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ONTARIO GEOLOGICAL SURVEY MAP 80713 **GEOCHEMICAL SERIES** 

# Interdisciplinary Research an Environmental Component (Acid Rain) in Regional Geochemical Surveys (Wawa Area)

**Algoma District** 

NTS References: 42C/2, 3, 6, 7, 8, 9, 10, 15, 16 ODM-GSC Aeromagnetic Maps: 2192G, 2176G, 2177G, 2193G, 2207G, 2208G, 2194G, 2195G, 2209G ODM Compilation Map: 2220

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> "There is nothing more difficult to carry out, nor more doubtfu of success, nor more dangerous to handle, than to initiate a new order of things. For the reformer has enemies in all who profit by the old order, and only lukewarm defenders in all hose who would profit by the new order. This luke-warmness arises partly from the fear of their adversaries who have the law in their favour; and partly from the incredulity of mankind, who do not truly believe in anything new until they have actual

Machiavelli, The Prince (1513) as quoted by Stafford Beer

LAKE SUPERIOR

Figure 1. Sampled lake locations during the OGS-GSC recon-

LAKE SUPERIOR

Figure 2. Locations of lakes sampled during the OGS-GSC

The interdisciplinary team

Wawa 1980 project described here).

approach to research

reconnaissance geochemical surveys having rela-

tively low, or high pH. Lakes with near neutral pH are

not included. (The rectangle is the area included in the

The WAWA project generated a relatively large volume

of close knit interdisciplinary data and information on

over 50 lakes. This was possible owing to a novel

approach to the organization of the activity of the team.

Briefly, each Spring the team decided on a goal for the

conceptual model. Other conceptual models were used

vear's activity which was incorporated in a simple

to focus attention on the data gathering process.

discipline by discipline. During a 2-week field trip each

discipline collected data information and samples ac-

cording to the prearranged plan plus other pertinent

information required from particular lakes included in

the project. The data, and samples were worked on

during the fall and winter and preliminary information

on the project was released during the Ontario Geolog-

ical Survey Geoscience Meetings in December. De-

tailed data listings and descriptions of each annual

cycle of work are included in OGS Open File Reports

Serendipity from the project

At the time the project was planned in 1980 the study of

aspect of the limnological investigation with no direct

bearing on the geochemical processes related to Acid

Rain. It is to Professor Dickman's credit that he per-

ceived the importance of the relationship he discovered

studied in 1980 and the details of the diatom flora in

lakes. From this beginning was developed a "Diatom

Inferred pH" method for the determination of the pH

history of lakes on a regional (not local) scale. As time

went on it was realised that the regional approach to

Diatom Inferred pH" measurements in selected lake

Rain) component in Regional Geochemical Surveys

sediment cores provides important information with

respect to the development of an environmental (Acid

and in the more general field of acid rain studies.

samples of sediment taken from the bottom of the same

between the pH of the 20 lakes along the "gradien

the biota in the lakes was considered an important

No 5342 (1981) and (5483) 1984.

east of Lake Superior.

pH 8.0 - 8.5

pH 5.0 - 5.5 ...

pH 4.5 -4.9.....

naissance geochemical surveys in the area north and

in Decision and Control (New York, John Wiley & Sons, 1966), p.3

### ntroduction

Regional geochemical mapping has evolved from geochemical prospecting at the regional level which was pioneered by Hawkes and his co-workers in New Brunswick in the early 1950's. These workers used a cold extraction test (Bloom 1955) to determine the neavy metal (i.e. zinc, copper and lead) content of stream sediments collected systematically within the area being studied. More recently joint Provincial/Federal agreements resulting in joint activity including the eological Survey of Canada and the Ontario ical Survey have produced reconnaissance geochem cal maps for an area from the east shore of Lake Superior to the Manitoba border (OGS Open File Reports 5248, 5249, 5266, 5267, 5284 and 5285) and in an area of Southeastern Ontario (OGS Open File Reports No 5227 and 5228). The OGS/GSC reconnaissance level maps involved the study of the content of uranium and other elements in water and lake sediments using a sample density of one site per 13 sq km. The aim of the reconnaissance geochemical mapping was to assist in mineral resource appraisal, more specifically, to facilitate the discovery of uranium deposits. In the western area of these surveys over 6,000 lakes were sampled for both water and lake sediment. A new departure in the interpretation of patterns on reconnaissance geochemical maps was made by Coker and Shilts (1979). They related the patterns on the geochemical maps north of Lake Superior to the problem of "Acid Rain" and pointed out that the pH of

lakes in the area is largely controlled by the geological conditions of the catchment area within which lakes are In 1980 R.B.Barlow and I. Thomson hired the author to design a followup level research project to study the geochemical processes associated with change in the acidity of lakes with special reference to those related to acid rain. At the time it was believed that once these processes were well understood it would be relatively simple to include an "environmental component" in future regional geochemical surveys undertaken by the Ontario Geological Survey. Such a component must yield reliable data pertinent to the problem of Acid Rain and occupy no more than a few minutes as a lake is being sampled for mineral resource appraisal purposes.

# The Wawa interdisciplinary

The starting point of the acid rain project was a close study of the reconnaissance geochemical map coverage of the area along the north shore of Lake Superior (Figure 1) and more specifically, the patterns for the incidence of lakes sampled with relatively high or low pH (Figure 2). The WAWA project and related research has now run for four years. Briefly, during the first year (1980) a series of 20 specially selected lakes were studied. The lakes were chosen to lie along a pH "gradient" within a strip of country 20km x 100km located to the northwest of Wawa (see Figure 2). The lakes were selected from 164

sampled in the strip during the reconnaissance geochemical mapping of the area on the basis of lakewater pH. During the second year of the WAWA poject (1981) the aim was to discover details of the pH of a series of four lakes located in each of five catchment areas. The principal objective here was to provide information on the behaviour of lakes in catchment areas where the geological conditions resulted in acid, neutral or alkaline conditions in lake water at the time of sampling. The third year's research (1982) was concerned with the verification of observations in lakes made during the previous two years and the study of a small number of new lakes where the conditions were likely to be extreme (i.e. at a mine tailings pond). A second aim was to standardize the methodology developed so far for the inclusion of an "environmental component" in future regional geochemical surveys. The 1983 study was a practical application of the use of the "environmental component" in 70 lakes in the Sudbury area. Although the data from the fourth year's (1983) study is still being compiled highlights from it are included here because they provide further insight into the development of an environmental (acid rain) component in regional geochemical surveys.

## The interdisciplinary team

The researchers involved in the WAWA interdisciplinary team included J.A.C. Fortescue (Geochemist) coordina tor of the project (1982/3), I. Thomson (Geochemist) coordinator (1980/1), Professor M. Dickman, Depart ment of Biological Sciences. Brock University (Limnologist) and Professor J. Terasmae (1980/2) Department eological Sciences Brock, University (Palynolo During 1980 and 1981 J.A.C. Fortescue worked on the design and implementation of the work as a Consultant to the Ontario Geological Survey prior to joining the Ontario Geological Survey as a Research Geochemis in May 1982. I. Thomson ceased to work on the project in October 1981 when he left the Ontario Geologica Survey. The team is grateful to Roger Barlow, Chief or the Geophysics/Geochemistry Section, Ontario Geol ogical Survey for his general comments and encourage ment throughout the project.

surveys carried out by the Ontario Geological Survey.

The purpose of this broadsheet 1. To display highlights of the Wawa project of general interest to researchers into the problem of Acid Rain

2. To explain why the problem of Acid Rain is considered a part of regional geochemical

## Highlights of the research

1. The regional patterns for pH in lakewaters north of Lake Superior are reproducible even though absolute values vary from year to year for a given lake. Hence regional geochemical surveys can identify areas where lakes susceptible to Acid Rain effects

2. A study of lakewater chemistry of more than 50 lakes indicates, as predicted from theory. that lakes with a pH of 6.3, or less, may be susceptible to Acid Rain effects. Hence regional geochemical surveys can identify lakes likely to be susceptible to Acid Rain.

3. Research during 1980, 1981 and 1982 has demonstrated that fossil pollen studies augmented by <sup>137</sup>Cs measurements of lake sediment cores can establish the sedimentation rate of a lake. Hence short lake sediment cores are suitable as potential history books for the study of the pH history of lakes during the past 100 years. 4. The Diatom Inferred pH method as developed during this research can be used to describe in detail the pH history of a lake during the past 100 years. Hence it is practical to

distinguish lakes with a low pH now which are naturally acid from those which have changed acidity during the past 100 years due to Acid Rain. 5. Our work has demonstrated that geological conditions within a catchment area determine to pH of lakes within it. Consequently, the discovery of a single lake susceptible to Acid Rain during a regional geochemical survey can lead to the discovery of others during

6. The Diatom Inferred pH technique is not practical for routine application to lake sediment cores collected during regional geochemical surveys. Consequently, more research is required to provide a reliable substitute for this technique. 7. The fully interdisciplinary team approach used for this project involving the Ontario Geological Survey staff and university staff under contract working together over a period

of more than one season increased the value of the data gathered. These important

## General conclusion

the effects of Acid Rain.

This work was demonstrated that it is now feasible to include an "Environmental component" (Acid Rain) in future regional geochemical surveys designed to identify lakes susceptible to

findings may not have been possible without this approach

### THE 1980 PROJECT

The 1980 project: A Study of a Lake "pH Gradient"

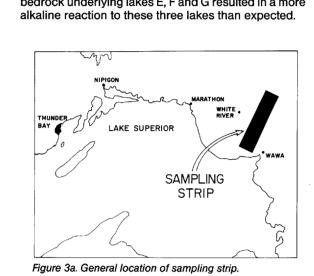
A: Selection of field area

Inspection of the reconnaissance geochemical survey data for lakewater pH (Figures 1 and 2) suggested that it would be practical to study a series of lakes each of different pH ranging from around 4.5 to 8.0 in an area located to the northwest of Wawa. In order to do this a sampling strip 20 km x 100 km with its long axis in the direction of the prevailing wind was examined. The strip included 164 lakes sampled during the previous geochemical survey, of which 20 were selected for detailed The location of the sampling strip is shown in Figure 3. In Figure 4 details on the pH in the 164 lakes in the strip are indicated by symbols and the pH of the lakes selected for study by numbers in circles in the adjacent map strip. Also on Figure 4 is an indication of the area o the lakes selected, their code letters which are listed from south to north and the general geology of the strip area, which includes both granitic rocks and

On Figure 5 relationships between the lake areas and the catchment areas for lakes included in the 1980 study are listed. An attempt was made to include lakes of various shapes and sizes typical of the sampling strip as a whole. A conceptual model of a typical lake basin included in the study appears on Figure 6 which also lists the routine observations made for each of the 20 The conceptual model for catchment area data (Figure 6) is an ideal one and in practice it was not possible to collect all the required information. This was the case particularly for the Quaternary geological information because the area of the sampling strip had not been mapped for this parameter. The dotted lines on Figure 5 refer to the approximate location of bedrock not Quaternary geological contacts.

#### General conclusion regarding the selection of lakes along a

When, during the planning stage of the project, the "pH gradient" based on the 20 selected lakes was drawn up (Figure 7) it was found that it departed from the idea gradient" (Figure 8) in two ways. First because the slope of the "gradient" was steep at its ends and nearly flat in the middle and second because the "greenstone" bedrock underlying lakes E, F and G resulted in a more alkaline reaction to these three lakes than expected.



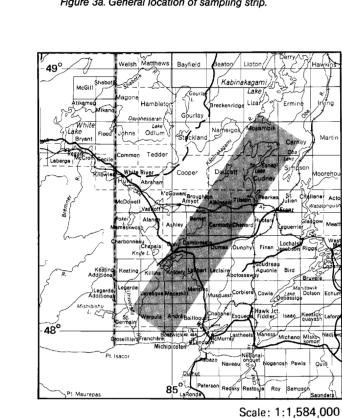


Figure 3b. Detailed location map of the sampling strip.

The 1981 project: The Study of

The interpretation of the data and information obtained

during the 1980 activity focused attention on small

lakes located at the highest point in catchment areas as

being those likely to be most susceptible to the effects

of Acid Rain. This was because they tended to have

In 1981 the same team planned to update the 1980

methods and apply them to a set of 20 lakes located in

fours in each of five catchment areas. The catchment

areas were chosen so as to have relatively uniform

An idealized conceptual model of a catchment area

suitable for study was drawn (Figure 22) and a list of

parameters expected to change in each area selected

was also included in the pre-planning process (Figure

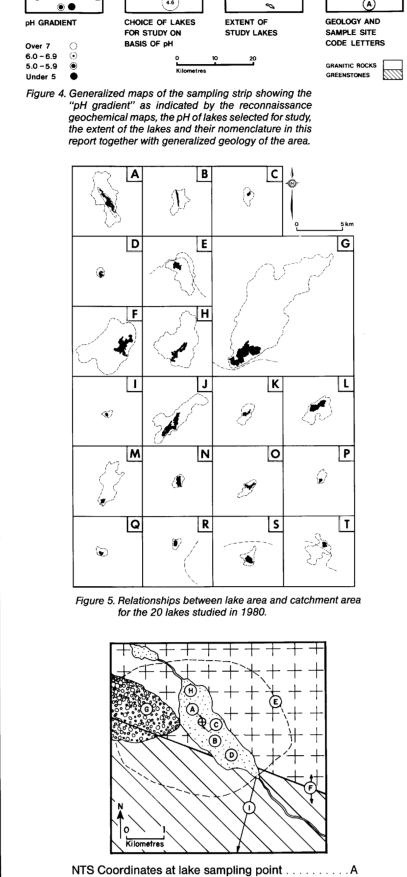
The location of the catchment areas selected for study

both low pH and low alkalinity.

geological substrate.

'STAIRCASE OF LAKES'

THE 1981 PROJECT



Elevation of lake above sea level (m)

Bedrock Geology (granite/greenstone)

Surficial geological features (if mapped)

Position of lake in 'Staircase' (here second) .

Distance of lake from margin of Lake Superior

Figure 6. Conceptual model of a catchment area studied

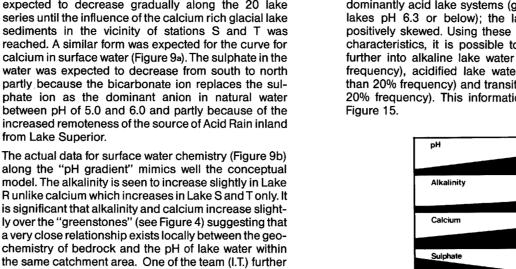
including a list of parameters measured at each lake.

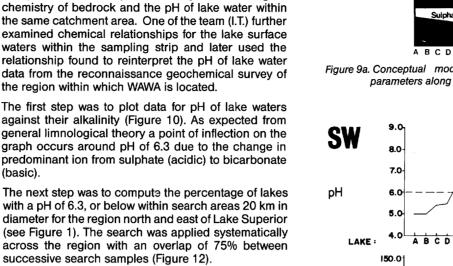
Lake depth at sampling point .

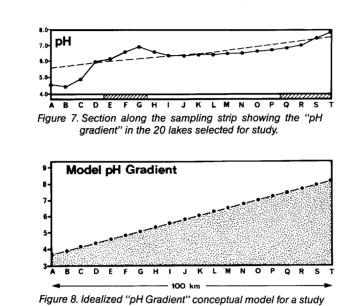
Lake catchment area

- B

#### B: Lake surface water chemistry (I.T.) The conceptual model for lake surface water chemistry observations along the "pH gradient" at WAWA is illustrated on Figure 9a which also repeats the pH gradient model. Briefly, alkalinity of the lakes was expected to decrease gradually along the 20 lake series until the influence of the calcium rich glacial lake sediments in the vicinity of stations S and T was reached. A similar form was expected for the curve for calcium in surface water (Figure 9a). The sulphate in the water was expected to decrease from south to north partly because the bicarbonate ion replaces the sulphate ion as the dominant anion in natural water between pH of 5.0 and 6.0 and partly because of the







of the Acid Rain problem.

The following conclusions were drawn from this study 1. There is evidence of an increase in the frequency of acid lakes from northwest to southeast around th margin of Lake Superior. This gradient shows a general correlation with precipitation (Figure 13) and hence, by inference, exposure to "acid rain". 2. At the local scale, the highest frequency of acid lakes tends to occur over granitic (felsic igneous) bedrock (Figure 14) where the geology can provide, at best, only minimal quantities of carbonate to lake 3. A local gradient is seen north and east of Sault Ste. Marie with the frequency of acid lakes decreasing with distance from town. It is suggested that this pattern may reflect local total, pervasive low level acidification of lakes due to sulphur emissions from the steel mills in the city. 4. No such clear gradient pattern is noted at Wawa, despite the presence of the sintering plant (a known source of SO<sub>2</sub>) with associated fume kill. It is suggested that the availability of carbonate in the 'greenstone" rocks around Wawa provides sufficient ouffering capacity to reduce the local impact of sulphur emissions on the lake water systems. 5. Large areas along the northern part of the regional survey area are characterized by a low (5% or less) requency of acid lakes. These areas are underlain largely by calcareous drift in the east and central sections and diabase (a rock type somewhat enriched in Ca and ferromagnesium minerals which

weather to yield carbonate complexes) in the west.

These geological substrates are considered to pro-

water systems. These areas are further character-

Uniform

Decreases

less exposure to acid rain.

Lakewater ph

Lakewater Alkalinit

Plant Cover Type:

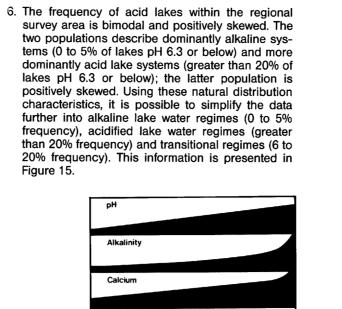
Around Shoreline

Relief Around

**Surficial Cover** 

vide a high carbonate buffering capacity to the lake

ized by lower annual precipitation rates and hence



Alkalinity (mg/L CaCO<sub>3</sub>)

Lake T is off scale.

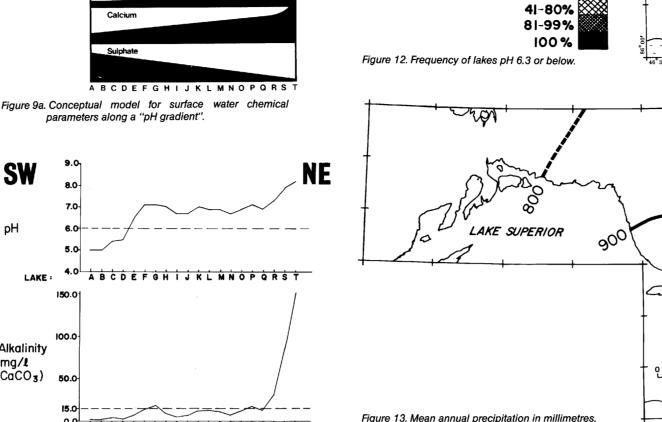
Figure 10. Relationship between pH and alkalinity (total inflec-

tion point) in surface waters along the pH "gradient".

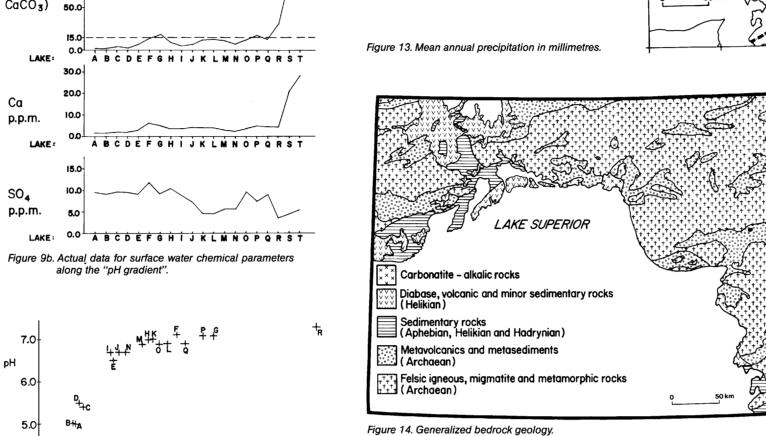
WAWA SAMPLE STRIP (EACH UNIT 5 x 20 km)

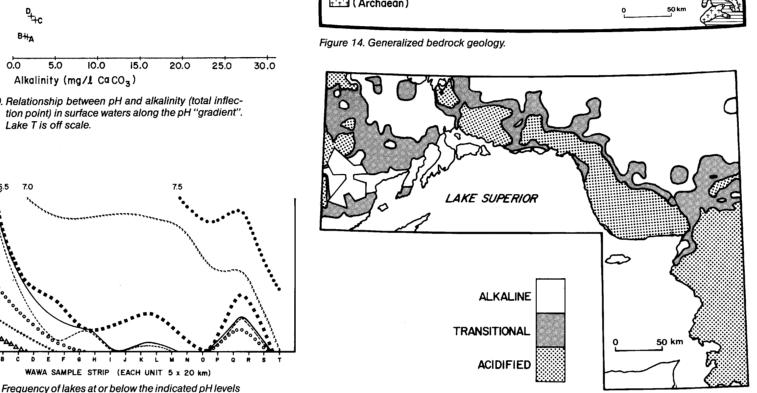
Figure 11. Frequency of lakes at or below the indicated pH levels

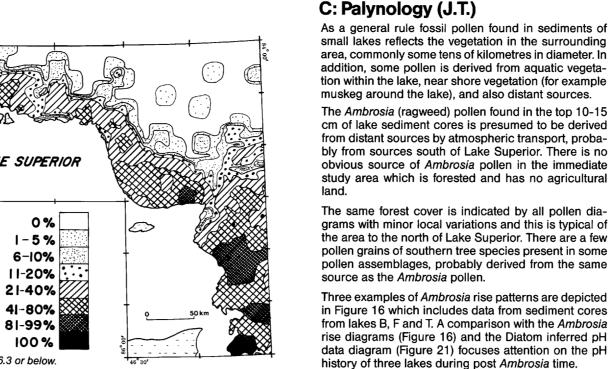
along Wawa Sampling Strip.

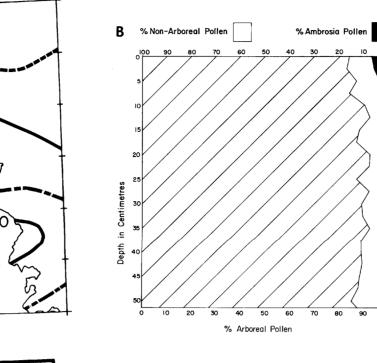


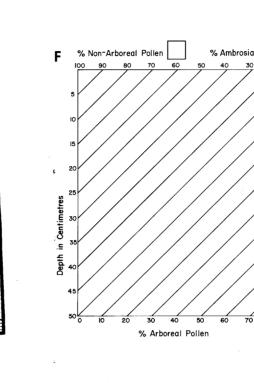
NO DATA



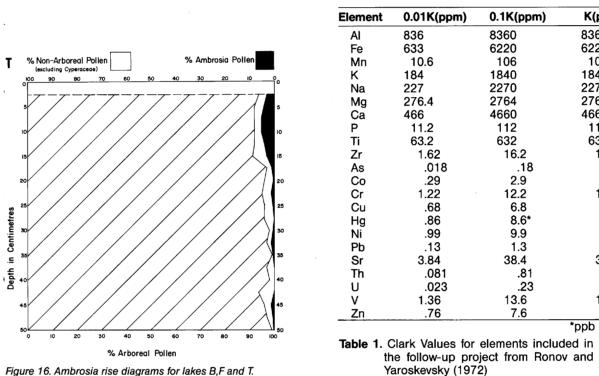








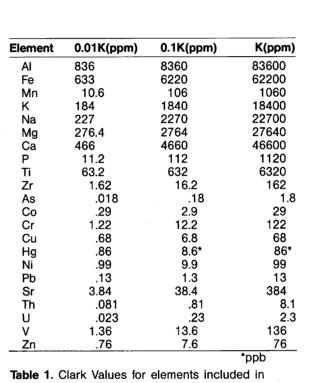
% Arboreal Pollen



## D: Geochemistry of lake sediment

7. Prior to the commencement of the field work it was envisaged that some elements would show an increase in abundance in post Ambrosia time, some a decrease majority remain at the same level. (Figure 17). In order to facilitate comparisons between the abundance of elements within the same core and from core to core, the weight percent data as received from the mistry laboratory (i.e. in % or ppm) was transformed Clarke (K) units by dividing the analytical result (in parts per million) by the estimate for the abundance for the element in the Earth's Crust (also in parts per million). Data for Lake B, whose water was measured at a pH of 5.0 and Lake T whose water was measured at a pH of 8.2, are included here as examples of abundance eochemistry for typical lake sediment cores. (Table 2 and Table 3). Geochemical data sets for all the elements listed in Table 1 for sediment cores from all 20 lakes are included in the Open File Report (No 5342), together with details of the techniques used. During the 1980 project the sample interval for all lake sediment cores was set at 2.5 cm making 20 samples

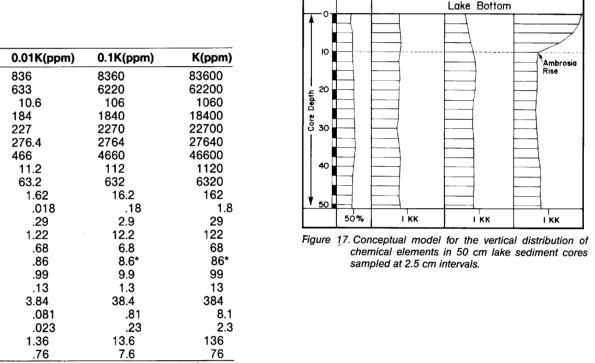
error of the methods.



The conceptual model for the vertical distribution of an element in a lake sediment core is presented in Figure owing to increased mobility due to Acid Rain and the

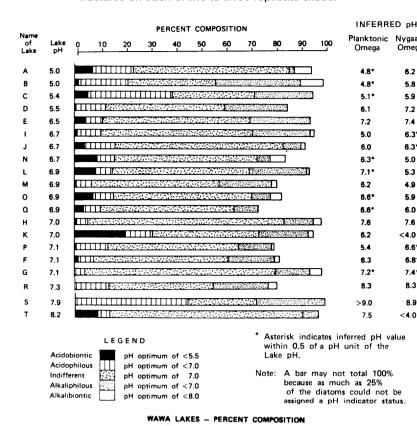
within a 50 cm core (Tables 2 and 3). In most cores the top 4 samples were located in the post Ambrosia portion of the core. Let us consider briefly patterns for elements in cores from lake B (Table 2) and Lake 1 -Both the wet weight and the dry weight of the cores tend to increase down core but such variations are slight compared with the errors involved. -The Loss on Ignition in samples of both cores decreases slightly down core as might be expected. -Aluminium is slightly lower in post compared with pre Ambrosia material in core B whereas there is an increased level of this element in the post Ambrosia of -Calcium increases slightly down core in core B and is extremely high in Lake T as expected. -Phosphorus increases slightly down core B and remains relatively constant in core T but is high in the surface sample from this core. -Arsenic is enhanced in the top 6 cm of core B with a sharp positive gradient of concentration. A similar gradient occurs in core T except that the pre Ambro sia material has a higher content than in core B. -Chromium is slightly higher in core B compared with core T but both cores show a uniform level close to the

-Copper is slightly enhanced in the top 5 cm of core B and this pattern is somewhat more pronounced in -Mercury increases slightly upwards in both cores although the overall level is higher in core B. Both cores have a sharp increase in mercury, in post Ambrosia time. -Nickel is relatively uniform in both cores and at the same general level of concentration. Lead, like arsenic, sharply increases in late pre Ambrosia time and in post Ambrosia time. This is considered to be an anthropogenic effect. -Uranium is relatively uniform in both cores except i the top sample which has over 2 K in the core 1 sample compared with around 1 K lower down and 0.87 K in core B compared 1.5 K lower down. -Vanadium is relatively uniform in content in both cores. —Zinc is like Arsenic and Lead in having a positive concentration gradient in samples laid down in post Ambrosia time.



#### Variance associated with the estimation of pH from Diatom

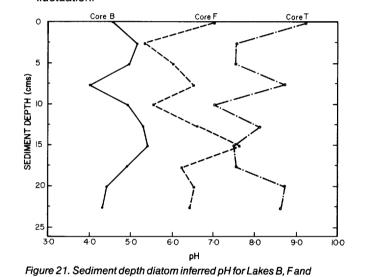
When six hundred frustules were counted for each of two replicate slides, the average pH ranged between ±0.4 pH units of the mean. Although the precision of this estimate can be improved slightly by increasing the number of frustules to 2,000 per slide, and the number of slides to five (pH = mean  $\pm$  0.2 of a pH unit), we fee that the added precision does not warrant the enormous increase in expended effort. In addition, accuracy may not improve significantly with increased replication. For this reason, we recommend counting 600 frustules on each of two to three replicate slides.



IN TERMS OF pH PREFERENCE Figure 20. Percent change in composition of lakes A to T with

#### Diatom inferred pH for three Wawa study lakes

Three lakes were chosen for diatom analysis on the basis of their location in the 100 km long transect. Lake B was a clearwater, poorly buffered lake at low pH near the start of the transect. Lake F was a humic lake of neutral pH in the central area of the transect and lake T was located furthest from Lake Superior in a carbonate rich clay overburden area. Cesium-137 data indicated that the top 2 cm of sediment in each of the replicated cores taken from these three lakes represents an age of roughly 10 to 15 years. Thus, it is evident that during the last 10-15 years, only lake B was acidifying. The diatom inferred oH has a precision of approximately ½ a pH unit. herefore, it is not surprising that the diatom inferred pH of Lake B at 0 cm (4.6) is not identical to the pH we field pH of the lake ws 4.5. The precision of the field pH technique was fairly high (0.1 of a pH unit). However. seasonal variation in pH may exceed 0.5 of a pH unit. The surface sediment diatom inferred pH is based on a composite sample of the average pH of the lake over the last five years. For this reason it reflects long term trends while ignoring or averaging out short term seasonal



Lake B reached its lowest level (pH 4.0 at a depth of 8

cm) roughly 40 years ago (according to Cesium-137

projections). Possibly a forest fire or logging operation

caused this decrease in pH at that time. Further work is

inferred by diatom analysis and the actual changes that

The diatom inferred pH of Lake F based on its surface sediments was 6.9 (Figure 21). The observed pH was

'.1. Over the last 10-15 years, Lake F appears to be pecoming less acid. In 1978 the Ontario Geological

Survey measured a pH of 6.6 in Lake Findicating that its

pH has shifted over half a unit in pH in just two years

The diatom inferred pH pattern supports this observa-

tion of rapid de-acidification. The reasons for this shift

The lowest diatom inferrered pH of this humic lake was

Increase in the amount of humic matter generated in

and around the lake will act to alter its buffering

capacity, according to recent studies. Further study is

clearly needed to better understand the reason for the

Lake Tranged in diatom inferred pH from a low of 7.0 to

a high of 8.8. During the last 10-15 years it appears to

be becoming more alkaline. In 1978 its observed

was 8.8 while at 2 cm it was 7.8 confirming the above

trend of increasing pH. The fact that even well buffered

lakes such as "T" may change 1-2 pH units over a 200

year history was unexpected. Classically, these lakes

have been thought to be fairly pH stable due to their

summer pH was 8.0 while in 1980 its summer pH was

reported as 8.2. The diatom inferred pH at the surface

large shifts in pH over the last 200 years in Lake F.

5.4 and the highest diatom inferred pH was 7.8.

and those preceeding it (Figure 21) are not known.

planned to permit us to pin down the changes in pH as

have been recorded in the lake's watershed.

### T, Wawa Sampling Strip.

out, accumulating in the lake's sediments. Therefore, it is possible to take a sediment core from a lake and use it to analyze the change in diatom species composition a successively deeper, and hence older, periods in the lake's past. It should also be possible to infer the pH o any lake at different periods (depths) in the lake's pas from the ratio of acid-loving diatoms (acidophilic to acidobiontic) in the surface sediments of the twenty Wawa study lakes. These lakes ranged in pH from 4.6 to 8.2, in elevation from 312-444 m above mean sea level, in surface area from 0.03 to 3.0 km<sup>2</sup>, in depth from 2 to 42 m and in total inflection point alkalinity from 1-180 microequivalents/litre.

Year after year, diatoms growing in a lake die and settle

Figure 18. Fingerprint diagrams for Arsenic and Lead in lake

E: Diatom inferred pH (M.D.)

sediment cores from the Wawa sampling strip.

## Diatom indicators of lake pH

 4.21
 44.8
 0.1127
 5.1116
 0.6402
 1.056
 0.0780
 0.1626
 0.3605
 0.189
 0.870
 0.0820
 0.2247

 7.80
 43.8
 0.1217
 0.0427
 0.6545
 1.056
 0.1467
 0.2768
 0.3140
 0.194
 0.870
 0.1506
 0.5368

 6.08
 43.4
 0.1108
 5.1760
 1.7786
 1.222
 0.0874
 0.1950
 0.3605
 0.204
 0.244
 0.1087
 0.0976
 0.3763

 5.79
 43.4
 0.1360
 4.6524
 0.6893
 1.278
 0.1012
 0.1781
 0.5233
 0.219
 0.244
 0.1225
 0.3000

Table 3. Sample weight data, loss on ignition and element abundance data for each of 20 subsamples for Core T

n summary, the vertical distribution patterns for ele-

ments in 50 cm lake sediment core samples at 2.5 cr

intervals exhibit characteristic shapes similar to those

shown on Figure 17. Elements which appear to be

Because the patterns for arsenic and lead appeared t

show an increase in content in late pre Ambrosia as well

as in more recent time, sediment fingerprint diagrams

lakes were drawn (Figure 18). This summary of the data

indicates that arsenic has increased gradually in all

lakes during both pre and post Ambrosia time. In the

case of lead a similar increase is seen which is most

This interpretation should be treated with caution and

Class A Class B Class

marked in the lakes A. B. C and D in post Ambrosia tim

for the content of both elements (in K units) in all 2

copper, lead, mercury and zinc

requires verification.

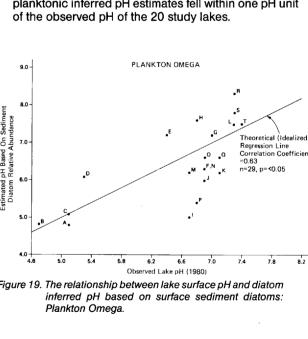
enhanced in post Ambrosia time include arsenic,

The percent composition of acid and alkaline-loving diatom species changes as one travels along the Wawa sampling strip from lakes A to T. (Figure 20). In general the more acidobiontic and acidophilic diatom species in a lake's surface sediments, the lower its pH. However. lakes K and T were obvious exceptions to this generalization. If only the planktonic diatoms were used in the calculations of lake pH from the Nygaard Index the correlation between lake pH and diatom inferred pH was better than if both benthic and planktonic diatoms were considered together (Figures 19 and 20).

## Nygaard Omega vs Plankton

When the pH was estimated from the 20 study lakes, using the Nygaard omega formula (Nygaard 1956) the diatom inferred pH was consistently higher than the observed lake pH (Figure 20). When the omega value was calculated by omitting the benthic diatom taxa, a significant correlation (p 0.05) was recorded for the planktonic diatom inferred pH regressed against the observed lake pH. Thus the pH of a lake's surface is better reflected by its plantonic diatoms than its benthic diatoms because the benthic diatoms inhabit a portion of the lake where the pH differs substantially from that of the lake's open water environment.

Forty-one percent of the study lakes had a summer pH within one-half a pH unit of the planktonic diatom inferred pH while only 35% of the study lakes had pH values which fell within half a pH unit of the observed pH. (Figure 20). Yearly, three-quarters (74%) of the planktonic inferred pH estimates fell within one pH unit



#### 1. The pH pattern in surface lake waters is verifiable from year to year even though the absolute pH values vary from year to year. 2. Regional geochemical element abundance patterns in sediment collected deeper than 25 cm below the lake bottom are uniform and repeatable.

huge buffering capacity.

3. Alkalinity of surface lake waters relates to geological conditions within the catchment area. It is low in granitic areas, medium in areas underlain by metasediments and metavolcanics and high in areas of carbonate-rich volcanics. Hence, geology usually determines the alkalinity and pH of lake waters. 4. Palynological investigations of center lake sediment cores confirmed that the Ambrosia rise can be letected in lakes in the Wawa area. Arsenic, Lead, Mercury, Zinc and, possibly Copper levels increase in lake sediment cores in post Ambrosia time probably due to anthropogenic effects although some other mechanism may be involved for some elements. 6. The "Diatom inferred pH" method as tried on 3 cores shows promise of being an important component of top of the lake series in a given catchment area are

"Acid Rain" research. 7. There is some evidence that small lake basins at the more susceptible to Acid Rain than lakes further down in the catchment. 8. Among the softwater lakes (i.e. those with low total dissolved solids) there are two types, one brown in colour due to humic substances, it is less easily acidified than the other, which is clear.

## nferred pH measurements

1983: A Comparison between Diatom Inferred pH Changes and Diatom Populations in Brownwater and Clearwater Lakes. Brock University for M.Sc. p. 194. (July, 1983)

p. 169. (May, 1983) 1983: A Comparative Study of the Change in Diatom inferred pH of a Staircase of Lakes in the Algoma District, Northern Ontario. Brock University for

> This sheet was compiled from material selected from OGS Open File Reports 5342 (Fortescue et al., 1981) and OFR 5483 (Fortescue et al., 1984). Sections of this sheet written by other members of the team are indicated beside the titles. The initials I.T. refers to lan Thomson, J.T. to J. Terasmae, M.D. to M. Dickman and J.F. to J. Fortescue.

Every possible effort has been made to ensure the accuracy of the information presented on this map: however, the Ontario Ministry of Natural Resources does not assume any liability for errors that may occur. Users may wish to verify critical information; sources include both the references listed here, and information on file at the Resident or Regional Geologist's office and the Mining Recorder's office nearest the map-area.

Information from this publication may be quoted if credit is given. It is recommended that reference be made in the following form: Fortescue, J.A.C. 1984: Interdisciplinary Research for an Environmental Component (Acid Rain) in Regional Geochemical Sur-

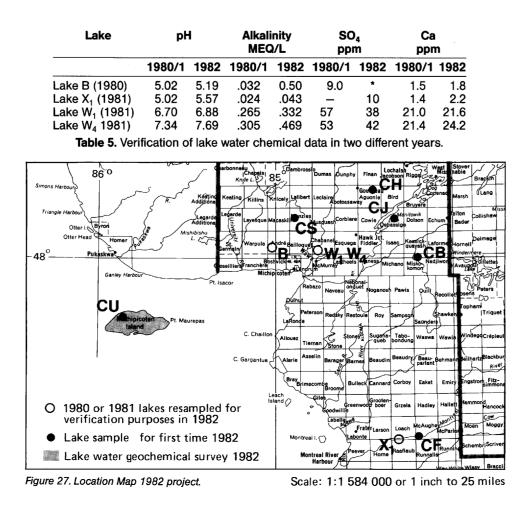
## THE 1982 PROJECT

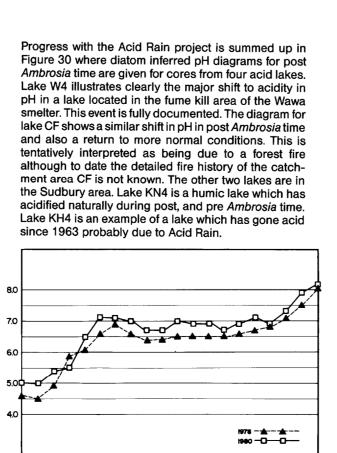
The 1982 project: Verification and Standardization

As a result of the interpretation of the 1980 and 1981 data it became clear that effort was needed to verify and standardize the performance of the different analytical techniques in order to obtain the most reliable data Another aspect of this activity was to examine a relatively small number of new lakes in order to further clarify the data collection process particularly under marginal conditions-for example in an old tailings pond. The lakes sampled during the 1982 project are indicated in Figure 27. Perhaps the most important verification study of the whole project is shown in Figure 28 where the surface water pH data from the 1978 reconnaissance geochemical map are plotted with the 1980 data from the same lakes which are located along the "pH gradient". Verification of a different kind is included in Figure 29 where element abundance data together with diatom inferred pH data (where available) for eight lakes with different pH of their waters. This diagram demonstrates that the methodology for multi-element chemical analysis of small (i.e. 0.5 cm) subsamples of lake sediment core materials is appropriate for describing details of the multi-element patterns. The figure also illustrates the diatom inferred pH history for the lakes and the sample to sample variation expected in this method. An example of the advantage of multi-element geochemical data (transformed to Clarkes) is shown in Core B (Figure 29) where all elements show effects of compac tion of the core. If only calcium had been determined.

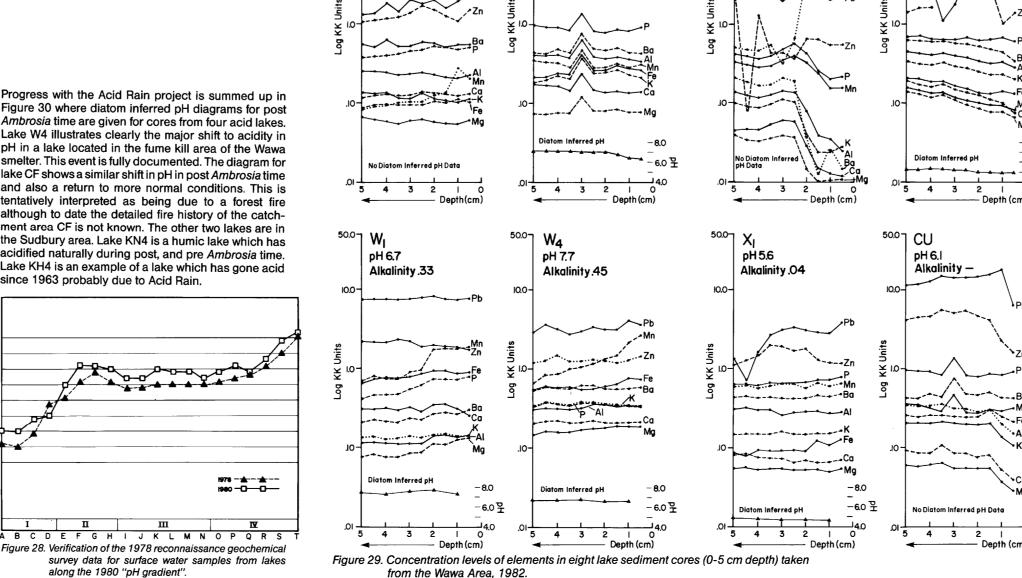
one might think the concentration gradient might be

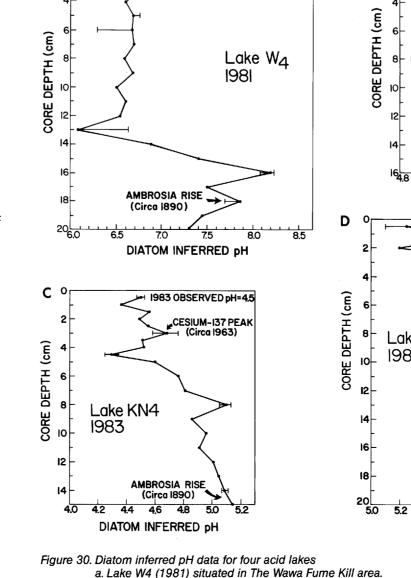
due to the effects of Acid Rain.



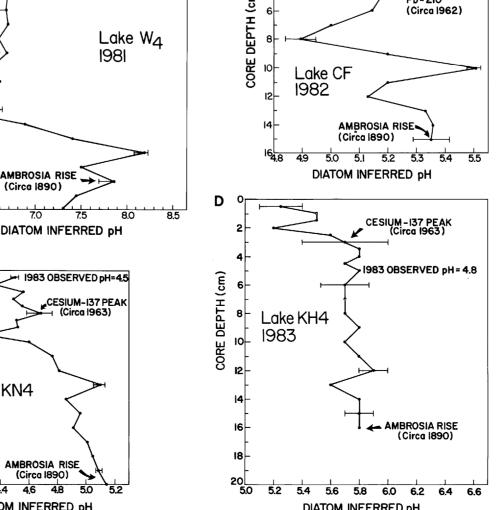


along the 1980 "pH gradient".





tion of humic acids.



b. Lake CF (1982) showing a pH change due to natural causes (i.e. a forest fire).

d. Lake KH4 (Sudbury 1983) which has gone acid since 1963

c. Lake KN4 (Sudbury Area 1983) which is going acid naturally due to an accumula-

DIATOM INFERRED pH

1982 OBSERVED pH=5.3

by Acid Rain which are as effective as palynology and diatom inferred pH but are less time consuming and 4. The Wawa project data base provides a unique opportunity to continue this research to a successful conclusion. Using an approach similar to that used

study of palynology and diatom inferred pH are more

complicated and not practical as components of

Further studies are required to develop techniques

for the identification and description of lakes affected

regional geochemical surveys.

1. In general, the methodology developed during the

## References

project for surface water chemistry, sediment geo 1955: A field method for the determination of ammochemistry, palynology and diatom inferred pH meanium citrate soluble heavy metals in soils and surements is suitable for inclusion in regional lake alluvium, Economic Geology 50(5), p. 533-541. sediment surveys and is capable of distinguishing Coker, W.B. and Shilts, W.W. between acid lakes which are natural and those 1979: Laucustrine Geochemistry around the north which have been affected by man's activities. shore of Lake Superior: Implications for Evalua-2. The surface water chemistry and the multi-element tion of the Effects of Acid Precipitation p.1-15 in geochemistry of the lake sediment core samples is Current Research, Part C Geol. Surv. of Canada, relatively simple to carry out and could be incorporated in future regional geochemical surveys. The

Dickman, M., Dixit, S., Fortescue, J.A.C., Barlow, R., and In Press: Diatoms as indicators of the rate of lake acidifi cation; Water, Air and Soil pollution. Volume 20. Dickman, M., and Fortescue, J.A.C. In Press: Rates of Lake Acidification Inferred from Sediment Diatoms for 8 Lakes located north of Lake Superior, Canada. Paper accepted for publication

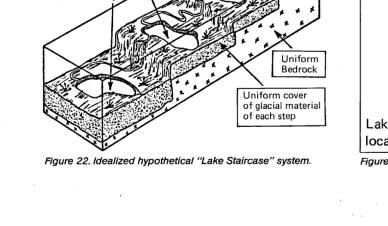
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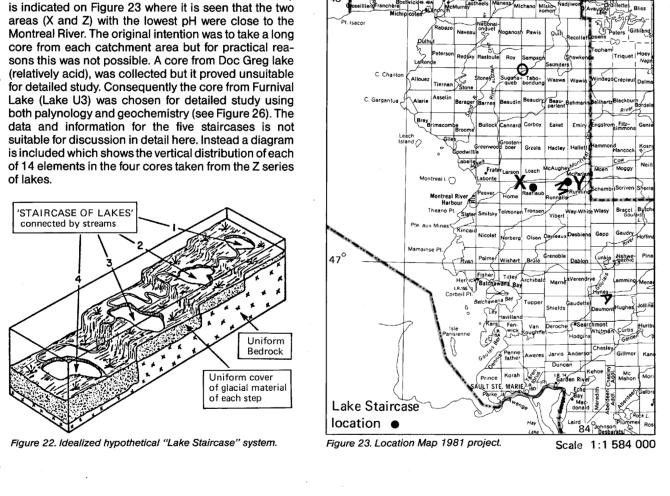
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Reinhold, New York.

vevs (Wawa Area), Algoma District, Ontario Geological Survey Map 80 713, Geochemical Series, compiled





mg/CaCO (greenstone) 6.70 13.25 5.18 (calcareous drift) Table 4. Surface water chemical data for staircase lakes.

pollution relatively uniform for all four Figure 24. Listing of the variation in the principal parameters in a hypothetical lake staircase suitable for inclusion in the 1981 Follow-up Level study in the Wawa area.

in area including al four lake basins Effects of airborne

Increases in area and depth Uniform lithology and geochemistry Figure 25. The Z lake staircase: diagrams for diatom inferred pH and element abundance in th post Ambrosia lake sediment core material.

Alkalinity.12

40 4.5 50 5.5 60 40 4.5 60 40 4.5 60 40 4.5 60 40 4.5 60 40 4.5 60 40 4.5 60 40 4.5 60 40 4.5 60 40 4.5 60 4

Figure 15. Principal lake water regimes.

Figure 26. Vertical distribution patterns for Picea, Pinus, and Betula pollen for selected elements in Long Core U3. **Conclusions** 

/ariations in pH and alkalinity of the staircase lakes are In summary, the 1981 project provided much informalisted in Table 4 where the Z lakes are seen to have low tion regarding the pH and geochemical conditions of alkalinity and a pH range of from 5.17 to 5.64 with the the five lake series studied. This information is of top lake having the lowest pH. Diatom inferred pH curves for each lake sediment core taken at 1 cm intervals from 0 to 20 cm down cores and the associated geochemical data for 14 elements are plotted on Figure 25. The data points for individual elements are ioined to make lines when they are situated close ogether and are plotted as points where erratic values In general, the curves for diatom inferred pH and element abundance are typical for those encountered in four of the catchment areas. In the W catchment area increase in copper and decrease in most other elefor iron manganese and certain other elements are

have been going acid during the recent past. Note that

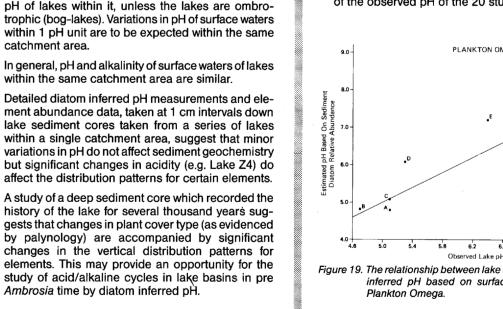
the change in pH is accompanied by changes in the

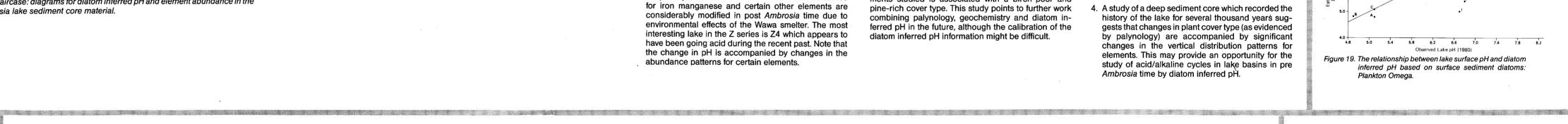
abundance patterns for certain elements.

1981 OBSERVED pH=7.3

considerable importance in planning further regional geochemical surveys in the area and is also important in relation to the acid rain problem. The possibility of using lake sediment cores for diatom inferred pH studies in pre Ambrosia time, particularly in relation to plant cover type changes related to climatic change since the melting of the ice in the area some 9000 years B.P., was proven on the basis of the data for palynology and element abundance derived from the deep core from Furnival lake (Figure 25), where the ments studied is associated with a birch-poor and considerably modified in post *Ambrosia* time due to combining palynology, geochemistry and diatom inenvironmental effects of the Wawa smelter. The most ferred pH in the future, although the calibration of the interesting lake in the Z series is Z4 which appears to diatom inferred pH information might be difficult.

. Geology underlying the catchment area governs the pH of lakes within it, unless the lakes are ombrotrophic (bog-lakes). Variations in pH of surface waters within 1 pH unit are to be expected within the same catchment area. 2. In general, pH and alkalinity of surface waters of lakes within the same catchment area are similar. Detailed diatom inferred pH measurements and element abundance data, taken at 1 cm intervals down lake sediment cores taken from a series of lakes within a single catchment area, suggest that minor variations in pH do not affect sediment geochemistry but significant changes in acidity (e.g. Lake Z4) do affect the distribution patterns for certain elements. pine-rich cover type. This study points to further work 4. A study of a deep sediment core which recorded the history of the lake for several thousand year's suggests that changes in plant cover type (as evidenced by palynology) are accompanied by significant changes in the vertical distribution patterns for





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