) *D. oblonga* "gassowskii". lateral view, James Lake Basin 2, x248.
- 8) *D. oblonga* "gassowskii". lateral view, Ardoch Lake, x246.
- 9) *Diffflugia oblonga* "venusta". lateral view, Little Green Lake, x430.
- 10) *D. oblonga* "venusta". lateral view, James Lake Basin 1, x500.
- 11) *Diffflugia oblonga* "bryophila". James Lake Basin 1, x390.

PLATE 11

- 1) *Diffugia protaeiformis* "smilion". lateral view, Ardoch Lake, x567.
- 2) *Diffugia protaeiformis* "amphoralis". apertural view, Little Green Lake, x850.
- 3) *D. protaeiformis* "amphoralis", lateral view, Little Green Lake, x667.
- 4) *D. protaeiformis* "amphoralis", lateral view, Little Green Lake, x650.
- 5) *Diffugia protaeiformis* "elegans". lateral view, James Lake Basin 1, x573.
- 6) *D. protaeiformis* "elegans". lateral view, Little Green Lake, x725.
- 7) *Diffugia oblonga* "lanceolata". apertural view, broken apertural rim, James Lake Basin 1, x643.
- 8) *Diffugia oblonga* "lacustris". apertural view, James Lake Basin 1, x682.
- 9) *Diffugia oblonga* "venusta". apertural view, Ardoch Lake, x400.

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Plate 12

- 1) *Cyclotella pseudostelligera*, James Lake basin 1, x 11360.
- 2) *Cyclotella michiganiana*, James Lake basin 1, x 11094
- 3) *Cyclotella michiganiana*, James Lake basin 1, x 8643
- 4) *Nitzschia* sp. 4, James Lake basin 1, x 3314

APPENDIX A

Table A-1: 1976/77 National Geochemical Reconnaissance Survey data (Open File 899) for lake water and sediment geochemistry of lakes in the Ardoch area.

Lake/Stream	Sample	Depth m	Bedrock	Zn ppm	Cu ppm	Pb ppm	Ni ppm	Co ppm	Ag ppm	Mn ppm	As ppm	Mo ppm	Fe %	Hg ppb	LOI %	U ppm
1976 LAKE SEDIMENTS																
James Lake	761242	8	mble	430	94	10	17	6	0.1	330	8	17	1	580	64.2	2.6
James Lake	761243	8	mrbl	465	80	8	14	5	0.1	335	8	14	0.9	510	55.2	2.3
Crooked Lake	761244	18	amph	48	26	2	7	1	0.1	200	2	9	0.4	110	50.6	3
Ardoch Lake	763085	14	prgs	92	34	4	15	8	0.1	325	1.5	1	1.8	40	45.8	3.2
Little Green Lake	763087	23	mrbl	320	76	2	14	3	0.1	485	33	10	1.45	120	36.6	2.6
Cards Lake	763088	5	amph	44	26	4	6	2	0.1	85	1.5	5	0.5	70	87.6	2.6
1977 LAKE SEDIMENTS																
Little Cards Lake	776002	5	apbg	76	68	4	14	6	0.1	465	2	3	1.84	110	76.5	1.4
Abs Lake	776003	10	apbg	80	40	4	15	8	0.2	650	2	5	1.78	72	71.3	3
Lukeward Lake	776004	3	mrbl	40	11	4	7	1	0.1	35	3	5	0.04	62	88.7	1.7
Struthers Lake	776005	5	mrbl	31	12	8	4	1	0.1	70	4	14	0.11	72	87.8	6.5
Little Green Lake	776006	20	mrbl	256	68	12	15	5	0.3	510	58	17	1.46	110	52.1	3.5
Deep Lake	776007	22	mrbl/scht	88	48	7	10	2	0.1	830	6	7	1.31	140	61.7	1.1
Watson's Lake	776008	6	mrbl	34	10	3	3	1	0.1	45	2	5	0.12	62	92.7	1.5
Johnson Lake	776009	9	mrbl	260	46	9	8	4	0.2	150	16	8	1.14	n/a	n/a	n/a
Mud Lake	776010	3	schl/mrbl	144	32	5	19	6	0.1	225	6	4	1.32	90	58.6	4
Mud Lake	776011	6	schl/mrbl	39	22	12	6	2	0.2	165	3	6	0.48	72	64.3	1
Mud Lake	776012	2	schl/mrbl	144	22	18	11	6	0.1	345	8	1	1.04	130	48.5	3.9
Mud Lake	776013	2	schl/mrbl	128	21	6	12	5	0.1	225	4	1	1.06	90	51.4	2.9
Mud Lake	776014	2	schl/mrbl	140	21	17	10	7	0.1	370	6	2	1.21	90	n/a	4.7
James Lake	776015	12	mrbl	292	75	12	16	3	0.4	385	19	18	0.69	370	64.6	1.7
James Lake	776016	6	mrbl	260	52	8	10	3	0.2	330	14	9	0.93	240	83.6	2.3
1977 STREAM SEDIMENTS																
Buckshot Creek	774002	1	mrbl	23	6	3	3	3	0.1	155	4	1	0.76	20	1.7	n/a
near Cards Lake	774003	0.65	mrbl	16	3	3	3	1	0.1	105	0.5	1	0.42	20	3.3	n/a
Conns Creek	774004	1.25	mrbl	47	8	11	5	4	0.1	160	2	1	0.75	40	1	n/a
highway	774005	0.05	mrbl	50	8	7	5	4	0.1	630	18	1	0.88	130	3	n/a
Conns Creek	774006	0.25	mrbl	49	8	5	5	4	0.1	635	6	1	0.91	58	0.5	n/a
Buckshot Creek	774008	2	mrbl	62	6	7	6	4	0.1	205	2	1	1.04	58	5.6	n/a

APPENDIX B

Table B-1: Geochemistry of rock found around James Mine. Analyses performed by Acme Laboratories Ltd., BC. Analysis was done by aqua regia digestion followed by ICP-ES determination. D.L. is the detection limit of the elemental analysis. Determination of As, Cr, Sb, Au are expected not to be precise due to loss by volatilization.

ELEMENT	Mo	Cu	Pb	Zn	Ag	Ni	Co	Mn	Fe	As	U	Au
SAMPLES	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	%	ppm	ppm	ppm
D.L.	2	2	5	2	0.5	2	2	5	0.01	5	10	4
%Error ±	n/a	2	8	1	5.6	14	0	1	0.56	n/a	10	n/a
95-CPA-1001	3	4379	25	366	78.2	6	< 2	120	0.39	48	< 10	< 4
95-CPA-1002	2	3211	17	108	7.2	47	49	388	5.11	< 5	15	< 4
95-CPA-1003	< 2	272	25	119	1.8	14	30	555	5.35	< 5	20	< 4

ELEMENT	Th	Sr	Cd	Sb	Bi	V	Ca	P	La	Cr	Mg	Ba
SAMPLES	ppm	ppm	ppm	ppm	ppm	ppm	%	%	ppm	ppm	%	ppm
D.L.	2	2	0.4	5	5	2	0.01	0.002	2	2	0.01	1
%Error ±	n/a	0	n/a	29	n/a	1	0.14	0.599	n/a	0	0.35	1
95-CPA-1001	< 2	46	4.3	1616	150	3	0.85	0.013	< 2	8	0.64	67
95-CPA-1002	2	602	0.6	18	< 5	164	5.36	0.086	< 2	76	3.92	268
95-CPA-1003	2	303	< .4	14	< 5	266	7.4	0.167	< 2	12	2.83	473

ELEMENT	Ti	Al	Na	K	W	Zr	Sn	Y	Nb	Be	Sc	Hg
SAMPLES	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppb
D.L.	0.01	0.01	0.01	0.01	4	2	2	2	2	1	1	10
%Error ±	0	0.8	0	1.44	n/a	5	50	0	0	0	0	0
95-CPA-1001	< .01	0.31	0.11	0.12	< 4	2	< 2	< 2	< 2	< 1	< 1	630
95-CPA-1002	0.85	4.84	1.42	2.16	11	28	7	6	4	1	23	170
95-CPA-1003	0.92	6.25	2.47	2.78	< 4	39	2	13	2	1	25	80

Table B-2: Unpublished analyses (complements of A.L. Sangster, GSC) of Grenville marble-hosted zinc occurrences just north of Little Green Lake. Property names are not found on maps. Precision and accuracy of analyses are not available.

SAMPLE	PROPERTY	LOCATION	Cu ppm	Pb ppm	Zn ppm	Hg ppb	Au ppb	As ppm	Cd ppm	Fe ppm
SFB-86-0074	Ducharme	Johnson Lk	36	3610	316100	29000	7	322	442	1
SFB-86-0076	Ducharme	Johnson Lk	32	1584	270700	17000	3	65	467	1
SFB-86-0075	Ducharme	Johnson Lk	51	7440	222800	21000	3	93	390	1
SFB-86-0072	Maly	north	60	1786	98000	117000	22	374	228	4
SFB-86-0073	Maly	north	15	689	191400	211000	4	95	727	2
SFB-86-0078	Ducharme stream	stream	56	1610	13000	26000	< DL	1740	120	3
SAMPLE	PROPERTY	LOCATION	Ag ppm	Sb ppm	Ni ppm	Mo ppm	Mn ppm	Co ppm	Ba ppm	Sr ppm
SFB-86-0074	Ducharme	Johnson Lk	1	348	11	2	175	4	65	43
SFB-86-0076	Ducharme	Johnson Lk	0	32	8	6	314	2	25	53
SFB-86-0075	Ducharme	Johnson Lk	1	72	9	10	269	2	80	60
SFB-86-0072	Maly	north	15	123	33	16	329	15	3000	196
SFB-86-0073	Maly	north	20	98	8	8	285	5	5000	219
SFB-86-0078	Ducharme stream	stream	2	2930	23	238	360	19	760	128

Table B-3: Geochemistry of till, soil, and humus samples performed by Acme Laboratories Ltd., BC.

Analysis was done by aqua regia digestion followed by ICP-ES determination. D.L. is the detection limit of the elemental analysis. The T-series is till, the B-series is soil, and the H-series is humus.

LAKE	SAMPLE TYPE	ELEMENT SAMPLE	Mn ppm	Cu ppm	Pb ppm	Zn ppm	As ppm	Sr ppm	V ppm	Ba ppm	La ppm	Hg ppb
		D.L.	2	1	3	1	2	1	1	1	1	10
		%Error ±	23	7	4	2	n/a	0	1	5	7	19
Ardoch Lake	soil near lake	031C9504-B01	4458	13	18	85	3	15	72	192	81	205
	humus near lake	031C9504-H01	641	14	51	86	< 2	37	28	114	14	150
Little Green Lake	till at road cut	031C9501-T01	878	103	23	153	28	25	113	99	116	70
	till near lake	031C9501-T02A	654	97	37	274	111	227	86	123	24	220
	soil at road cut	031C9501-B01	1000	94	25	148	32	27	117	96	115	55
	soil near lake	031C9501-B02	1586	121	66	246	154	38	153	115	54	260
	humus near lake	031C9501-H01	1423	34	147	295	20	77	38	295	11	290
James Lake	soil near lake	031C9502-B01	2093	150	171	173	20	26	47	275	59	575
	soil in woods	031C9502-B02	213	48	12	77	8	15	64	83	18	60
	humus near lake	031C9502-H01	2231	17	353	261	10	48	22	306	5	465
LAKE	SAMPLE TYPE	ELEMENT	U ppm	Au ppm	Th ppm	Co ppm	Cd ppm	Sb ppm	Cr ppm	Ag ppm	Ni ppm	Mo ppm
		SAMPLE #	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
		D.L.	5	2	2	1	0.2	2	1	0.3	1	1
		%Error ±	n/a	n/a	0	0	27.3	n/a	0	n/a	23	0
Ardoch Lake	soil near lake	031C9504-B01	< 5	< 2	5	13	1.1	< 2	33	0.3	24	1
	humus near lake	031C9504-H01	< 5	< 2	< 2	4	0.8	< 2	13	0.3	13	1
Little Green Lake	till at road cut	031C9501-T01	< 5	< 2	14	22	1.3	< 2	50	0.4	70	2
	till near lake	031C9501-T02A	< 5	< 2	4	18	0.7	5	18	0.5	29	2
	soil at road cut	031C9501-B01	< 5	< 2	14	23	1.2	< 2	46	0.4	70	2
	soil near lake	031C9501-B02	< 5	< 2	9	36	1.5	5	50	1.1	44	1
	humus near lake	031C9501-H01	< 5	< 2	2	8	2.4	2	17	0.6	16	1
James Lake	soil near lake	031C9502-B01	< 5	< 2	9	14	1.8	< 2	21	2.5	38	13
	soil in woods	031C9502-B02	< 5	< 2	4	11	0.5	< 2	33	0.5	20	2
	humus near lake	031C9502-H01	< 5	< 2	< 2	5	6.1	< 2	9	0.5	22	3
LAKE	SAMPLE TYPE	ELEMENT	Bi ppm	B ppm	Ca %	Mg %	Fe %	Ti %	Al %	Na %	K %	P %
		SAMPLE #	ppm	ppm	%	%	%	%	%	%	%	%
		D.L.	2	3	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.001
		%Error ±	n/a	50	1.35	2.25	1.75	9.01	2.02	0.00	1.25	1.562
Ardoch Lake	soil near lake	031C9504-B01	3	4	0.74	0.89	5.73	0.11	2.48	0.02	0.08	0.09
	humus near lake	031C9504-H01	< 2	12	4.72	1.05	1.81	0.05	0.96	0.02	0.08	0.064
Little Green Lake	till at road cut	031C9501-T01	2	< 3	1.04	2.24	4.94	0.37	2.12	0.05	0.60	0.119
	till near lake	031C9501-T02A	< 2	< 3	19.26	1.78	3.94	0.15	1.19	0.04	0.43	0.117
	soil at road cut	031C9501-B01	< 2	< 3	1.05	2.06	5.05	0.35	2.04	0.05	0.58	0.121
	soil near lake	031C9501-B02	4	3	1.64	1.54	6.92	0.31	2.32	0.06	0.38	0.234
	humus near lake	031C9501-H01	< 2	19	3.67	0.35	1.48	0.07	0.81	0.02	0.12	0.150
James Lake	soil near lake	031C9502-B01	4	< 3	2.54	0.26	10.23	0.02	4.71	0.01	0.05	0.105
	soil in woods	031C9502-B02	< 2	3	0.44	0.89	2.86	0.17	2.27	0.02	0.06	0.046
	humus near lake	031C9502-H01	< 2	9	2.33	0.11	0.81	0.01	0.53	< .01	0.11	0.08

Table B-4a: Ardoch Lake water profile data recorded from a hydrolab during the summer field program.

031C9504 ARDOCH LAKE					
Depth m	Temperature °C	Dissolved Oxygen ppm	Conductivity µS/cm	pH	Eh mV
Error ±	0.10	0.10	10	0.01	10
0	23.50	11.18	228	8.54	328
1	23.47	11.10	228	8.55	328
2	23.44	11.09	228	8.55	328
3	23.44	11.07	228	8.55	328
4	23.40	11.05	229	8.56	329
5	23.36	11.05	229	8.56	329
6	23.24	11.03	229	8.56	330
7	21.03	15.06	239	8.55	335
8	14.47	15.46	245	8.44	347
9	11.48	10.64	251	8.09	369
10	10.16	5.52	256	7.89	380
11	9.34	0.79	261	7.66	388
12	8.52	0.31	260	7.59	389
13	8.24	0.23	263	7.51	390
14	8.02	0.21	266	7.45	361

Table B-4b: Little Green Lake water profile data recorded from a hydrolab during the summer field program.

031C9501 LITTLE GREEN LAKE					
Depth m	Temperature °C	Dissolved Oxygen ppm	Conductivity µS/cm	pH	Eh mV
Error ±	0.10	0.10	10	0.01	10
0	25.90	10.9	268	8.20	325
1	25.90	10.6	268	8.30	326
2	25.90	10.5	269	8.30	327
3	25.90	10.5	268	8.30	329
4	25.80	10.5	269	8.30	331
5	23.30	15.5	269	8.30	338
6	18.50	18.6	271	8.30	345
7	14.60	18.2	274	8.30	353
8	12.00	17.8	275	8.30	358
9	10.10	17.3	276	8.20	362
10	8.50	15.6	279	8.10	370
11	7.70	14.3	280	8.00	376
12	7.00	12.9	280	7.90	381
13	6.40	11.6	279	7.80	385
14	5.70	9.6	280	7.70	391
15	5.33	1.1	287	7.50	401
16	5.23	0.7	287	7.50	402
17	5.30	0.5	286	7.40	403
18	5.30	0.3	287	7.40	403
19	5.20	0.3	288	7.40	403
20	5.10	0.3	306	7.40	392
21	5.10	0.3	269	7.30	243

Table B-4c: James Lake basin 1 water profile data recorded from a hydrolab during the summer field program.

031C9502 JAMES LAKE BASIN 1					
Depth m	Temperature °C	Dissolved Oxygen ppm	Conductivity μS/cm	pH	Eh mV
Error ±	0.10	0.10	10	0.01	10
0	24.55	10.60	275	8.15	306
1	24.55	10.56	275	8.14	309
2	24.47	10.59	276	8.14	310
3	24.11	11.93	277	8.12	314
4	20.21	18.20	316	7.96	330
5	14.48	13.38	350	7.79	345
6	11.50	5.99	354	7.52	361
7	8.62	4.66	361	7.47	365
8	7.30	1.98	359	7.40	369
9	6.37	0.76	359	7.34	372
10	5.72	0.62	366	7.27	374
11	5.33	0.28	430	6.93	200
12	5.14	0.33	767	6.49	147
13	5.15	0.61	823	6.43	135

Table B-4d: James Lake basin 2 water profile data recorded from a hydrolab during the summer field program.

031C9503 JAMES LAKE BASIN 2					
Depth m	Temperature °C	Dissolved Oxygen ppm	Conductivity μS/cm	pH	Eh mV
Error ±	0.10	0.10	10	0.01	10
0	24.50	10.50	275	8.11	312
1	24.57	10.39	276	8.11	314
2	24.53	10.33	276	8.11	315
3	24.27	10.38	275	8.09	318
4	19.60	10.61	320	7.86	339
5	14.87	10.95	350	7.64	355
6	11.70	5.84	364	7.51	364
7	9.03	1.45	370	7.39	370
8	7.70	0.57	369	7.35	372
9	6.61	0.42	371	7.31	373
10	5.92	0.21	384	7.16	267
11	5.56	0.19	394	7.08	133

Table B-5: Alkalinity and total organic content of the lake waters. TOC was determined by Shimadzu series 5000 analyzer. Alkalinity was calculated by titration and converted to meq/L units.

LAKES	SAMPLE #	TOC ppm	ALKALINITY	
			Titration Calculated ppm	HCO ₃ meq/L
	D.L.	1	1	
	% Error ± (precision)	7	0	
	% Error ± (accuracy)	0	n/a	
Little Green Lake	031C-95-01-01.0 A	5.5	134	2.67
	031C-95-01-08.0 A	5.3	144	2.88
	031C-95-01-21.0 A	5.4	150	3.00
James Lake basin 1	031C-95-02-01.0 A	7.9	139	2.77
	031C-95-02-05.0 A	7.8	183	3.65
	031C-95-02-12.0 A	11.9	283	5.66
	031C-95-02-INT A	10.6	233	4.66
James Lake basin 1	031C-95-03-01.0 A	8.1	137	2.74
	031C-95-03-04.0 A	7.6	147	2.93
	031C-95-03-06.0 A	6.8	187	3.74
	031C-95-03-11.0 A	7	199	3.97
	031C-95-03-INT A	6.7	194	3.88
Ardoch Lake	031C-95-04-01.0 A	5.2	113	2.26
	031C-95-04-06.0 A	4.4	113	2.26
	031C-95-04-09.0 A	5.1	124	2.49
	031C-95-04-14.0 A	5.5	136	2.73
	031C-95-04-INT A	6.4	135	2.70

Table B-6: Silica and Sulphur in lake waters. Both analyses determined by ICP-ES.

LAKE	ELEMENT	S ppm	Si ppm
	D.L.	0.050	0.025
	% Error ± (precision)	0.330	0.548
	% Error ± (accuracy)	n/a	0.569
Little Green Lake	031C-95-01-01.0 A	3.606	1.273
	031C-95-01-08.0 A	3.745	1.547
	031C-95-01-21.0 A	3.835	2.458
	031C-95-01-INT A	3.647	3.798
James Lake basin 1	031C-95-02-01.0 A	2.934	2.213
	031C-95-02-05.0 A	4.095	2.701
	031C-95-02-12.0 A	2.307	9.383
	031C-95-02-INT A	3.660	6.567
James Lake basin 2	031C-95-03-01.0 A	2.933	2.251
	031C-95-03-04.0 A	3.202	2.192
	031C-95-03-06.0 A	4.040	3.168
	031C-95-03-11.0 A	4.582	5.001
	031C-95-03-INT A	4.224	4.981
Ardoch Lake	031C-95-04-01.0 A	2.854	1.247
	031C-95-04-06.0 A	2.876	1.276
	031C-95-04-09.0 A	2.797	1.149
	031C-95-04-14.0 A	2.648	2.816
	031C-95-04-INT A	2.669	2.758

Table B-7: Water geochemistry of anions by Dionex Ion Chromatography Analyzer.

[illegible]

Table B-8: All raw data for water trace element geochemistry. All analyses were determined by ICP-MS Direct except for Se and Hg which were determined by ICP-MS Hydride.

SAMPLE	Depth m	Al ppb	Ti ppb	V ppb	Cr ppb	Fe ppb	Mn ppb	Co ppb	Ni ppb	Pb ppb	U ppb	Se ppb	Hg ppb
D.L.		2	0.5	0.1	0.1	5	0.1	0.05	0.2	0.1	0.005	0.004	0.004
% Error ±		n/a	11.8	16.5	21.3	n/a	18.6	11.56	n/a	n/a	6.307	2.444	n/a
031C-95-01-01.0 A	1.0	<DL	<DL	0.5	1.2	<DL	0.7	0.06	<DL	0.3	0.153	0.080	0.011
031C-95-01-08.0 A	8.0	<DL	<DL	0.5	1.1	<DL	0.8	0.06	0.3	0.2	0.135	0.082	<DL
031C-95-01-21.0 A	21.0	<DL	0.6	0.7	1.9	<DL	42.0	0.05	<DL	<DL	0.118	0.091	<DL
031C-95-01-INT A	>21.0	6	1.3	2.0	2.5	6	296.3	0.08	0.3	0.3	0.389	0.154	<DL
031C-95-02-01.0 A	1.0	<DL	0.6	0.8	2.2	<DL	3.1	<DL	0.2	<DL	0.177	0.101	0.021
031C-95-02-05.0 A	5.0	<DL	0.7	0.9	2.8	<DL	2.2	0.07	0.2	<DL	0.199	0.091	<DL
031C-95-02-12.0 A	12.0	6	3.5	2.1	4.9	428	<DL	0.97	<DL	0.1	0.141	0.122	0.006
031C-95-02-INT A	>12.0	3	2.4	1.7	2.7	80	1531.2	0.31	<DL	0.6	0.274	0.152	<DL
031C-95-03-01.0 A	1.0	<DL	0.7	0.5	1.0	<DL	0.5	0.06	<DL	<DL	0.187	0.102	<DL
031C-95-03-04.0 A	4.0	<DL	0.6	0.7	2.1	<DL	1.2	0.07	0.2	<DL	0.194	0.101	0.013
031C-95-03-06.0 A	6.0	<DL	0.9	0.8	2.3	<DL	2.4	0.08	<DL	<DL	0.192	0.092	0.006
031C-95-03-11.0 A	11.0	<DL	1.4	0.9	2.4	<DL	1463.6	0.16	<DL	0.1	0.136	0.086	<DL
031C-95-03-INT A	>11.0	<DL	1.2	0.4	2.4	12	802.1	0.13	0.8	0.1	0.191	0.086	<DL
031C-95-04-01.0 A	1.0	5	<DL	0.8	1.6	<DL	2.8	<DL	<DL	<DL	0.060	0.070	0.009
031C-95-04-06.0 A	6.0	5	<DL	0.6	0.9	<DL	1.6	<DL	<DL	<DL	0.069	0.075	<DL
031C-95-04-09.0 A	9.0	<DL	<DL	0.5	2.1	<DL	6.6	0.07	0.5	<DL	0.057	0.080	<DL
031C-95-04-14.0 A	14.0	<DL	0.8	0.4	1.0	<DL	609.3	0.10	<DL	<DL	0.042	0.076	<DL
031C-95-04-INT A	>14.0	<DL	0.8	0.6	1.3	<DL	540.5	0.33	<DL	<DL	0.055	0.073	<DL

SAMPLE	Depth m	Cu ppb	Zn ppb	As ppb	Rb ppb	Sr ppb	Y ppb	Mo ppb	Ag ppb	Cd ppb	In ppb	Sb ppb	Li ppb
D.L.		0.1	0.5	0.1	0.05	0.5	0.01	0.05	0.05	0.05	0.01	0.01	0.005
% Error ±		9.4	1.9	20.0	0.43	1.5	n/a	15.26	n/a	n/a	n/a	7.52	1.420
031C-95-01-01.0 A	1.0	0.6	1.0	0.9	1.40	71.7	<DL	0.47	<DL	0.07	<DL	0.17	0.367
031C-95-01-08.0 A	8.0	0.7	1.3	1.0	1.35	71.2	<DL	0.43	<DL	0.05	<DL	0.16	0.364
031C-95-01-21.0 A	21.0	0.3	1.1	0.9	1.45	74.6	<DL	0.38	<DL	<DL	<DL	0.16	0.354
031C-95-01-INT A	>21.0	1.1	4.9	9.9	1.55	76.7	0.01	3.87	<DL	<DL	<DL	1.29	0.415
031C-95-02-01.0 A	1.0	0.5	0.8	1.5	1.19	83.7	0.01	0.96	<DL	<DL	<DL	0.29	0.171
031C-95-02-05.0 A	5.0	0.3	0.9	1.3	1.10	96.4	0.02	0.74	<DL	<DL	<DL	0.26	0.197
031C-95-02-12.0 A	12.0	<DL	1.0	5.1	1.70	126.3	0.19	0.28	<DL	<DL	<DL	0.39	0.273
031C-95-02-INT A	>12.0	0.9	1.5	11.9	1.47	114.2	0.11	1.71	<DL	<DL	<DL	0.84	0.254
031C-95-03-01.0 A	1.0	0.4	0.6	1.4	1.22	85.6	<DL	0.95	<DL	<DL	<DL	0.28	0.177
031C-95-03-04.0 A	4.0	0.4	0.8	1.4	1.17	86.8	0.01	0.85	<DL	<DL	<DL	0.29	0.171
031C-95-03-06.0 A	6.0	0.2	0.9	1.3	1.14	1.5	0.03	0.75	<DL	<DL	<DL	0.24	0.203
031C-95-03-11.0 A	11.0	0.2	1.8	1.1	1.29	14.9	0.03	0.46	<DL	<DL	<DL	0.23	0.207
031C-95-03-INT A	>11.0	0.5	2.3	1.5	1.25	13.5	0.03	0.65	<DL	0.20	<DL	0.28	0.210
031C-95-04-01.0 A	1.0	0.9	<DL	0.4	1.34	61.3	<DL	0.10	<DL	<DL	<DL	0.07	0.569
031C-95-04-06.0 A	6.0	0.3	<DL	0.3	1.36	6.8	<DL	0.10	<DL	<DL	<DL	0.08	0.595
031C-95-04-09.0 A	9.0	0.6	<0.5	0.3	1.30	62.5	<0.01	0.10	<0.05	0.20	<0.01	0.06	0.567
031C-95-04-14.0 A	14.0	0.1	<0.5	0.3	1.44	63.5	0.01	0.06	<0.05	<0.05	<0.01	0.05	0.576
031C-95-04-INT A	>14.0	0.2	1.7	0.5	1.39	64.0	0.01	0.09	<0.05	<0.05	<0.01	0.07	0.581

[illegible]

Table B-9: Water chemistry of each lake; alkali (Na+K), magnesium (Mg), calcium (Ca), sulphate (SO₄), and carbonate (HCO₃)

LITTLE GREEN LAKE						
Depth (m)	Cation			Anion		
	Element	ppm (mg/L)	meq/L	Element	ppm	meq/L
1.0	Ca	41	2.05	SO ₄	10.8	0.23
8.0		44.5	2.23		11.2	0.23
12.0		46.7	2.34		11.8	0.23
INT		50.3	2.52		n/a	n/a
1.0	Mg	8.8	0.73	Cl	0.99	0.03
8.0		8.9	0.74		1.04	0.03
12.0		8.9	0.74		1.16	0.03
INT		8.6	0.72		n/a	n/a
1.0	Na + K	1.6	0.02	HCO ₃	134	2.67
8.0		1.7	0.02		144	2.88
12.0		1.73	0.02		150	3
INT		1.72	0.02		n/a	n/a

JAMES LAKE BASIN 1						
Depth (m)	Cation			Anion		
	Element	ppm (mg/L)	meq/L	Element	ppm	meq/L
1.0	Ca	47.5	2.38	SO ₄	8.46	0.02
5.0		65.1	3.26		6.72	0.03
12.0		80	4		12.3	0.06
INT		73.6	3.68		10.6	0.04
1.0	Mg	5.5	0.46	Cl	0.78	0.18
8.0		5.8	0.48		1.16	0.26
12.0		6.2	0.52		2.01	0.14
INT		5.8	0.48		1.26	0.22
1.0	Na + K	1.34	0.02	HCO ₃	139	2.77
8.0		1.41	0.02		183	3.65
12.0		2.01	0.02		283	5.66
INT		1.87	0.02		233	4.66

ARDOCH LAKE						
Depth (m)	Cation			Anion		
	Element	ppm (mg/L)	meq/L	Element	ppm	meq/L
1.0	Ca	36.8	1.84	SO ₄	8.5	0.18
6.0		37	1.85		8.5	0.18
9.0		41.7	2.09		8.32	0.17
14.0		45.1	2.26		7.8	0.16
INT		44.6	2.23		7.89	0.16
1.0	Mg	5.8	0.48	Cl	0.95	0.03
6.0		5.8	0.48		0.89	0.03
9.0		5.7	0.48		1.09	0.03
14.0		5.8	0.48		1.14	0.03
INT		5.7	0.48		1.04	0.03
1.0	Na + K	1.68	0.06	HCO ₃	113	2.26
6.0		1.67	0.05		113	2.26
9.0		1.67	0.05		124	2.49
14.0		1.72	0.06		136	2.73
INT		1.7	0.06		135	2.7

JAMES LAKE BASIN 2						
Depth (m)	Cation			Anion		
	Element	ppm (mg/L)	meq/L	Element	ppm	meq/L
1.0	Ca	47.2	2.36	SO ₄	8.67	0.18
4.0		51	2.55		9.39	0.2
6.0		66.9	3.35		12.4	0.26
11.0		69.8	3.49		13.5	0.28
INT		68.8	3.44		12.5	0.26
1.0	Mg	5.5	0.46	Cl	0.78	0.02
4.0		5.5	0.46		0.82	0.02
6.0		5.9	0.49		1.35	0.04
11.0		6	0.5		1.44	0.04
INT		6	0.5		1.35	0.04
1.0	Na + K	1.33	0.03	HCO ₃	137	2.74
4.0		1.3	0.03		147	2.93
6.0		1.43	0.05		187	3.74
11.0		1.58	0.05		199	3.97
INT		1.59	0.05		194	3.88

Table B-10: Lake geochemistry for Ardoch Lake. Analysis done by ICP-MS and Hg analysis by Cold Vapor AA.

ELEMENT DEPTH	LOI %	Al %	Ti %	Na %	K %	Ca %	Mg %	P %	Fe %	Mn ppm	As ppm	Co ppm	Cr ppm	Cu ppm	Hg ppb	Mo ppm
D.L.	0.1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	2	2	1	1	1	10	1
% Error ±	0.2	2.34	0.00	3.13	12.71	2.06	4.63	3.595	2.67	3	3	2	9	3	10	3
0-2 cm	40.6	1.04	0.07	0.04	0.22	7.98	1.06	0.113	2.12	757	7	7	23	32	125	2
2-4 cm	40.2	1.10	0.07	0.05	0.23	7.30	1.09	0.108	2.20	748	5	7	23	34	125	3
4-6 cm	40.7	1.11	0.07	0.05	0.23	6.10	1.08	0.113	2.17	705	5	7	23	34	130	3
6-8 cm	41.5	1.01	0.07	0.05	0.20	4.37	0.97	0.103	1.83	573	7	6	21	33	110	3
8-10 cm	45.3	0.93	0.06	0.05	0.18	3.74	0.88	0.100	1.64	508	3	6	19	34	90	3
10-12 cm	47.5	0.94	0.06	0.05	0.18	3.85	0.89	0.107	1.68	533	3	6	19	33	85	3
12-14 cm	48.6	0.84	0.06	0.05	0.17	6.10	0.86	0.098	1.47	521	2	5	17	28	60	3
14-16 cm	47.9	0.80	0.05	0.04	0.17	6.82	0.83	0.104	1.41	513	2	5	16	28	65	2
16-18 cm	46.8	0.81	0.06	0.05	0.17	9.09	0.88	0.089	1.44	535	< 2	5	16	27	50	2
18-20 cm	45.8	0.80	0.05	0.04	0.17	9.83	0.87	0.082	1.42	530	< 2	5	16	26	50	2
20-22 cm	45.2	0.78	0.05	0.04	0.16	11.23	0.85	0.078	1.43	530	< 2	5	16	25	35	2
22-24 cm	43.4	0.75	0.05	0.04	0.16	13.15	0.85	0.069	1.41	539	< 2	4	15	23	40	2
24-26 cm	41.9	0.73	0.05	0.04	0.18	13.10	0.83	0.070	1.37	532	< 2	4	14	21	40	2
26-28 cm	42.3	0.73	0.05	0.04	0.17	13.50	0.84	0.068	1.34	523	2	4	14	24	40	2
28-30 cm	41.8	0.73	0.05	0.04	0.16	12.27	0.82	0.068	1.32	498	< 2	4	14	23	40	2
30-32 cm	42.5	0.76	0.05	0.04	0.16	11.93	0.84	0.071	1.40	502	2	5	15	25	50	2
32-34 cm	43.3	0.78	0.05	0.04	0.16	10.36	0.83	0.079	1.47	466	< 2	5	16	27	50	2
34-36 cm	44.0	0.79	0.06	0.04	0.16	8.03	0.81	0.075	1.39	431	< 2	5	16	27	50	2
36-38 cm	44.8	0.82	0.06	0.05	0.17	7.83	0.85	0.074	1.41	438	2	5	17	26	55	2
38-40 cm	45.4	0.80	0.06	0.04	0.17	7.86	0.83	0.071	1.35	417	2	5	16	27	60	2
40-42 cm	45.6	0.81	0.06	0.05	0.16	8.80	0.84	0.074	1.36	459	< 2	5	16	28	50	2
42-44 cm	45.4	0.79	0.05	0.04	0.16	8.80	0.82	0.071	1.33	446	< 2	5	16	26	45	2
44-46 cm	45.0	0.84	0.06	0.05	0.18	10.02	0.92	0.079	1.47	546	2	5	17	29	85	2
46-48 cm	44.4	0.87	0.06	0.05	0.18	8.99	0.94	0.082	1.51	538	3	6	18	29	65	3
48-50 cm	43.6	0.84	0.06	0.05	0.18	8.45	0.89	0.080	1.45	501	< 2	6	17	28	55	3
50-52 cm	43.3	0.72	0.05	0.04	0.15	6.76	0.73	0.070	1.23	411	< 2	5	15	24	65	2
52-54 cm	44.4	0.90	0.06	0.05	0.18	8.10	0.91	0.085	1.51	511	< 2	6	18	31	50	2
54-56 cm	44.3	0.82	0.06	0.05	0.17	10.76	0.88	0.079	1.43	541	< 2	5	16	29	50	2
56-58 cm	44.5	0.77	0.06	0.04	0.17	12.97	0.89	0.085	1.45	592	< 2	5	16	28	50	2
58-60 cm	44.3	0.82	0.06	0.05	0.17	12.70	0.94	0.083	1.55	610	< 2	6	18	29	40	2

TableB-10: (cont'd).

ELEMENT	Ni ppm	Pb ppm	Sr ppm	Zn ppm	Ag ppm	Au ppm	U ppm	Th ppm	Cd ppm	Sb ppm	Bi ppm	La ppm	Ba ppm	B ppm	V ppm	W ppm
DEPTH																
D.L.	1	3	1	1	0.3	2	5	2	0.2	2	2	1	1	3	1	2
% Error ±	3	6	3	2	0.0	n/a	34	22	7.9	11.3	n/a	10	2	5	1	n/a
0-2 cm	17	141	68	333	<.3	<2	8	4	2.3	<2	<2	17	134	11	31	<2
2-4 cm	17	124	64	501	0.4	<2	6	3	2.4	<2	<2	17	130	12	32	<2
4-6 cm	17	107	56	417	0.3	<2	<5	3	2.5	<2	<2	18	124	12	33	<2
6-8 cm	14	72	43	264	0.3	<2	<5	3	1.6	<2	<2	18	106	14	29	<2
8-10 cm	13	46	40	343	<.3	<2	<5	2	1.3	<2	<2	16	96	15	27	<2
10-12 cm	13	38	40	417	<.3	<2	5	3	1.0	2	<2	17	98	16	28	<2
12-14 cm	12	15	51	241	<.3	<2	<5	2	0.7	<2	<2	15	98	16	26	<2
14-16 cm	11	14	54	328	<.3	<2	5	2	0.8	<2	<2	14	98	15	24	<2
16-18 cm	11	9	65	242	<.3	<2	8	2	0.5	<2	<2	13	106	14	25	<2
18-20 cm	11	10	69	377	0.3	<2	7	2	0.7	<2	3	12	107	13	24	<2
20-22 cm	11	12	72	246	<.3	<2	6	<2	0.7	<2	<2	11	109	12	23	<2
22-24 cm	10	5	80	229	0.4	<2	6	2	0.5	<2	<2	12	114	10	23	<2
24-26 cm	10	6	79	209	0.3	<2	9	2	0.6	<2	<2	11	112	10	22	<2
26-28 cm	10	6	81	178	0.3	<2	5	2	0.5	<2	<2	12	114	10	22	<2
28-30 cm	10	7	75	322	0.3	<2	7	<2	0.6	<2	<2	12	109	10	21	<2
30-32 cm	11	9	74	183	0.3	<2	<5	2	0.7	2	<2	13	112	12	23	<2
32-34 cm	11	4	70	207	0.5	<2	6	2	0.8	<2	<2	14	111	13	23	<2
34-36 cm	12	6	60	252	<.3	<2	<5	3	0.4	<2	<2	14	103	12	24	<2
36-38 cm	11	8	60	291	<.3	<2	6	2	0.7	<2	<2	14	106	13	24	<2
38-40 cm	11	5	61	231	<.3	<2	<5	2	0.5	2	<2	14	106	12	24	<2
40-42 cm	12	4	67	270	<.3	<2	<5	<2	0.8	<2	<2	14	110	13	24	<2
42-44 cm	10	6	65	233	<.3	<2	5	2	0.6	<2	<2	13	108	12	23	<2
44-46 cm	13	6	68	201	0.4	<2	14	4	0.3	2	<2	16	115	14	26	<2
46-48 cm	13	3	63	305	<.3	<2	11	3	0.3	<2	<2	16	115	15	28	<2
48-50 cm	13	3	59	227	0.3	<2	11	3	0.5	<2	<2	16	108	14	27	<2
50-52 cm	11	5	48	184	<.3	<2	12	2	0.5	<2	<2	13	90	11	22	<2
52-54 cm	14	6	59	244	<.3	<2	11	3	0.3	<2	<2	18	112	15	28	<2
54-56 cm	12	<3	68	222	0.4	<2	14	3	0.4	<2	<2	15	113	14	26	<2
56-58 cm	11	<3	75	221	0.3	<2	13	3	0.2	<2	<2	13	117	12	25	<2
58-60 cm	13	3	76	320	<.3	<2	11	3	0.3	<2	<2	15	120	13	26	<2

Table B-11: Lake sediment geochemistry for Little Green Lake.

ELEMENT DEPTH	LOI %	Al %	Ti %	Na %	K %	Ca %	Mg %	P %	Fe %	Mn ppm	As ppm	Co ppm	Cr ppm	Cu ppm	Hg ppb	Mo ppm
D.L.	0.10	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	2	2	1	1	1	10	1
% Error ±	0.2	2.34	0.00	3.13	12.71	2.06	4.63	3.595	2.67	3	3	2	9	3	10	3
0-2 cm	46.7	0.66	0.05	0.02	0.12	18.81	0.61	0.058	1.19	842	26	5	11	45	130	6
2-4 cm	49.4	0.65	0.06	0.03	0.13	18.14	0.65	0.076	1.40	813	35	4	10	62	140	9
4-6 cm	51.8	0.54	0.05	0.03	0.11	16.79	0.56	0.117	1.37	752	43	3	8	67	125	9
6-8 cm	53.0	0.56	0.05	0.03	0.11	16.94	0.56	0.101	1.42	745	47	4	9	69	110	10
8-10 cm	52.3	0.55	0.05	0.03	0.10	18.00	0.55	0.068	1.60	747	52	4	8	67	105	10
10-12 cm	49.6	0.63	0.06	0.03	0.12	16.38	0.58	0.075	1.51	642	47	4	10	61	115	9
12-14 cm	49.8	0.69	0.05	0.03	0.14	14.22	0.66	0.069	1.65	654	57	4	11	68	85	10
14-16 cm	49.9	0.67	0.06	0.03	0.15	14.97	0.67	0.067	1.57	683	56	4	11	69	100	11
16-18 cm	50.8	0.66	0.06	0.04	0.15	15.73	0.69	0.084	1.71	724	62	5	11	74	95	13
18-20 cm	49.2	0.81	0.06	0.04	0.19	13.40	0.82	0.103	1.64	750	54	5	13	76	110	13
20-22 cm	51.0	0.65	0.06	0.04	0.14	14.61	0.68	0.087	1.59	653	62	4	11	74	105	13
22-24 cm	54.3	0.59	0.05	0.03	0.12	13.58	0.62	0.075	1.69	567	69	4	9	79	105	12
24-26 cm	53.1	0.58	0.05	0.04	0.12	14.27	0.60	0.095	1.74	605	80	4	9	81	95	13
26-28 cm	52.9	0.52	0.04	0.03	0.10	16.83	0.53	0.086	1.39	578	67	3	9	73	80	12
28-30 cm	54.9	0.49	0.04	0.02	0.09	16.43	0.47	0.073	1.38	568	70	3	7	72	80	14
30-32 cm	56.4	0.51	0.04	0.03	0.10	13.76	0.51	0.168	1.63	601	77	4	8	80	90	15
32-34 cm	55.9	0.55	0.05	0.03	0.12	14.57	0.58	0.079	1.68	569	73	4	9	80	90	15
34-36 cm	57.2	0.48	0.04	0.03	0.10	15.44	0.53	0.067	1.54	511	64	4	8	78	85	15
36-38 cm	55.0	0.45	0.04	0.03	0.09	18.72	0.51	0.060	1.53	532	63	4	7	74	125	15
38-40 cm	51.6	0.43	0.04	0.03	0.08	24.28	0.50	0.123	1.46	641	59	3	6	70	85	13
40-42 cm	55.9	0.64	0.05	0.04	0.12	11.25	0.56	0.078	2.22	496	99	5	9	105	110	22
42-44 cm	54.3	0.59	0.05	0.04	0.12	12.93	0.63	0.100	1.95	505	97	4	10	101	110	21
44-46 cm	55.6	0.72	0.07	0.04	0.15	9.97	0.74	0.098	2.35	511	108	5	12	119	120	24
46-48 cm	61.1	0.67	0.06	0.03	0.12	6.34	0.60	0.085	2.73	463	136	5	11	124	140	28
48-50 cm	57.8	0.58	0.05	0.03	0.11	13.02	0.59	0.088	2.16	525	109	5	10	97	120	22
50-52 cm	57.7	0.51	0.04	0.03	0.09	13.98	0.51	0.081	1.68	471	88	4	8	88	100	22
52-54 cm	53.5	0.32	0.02	0.02	0.05	24.48	0.42	0.049	0.97	464	49	3	5	55	70	12
54-56 cm	56.4	0.27	0.02	0.02	0.05	22.82	0.36	0.040	0.77	438	35	2	4	41	55	9
56-58 cm	50.1	0.28	0.02	0.02	0.06	29.12	0.42	0.043	0.81	565	37	2	4	38	45	8
58-60 cm	49.7	0.26	0.02	0.02	0.05	28.39	0.40	0.038	0.84	607	43	2	4	32	45	8
60-62 cm	53.3	0.40	0.03	0.02	0.07	19.76	0.43	0.062	1.30	540	72	3	6	57	85	15
62-64 cm	50.5	0.31	0.03	0.02	0.06	27.21	0.42	0.068	0.92	652	50	3	5	40	60	8
64-66 cm	48.4	0.16	0.02	0.02	0.05	32.28	0.37	0.061	0.47	770	36	1	1	26	65	6
66-68 cm	59.9	0.10	0.02	0.01	0.03	25.97	0.28	0.027	0.37	599	29	< 1	< 1	20	35	3
68-70 cm	49.0	0.27	0.02	0.02	0.06	28.91	0.39	0.038	0.79	688	46	1	1	34	60	7
70-72 cm	51.8	0.30	0.02	0.02	0.07	26.65	0.39	0.042	1.10	594	52	< 1	2	46	80	9

Table B-11: (cont'd).

ELEMENT DEPTH	Ni ppm	Pb ppm	Sr ppm	Zn ppm	Ag ppm	Au ppm	U ppm	Th ppm	Cd ppm	Sb ppm	Bi ppm	La ppm	Ba ppm	B ppm	V ppm	W ppm
D.L.	1	3	1	1	0.3	2	5	2	0.2	2	2	1	1	3	1	2
% Error ±	3	6	3	2	0.0	n/a	34	22	7.9	11.3	n/a	10	2	5	1	n/a
0-2 cm	15	110	89	405	0.4	<2	6	<2	2.7	10	3	7	110	9	23	2
2-4 cm	16	55	91	391	0.4	<2	7	<2	1.8	12	<2	9	115	11	22	<2
4-6 cm	14	22	87	363	<3	<2	5	2	1.2	9	3	8	108	11	18	<2
6-8 cm	15	16	87	351	0.4	<2	<5	<2	1.1	10	<2	7	111	11	19	<2
8-10 cm	15	16	91	373	<3	<2	<5	<2	1.0	10	<2	6	113	9	20	<2
10-12 cm	15	9	84	321	<3	<2	5	<2	0.9	12	<2	9	117	10	21	<2
12-14 cm	18	8	83	351	<3	<2	<5	<2	1.1	12	<2	10	122	11	23	<2
14-16 cm	17	18	87	332	<3	<2	5	2	1.2	14	<2	11	121	11	24	<2
16-18 cm	18	21	94	335	0.3	<2	<5	<2	1.2	13	<2	11	124	12	25	<2
18-20 cm	20	20	89	593	0.3	<2	<5	2	1.2	13	<2	14	130	11	27	<2
20-22 cm	18	15	89	392	<3	<2	5	<2	1.3	11	<2	11	118	10	24	<2
22-24 cm	17	11	82	437	<3	<2	<5	<2	1.1	13	<2	10	109	11	22	<2
24-26 cm	18	11	85	403	0.3	<2	<5	<2	1.4	16	<2	10	112	11	23	<2
26-28 cm	15	7	85	416	0.3	<2	<5	2	1.1	13	<2	8	110	10	20	<2
28-30 cm	15	8	82	386	0.3	<2	<5	<2	1.3	13	<2	6	103	11	21	<2
30-32 cm	18	5	75	431	0.4	<2	6	<2	1.3	14	<2	9	107	12	21	<2
32-34 cm	18	7	82	450	<3	<2	<5	<2	1.3	12	<2	8	109	12	22	<2
34-36 cm	18	7	79	465	0.3	<2	6	<2	1.3	14	2	8	98	11	19	<2
36-38 cm	18	4	88	443	<3	<2	5	<2	1.5	15	<2	7	102	11	18	<2
38-40 cm	17	4	106	577	<3	<2	<5	<2	1.0	13	<2	6	116	9	16	<2
40-42 cm	26	7	69	664	<3	<2	7	2	1.5	18	<2	9	98	15	25	<2
42-44 cm	24	7	77	561	0.3	<2	7	2	1.6	18	<2	12	105	14	23	<2
44-46 cm	28	7	68	577	0.4	<2	7	2	1.9	22	<2	13	108	16	29	<2
46-48 cm	29	6	52	513	0.3	<2	10	<2	1.8	21	<2	12	89	17	29	<2
48-50 cm	24	4	81	464	0.4	<2	6	2	1.4	16	<2	11	102	14	24	<2
50-52 cm	22	5	80	426	0.3	<2	<5	<2	1.3	16	<2	8	101	14	20	<2
52-54 cm	13	<3	102	289	<3	<2	<5	<2	0.9	9	<2	4	99	8	13	<2
54-56 cm	12	3	95	227	0.4	<2	<5	<2	0.7	8	<2	2	89	7	10	<2
56-58 cm	10	<3	108	240	0.3	<2	<5	<2	0.9	8	<2	3	102	8	11	<2
58-60 cm	10	<3	102	240	<3	<2	<5	<2	0.7	7	<2	2	96	6	11	<2
60-62 cm	13	3	89	325	0.3	<2	<5	<2	1.2	13	<2	5	96	9	18	<2
62-64 cm	12	3	109	291	0.3	<2	<5	2	0.6	9	<2	3	107	8	12	<2
64-66 cm	8	3	110	217	<3	<2	6	<2	<2	9	<2	<1	100	5	7	3
66-68 cm	3	<3	89	137	<3	<2	<5	<2	<2	7	<2	<1	77	4	5	2
68-70 cm	7	<3	103	260	<3	<2	<5	<2	<2	9	<2	<1	99	6	9	<2
70-72 cm	9	<3	100	320	<3	<2	9	<2	<2	10	<2	2	99	7	11	<2

Table B-12: Lake sediment geochemistry for basin 1 of James Lake.

ELEMENT DEPTH	LOI %	Al %	Ti %	Na %	K %	Ca %	Mg %	P %	Fe %	Mn ppm	Co ppm	Cr ppm	Cu ppm	Hg ppb	Mo ppm	As ppm
D.L.	0.10	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	2	1	1	1	10	1	2
% Error ±	0.2	2.34	0.00	3.13	12.71	2.06	4.63	3.595	2.67	3	2	9	3	10	3	3
0-2 cm	57.2	0.47	0.02	0.01	0.05	5.10	0.18	0.087	2.91	968	7	6	65	510	15	47
2-4 cm	58.3	0.44	0.02	0.01	0.05	4.31	0.17	0.087	2.4	854	5	6	67	530	13	43
4-6 cm	63.7	0.42	0.02	0.02	0.04	4.30	0.15	0.083	2.33	834	5	5	80	650	15	30
6-8 cm	62.4	0.37	0.02	0.01	0.04	6.23	0.14	0.076	2.11	758	3	4	80	655	14	28
8-10 cm	62.1	0.30	0.01	0.01	0.02	8.11	0.12	0.065	1.41	647	2	3	72	455	12	23
10-12 cm	60.5	0.25	0.01	0.02	0.03	11.47	0.11	0.065	1.18	597	1	2	71	320	13	25
12-14 cm	59.8	0.29	0.01	0.01	0.03	10.74	0.12	0.069	1.25	571	2	3	72	320	15	25
14-16 cm	58.2	0.24	0.01	0.01	0.03	12.05	0.10	0.058	1.32	498	1	2	74	360	16	23
16-18 cm	55.0	0.25	0.01	0.01	0.02	17.54	0.13	0.059	1.25	528	1	1	67	210	15	25
18-20 cm	53.8	0.19	0.01	0.01	0.01	19.72	0.10	0.055	1.09	545	1	2	53	185	11	24
20-22 cm	53.9	0.13	< 0.1	0.01	0.02	16.74	0.08	0.053	1.16	487	1	< 1	59	210	12	27
22-24 cm	53.4	0.14	< 0.1	0.02	0.02	19.74	0.09	0.059	1.23	588	2	< 1	61	195	17	43
24-26 cm	54.3	0.17	0.01	0.02	0.02	17.54	0.10	0.06	1.52	588	3	1	65	220	19	52
26-28 cm	55.8	0.15	0.01	0.01	0.02	13.95	0.09	0.061	1.84	515	2	1	67	290	17	40
28-30 cm	55.0	0.15	0.01	0.02	0.02	15.65	0.08	0.06	2.02	521	2	1	70	240	16	39
30-32 cm	56.7	0.17	0.01	0.01	0.01	16.40	0.09	0.058	1.85	548	3	1	63	320	17	46
32-34 cm	56.8	0.18	0.01	0.01	0.02	13.97	0.10	0.062	1.99	633	2	2	76	360	19	42
34-36 cm	55.1	0.28	0.02	0.02	0.03	13.52	0.15	0.07	2.19	787	3	3	79	395	19	52
36-38 cm	57.1	0.31	0.02	0.02	0.03	14.19	0.16	0.069	2.06	634	3	4	78	405	17	49
38-40 cm	59.7	0.32	0.02	0.02	0.03	12.28	0.18	0.066	1.82	639	2	5	64	380	13	51
40-42 cm	54.1	0.34	0.02	0.01	0.03	15.20	0.20	0.068	1.94	757	2	6	56	320	12	52
42-44 cm	51.4	0.29	0.02	0.02	0.03	16.93	0.18	0.066	2.11	931	2	4	58	320	14	74
44-46 cm	52.1	0.43	0.03	0.01	0.03	12.67	0.26	0.072	2.43	1066	4	8	57	400	12	96
46-48 cm	52.8	0.38	0.02	0.02	0.04	16.23	0.23	0.073	2.85	2008	4	6	58	450	11	137
48-50 cm	51.6	0.35	0.02	0.02	0.03	13.33	0.21	0.092	5.62	6936	4	6	57	410	8	157
50-52 cm	52.9	0.31	0.02	0.02	0.03	10.56	0.19	0.083	4.56	5061	7	6	49	375	9	163
52-54 cm	52.8	0.48	0.04	0.02	0.04	12.13	0.30	0.067	3.00	1976	8	9	54	375	15	155
54-56 cm	51.1	0.38	0.03	0.02	0.03	14.31	0.24	0.072	2.49	1480	6	7	55	375	13	126
56-58 cm	50.6	0.26	0.01	0.02	0.03	14.72	0.17	0.074	3.51	2935	6	5	58	125	15	151
58-60 cm	50.1	0.27	0.01	0.02	0.03	14.60	0.19	0.067	3.33	3880	5	5	53	240	14	177
60-62 cm	49.5	0.38	0.02	0.02	0.02	12.46	0.24	0.075	4.06	3135	8	7	57	235	18	193

Table B-12: (cont'd).

ELEMENT DEPTH	Ni ppm	Pb ppm	Sr ppm	Zn ppm	Ag ppm	Au ppm	U ppm	Th ppm	Cd ppm	Sb ppm	Bi ppm	La ppm	Ba ppm	B ppm	V ppm	W ppm
D.L.	1	3	1	1	0.3	2	5	2	0.2	2	2	1	1	3	1	2
% Error ±	3	6	3	2	0.0	n/a	34	22	7.9	11.3	n/a	10	2	5	1	n/a
0-2 cm	18	148	41	568	0.3	<2	<5	<2	2.1	12	2	10	44	12	13	<2
2-4 cm	15	109	38	541	0.4	<2	<5	<2	1.6	8	<2	10	46	13	11	<2
4-6 cm	19	90	40	717	<3	<2	<5	<2	1.7	10	<2	11	36	15	10	<2
6-8 cm	19	53	54	560	0.3	<2	<5	<2	1.3	10	<2	11	60	15	8	<2
8-10 cm	17	30	66	561	<3	<2	<5	<2	1.0	12	<2	9	119	14	7	<2
10-12 cm	17	17	85	432	<3	<2	<5	<2	0.9	9	<2	9	144	13	5	<2
12-14 cm	16	21	84	442	<3	<2	<5	<2	0.9	10	<2	9	143	16	6	<2
14-16 cm	18	8	92	387	<3	<2	<5	<2	1.0	12	<2	10	114	13	5	<2
16-18 cm	15	10	121	329	<3	<2	<5	<2	0.8	11	<2	9	170	12	6	<2
18-20 cm	13	8	130	325	<3	<2	<5	<2	0.8	7	<2	7	177	9	5	<2
20-22 cm	15	5	116	324	<3	<2	<5	<2	0.5	9	<2	7	160	9	4	<2
22-24 cm	17	9	130	366	<3	<2	<5	<2	0.7	12	<2	8	171	10	5	<2
24-26 cm	20	14	122	387	<3	<2	<5	<2	0.6	10	<2	10	158	12	7	<2
26-28 cm	19	10	106	358	<3	<2	<5	<2	0.7	12	<2	9	98	11	6	<2
28-30 cm	22	10	113	430	<3	<2	<5	<2	0.8	12	<2	9	108	11	6	<2
30-32 cm	20	13	109	403	<3	<2	<5	<2	1.0	14	<2	10	135	10	8	<2
32-34 cm	22	11	106	403	<3	<2	<5	<2	1.3	13	<2	12	95	11	8	<2
34-36 cm	21	13	112	514	<3	<2	<5	<2	0.8	15	<2	15	90	12	11	<2
36-38 cm	18	11	105	545	0.3	<2	<5	<2	1.0	11	<2	14	98	12	12	<2
38-40 cm	17	9	96	469	<3	<2	<5	<2	1.8	8	<2	12	105	11	14	<2
40-42 cm	16	9	105	345	<3	<2	<5	<2	0.5	10	<2	12	124	10	13	<2
42-44 cm	15	12	112	349	0.3	<2	<5	<2	0.3	14	<2	13	113	10	12	<2
44-46 cm	17	18	102	396	0.4	<2	<5	<2	0.6	12	<2	13	100	10	24	<2
46-48 cm	14	22	115	470	0.3	<2	<5	<2	<2	11	<2	14	111	10	20	<2
48-50 cm	14	19	102	381	<3	<2	<5	<2	<2	11	<2	12	107	8	22	<2
50-52 cm	13	17	98	331	<3	<2	<5	<2	<2	10	<2	13	87	7	23	<2
52-54 cm	17	17	97	389	<3	<2	<5	<2	0.3	13	<2	13	101	9	28	<2
54-56 cm	15	13	114	351	0.4	<2	<5	<2	0.5	11	<2	15	136	11	21	<2
56-58 cm	13	13	136	376	0.4	<2	<5	<2	1.3	12	<2	17	126	11	19	<2
58-60 cm	15	19	127	315	0.4	<2	<5	<2	1.2	11	<2	16	125	10	19	<2
60-62 cm	18	20	115	429	0.7	<2	<5	<2	1.8	10	<2	18	84	10	27	<2

Table B-13: Lake sediment geochemistry for basin 2 of James Lake.

ELEMENT DEPTH	LOI %	Al %	Ti %	Na %	K %	Ca %	Mg %	P %	Fe %	Mn ppm	As ppm	Co ppm	Cr ppm	Cu ppm	Hg ppb	Mo ppm
D.L.	0.10	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	2	2	1	1	1	10	1
% Error ±	0.2	2.34	0.00	3.13	12.71	2.06	4.63	3.595	2.67	3	3	2	9	3	3	3
0-2 cm	65.10	0.56	0.02	0.02	0.05	7.43	0.3	0.091	1.62	865	25	8	10	54	235	17
2-4 cm	59.00	0.69	0.03	0.02	0.06	8.95	0.36	0.086	2.07	1006	33	10	12	61	290	20
4-6 cm	58.10	0.70	0.03	0.02	0.05	9.39	0.37	0.081	2.37	1005	36	10	13	62	310	19
6-8 cm	67.80	0.53	0.02	0.01	0.04	7.28	0.27	0.072	1.69	760	25	7	9	48	230	16
8-10 cm	78.00	0.32	0.01	0.01	0.04	5.39	0.17	0.056	0.86	494	15	4	5	32	150	9
10-12 cm	78.50	0.35	0.01	0.02	0.04	4.79	0.18	0.065	0.89	544	17	4	6	41	170	13
12-14 cm	73.40	0.54	0.02	0.01	0.05	4.15	0.23	0.083	1.54	717	32	7	9	73	340	25
14-16 cm	79.80	0.44	0.01	0.02	0.04	2.90	0.17	0.082	1.18	713	28	7	7	84	440	18
16-18 cm	81.30	0.42	0.01	0.02	0.04	2.66	0.17	0.081	1.08	692	25	6	7	83	425	16
18-20 cm	76.60	0.40	0.01	0.01	0.03	2.23	0.16	0.086	0.89	584	23	5	6	82	415	16
20-22 cm	69.20	0.44	0.01	0.02	0.04	2.18	0.17	0.096	0.83	538	23	4	6	90	425	18
22-24 cm	73.90	0.42	0.01	0.02	0.04	2.18	0.18	0.088	0.86	512	23	4	6	105	510	19
24-26 cm	75.00	0.43	0.01	0.02	0.03	2.51	0.19	0.076	1.02	501	22	4	6	110	455	22
26-28 cm	73.00	0.45	0.02	0.03	0.04	3.47	0.20	0.069	1.11	520	22	4	7	102	420	18
28-30 cm	71.10	0.45	0.02	0.02	0.03	4.32	0.21	0.067	1.01	508	19	4	8	98	415	18
30-32 cm	69.70	0.42	0.02	0.02	0.03	4.78	0.19	0.066	0.98	499	22	4	6	97	385	18
32-34 cm	68.50	0.39	0.01	0.02	0.03	7.07	0.19	0.063	0.95	531	22	4	6	96	305	18
34-36 cm	69.00	0.36	0.01	0.02	0.03	6.18	0.17	0.064	0.89	484	20	4	5	94	350	17
36-38 cm	66.60	0.41	0.01	0.02	0.03	6.64	0.19	0.069	0.91	508	21	4	7	88	295	20
38-40 cm	67.50	0.17	<.01	0.01	0.02	3.59	0.08	0.031	0.37	223	10	1	2	43	350	9
40-42 cm	70.60	0.33	0.01	0.02	0.03	5.39	0.13	0.061	0.77	417	21	3	4	92	350	20
42-44 cm	68.30	0.36	0.01	0.02	0.03	6.98	0.16	0.06	0.74	449	22	3	5	101	350	22
44-46 cm	64.80	0.46	0.01	0.02	0.04	6.84	0.20	0.058	1.23	478	22	4	7	105	420	19
46-48 cm	61.30	0.47	0.01	0.02	0.03	9.97	0.22	0.06	1.31	492	21	4	7	98	305	23
48-50 cm	68.80	0.37	0.01	0.02	0.02	9.71	0.22	0.058	1.00	443	17	3	6	72	180	18
50-52 cm	66.00	0.34	0.01	0.02	0.03	10.41	0.20	0.058	1.18	488	20	3	6	90	230	21
52-54 cm	62.00	0.46	0.01	0.02	0.04	8.98	0.22	0.061	2.14	518	31	5	7	108	270	22
54-56 cm	58.20	0.39	0.01	0.02	0.04	13.06	0.21	0.055	1.70	534	29	5	6	82	200	22
56-58 cm	58.20	0.33	0.01	0.03	0.05	13.43	0.18	0.057	1.59	541	28	5	5	83	210	24
58-60 cm	58.90	0.30	<.01	0.02	0.03	10.95	0.15	0.051	1.57	485	26	3	5	94	275	19
60-62 cm	58.40	0.27	<.01	0.02	0.03	12.45	0.15	0.052	1.64	496	27	3	5	93	235	23
62-64 cm	57.20	0.28	0.01	0.02	0.02	12.67	0.15	0.051	1.82	498	32	4	5	92	235	25
64-66 cm	58.90	0.32	0.01	0.02	0.02	11.93	0.17	0.054	2.06	534	42	5	5	93	225	29

Table B-13: (cont'd).

ELEMENT DEPTH	Ni ppm	Pb ppm	Sr ppm	Zn ppm	Ag ppm	Au ppm	U ppm	Th ppm	Cd ppm	Sb ppm	Bi ppm	La ppm	Ba ppm	B ppm	V ppm	W ppm
D.L.	1	3	1	1	0.3	2	5	2	0.2	2	2	1	1	3	1	2
% Error ±	3	6	3	2	0.0	n/a	34	22	7.9	11.3	n/a	10	2	5	1	n/a
0-2 cm	16	130	63	531	0.4	<2	<5	<2	3.0	11	<2	8	93	11	24	<2
2-4 cm	19	173	72	615	0.6	<2	<5	<2	3.6	14	<2	10	106	12	29	<2
4-6 cm	20	188	75	657	0.8	<2	<5	<2	3.5	13	<2	11	97	12	28	<2
6-8 cm	15	137	62	458	0.5	<2	<5	<2	3.3	10	<2	7	97	10	21	<2
8-10 cm	8	78	49	412	0.3	<2	<5	<2	3.0	5	<2	4	73	8	12	<2
10-12 cm	11	88	46	533	<3	<2	<5	<2	3.9	6	<2	6	83	12	13	<2
12-14 cm	17	119	46	541	0.4	<2	<5	<2	4.3	14	<2	11	100	15	18	<2
14-16 cm	17	64	41	656	0.3	<2	<5	<2	3.2	11	<2	13	102	20	14	<2
16-18 cm	16	61	39	714	0.3	<2	<5	<2	3.0	14	<2	13	97	20	14	<2
18-20 cm	13	51	36	504	<3	<2	<5	<2	2.6	14	<2	12	100	20	12	<2
20-22 cm	15	54	35	662	0.4	<2	<5	<2	2.7	16	<2	12	91	20	11	<2
22-24 cm	20	34	33	640	<3	<2	<5	<2	3.1	15	<2	12	94	19	10	<2
24-26 cm	24	22	34	578	<3	<2	<5	<2	2.8	18	<2	14	100	21	12	<2
26-28 cm	23	18	42	621	<3	<2	<5	<2	2.7	16	<2	15	110	20	12	<2
28-30 cm	22	14	50	558	<3	<2	<5	<2	2.4	16	<2	14	128	18	12	<2
30-32 cm	22	10	50	533	0.3	<2	<5	<2	2.6	15	<2	14	124	18	12	<2
32-34 cm	22	8	69	678	<3	<2	<5	<2	2.4	13	<2	12	123	19	11	<2
34-36 cm	23	8	61	622	0.3	<2	<5	<2	2.5	13	<2	12	122	17	10	<2
36-38 cm	23	8	68	481	<3	<2	<5	<2	2.5	16	<2	12	138	17	11	<2
38-40 cm	11	3	34	253	<3	<2	<5	<2	1.3	8	<2	5	68	8	5	<2
40-42 cm	21	6	57	702	<3	<2	<5	<2	2.8	12	<2	12	124	17	8	<2
42-44 cm	23	6	68	595	<3	<2	<5	<2	3.2	15	<2	14	139	17	9	<2
44-46 cm	26	9	65	718	0.3	<2	<5	<2	3.2	17	<2	15	143	17	12	<2
46-48 cm	20	9	89	696	<3	<2	7	<2	2.8	10	<2	13	170	15	12	<2
48-50 cm	15	7	88	543	<3	<2	<5	<2	4.2	10	<2	9	171	13	11	<2
50-52 cm	18	7	87	742	<3	<2	9	<2	4.2	15	<2	10	152	14	10	<2
52-54 cm	23	8	80	717	<3	<2	5	<2	3.0	18	<2	12	143	16	14	<2
54-56 cm	20	8	110	587	<3	<2	6	<2	2.7	13	<2	11	191	13	13	<2
56-58 cm	17	5	113	555	<3	<2	8	<2	2.4	13	<2	10	185	12	11	<2
58-60 cm	21	7	90	633	<3	<2	6	<2	2.3	15	<2	10	151	13	9	<2
60-62 cm	20	9	102	615	<3	<2	8	<2	2.4	17	<2	9	162	13	10	<2
62-64 cm	22	6	101	600	<3	<2	5	<2	2.5	15	<2	10	160	13	10	<2
64-66 cm	23	10	96	648	0.3	<2	8	<2	2.3	16	<2	12	163	14	12	<2

APPENDIX C

Table C-1: Selected sample depths and corresponding field numbers for diatom analysis in James Lake.

Sample Depth (cm)	JAMES LAKE	
	Basin 1	Basin 2
0-2	031C9502-001	031C9503-001
2-4		
4-6		
6-8		
8-10	031C9502-005	031C9503-005
10-12		
12-14		
14-16		
16-18		031C9503-009
18-20	031C9502-010	
20-22		
22-24		
24-26		
26-28		
28-30	031C9502-015	031C9503-015
30-32		
32-34		
34-36		
36-38		031C9503-019
38-40	031C9502-020	
42-44		
44-46		
46-48		
48-50	031C9502-025	031C9503-025
50-52		
52-54		
54-56		
56-58		031C9503-029
58-60	031C9502-031	

Table C-2: Abbreviated taxonomy for all species and strains in study lakes.

ABBREVIATED TAXONOMY

Arcella discoides Ehrenberg 1843
Arcella vulgaris Ehrenberg 1830 "angulosa" Perty 1852
Arcella vulgaris Ehrenberg 1830 "vulgaris" Ehrenberg 1830
Arcella dentata Ehrenberg 1832
Bullinularia indica (Penard)= *Bulinella indica* Penard 1907
Centropyxis aculeata (Ehrenberg)= *Arcella aculeata* Ehrenberg 1832 "aculeata" (Ehrenberg)= *Arcella aculeata*
Centropyxis aculeata (Ehrenberg)= *Arcella aculeata* Ehrenberg 1832 "discoides" Penard 1890
Centropyxis aculeata (Ehrenberg)= *Arcella aculeata* Ehrenberg 1832 "ecornis" (Ehrenberg)= *Arcella ecornis*
Centropyxis constricta (Ehrenberg)= *Arcella constricta* Ehrenberg 1843 "constricta" (Ehrenberg)= *Arcella*
Centropyxis constricta (Ehrenberg)= *Arcella constricta* Ehrenberg 1843 "cassis" Deflandre 1929
Centropyxis constricta (Ehrenberg)= *Arcella constricta* Ehrenberg 1843 "platystoma" (Penard)= *Diffugia*
Centropyxis constricta (Ehrenberg)= *Arcella constricta* Ehrenberg 1843 "spinifera" Playfair 1918
Cucurbitella corona (Wallich)= *Diffugia corona* Wallich 1864
Cucurbitella tricusps (Carter)= *Diffugia tricusps* Carter 1856 "gramen" (Penard)= *Diffugia gramen* Penard 1902
Cucurbitella tricusps (Carter)= *Diffugia tricusps* Carter 1856 "oviformis" (Cash)= *Diffugia oviformis* Cash 1909
Cucurbitella tricusps (Carter)= *Diffugia tricusps* Carter 1856 "achlora" (Penard)= *Diffugia achlora* Penard 1902
Cucurbitella tricusps (Carter)= *Diffugia tricusps* Carter 1856 "tuberculata" (Wallich)= *Diffugia tuberculata*
Cucurbitella tricusps (Carter)= *Diffugia tricusps* Carter 1856 "lobostoma" (Leidy)= *Diffugia lobostoma* Leidy
Cucurbitella tricusps (Carter)= *Diffugia tricusps* Carter 1856 "labiosa" (Wailes)= *Diffugia labiosa* Wailes 1919
Cyclopyxis kahli (Deflandre)= *Arcella kahli* Deflandre 1929
Diffugia ampullula Playfair 1918
Diffugia globulus (Ehrenberg)= *Arcella globulus* Ehrenberg 1848 "globulus" (Ehrenberg)= *Arcella globulus*
Diffugia globulus (Ehrenberg)= *Arcella globulus* Ehrenberg 1848 "globulosa" Dujardin 1837
Diffugia lanceolata Penard 1890
Diffugia lithophilia Penard 1902
Diffugia oblonga Ehrenberg 1832 "bacillifera" Penard 1890
Diffugia oblonga Ehrenberg 1832 "bryophila" Penard 1902
Diffugia oblonga Ehrenberg 1832 "cylindrus" Thomas 1953
Diffugia oblonga Ehrenberg 1832 "gassowskii" Ogden 1980
Diffugia oblonga Ehrenberg 1832 "lacustris" Penard 1899
Diffugia oblonga Ehrenberg 1832 "petricola" Cash 1909
Diffugia oblonga Ehrenberg 1832 "venusta" Penard 1902
Diffugia protaeiformis Lamarck 1816 "amorphalis" Cash and Hopkinson 1909
Diffugia protaeiformis Lamarck 1816 "bicornis" Penard 1890
Diffugia protaeiformis "elegans" Penard 1890
Diffugia protaeiformis Lamarck 1816 "smilion" Thomas 1953
Diffugia urceolata Carter 1864 "elongata" Penard 1905
Diffugia urceolata Carter 1864 "mica" Frenzel 1892
Diffugia urceolata Carter 1864 "urceolata" Carter 1864
Diffugia rotunda Ogden 1980
Diffugia viscidula Penard 1902
Euglypha acanthophora (Ehrenberg)= *Diffugia acanthophora* Ehrenberg 1841
Euglypha cashii Ogden 1980
Euglypha sp.1
Heleopera sphagni (Leidy)= *Diffugia sphagni* Leidy 1874
Lagenodiffugia vas (Leidy)= *Diffugia vas* Leidy 1874
Lesquereusia jurassica Schlimberger 1845
Lesquereusia spiralis (Ehrenberg)= *Diffugia spiralis* Ehrenberg 1840
Nebela collaris (Ehrenberg)= *Diffugia collaris* Ehrenberg 1848
Oopyxis sp.1
Pontigulasia elisa (Penard)= *Diffugia elisa* Penard 1893
Trinema enchelys (Ehrenberg)= *Euglypha enchelys* Ehrenberg 1838

Table C-3: Thecamoebian percent abundances for Ardoch Lake.

ARDOCH LAKE										
Sample number	04-01	04-02	04-03	04-04	04-05	04-10	04-15	04-20	04-25	04-30
Depth (cm)	0-2	2-4	4-6	6-8	8-10	18-20	28-30	38-40	48-50	58-60
Fractional split	1/16	1/8	1/8	1/8	1/8	1/8	1/8	1/8	1/16	1/16
Total specimens in split	490	678	558	879	682	1311	1494	717	894	496
Total specimens in 30 cc.	7872	5424	4448	7032	5456	10488	11936	5736	14304	7936
Total specimens in 1 cc.	262	181	148	234	182	350	398	191	477	265
<i>Arcella discoides</i>	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Arcella vulgaris</i> 'angulosa'	0.00	0.59	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00
<i>Arcella vulgaris</i> 'vulgaris'	2.86	2.36	1.79	0.68	0.59	0.00	0.40	0.00	0.00	0.00
<i>Bullinularia indica</i>	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis constricta</i> 'constricta'	0.82	1.77	2.15	0.34	0.29	0.23	0.40	0.56	0.45	0.45
<i>Centropyxis constricta</i> 'cassisi'	2.45	3.54	3.58	3.75	1.76	2.29	1.20	3.91	5.82	5.82
<i>Centropyxis constricta</i> 'spinifera'	1.22	0.00	1.43	1.71	1.17	0.00	1.00	1.67	3.58	3.58
<i>Centropyxis aculeata</i> 'aculeata'	5.31	7.37	7.53	9.22	15.25	5.72	9.84	16.74	13.42	13.42
<i>Centropyxis aculeata</i> 'aerophila'	6.53	0.00	1.08	1.71	0.59	0.23	0.40	0.56	0.89	0.89
<i>Centropyxis aculeata</i> 'discoides'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'ecornis'	0.00	2.95	2.51	3.07	4.40	2.52	1.41	1.67	2.01	2.01
<i>Cucurbitella tricusps</i> 'achlora'	44.90	51.62	50.90	47.78	47.80	67.05	73.49	47.98	36.91	36.91
<i>Cucurbitella tricusps</i> 'gramen'	0.00	0.00	0.00	0.34	0.59	0.46	0.20	0.00	0.00	0.00
<i>Cucurbitella tricusps</i> 'labiosa'	9.39	1.47	2.87	1.71	0.59	0.23	0.20	1.26	0.67	0.67
<i>Cucurbitella corona</i>	0.00	1.77	0.36	1.02	0.88	0.69	0.20	1.95	1.34	1.34
<i>Cyclopyxis kahli</i>	0.00	0.29	5.38	2.39	0.88	2.29	0.20	0.28	0.67	0.67
<i>Diffugia ampullula</i>	2.04	1.47	0.72	0.68	0.00	0.00	0.20	1.39	1.57	1.57
<i>Diffugia globulus</i> 'globulus'	2.86	2.06	1.79	1.71	1.47	0.92	1.00	1.12	0.89	0.89
<i>Diffugia globulus</i> 'globulosa'	0.41	0.00	0.00	0.68	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia lithophila</i>	2.45	2.06	1.79	2.05	1.47	0.69	0.60	1.12	3.36	3.36
<i>Diffugia oblonga</i> 'lacustris'	1.22	0.59	0.00	0.68	1.17	0.92	0.40	1.12	0.45	0.45
<i>Diffugia oblonga</i> 'vanusta'	0.00	2.95	1.79	2.39	3.23	1.60	1.41	1.67	8.72	8.72
<i>Diffugia oblonga</i> 'bryophila'	0.82	0.88	0.00	0.68	0.00	0.00	0.00	0.28	0.00	0.00
<i>Diffugia oblonga</i> 'gassowski'	0.00	0.00	0.00	0.68	2.35	0.23	0.00	0.28	0.89	0.89
<i>Diffugia oblonga</i> 'petricola'	1.22	0.59	0.00	0.34	0.88	0.23	1.00	0.56	0.67	0.67
<i>Diffugia protaeiformis</i> 'amorphalis'	0.41	0.59	0.36	1.02	0.59	0.23	0.00	0.84	0.00	0.00
<i>Diffugia protaeiformis</i> 'bicornis'	0.41	0.00	0.00	0.00	0.00	0.23	0.60	0.56	0.00	0.00
<i>Diffugia protaeiformis</i> 'elegans'	2.45	1.77	1.79	5.12	3.52	1.83	0.80	1.12	2.91	2.91
<i>Diffugia protaeiformis</i> 'smilion'	0.41	0.29	1.08	0.68	1.76	0.00	0.00	0.00	0.67	0.67
<i>Diffugia urceolata</i> 'urceolata'	1.22	2.06	1.08	2.05	0.88	0.69	0.60	3.07	4.03	4.03
<i>Diffugia urceolata</i> 'elongata'	0.82	2.06	1.43	0.68	2.05	1.60	0.80	3.07	2.68	2.68
<i>Diffugia urceolata</i> 'mica'	2.86	2.06	0.72	1.37	3.23	1.60	1.20	3.63	1.79	1.79
<i>Diffugia urceolata</i> 'minor'	0.82	0.00	0.00	0.00	0.00	0.69	0.00	0.56	0.00	0.00
<i>Diffugia rotunda</i>	0.00	0.00	0.00	0.34	0.00	0.23	0.00	0.00	0.00	0.00
<i>Diffugia viscidula</i>	1.63	0.88	0.00	0.00	0.00	3.20	0.80	2.51	3.13	3.13
<i>Euglypha cashii</i>	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00
<i>Heleopera sphagni</i>	0.82	2.65	2.87	1.37	1.17	2.75	0.20	0.00	0.89	0.89
<i>Lagendiffugia vas</i>	0.41	0.59	0.72	0.34	0.88	0.00	1.00	0.28	0.67	0.67
<i>Lesquereusia jurassica</i>	1.22	0.29	1.08	1.02	0.29	0.00	0.40	0.28	0.45	0.45
<i>Oopyxis</i> sp. 1	1.63	0.59	0.72	1.02	0.00	0.46	0.00	0.00	0.00	0.00
<i>Pontigulastia elisa</i>	0.00	0.59	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<45 µm size fraction	0.41	0.88	1.08	1.37	0.00	0.00	0.00	0.00	0.45	0.45

Table C-4: Standard errors for thecamoebian counts of Ardoch Lake.

ARDOCH LAKE										
Sample number	04-01	04-02	04-03	04-04	04-05	04-10	04-15	04-20	04-25	04-30
<i>Arcella discoides</i>	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Arcella vulgaris</i> 'angulosa'	0.00	0.13	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
<i>Arcella vulgaris</i> 'vulgaris'	0.61	0.59	0.40	0.18	0.13	0.00	0.14	0.00	0.00	0.00
<i>Bullinularia indica</i>	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis constricta</i> 'constricta'	0.16	0.44	0.49	0.08	0.05	0.07	0.14	0.13	0.12	0.25
<i>Centropyxis constricta</i> 'cassis'	0.52	0.90	0.83	1.10	0.44	0.81	0.45	1.03	1.72	0.34
<i>Centropyxis constricta</i> 'spinifera'	0.25	0.00	0.32	0.49	0.29	0.00	0.37	0.43	1.05	0.34
<i>Centropyxis aculeata</i> 'aculeata'	1.15	1.90	1.76	2.72	3.96	2.06	3.79	4.46	4.00	0.61
<i>Centropyxis aculeata</i> 'aerophila'	1.42	0.00	0.23	0.49	0.13	0.07	0.14	0.13	0.25	0.70
<i>Centropyxis aculeata</i> 'discoides'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'ecornis'	0.00	0.75	0.57	0.89	1.13	0.90	0.53	0.43	0.59	0.97
<i>Cucurbitella tricusps</i> 'achlora'	9.92	13.42	12.00	14.15	12.46	24.26	28.39	12.83	11.02	12.55
<i>Cucurbitella tricusps</i> 'gramen'	0.00	0.00	0.00	0.08	0.13	0.15	0.06	0.00	0.00	0.00
<i>Cucurbitella tricusps</i> 'labiosa'	2.06	0.36	0.66	0.49	0.13	0.07	0.06	0.32	0.18	0.16
<i>Cucurbitella corona</i>	0.00	0.44	0.06	0.29	0.21	0.23	0.06	0.50	0.38	0.25
<i>Cyclopyxis kahli</i>	0.00	0.05	1.25	0.69	0.21	0.81	0.06	0.05	0.18	0.06
<i>Diffugia ampullula</i>	0.43	0.36	0.15	0.18	0.00	0.00	0.06	0.35	0.45	0.00
<i>Diffugia globulus</i>	0.61	0.52	0.40	0.49	0.36	0.32	0.37	0.28	0.25	0.06
<i>Diffugia globulus</i> 'globulosa'	0.06	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia lithophila</i>	0.52	0.52	0.40	0.59	0.36	0.23	0.22	0.28	0.99	0.06
<i>Diffugia oblonga</i> 'lacustris'	0.25	0.13	0.00	0.18	0.29	0.32	0.14	0.28	0.12	0.00
<i>Diffugia oblonga</i> 'vanusta'	0.00	0.75	0.40	0.69	0.82	0.57	0.53	0.43	2.59	1.77
<i>Diffugia oblonga</i> 'bryophila'	0.16	0.21	0.00	0.18	0.00	0.00	0.00	0.05	0.00	0.43
<i>Diffugia oblonga</i> 'gassowskii'	0.00	0.00	0.00	0.18	0.59	0.07	0.00	0.05	0.25	0.06
<i>Diffugia oblonga</i> 'petricola'	0.25	0.13	0.00	0.08	0.21	0.07	0.37	0.13	0.18	0.00
<i>Diffugia protaeiformis</i> 'amorphalis'	0.06	0.13	0.06	0.29	0.13	0.07	0.00	0.20	0.00	0.00
<i>Diffugia protaeiformis</i> 'bicornis'	0.06	0.00	0.00	0.00	0.00	0.07	0.22	0.13	0.00	0.00
<i>Diffugia protaeiformis</i> 'elegans'	0.52	0.44	0.40	1.50	0.90	0.65	0.30	0.28	0.85	0.34
<i>Diffugia protaeiformis</i> 'smilion'	0.06	0.05	0.23	0.18	0.44	0.00	0.00	0.00	0.18	0.43
<i>Diffugia urceolata</i> 'elongata'	0.16	0.52	0.32	0.18	0.52	0.57	0.30	0.80	0.79	0.61
<i>Diffugia urceolata</i> 'mica'	0.61	0.52	0.15	0.39	0.82	0.57	0.45	0.95	0.52	0.88
<i>Diffugia urceolata</i> 'minor'	0.16	0.00	0.00	0.00	0.00	0.23	0.00	0.13	0.00	0.00
<i>Diffugia urceolata</i> 'urceolata'	0.25	0.52	0.23	0.59	0.21	0.23	0.22	0.80	1.19	0.25
<i>Diffugia rotunda</i>	0.00	0.00	0.00	0.08	0.00	0.07	0.00	0.00	0.00	0.00
<i>Diffugia viscidula</i>	0.34	0.21	0.00	0.00	0.00	1.15	0.30	0.65	0.92	0.43
<i>Euglypha cashii</i>	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
<i>Heleopera sphagni</i>	0.16	0.67	0.66	0.39	0.29	0.98	0.06	0.00	0.25	0.16
<i>Lagendiffugia vas</i>	0.06	0.13	0.15	0.08	0.21	0.00	0.37	0.05	0.18	0.00
<i>Lesquereusia jurassica</i>	0.25	0.05	0.23	0.29	0.05	0.00	0.14	0.05	0.12	0.00
<i>Oopyxis</i> sp. 1	0.34	0.13	0.15	0.29	0.00	0.15	0.00	0.00	0.00	0.00
<i>Pontigulastia elisa</i>	0.00	0.13	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<45 µm size fraction	0.06	0.21	0.23	0.39	0.00	0.00	0.00	0.00	0.12	0.06

Table C-5: Thecamoebian percentage abundances for Little Green Lake.

LITTLE GREEN LAKE											
Sample number	01-01	01-02	01-03	01-04	01-05	01-10	01-15	01-20	01-25	01-30	01-35
Depth (cm)	0-2	2-4	4-6	6-8	8-10	18-20	28-30	38-40	48-50	58-60	68-70
Split	1/4	5/32	1/16	1/8	1/8	1/8	9/32	17/64	1/8	1/8	1/8
Total number counted	304	292	318	414	448	420	379	304	5106	2625	4206
Total specimens in 30 cc.	1216	1869	4992	3312	3584	3360	1348	1145	40632	21000	33648
Total specimens in 1 cc.	41	62	166	110	119	112	45	38	1354	700	1122
<i>Arcella discoides</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.91	0.82	0.80	0.57
<i>Arcella vulgaris</i> 'angulosa'	0.00	0.00	0.00	0.00	0.00	0.00	1.58	1.32	0.00	0.34	0.00
<i>Arcella vulgaris</i> 'vulgaris'	0.00	0.00	0.00	0.00	0.89	0.00	8.44	5.92	0.00	1.60	1.14
<i>Centropyxis aculeata</i> 'aculeata'	18.42	12.33	25.79	30.92	14.29	14.29	26.39	24.01	0.71	2.86	5.85
<i>Centropyxis aculeata</i> 'aerophilia'	0.00	0.00	0.00	0.00	0.00	0.00	1.06	0.00	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'discoides'	4.61	13.01	9.43	9.66	4.46	9.52	2.64	0.99	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'ecornis'	11.84	8.22	19.50	21.26	13.39	21.90	6.33	4.61	0.65	0.69	1.14
<i>Centropyxis constricta</i> 'constricta'	1.97	7.53	12.58	3.86	8.93	5.71	6.33	3.29	0.12	0.00	0.86
<i>Centropyxis constricta</i> 'cassisi'	4.61	5.48	0.63	0.00	0.89	2.86	4.22	11.84	0.24	1.71	1.85
<i>Centropyxis constricta</i> 'platystoma'	0.00	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis constricta</i> 'spinifera'	0.00	1.37	0.63	0.00	0.00	0.00	0.53	1.97	0.12	0.80	0.29
<i>Cucurbitella corona</i>	0.00	0.68	0.63	0.00	0.00	0.00	0.00	0.99	0.00	0.00	0.14
<i>Cucurbitella tricuspidis</i> 'achlora'	18.42	4.79	0.63	0.00	2.68	7.62	2.64	0.99	92.19	87.77	83.31
<i>Cucurbitella tricuspidis</i> 'labiosa'	3.95	2.05	1.26	0.00	0.89	0.95	1.58	0.99	0.29	0.00	0.00
<i>Cucurbitella tricuspidis</i> 'tuberculata'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.93	0.00	0.00	0.00
<i>Cyclopyxis kahl</i>	3.29	3.42	2.52	1.93	1.79	3.81	3.69	0.33	0.00	0.00	0.43
<i>Diffugia globulus</i> 'globulus'	3.95	0.68	0.00	0.00	0.89	2.86	3.17	1.97	0.35	0.23	0.57
<i>Diffugia globulus</i> 'globulosa'	0.00	1.37	1.26	0.00	2.68	0.00	1.06	0.33	0.00	0.00	0.00
<i>Diffugia lanceolata</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.32	0.29	0.00	0.57
<i>Diffugia lithophilus</i>	5.26	4.79	5.03	0.00	1.79	1.90	2.11	2.30	0.88	0.34	0.14
<i>Diffugia urceolata</i> 'elongata'	3.95	4.11	2.52	1.93	3.57	5.71	0.53	2.30	0.53	0.46	0.43
<i>Diffugia urceolata</i> 'mica'	0.00	2.74	1.89	1.45	0.00	0.00	3.17	3.62	1.12	0.00	0.00
<i>Diffugia urceolata</i> 'urceolata'	3.29	2.05	1.89	2.17	3.57	2.86	0.53	0.66	0.00	0.34	0.14
<i>Diffugia oblonga</i> 'bryophila'	0.00	0.00	0.00	0.00	0.00	0.95	0.53	0.66	0.00	0.00	0.00
<i>Diffugia oblonga</i> 'lacustris'	0.00	0.00	0.00	0.00	0.00	1.90	0.53	0.00	0.00	0.23	0.00
<i>Diffugia oblonga</i> 'gassowskii'	0.00	0.00	0.00	0.00	0.89	1.90	1.85	1.32	0.06	0.00	0.00
<i>Diffugia oblonga</i> 'petricola'	1.97	1.37	0.63	0.97	1.79	0.95	1.06	1.97	0.00	0.00	0.43
<i>Diffugia oblonga</i> 'venusta'	0.66	0.00	0.00	0.48	0.00	2.86	0.00	1.32	0.24	0.69	0.43
<i>Diffugia protaeiformis</i> 'amorphalis'	0.00	0.00	1.26	0.00	1.79	0.00	0.00	0.00	0.00	0.11	0.57
<i>Diffugia protaeiformis</i> 'elegans'	1.32	4.11	0.63	1.69	2.68	0.00	1.06	0.33	0.24	0.11	0.57
<i>Diffugia protaeiformis</i> 'smilion'	0.00	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia rotunda</i>	0.66	1.37	0.63	0.00	0.00	0.00	0.53	2.30	0.00	0.11	0.00
<i>Diffugia viscidula</i>	0.00	1.37	1.26	0.00	2.68	0.95	2.11	0.00	0.00	0.00	0.00
<i>Heleopera sphagni</i>	3.95	3.42	3.77	0.00	0.89	0.95	0.53	1.64	0.12	0.00	0.00
<i>Lesquereusia jurassica</i>	1.32	2.05	3.14	19.32	9.82	4.76	4.75	0.66	0.00	0.11	0.00
<i>Nebela collaris</i>	0.00	2.74	1.89	0.00	0.00	0.00	1.06	0.00	0.00	0.11	0.00
<i>Oopyxis</i> sp.1	0.00	0.00	0.00	0.00	0.00	0.00	4.22	3.95	0.53	0.57	0.57
<i>Pontigulasia elisa</i>	0.00	0.00	0.63	0.00	0.89	0.00	0.53	0.00	0.00	0.00	0.00
<45 µm size fraction	3.29	3.42	0.00	4.35	17.86	4.76	4.75	3.29	0.53	0.00	0.00
test fragments	3.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cysts	0.00	2.74	0.00	0.00	0.00	0.00	0.53	0.99	0.00	0.00	0.00

Table C-6: Standard errors for thecamoebian counts of Little Green Lake.

LITTLE GREEN LAKE											
Sample number	01-01	01-02	01-03	01-04	01-05	01-10	01-15	01-20	01-25	01-30	01-35
<i>Arcella discoidea</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.18	0.58	0.40	0.36
<i>Arcella vulgaris</i> 'angulosa'	0.00	0.08	0.00	0.00	0.00	0.00	0.28	0.20	0.00	0.17	0.00
<i>Arcella vulgaris</i> 'vulgaris'	0.00	0.00	0.00	0.00	0.16	0.00	1.62	1.00	0.00	0.81	0.73
<i>Centropyxis aculeata</i> 'aculeata'	3.18	2.08	4.63	6.27	3.00	2.90	5.11	4.16	0.50	1.45	3.79
<i>Centropyxis aculeata</i> 'aerophila'	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'discoidea'	0.77	2.19	1.68	1.94	0.92	1.93	0.49	0.14	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'ecornis'	2.04	1.37	3.49	4.30	2.81	4.46	1.21	0.77	0.45	0.34	0.73
<i>Centropyxis constricta</i> 'constricta'	0.31	1.26	2.24	0.76	1.87	1.15	1.21	0.54	0.08	0.00	0.55
<i>Centropyxis constricta</i> 'cassis'	0.77	0.91	0.08	0.00	0.16	0.56	0.80	2.04	0.16	0.87	1.19
<i>Centropyxis constricta</i> 'platystoma'	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis constricta</i> 'spinifera'	0.00	0.20	0.08	0.00	0.00	0.00	0.07	0.31	0.08	0.40	0.18
<i>Cucurbitella corona</i>	0.00	0.08	0.08	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.08
<i>Cucurbitella tricuspidis</i> 'achlora'	3.18	0.79	0.08	0.00	0.54	1.54	0.49	0.14	65.87	44.96	54.02
<i>Cucurbitella tricuspidis</i> 'labiosa'	0.66	0.32	0.20	0.00	0.16	0.17	0.28	0.14	0.20	0.00	0.00
<i>Cucurbitella tricuspidis</i> 'tuberculata'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.00	0.00	0.00
<i>Cyclopyxis kahli</i>	0.54	0.56	0.43	0.37	0.35	0.76	0.69	0.00	0.00	0.00	0.27
<i>Diffugia globulus</i> 'globulus'	0.66	0.08	0.00	0.00	0.16	0.56	0.59	0.31	0.24	0.11	0.36
<i>Diffugia globulus</i> 'globulosa'	0.00	0.20	0.20	0.00	0.54	0.00	0.18	0.00	0.00	0.00	0.00
<i>Diffugia lanceolata</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.36
<i>Diffugia lithophila</i>	0.89	0.79	0.88	0.00	0.35	0.37	0.38	0.37	0.62	0.17	0.08
<i>Diffugia urceolata</i> 'elongata'	0.66	0.67	0.43	0.37	0.73	1.15	0.07	0.37	0.37	0.22	0.27
<i>Diffugia urceolata</i> 'mica'	0.00	0.44	0.31	0.27	0.00	0.00	0.59	0.60	0.79	0.00	0.00
<i>Diffugia urceolata</i> 'urceolata'	0.54	0.32	0.31	0.42	0.73	0.56	0.07	0.08	0.00	0.17	0.08
<i>Diffugia oblonga</i> 'bryophila'	0.00	0.00	0.00	0.00	0.00	0.17	0.07	0.08	0.00	0.00	0.00
<i>Diffugia oblonga</i> 'lacustris'	0.00	0.00	0.00	0.00	0.00	0.37	0.07	0.00	0.00	0.11	0.00
<i>Diffugia oblonga</i> 'gassowskii'	0.00	0.00	0.00	0.00	0.16	0.37	0.33	0.20	0.03	0.00	0.00
<i>Diffugia oblonga</i> 'petricola'	0.31	0.20	0.08	0.17	0.35	0.17	0.18	0.31	0.00	0.00	0.27
<i>Diffugia oblonga</i> 'venusta'	0.08	0.00	0.00	0.07	0.00	0.56	0.00	0.20	0.16	0.34	0.27
<i>Diffugia protaeiformis</i> 'amorphalis'	0.00	0.00	0.20	0.00	0.35	0.00	0.00	0.00	0.00	0.05	0.36
<i>Diffugia protaeiformis</i> 'elegans'	0.20	0.67	0.08	0.32	0.54	0.00	0.18	0.00	0.16	0.05	0.36
<i>Diffugia protaeiformis</i> 'smilion'	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia rotunda</i>	0.08	0.20	0.08	0.00	0.00	0.00	0.07	0.37	0.00	0.05	0.00
<i>Diffugia viscidula</i>	0.00	0.20	0.20	0.00	0.54	0.17	0.38	0.00	0.00	0.00	0.00
<i>Heleopera sphagni</i>	0.66	0.56	0.65	0.00	0.16	0.17	0.07	0.26	0.08	0.00	0.00
<i>Lesquereusia jurassica</i>	0.20	0.32	0.54	3.91	2.06	0.95	0.90	0.08	0.00	0.05	0.00
<i>Nebela collaris</i>	0.00	0.44	0.31	0.00	0.00	0.00	0.18	0.00	0.00	0.05	0.00
<i>Oopyxis</i> sp.1	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.66	0.37	0.28	0.36
<i>Pontigulastia elisa</i>	0.00	0.00	0.08	0.00	0.16	0.00	0.07	0.00	0.00	0.00	0.00
<45 µm size fraction	0.54	0.56	0.20	0.86	3.76	0.95	0.90	0.54	0.37	0.00	0.00
test fragments	0.54	0.79	0.54	0.56	0.16	0.17	0.00	0.00	0.00	0.00	0.00
cysts	0.00	0.44	0.00	0.00	0.54	0.00	0.07	0.14	0.00	0.00	0.00

Table C-7: Thecamoebian percent abundances for basin I of James Lake.

JAMES LAKE basin I										
Sample number	02-01	02-02	02-03	02-04	02-05	02-10	02-15	02-20	02-25	02-30
Depth (cm)	0-2	2-4	4-6	6-8	8-10	18-20	28-30	38-40	48-50	58-60
Fractional split	1/8	1/8	1/8	1/8	1/8	1/8	1/8	1/8	1/8	1/8
Total specimens in split	252	291	343	386	322	352	341	349	385	365
Total specimens in 30 cc.	2016	2328	2744	3088	2576	2816	2728	2792	3080	2920
Total specimens in 1 cc.	67	78	91	103	86	94	91	93	103	97
<i>Arcella discoides</i>	0.00	0.00	8.16	5.70	6.21	8.52	8.80	8.60	8.57	9.59
<i>Arcella denata</i>	0.00	0.00	0.00	1.04	0.00	0.00	0.00	0.00	0.26	0.00
<i>Arcella vulgaris</i> 'angulosa'	0.00	1.03	1.17	1.55	1.24	3.41	2.05	2.29	1.30	1.10
<i>Arcella vulgaris</i> 'vulgaris'	15.08	14.43	4.96	4.40	4.66	11.65	3.52	3.15	3.38	2.47
<i>Bullinularia indica</i>	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.86	0.26	0.55
<i>Centropyxis aculeata</i> 'aculeata'	18.25	18.21	7.87	20.73	16.15	14.20	24.05	16.33	24.42	30.14
<i>Centropyxis aculeata</i> 'aerophila'	0.00	1.72	0.87	1.04	0.00	0.28	0.00	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'discoides'	3.57	1.37	1.46	2.33	2.80	2.84	0.29	0.57	1.56	0.27
<i>Centropyxis aculeata</i> 'ecornis'	4.37	1.03	1.75	1.30	0.00	0.28	1.17	0.00	1.30	0.82
<i>Centropyxis constricta</i> 'constricta'	3.17	1.37	0.87	2.07	4.04	1.99	1.17	1.15	2.86	2.47
<i>Centropyxis constricta</i> 'cassis'	6.75	4.81	7.00	3.63	2.17	2.84	1.17	3.15	2.60	0.27
<i>Centropyxis constricta</i> 'platystoma'	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis constricta</i> 'spinifera'	0.00	1.03	1.46	3.37	4.04	0.85	1.17	0.57	0.52	1.37
<i>Cucurbitella corona</i>	0.00	0.00	0.29	0.26	0.00	0.00	0.29	0.00	0.00	0.00
<i>Cucurbitella tricuspidis</i> 'achlora'	1.98	5.50	5.83	1.55	4.35	2.84	2.93	0.86	0.26	2.47
<i>Cucurbitella tricuspidis</i> 'gramen'	1.19	1.37	3.21	2.07	1.86	1.99	2.64	2.01	0.00	1.92
<i>Cucurbitella tricuspidis</i> 'labiosa'	2.78	4.12	8.45	6.22	7.76	8.24	8.80	6.59	2.08	5.75
<i>Cucurbitella tricuspidis</i> 'lobostoma'	0.00	0.00	0.29	0.00	0.00	0.00	2.64	0.00	0.00	1.64
<i>Cucurbitella tricuspidis</i> 'oviformis'	0.00	0.00	0.29	0.78	1.24	1.42	0.59	0.00	2.34	0.27
<i>Cucurbitella tricuspidis</i> 'tuberculata'	0.00	0.00	0.00	0.00	0.93	3.41	7.33	4.87	0.26	8.22
<i>Cyclopyxis kahli</i>	1.98	1.72	0.00	2.33	0.93	1.70	1.17	2.29	0.52	0.00
<i>Diffugia globulus</i> 'globulus'	3.17	3.78	4.66	2.33	3.11	2.27	2.64	2.01	1.82	0.55
<i>Diffugia globulus</i> 'globulosa'	0.00	0.00	0.00	3.11	0.00	0.85	0.88	0.86	1.30	0.00
<i>Diffugia lithophila</i>	7.54	6.53	4.66	3.63	3.11	1.14	0.88	4.58	6.75	4.11
<i>Diffugia oblonga</i> 'bacillifera'	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia oblonga</i> 'bryophila'	0.40	0.69	1.17	1.04	0.62	0.00	0.88	0.00	0.78	0.27
<i>Diffugia oblonga</i> 'lacustris'	0.00	0.00	0.00	0.26	0.00	0.00	0.29	1.15	0.00	0.55
<i>Diffugia oblonga</i> 'lanceolata'	0.00	0.00	0.58	0.00	0.00	0.00	0.00	0.00	0.52	0.55
<i>Diffugia oblonga</i> 'gassowskii'	0.40	0.69	0.87	0.78	1.24	0.00	2.35	2.87	2.08	0.27
<i>Diffugia oblonga</i> 'petricola'	1.19	0.34	0.87	0.78	0.00	0.28	0.00	0.57	2.34	0.00
<i>Diffugia oblonga</i> 'venusta'	0.40	0.00	0.00	0.52	0.31	0.00	0.29	0.00	0.00	0.00
<i>Diffugia protaeiformis</i> 'amorphalis'	0.79	1.03	0.87	0.52	0.93	0.00	0.00	0.00	0.00	0.00
<i>Diffugia protaeiformis</i> 'bicornis'	0.00	0.00	0.29	0.00	0.00	0.28	0.00	0.00	0.00	0.00
<i>Diffugia protaeiformis</i> 'elegans'	1.98	4.12	1.17	0.78	1.55	0.00	0.29	1.43	0.00	0.55
<i>Diffugia protaeiformis</i> 'smilion'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia urceolata</i> 'elongata'	1.59	1.03	2.92	1.30	1.55	0.00	0.59	0.00	1.04	0.00
<i>Diffugia urceolata</i> 'mica'	0.00	2.75	3.21	2.33	0.93	0.00	0.59	0.00	0.00	0.00
<i>Diffugia urceolata</i> 'urceolata'	5.95	4.47	6.41	2.85	1.86	2.56	1.47	1.43	2.60	3.01
<i>Diffugia rotunda</i>	0.79	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia viscidula</i>	0.79	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Euglypha acanthophora</i>	6.75	11.00	5.83	3.89	4.04	1.70	3.23	1.72	1.04	0.00
<i>Euglypha cashii</i>	1.59	1.72	1.17	1.04	1.86	1.14	0.88	0.57	0.00	0.00
<i>Euglypha</i> sp.1	0.00	0.00	0.58	0.52	0.31	0.85	0.00	0.00	0.26	0.00
<i>Heleopera spaghni</i>	3.17	0.00	0.29	2.07	1.86	0.57	0.00	1.15	1.04	0.27
<i>Lesquereusia jurassica</i>	1.19	0.69	2.62	1.81	4.04	1.99	3.52	2.87	2.86	1.92
<i>Oopxis</i> sp.1	0.00	0.00	6.71	7.77	11.49	19.03	11.44	20.34	13.51	12.33
<i>Nebela collaris</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.86	2.86	2.74
<i>Trinema encheilus</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15	0.26	0.00
<45 µm size fraction	2.38	0.00	1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cysts	0.40	1.37	0.00	2.07	2.80	0.85	0.00	3.15	6.49	3.56

Table C-8: Standard errors of thecamoebian counts for James Lake, basin 1.

JAMES LAKE basin 1										
Sample number	02-01	02-02	02-03	02-04	02-05	02-10	02-15	02-20	02-25	02-30
<i>Arcella discoides</i>	0.00	0.00	1.47	1.10	1.10	1.58	1.59	1.60	1.71	1.84
<i>Arcella dentata</i>	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00
<i>Arcella vulgaris</i> 'angulosa'	0.00	0.14	0.19	0.28	0.20	0.61	0.35	0.41	0.24	0.18
<i>Arcella vulgaris</i> 'vulgaris'	2.37	2.40	0.88	0.85	0.82	2.17	0.62	0.57	0.66	0.45
<i>Bullinularia indica</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.08
<i>Centropyxis aculeata</i> 'aculeata'	2.87	3.04	1.42	4.08	2.91	2.65	4.41	3.07	4.92	5.84
<i>Centropyxis aculeata</i> 'aerophilia'	0.00	0.26	0.13	0.18	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'discoides'	0.54	0.20	0.24	0.44	0.48	0.51	0.00	0.08	0.29	0.00
<i>Centropyxis aculeata</i> 'ecomis'	0.66	0.14	0.29	0.23	0.00	0.00	0.19	0.00	0.24	0.13
<i>Centropyxis constricta</i> 'constricta'	0.47	0.20	0.13	0.38	0.71	0.35	0.19	0.19	0.55	0.45
<i>Centropyxis constricta</i> 'cassis'	1.04	0.78	1.26	0.69	0.37	0.51	0.19	0.57	0.50	0.00
<i>Centropyxis constricta</i> 'platystoma'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis constricta</i> 'spinifera'	0.00	0.14	0.24	0.64	0.71	0.13	0.19	0.08	0.07	0.24
<i>Cucurbitella corona</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Cucurbitella tricuspidis</i> 'achlora'	0.28	0.90	1.04	0.28	0.76	0.51	0.51	0.13	0.00	0.45
<i>Cucurbitella tricuspidis</i> 'gramen'	0.15	0.20	0.56	0.38	0.31	0.35	0.46	0.35	0.00	0.35
<i>Cucurbitella tricuspidis</i> 'labiosa'	0.41	0.67	1.53	1.21	1.38	1.53	1.59	1.22	0.39	1.09
<i>Cucurbitella tricuspidis</i> 'lobostoma'	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.29
<i>Cucurbitella tricuspidis</i> 'oviformis'	0.00	0.00	0.00	0.13	0.20	0.24	0.08	0.00	0.45	0.00
<i>Cucurbitella tricuspidis</i> 'tuberculata'	0.00	0.00	0.00	0.00	0.14	0.61	1.32	0.90	0.00	1.57
<i>Cyclopyxis kahli</i>	0.28	0.26	0.00	0.44	0.14	0.29	0.19	0.41	0.07	0.00
<i>Diffugia globulus</i> 'globulus'	0.47	0.61	0.83	0.44	0.54	0.40	0.46	0.35	0.34	0.08
<i>Diffugia globulus</i> 'globulosa'	0.00	0.00	0.00	0.59	0.00	0.13	0.13	0.13	0.24	0.00
<i>Diffugia lithophila</i>	1.17	1.07	0.83	0.69	0.54	0.19	0.13	0.84	1.34	0.77
<i>Diffugia oblonga</i> 'bacillifera'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia oblonga</i> 'bryophila'	0.00	0.08	0.19	0.18	0.08	0.00	0.13	0.00	0.13	0.00
<i>Diffugia oblonga</i> 'lacustris'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.08
<i>Diffugia oblonga</i> 'lanceolata'	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.07	0.08
<i>Diffugia oblonga</i> 'gassowskii'	0.00	0.08	0.13	0.13	0.20	0.00	0.40	0.52	0.39	0.00
<i>Diffugia oblonga</i> 'petricola'	0.15	0.00	0.13	0.13	0.00	0.00	0.00	0.08	0.45	0.00
<i>Diffugia oblonga</i> 'venusta'	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia protaeiformis</i> 'amorphalis'	0.09	0.14	0.13	0.07	0.14	0.00	0.00	0.00	0.00	0.00
<i>Diffugia protaeiformis</i> 'bicornis'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia protaeiformis</i> 'elegans'	0.28	0.67	0.19	0.13	0.25	0.00	0.00	0.24	0.00	0.08
<i>Diffugia protaeiformis</i> 'smilion'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia urceolata</i> 'elongata'	0.22	0.14	0.51	0.23	0.25	0.00	0.08	0.00	0.18	0.00
<i>Diffugia urceolata</i> 'mica'	0.00	0.43	0.56	0.44	0.14	0.00	0.08	0.00	0.00	0.00
<i>Diffugia urceolata</i> 'urceolata'	0.91	0.72	1.15	0.54	0.31	0.45	0.24	0.24	0.50	0.56
<i>Diffugia rotunda</i>	0.09	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia viscidula</i>	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Euglypha acanthophora</i>	1.04	1.82	1.04	0.74	0.71	0.29	0.57	0.30	0.18	0.00
<i>Euglypha cashii</i>	0.22	0.26	0.19	0.18	0.31	0.19	0.13	0.08	0.00	0.00
<i>Euglypha</i> sp. 1	0.00	0.00	0.08	0.07	0.00	0.13	0.00	0.00	0.00	0.00
<i>Heleopera sphagni</i>	0.47	0.00	0.00	0.38	0.31	0.08	0.00	0.19	0.18	0.00
<i>Lesquereusia jurassica</i>	0.15	0.08	0.45	0.33	0.71	0.35	0.62	0.52	0.55	0.35
<i>Oopyxis</i> sp. 1	0.00	0.00	1.20	1.52	2.06	3.56	2.08	3.83	2.71	2.37
<i>Nebela collaris</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.55	0.51
<i>Trinema enchelys</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00
<45 µm size fraction	0.35	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cysts	0.00	0.20	0.00	0.38	0.48	0.13	0.00	0.57	1.29	0.67

Table C-9: Thecamoebian percentage abundances for basin 2 of James Lake.

JAMES LAKE basin 2										
Sample number	03-01	03-02	03-03	03-04	03-05	03-10	03-15	03-20	03-25	03-30
Depth (cm)	0-2	2-4	4-6	6-8	8-10	18-20	28-30	38-40	48-50	58-60
Fractional split	1/4	1/8	1/8	1/8	1/8	1/4	1/4	1/4	1/8	1/8
Total species in split	387	439	598	436	276	380	322	227	336	350
Total specimens in 30 cc.	1548	3512	4784	3488	2208	1520	1288	908	2688	2800
Total specimens in 1 cc.	52	117	159	116	74	51	43	30	90	93
<i>Arcella dentata</i>	0.00	0.23	0.00	0.46	0.00	0.00	0.00	0.88	0.00	0.00
<i>Arcella discoides</i>	4.39	5.24	4.01	5.05	6.52	7.37	11.18	7.05	11.31	8.57
<i>Arcella vulgaris</i> 'angulosa'	0.78	0.46	1.34	2.75	0.00	0.00	0.00	4.41	1.19	3.43
<i>Arcella vulgaris</i> 'vulgaris'	0.78	4.10	2.68	1.83	1.45	4.74	7.14	7.05	1.79	5.14
<i>Bullinularia indica</i>	0.00	1.14	0.67	1.38	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'aculeata'	30.23	23.01	26.09	13.76	28.26	32.11	27.33	28.19	29.76	28.00
<i>Centropyxis aculeata</i> 'aerophila'	0.78	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'discoides'	0.00	0.91	0.67	0.00	0.72	2.11	0.00	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'ecornis'	4.91	3.42	2.34	1.38	5.07	0.53	1.24	0.00	0.00	0.00
<i>Centropyxis constricta</i> 'constricta'	6.46	7.06	2.68	4.59	6.52	1.05	3.11	4.41	4.17	0.57
<i>Centropyxis constricta</i> 'cassisi'	6.20	5.92	3.68	7.34	2.90	2.63	1.86	1.76	2.98	1.71
<i>Centropyxis constricta</i> 'platystoma'	0.78	2.51	0.67	1.38	2.17	0.79	0.00	0.00	0.00	0.00
<i>Centropyxis constricta</i> 'spinifera'	1.29	2.28	2.68	3.21	2.90	0.53	0.00	0.00	1.19	1.71
<i>Cucurbitella corona</i>	0.52	1.59	3.34	0.46	0.00	0.53	0.00	0.00	0.00	0.00
<i>Cucurbitella tricuspidis</i> 'achlora'	1.29	2.28	3.01	5.05	4.35	3.16	2.48	4.41	2.38	2.86
<i>Cucurbitella tricuspidis</i> 'gramen'	6.20	5.01	4.01	8.26	5.07	5.26	1.24	0.00	0.60	0.00
<i>Cucurbitella tricuspidis</i> 'labiosa'	9.82	7.52	6.35	7.80	5.80	12.11	5.90	10.57	9.52	9.71
<i>Cucurbitella tricuspidis</i> 'lobostoma'	0.26	0.23	0.67	0.92	0.00	0.00	3.11	0.88	1.19	1.71
<i>Cucurbitella tricuspidis</i> 'oviformis'	0.26	1.82	1.00	2.75	0.72	1.58	0.00	0.00	0.00	1.14
<i>Cucurbitella tricuspidis</i> 'tuberculata'	1.29	1.82	5.02	4.13	0.72	0.00	3.11	5.29	1.19	10.29
<i>Cyclopyxis kahli</i>	0.00	0.46	1.34	1.38	2.17	2.11	0.00	1.76	1.79	1.14
<i>Diffugia globulus</i> 'globulus'	1.03	2.96	1.67	3.67	5.07	4.74	2.48	2.64	1.19	2.86
<i>Diffugia globulus</i> 'globulosa'	1.29	0.91	0.00	0.00	2.17	0.00	0.00	1.32	4.76	0.00
<i>Diffugia lithophila</i>	0.26	0.46	2.01	0.92	2.90	1.58	1.24	1.76	2.98	2.29
<i>Diffugia oblonga</i> 'bryophila'	0.00	0.23	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia oblonga</i> 'gassowskii'	0.26	0.23	1.34	0.00	0.00	0.53	0.00	0.44	0.00	0.00
<i>Diffugia oblonga</i> 'lacustris'	0.00	1.14	0.67	0.92	0.00	0.00	0.00	0.00	0.60	0.00
<i>Diffugia oblonga</i> 'petricola'	1.29	0.46	0.67	1.38	0.00	0.00	1.24	0.00	1.79	0.57
<i>Diffugia oblonga</i> 'venusta'	0.52	2.05	0.67	0.00	0.00	0.00	0.62	0.00	0.60	0.00
<i>Diffugia protaeiformis</i> 'bicornis'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia protaeiformis</i> 'amorphalis'	0.52	1.14	1.34	0.46	0.00	0.00	0.00	0.88	0.60	0.00
<i>Diffugia protaeiformis</i> 'elegans'	2.33	1.82	3.01	3.21	0.00	0.53	1.24	1.76	0.00	1.14
<i>Diffugia protaeiformis</i> 'smilion'	1.29	0.00	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.00
<i>Diffugia urceolata</i> 'urceolata'	2.07	0.68	2.01	1.38	3.62	1.58	4.97	2.64	4.76	4.57
<i>Diffugia urceolata</i> 'elongata'	2.33	0.91	1.34	0.00	0.72	0.53	1.24	0.88	0.00	0.57
<i>Diffugia urceolata</i> 'mica'	2.33	0.68	0.67	0.46	0.00	0.53	1.86	0.00	0.00	0.00
<i>Diffugia rotunda</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.00	0.00	0.00
<i>Diffugia viscidula</i>	0.78	1.14	0.33	0.00	0.00	0.00	0.31	0.00	2.98	0.00
<i>Euglypha acanthophora</i>	0.00	1.37	1.67	2.29	0.00	1.05	3.73	2.64	1.79	5.71
<i>Euglypha cashii</i>	0.00	0.00	0.33	0.00	2.90	2.63	1.24	0.00	1.19	2.29
<i>Euglypha</i> sp.1	0.00	0.00	0.00	0.00	0.00	3.68	0.00	0.00	0.60	0.57
<i>Heleopera sphagni</i>	2.07	0.23	0.00	1.38	0.00	0.00	2.17	0.00	1.19	0.57
<i>Lesquereusia jurassica</i>	1.55	2.28	2.34	1.83	1.45	2.11	2.48	7.93	2.38	1.14
<i>Lesquereusia spiralis</i>	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Nebela collaris</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.44	2.98	0.00
<i>Oopyxis</i> sp.1	1.81	2.05	3.34	6.88	2.17	3.16	3.73	0.00	0.00	0.57
<i>Pontigulasia elisa</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Trinema enchelys</i>	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00
<45 µm size fraction	1.03	0.00	1.34	0.00	2.17	0.26	0.00	0.00	0.00	0.57
cysts	1.03	0.46	2.68	0.46	1.45	0.00	2.48	0.00	0.60	0.57

Table C-10: Standard errors for thecamoebian counts for James Lake, basin 2.

JAMES LAKE basin 2										
Sample number	03-01	03-02	03-03	03-04	03-05	03-10	03-15	03-20	03-25	03-30
<i>Arcella dentata</i>	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.09	0.00	0.00
<i>Arcella discoidea</i>	0.84	1.07	0.96	1.03	1.05	1.41	1.98	1.03	0.65	1.58
<i>Arcella vulgaris</i> 'angulosa'	0.12	0.07	0.31	0.55	0.00	0.00	0.00	0.63	0.06	0.61
<i>Arcella vulgaris</i> 'vulgaris'	0.12	0.83	0.63	0.36	0.21	0.90	1.25	1.03	0.09	0.94
<i>Bullinularia indica</i>	0.00	0.21	0.14	0.26	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'aculeata'	5.92	4.80	6.36	2.85	4.66	6.23	4.88	4.21	1.71	5.21
<i>Centropyxis aculeata</i> 'aerophila'	0.12	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'discoidea'	0.00	0.17	0.14	0.00	0.09	0.38	0.00	0.00	0.00	0.00
<i>Centropyxis aculeata</i> 'ecornis'	0.94	0.69	0.55	0.26	0.81	0.07	0.19	0.00	0.00	0.00
<i>Centropyxis constricta</i> 'constricta'	1.25	1.46	0.63	0.93	1.05	0.18	0.53	0.63	0.23	0.08
<i>Centropyxis constricta</i> 'cassis'	1.19	1.22	0.88	1.51	0.45	0.49	0.31	0.23	0.16	0.29
<i>Centropyxis constricta</i> 'platystoma'	0.12	0.50	0.14	0.26	0.33	0.13	0.00	0.00	0.00	0.00
<i>Centropyxis constricta</i> 'spinifera'	0.23	0.45	0.63	0.65	0.45	0.07	0.00	0.00	0.06	0.29
<i>Cucurbitella corona</i>	0.07	0.31	0.80	0.07	0.00	0.07	0.00	0.00	0.00	0.00
<i>Cucurbitella tricuspidis</i> 'achlora'	0.23	0.45	0.72	1.03	0.69	0.59	0.42	0.63	0.13	0.51
<i>Cucurbitella tricuspidis</i> 'gramen'	1.19	1.03	0.96	1.70	0.81	1.00	0.19	0.00	0.02	0.00
<i>Cucurbitella tricuspidis</i> 'labiosa'	1.91	1.55	1.53	1.60	0.93	2.33	1.03	1.56	0.54	1.79
<i>Cucurbitella tricuspidis</i> 'lobostoma'	0.00	0.00	0.14	0.17	0.00	0.00	0.53	0.09	0.06	0.29
<i>Cucurbitella tricuspidis</i> 'oviformis'	0.00	0.36	0.22	0.55	0.09	0.28	0.00	0.00	0.00	0.19
<i>Cucurbitella tricuspidis</i> 'tuberculata'	0.23	0.36	1.21	0.84	0.09	0.00	0.53	0.76	0.06	1.90
<i>Cyclopyxis kahli</i>	0.00	0.07	0.31	0.26	0.33	0.38	0.00	0.23	0.09	0.19
<i>Diffugia globulus</i> 'globulus'	0.18	0.60	0.39	0.74	0.81	0.90	0.42	0.36	0.06	0.51
<i>Diffugia globulus</i> 'globulosa'	0.23	0.17	0.00	0.00	0.33	0.00	0.00	0.16	0.27	0.00
<i>Diffugia lithophila</i>	0.00	0.07	0.47	0.17	0.45	0.28	0.19	0.23	0.16	0.40
<i>Diffugia oblonga</i> 'bryophila'	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia oblonga</i> 'gassowskii'	0.00	0.00	0.31	0.00	0.00	0.07	0.00	0.00	0.00	0.00
<i>Diffugia oblonga</i> 'lacustris'	0.00	0.21	0.14	0.17	0.00	0.00	0.00	0.00	0.02	0.00
<i>Diffugia oblonga</i> 'petricola'	0.23	0.07	0.14	0.26	0.00	0.00	0.19	0.00	0.09	0.08
<i>Diffugia oblonga</i> 'venusta'	0.07	0.40	0.14	0.00	0.00	0.00	0.08	0.00	0.02	0.00
<i>Diffugia protaeiformis</i> 'bicornis'	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Diffugia protaeiformis</i> 'amorphalis'	0.07	0.21	0.31	0.07	0.00	0.00	0.00	0.09	0.02	0.00
<i>Diffugia protaeiformis</i> 'elegans'	0.43	0.36	0.72	0.65	0.00	0.07	0.19	0.23	0.00	0.19
<i>Diffugia protaeiformis</i> 'smilium'	0.23	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
<i>Diffugia urceolata</i> 'elongata'	0.43	0.17	0.31	0.00	0.09	0.07	0.19	0.09	0.00	0.08
<i>Diffugia urceolata</i> 'mica'	0.43	0.12	0.14	0.07	0.00	0.07	0.31	0.00	0.00	0.00
<i>Diffugia urceolata</i> 'urceolata'	0.38	0.12	0.47	0.26	0.57	0.28	0.86	0.36	0.27	0.83
<i>Diffugia rotunda</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00
<i>Diffugia viscidula</i>	0.12	0.21	0.06	0.00	0.00	0.00	0.00	0.00	0.16	0.00
<i>Euglypha acanthophora</i>	0.00	0.26	0.39	0.45	0.00	0.18	0.64	0.36	0.09	1.04
<i>Euglypha cashii</i>	0.00	0.00	0.06	0.00	0.45	0.49	0.19	0.00	0.06	0.40
<i>Euglypha</i> sp.1	0.00	0.00	0.00	0.00	0.00	0.69	0.00	0.00	0.02	0.08
<i>Heleopera sphagni</i>	0.38	0.00	0.00	0.26	0.00	0.00	0.36	0.00	0.06	0.08
<i>Lesquereusia jurassica</i>	0.28	0.45	0.55	0.36	0.21	0.38	0.42	1.16	0.13	0.19
<i>Lesquereusia spiralis</i>	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Nebela collaris</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.16	0.00
<i>Oopyxis</i> sp.1	0.33	0.40	0.80	1.41	0.33	0.59	0.64	0.00	0.00	0.08
<i>Pontigulasia elisa</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Trinema enchelys</i>	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00
<45 µm size fraction	0.18	0.00	0.31	0.00	0.33	0.00	0.00	0.00	0.00	0.08
cysts	0.18	0.07	0.63	0.07	0.21	0.00	0.42	0.00	0.02	0.08

Table C-11: Abbreviated taxonomy for all species and strains in James Lake

ABBREVIATED TAXONOMY

Achnanthes minutissima and vars.
Achnanthes spp.
Amphora spp.
Amphipleura pellucida
Asterionella formosa
Caloneis silicula
Cocconeis placentula
Cyclotella bodanica
Cyclotella michiganiana and vars.
Cyclotella pseudostelligera
Cymbella descripta
Cymbella minuta
Cymbella spp.
Denticula kuetzingii
Diploneis spp.
Epithemia adnata
Eunotia spp.
Fragilaria crotonensis
Fragilaria nanana
Fragilaria tenera
Fragilaria ulna var. *danica*
Fragilaria spp.
Gomphonema angustatum
Gomphonema gracile
Gomphonema spp.
Gyrosigma acuminatum
Hannaea cyclosum
Hantzschia amphioxys
Mastogloia smithii
Navicula cryptotenella
Navicula radiosa
Navicula spp.
Neidium alpinum
Nitzschia acicularis
Nitzschia sp. no.4
Nitzschia spp.
Pinnularia spp.
Rhopalodia gibba
Stauroneis anceps
Staurosira construens
Stephanodiscus cf. *hantzschii*
Tabellaria flocculosa
 Unidentified diatom valves
 Chrysophyte cysts
 Mallomonas scales
 Sponge spicule fragments

Table C-12: Diatom percent abundances for basin I of James Lake.

JAMES LAKE basin I							
Sample number	DT-95-387	DT-95-391	DT-95-393	DT-95-394	DT-95-395	DT-95-396	DT-95-397
Depth (cm)	0-2	8-10	18-20	28-30	38-40	48-50	58-60
Total no. of diatoms counted	699.0	609.0	683.0	672.0	896.0	804.0	841.0
<i>Achnanthes minutissima</i> & vars.	3.3	1.0	6.6	4.0	8.9	3.6	2.0
<i>Achnanthes</i> spp.	0.3	0.0	0.0	0.0	0.0	0.0	0.0
<i>Amphipleura pellucida</i>	0.0	0.0	0.0	0.0	0.0	0.1	0.1
<i>Amphora</i> spp.	0.0	0.0	0.0	0.0	0.2	0.0	0.2
<i>Asterionella formosa</i>	1.1	0.7	0.4	0.3	0.0	0.0	0.0
<i>Caloneis silicula</i>	0.1	0.0	0.0	0.0	0.2	0.0	0.0
<i>Cocconeis placentula</i>	0.0	0.2	0.0	0.0	0.0	0.0	0.0
<i>Cyclotella bodanica</i>	0.3	0.0	0.7	0.0	0.2	2.2	0.0
<i>Cyclotella michiganiana</i> & vars.	65.7	60.8	51.4	71.6	53.7	51.4	58.1
<i>Cyclotella pseudostelligera</i>	1.3	0.2	1.5	1.5	0.0	6.7	0.5
<i>Cymbella</i> spp. (mostly <i>C. descripta</i>)	0.4	0.8	0.6	0.9	1.7	1.9	1.4
<i>Diploneis</i> spp.	0.0	0.5	0.1	0.0	0.2	0.7	0.1
<i>Eunotia</i> spp.	0.0	0.3	0.1	0.0	0.0	0.1	0.0
<i>Fragilaria crotonensis</i>	0.4	8.2	10.2	2.8	5.4	4.6	10.0
<i>Fragilaria cyclopus</i>	0.1	0.2	0.0	0.0	0.0	0.2	0.0
<i>Fragilaria nanana</i>	9.7	12.3	8.6	4.6	9.3	4.5	7.7
<i>Fragilaria tenera</i>	14.6	8.5	9.8	7.7	11.7	16.3	6.9
<i>Fragilaria</i> spp.	0.6	0.3	0.3	0.3	0.2	0.0	0.6
<i>Gomphonema</i> spp.	0.0	0.5	0.9	0.9	1.1	0.2	0.4
<i>Hantzschia amphioxys</i>	0.0	0.0	0.0	0.0	0.4	0.0	0.0
<i>Mastogloia smithii</i>	0.0	0.3	0.0	0.3	0.1	0.0	0.2
<i>Navicula cryptotenella</i>	0.3	0.2	0.6	1.6	1.0	1.0	1.2
<i>Navicula radiosa</i>	0.0	0.3	0.9	0.0	0.0	0.5	0.0
<i>Navicula</i> spp.	0.0	0.7	0.4	0.0	0.1	0.4	0.0
<i>Neidium alpinum</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.1
<i>Nitzschia acicularis</i>	0.0	0.7	4.5	0.1	0.0	0.0	0.2
<i>Nitzschia</i> sp. no. 4	0.3	0.0	0.0	0.1	3.2	2.6	2.3
<i>Nitzschia</i> spp.	0.1	3.4	0.1	1.6	0.0	0.0	0.5
<i>Pinnularia</i> spp.	0.1	0.0	0.0	0.0	0.0	0.4	0.1
<i>Stauroneis unceps</i>	0.0	0.0	0.0	0.0	0.0	0.7	0.0
<i>Stephanodiscus</i> cf. <i>hantzschii</i>	0.0	0.0	0.0	0.7	2.2	0.5	5.5
<i>Tabellaria flocculosa</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Unidentified diatom valves	1.1	0.0	2.0	0.7	0.0	1.2	1.7
Chrysophyte cysts	264.0	93.0	98.0	106.0	116.0	83.0	134.0
Mallomonas scales (mainly <i>crassisquama</i> & <i>caudata</i>)	29.0	95.0	138.0	112.0	157.0	215.0	149.0
Sponge spicule fragments	0.0	0.0	1.0	0.0	1.0	0.0	2.0

Table C-13: Diatom percent abundances for basin 2 of James Lake.

JAMES LAKE basin 2							
Depth (cm)	0-2	8-10	16-18	28-30	36-38	48-50	56-58
Sample number	DT-96-40	DT-96-44	DT-96-46	DT-96-48	DT-96-50	DT-96-53	DT-96-55
Total no. of diatoms counted	618.0	447.0	559.0	564.0	609.0	794.0	712.0
<i>Achnanthes minutissima</i> and vars.	5.5	4.3	4.7	3.5	3.4	4.9	4.2
<i>Achnanthes</i> spp.	0.2	0.2	0.0	0.0	0.0	0.1	0.0
<i>Amphora</i> spp.	0.0	1.3	0.5	0.0	0.0	0.0	0.0
<i>Amphipleura pellucida</i>	0.3	0.0	0.4	0.2	0.3	0.1	0.1
<i>Asterionella formosa</i>	0.3	0.7	0.0	0.0	0.0	0.0	0.0
<i>Caloneis silicula</i>	0.0	1.1	1.1	0.0	0.0	0.0	0.0
<i>Cocconeis placentula</i>	0.0	0.0	0.5	0.2	0.3	0.4	0.3
<i>Cyclotella bodanica</i>	0.6	3.4	0.4	0.0	0.0	0.0	0.3
<i>Cyclotella michiganiana</i> and vars.	77.7	64.4	44.4	42.4	53.2	36.5	54.2
<i>Cyclotella pseudostelligera</i>	1.9	2.5	3.8	0.7	0.7	4.7	2.2
<i>Cymbella</i> spp.	2.3	2.2	3.4	1.4	1.0	1.5	0.7
<i>Denticula kuetzingii</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.1
<i>Diploneis</i> spp.	0.0	0.0	0.0	0.0	0.0	0.0	0.1
<i>Epithemia adnata</i>	0.2	0.2	0.0	0.0	0.0	0.1	0.0
<i>Eunotia</i> spp.	0.2	0.0	0.0	0.0	0.0	0.0	0.0
<i>Fragilaria crotonensis</i>	1.5	3.6	12.2	19.5	10.0	4.4	8.3
<i>Fragilaria cyclopus</i>	0.2	1.1	0.2	0.0	0.0	0.0	0.0
<i>Fragilaria nanana</i>	0.2	1.3	4.1	11.5	11.2	16.8	9.7
<i>Fragilaria tenera</i>	1.1	0.9	14.1	11.5	14.1	20.4	11.2
<i>Fragilaria</i> spp.	0.5	0.9	0.2	0.2	0.0	0.9	0.0
<i>Gomphonema</i> spp.	0.0	0.9	0.2	0.4	0.3	0.8	1.0
<i>Gyrosigma acuminatum</i>	0.0	0.0	0.2	0.0	0.0	0.1	0.0
<i>Mastogloia smithii</i>	1.3	0.4	0.9	0.4	0.3	0.5	0.1
<i>Navicula cryptotenella</i>	0.6	2.0	1.6	2.0	1.5	1.3	2.7
<i>Navicula radiosa</i>	0.6	1.1	0.4	0.0	0.0	0.5	0.6
<i>Navicula</i> spp.	0.6	0.9	0.4	0.2	0.5	0.5	0.1
<i>Nitzschia acicularis</i>	0.3	0.0	0.9	2.1	1.3	2.6	1.5
<i>Nitzschia</i> sp. no.4	0.5	1.1	1.1	0.7	0.7	1.6	1.5
<i>Nitzschia</i> spp.	0.2	0.0	0.5	0.0	0.2	0.8	0.1
<i>Pinnularia</i> spp.	0.6	0.2	0.9	0.0	0.0	0.0	0.0
<i>Rhopalodia gibba</i>	0.0	0.9	0.0	0.0	0.0	0.0	0.1
<i>Stauroneis anceps</i>	0.3	0.2	0.0	0.0	0.0	0.0	0.0
<i>Stauroneis construens</i>	1.1	1.1	0.0	0.0	0.0	0.5	0.0
<i>Stephanodiscus</i> cf. <i>hantzschii</i>	0.0	0.0	0.0	0.7	0.0	0.0	0.0
<i>Tabellaria flocculosa</i>	0.0	0.0	0.5	0.2	0.0	0.0	0.0
Unidentified diatom valves	1.1	2.9	2.7	2.3	1.0	0.0	0.6
Chrysophyte cysts	78.0	78.0	144.0	106.0	180.0	62.0	56.0
Mallomonas scales (mainly <i>crasssquama</i> & <i>caudata</i>)	43.0	27.0	32.0	147.0	210.0	157.0	171.0
Sponge spicule fragments	0.0	0.0	2.0	1.0	0.0	0.0	0.0

IMAGE EVALUATION TEST TARGET (QA-3)

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