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Some Paleolimnological Aspects of the Most Recent Sediments of Lac Laflamme (Laurentides Provincial Park, Quebec) in Relation to Atmospheric Transportation of Pollutants

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Abstract

The present paleolimnological study, which deals essentially with the geochemical and biological characteristics of the most recent sediments of Lac Laflamme, is part of an integrated research program recently initiated by Environment Canada. This research program is aimed at achieving a better understanding of the effects produced on the environment by the fallout of pollutants transported over long distances in the atmosphere.

This report deals with the geochronological and geochemical aspects, and with the composition and abundance of the fossil groups of algae and crustaceans over time.

The stratigraphic increase in ^{137}Cs, Na, Cu, S, Ca, Hg, Ni, Pb and Zn, beginning primarily in the levels corresponding to the 1940s, reflects the quantities of these elements released into the atmosphere by various anthropogenic activities. However, for the same period of time, there is a slight decline in Al and Ca levels in the sediments of Lac Laflamme, which may be attributable to the greater mobility of these elements as a result of the effects of precipitation acidification.

To date, the high capacity of the loose sediments in the lake for ion exchange has prevented acidification of the lake's waters, which still maintain a pH level of approximately 6.1. This neutralization capacity has thus enabled the paleocommunities of algae and cladocerans to remain in equilibrium over the past several hundred years.

Résumé

La présente étude paléolimnologique, qui traite essentiellement des caractéristiques géochimiques et biologiques des sédiments les plus récents du lac Laflamme, fait partie d'un programme de recherche intégré qui a été lancé dernièrement par Environnement Canada. Ce programme de recherche vise à mieux comprendre les effets provoqués sur l'environnement par les retombées de substances polluantes transportées sur de longues distances par voies atmosphériques.

Les aspects géochronologiques, géochimiques, ainsi que la composition et l'abondance des assemblages fossiles d'algues et de crustacés en fonction du temps font l'objet du présent rapport.

L'augmentation stratigraphique du ^{137}Cs, du Na, du Cu, du S, du Ca, du Hg, du Ni, du Pb et du Zn et ce, principalement à partir des niveaux contemporains des années 1940, reflète les quantités émises de ceux-ci dans l'atmosphère par les diverses activités anthropiques. Par contre, pour le même intervalle de temps, on constate une légère diminution dans les sédiments du lac Laflamme de l'Al et du Ca qui serait attribuable à une plus grande mobilité des ces éléments provoquée par les effets de l'acidification des précipitations.

La grande capacité d'échange ionique des sédiments meubles du bassin du lac a jusqu'ici contrecarré l'acidification des eaux du lac dont le pH se maintient encore aux environs de 6.1. Ce pouvoir de neutralisation a donc permis aux paléo-communautés d'algues et de cladocères de se maintenir en équilibre depuis les quelque cent dernières années.

Introduction

The transportation of atmospheric pollutants over long distances and the resulting acid precipitation are facts which are now recognized scientifically and politically. In the Scandinavian countries, a number of studies dealing with the chemistry of this precipitation (Barrett and Brodin 1955; De Bary and Junge 1963; Oden 1968; Bolin *et al.* 1971; Oden 1971; Ottar 1972; Dovland *et al.* 1976; Semb 1978) and with its effects on the various ecosystems (Jensen and Snekvik 1972; Almer *et al.* 1974; Grahn *et al.* 1974; Dickson 1975; Gjessing *et al.* 1976; Hendrey and Wright 1976; Hendrey *et al.* 1976; Knabe 1976; Leivestad *et al.* 1976; Malmer 1976; Schoefield 1976; Wright and Gjessing 1976; Grahn 1977) have demonstrated that the deterioration in precipitation quality is increasing in intensity and is being felt over ever wider areas.

More recently, in North America, studies by Linzon (1958), Gorham and Gordon (1960), Thomas (1962), Waller (1963), Beamish and Harvey (1972), Beamish (1974), Likens and Bormann (1974), Beamish *et al.* (1975), Sprules (1975), Dillon *et al.* (1978a), Gronan and Schofield (1979). Baker and Schofield (1980), Dillon (1980), Harvey (1980), Hendrey *et al.* (1980), Jones *et al.* (1980), Schindler *et al.* (1980) and Shaw (1980) have also demonstrated that the long-range transport of airborne pollutants and the effects of acid precipitation on terrestrial and aquatic ecosystems are among the major ecological phenomena of the 1980's facing the North American scientific community.

The cause of this acidification of water bodies lies in the acid precipitation generated by emissions of SO_X and NO_X in such highly industrialized regions as the United Kingdom, Germany, the Sudbury area of Ontario, the U.S.-Canadian Great Lakes and the east coast of the United States.

In Quebec few studies have been performed to date specifically in this area with respect to emissions of SO_x and NO_x from industrial centres. The emission of fluorine into the atmosphere during the process of electrolysis of alumina (Al_2O_3) in the production of aluminum does not appear to have attracted the attention of the scientific community as a potential source of acid rain. Although Quebec has been a major producer of aluminum for a number of years, to date only Leblanc and Comeau (1972) have studied the effects of the fluorine emitted by the Arvida aluminum plant on vegetation. Ouellet and Michaud (unpublished) have found fluorine levels in the snow in the vicinity of the Arvida and Isle-Maligne aluminum plants of 23 ppm, or 1000 times higher than those in areas unaffected by this industry.

In contrast, the effects on the environment of the Murdochville copper smelters have been studied by Robitaille *et al.* (1977) and by Robitaille (1979). Journault-Dupont (1979) has studied the ecological repercussions of the Rouyn-Noranda smelter. In addition, a number of studies (Ouellet 1975; Ouellet and Poulin 1975, 1977; Jones *et al.* 1976; Ouellet 1978; Delisle 1979) have demonstrated the atmospheric transportation of other substances, including Hg and Pb, over the entire area of Quebec. More recently, Auclair *et al.* (1980) and Jones *et al.* (1980) have studied the evolution of acidity in a number of lakes in Quebec.

In 1978, in view of the urgent need for a better understanding of the long-range transport of airborne pollutants and the acid precipitation associated with it, the United States and Canada created an advisory group designed to improve the coordination of research and exchanges of scientific information on long-range atmospheric transport. In Europe, the OECD launched a similar program in 1972, with the final report having been submitted in 1977. The report confirmed that pollutants were in fact being transported over long distances and that the quality of the air in all the countries of Europe has deteriorated significantly as a result of emissions from neighbouring countries. Since 1977, the European Economic Community (EEC) has been involved in a similar program.

Recently, the U.S.-Canadian advisory research group on the long-range transport of airborne pollutants submitted a preliminary report on the present situation in eastern North America. This part of the continent has been identified as the scene of the most serious problem, because of the low neutralization potential of the Precambrian geological substratum and the high level of pollutants originating in the industrial regions of the eastern United States and the U.S.-Canadian Great Lakes area. The transportation of pollutants from the latter region is facilitated by the prevailing westerly winds through the St. Lawrence River valley. As a result of these factors, it appears that nearly all of Quebec north of the St. Lawrence is potentially subject to acidification and hence to irreversible ecological damage.

In order to achieve a better understanding of the effects and repercussions of acid rain on Quebec's terrestrial and aquatic ecosystems, Environment Canada has recently launched an integrated study of these phenomena in the Lac Laflamme watershed, which is located in the southeastern portion of Laurentides Provincial Park.

The present paleolimnological study, which is part of this holistic approach, deals essentially with the characteristics of the most recent lacustrine sediments (0-30 cm) of Lac Laflamme. Its aim is to provide a stratigraphic study of the sediments deposited in this lake over the past century by means of various paleolimnological methods, including geochemistry and the composition and abundance of the phyto- and zooplanktonic fossil communities. The purpose here is to identify certain anthropogenic effects related directly or indirectly to the atmospheric transport of pollutants.

EFFECTS OF WATER ACIDIFICATION ON PLANKTONIC COMMUNITIES

Phytoplankton

A number of studies performed on acidified and non-acidified lakes in Ontario (Conroy 1971; Conroy *et al*. 1976; Kwiatkowski and Roff 1976; Yan and Stokes 1978; Muller 1980; Schindler *et al*. 1980; Stokes 1980), in Norway (Gjessing *et al*. 1976; Hendrey and Wright 1976; Wright and Gjessing 1976) and in Sweden (Hornstrom and Ekstrom 1973; Almer *et al*. 1974; Grahn *et al*. 1974; Dickson 1975) have demonstrated the effects of the acidification of lakes on phytoplanktonic communities. Four principal conclusions emerge from these studies:

—the primary productivity of these lakes declines by a factor of from 2 to 10;

—the diversity and number of species in the various communities declines;

—species tolerant of acid environments dominate the communities, while intolerant species diminish or disappear;

—the increase in water transparency and the reduction in nutrients promotes the development of the benthic plant community.

According to the same studies, it is generally accepted that a pH level of 5-6 is often critical for certain species. The number of species increases when the pH of the environment rises above 5.5, but declines when the acidity drops below this level. It would appear that the increased toxicity of the heavy metals in low-pH aquatic environments plays an important role in controlling the diversity of the species (Altshuller and McBean 1979). According to Leivestad *et al*. (1976), in a study of 55 lakes in Norway, the average number of algae species drops from 75 to 21 in lakes with an average pH of 6.0 and 4.0 respectively.

According to Almer *et al*. (1974), the phytoplanktonic flora of Swedish lakes with neutral pH levels generally consists of 35-45% chlorophytes, 25-30% cyanophytes and 10-15% diatoms and chrysophytes. In contrast, according to the same authors, in lakes having pH levels of about 5, blue-green algae (cyanophytes) and diatoms become less abundant, while dinoflagellates and green algae (chlorophytes) become more abundant. In some acid-stressed lakes in Ontario, two species of dinoflagellates (*Peridinium limbatum* and *P. inconspicuum*) constitute up to 50% of the phytoplanktonic biomass (Yan and Stokes 1978; Stokes 1980).

The typical species dominating the phytoplanktonic community in acid lakes are *Peridinium inconspicuum*, *P. limbatum*, *Gymnodinium* spp., *Ankistrodesmus convolutus*, *Oocystis submariana*, *O. lacustris*, *Dinobryon sertularia*, *D. crenulatum*, *Eunotia* spp., *Tabellaria binolis* and *Amphicampa hemicyclus*. *Mougeotia* spp., *Eunotia lunaris and Tabellaria flocculosa* are the dominant species in the periphytic algae community.

Zooplankton

The pH level affects the zooplanktonic community as well, in terms of both quality and quantity. In this study of 47 mountain lakes in the La Cloche du Nord area, in Ontario, Sprules (1975) has demonstrated that the structure of the zooplanktonic communities is determined largely by the pH and to a lesser extent by the area and depth of the bodies of water concerned. *Mesocyclops edox*, *Cyclops bicuspidatus thomasi*, *Diaptomus minutus*, *Holopedium gibberum*, *Diaphanosoma leuchtenbergianum* and *Bosmina* sp. are the common species found at all pH levels (3.8-7.0). *Tropocyclops prasinus mexicanus*, *Epischura lacustris*, *Diaptomus oregonensis*, *Leptodora kindtii*, *Daphnia galeata mendotae*, *D. retrocurva*, *D. ambigua* and *D. longiremis*, together with certain other rare species, represent 64% of all the species found and are rarely or never encountered at pH levels below 5.0. *Polyphemus pediculus*, *Daphnia catawba* and *D. pulicaria* are found primarily in lakes with low pH levels.

According to the same study, the zooplanktonic communities become more complex as the pH increases. With a pH above 5.0, the communities contain 9 to 16 species; in lakes with a pH of 5.0 or less, the communities include from 1 to 7 species, of which only one or two are dominant. Similar phenomena have been reported in the Scandinavian countries by Almer *et al.* (1974) and by Hanson (1974).

EFFECTS OF POLLUTANTS ON THE QUALITY OF LACUSTRINE SEDIMENTS

The addition of pollutants to a watershed, from terrestrial or atmospheric sources, can affect not only the aquatic communities but also the quality of the sediments of the lacustrine basins. In some cases, when the level of contamination is high enough to affect or endanger the existence of certain species which are capable of leaving fossil traces (diatoms, zooplankton, molluscs, pollen, etc), it is thus possible, using paleolimnological methods, to study various aspects of the evolution of the aquatic environment over long periods of time. The changes brought about by acid rain on the phyto- and zooplanktonic communities should therefore be detectable by qualitative and quantitative study of the remains of these organisms preserved in the sediments. According to Davis and Berge (1980), who have studied the evolution of Diatoma fossils in a number of Norwegian lakes over a stratigraphic interval of 300 years, the acidobiontic species (optimum pH < 5.5) such as *Semiorbis hemicyclus, Tabellaria binalis, Anomoeoneis serians, Eunotia bactriana* and *E. microcephala* are significantly more abundant in the most recent sediments sampled. Davis *et al.* (1980) have also reported similar paleolimnological changes in their study of a number of short core-samples of sediments from lakes in New England. In a similar study dealing with the recent evolution of fossil zooplanktonic communities, Brakke (1980) observed a particularly marked reduction in the average number of species in the most recent stratigraphic intervals of certain acidified Norwegian lakes. It appears that acidification has permitted such species as *Alonella nana, A. rustica, A. excisa* and *Rhynchotalona falcota* to become more firmly established in the zooplanktonic community at the expense of *Alona quadrangularis, A. costata, Chydorus sphaericus* and *C. piger.*

In contrast, in certain cases where the level of contamination in the watershed is low, the structure of the communities may remain stable for long periods of time. It is possible nonetheless to detect recent input of foreign substances by atmospheric means directly through geochemical analysis of the sediments. Ouellet and Poulin (1975, 1976, 1977), Herron *et al.* (1976), Davis and Norton (1978), Norton *et al.* (1978) and Delmas and Legrand (1980) have demonstrated that atmospheric transportation of trace metals has become an intercontinental phenomenon and that concentrations of certain elements have been rising increasingly rapidly for more than a century.

DESCRIPTION OF THE STUDY SITE

Lac Laflamme is located (47°19′; 71°07′) in the southern portion of Laurentides Provincial Park, within the Montmorency forest, approximately 90 km north of Quebec City. The geology of this region is complex and as yet relatively unknown. The major portion of the substratum is composed of granitic and igneous Precambrian rocks. Loose deposits, of glacial and fluvioglacial origin, cover the crystalline substratum. These deposits are thicker at low altitudes and frequently absent in the higher areas. Annual precipitation in this region is approximately 1520 mm, and the average annual temperature is 0°C.

The Montmorency forest is part of the Laurentian-Onatchiway forest region (Rowe 1959). It is characterized by coniferous forests dominated by balsam fir and black spruce in association wth white birch and white spruce.

Lac Laflamme lies at an altitude of approximately 800 m, in the centre-east portion of the Montmorency River basin. The area of the lake's watershed is approximately 0.69 km^2, while that of the lake is 0.06 km^2. The lake is generally oval, with a maximum depth of only 4 m. Its banks are primarily organic and the dominant plant associations include alders and the marshy stands of spruce at Ledum. Sphagnum spruce forests, last logged during the winter of 1943-44 (personal communication, Mr. Paul Boulianne), dominate the entire basin of the lake.

During the summer, hydromacrophytes such as *Nuphar, Nymphea, Potamogeton, Chara,* and *Myriophyllum* occupy nearly 20% of the lake's surface area. According to Jones and Bisson (1980), who give a detailed description of the chemistry of the waters and snow of this lake, the pH is about 6.1, while the average conductivity is approximately 35 μmhos/cm.

Methods

SAMPLING

On January 28, 1980, stratigraphic samples of the first 27 cm of organic sediments of Lac Laflamme were taken by means of an Ekman bucket (30 x 30 x 30 cm), through a 1-m^2 opening in the ice cover. This area represented the geometric centre of the lake, where the water reached a maximum depth of 4 m. The stratigraphic column of sediments collected was sectioned off on the spot into intervals of 0.5 cm. In the laboratory, the sediments were stored at 4°C whenever possible.

^{137} CESIUM

Measurements of ^{137}Cs were performed on a sample of approximately 15 g placed in a plastic container, by means of a 7.5-cm-diameter counting tube connected to a 512-channel analyser. The efficiency of the NaI (T1) crystal in photopic detection of γ emission at 662 keV was established at 26% from standard sediments. Counting time ranged from 45 min to 8 h, depending on the ^{137}Cs content.

GEOCHEMISTRY

The pH of the sediments was assessed in the laboratory by means of a pH meter, using 10 g of fresh sample to which 20 ml of 0.015 *M* $CaCl_2$ had been added. After the mixture was shaken for 30 min, it was then allowed to settle for 30 min. The electrode was inserted into the supernatant solution to determine the pH.

Moisture (H_2O) and organic carbon content were assessed by means of the weight loss method, with the samples being heated to 110°C and 550°C successively.

The methods of geochemical analysis are based on procedures used by Guimont and Pichette (1979). For metallic sediments such as Al, Ca, Fe, Mg, Na, Ag, Co, Cu, Mn, Ni, Pb and Zn, approximately 1 g of each sample was dried and calcined at 550°C for one hour. The soluble portions of the elements were extracted by means of concentrated nitric acid for 20 min. These metallic elements were measured by means of a Perkin-Elmer atomic absorption spectrophotometer, model 403.

Total S was analyzed by transforming it into SO_2 by combustion and then quantifying the SO_2 by means of infra-red radiation.

The quantity of Hg was determined by extracting 1 g of each sample by means of sulphuric and nitric acids. The organic material was then destroyed using potassium persulphate and potassium permanganate solutions. Measurements were performed by atomic absorption spectrometry, using the cold vapour technique, on an MAS-50 cold vapour atomic absorption spectrophotometer.

BIOLOGY

Fossil Diatoms

The relative abundance of fossil diatoms was estimated by placing approximately 0.1 mL of a sub-sample of sediments from each of the 18 stratigraphic levels studied on a microscope slide. The presence of each species (taxon) appearing on the slide was quantified in relation to the five different classes. If individuals of the same species appeared 70 times or more in 100 different ocular fields, this species was classified as abundant (a). The other classes of relative abundance were established as follows: 70-50%-common (c); 50-10%-moderate (m); $<$ 10%-rare (r); and if the taxonomic group appeared in the 100 microscopic fields only once, it was reported as "trace" (t).

Fossil diatoms were identified on the basis of the criteria established by Hustedt (1942), Van Heurck (1963), Patrick and Reimer (1966, 1975) and Contant and Duthie (1978). The other algae were identified by means of the criteria used by Prescott (1962), Takahaski (1978) and Smol (1980).

Fossil Crustaceans

The laboratory technique used to determine the number of individuals from different fossil zooplankton species is based on that of Frey (1980). Microscope slides are prepared by digesting 1 or 2 mL of fresh sediments, depending on the density of the organisms, in a 10% KOH solution heated in a water bath. In order to eliminate undesirable large particles, the solution is then strained through a 20-μm mesh screen. A micropipette is used to place a quantity of the solution on a microscope slide. Under the microscope, each animal structure present along the transverses is identified and numbered separately. Identification and microscopic counting continue until the largest structure for each of the species present totals the equivalent of 200 individuals for all species. The fossil crustaceans are identified by means of the criteria established by Frey (1962, 1965, 1976 and 1980), Megard (1967) and Smirnov (1971).

Results

GEOCHEMISTRY

Table 1 gives the geochemical results, together with the detection limit and standard deviation for ^{137}Cs, pH, moisture (H_2O), C, Al, Ca, Fe, Mg, Na, total S, Ag, Co, Cu, Hg, Mn, Ni, Pb and Zn, for 18 stratigraphic intervals.

A comparative illustration of the stratigraphic distribution of these geochemical parameters appears in Figure 1. Parameters showing relatively major variations in stratigraphic abundance (^{137}Cs, Al, Ca, Fe, Na, S, Co, Cu, Hg, Mn, Ni, Pb, Zn) are shown graphically in Figures 2 to 14.

The variables ^{137}Cs, Ni, Pb, Zn, Hg, and to a lesser extent, Al, Ca, Fe, Na, S, Co and Ca, show the most marked stratigraphic fluctuations, primarily after the 12-cm level. In contrast, the other variables, including Mn, pH, H_2O, C, Mg and Ag, show little or no variation over the intervals studied.

BIOLOGY

Fossil Diatoms

The relative abundance of each taxon identified for the 18 stratigraphic intervals from 0-27 cm appears in Table 2. The comments concerning the environmental conditions suggested by the presence of several indicative species are drawn from Patrick and Reimer (1966, 1975) and from Hustedt (1942) and Prescott (1962).

The majority of the 91 taxa identified belong to the large group of the Diatoma. Almost all of these are characteristic of an environment that is slightly acidic and low in mineral substances. *Amphora normanii* and *Navicula americana* are alkalinophilic species which have been identified at certain levels. In addition to the presence of a large number of species that are unaffected by pH conditions, some (approximately 38%) are tychoplanktonic, that is, they come from the littoral zone and are thus largely epiphytic.

In addition to the diatoms, the cyanophytes and chlorophytes are each represented by three taxa, the chrysophytes by seven and the pyrophytes by a single taxon.

The presence of cyanophytes (*Chroococcus* sp., *Oscillatoria Bornetii, O. negra*) in the upper portion of the sample is attributable to their differential preservation over time. This is why they have not been found in the underlying layers of the sample.

In general, there is no marked fluctuation in the abundance and composition of the species in the various stratigraphic levels studied. The fossil groups are dominated primarily by *Gomphonema truncatum* var. *capitatum, Melosira* cf. *excurrens, M. distans, M. islandica, Navicula elginensis* and *Pinnularia acrosphaeria*. Other species of secondary importance are *Dinobryon* sp., *Synura petersenii, Navicula cuspidata, Tabellaria fenestrata* and *T. flocculosa.*

Fossil Crustaceans

The relative abundance of 20 species of crustaceans of the Order Cladocera preserved in the sediments of seven different stratigraphic levels appears in Table 3.

With the exception of *Daphnia catawba*, which is characteristic of the limnetic zone (Bernard and Lagueux 1972), all the species are members of the chydorid family and are found in the shore zone. *Alona affinis, A. quadrangularis, Alonella excisa, A. nana, Chydorus sphaericus* and *Daphnia catawba* are the dominant species in the fossil "community" and represent almost 90% of the total. Species accounting for 2-10% are *Acroperus harpae, Alona costata, A. intermedia, A. circumfimbriata, A. guttata, Chydorus piger* and *Disparalona acutirostris*. The other taxa, none of which exceed 2%, are *Alona rustica, A. exigua, Camptocercus* sp., *Eurycercus* sp., *Pleuroxus denticulatus, Pleuroxus trigonellus* and *Graptoleberis testudinaria*.

Most of the species show no marked change between the stratigraphic levels. Only the relative abundance of *Alonella excisa* (X = 12.66%) and *Daphnia catawba* (X = 20.00%) declines by approximately 50% from the bottom to the top of the stratigraphic interval studied.

Table 1. Stratigraphic distribution of geochemical parameters in the most recent sediments of Lac Laflamme

Depth (cm)	^{137}Cs (pCi/g)	pH	%					ppm										
			H_2O	C	Al	Ca	Fe	Mg	Na	S	Ag	Co	Cu	Hg	Mn	Ni	Pb	Zn
0 - 0.5	6094	4.8	97.9	40.0	0.118	0.34	0.58	560.0	93.0	2500.0	0.01	5.0	13.0	0.175	56.0	11.0	62.0	112.0
0.5- 1.0	4259	4.8																
1.0- 1.5	4416	4.8	93.6	36.0	0.132	0.49	0.56	576.0	74.0	2600.0	0.01	4.0	11.0	0.200	56.0	11.0	49.0	109.0
1.5- 2.0	4273	4.8																
2.0- 2.5	2562	4.8	93.2	37.0	0.132	0.34	0.54	522.0	74.0	2800.0	0.01	4.0	13.0	0.205	54.0	10.0	41.0	113.0
2.5- 3.0	3823	4.8																
3.0- 3.5	2376	4.8	92.4	37.0	0.132	0.48	0.53	566.0	68.0	3000.0	0.01	5.0	11.0	0.200	58.0	10.0	32.0	117.0
3.5- 4.0	2715	4.8																
4.0- 4.5	2287	4.8																
4.5- 5.0	1812	4.8																
5.0- 5.5	1144	4.8																
5.5- 6.0	1654	4.8	91.6	38.0	0.127	0.34	0.53	428.0	49.0	2200.0	0.01	4.0	12.0	0.225	56.0	6.0	30.0	108.0
6.0- 6.5	986	4.8																
6.5- 7.0	1308	4.8																
7.0- 7.5	1171	4.8	91.3	37.0	0.129	0.43	0.52	456.0	52.0	2400.0	0.01	4.0	11.0	0.215	56.0	8.0	30.0	98.0
7.5- 8.0	582	4.8																
8.0- 8.5	735	4.8																
8.5- 9.0	126	4.8	90.4	38.0	0.128	0.33	0.49	414.0	42.0	2200.0	0.01	5.0	9.0	0.205	54.0	6.0	14.0	80.0
9.5-10.0		4.8	91.1	37.0	0.133	0.53	0.49	430.0	45.0	2000.0	0.01	5.0	10.0	0.185	54.0	7.0	8.0	72.0
10.0-10.5	262	4.8																
11.0-11.5		4.8	91.0	35.0	0.154	0.59	0.51	536.0	65.0	2400.0	0.01	3.0	11.0	0.170	54.0	5.0	8.0	67.0
12.0-12.4	127	4.8	91.3	36.0	0.155	0.48	0.52	514.0	56.0	2000.0	0.01	4.0	9.0	0.150	52.0	6.0	2.0	55.0
14.0-14.5		4.8	91.3	35.0	0.159	0.50	0.50	472.0	60.0	1900.0	0.01	3.0	8.0	0.170	54.0	7.0	2.0	52.0
16.0-16.5		4.8	91.0	36.0	0.142	0.50	0.50	416.0	49.0	2400.0	0.01	4.0	10.0	0.155	52.0	6.0	2.0	57.0
18.0-18.5		4.8	90.8	35.0	0.137	0.52	0.52	518.0	47.0	2400.0	0.01	3.0	9.0	0.145	54.0	7.0	2.0	68.0
20.0-20.5		4.8	90.7	35.0	0.138	0.52	0.52	476.0	48.0	2300.0	0.01	4.0	8.0	0.140	50.0	6.0	2.0	58.0
22.0-22.5		4.8	90.2	35.0	0.145	0.53	0.53	558.0	47.0	2100.0	0.01	4.0	9.0	0.125	52.0	7.0	2.0	63.0
24.0-24.5		4.8	89.7	36.0	0.149	0.50	0.50	512.0	60.0	2200.0	0.01	4.0	8.0	0.210	52.0	6.0	2.0	55.0
26.0-26.5		4.8	90.6	35.0	0.140	0.51	0.51	486.0	66.0	2300.0	0.01	2.0	8.0	0.140	50.0	7.0	3.0	48.0
26.5-27.0		4.8	90.8	37.0	0.145	0.50	0.50	504.0	88.0	2300.0	0.01	3.0	9.0	0.200	48.0	7.0	2.0	54.0
Detection limit					0.02	0.02	0.01	1.0	1.0	20.0	0.2	2.0	1.0	0.005	12.0	1.0	2.0	2.0
Standard deviation %	26	0.7	0.06	4.3			4.5					15.0	12.0	13.0	12.0	7.0	14.0	6.0

Table 2. Relative abundance of fossil diatoms in the most recent sediments of Lac Laflamme.
(a = abundant, c = common, m = moderate, r = rare, t = trace)

	Depth (cm)																		
Species	0.5	1.5	2.5	3.5	6.0	7.5	9.0	10.0	11.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	27.0	Comments
CYANOPHYTA																			
Chroococcus sp.	t																		calm lakes and rivers
Oscillatoria Bornetii	m																		shallow lakes and ponds
Oscillatoria negra	m	c	r																
CHLOROPHYTA																			
Cosmarium sp.						t			r										euplanktonic
Franceia Droescheri					c	r	r	r	c-m										
Oocystis sp.			t																
CHRYSOPHYTA																			
Chrysosphaerelia brevispina					t								t						
Chrysophyte (cysts)				m	m	t	r	t		m	c	m	c	r	c	r	r	m	
Mallomonas cf. *fastigata*							t					r				t			
Dinobryon (cysts)	m	m	m-r	c	c	m	r	m	r	m	c	m	c	m	r	m	r	r	
Mallomonas crassisquama										t									
Spiniferomonas cf. *abei*			r	r						t		t	r	r	r	m	m		
Synura petersenii				c	m	m	m-c	m-c	m	m	m	c	m	m	m	m	t	m	
DIATOMACEAE																			
Amphicampa mirabilis	m	r	r							t									alkalinophilic
Amphora cf. *normanii*									r	r					m				epiphytic and well oxygenated waters
Amphora ovalis var. *pediculus*	m		m	m	r			r		m	m	m	r	r	r		m	m	fresh to slightly brackish water
Aloneis ventricosa var. *alpina*										t									
Cocconeis cf. *fluviatilis*								r		t				t	t				
Coscinodiscus sp.		t								r									
Cyclotella bodanica		m			c	m	c		m-c	m	m	m	r	m		r	r	c	
Cymbella heteropleura var. *subrostra*																		r	
Cymbella cuspidata		m	t							t	m	m		r		m		r	slightly acidic to neutral water

Table 2. (Cont.)

Species	Depth (cm) 0.5	1.5	2.5	3.5	6.0	7.5	9.0	10.0	11.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	27.0	Comments
Cymbella irregularis																	t		
Cymbella lunata	m	m	r							r	t	m		m	c	t			
Cymbella minuta										m		r		r	r	m		m	
Cymbella minuta var. *minuta*			r	m	m	r	r	t											pH immaterial, alkalinophilic
Cymbella inaequalis																			oligohalobic, alkalinophilic
Cymbella tumida									r	t									oligohalobic, alkalinophilic
Diploneis elliptica																	t		
Eunotia curvata	r		r		r			t				m		r		r	r	t	acidophilic, cold waters
Eunotia bidentula							r			t	r	m							slightly acidic waters, low in mineral salts
Eunotia maiora							r			t	r	m							slightly acidic waters, low in mineral salts
Eunotia maior var. *maior*								r	t										
Eunotia Naegelii																	t		acidic to neutral waters
Eunotia pectinalis var. *major*	r			r							t								acidic to neutral waters
Eunotia pectinalis var. *ventricosa*				r															waters low in mineral salts
Eunotia praerupta	m	r	t	t				r		t									waters with pH ± neutral
Eunotia soleirolii																		t	slightly acidic waters
Eunotia serra			t			t				t								m	oligotrophic-dystrophic
Eunotia serra var. *diadema*																		t	
Fragilaria construens	r	r	m			m	r	r	m		m	r		m					slightly alkaline waters
Fragilaria pinnata																			
Frustulia rhomboïdes					m		m									r	m	m	slightly acidic waters, oligotrophic waters
Frustulia rhomboïdes var. *crassinervia*			m						m	r							m	c	
Frustulia rhomboïdes var. *saxonica*	r	r	t	t	m	t	r	t	m	r	m	t	t	t	t	t	t	t	pH ± neutral, low in mineral salts

Table 2. (Cont.)

Species	Depth (cm)																		Comments
	0.5	1.5	2.5	3.5	6.0	7.5	9.0	10.0	11.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	27.0	
Frustulia vulgaris			t			r	t				r			t	t				pH ± neutral oligotrophic
Gomphonema angustatum				r							r			t					epiphytic and tychoplanktonic
Gomphonema truncatum var. *turgidum*																			
Gomphonema truncatum var. *capitatum*	r	m	a	m	c	m	c	r	c	c	c	c	c	c	c	c	m	c	oligotrophic
Melosira cf. *excurrens*	r	a	r	t	c	t	c	c	c	r	c	c	c	c	c	c	c	c-a	slightly acidic
Melosira distans	r	t	t	t	c	t	c	c	c	r	c	c	c	c	c	r	c	m	oligohalobic, alkalinophilic
Melosira granulata																			
Melosira islandica	c	c	a	c	c	t	c	c	c	m	c	c	c	c	c	c	r	r	oligotrophic
Melosira sp.				t	t	t	m	c	c										fresh water
Meridion circulare				t							r								running water
Meridion circulare var. *constrictum*						r													running water
Navicula americana		r		m					c	m									alkalinophilic and pH ± neutral
Navicula atomus												r	t	r		m			
Navicula aurora				r															pH ± neutral
Navicula capitata		m	r	r						m	m	m	r		r		m	m	high tolerance
Navicula cuspidata	m	m	m	r	m-c			r-m	r	m	m	c	c	m	r		m	m	high tolerance
Navicula elginensis	c	c	c	c	m	c	m	m	c	c	c	c	c	c	c	c	c	c	high tolerance
Navicula globulifera											t	r							
Navicula mutica var. *cohrii*	m	r	a									r							fresh and brackish waters
Navicula latissima												t	r						
Navicula radiosa			c	m	m		r-m							m	r				common and high tolerance
Navicula schroetieri var. *escambia*											c								
Navicula radiosa var. *tenella*	r	m	m	m								r			r				pH ± neutral
Navicula variostriae																	r		

Table 2. (Cont.)

Species	Depth (cm) 0.5	1.5	2.5	3.5	6.0	7.5	9.0	10.0	11.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	27.0	Comments
Neidium affine var. *undulatum*						r	r				r		t	m					lacustrine
Neidium dubium						t													water and rivers pH immaterial
Neidium gracile aequale									m	m	r	m	m	r	r	r	r	r	lakes and marshes
Neidium hitchcockii	m	r	r	t				t	r		r	t	r						in rivers
Neidium iridis										m									
Neidium iridis var. *amphigomphus*	r	r	m	r		t	r				t	m							pH immaterial and oligosaprobic
Nitzschia acicularis	m	r	m							m								r	pH immaterial
Nitzschia filiformis	m	r	m				m	r		t	r	r	t	t	t		r	r	pH immaterial
Nitzschia palea																			
Nitzschia sp.					r	r	t												pH immaterial
Pinnularia abaujensis	c	m	c	r				c		m				t	t	r			waters low in mineral salts and tychoplanktonic
Pinnularia acrosphaeria	c	a	a	c-a	c	c	m	c-a	c-a	c	a	c	m	c	m	m	m	m	pH ± neutral in lakes and ponds
Pinnularia divergens																	r	r	
Pinnularia gentilis					m	r		r				m		m		r	t		waters low in mineral salts and tychoplanktonic
Pinnularia latevittata														r	r				
Pinnularia maior		m		m	m	m				m		m	m		r	m	r	r	waters low in mineral salts and slightly acidic
Pinnularia maior var. *transversa*																			
Pinnularia nobilis	r	m	a			m	m			t	m			r		m	r	r	waters low in mineral salts and slightly acidic
Pinnularia polyonca			a			m					t	r	r		r				tychoplanktonic
Stauroneis acuta				r					t	r		c	c	c	m	m	m	m	tychoplanktonic and oligohalobic

Table 2. (Cont.)

Species	Depth (cm)																	Comments
	0.5	1.5	2.5	3.5	6.0	7.5	9.0	10.0	11.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	27.0	
Stauroneis acuta var. *acuta*									t				m						streams and lakes
Stauroneis anceps	m					m	m			c	c	m	m	m	m	c	c	mq	eurytrophic and pH immaterial
Stauroneis phoenicentron	r	r	r	r	m	m	r			m-r	t	m			t		t	m	oligohalobic and pH immaterial
Surirella elliptica			m																tychoplanktonic
Surirella linearis	m	m	m	r		t	r						t	r	m			r	tychoplanktonic
Surirella ovalis								t	r										tychoplanktonic
Surirella robusta var. *splendida*	t																	r	tychoplanktonic
Surirella sp. (large)	t	r	m												t				tychoplanktonic
Surirella sp. (small)	m															t	r		euplanktonic
Synedra delicatissima		r																	slightly brackish waters
Synedra radians																			
Synedra sp.							r												
Tabellaria fenestrata	r	r	m	m	r	m-c	m	r	m	t	m	r	r	m	m	r	t	m-r	epiphytic and waters pH ±neutral
Tabellaria flocculosa	r	t	t	m	m	m	r	r	r	m	m	m	r	r	r	r	r	r	high tolerance
Tetracyclus lacustris	r	r	t																
PYRROPHYTA																			
Peridinium sp. plates only											t	t		t					
POLLEN																			
Betula							r	r	r	m	t	r	r			t	m	c-m	
Pinus (large)	r	c	r-m	r			r	r	m	r	m	t	r	r		t	m	c-m	
Pinus (small)							r					t							
Picea																r	c		
Sphagnum (leaf)										t							t		
OTHERS																			
Arcella cf. *vulgaris*						t													ponds
Euglypha sp.								t											
Cladoceran (debris)	t	t				t		t	t										

Table 2. (Cont.)

Species	Depth (cm) 0.5	1.5	2.5	3.5	6.0	7.5	9.0	10.0	11.5	12.5	14.5	16.5	18.5	20.5	22.5	24.5	26.5	27.0	Comments
Fungae	t		r		t	t	t	t											
Ostracodes (valves)	t																		
Needles of rough sponges	r	r	t	t	r	t													
Needles of smooth sponges	r	m	t	t	r	m	m	t	r	r	t	t	t	t	r	t	r	t	

Table 3. Relative abundance of Cladocera by stratigraphic interval in the most recent sediments of Lac Laflamme, Quebec. The percentage of each species is calculated from a total count of approximately 200 individuals per level.

Depth (cm)	*Acroperus harpae*	*Alona affinis*	*Alona costata*	*Alona intermedia*	*Alona quadrangularis*	*Alona rustica*	*Alona circumfimbriata*	*Alona guttata*	*Alonella excisa*	*Alonella exigua*
0.5	3.65	13.54	2.08	0.00	20.83	1.04	13.54	0.00	5.73	1.56
1.5	4.50	17.12	2.70	0.90	13.51	0.00	7.21	0.00	8.11	0.90
3.5	6.25	21.09	3.13	1.56	7.81	0.00	3.91	0.00	9.38	0.00
6.0	4.85	20.39	2.91	0.00	9.71	0.00	5.83	0.97	9.71	0.00
7.5	5.71	25.71	1.43	0.00	12.86	0.00	8.57	1.43	15.00	0.00
11.5	1.39	16.67	0.00	1.39	16.67	0.00	4.86	2.78	15.28	1.39
26.5	3.80	17.72	1.27	2.53	17.72	0.00	5.06	1.27	12.66	1.27

Depth (cm)	*Alonella nana*	*Camptocercus* sp.	*Chydorus sphaericus*	*Chydorus piger*	*Disparalona acutirostris*	*Eurycercus* sp.	*Pleuroxus denticulatus*	*Pleuroxus trigonellus*	*Graptoleberis testudinaria*	*Daphnia catawba*
0.5	14.58	0.00	15.63	3.13	2.08	0.00	1.04	1.04	0.52	9.86
1.5	18.02	0.00	17.12	4.50	3.60	0.00	0.90	0.00	0.90	15.27
3.5	17.19	0.00	16.02	3.91	8.98	0.00	0.00	0.00	0.78	16.34
6.0	15.53	0.00	14.56	3.88	1.43	1.43	0.00	1.43	1.43	19.69
7.5	13.57	0.00	5.71	4.29	1.43	1.43	0.00	1.43	1.43	22.22
11.5	20.14	1.39	13.89	1.39	1.39	0.00	0.00	0.00	1.39	26.15
26.5	16.46	1.27	11.39	2.53	2.53	1.27	0.00	0.00	1.27	20.00

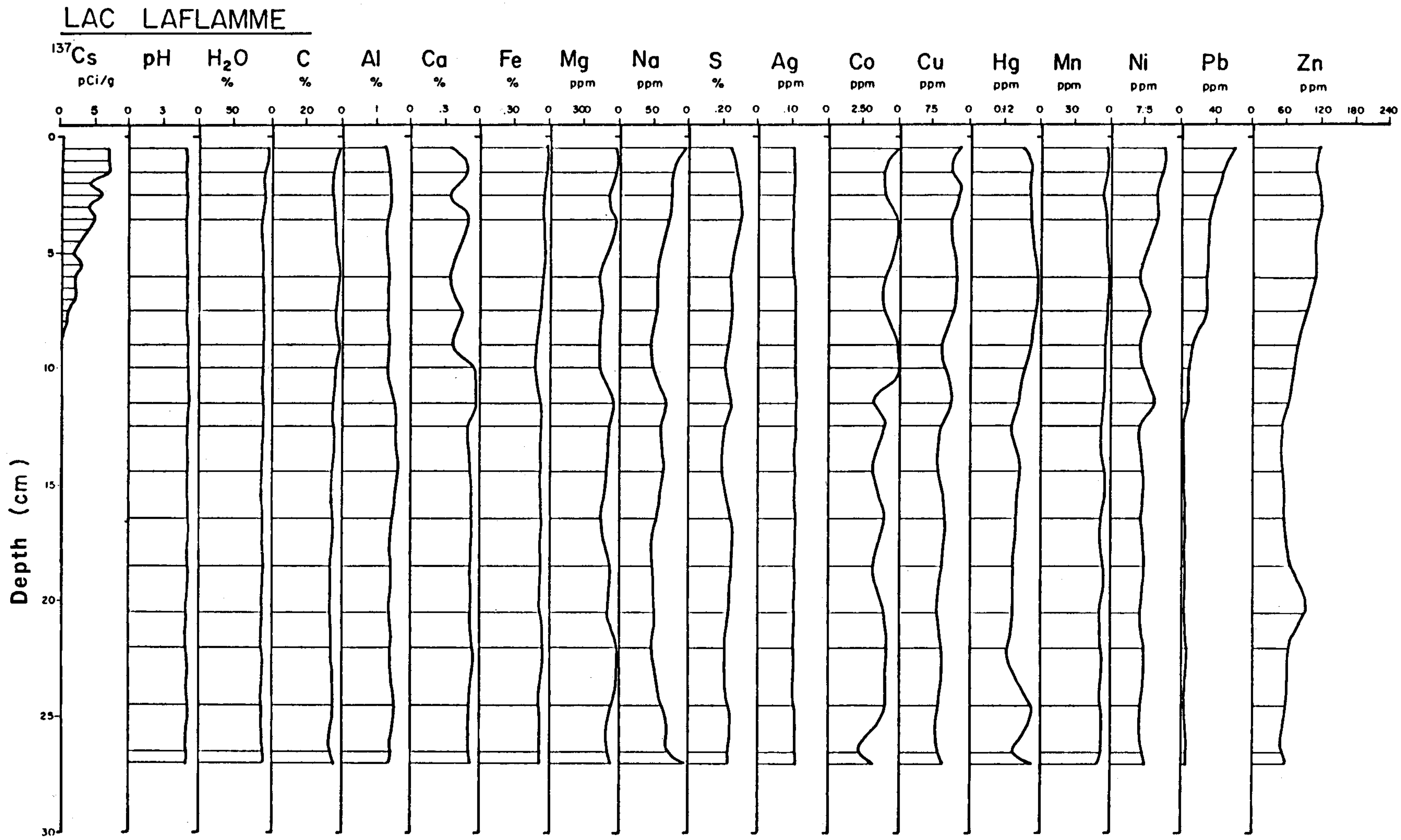

Figure 1. Geochemical diagram of the most recent sediments of Lac Laflamme

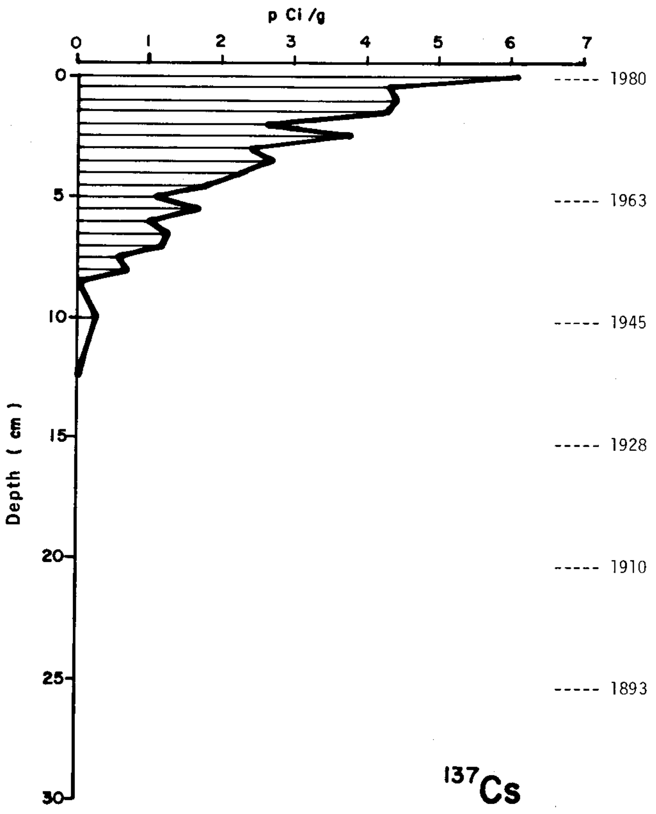

Figure 2. Stratigraphic distribution of ^{137}Cs in the most recent sediments of Lac Laflamme

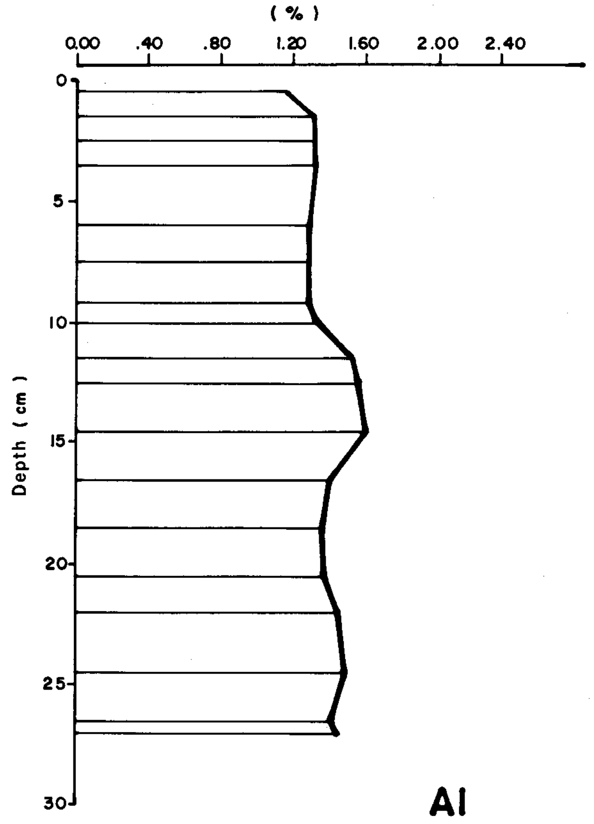

Figure 3. Stratigraphic distribution of Al in the most recent sediments of Lac Laflamme

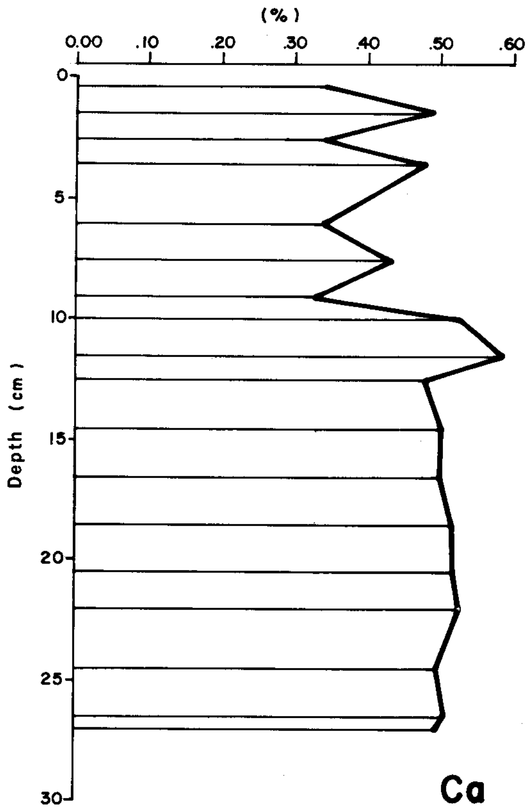

Figure 4. Stratigraphic distribution of Ca in the most recent sediments of Lac Laflamme

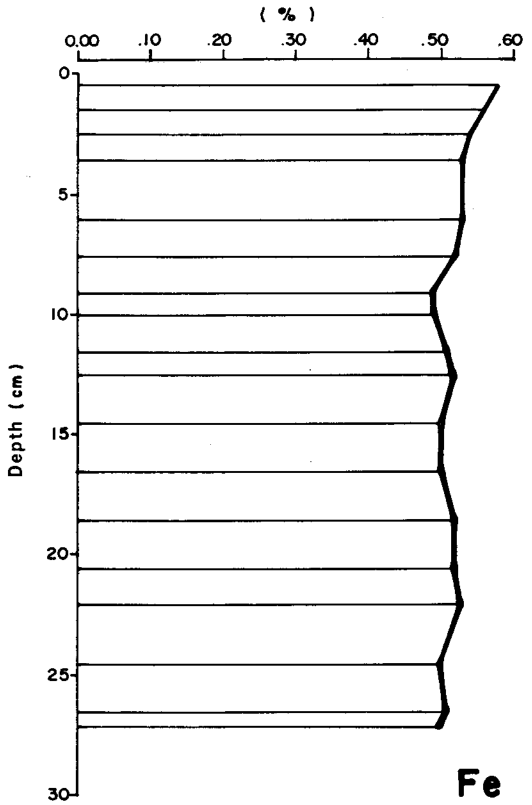

Figure 5. Stratigraphic distribution of Fe in the most recent sediments of Lac Laflamme

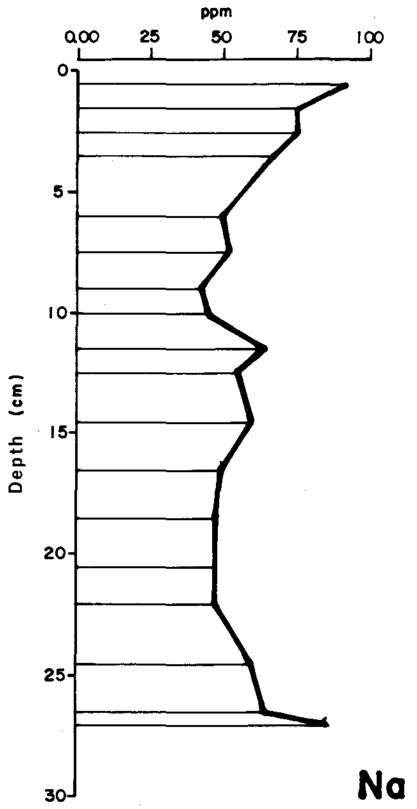

Figure 6. Stratigraphic distribution of Na in the most recent sediments of Lac Laflamme

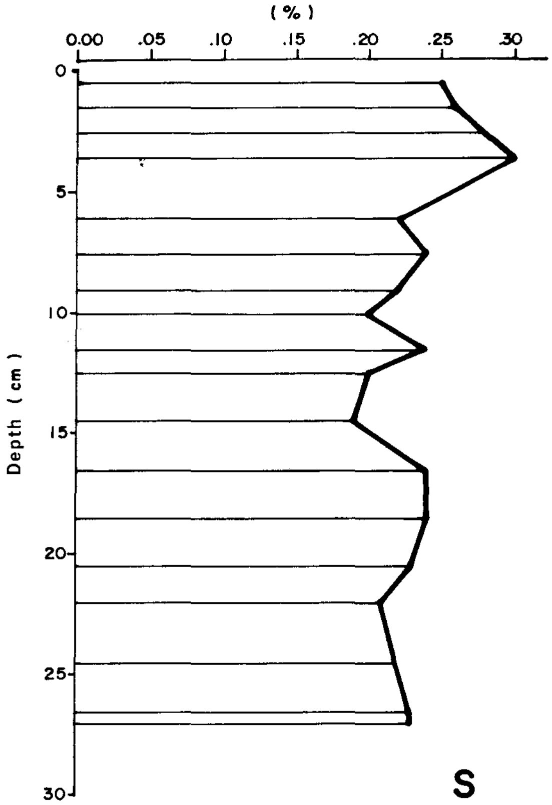

Figure 7. Stratigraphic distribution of S in the most recent sediments of Lac Laflamme

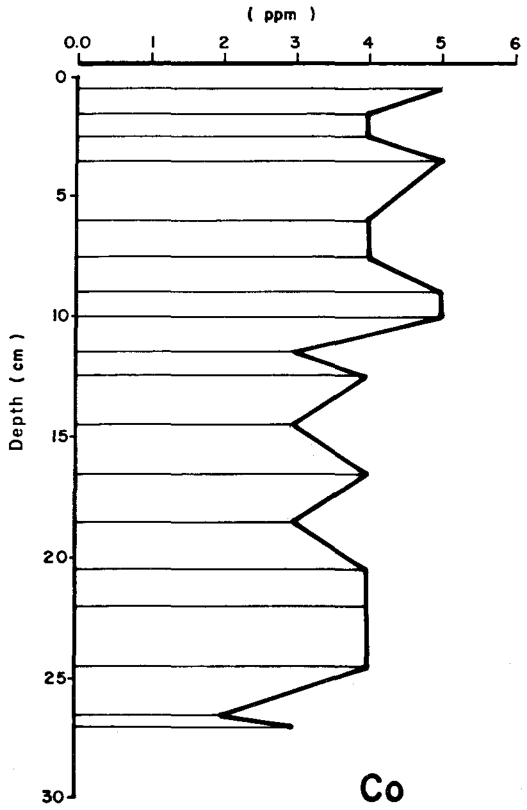

Figure 8. Stratigraphic distribution of Co in the most recent sediments of Lac Laflamme

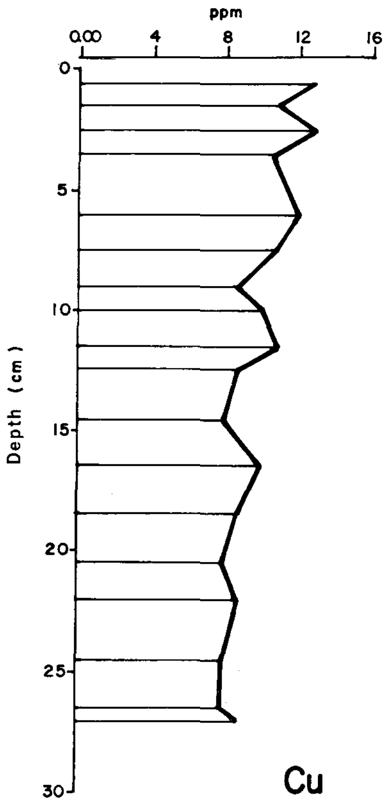

Figure 9. Stratigraphic distribution of Cu in the most recent sediments of Lac Laflamme

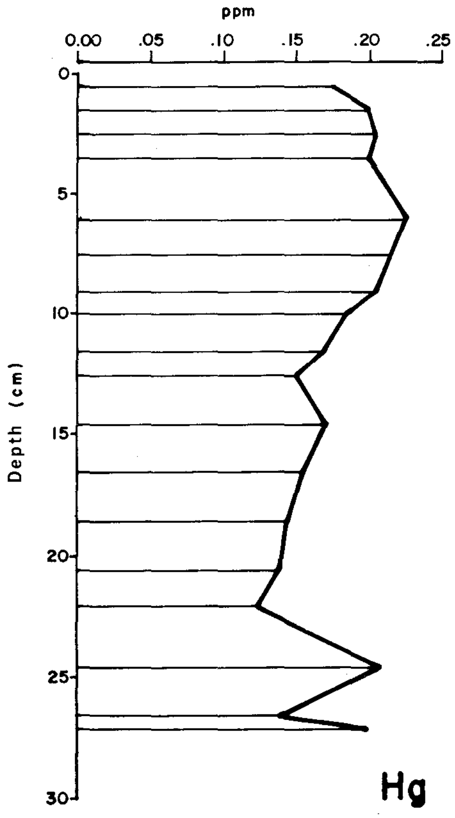

Figure 10. Stratigraphic distribution of Hg in the most recent sediments of Lac Laflamme

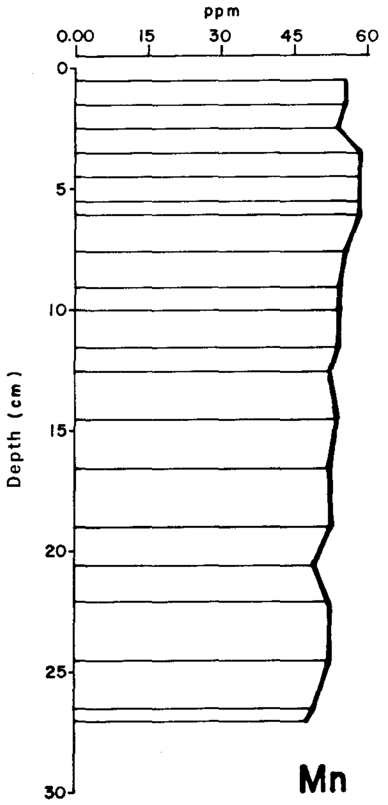

Figure 11. Stratigraphic distribution of Mn in the most recent sediments of Lac Laflamme

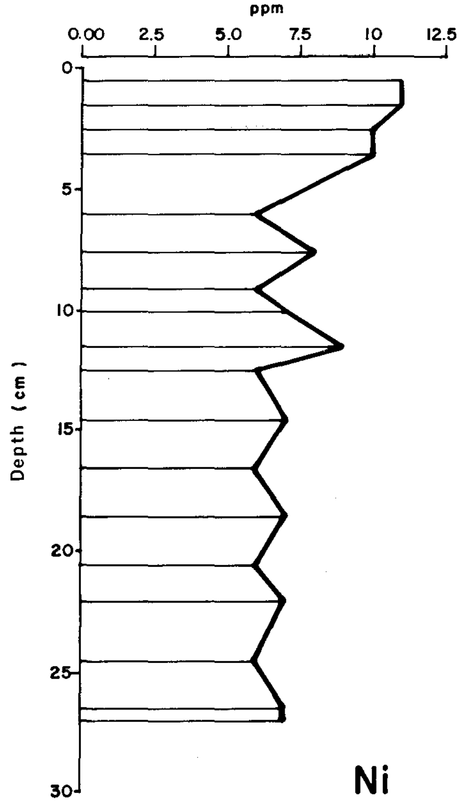

Figure 12. Stratigraphic distribution of Ni in the most recent sediments of Lac Laflamme

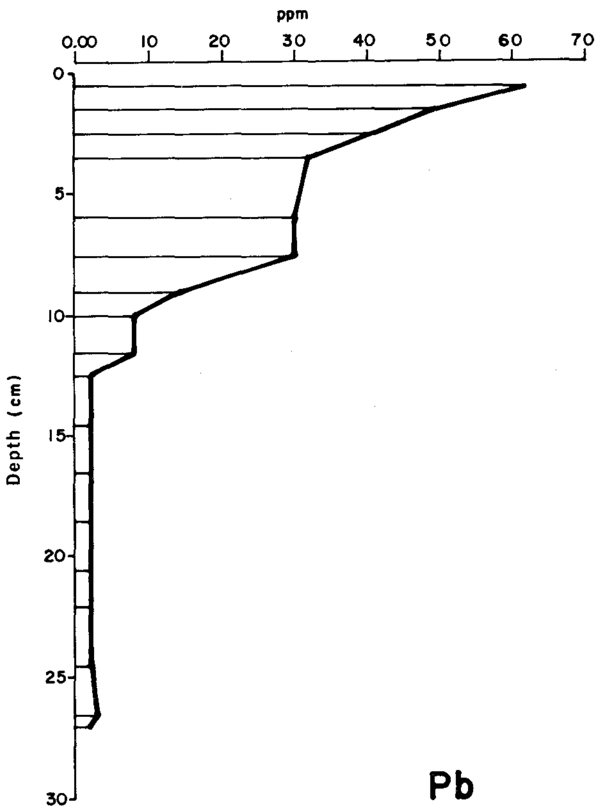

Figure 13. Stratigraphic distribution of Pb in the most recent sediments of Lac Laflamme

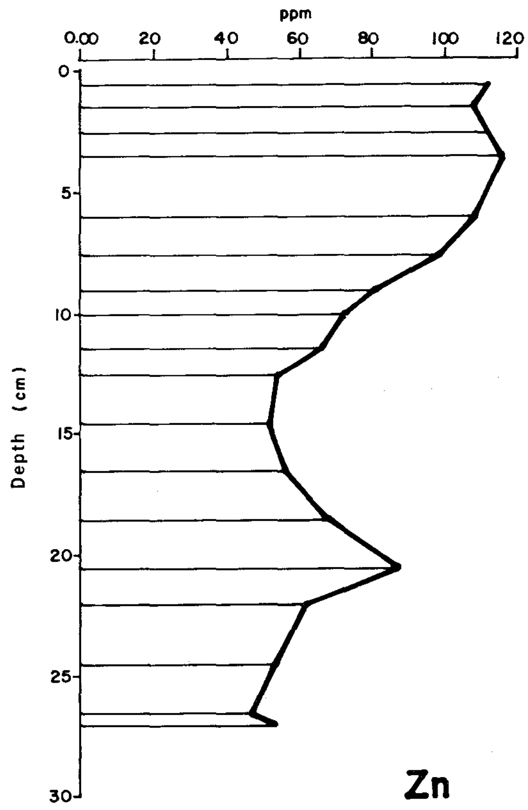

Figure 14. Stratigraphic distribution of Zn in the most recent sediments of Lac Laflamme

Discussion

GEOCHRONOLOGY

Quantification of the artificial and natural radioelements in the environment, including ^{137}Cs, ^{3}H (tritium), ^{14}C, ^{210}Pb and the isotopes, is a method currently used in the field of geochronology of recent sediments (Krishnaswami *et al.* 1971; Ouellet and Poulin 1976; Robbins 1978; Robbins *et al.* 1978; Smith and Walton 1980; etc).

For unknown reasons, the stratigraphic distribution of ^{137}Cs in the sediments of Lac Laflamme (Figs. 1 and 2) is very unusual. The concentrations of this element, which measure more than 6000 pCi/g at the surface, are approximately 200-700 times higher than any other concentration reported in the literature. Plato (1972) and Robbins *et al.* (1978) report maximum concentrations of 8.07 and 21.3 pCi/g.

This curve is also unusual in that it should drop in the top few (0-3) cm. This fact is related to the maximum abundance of this element in the atmosphere, which culminated with the numerous test explosions of nuclear bombs that took place in 1961-62.

The extremely organic nature of the sediments (40%) may well explain the very high activity of ^{137}Cs in the sediments of Lac Laflamme. There does not appear to be any record in the literature of analysis for ^{137}Cs in highly organic sediments like those in the present study. Smith and Walton (1980) have found that excess concentrations of ^{210}Pb in the organic portion (4%) of the sediment layers in the Saguenay are higher by a factor of two. The authors attribute this fact to the higher power of absorption of lead and of the heavy metals by organic matter, which is largely autochthonous in origin, compared with inorganic matter, which comes mainly from the terrigenous environment. Ouellet (1979) has also demonstrated a higher power of complexing of the heavy metals by fine organic and inorganic matter in his study of the superficial sediments of the Saguenay River and Lac Saint-Jean.

As regards the exponential form of the stratigraphic distribution of ^{137}Cs and the absence of a maximum at the level corresponding to the period 1961-62, there are three plausible explanations. The re-suspension of surface sediments by physical or biological agents and their preferential re-deposition at the sampling point may be the cause. If we consider the lake's relatively shallow depth of 4 m, this seems highly plausible. Secondly, the fact that the radiological activity of ^{137}Cs in the most recent sediments is higher than anticipated on the basis of contemporary fallout in these strata could be the result of its transportation from the watershed. Thirdly, the role of the lake's many hydromacrophytes in recycling ^{137}Cs remains unknown and may well influence the stratigraphic distribution.

Although the ^{137}Cs curve includes a number of irregularities, it is still useful for evaluating the rate of sedimentation in the lake. If we recall that the presence of ^{137}Cs in the environment is the result of the nuclear testing that began in 1952 (Health and Safety Laboratory, 1972), Figure 2 enables us to deduce that this date corresponds to the stratigraphic level of 8 cm. Because of the percentage of error in the analysis of ^{137}Cs, there is no point here in allowing a period of one or two years for the transportation process. If we consider the stratigraphic level of 8 cm as contemporary with the year 1952, the annual sedimentation rate is thus 2.85 mm.

This high rate of sedimentation appears plausible considering pelagic production and annual allochthonous input as well as the organic material generated by the hydromacrophytes that abound in all the shallow portions of the lake. The very slight compaction of the most recent sediments also contributes to over-estimation of the average rate of sedimentation of the entire postglacial deposit. Ouellet and Poulin (1975, 1976) have estimated the average rate of postglacial sedimentation in Waterloo and Matamek lakes at 1 mm/year.

GEOCHEMISTRY

In order to facilitate the discussion of the geochemical elements in Figure 1, they are classed in three groups on the basis of their stratigraphic fluctuation (Table 4).

Table 4. **Classification of geochemical elements by stratigraphic fluctuations in the most recent sediments of Lac Laflamme.**

Number	Elements	Fluctuation
1	^{137}Cs, Cu, Hg, Ni, Pb, Zn	Major
2	Al, Ca, Fe, Na, S, Co, Mn	Moderate
3	pH, H_2O, C, Mg, Ag	None

The first group includes ^{137}Cs (Fig. 2), Cu (Fig. 9), Hg (Fig. 10), Ni (Fig. 12), Pb (Fig. 13) and Zn (Fig. 14), which are the elements showing major quantitative fluctuations over time. The concentration of these elements in the core-sample increases perceptibly, primarily after the 12-cm level (1940). The average factor of anthropic enrichment is 6000 (^{137}Cs), 1.5 (Cu), 1.4 (Hg), 1.8 (Ni), 30.0 (Pb) and 2.0 (Zn) respectively. For the second group, the form of each curve varies slightly, again after the 12-cm level, negatively for Al (Fig. 3) and Ca (Fig. 4) or positively for Fe (Fig. 5), Na (Fig. 6) and Co (Fig. 8). The concentrations of S (Fig. 7) and Mn (Fig. 11) first increase and then decrease within the same stratigraphic interval.

The third and last group, which includes pH, H_2O, C, Mg and Ag, shows no stratigraphic fluctuation over any of the different levels of the short core-sample studied and their detailed stratigraphic distribution is thus not shown in the present report.

Assuming there has never been any major disturbance within the watershed, the causes of the substantial increase in Pb, Ni, Zn, Cu and Hg, as discussed previously for ^{137}Cs, can only be related directly or indirectly to atmospheric transportation. The increase of these elements in the atmosphere affects the quality of the sediments in Lac Laflamme through both wet and dry types of fallout.

The use of fossil fuels as an energy source, together with the products given off by refineries of sulphurous ores, is thought to be the primary source for the recent increase of these elements in the atmosphere (Bertine and Goldberg 1971; Journault-Dupont 1979). Ouellet (unpublished) has demonstrated that the recent increase of these elements in lacustrine sediments is a general phenomenon throughout Quebec.

Ouellet and Poulin (1976) and Ouellet (1980) have estimated, on the basis of the appearance of *Ambrosia* pollen, that the increase of Pb in the sediments of Lac Saint-Jean and Lac Waterloo corresponds to the period of deforestation of the watershed for agricultural purposes, which occurred around the years 1850 and 1830 respectively and hence long before the date of 1940 for Lac Laflamme. It could be that the increase of Pb in the lacustrine sediments coming essentially from atmospheric sources, as in Lac Laflamme, is a more recent phenomenon than that of Pb transported by water and originating to a large extent directly from human activities within the watershed of the lake.

The anthropic increase in Cu is certainly not as dramatic as that of Pb, but if the ideal curve is traced for the points reflecting the stratigraphic distribution of this element, the slope of the curve is always positive (Fig. 9) and it is marked by a break in the slope at approximately the 12-cm stratigraphic level. One can deduce from this that the presence of Cu in the atmosphere is a phenomenon which began slowly over half a century ago but took a marked upturn during the 1940s.

The standstill in the increase of Zn beyond the 6-cm stratigraphic level, that is, since approximately 1960, may well be explained by a reduction in the consumption of polluting fuels, such as coal, which has been reflected in Quebec by an increase in the consumption of oil and electricity, which are less polluting energy sources. On the other hand, greater acidification of the lake waters may have facilitated the liberation of Zn and its transportation outside the basin, although this is highly unlikely in the present situation in view of the fact that the pH of Lac Laflamme is still 6.1.

The same reasons might also explain the decrease in Hg for the 0-6 cm stratigraphic interval. This curve resembles the one described by Thomas (1972) in his study on the evolution of Hg in the sediments of Lake Ontario. He explains its decline as the result of the greater restrictions placed on the use of this element by various bodies in recent years.

The reasons for the evolution of the curves for the second group of geochemical elements (Al, Ca, Fe, Na, S, Co, Mn) over the past 100 years or so remain much more speculative than those discussed above for the first group. These stratigraphic variations are relatively small because some of these elements are rarely transported by atmospheric means or because certain underlying phenomena, such as pH and Eh, can influence the quantitative aspect indirectly, either in the various phases of the metabolism of the lake or in the watershed as a whole.

The reasons for the decreased levels of Al and Ca in the sediments of the upper portion of the core-sample are probably chemical in nature. It is well known that Al (Burrows 1977) and Ca (Watt *et al.* 1978. Henriksen 1979; Jones *et al.* 1980) tend to increase and to decrease their mobility respectively with the acidification of the surface waters. Although the average pH of the waters of Lac Laflamme remains above 6.0, Jones and Bisson (1980) have measured minimal pH levels of 3.9 in the snow and in the spring meltwater.

It is therefore logical to assume that even though the input of these two elements into the lake has probably increased over the past 40 years (12-cm level), net losses have also increased simultaneously as a result of the greater solubilization of these elements, primarily in the spring. In contrast, the maximum Ca level of 0.59% at the 11-cm stratigraphic level could well be associated with the effects of the most recent logging operations, which took place in 1943-44.

It would certainly be interesting to compare the decline of these elements in the sediments of Lac Laflamme with those of an acidified lake, such as Lac Tantaré, some 60 km to the southwest. We can conclude that the geological substratum and, in particular, the loose deposits of the Lac Laflamme basin possess a relatively high buffering power which is still able, through its high capacity for ion exchange, to minimize the effects of the acidity (pH 4.1; Jones and Bisson 1980) of the solid and liquid precipitations.

The continuing increase in Na and the more moderate increase in Fe in the sediments of Lac Laflamme over the past 30 years may be directly associated with the higher concentrations of these elements in the atmosphere and hence in both wet and dry forms of precipitation. The increasingly intensive use of NaCl as a road-salting agent in recent years appears to be one of the principal sources contributing to this increase. As with many other elements, it may be that the acidification of precipitation brought about by emissions of SO_X and NO_X into the atmosphere has promoted a slight leaching of Na and Fe in the watershed and hence their use by aquatic organisms and subsequent deposition through the various processes of lacustrine sedimentation. Particularly in the case of Fe, the filling in of the lacustrine basin by the accumulation of sediments will, despite the shallowness of the lake, promote an even more rapid rate of hypolimnic oxygenation and hence the precipitation of Fe in the form of $Fe(OH)_3$, $FeO(OH)$ or its co-precipitation with other elements.

The behaviours of S (Fig. 6) and Mn (Fig. 9) remain difficult to explain because of their slight stratigraphic fluctuations. The very slight increase in S up to the 6-cm level and the subsequent sharper rise to a maximum at the 3.5-cm level may certainly be of atmospheric origin. Its decline, beginning in the late 1950's, also corresponds to the reduction in Hg (Fig. 8) and Zn (Fig. 12). It is thus possible that the curve for S also reflects the reduced use of fossil coal as an energy source as well as the effects of the anti-pollution measures introduced in recent decades.

Although the curve for Co shows a slight increase at about the 12-cm level, it is so minor that no valid interpretation can be offered. The same is generally true of Mn. The reasons for the stratigraphic variations of Mn remain obscure. In a number of paleolimnological studies, Ouellet and Poulin (1974, 1975, 1976) and Ouellet (1978, 1979) have shown that Mn can vary positively or negatively over the postglacial lacustrine deposits as a whole independently of the organic matter. Acidification of precipitation tends to enhance the solubilization of the Mn in the geological substratum (Jones *et al.* 1980) and, as with Fe, this should be reflected in an increase in lacustrine sediments caused by the precipitation or co-precipitation of this element in the aerobic aqueous environment. The stratigraphic fluctuation of this element at the 3.5-cm level is so slight that it seems to be insignificant. It is interesting, however, to note that this slight decline corresponds to the decline in S, Hg and Zn as well. A reduction in fallout from atmospheric sources is thus also plausible.

Finally, for the third and last group of geochemical variables (Table 4), including pH, H_2O, C, Mg and Ag, all of which are characterized by little or no quantitative fluctuation over time, there may be two principal reasons for this situation. The behaviour of pH, H_2O, C and Mg may reflect the absence of significant disturbances within the watershed (forest fires, logging) or even within the lacustrine basin (accelerated eutrophication). The relatively low level of Ag, which was close to the detection limit for the method of analysis used, makes it impossible to demonstrate the existence of any evolutionary tendencies.

Stratigraphic study of the sediments of a number of highly acidified lakes would enable us to determine the causes of these geochemical fluctuations more accurately. In such lakes, the reduction of certain elements will be more obviously associated with the physico-chemical effects of the pH level than with the direct input of these elements into the watershed by atmospheric means.

BIOLOGY

Fossil Diatoms

The great majority of the diatoms in the fossil groups are characteristic of cold, slightly acidic waters with low mineral content.

The abundance and stratigraphic diversity of the 91 taxa identified in the most recent sediments of Lac

Laflamme show no sustained fluctuation that could be interpreted as the result of paleoecological changes in the environmental conditions of the lacustrine environment. Even around the 12-cm level (1952), where certain geochemical disturbances have been detected and discussed earlier in this study, there is no indication of changes in the fossil groups that could be firmly associated with the effects of acid precipitation.

Some acidophilic species, such as *Tetracyclus lacustris* and *Amphicampa mirabilis*, which are absent in the lower portion of the sample, make a slight appearance towards the 2.5-cm level. In the present situation, it is quite possible that their presence in the spectrum of the various taxa is the result of diagenesis of the sediments, resulting from their differential preservation, as in the case of the cyanophytes. The presence of trace levels of these two species at a single lower level in each case does not completely eliminate this hypothesis.

Although the increase in the various acidophilic species of *Eunotia* spp., which appear in greater diversity and abundance towards the upper portion of the lacustrine deposit, can be interpreted as progress towards acidification of the environment, the evolution of other alkalinophilic species seems to be indicative of the opposite tendancy. These species, such as *Amphora* cf. *normanii* and *Navicula americana*, also assume some importance at the superficial and intermediate levels (11-11.5 cm) and thus contradict this possible tendency towards acidification. The increase in the diversity and abundance of these alkalinophilic species could be the result of the effects of a forest fire in the watershed of Lac Laflamme prior to 1952, which would have promoted the development of alkalinophilic species through the production of basic salts. In Scandinavia, systematic efforts have been made to burn off island vegetation in order to minimize the effects of lake acidification (personal communication, Rosenquist). In the case of the Lac Laflamme basin, this hypothesis must be rejected because of the presence of a coniferous forest approximately 40 years old. In addition, the effects of this hypothetical fire would have certainly brought about more significant changes in the geochemical composition of the lacustrine sediments. It should be noted here that the slight increase in Ca in the sediments, which appears to have been caused by logging operations in the basin in 1943-44, also corresponds to an increase in the diversity and abundance of these alkalinophilic species.

In short, the 91 taxa of fossil algae identified in the 18 stratigraphic levels of the most recent sediments (0-100 years) of Lac Laflamme indicate no significant paleoenvironmental changes resulting from the effects of acid rain. The evolution in the diversity and abundance of several species, which are present only in very small quantities, could possibly be indicative of acidification, whereas, at the same time, certain others tend to suggest alkalinization. This situation is thus contradictory and ambiguous.

Fossil Crustaceans

The evolution of the fossil zooplanktonic groups of the seven stratigraphic levels of Lac Laflamme studied reveals no tendency which can be associated with the acidification of the lacustrine environment. Only the distribution of *Daphnia catawba,* which unlike the other species, is characteristic of the limnetic zone, varies significantly in abundance. This reduction towards the upper levels may be a consequence of the expansion of the riparian zone rather than the acidification of the environment. This species cannot tolerate a pH below 5.2, a level not yet reached in Lac Laflamme.

Conclusion

The principal conclusions of the paleolimnological study of the most recent sediments of Lac Laflamme are as follows.

1. Quantification of ^{137}Cs has enabled us to assess the average rate of sedimentation at 2.85 mm/year.

2. The high annual rate of sedimentation in the lake may be the result of the high productivity of the hydromacrophytes that abound in the shallow areas.

3. The concentration of ^{137}Cs in the sediments is approximately 300 times higher than any reported in the literature for similar studies.

4. The stratigraphic curve for ^{137}Cs does not correspond to the estimated atmospheric activity since 1952. The maximum activity occurs at the surface rather than near the levels corresponding to the years 1961-62. Possible recycling by macrophytes and preferential sedimentation at the sampling point could explain the behaviour of the ^{137}Cs.

5. The increase in ^{137}Cs, S, Ca, Hg, Ni, Pb and Zn, primarily above the 12-cm level, is anthropogenic in origin and the result of atmospheric transportation. However, the stabilization in the input of Hg, Zn and, to a lesser extent, S, above the 3-cm level, appears to be associated with reductions in the emissions of these elements into the atmosphere. This may be the result of the reduced use of polluting fossil fuels and the anti-pollution measures introduced in the last decade.

6. The low quantitative reduction in Al and Ca for the 0-12 cm interval may be interpreted to be the result of acidification of precipitation because of their greater mobility at more acidic pH levels. The same would seem to be generally true of Fe, but its mobility in the watershed does not persist in the lacustrine basin. The high rate of hypolimnetic oxygenation in the lake may encourage its precipitation.

7. The pronounced stratigraphic increase in Na over the past 50 years seems to be associated, through atmospheric transportation, with its extensive use on roads for salting purposes.

8. The high stratigraphic stability of H_2O, C and Mg in the sediments confirms the lack of major disturbances in the lacustrine system over the past century. Such disturbances could have been caused by anthropogenic modifications within the watershed, including logging operations during the winter of 1943-44.

9. Stratigraphic study of the fossil combinations of algae and crustaceans shows no fluctuation that could be the result of acidification of the waters of Lac Laflamme.

10. The high capacity of the loose deposits in the lake basin for ion exchange has assisted to date in neutralizing the effects of acid precipitation and has thus allowed the pH of the waters of the lake to remain at a very acceptable level.

11. Similar studies should be carried out on other lakes that are already highly acidified to achieve a better understanding of the effects of atmospheric transportation of pollutants and the acidification of precipitation on Quebec's lacustrine ecosystems. Special attention should be given to qualitative and quantitative aspects, and to the means by which the various types of loose sediments reach the watersheds of these lakes.

References

Almer, B., Dickson, W., Ekstrom, C., Horstrom, E. and Miller, U. 1974. Effects of acidification on Swedish Lakes, Ambio, 3: 30.

Altshuller, A.P. et McBean, G.A. 1979. Le transport des polluants atmosphériques sur de grandes distances en Amérique du Nord, 46 p. Un examen préliminaire préparé par le Groupe consultatif de recherche États-Unis-Canada sur le transport des polluants atmosphériques sur de grandes distances.

Auclair, J.C., Brakke, D.F. and Jones, H.G. 1980. Chemical and biological characteristics of Lake Tantarie: an acidic ecosystem in the Laurentian Park area of Quebec. 63e Congrès canadien de chimie, Ottawa, 8-11 juin.

Baker, J.P. and Schofield, C.L. 1980. Aluminium toxicity to fish as related to acid precipitation and Adirondack surface water quality. Abstract: International Conference on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, March 11-14.

Barrett, E. and Brodin, G. 1955. The acidity of Scandinavian precipitation. Tellus, 7: 251-257.

Beamish, R.J. 1974. Loss of fish populations from unexploited remote lakes in Ontario, Canada as a consequence of atmospheric fallout of acid. Water Res. 8: 85-95.

Beamish, R.J. and Harvey, H.H. 1972. Acidification of the La Cloche Mountain Lakes, Ontario, and resulting fish mortalities. J. Fish. Res. Board Can. 29: 1131-1143.

Beamish, R.J., McFarlane, G.A., Van Loon, J.C. and Lichwa, J. 1975. An examination of the possible effects of Sudbury nickel mining and smelting operations on fishes and the water chemistry of lakes within the White-fish Lake Indian Reserve. Fish. Mar. Serv. Tech. Rep. 579:52.

Bernard, J.G. et Lagueux, R. 1972. Association plantonique (Cladocères et Copépodes) d'un lac dimictique du parc des Laurentides, Québec. Naturaliste canadien, 99: 381-409.

Bertine, K.K. and Goldberg, E.D. 1971. Fossil fuel combustible and the major sedimentary cycle. Science, 173:233-235.

Bolin, B., Granot, L., Ingelstam, L., Johannesson, M., Mattson, E., Oden, S., Rohde, S. and Tamm, C.O. 1971. Air pollution across national boundaries. The impacts on the environment of sulfur in air and precipitation. Swedish Lake Study for the United Nations Conference on the Human Environment, 96 pp.

Brakke, D.F. 1980. Atmospheric deposition in Norway during the last 300 years as recorded in SNSF lake sediments. III. Cladoceran community structure and stratigraphy. International Conference on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, March 11-14.

Burrows, W.D. 1977. Aquatic aluminum chemistry toxicology and environmental prevalence. Crit. Rev. Environ. Control: 167-216.

Conroy, N. 1971. Classification of Precambrian Shield Lakes based on factors controlling biological activity. Master of Science Thesis, McMaster University, 115 pp.

Conroy, N., Hawley, K., Keller, W. and Lafrance, C. 1976. Influence of the atmosphere on lakes in the Sudbury area. J. Great Lakes Res. 2, Suppl. 1: 146-165.

Contant, H. and Duthie, H.C. 1978. The phytoplankton of Lac St. Jean, Québec. Bibliotheca Phycologica, Band 40.

Cronan, C.S. and Schofield, C.H. 1979. Aluminium leaching response to acid precipitation: Effects on high-elevation watersheds in the northeast. Science, 204: 304-306.

Davis, R.B. and Berge, F. 1980. Atmospheric deposition in Norway during the last 300 years as recorded in SNSF lake sediments. II: Diatom stratigraphy and inferred pH. International Conference on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, March 11-14.

Davis, R.B. and Norton, S.A. 1978. Paleolimnology studies of human impact on lakes in the United States, with emphasis on research in New England. Proc. of the II International Symposium on Paleolimnology, Poland.

Davis, R.B., Norton, S.A., Brakke, D.F., Berge, F. and Hess, C.T. 1980. Atmospheric deposition in Norway during the last 300 years as recorded in SNSF lake sediments. IV: Synthesis, and comparison with New England. International Conference on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, March 11-14.

Delisle, C.E. 1979. Impacts des précipitations acides contaminées par les métaux lourds sur les écosystèmes aquatiques. Comptes rendus de la Conférence sur les contaminants dans l'environnement, Québec, 14-15 mai, p. 5.0-5.26.

De Bary, E. and Junge, C. 1963. Distribution of sulfur and chlorine over Europe. Tellus, 15: 370-381.

Delmas, R. and Legrand, M. 1980. The acidity of polar precipitation: A natural reference level for acid rains. Abstract: International Conference on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, March 11-14.

Dickson, W. 1975. The acidification of Swedish lakes. Rep. Inst. Freshwater Res. Drottningholm, 54: 8-20.

Dillon, P.J. 1980. Chemistry of precipitation, water and sediments in lakes and watersheds, Ontario. Abstract: International Conference on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, March 11-14.

Dillon, P.J., Jeffries, D.S. and Scheider, W.A. 1978a. Acid precipitation in south-central Ontario: recent observations. J. Fish. Res. Board Can. 35: 809-815.

Dillon, P.J. Yan, N.D., Scheider, W.A. and Conroy, N, 1978b. Acid lakes in Ontario, characterization, extent, and responses to nutrient additions. Ergebnisse der Limnologie. Proceedings of a Conference on Lake Metabolism and Management, Uppsala, Sweden, August, 1977.

Dovland, H., Joranger, E. and Semb, A. 1976. Deposition of air pollutants in Norway, pp. 14-35. *In* Impact of acid precipitations on forest and freshwater ecosystems in Norway. Edited by F.H. Braekke. SNSF-project, Aas, Norway, Research, Dept., 6/76, 111 p.

Frey, D.G. 1962. Supplement to: The taxonomic and phylogenetic significance of the head pores of the Chydoridae (Cladocera). Int. Rev. Ges. Hydrobiol. 47: 603-609.

Frey, D.G. 1965. Differentiation of *Alona costata* Sars trom two related species (Cladocera, Chydoridae). Crustaceana, 8: 159-173.

Frey, D.G. 1976. MS. Chydorids known or anticipated to occur in the Lake Itasca region (Provisional key to female chydorids of the Itasca region).

Frey, D.G. 1980. Cladocera. Int. geol. correlation program., project 158.

Gjessing, E.T., Henriksen, A., Johannessen, M. and Wright, F.F. 1976. Effects of acid precipitation on freshwater chemistry. *In* Impact of acid precipitation on by F.H. Braekke. Research Report No. 6, SNSF-project, Norway, pp. 64-85.

Gorham, E. and Gordon, A.G. 1960. The influence of smelter fumes upon the chemical composition of lake waters near Sudbury, Ontario, and upon the surrounding vegetation. Can. J. Bot. 38: 477-487.

Grahn, O., Hultberg, H. and Landner, L. 1974. Oligotrophication self accelerating process in lakes subjected to excessive supply of acid substances. Ambio, 3: 8.

Guimont, J. et Pichette, M. 1979. Méthodes de dosage d'éléments en traces dans les sédiments, les roches et les eaux. Rapport AC-5, Direction de l'analyse et contrôle, Ministère des Richesses naturelles, Gouvernement du Québec.

Hanson, M. 1974. Zooplankton Fulufjällsjör med lugt pH. Freshwater Research Laboratory, Drottningholm, Sweden, Information, 5: 17.

Harvey, H.H. 1980. Continuing changes in the fish fauna of the La Cloche Mountain Lakes. Abstract: International Conference on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, March 11-14.

Health and Safety Laboratory Fallout. 1972. Program U.S. Atomic Energy Commission, HASL-258, A-40-41, A-93-94.

Hendrey, G.R., Baalsrud, K., Traaen, T.S., Laake, M. and Raddum, G. 1976. Acid precipitation, some hydrobiological changes. Ambio. 5(5-6): 224.

Hendrey, G.R., Galloway, J.N., Northon, S.A. and Schofield C.L. 1980. Sensitivity of the eastern United States to acid precipitation impacts on surface waters. Abstract: International Conference on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, March 11-14.

Hendrey, G.R. and Wright, R.F. 1976. Acid precipitation in Norway; effects on aquatic fauna. J. Great Lakes Res. Suppl. 1, Proc. Symp. Atmospheric Contribution to the Chemistry of Lake Waters, 2: 192-207.

Henriksen, A. 1979. A simple approach for identifying and measuring acidification of freshwater. Nature, 278: 542-544.

Herron, M.M., Langway, C.C. Jr., Weiss, H.V., Hurley, J.P., Kerr, R.J. and Cragin, J.H. 1976. Vanadium and other elements in Greenland ice core. CRREL Report 76-24: 1-4, National Science Foundation.

Hornstrom, A. and Ekstrom, C. 1973. The effect of acidification on west-coast lakes. Statens Naturvardisverk (Sweden), 7: 97.

Hustedt, F. 1942. *In* Das Phytoplakton der Siisswassers. Die Binnengewasser, Bd., 16, Teil 2, 2 Halfte, Stuttgart.

Jensen, K.W. and Snekvik, E. 1972. Low pH levels wipe out salmon and trout populations in southernmost Norway. Ambio, 1: 223-225.

Jones, H.G. et Bisson, M. 1980. Le lac Laflamme: qualité de l'eau et de la neige (hiver 1979-1980). INRS-Eau, rapport scientifique N° 123. (Pour Environnement Canada).

Jones, H.G., Ouellet, M. and Brakke, D.F. 1980. The evolution of acidity in surface waters of Laurentides Park (Quebec, Canada) over a period of 40 years. International Conference on Ecological Impact of Acid Precipitation, Sandefjord, Norway, March 11-14.

Jones, H.G., Ouellet, M., Potvin, L., Sasseville, J.L. et Visser, S.A. 1976. Quelques aspects environnementaux du mercure dans la région du lac Mistassini. INRS-Eau, rapport scientifique N° 68, 102 p. (Rapport soumis aux Services de protection de l'environnement du Québec et à Environnement Canada).

Journault-Dupont, C. 1979. Étude écologique de la région de Rouyn-Noranda. Comptes rendus de la Conférence sur les contaminants dans l'environnement, Québec, 14-15 mai 1979, pp. 11.0-11.43.

Knabe, W. 1976. Effects of sulfur dioxide on terrestrial vegetation. Ambio, 5(5-6): 214.

Krishnaswami, S., Lal, D., Martin, J.M. and Meybeck, M. 1971. Geochronology of lake sediments. Earth Planet. Sci. Lett. 11: 407-414.

Kwiatkowski, R.E. and Roff, J.C. 1976. Effects of acidity on the phytoplankton and primary production of selected northern Ontario Lakes. Can. J. Bot. 56: 2546-2561.

Leblanc, F., Rao, D.N. and Comeau, G. 1972. Indices of atmospheric purity and fluoride pollution pattern in Arvida, Quebec. Can. J. Bot. 50: 991-998.

Leivestad, H., Hendrey, G., Muniz, I.P. and Snekvik, E. 1976. Effects of acid precipitation on freshwater organisms, pp. 86-11. *In* Impacts of precipitation on forest and freshwater ecosystems in Norway, Edited by F.H. Braekke. SNSF-project, Aas, Norway, Research, Dept. 6/76. 111 p.

Likens , G.E. and Bormann, F.H. 1974. Acid rain: a serious regional environmental problem. Science, 184: 1176-1179.

Linzon, S.N. 1958. The influence of smelter fumes on the growth of white pine in the Sudbury region, Ontario. Dept. Lands For., Ontario Dept. Mines, Toronto, Ont. 45 pp.

Malmer, N. 1976. Acid precipitation: chemical changes in the soil. Ambio, 5(5-6): 231.

Megard, R.O. 1967. Three new species of *Alona* (Cladocera, Chydoridae from the United States). Int. Rev. Ges. Hydrobiol. 52: 37-50.

Muller, P. 1980. Effects of artificial acidification on the growth of periphyton. Can. J. Fish. Aquat. Sci. 37: 355-363.

Norton, S.A., Dubiel, R.F., Sasseville, D.R. and Davis, R.B. 1978. Paleolimnological evidence for increased zinc loading in lakes of New England, U.S.A. Verh. Internat. Verein. Limnol. 20: 538-545.

Oden, S. 1968. Nederbördens och fuftens försurningdess orsaker, förlopp och verkani olika miljöer. (The acidification of air and precipitation and its consequences on the natural environment). Ecol. Comm. Bull. 1: 87.

Oden, S. 1971. Acidification of the precipitation-a general threat against the ecosystems. *In* Forurensning og biologisk miljovern (Edited by Mysterund *I*: 63-98, Universitetsforlaget.

Ottar, B. 1972. Säure Niederschlage in Skandinavien. Umschau, 72: 290-291.

Ouellet, M. 1975. Augmentation récente de métaux lourds dans les sédiments de plusieurs lacs de l'Ontario et du Québec. Conférence internationale sur les métaux lourds dans l'environnement, Toronto, 27-31 octobre.

Ouellet, M. 1978. Some paleolimnological and surface bottom geochemical aspects of Matamek Lakes. 31st Annual Meeting of the Canadian Conference for Fisheries Research, Ottawa, January 4-5.

Ouellet, M. 1979. Géochimie et granulométrie des sédiments superficiels du lac Saint-Jean et de la rivière Saguenay. INRS-Eau, rapport scientifique N° 104.

Ouellet, M. 1980. Géochimie et paléolimnologie du lac Saint-Jean. *Dans* Productivité biologique des eaux du lac Saint-Jean, INRS-Eau, rapport scientifique N° 76.

Ouellet, M. et Poulin, P. 1975. Quelques aspects paléoécologiques de la tourbière de lac Desaulniers et quelques spectres sporo-polliniques modernes du bassin de la Grande Rivière, baie James, Québec. INRS-Eau, rapport scientifique N° 67, 48 p., 2 annexes. (Pour la Société d'énergie de la baie James).

Ouellet, M. et Poulin, P. 1976. Études paléoécologiques des sédiments du lac Waterloo, Québec, INRS-Eau, rapport scientifique N° 64, 87 p. (Pour le Ministère des Richesses naturelles du Québec).

Ouellet, M. et Poulin, P. 1977. Résultats préliminaires sédimentologiques et paléolimnologiques de la région de la rivière Matamek. Compte rendu des activités et avancement des travaux. INRS-Eau, rapport interne N° 55, 74 p. (Pour Woods Hole Oceanographic Institution).

Patrick, R. and Reimer, C.W. 1966. The Diatoms of the United States. Monogr. Acad. Nat. Sci. Philadelphia, 13: 688.

Patrick, R. and Reimer, C.W. 1975. The Diatoms of the United States. Vol. 2, Part 1, Monograph 7, Acad. Nat. Sciences of Philadelphia, 13: 213 p.

Plato, P.A. 1972. Distribution of Caesium-137 and naturally occurring radionuclides in sediments of Lake Michigan. Radiat. Data Reports, 13: 181-187.

Prescott, G.W. 1962. Algae of the Western Great Lakes Area. Wm. C. Brown Company, Publishers, Iowa, 977 pp.

Robbins, J.A. 1978. Geochemical and geophysical applications of radioactive lead isotopes. *In* Biogeochemistry of lead. Edited by J.P. Nriagu. Elsevier, 285-393 pp.

Robbins, J.A., Edgington, D.N. and Kemp, A.L.W. 1978. Comparative ^{210}Pb, ^{137}Cs and pollen geochronologies of sediments from Lakes Ontario and Erie. Quat. Res. 10: 256-278.

Robitaille, G. 1979. La pollution et les cernes annuels d'*Abies balsamea*. Comptes rendus de la Conférence sur les contaminants dans l'environnement, Québec, 14-15 mai, p. 14.0-14.18.

Robitaille, G., Leblanc, F. and Rao, D.N. 1977. Acid rain: a factor contributing to the paucity of epiphytic Cryptograms in the vicinity of a copper smelter. Rev. Bryol. Lichénol., 43(1):53-66.

Rowe, S. 1959. Forest regions of Canada. Canada Dept. of Northern Affairs and National Resources, Forestry Branch, Bull. No. 123, 71 p.

Schindler, D.W., Wagermann, R., Cook, R.B., Ruszczynski, T. and Proko-Powich, J. 1980. Experimental acidification of Lake 223, Experimental Lakes Area. Background data and the first three years of acidification. Can. J. Fish. Aquat. Sci. 37: 342-354.

Schoefield, C.L. 1976. Acid precipitation: effects of fish. Ambio, 5(5-6): 228.

Semb, A. 1978. Deposition of trace elements from the atmosphere in Norway. SNSF-project, Aas, Norway Research Dept. 13/78, 28 p.

Shaw, R.W. 1980. Origins of acidic materials transported and deposited by the atmosphere to Atlantic Canada. Abstract: International Conference on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, March 11-14.

Smirnov, N.N. 1971. Chydoridae fanny mira. Fauna SSSR, Rakoograznye (Crustacea), Vol. 1, No. 2. Akademija Nauk SSR, Zoologicheskii Institut, new series 101.

Smith, J.N. and Walton, A. 1980. Sediment accumulation rates and geochronologies measured in the Saguenay Fjord using the ^{210}Pb dating method. Geochim. Cosmochim. Acta. 44: 225-240.

Smol, J.P. 1980. Fossil Synuracean (chrysophyceae) scales in lake sediments: a new group of paleoindicators. Can. J. Bot. 58(4): 458-665.

Sprules, W.G. 1975. Midsummer crustacean zooplankton communities in acid-stressed lakes. J. Fish Res. Board Can. 32: 389-395.

Stokes, P.M. 1980. Phytoplankton of acidic lakes in Killarney Ontario: community structure related to water chemistry. Abstract: International Conference on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, March 11-14.

Takahaski, E. 1978. Electron microscopical studies of the Synuraceae (Chrysophyceae) in Japan: taxonomy and ecology. Tokyo University Press, Tokyo, 194 pp.

Thomas, M.D. 1962. Sulphur dioxide, sulphuric acid aerosol and visibility in Los Angeles. Air Water Pollut. Int. J. 6: 443-454.

Thomas, R.L. 1972. The distribution of mercury in the sediments of Lake Ontario. Can. J. Earth Sci. 9: 636-651.

Van Heurck. 1963 Traité des diatomées. N° 189.

Waller, R.E. 1963. Acid droplets in town air. Air Water Pollut. Int. J. 7: 773-778.

Watt, W.D., Scott, D., and Ray, S. 1978. Acidification and other chemical changes in Halifax County lakes after 21 years. Fisheries and Marine Service, Box 550, Halifax, N.S.

Weiss, H.V., Kaide, M. and Goldberg, E.D. 1971. Mercury in a Greenland ice sheet: evidence of recent input by man. Science, 174: 692-694.

Wright, R.F. and Gjessing, E.T. 1976. Acid precipitation: changes in the chemical composition of lakes. Ambio, 5(5-6): 219.

Yan, N.D. and Stokes, P. 1978. Phytoplankton of an acidic lake, and its responses to experimental alteration of pH. Environmental Conservation, 5: 93-100.

Plates I to V

PLATE I

Figs. 1-8. Diatoms in the most recent sediments of Lac Laflamme.

Fig. 1. *Diatoma* cf. *anceps* x 3000 (40 x 5 μm).
Fig. 2. *Fragilaria constricta* var. *constricta* x 3000 (33 x 6 μm).
Fig. 3. *Tabellaria fenestrata* x 2000 (52 x 8 μm).
Fig. 4. *Tabellaria fenestrata* x 5000.
Fig. 5. *Tabellaria flocculosa* x 5000.
Fig. 6. *Tabellaria flocculosa* x 1000 (66 x 0.49 μm).
Fig. 7. *Tabellaria flocculosa* x 5000 (17 x 6 μm).
Fig. 8. *Achnanthes* x 7000 (12 x 6 μm).

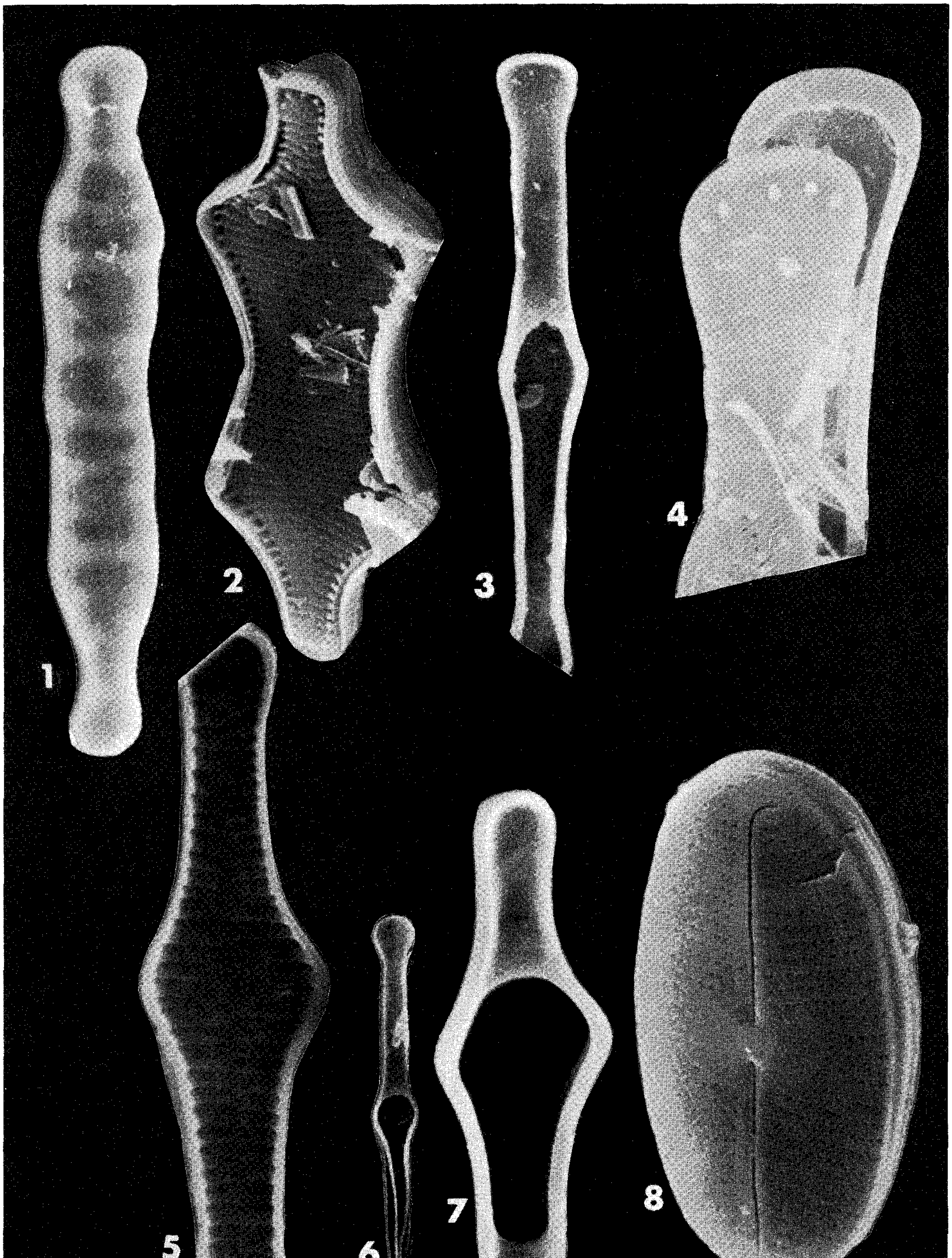
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PLATE II

Figs. 1-10. Diatoms in the most recent sediments of Lac Laflamme.

Fig. 1. *Eunotia pectinalis* var. *major* x 5000 (19 x 4.5 μm).
Fig. 2. *Eunotia serra* var. *diadema* x 2000 (35 x 9 μm).
Fig. 3. *Amphora ovalis* x 2000 (21 x 60 μm).
Fig. 4. *Cymbella lunata* x 2000 (36 x 7 μm).
Fig. 5. *Frustulia rhomboides* x 1000 (120 x 4.8 μm).
Fig. 6. *Navicula americana* x 2000 (33 x 9 μm).
Fig. 7. *Navicula* cf. *atomus* x 10 000 (5 x 1 μm).
Fig. 8. *Navicula capitata* x 1000 (90 x 15 μm).
Fig. 9. *Navicula elginensis* x 2000 (45 x 10.5 μm).
Fig. 10. *Navicula globulifera* x 2000 (7.5 x 64 μm).

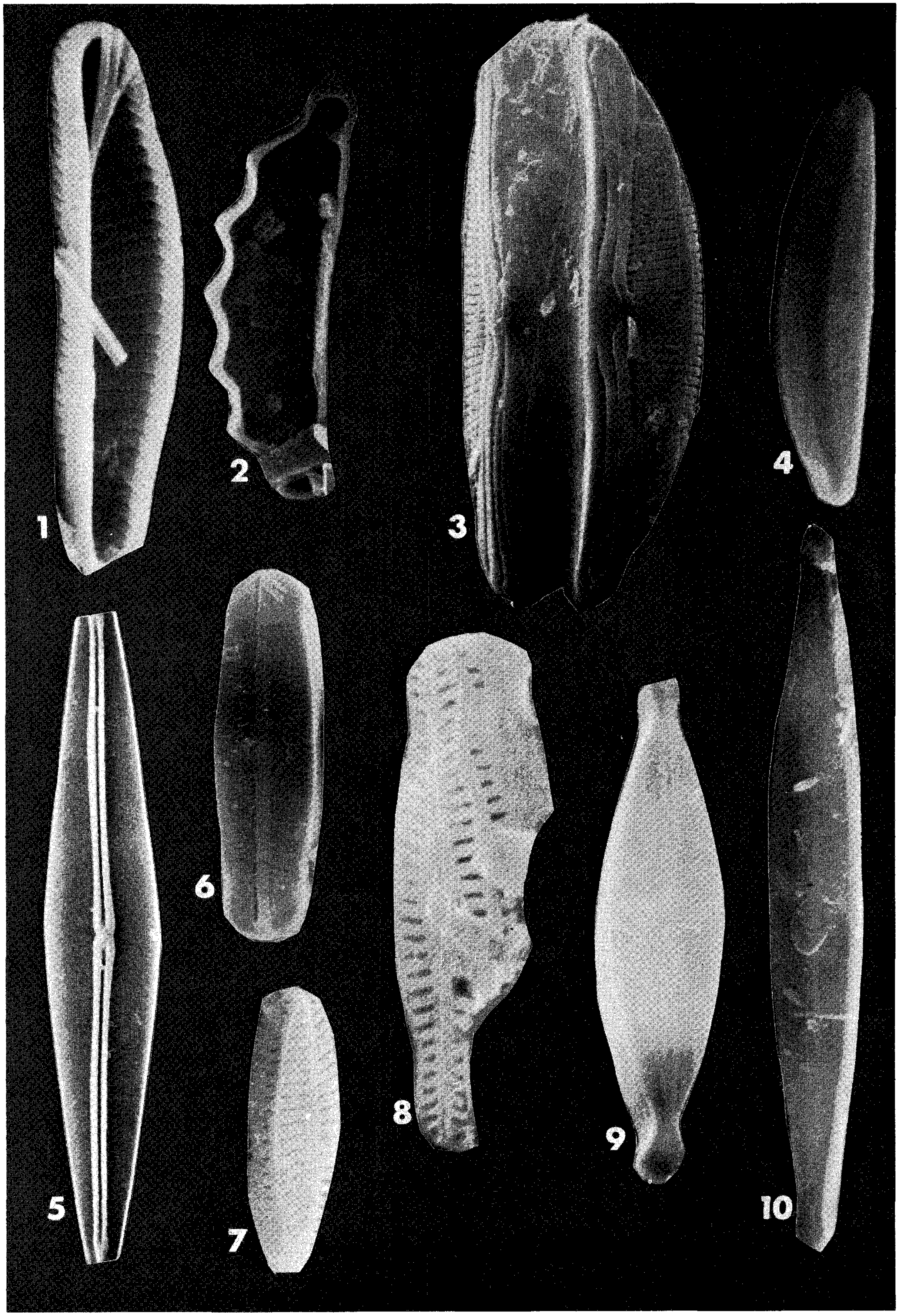
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PLATE III

Figs. 1-9. Diatoms in the most recent sediments of Lac Laflamme.

Fig. 1. *Navicula* cf. *variostriata* var. *variostriata* x 3000 (37 x 10 μm).
Fig. 2. *Neidium gracile* var. *aequale* x 2000 (21 x 13 μm).
Fig. 3. *Neidium iridis* var. *amphigomphus* x 700 (27 x 134 μm).
Fig. 4. *Pinnularia acrosphaeria* var. *acrosphaeria* x 2000 (47 x 10 μm).
Fig. 5. *Pinnularia maior* x 700 (29 x 124 μm).
Fig. 6. *Stauroneis acuta* x 700 (157 x 25.7 μm).
Fig. 7. *Stauroneis phoenicentron* x 700 (29 x 168 μm).
Fig. 8. *Nitzschia filiformis* x 1000 (4 x 80 μm).
Fig. 9. *Nitzschia filiformis* x 1000 (4 x 39.2 μm).

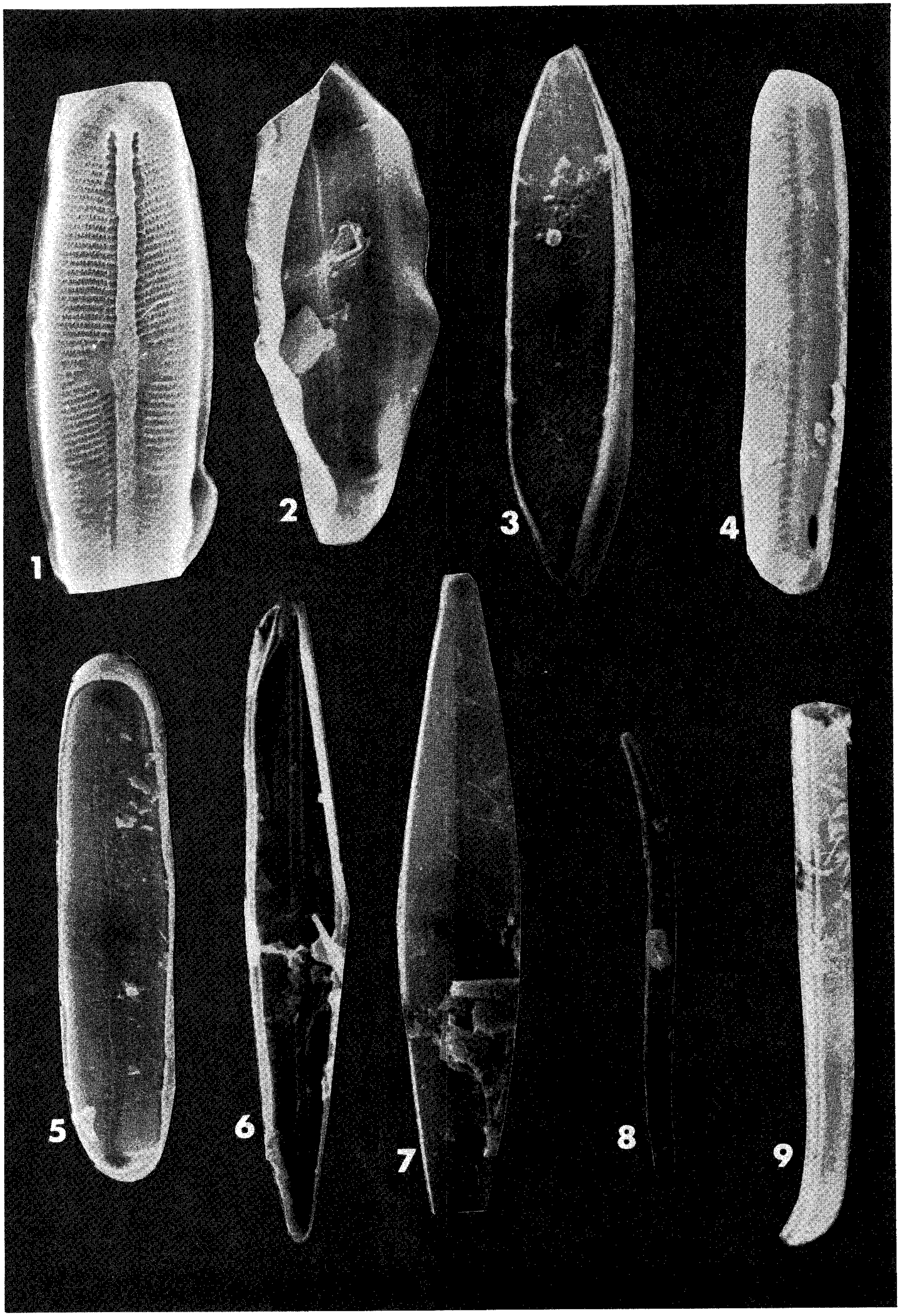
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PLATE IV

Figs. 1-7. Diatoms in the most recent sediments of Lac Laflamme.

Fig. 1. *Melosira ambigua* x 2000.
Fig. 2. *Melosira ambigua* x 7000.
Fig. 3. *Melosira distans* x 7000.
Fig. 4. *Melosira islandica* x 3000.
Fig. 5. *Melosira islandica* x 7000.
Fig. 6. *Melosira islandica* x 10 000.
Fig. 7. *Mallomonas crassisquama* x 15 000.

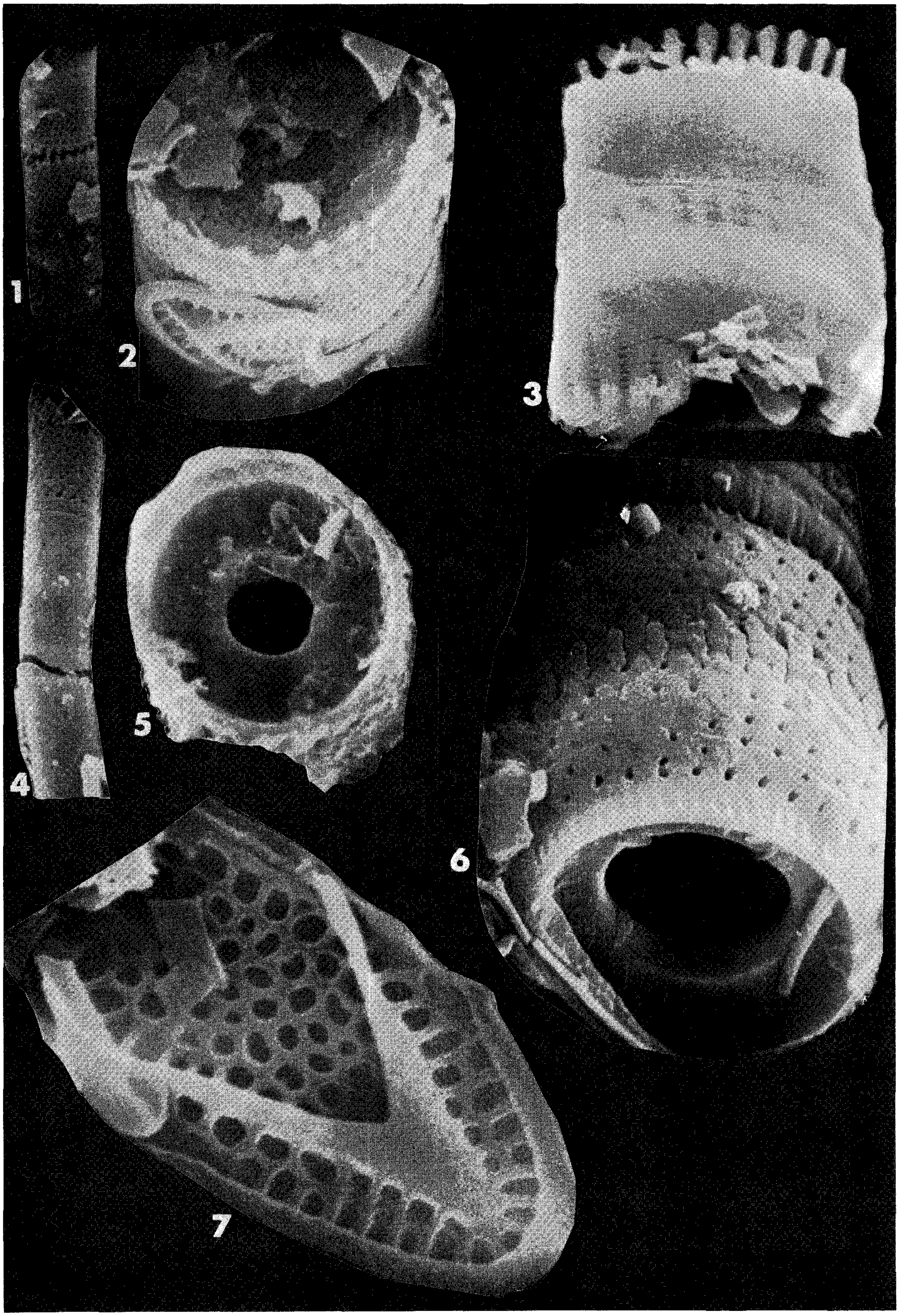
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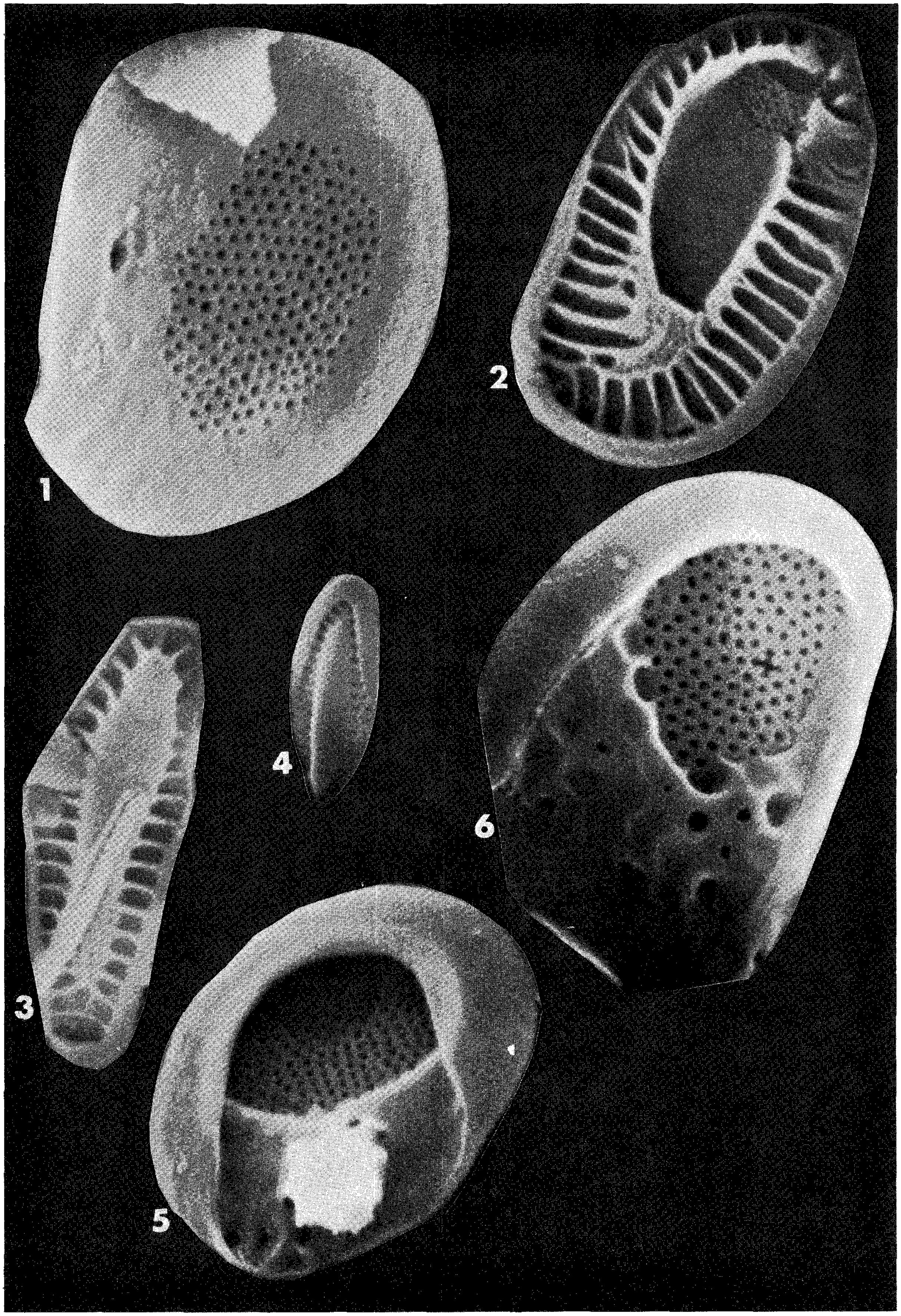
PLATE V

Figs. 1-6. Diatoms in the most recent sediments of Lac Laflamme.

Fig. 1. *Mallomonas* cf. *fastigata* x 20 000.
Fig. 2. *Synura* cf. *petersenii* x 20 000 (4.3 x 3 μm).
Fig. 3. *Synura* cf. *petersenii* x 20 000.
Fig. 4. *Synura* cf. *petersenii* x 10 000 (4 x 1.5 μm).
Fig. 5. *Synura mammilosa* x 15 000 (5 x 4 μm).
Fig. 6. *Spiniferomonas* cf. *abei* x 20 000.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