PALEOECOLOGICAL STUDIES OF THREE LATE-QUATERNARY LACUSTRINE DEPOSITS FROM THE KINGSTON REGION AND SOME GEOCHEMICAL OBSERVATIONS OF BOTTOM SURFACE SEDIMENTS OF LAKES FROM SOUTHWESTERN QUEBEC

by

Marcel H. Ouellet

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Supervisor

Candidate

To Professors: Leblanc

Reed

Dickman

This thesis having been approved in respect to form and mechanical execution is referred to you for judgment upon its substantial merit.

Dean

Approved as satisfying in substance the doctoral thesis requirement of the University Ottawa.

Major Professor

Date of Examination, Feb., 5 1974

ABSTRACT

The main purpose of this work is to investigate Late-Quaternary lacustrine sediments by using three quantitative and qualitative methods (palynology, malacology and geochemistry) so as to promote a better understanding of the limnological evolution of lakes. Three lacustrine deposits from the Kingston Region were each sampled, radiocarbon-dated and analyzed stratigraphically for more than 50 parameters. The present study suggests the existence of an abundant aquatic vegetation in Atkins Lake, Grady Lake and in the Cataraqui River Marsh 11,100±270, 10,500±180 and 10,200±180 years ago respectively, bordered by a forest-tundra quite similar to the one prevailing today in the Canadian Low Arctic.

Stratigraphic variations in pollen types such as spruces, pines and thermophilous hardwood trees suggest several climatic oscillations prior to colonial time in the Kingston Region.

The quantitative distribution of 27 different molluscan species and forms from the Atkins Lake deposit does not correlate with the climatic fluctuations detected by pollen analysis. The mollusc abundance associated largely with the marly sediments seem to be inversely proportional to the paleoproductivity of the deposit which was estimated by the sedimentary chlorophyll degradation products.

The bottom surface sediments of nine Gatineau Area lakes were analyzed chemically so as to facilitate geochemical interpretation of the three fossil sites from the Kingston Region. The results show that the trophic level of a lake can be grossly characterized by the composition of its sediments.

The stratigraphic composition of each deposit demonstrates the high sensitivity of lakes to allochthonous and autochthonous ecological changes.

RESUME

Le but principal de cette étude multidisciplinaire de dépots lacustres d'âge quaternaire supérieur est de retracer l'évolution limnologique des lacs au moyen de trois méthodes paléoécologiques (palynologie, malacologie et géochimie). Des carottes de sédiments provenant de trois dépôts de la région de Kingston ont été prélevées, datées au moyen du radiocarbon et analysées stratigraphiquement pour plus de 50 paramètres chacune.

Cette étude révèle l'existence d'une végétation abondante dans les lacs Atkins et Grady ainsi que dans le marais de la rivière Cataraqui il y a 11,100±270, 10,500±180 et 10,200±180 années respectivement. Pendant le retrait de la calotte glaciaire, une végétation hémiarctique a graduellement envahi la région de Kingston. Les variations stratigraphiques dans les spectres sporo-polliniques démontrent que plusieurs fluctuations climatiques se sont succédées avant l'avènement de la colonisation. La distribution quantitative de 27 différentes espèces et formes de mollusques des sédiments du lac Atkins ne semble pas être attribuable aux diverses fluctuations climatiques. La distribution stratigraphique des mollusques, associée principalement à des sédiments marneux, est inversement proportionnelle à la paléoproductivité du lac déterminée par le biais des produits de dégradation de la chlorophylle.

Les analyses chimiques des sédiments de surface prélevés dans neuf lacs de la région de la Gatineau et qui semblent refléter le niveau trophique de ces lacs ont facilité l'interprétation géochimique des trois dépôts du Quaternaire supérieur de la région de Kingston.

Les analyses des profils des trois dépôts lacustres démontrent que la productivité des lacs est fortement influencée par les changements écologiques allochtones et autochtones.

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I INTRODUCTION

A. General Theoretical Considerations

Paleoecology is the part of geobiological science especially devoted to the understanding of interrelationships between dead organisms and their environment. It is related to ecology which is concerned with the study of the interactions of living animals and plants with their physical, chemical, and biological environment.

In theory paleoecology can be described as ecology projected backward in time. In practice, however, paleoecology is handicapped by the scattered and differential preservation of ancient organisms. Fortunately for Quaternary paleoecologists, the great majority of fossils on which their studies are based are still represented in today's biota. The assumption that vital needs of plants and animals have not changed with time greatly facilitates the interpretation of paleoenvironments.

Various environmental factors in ancient habitats, such as temperature, chemical composition, and humidity are not directly recorded in the sediments. The paleoecologist had to develop his own techniques and procedures so as to reconstruct, from the enclosing matrix of sediments, the original environmental conditions, as well as to estimate the nature and the quantity of organisms that lived in ancient environments. Paleoecology lacks a coherent body of fundamental principles and concepts because of the inherent limitations of the subject and the relative newness of the field. At its present stage of development the subject relies on empirically derived concepts, a multiplicity of investigative techniques, and diversity of ideas and observations, still unintegrated. Consequently it is very difficult to justify the validity of our assertions concerning past environments and communities of organisms. The only criteria to substantiate our paleoecological observations are the internal consistency of multiple sets of independent data leading to the same final conclusions, and the geological and biological interpretation as referred to present-day environments and organisms.

Although Quaternary terrestrial paleoecology is dominated by stratigraphic pollen analysis (Cushing, 1967), many other remains found in lake and bog sediments are submitted to the same kind of stratigraphic and ecologic investigations. It is the hope of the writer that the palynological aspects of this present study along with the malacological and chemical investigations will contribute to a better understanding of the Quaternary history of the Kingston Region and, more particularly, to the ontogeny of lakes.

Let us now consider the assumptions, procedures, viewpoints, and limitations of the three different methods on which this paleoecological work is based.

1. Palynology

In the process of reproduction, plants produce pollen and spores in various quantities. The great majority of these reproductive units are incorporated with different kinds of sediment on the surface of the earth without completing their sexual function.

The remarkable durability of the exine of the pollen grains (Jentys-Szafer, 1928; Lewis and Coche, 1929; Erdtman, 1931; Godwin, 1934; Sangster and Dale, 1961, 1964) is the fundamental basis of palynology. Since their composition is relatively stable, pollen and spores are generally preserved through the ages in certain suitable media such as lake or bog sediments. The structure and morphology of pollen grains are sometimes sufficiently distinctive so that, from them, the specific identity of the parent plant can be established more or less accurately. As noted by Faegri and Iversen (1964), the units of classification in palynology "Pollen Species", vary considerably in taxonomic value, sometimes including part or all of a large family and at other times a single species or only a few closely related species. Several workers, Faegri (1945), Christensen (1946), Cain and Cain (1948), Iversen and Troels-Smith (1950), Davis (1958) and others, have tried to subdivide the taxonomic units further by statistical methods but very few have been successful .

In a pollen diagram the percentages of the different types of pollen are a function not only of the various species which form the contemporary forest but also of the quantity of pollen produced by each species.

Obviously a pollen spectrum does not give the exact numerical composition of present or past vegetation, but it is assumed that sustained stratigraphical variations of these percentages are correlated with changes in climate and other ecological factors. To attain correct interpretations of a pollen diagram the investigator must be aware of the following important factors:

a) The relative amount of pollen produced by each species.
b) The chief mechanism of transport.
c) The distance that pollen is likely to be carried from the parent plant.
d) The susceptibility of each pollen type to corrosion.
e) The correct identification of the pollen.

Pollination mechanisms accountable for grain dispersal can be included in two different groups; namely, physical agencies and animal agencies (Percival, 1965). The first group consists of plants pollinated by wind, water, and rain. The second group, zoogamous plants, comprises plants pollinated by insects, birds, bats, and molluscs. Generally plants producing a great quantity of pollen possess a more primitive and less efficient mechanism of pollination. Each type is characterized by fundamental structural differences in pollen morphology which offer clues to its mode of distribution.

Since hydrophilous pollen grains usually lack a well developed exine, such pollen grains are rarely preserved in sediment. In zoogamous flowers the grains are generally adhesive and the ektexine bears a wide variety of prominent protuberances and pits (Rowley, 1959, 1960; Yamazaki and Taheoka, 1962; Echlin, 1968). A small quantity of these is needed to complete the reproductive function. Nothing can be deduced from the absence of zoogamous pollen species in sediment and even when found they are always under-represented (Faegri and Iversen, 1964). Some plants, such as willows and maples, are pollinated by both wind and insects; they share morphological characteristics of both groups and when present in pollen analysis they are ordinarily also underrepresented.

Most gymnosperm pollen is widely distributed by wind. Catkin-bearing angiosperms, such as Quercus, Corylus, and Betula, lend themselves to wind dispersal of pollen. Anemophilous pollen types, which are extremely common in any pollen analysis, are usually overrepresented. They are characterized by smooth surfaces or by other structures, such as air bladders, which increase their buoyancy. These types are reported to have been transported by wind over very long distances. Erdtman (1936, 1937) cites examples of arboreal pollen grains being wind transported from Labrador to Greenland, a distance of over 1,000 kilometers. Faegri and Iversen (1964) conclude that a distance of 50 to 100 kilometers is a natural limit for pollen dispersal; the percentage of pollen travelling beyond that distance is considered negligible. Godwin (1934) and Tauber (1965) give excellent summaries and discussions of opinions and results on several types of pollen transported by wind.

Attempts have been made to establish correction factors (Davis, 1963) which can be applied to pollen concentration so as to agree more precisely with some phytosociological measurement of vegetation, such as percent cover, relative basal area, relative frequency or relative density (Pohl, 1937; Potzger, Courtemanche, Sylvio and Hueber, 1956; Davis and Goodlett, 1960; Davis, 1963; Heim, 1963; Potter and Rowley, 1960; Livingstone, 1968; and others). Workers have not been entirely successful in the attempt to correlate qualitatively and quantitatively a modern vegetation with its pollen rain since many variables cannot yet be delimited accurately.

Although a pollen spectrum does not give sufficient information in itself for the numerical determination of corresponding vegetation types, it is absolutely necessary to know the pollen production ratios between different plant species. Pohl (1937), and Hyde (1951) show that it is relatively easy to find the average amount of pollen produced by every plant species over a number of years, the number of flowers in bloom being highly variable within each species and each individual.

A considerable number of studies done on the direct correlation between plant associations and their pollen spectra give us a great deal of data without absolute practical meaning. However, phytogeographical zones can be correctly delimited on a wide scale on the basis of these data. In the USSR Gritchouk (1941), in Great Britain Godwin (1940, 1956), and in Canada Lichti-Federovich and Ritchie (1965, 1969), and Davis (1967) were able to establish floristic provinces such as steppe, taiga, tundra, etc. Each phytogeographical unit has a characteristic pollen spectrum.

In pollen analysis these phytogeographic provinces or regions should be considered to be stratigraphically equivalent to pollen zones. An optimistic point of view suggests that the subdivision of these zones into increasingly fine units could lead to a possible reconstruction of past associations. As a result of limitations of palynological method, one should be cautious in making these subdivisions. Perhaps a better approach to this problem would be to use data from interdisciplinary methods of investigation.

2. Malacology

Based on the principle of Uniformitarism, it is generally accepted (Geyer, 1922; Baker, 1937; Eiseley, 1937; Sparks, 1961, 1964; Taylor, 1960, 1966; La Rocque, 1966; Frey and Leonard, 1967) that the ecology of nonmarine molluscan species found in Quaternary deposits is the same or quite similar to that of their modern living representatives. Since we are aware of the ecological needs, tolerance limits, and distributions of modern species, it is fairly easy to reconstruct and interpret paleo-environments if the proper techniques and methods are used. Assuming that the knowledge of modern species is sufficient, this investigation can be done by gathering qualitative and quantitative information from each successive stratum of a deposit containing an assemblage of nonmarine molluscs.

Regardless of the kind of fossil being used to determine paleoenvironments, several problems will remain unsolved as it is impossible to make direct environmental observations and as the data obtained from the fossils and their enclosing matrix are constantly being submitted to some diagenesis. The choice of a basis for any paleoecological investigation must depend on a great number of factors, such as the biostratigraphic, lithologic, and geographic nature of a deposit. Furthermore, the specialization of the investigator, which is not always the most suitable for a particular deposit, has a strong influence on the accuracy with which the paleoenvironment is reconstructed. It is quite evident that each type of fossil assemblage and method used in paleoecological investigations has its own limits which often differ considerably from one another. The paleoecologist will achieve better results by making use of several complementary fields of specialization as is done in this thesis.

When making a detailed reconstruction of paleoenvironments the relative frequencies of each species within a deposit are far more helpful than a list of species only. As mentioned by West (1968), "the difference between qualitative and quantitative analysis is analogous to the difference between a simple plant list from a plant community and a detailed plant-sociological description of the same community". Quantitative changes within deposits are the basis of detailed interpretation of fossil paleoenvironments.

The quantitative use of Quaternary nonmarine molluscan assemblages in paleoenvironments is sometimes more appropriate than the use of other types of fossils. Unlike vertebrate fossils or plant macrofossils, molluscs are found in great numbers in most calcareous deposits, in or close to the habitat in which they have lived, despite the fact they are more mobile than other types. Their counts give absolute estimates of the number of individuals for each species that lived in the past. Counts of pollen, seeds, leaves, twigs and roots are less significant than mollusc counts since they represent only parts of individuals and, therefore, have no direct numerical relationship to the abundance of a species.

On the other hand, the quantitative use of Quaternary nonmarine molluscan assemblages in paleoenvironments is not always entirely successful. Because identification of molluscan fossils is based essentially on their shells, certain taxonomic problems arise when the identification of living species is based on criteria found in the soft parts. La Rocque (1966) discusses this drawback and concludes that the identification of the shell is almost always equivalent to the identification of the species, as in the Succineidae for instance. The problem of species identification of fossil shell is negligible when compared to the one encountered in palynology.

Unfortunately fossil molluscs are preserved only in sediments which have not been intensively leached and are, therefore, restricted largely to calcareous deposits. The absence of such deposits from most of the Canadian Shield of Northern Canada considerably reduces the value of molluscs as paleoecological indicators. Very little is yet known (Tuthill, 1967) about the migration of freshwater molluscs in Northern Canada during the Quaternary. Many species may be living there today, but no paleoecological significance can be derived from their absence in most of the Quaternary deposits.

Another important problem limiting qualitative studies of Quaternary molluscan assemblages in paleoenvironments results from the fact that, unlike most plants, practically all molluscs have a wide tolerance to habitat and climate. Furthermore accurate descriptive ecology of modern molluscan species has been nearly non-existent up to now. Many species of Physa, Helisoma, Gyraulus, Valvata, Lymnaea and Sphaeriidae are found in many types of environment from Mexico to the Arctic. Today detailed reconstruction of paleoenvironments by fossil shell investigations is not yet comparable to the palynological method. We can and should attempt to interpret fossil molluscan populations but we should not endeavour to go beyond the limits established by their present day ecology.

To eliminate some of these inconveniences, Boycott (1934) divided molluscan fossils into ecological groups based on their respiratory system while Sparks (1961) based his grouping on the range of northern latitudinal distribution of each species. These crude groupings have provided some reasonable, systematic pictures of climatic trends and ecological changes in several fossil deposits found in Great Britain. Similar but more detailed methods were extensively used by Lozek (1964a, 1964b, 1967) in Czechoslovakia. He contributed substantially to our knowledge of the Quaternary environment of Central Europe.

In spite of these limitations, studies of molluscan fossil assemblages provide sufficient evidence for at least partial interpretation of paleoenvironments. At the present stage of knowledge, workers should be particularly careful in building refined interpretations on the molluscs counted in Quaternary sediments. The ultimate aim is to distinguish the exact environments in which the fauna has lived and to reconstruct the history of Quaternary events. The achievement of this goal will require a wide range of experience in stratigraphy, and expanded knowledge of the ecology, biology and distribution of modern species. Clark's voluminous work (in press) on the molluscan fauna of the Hudson Bay Drainage will provide valuable information for future paleoecological studies.

3. Geochemistry

The chemistry of an environment is important and reflects the action of both past and present biotic and abiotic factors. In paleoecology, just as in ecology, biotic and abiotic factors acting in an ecosystem cannot be studied independently since they are intimately related to one another. Information concerning one of these factors helps us to understand the others. Consequently, quantitative studies of the chemistry of Quaternary deposits give us better clues to the understanding of the biota which lived in paleo-environments.

Ecologists have established that to survive within an environment all organisms must obey the law of tolerance (Liebig, 1840; Blackman, 1905; Shelford, 1911) which has been governing the life on our planet since the appearance of the first cell. This law becomes extremely important in paleoecology as it limits paleoenvironment interpretations to a narrow range of logical possibilities.

Although geochemical paleoenvironmental studies have recently received considerable attention especially in the discipline of organic geochemistry, there does not actually exist any strongly established paleobiochemical system comparable to the pollen analysis method. Up to now investigations done in the field of paleoecology have been based mostly on the morphological study of fossils. In the near future, recent developments in analytical chemistry will probably reverse this trend and eliminate long hours of routine examinations and taxonomic problems. Nevertheless, certain difficulties will always remain in the chemical reconstitution of ancient biotopes, most of which have unfortunately been submitted to some diagenesis. A chemical system characterizing a particular environment is very seldom preserved as such for a long period of time. Postdepositional changes establish new chemical equilibria which are often different from the original ones.

Chemical elements found in paleoenvironments respond to specific weathering cycles governed by their chemical properties as well as by the physical and chemical properties of the minerals in which they are found. Geochemists (Keith and Degens, 1959) have grouped elements according to their tendencies to be concentrated in specific sedimentary types. The most important groups are: the clay minerals (Al, Si, K, Mg), oxides (Fe, Mn), organic material (C, N, H, O), sulphides (Fe, S), carbonates (Ca, Mg, C), and phosphates (P, Ca, F). On the other hand, Nicholos (1961), a botanist, categorized the essential nutrients for plants as follows: (a) the major elements including N, P, K, Ca, and S; (b) the minor elements, or trace elements, including Fe, Cu, Zn, Mn, B, Na, and Cl; (c) an ultra-micro group, including Co, Mo, and V. He also pointed out that these latter elements have been proven essential only for certain plants including micro-organisms.

Whatever method is used to classify chemical elements, all workers agree to their fundamental importance in physical and biological systems as well as to their various amounts in any kind of ecosystem which permits characterization of the habitat to some extent. Although presently it is not possible to separate the allochthonous elements from autochthonous ones which reflect the chemistry of the environment during deposition, it has been established (Black and Mitchell, 1952; Krauskopf, 1955; Goldberg, 1957) that chemical elements can be enriched and that they can be specific of life processes. Calcium carbonate precipitation caused by photosynthetic activities as well as sulfur deposits concentrated by means of bacterial activities are good examples of these biological processes (Ruttner, 1953). Coal and petroleum are also characteristic of sedimentary products typical of life processes (Hodgson, Hitchon, Elofson, Baker and Peake, 1960).

Paleogeochemical analysis of lacustrine and paludal sediments is a small part of paleolimnology which aims at the reconstruction of the evolutionary stages of a lake. The basic data from which the history of a lake is constructed comes from analysis of its sediments. As long as a lake exists, sediment accumulation causes progressive change, but for any short period of time (measured in hundreds of years), there is a tendency for the aquatic ecosystem to come to equilibrium.

In North America, lacustrine deposits accumulated in depressions of glacial origin usually begin with a meter or two of glacio-fluvial material, followed by silt and clay representing the oligotrophic stage. Lake sediments located in calcareous areas have often shifted with time to alkalitrophic (Naumann, 1932) and eutrophic stages. The first stage is stratigraphically represented by marl while the second is characterized by organic sediments such as copropel and gyttja. In more acidic areas the alkalitrophic stage is often missing and lake development passes directly from the mesotrophic to the eutrophic stage. In populated areas, within the top meter of sediments, this natural eutrophic stage is replaced by an hypereutrophic (anthropoeutrophication, cultural eutrophication; Wetzel, 1966a), a stage reflecting human activities. In other cases, if the lake becomes completely filled with sediment, peat succeeds gyttja and is followed by sedge and forest peat.

Paleolimnology is not only concerned with the reconstruction of a lake's history in terms of developmental stages but also attempts to reconstruct abiotic and biotic factors which played important roles during and after the formation of a lake.

For convenience and easier understanding, the geochemical aspect of this work has been arbitrarily divided into three subsections, namely: (1) trace elements, (2) general chemistry and (3) sedimentary chlorophyll degradation products (SCDP). Lack of financial assistance prevented a deeper stüdy of several geochemical compounds which might have supplied valuable paleoecological information.

B. The Study Area

1. Location

Three sites located near the northeastern extremity of Lake Ontario have been investigated (Fig. 1, p. 17). In this study the area designated as "the Kingston Region" (Fig. 2, p. 18) lies roughly between 75°30' and 76°45' West longitude and 44°10' and 45°00' North latitude and includes the counties of Frontenac and Leeds in the Province of Ontario.

The Cataraqui River Marsh is located in the Kingston Township of the Frontenac County (44°17' North latitude, 76°27' West longitude) at 246 feet (75.0 m) above sea level, which is also the elevation of Lake Ontario (Fig. 3, p. 19). It is an extensive sedge-typha marsh about one mile long on the west bank of the Cataraqui River immediately south of the MacDonald-Cartier Freeway (Fig. 4, p. 20).

The following plant species are commonly found in the marsh: *Agrostis alba* var *major*, *Calamagrostis canadensis*, *Carex atherodes*, *Carex Bebbii*, *Carex lacustris*, *Elocharis palustris*, *Eupatorium perfoliatum*, *Glyceria striata*, *Iris versicolor*, *Juncus effusus*, *Phalaris arundinaceae*, *Poa palustris*, *Salix discolor*, *Salix nigra*, *Typha angustifolia*, *Typha latifolia*. A few high trees such as *Acer rubrum*, *Fraxinus nigra* and *Ulmus americana* grow on small elevations within the marsh.

Grady Lake is situated in North Crosby Township of Leeds County (44°43'39" North latitude, 76°22'36" West

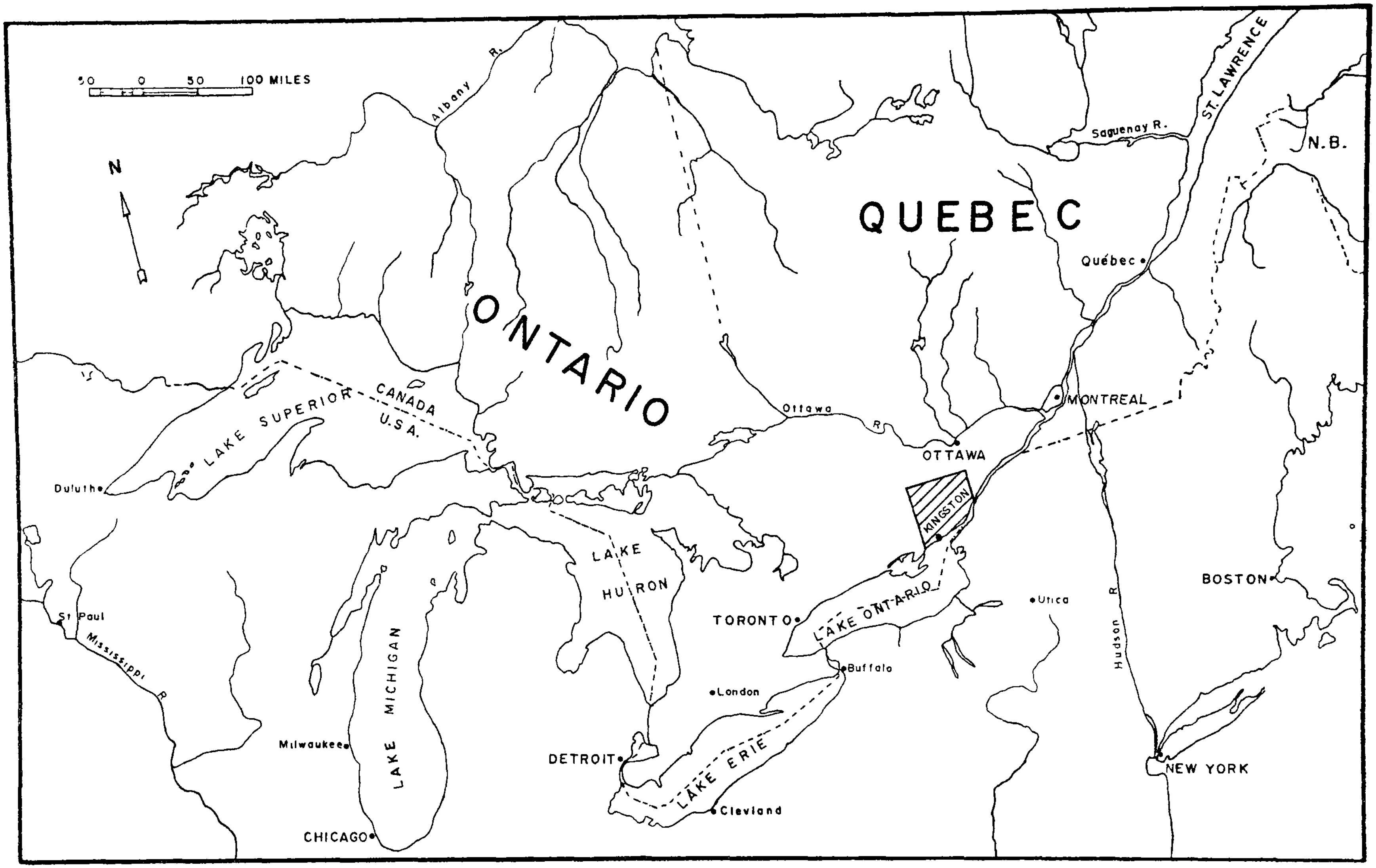


Figure 1. Index map of the Great Lakes-St.Lawrence Region showing the location of the Kingston Region.

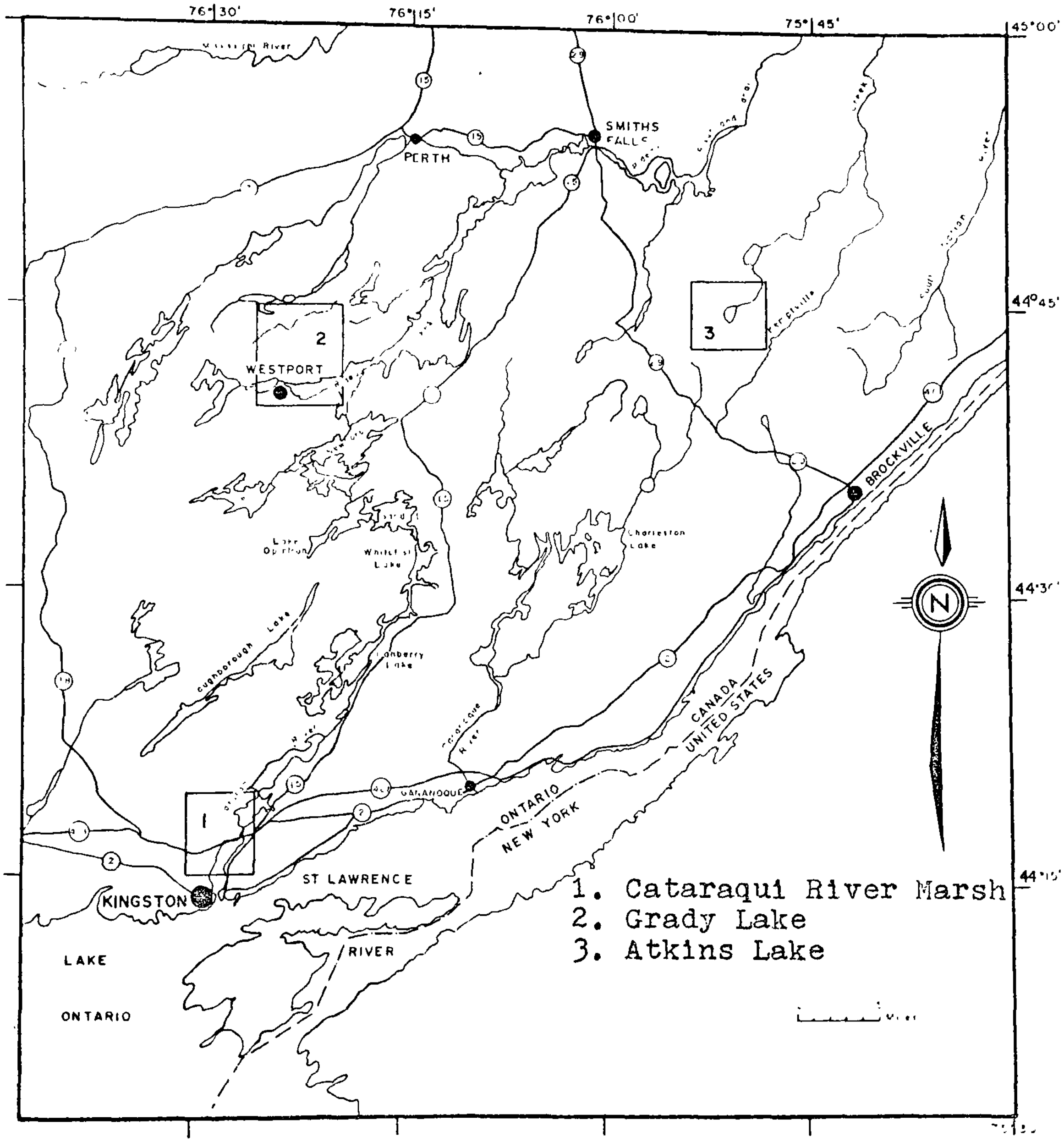


Figure 2. Map of the Kingston Region showing the general location of the three sites studied.

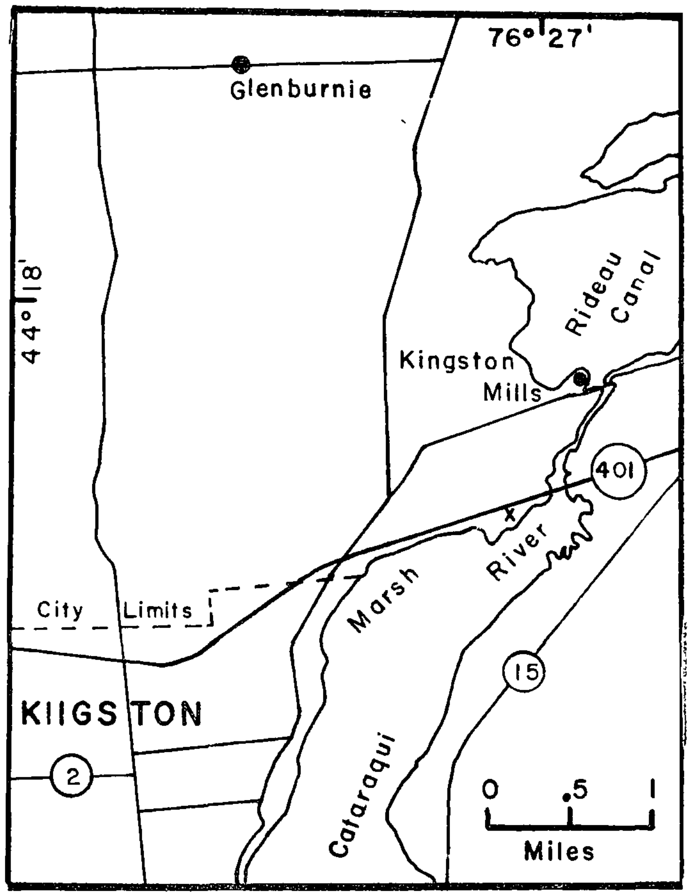


Figure 3. Map of the Cataraqui River Marsh area. X-Sampling site.

Figure 4. View of the Cataraqui River Marsh from the Macdonald-Cartier Freeway.

longitude) at 563 feet (172.5m) above the sea level, in a depression of the Frontenac Axis at about 3 miles (4.8 km) north-northeast of Westport (Fig. 5, p. 22). It is outside the Champlain Sea limits and above any late-glacial lake such as Lake Iroquois.

Its shape is fairly regular. It has a diameter of 2,000 feet (610 m) and the surrounding terrain is about 75 feet (23 m) high (Fig. 6, p. 23). Presently it is an eutrophic body of water with abundant aquatic vegetation. Plant zonations such as Potamogeton, Nuphar, Nymphaea, Sagittaria, Scirpus, Elodea, Vallisneria and Typha are well-developed in the shallow parts of the lake.

Atkins Lake lies in a small depression of the gently dipping Ordovician dolomitic limestone of the Central St. Lawrence Lowland (Fig. 7-8, p. 24). It is located within the Kitley and Elizabethtown Townships of Leeds County (44°45' North latitude, 75°51' West longitude) at 381 feet (116.5 m) above sea level (Fig. 9, p. 25). This lake basin rests a few hundred feet outside the westernmost limits of the Champlain Sea (Henderson, 1970).

The lake, which is one mile (1.6 km) long in a north-south direction, has a water depth of less than one meter except for a small central depression which has a water depth of 3.30 meters but contains less than one meter of organic sediment. The bottom is loose mud and detritus which shifts under the action of waves.

Some Scirpus and Potamogeton grow out as far as the

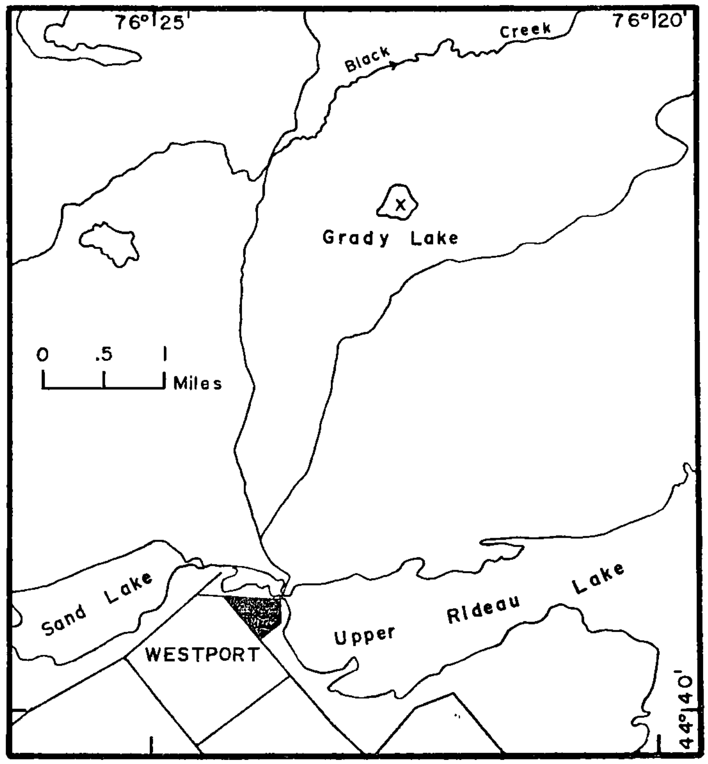


Figure 5. Map of the Grady Lake area.

Figure 6. View of Grady Lake.

Figure 7. Topography of Lake Atkins watershed.

Figure 8. View of Atkins Lake.

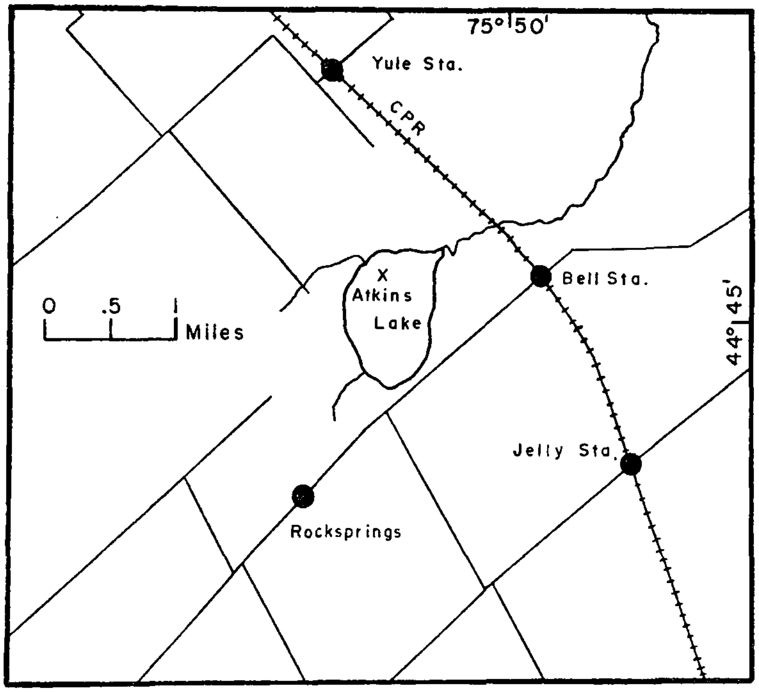


Figure 9. Map of Atkins Lake area.

middle of the lake but they are denser by the shore where wide bands of Nymphaea and Nuphar are frequent. Other common aquatic plants by the shore are: Chara, Myriophyllum, Potamogeton, Scirpus and Typha. There also are shrubs such as Myrica Gale, Cornus and Salix.

2. Geological Setting

The Kingston Region covers parts of two Canadian physiographic provinces (Fig. 10, p. 27). They are the Canadian Shield, commonly known in that part of the country as the Frontenac Axis, and the St. Lawrence Lowland. The Axis cuts the St. Lawrence Lowland Province into two units. The northeastern one, known as the Central St. Lawrence Lowland (Ottawa-St. Lawrence Lowland of Wilson, 1946), on which rests the Atkins Lake site, and the West St. Lawrence Lowland, on which the Cataraqui River Marsh site is found.

The Frontenac Axis, which crosses the St. Lawrence River between Gananoque and Brockville, connects the Canadian Shield with the Adirondack Mountains in Northern New York State. The area underlain by Precambrian rocks of the Grenville Structural province (Muller and Knight, 1907) represents a very ancient peneplain (950±150 million years, Stockwell, 1961), which was submitted to long periods of erosion prior to the Cambrian Period (Wilson, 1901, 1904). Subsequent erosion did not affect the topography of the shield to any great extent. The knobs, ridges and hills have been rounded and generally streamlined by glacial erosion, producing the characteristic

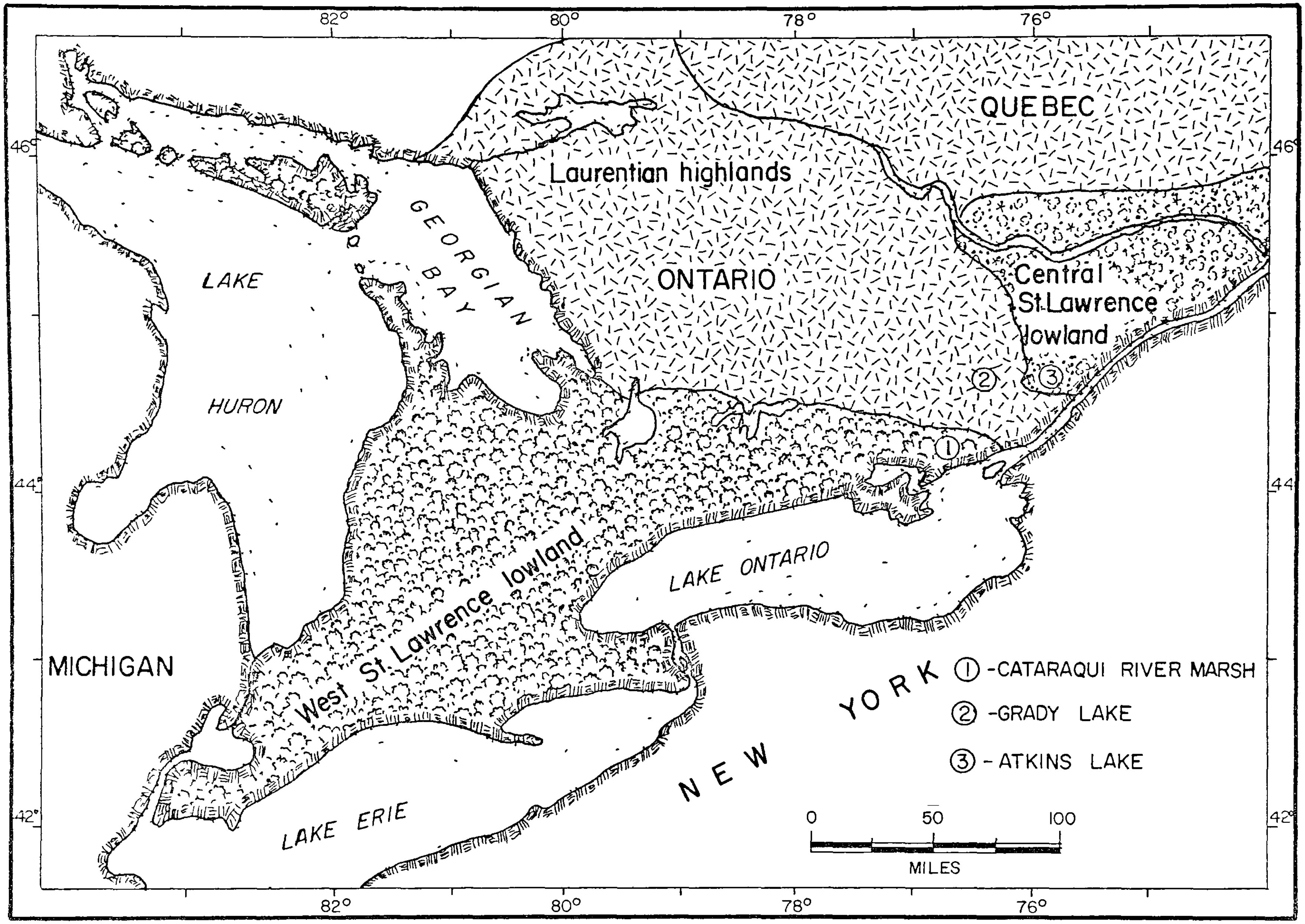


Figure 10. Geological sketch map of Southern Ontario and Quebec.

roches moutonnées form. This peneplain slopes gently from northwest to southeast from a maximum of 800 feet (243 m) northwest of Westport to a minimum of about 275 feet (84 m) in the vicinity of the Thousand Islands. The topography has been strongly influenced by the structure and character of the underlying rocks. Differences in the hardness of the rocks have caused a series of ridges and hollows which correspond in direction with the general gneissic structures (M. B. Baker, 1923). The Precambrian rocks, which do not exceed 300 feet (91.5 m) in relief, are composed of high resistant quartzite, granitic gneiss and other metamorphic rocks. Most of the lakes of the region are located within this type of topography. More details on the geology of the Precambrian rocks are found in the works of Wilson (1901, 1904), Wynne-Edward (1957), Hewitt (1964), and Douglas (1970).

To the east and northeast of the Frontenac Axis lie undisturbed Paleozoic rocks of the of the Central St. Lawrence Lowland which dip gently from a maximum elevation of 500 feet (152 m) at the Frontenac Axis edge to a minimum of 70 feet (21.3 m) above sea level near the mouth of the Ottawa River (Wilson, 1946). The Precambrian-Paleozoic contact follows a rough line from Brockville on the St. Lawrence River to Arnprior on to Ottawa via Westport, Perth and Carleton Place. This line probably marks the western limit of the Champlain Sea. The Potsdam or

Nepean dolomitic sandstone, Cambro-Ordovician in age, rests unconformably on the Precambrian rocks. In a few places Precambrian knobs are exposed above the Paleozoic formations. The Beekmantown group , which is mainly composed of dolomite and limestone, covers most of the Central St. Lawrence Lowland area.

To the southwest of the Frontenac Axis, a distinct escarpment in the Black River and Trenton limestones which is Ordovician in age and overlaps the Precambrian rocks, marks the northern edge of the Lake Ontario Homocline. The topography is generally quite level, and wide areas of the dull-gray fissured limestone are exposed either at the surface or beneath a few inches of soil.

Chapman and Putnam (1937, 1940, 1951) divide the Paleozoic rock area of Southern Ontario into much smaller units according to the topographic forms, depth, and character of the surface deposits, and to the kind and configuration of the bedrock outcrops. Their excellent description of these units provides a detailed background for an understanding of the landforms of the main agricultural portion of the region.

3. General History of the Quaternary

During the Quaternary period the Kingston Region was overrun by four ice-sheets which spread out from centers in Northern Canada. However, only the Wisconsin glacier, which started to retreat about 20,000 years ago, has left deposits in the area. When the deglaciation took place in the Lake Ontario basin, several proglacial lakes were formed between the ice fronts and the southern, newly uncovered ground (Hough, 1958; Mirynech, 1962; Prest, 1970).

As the retreating ice uncovered the Mohawk Valley at Rome, New York, letting the water flow into the Hudson River, the stage known as Lake Iroquois (Spencer, 1889; Coleman, 1937) was initiated. According to Karrow, Clark and Terasmae (1961), this event occurred about 13,000 years ago. Further glacial recession at the east end of Lake Ontario opened the Covey Hill outlet (Leverett and Taylor, 1915) and finally the St. Lawrence drainage about 11,500 years ago. Because of the isostatic depression of land in the St. Lawrence Valley, the water level in the Ontario basin dropped at least 300 feet (91.5 m) below the present level, yet it remained above the sea level of that time. With a more rapid differential isostatic uplift in the Kingston Region, the low water level of the Admiralty stage of Lake Iroquois rose and gave birth to Lake Ontario. At about the same time in the St. Lawrence Valley, the Champlain Sea, which had originally replaced the lacustrine episode of the Fort Ann stage of Lake Vermont (MacClintock, 1958) was retreating eastwards. Several new radiocarbon dates (Lowdon and Blake, 1968, 1970) such as the one from the Cataraqui River Marsh suggest that Lake Ontario existed 10,000 years ago.

The Frontenac Axis area contains very little geological information related to the Quaternary history of the Great Lakes. Henderson (1967) attributes this to the fact that the water of proglacial Lake Iroquois stood along the margin of the melting ice and did not allow any geological structures to be formed. The same author believes there were some well-developed beaches and bars, related to the Champlain Sea, stretching from Brockville to Smiths Falls and passing through the southeastern area of Atkins Lake and possibly the Charleston Lake basin.

4. Drainage

The drainage pattern of the region is immature. Each river passes through several lakes. The Rideau Water System is the main drainage of the area (Fig. 2, p. 18). North of the Upper Rideau Lake (409 feet, 149 m, above sea level) the region drains into the Ottawa River via the Rideau, South Nation and Mississippi Rivers. The southern part drains into the St. Lawrence River and Lake Ontario (246 feet or 75 m above sea level) by the Cataraqui, Gananoque, Napanee and Rainy Rivers. Extensive, poorly drained areas which produced a large number of organic deposits are found near the Precambrian-Paleozoic contact.

5. Early Development

Several authors (Hennepin, 1697; Dionne, 1963; Keenan, 1965), greatly inspired by Champlain's report of his voyages to the Huron and Iroquois country in 1615, state that, prior to the arrival of Europeans, the eastern shore of Lake Huron and the northern shore of Lake Ontario supported important Indian agricultural settlements. Some believe that agricultural land in the Lake Simcoe district was as considerable as it is today. This pre-European agriculture has been found by McAndrews (personal communication) in a pollen diagram from that area.

Even if the first white settlement in Upper Canada was Fort Frontenac established in 1673,(on the present site of Kingston) no extensive clearing was done prior to 1784, the year of the arrival of the United Empire Loyalists. By 1850, settlers had cleared the land on the limestone plains south of the Canadian Shield, mainly to free the land for agricultural use as well as to produce potash and timber for export.

The Rideau Canal, constructed for military purposes by the British Government between 1827-1832, had a great influence on the development of the region by providing a transportation route towards the interior for the lumber industry and, unfortunately, for settlement on the Frontenac Axis later on (Legget, 1955).

In contrast with the agriculturally motivated settlement along the Lake Ontario front, the penetration and early exploitation of the Ottawa Valley and the Canadian Shield were influenced by the lumber industry in search of high quality timber (white and red pines) for export. For more than a century Kingston and Ottawa have been important centers of raft departure for Montreal and the United States. During the early part of this century the demand for quality hardwood from the United States market resulted in the first major cutting operations in the stands of tolerant hardwoods growing on many parts of the shield.

Farming on the shield has never been prosperous. Following the 1891 census to the present day land abandonment and depopulation of the rural area are quite evident. On the limestone plains much of the land is also unsuitable for agricultural uses but, as a result of economical misconceptions, large areas of marginal land have been cultivated and then abandoned (Jones, 1946).

Today marginal farming is continued mainly by the older generation; a considerable number of woodlots are still being misused, and pollution of water bodies has reached an alarming degree. Fortunately the government's conservation agencies are now conscious of this deplorable situation and tend to reorientate these fallacious interests toward more profitable uses of the natural resources.

6. Modern Climate

Kingston has the only meteorological station within the region studied, with 69 years of recorded data, but it has unfortunately been closed for several years. The other nearby stations are: Brockville, Kemptville, Ottawa, Renfrew, Tweed, Trenton and Belleville.

According to Thornthwaite (1948), the area belongs to the humid climatic province and, more specifically, to the moderate humid type B2 with adequate rainfall in all seasons. Based on the Köppen classification (Trewartha, 1954) the climate of the area is of type Dfb, a snow forest climate similar to that of Southern Ontario with the coldest month below 26.6°F and the warmest month above 50°F but below 71.6°F, and with fairly equal precipitation throughout the year. Chapman and Putnam (1937), Sanderson (1950), and Brown, McKay and Chapman (1968) have studied the climate of Southern Ontario. The climatic values for the Cataraqui River Marsh area and for the Grady Lake area (Table 1, p. 314) have been read from their maps. A distance of 35 miles (56.3 km), an increase in elevation of 350 feet (106 m) between the southern and the northern sites, produces a climatic macrogradient toward cooler and more continental conditions in a northern direction.

The effect of Lake Ontario on the climate of the region is reflected in the data of the above named authors. The mean annual temperature in the northern area is lower than that of the south by 2°F and the winter temperature by 4°F. The absolute maximum temperature in summer is lower by the lake, but in winter the absolute minimum temperature is found in the Grady Lake area. Moreover, the average length of the growing season is shorter by 10 days, and the length of frost-free period by 24 days in the northern part of the region, whereas the potential evapotranspiration and the average annual water deficiency are higher by the Lake Ontario shore.

On the basis of the above meteorological data, Putnam and Chapman (1938) include a strip of land north of Lake Ontario and east of Lake Erie in the South Slope climatic region, which also encompasses the southwest corner of Frontenac County. On the other hand, Atkins and Grady lakes are placed within the Eastern Ontario climatic region bordered on the east by the Ottawa and St. Lawrence rivers.

7. Present vegetation

Halliday (1937) and Rowe (1959) include the Kingston Region in the Great Lakes-St. Lawrence Forest Region of Canada. This important region is essentially a transitional zone between the Boreal Forest Region to the north and the Deciduous one to the south. Since the vegetation of the Kingston Region derives its composition partly from the two surrounding forest regions, this ecotone is very often referred to as the Mixed Conifer Hardwood Forest. The Great Lakes-St. Lawrence Forest Region, which extends from Northwestern New Brunswick to Southeastern Manitoba, is divided into sixteen sections according to the relative abundance of different species (Fig.11, p. 37).

The three sites under investigation in the present study are each located in a separate section of the Great Lakes-St. Lawrence Forest Region. The Cataraqui River Marsh area, resting on the limestone plain south of the Precambrian boundary, is included in the Huron-Ontario Section, with its northern boundary running along the Precambrian-Paleozoic contact. The southern boundary of this section runs southwest from a few miles north of Belleville, in a line more or less parallel to the north shore of Lake Ontario, to the southeast end of Lake Huron. This forest section is characterized by its mixed forests which are predominantly deciduous. Its

Figure 11. Map of Southern Ontario and Quebec showing the forest regions and the relative location of the sites studied. After Rowe (1959).

—— Region boundary line

···· Section boundary line

DECIDUOUS FOREST REGION

D.1 Niagara Section

GREAT LAKES-ST. LAWRENCE FOREST REGION

L.1 Huron-Ontario Section

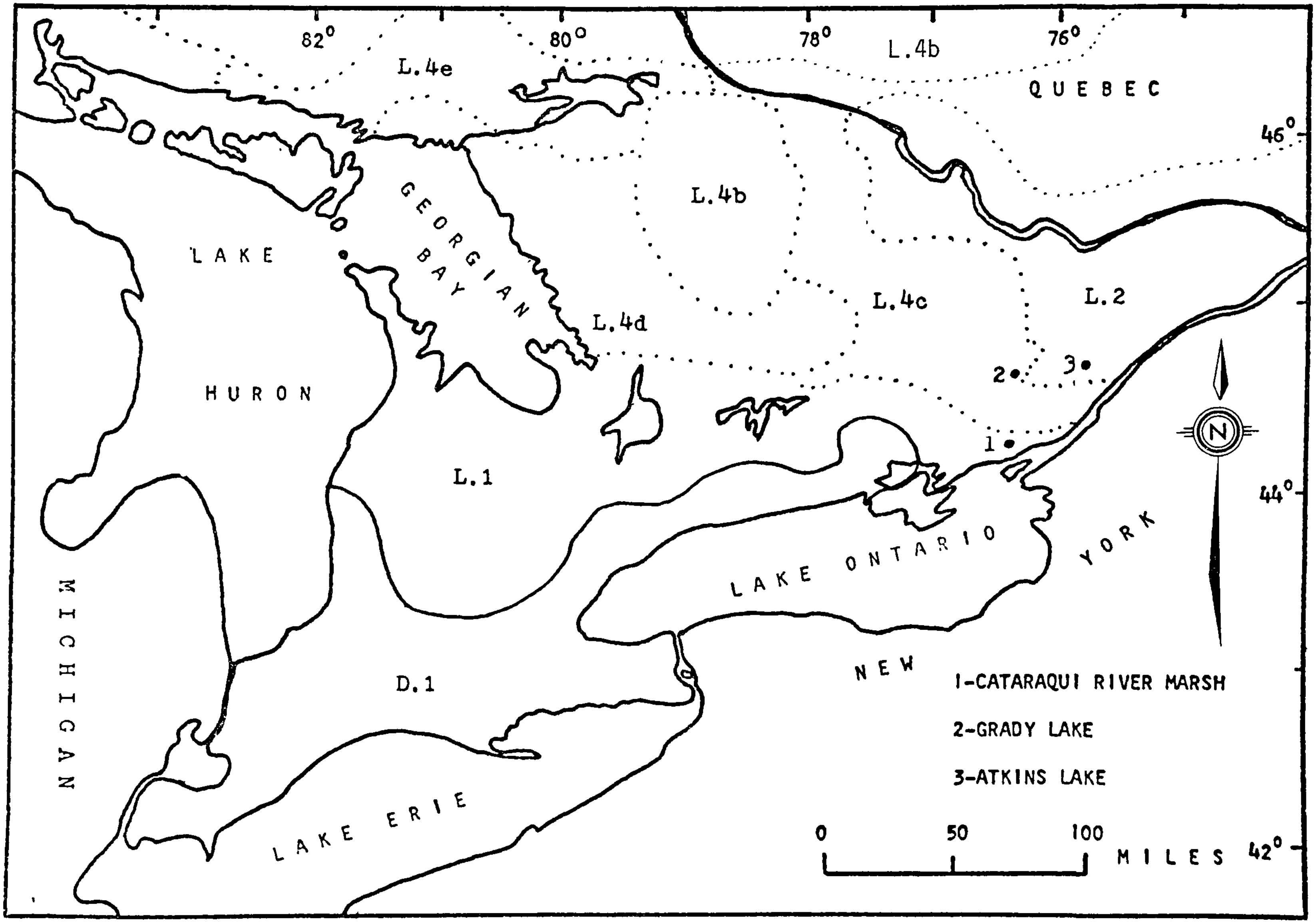
L.2 Upper St. Lawrence Section

L.4b Algonquin-Pontiac Section

L.4c Middle Ottawa Section

L.4d Georgian Bay Section

L.4e Sudbury-North Bay Section



82°
80°
78°
76°
L.4e
L.4b
QUEBEC
46°
L.4b
GEORGIAN BAY
LAKE HURON
L.4d
L.4c
L.2
2
3
1
L.1
44°
LAKE ONTARIO
NEW YORK
MICHIGAN
D.1
LAKE ERIE
N
1-CATARAQUI RIVER MARSH
2-GRADY LAKE
3-ATKINS LAKE
0 50 100 MILES
42°

northern limits coincide with the distribution limits of sycamore (*Platanus occidentalis*) and black walnut (*Juglans nigra*) which both enter from the southern Deciduous Region, and Jack pine (*Pinus banksiana*) from the northern Boreal Region. The dominant species within this section are sugar maple (*Acer saccharum*) and beech (*Fagus grandifolia*). Often associated with these are basswood (*Tilia americana*), white ash and red ash (*Fraxinus americana*, *F. pennsylvania*), yellow birch (*Betula lutea*), red maple (*Acer rubrum*), and red, white and bur oaks (*Quercus rubra*, *Q. alba*, *Q. macrocarpa*).

The Grady Lake area, situated on the Precambrian Shield, is included in the Middle Ottawa Forest Section with its Ontario part comprising the Frontenac Axis and the Upper Ottawa Valley. Compared to the Huron-Ontario Section, this area has fewer oaks, hickories and ashes and more boreal affinities.

The Atkins Lake area, located east of the Frontenac Axis and at the western limits of the postglacial Champlain Sea, belongs to the Upper St. Lawrence Section. The dominant cover type is composed of sugar maple (*Acer saccharum*) and beech (*Fagus grandifolia*), with red maple (*Acer rubrum*), yellow birch (*Betula lutea*), white elm (*Ulmus americana*), basswood (*Tilia americana*), white ash (*Fraxinus americana*), largetooth aspen (*Populus grandidentata*), and red and bur oaks (*Quercus rubra*, *Q. macrocarpa*).

Dansereau (1959) includes the St. Lawrence Plains and the Lower Ottawa Valley in his Maple Forest Zone, which has a pure deciduous *Aceretum saccharophori laurentianum* climax forest extending westward along the north shore of Lake Ontario to Brighton. The northern part of the Kingston Region is included in his Northern Hardwood Zone since coniferous species are present in the climax forest of the Aceretum saccharophori betulosum or Aceretum saccharophori tsugosum.

In a detailed study of the vegetation between Northern latitude 44°23' and 44°56' and Western Longitude 76°10' and 77°15', Beshel, Webber, and Tippett (1962) found that about 17 tree species reach their southern or northern limits within the Kingston Region. They also found that southern species decrease northward while boreal species increase. The vegetation of the Kingston Region was also studied by Macoun (1888), Fox and Soper (1952, 1953, 1955), Soper (1956, 1962), Jafri (1965), and Hainault (1968). According to Beshel, and others (1962) the leading dominant species are in order of decreasing importance: Acer saccharum, Ulmus americana, Thuja occidentalis, Pinus strobus and Ostrya virginiana.

In a study of the forest composition of the Frontenac Axis, Jafri (1965) concludes that many species shifted from colder, wetter aspects in the south to hotter, drier aspects in the north. He also maintains that nine species (Acer saccharum, Ostrya virginiana, Pinus strobus, Thuja occidentalis, Tsuga canadensis, Quercus borealis, Tilia americana, Ulmus americana, Populus grandidentata) constitute 75 per cent of the arboreal vegetation in the upland forests. In the wetland forests seven species (*Ulmus americana*, *Fraxinus nigra*, *Thuja occidentalis*, *Acer saccharinum*, *Acer rubrum*, *Abies balsamea*, *Betula alleghaniensis*) constitute over 90 per cent of the arboreal vegetation.

II. REVIEW OF PERTINENT LITERATURE

A. Palynology

It is generally accepted that modern pollen analysis came into existence in 1916, at the Sixteenth Meeting of the Scandinavian Naturalists in Oslo. At that meeting Leonart von Post presented a paper dealing with the techniques of pollen analysis as a botanical geological research method. This was the turning point for studies in forest development and past climatic changes. In 1921, Erdtman presented von Post's method outside the Scandinavian countries, and since that time it has been used extensively in all parts of the world.

However, it was only in 1945 that the term "palynology" was introduced by Hyde and Williams to include all works concerning pollen and spores. Although palynology is commonly regarded as a relatively new botanical science its historical development is closely associated with that of the microscope. Nehemiah Grew and Marcello Malpighi observed and described pollen nearly 300 years ago (Wodehouse, 1935). Many other early botanists and geologists have contributed to our present knowledge of plant microfossils. Wodehouse (1935) gave an excellent historical review which covers pollen work from its earliest days to the modern era.

In Scandinavia, before the development of the method of pollen analysis, pioneers such as Nathorst and Anderson (Faegri and

Iversen, 1964) by recording macrofossils preserved in peat bogs, postulated some postglacial climatic changes. Other pioneers, working mostly on microfossils, played an important role around the beginning of our century in developing modern pollen analysis. The Swiss geologist Früh (1885) was the first to publish a list of common tree pollens found in peat bogs. The Swedish zoologist Trybom (1888), studying the lacustrine deposits of Sweden, recognized the importance of pine and spruce pollen grains as index fossils. The German peat botanist Weber (1896) calculated different pollen ratios found in postglacial sediments. Lagerheim (1902), a paleontologist, discussed fossil pollen distribution and was the first to calculate a pollen spectrum. From this work Holst (1909) derived some postglacial climatic changes. Von Post, who was working on Swedish bogs, associated himself with Lingberg in Finland and gave the first pollen diagram[1].

The books published by Meinke (1927), Wodehouse (1935), Bertsch (1942), Erdtman (1943, 1952, 1957, 1965, 1970), Faegri and Iversen (1964), Erdtman, Berglund and Praglowski (1961, 1962), Kremp (1951), and Tschudy and Scott (1969),had a significant influence on modern palynology by setting forward new standards for the microscopic examination and illustration of pollen grains. Pokrovskaia (1950) notes that before 1940 the Western European workers knew very little about the palynological research done in Russia.[2]

[1] For the literature published in the early days of pollen analysis see Erdtman (1927, 1930, 1932, 1934, 1943).

[2] See recent review by Neustadt (1969) for palynological works done in Russia.

Today numerous journals regularly publish articles on plant microfossils and four international journals are devoted exclusively to palynology. The first International Palynological Conference met at Stockholm in 1950, and at the Eighth International Congress of Botany in Paris, in 1954, palynology was represented for the first time with its own section. The first American National Pollen Conference met in 1953 and has continued to meet informally since that time. Manten (1968) estimates the total number of printed palynological reports, each with an average of 33 pages, at 20,300. He states that the number is doubling at least every decade and that 56 per cent of all this literature is written in English and Russian. This proliferation of work shows that von Post's method was a tremendous contribution to science. It is currently applied all over the world in such fields of research as: stratigraphy, paleontology, paleolimnology, paleoclimatology, flora history, systematic botany, plant evolution, plant phylogeny, archeology, and in many other fields of research.

Von Post's ideas were applied and improved considerably in North America. Sears (1935a, b), Cain (1939), Davis (1965), Ogden (1965), and Terasmae (1967a) give hundreds of references to the palynological work done in North America. The reports show that most of the palynological research has been done in glaciated areas of the United States, and relatively little work has been done in Canada.

Although the Kingston Region acted as a migration route for terrestrial organisms for about 3,000 years in late and postglacial times, no important paleoecological investigation has been undertaken within this area. The paleoecological investigation of this particular region should contribute significantly to the explanation of the origin of the Canadian flora and fauna. Auer (1927a, b, 1928, 1930) published some very general results on peat bog stratigraphy from the study area and Southeastern Canada. For the first time in North America, he recognized postglacial climatic changes similar to those found by European workers at that time. The thirty pollen diagrams that he published are quite incomplete at the base, difficult to read, and sampled at intervals of 50 centimeters. Potzger (1953), Potzger and Courtemanche (1954, 1956a, 1956b) published several arboreal pollen diagrams corresponding to the physiographical regions of the province. Wenner (1947), Grayson (1956), Ignatius (1956), Legault (1958), Terasmae (1958, 1960), Lasalle (1966), Terasmae and Lasalle (1968) were other important contributors to the palynology of Quebec[1]. In Ontario the most important works were done by Janson and Halfert (1936), Terasmae (1967b), and McAndrews (unpublished). All these investigations from Quebec and Ontario gave results quite similar to those of the numerous palynological studies done in the glaciated area of Northern United States.

The pollen analyses which most closely resemble those from the Kingston Region are from New York State, by McCullock (1939), Sheldon (1952), and Cox (1959). The most

[1]See recent review by Richard (1970).

characteristic feature of the pollen diagrams from New York State is a pronounced bimodal curve of hemlock. This species appears in variable amounts in the pine period (B), increases to a maximum as pine decreases in the (C-1) period and maintains itself for a more or less extended length of time as the dominant pollen type. In the (C-2) period, Tsuga drops suddenly in most cases, or sometimes it disappears completely and reemerges as a dominant constituent in the (C-3) period. This bimodal Tsuga curve is also found in other states but apparently in a less pronounced way (Krauss and Kent, 1944; Deevey, 1943, 1951; Potzger and Friesner, 1948; Davis, 1958; Walker and Hartman, 1960; Whitehead and Bentley, 1963). In Southern Quebec, workers already cited, conclude that Tsuga occurs occasionally in two peaks, but little significance is attached to it. The (C-2) zone is interpreted as being a warm and dry interval between the lower (C-1) and the upper (C-3) zones with the latter zone believed to be characterized by a relatively moister and cooler climate (Sears, 1942a,b).

Another major difference between pollen diagrams from the Great Lakes' Region is the lack of a well-defined basal herbaceous pollen assemblage which is so typical in New England and the Maritime Provinces (Deevey, 1951; Leopold, 1956; Davis, 1958, 1960, 1961a, b; Martin, 1958; Livingstone and Livingstone, 1958; Ogden, 1959, 1960, 1961a, 1963; Beetham and Niering, 1961; Terasmae, 1963 ; Groot and Groot, 1964; Davis and Deevey, 1964; Livingstone and Estes, 1967; Anderson 1967). Deevey (1951) subdivides this assemblage into L1, L2 and L3 zones and he believes that it reflects a late-glacial climatic oscillation correlative with the Allerød-Younger Dryas pollen oscillation of Europe and the Two Creeks-Valders stage of the Great Lakes. Lasalle (1966), working in the west part of the St. Lawrence Lowlands, discovered in that area significant fluctuations in the basal non-arboreal pollen assemblages and correlated them with the Younger Dryas and the St. Narcisse readvances rather than with the Valders or Cochrane stages, which he believed to have had very little influence in the St. Lawrence Lowlands. The absence of a well-defined basal herbaceous assemblage (Rosendahl, 1948; Braun, 1950; Cushing, 1965, 1967) in most of the pollen diagrams from the Great Lakes Region is attributed to probable higher thermal gradient which existed between the southern margin of the continental ice sheet and the Gulf of Mexico (Bryan, 1928; Dillon, 1956). Sears (1948) believes that the general absence of evidence for tundra vegetation in the periglacial area may have been the result of bog basins retaining masses of stagnant ice after glacial recession and, therefore, the bog records not beginning for some time after the surrounding surface was ice free. Florin and Wright (1968) found good evidence for this hypothesis by studying the ecological distributions of diatom assemblages in late-glacial organic sediment of Minnesota.

Several investigations made in the United States, dealing with modern pollen rain as a method of recording the vegetation, were challenged by Davis (1963). She believes that absolute rather than relative pollen data give a more precise estimate of the past vegetation. In Canada (King and Kapp, 1963; Terasmae and Mott, 1964, 1965; Lichti-Federovich and Ritchie, 1965, 1969) studied modern pollen rain and found good regional correlation between pollen counts and surrounding vegetation. Potzger and others (1956), in a small detailed survey, found very few correlations between the pollen spectra and their surrounding vegetation, but this is probably due to the lack of regional representativeness of the quadrats sampled.

The palynological history of the Canadian Great Lakes has attracted several workers studying cores taken from the middle of the lakes or near the shore (Anderson and Terasmae, 1966; Lewis, Anderson and Berti, 1966; Bailey, 1969; Anderson, 1969; McAndrews, unpublished).

B. Malacology

The great frequency of molluscan fossils in Quaternary deposits has been noted since the middle of the nineteenth century in Europe and North America, but only recently have molluscan fossils been used and studied extensively as a tool for the interpretation of paleoenvironments. Early paleontologists working with nonmarine molluscs were unable to reach good paleoecological conclusions since they lacked knowledge of the morphology, classification, ecology and geographic distribution of living representatives. For these reasons most of the work on molluscs has dealt mainly with stratigraphy.

Many early attempts were made to study molluscan fossils in order to reconstruct ancient environments but most of them had little significance. Flint (1947) and Taylor (1960) believe that the study of fossils along with animals or plants could permit approximate reconstruction of paleoenvironments. To strengthen the data gathered from fossils it is necessary to investigate the Quaternary from as many different sources as possible.

With the development of limnology and ecology, pioneer workers such as Frank C. Baker (1867-1942), Bohmil Sterki (1846-1933), Bryan Walker (1856-1936), Joseph F. Whiteaves (1835-1909), Edward J. Whittaker (1891-1924), and others, laid down the basis of molluscan studies in North America. In Canada[1] the earliest significant publications on molluscs are those of Bell (1858, 1880), Dawson (1875), Léon Provancher (1891), Whiteaves (about 30 papers between 1862 and 1904), and Whittaker (1918, 1921, 1922a, 1922b).

Later, with refinements in the biogeological sciences, mainly after the war, the following North American workers brought malacology into our present era: S.T. Brooks (Pennsylvania), A.H. Clarke, Jr. (Canada), W.T. Clarke, Jr. (Texas), William H. Dall (United States and Canada), L.E. Daniels (Indiana), G.E. Fairbairn (Canada), Larry Frankel (Nebraska), Dorothea Franzen, John C. Freye, Calvin Goodrich, D.K. Greger, G.D. Hanna, H.B. Herrington, Claude W. Hibbard, H.B. Horberh (Illinois), E.C. Johnston, Aurèle La Rocque (Canada and Ohio),

[1] See La Rocque (1953, 1962)

G. K. MacMillan (Pennsylvania), Alan Mozley (Western Canada), Henry van der Schalie (Kansas), and William J. Wayne (Indiana).

Although the general literature on molluscs is fairly voluminous, only a small amount of it is concerned with Quaternary molluscan fossils. Six main works (Shimek, 1913; Geyer, 1922; Baker, 1937; Eiseley, 1937; Taylor, 1960; La Rocque, 1966, 1967, 1968, 1969a) deal with the ecological applications of Pleistocene nonmarine molluscs. Shimek's paper is useful for its information on the depositional environment of loess and especially for comparison of fossil assemblages and drift shells from modern lakes and streams. Geyer's essay deals with German postglacial nonmarine molluscs and attempts to detect the changes of climate that could have occurred during that time. He concludes that molluscs may be good indicators of climate but that climate is a multifaceted and complex sum of interrelating factors. He believes that molluscs are more sensitive to the quantity of moisture and type of substrate than to the temperature and that, with time, physiological adaptations are possible. Baker's work on Pleistocene nonmarine molluscs is valuable chiefly for the section on ecology. This is still being used but it is becoming increasingly unsatisfactory. In the section on systematics, he recognizes several subspecies and ecological variants of species by referring to the morphological characteristics of the shell. Taylor (1960), in his Late Cenozoic Molluscan Fauna From the High Plains, confirms some of Geyer's ideas. He points out that among the species studied in his report, some are more sensitive to temperature extremes and others to soil and available moisture. It is still impossible today to determine if temperature extremes or soil and available moisture are the most important factors for molluscs species. La Rocque (1966, 1967, 1968, 1969a), in his review on the Pleistocene Mollusca of Ohio, discusses classification, ecology, and present and past distributions of nonmarine molluscs from Ohio. He also treats the significance, use and limits of molluscan assemblages in paleoenvironmental studies. He then concludes that although the techniques and methods are satisfactory only for the time being, better ecological and taxonomical information is still needed to improve the quality of Pleistocene understanding based on molluscs.

Today there are two active schools studying freshwater molluscan assemblages from the glaciated area, quantitatively and qualitatively, as a paleoecological method. The first one, directed by Aurèle La Rocque from the State University of Ohio, has already trained several students in the study of pond and lake molluscs found in the eastern United States and Canada. In Czechoslovakia, the second school is directed by Lozek. It investigates calcareous lacustrine deposits using a method similar to that of La Rocque and his students (1963).

In Canada the first modern, detailed paleoecological investigation of Quaternary lacustrine deposits based on stratigraphical qualitative and quantitative molluscan assemblages was done by Shallom (1965) in the Matapédia County of Quebec. He reconstructed some of the paleolimnology of the lake studied but was unable to correlate his study with the Quaternary history of the St. Lawrence Valley. Clowers (1966), Gibson (1967), and Warner (1968) made comparable studies in Ontario and Quebec with similar results.

C. Geochemistry

Paleolimnology is a relatively new speciality of paleo-ecology which exists by virtue of its synthesis of methods from various analytical disciplines. Through geochemistry it tends to unify the abiotic and biotic factors found in our biosphere. It owes its abiotic existence to physics, chemistry and geology, whereas its biotic aspects are derived from botany and zoology. Paleolimnology is such a wide field of investigation that it does not have its own defined system of study. The literature is highly scattered and the same worker often does quite disparate research.

1. Trace Elements

For the past fifty years, economic geochemists have used the distribution of trace elements in all types of unconso-lidated deposits and plants as a prospecting method, a fact which has provided paleoecologists with an important body of informa-tion. In Russia and the United States, geobotany and biogeo-chemistry have been used extensively in the search for mineral deposits, in prospecting for water, and in geochemical mapping. These methods have also been widely used in agriculture, epide-miology, physiology and ecology. Biogeochemical prospecting assumes that there is a direct relationship between the chemical composition of a sediment and the plants or organic materials which are found in close proximity.

The behavior of trace elements in lacustrine and paludal environments has been used as a prospecting tool by numerous workers in different parts of the world. Lovering (1927), Forrester (1942) and Eckel (1949) have described native copper in peats of Montana and Colorado which was precipitated from copper-bearing water draining areas of copper mineralization. In Canada numerous studies in biogeochemistry were done by Warren (1962), Warren, Delavault and Irish (1952a, b), and Warren and Delavault (1954, 1955) at the University of British Columbia. These researchers demonstrated that under certain landscape conditions biogeochemical results can be correlated positively with mineral deposits.

In the Yukon Territory, Boyle (1957) found that zinc carried into bogs by surface water was concentrated in abnormal amounts in the peats. Ermengen (1957) also noted that the peat bogs in the Chibougamau area of Quebec concentrated zinc. Holman (1959) reported that a copper-rich swamp near Sackville, New Brunswick, had concentrated copper from spring waters emerging from a cupriferous Pennsylvanian sandstone. Furthermore, in New Brunswick, Hawkes and Salmon (1960) described concentrations of iron in living and decomposing organic matter in a swamp overlying a copper bearing iron sulphide deposit in the Bathurst area.

Gleeson (1960), Gleeson and Coope (1967) studied the behavior of trace elements in swamp environments in Ontario, Quebec and Newfoundland. Their results were comparable to each other and showed that certain trace elements tend to become regularly distributed in swamp profiles of glaciated regions and that the metal contents of the peats in swampy environments are related to the degree of humification and pH.

Fortescue and Hornbrook (1967), in a detailed study of the trace element distribution in several profiles of the Mer Bleue bog near Ottawa, also noted that each element has a distinctive vertical distribution pattern within the bog. The zinc distribution has relatively high values at the surface and near the bottom of the cores and low values in the middle.

In his study of the distribution of trace elements in Scottish peats, Mitchell (1954) collected samples from profiles of bogs overlying rocks containing background quantities of metals. He describes the quantities of copper, zinc, lead and nickel in the peats as tending to increase with depth. Salmi (1950, 1955, 1956), in his study of 50 swamps throughout Finland, found correlations between distribution of trace elements in bogs and mineralization on sites situated in its vicinities. He notes that iron, manganese, molybdenum and lead tend to be concentrated in the upper layers of the peat, while nickel, vanadium, titanium and cadmium are present in the greatest concentrations near the base of the peat. According to Gleeson and Coope (1967), in Norway Hvatum has shown that lead, zinc and molybdenum concentrate in the upper layer of the peat, whereas cobalt, copper and manganese are generally found in maximum concentrations at the top and bottom of the peat bogs that he sampled.

Bradley (1963) summarized some paleolimnological works done on Permian to Quaternary extinct lakes of North America most of which dealt with the sedimentary and paleontological aspects of paleoenvironments. Workers investigating the geochemical aspects of these lake deposits have restricted their work essentially to non-trace elements.

The first and still one of the most comprehensive series of paleolimnological investigations in North America was done by Deevey (1939, 1942), Hutchinson and Wollack (1940) and Patrick (1943). Each investigator studied the chemical, pollen and diatom composition of Linsley Pond but very little attention was given to the distribution of the trace elements in the sediments.

A recent study involving many of the same workers who had investigated Linsley Pond has yielded extensive paleolimnological information for Lago di Monterosi in Italy (Hutchinson, 1970). This site has several advantages over the ones studied earlier in Connecticut and those studied by the Freshwater Biological Association on Windermere in Britain. The history of Lago di Monterosi is not only much longer but it is located in an unglaciated area. The latter factor helps to distinguish external events due to glaciation from internal events probably attributable to the maturation of the lake. Cowgill and Hutchinson (1970), studying the vertical distribution of more than 29 trace elements from the sediments of Lago di Monterosi, have established the paleoecological conditions of the deposit and correlated their findings with the historical development of the Roman Empire which had a drastic effect on the trophic stage of the lake.

Benoit (1967) briefly reviews the geochemistry of some trace elements in relation with the trophic stage of lakes and rivers.

2. <u>General Chemistry</u>

The chemistry of the earth, more precisely known as the science of geochemistry, is broadly defined so as to include all parts of geology that involve chemical changes. The term geochemistry was introduced during the first part of the last century but the modern age of this discipline really started only with the beginning of our present century. The literature has grown more or less expotentially since the establishment of the Geophysical Laboratory at the Carnegie Institute in Washington in 1904. A great part of it is found in specialized journals devoted basically to chemistry, physics, geology, crystallography, petrology, sedimentology and pedology. All over the world today there are numerous scientific journals specifically related to geochemistry.

The brief review of the literature which follows is restricted as much as possible to papers dealing with general chemistry of Quaternary lake deposits. Paleolimnological studies of glaciated areas are of particular interest.

Early geochemical investigations of lake sediments were undertaken by Russell (1885) and Gilbert (1890), who were both geologists dealing with ancient lake basins of the semiarid Western and Southwestern United States. Bradley (1963) summarized their investigations. Reeves (1968) and other geologists reviewed works done on the same types of deposits mostly from Texas and Mexico.

Although the first limnological studies of Lake Geneva by Forel (1892), the father of limnology, were oriented toward physiochemical aspects of the aquatic environment, Forbes (1887) of the University of Wisconsin integrated biology as a component of limnology around 1900. Recently, mainly because of the initiative of D.G. Frey, the Governing Council of the International Association of Theoretical and Applied Limnology authorized, at the congress in Poland in 1965, a symposium on paleolimnology which was held in Hungary in 1967.

Hutchinson and Wollack (1940) dealt with several chemical aspects of the Linsley Pond sediments. The considerable increase in the inorganic content in the most recent unconsolidated sediment at the top of the profile is attributed to recent erosion of cultural origin. Using the constant ratios of lignin (the most resistant of all organic substances present) and crude protein over total ignition loss present at various levels, they concluded that the organic content of the sediment, at all depths of the profile, had essentially the same ratio to the original organic material deposited. Diagenetic changes are chemically significant only within the unconsolidated top sediment.

The apparent logarithmic increase of the organic matter at the base of the profile is interpreted as representing the growth-curve of the whole biocoenosis of the lake. This old idea of the dynamic trophic concept of a lake passing rapidly from the oligotrophic to the eutrophic level (Lindeman, 1942) finds less and less support on the part of paleolimnological investigators. Calculations of the sedimentation rate based on an absolute chronology led Livingstone (1957) to believe that the logarithmic increase in the biomass of the Linsley Pond biocoenosis is associated with a logarithmic decrease in the rate of allochtonous mineral sedimentation. Furthermore, Livingstone and others (1958) studied the effects of an Arctic environment on the origin and development of 4 freshwater lakes in Alaska. They found no dramatic sigmoïd increase in organic and chlorophyll content of the lake sediments. The drastic basal increase in organic content of lake sediments located in the temperate regions is probably associated with the invasion of a closed forest in the lake's drainage basin. Since the forest is an important agent in the reduction of erosion of inorganic fine material and contributes substantially to the organic matter found in the lake sediments, it can very easily account for this apparent sigmoïd growth of the whole biocoenosis. Moreover it appears that the silting might have controlled production of plankton organisms in the early history of the lake and again in recent years by interfering with the regeneration of nutrients in the diagenetic layer and, probably to a lesser extent, by reducing the light penetration below the water surface of the aquatic environment.

Unlike Hutchinson and Wollack (1940), Mackereth (1965, 1966), in his geochemical study of the sediments of several lake deposits from the English Lake District, interpreted most of his results as being directly controlled by allochthonous factors. The composition and rate of sediment accumulation on a lake bottom is directly related to the sediments carried into the lake and to the rate of erosion of the drainage basin. The thickness of the lacustrine deposits is by no means an index of paleoproductivity. It seems to be more closely related to the topography and geology of the surrounding area. If this is so, very little post-depositional diagenesis occurs since detritus reaching the lake bed has already been exposed to an oxidizing environment for a certain amount of time.

The concept of constant aging of lakes finds little support in paleolimnological investigations of the English Lake District. Following his geochemical investigation Mackereth concluded that, in postglacial time, lakes passed rapidly from an eutrophic stage to an oligotrophic one. The leaching of nutrients from the surrounding area first promoted phytoplankton productivity. Once the vegetation was established within that vicinity and after a long period of leaching nutrients carried to the lake gradually decreased and consequently so did the lake productivity.

On the basis of diatom assemblages found in lake sediments, Round (1957), Tutin (1969) and Crabtree (1969) tend to support this concept. These authors consider climatic changes as important factors in the control of the trophic level of lakes.

Horie (1966, 1969), from his numerous paleolimnological investigations of ancient lake sediments in Japan, suspects that subsidence of unstable earth crust within certain districts might have maintained lakes in the oligotrophic stage for a very long time. He also shows that an oligotrophic condition does not always become an eutrophic condition as a result of filling up by sediments. Fluctuations of nitrogen at different levels along sediment cores are believed to represent fluctuations of lake productivity. These fluctuations are attributed to climatic changes and crustal instability.

Cowgill's and Hutchinson's paleolimnological studies (1963, 1966, 1970) also are of special interest in our era of cultural environmental deterioration. In extensive investigations dealing with the chemistry and mineralogy of sediments from unglaciated deposits, they reconstructed a detailed history of these sites and showed the effect of ancient cultures on the ecosystem.

In similar investigations, restricted only to the top meter of sediment of Lake Washington, Edmondson (1969) correlated his findings to the historical development of the city of Seattle and more precisely to its sewage treatment plant development.

Another application of the geochemical study of lacustrine sediment is well illustrated by Kjensmo (1968) in works done in Norway while investigating the sediments of meromictic lake located within the maximum level reached in late-glacial time by the marine water. In this study he was able to differentiate the marine sediments according to chemical composition since their content in several inorganic elements and exchangeable cations was found to be higher than that of the freshwater sediments. The time of transgression was easily determined stratigraphically on that account. The meromictic stability of the lake studied was estimated to have been initiated about 2,000 years ago. The beginning of the meromictic stage is based on a sharp increase of the ratio of Fe/Mn at the 45 centimeter level. The high Fe fraction is assumed to have been conditioned by the FeS precipitation from the deep water of the lake. Furthermore, the level at which the meromictic stage of the lake starts is well defined by an accentuated decrease in the exchangeable cations.

Photosynthesis is generally accepted as the most important phenomenon in our biosphere but the growth of green plants is strongly controlled by the availability of nutrients. Brandt (1899, 1902) suggested that phytoplankton production is dependent upon the availability of nitrate and and phosphate present in the natural waters. Nathansohn (1906) pointed out that the stability of the water column, associated with the spring warming of the surface waters, is intimately correlated with plankton production. Since then, several workers (Atkins, 1923; Cooper, 1938, and others) have estimated phytoplankton productivity from the removal of nutrients from the water. The maximum total P value in the water column has been used as an index of fertility (Russell, 1935; Harvey, 1950, and others). Steele (1956), Riley and Conover (1956), and others showed that the behavior of P in an aquatic environment is not well enough known to be used alone as a reliable productivity index. Beeton (1965) used SO_4, Cl, Na, K, Ca and total dissolved solids as indices of the eutrophication of the St. Lawrence-Great Lakes. Although the role of these ions is not completely understood, changes in concentrations of these ions as well as total dissolved solids seem to be well correlated with other indices such as oxygen levels and changes in indicator organisms. Seddon (1967) found similar correlations in his study of 43 lakes in Wales. Hooper (1967) briefly reviewed the literature dealing with eutrophication indices and their relations to other indices of ecosystem change.

Within the present work, the exchangeable ions in the sediment are assumed to reflect the contemporary fertility of the environment at the time of deposition. Exchangeable ions within the very top of the sediment are believed to be in equilibrium with each other and with their immediate environment and also believed to be submitted to very little post-depositional diagenesis (Kjensmo, 1968; Edmondson, 1969). Consequently the quantity of exchangeable ions formed in sediment might be used as an index of paleoproductivity.

3. Sedimentary Chlorophyll Degradation Products (SCDP)

Since the beginning of modern limnology numerous investigators have tried to estimate the productivity of natural water bodies by means of various methods. Some of the most widely accepted methods still used today are: a) the light and dark bottle (Gaarder and Gran, 1927), b) organism count per unit volume, c) the weight of plankton in a measured volume of water, d) the amount of pigments as an index of productivity (Harvey, 1934; Strickland and Parson, 1965), and most recently e) the utilization of radioactive carbon (Steemann Nilsen, 1952; Ryther, 1956). These methods have certain limitations but they have contributed substantially to a better understanding of lake dynamics. More detailed information on primary productivity can be found in Ohle (1956), Ruttner (1953), Verduin (1956) and Yentsch (1966).

The possibility of finding reliable and widely accepted methods to estimate the ancient productivity of lakes from sediments is still not considered conclusive in paleolimnology. In estimating the paleoproductivity of lakes the paleolimnologist faces an extremely difficult situation which could be compared to that of a worker trying to reconstruct the life in a big city by studying the substances entering in its sewage treatment plant or, even worse, what goes out of the plant after treatment. The paleolimnologist's fundamental task is quite similar to that of an archeologist attempting to reconstruct the prehistorical civilizations or to that of an organic geochemist trying to elucidate the origin of life.

Indices of paleoproductivity determined from the analysis of bog, paludal, lacustrine and marine sediments such as density, dry weight, ignition loss and available nutrients have already been discussed above. The great similarity between the chemical structures of compounds present in petroleum or rock extracts and those of compounds in living organisms was first realized by Treibs (1934). He succeeded in identifying some metalloporphyrins and suggested that these compounds may be derived from chlorophyll or hemin, closely related to haemoglobin. This discovery of fossil chlorophyll-like products gave rise to the attractive idea of quantifying these products to obtain an index of paleoproductivity of green matter. From that time on, which also marked the foundation of organic geochemistry, a considerable amount of literature, overwhelming the scope of the present review, was published. The most up to date literature on the geochemistry of petroleum is found in Breger (1963) and Eglinton and Murphy (1969).

The detailed steps involved in the formation of SCDP found more particularly in recent sediments are discussed by Brown (1969). The SCDP found mostly in older deposits such as petroleum are dealt with by Hodgson and others (1960) and Baker (1969). It is generally accepted that chlorophyll[1] breaks down rapidly after the death of the green cells by losing its Mg atom and its phytol group. Yentsch (1966) and others show that in the ocean, sinking chlorophyll is almost all degraded into pigment-like chlorophyll (phaeophytin and phaephorbide) at a depth of about 150 meters and that darkness and grazing by herbaceous zooplankton play an important part in

[1]In the present work the term chlorophyll refers to chlorophyll a in general, regardless of the fact that it is recognized that minor amounts of other chlorophyll may be present with chlorophyll a.

these processes. Since the loss of the phytol causes only minor changes in the visible part of the absorption spectrum, phaeophytin and phaephorbide have the same absorption spectrum (Smith and Benitez, 1955) and form the most abundant products of SCDP in recent sediment acetone extracts. Products extracted from sediments and rocks by organic solvents have been identified by several workers (see reviews by Orr and Gray, 1957 and Vallentyne, 1955, 1960).

Theoretically the quantity of SCDP in sediments should be a direct function of environmental green matter at the time of deposition just as modern productivity is reflected by chlorophyll. At first this analogy seems quite attractive and reasonable but in practice it depends directly on a great number of variables which cannot be quantified by the paleolimnologist. Works done by Sargent (1940) and Edmondson (1955) tend to show a close correlation between photosynthesis per unit light and chlorophyll. This relationship is largely independent of both the species composition and the intensity of light. Even if algae have a tendency to develop more chlorophyll when grown in the shade, it was found that shade culture has a slower rate of photosynthesis. Vallentyne (1969) discusses, in a detailed review, the limitations inherent in the use of sedimentary organic compounds in providing valuable paleolimnological information. Although he has a pessimistic approach to this method, he does not reject its potentiality. The same author admits that the method already has contributed substantially to increasing our knowledge in paleolimnology. Vallentyne also emphasizes the lack of experimental and laboratory work dealing with the susceptibility of organic compounds to metabolic transformation at the molecular level in their contemporary and post-depositional environment.

Since most of the works dealing with the study of organic pigments of non-marine deposits has recently been reviewed by Margalef (1968), Brown (1968, 1969) and Swain (1970), the writer has judged it unnecessary to provide a detailed account of the literature in relation to SCDP. One of the most recent works in this field is that of Sanger and Gorham (1970) who demonstrate that the main source of sedimentary pigments within an eutrophic lake basin is of macrophytic and planktonic origin. The terrestrial flora do not seem to contribute significantly to the SCDP.

III. STUDY PROCEDURES

A. Palynology

The three sites described were sampled during the summer of 1966 with coring devices provided by the Palynological Laboratory of the Geological Survey of Canada. Different kinds of samplers adapted to each type of sediment were used so as to minimize disturbance and contamination of the samples. Atkins and Grady lake sediments were sampled from two flat-bottomed aluminum boats attached side by side. A Bendix depth recorder (Model DR-21) was used to locate the deepest spot of water, in order to find the best sampling site over which the boats were anchored. The mud-water interface of these two lakes was sampled using a coring device described by Brown (1956). The denser sediment underlying the top few centimeters was sampled with a stationary piston sampler similar to the one described by Livingstone (1955) and as modified by Deevey (1965).

The Geological Survey of Canada (G.S.C.) piston corer (Mott, 1966) was used to sample the Cataraqui River Marsh site. This sampler is quite useful in sampling woody and inorganic, fine sediment on account of its steel structure and lower cutting edge. It is designed to take cores 71 centimeters long with a diameter of 5.1 centimeters. Cores obtained from the Cataraqui River Marsh were extruded on the sampling site, wrapped in sarran and aluminum foil, properly labelled, and brought back to the laboratory. A duplicate core was taken from the three sites sampled, at the contact point between layers of organic and inorganic sediment, to provide sufficient material for radiocarbon dating.

In the laboratory, cores taken with the Brown and Livingstone samplers were extruded from the tubes as soon as possible. All cores and samples were kept under refrigeration, whenever possible, to prevent dessication and fungal growth. Before extracting the samples from the cores for pollen analysis, each core was cleaned by removing a thin surface layer with a spatula, and its texture was described. Then small samples, approximately 2-4 milliliters in volume, were withdrawn regularly along the cores at 5 centimeter intervals. Each sample was placed in a labelled plastic bag and stored in a refrigerator until needed for pollen study. A sample of about 10 to 20 centimeters containing the transitional zone between the organic and inorganic sediment was taken from one of the duplicate bottom cores at each site. The sample from the Cataraqui River Marsh site was dated by Isotopes Inc. of Westwood, N. J. Samples from the two other sites and one from the upper part of the Atkins Lake core were sent to the Radiocarbon Dating Laboratory of the Geological Survey of Canada for age determination. The remains of the cores were divided into sections 50 centimeters long to facilitate handling, then wrapped in sarran and aluminum foil, labelled, and stored in a cold room at 3°C.

Laboratory techniques used to prepare samples for pollen analysis are numerous and vary greatly from one laboratory to another. Many of these techniques have been treated in detail by Assarson and Granlund (1924), Wodehouse (1935), Erdtman (1943), Faegri and Iversen (1964), Ogden (1961b), Godwin (1956) and Brown (1960). The laboratory procedures adopted for this study were similar to those described by Faegri and Iversen (1964).

After completion of the treatment, the pollen sample was mixed with a few drops of Hoyer's solution (Anderson, 1954) on a microscope slide and then covered. The coverslip allowed the preparation to spread evenly. A liquid mounting medium such as Hoyer's solution was found to be most suitable for the aim of this study. This solution is prepared in large quantities, storage is relatively easy, and it can be used at any time. Another important advantage is that, if the prepared slide is examined within one week, the pollen grains can be turned over gently by pressure on the coverslip or by carefully pushing at the edge with a hard pencil. This was frequently found to be extremely useful.

The prepared pollen slides were counted at 100X, 400X and sometimes 1000X magnification. Routine identification involved comparing the fossil pollen with illustrations and descriptions found in standard references on pollen, such as: Wodehouse (1935), Erdtman (1943, 1952, 1957, 1965), Erdtman and others (1961, 1962), Faegri and Iversen (1964), Traverse (1955) and Ogden (1961b). Distinctive pollen grains, though not often encountered, were matched as closely as possible with type specimens of modern pollen which had been acetolyzed and deposited in the reference collection of the Geological Survey of Canada. Those grains whose affinities could not be established were listed as "unknown" on the diagrams. In this group unidentified grains, probably of common pollen types which had been broken or damaged, were included. Identification of fossil spores and pollen grains was done by making systematic traverses from left to right until 200 arboreal pollen grains had been recorded. Unfamiliar pollen types were sketched and the co-ordinates recorded for later identification. Comparing the three sites studied, fossil pollen grains from the Cataraqui River Marsh were the least numerous and they took longest to count. For a number of samples from this site as many as 20 traverses were required to count a minimum of 200 arboreal pollen grains compared with less than half of a traverse for some samples from the other two sites. This is probably the result of a high oxidizing power of the environment in which they were deposited.

The sum of the spore and pollen types counted in each sample was converted to a percentage of the total arboreal pollen (AP). This total count of the pollen, expressed in percentage, constituted the pollen spectrum of the sample analyzed. The computed results from each site studied are illustrated in this work by means of three pollen diagrams. The type of pollen diagram used here was selected for its legibility, each palynomorph having its own column. There are no overlapping curves which could possibly confuse the reader.

B. Malacology

The field technique used in sampling the sediment containing molluscan fauna studied at Atkins Lake was similar to the palynological method described above. The same equipment was utilized, the only difference being that to obtain representative stratigraphic samples of the fauna, three cores were taken side by side. This procedure is different from that of La Rocque (1966) who sampled a column of sediment, 1 foot by 1 foot and 2 inches thick (32.2 X 32.2 X 5.1 cm) and treated each sample as a unit. In the present study it was impossible to dig a pit to obtain a larger volume of sediment since the deposits were covered with water. Nevertheless, results have shown that the volume of sediment used was sufficient in most cases (Fig. 17, p. 96).

In the laboratory the cores were removed and stratigraphically matched. This was done quite easily since numerous markers were present, such as shell layers, lamination and variations in sedimentary type. From each core a section 15 centimeters long and stratigraphically equivalent was cut and put together to be finally considered as the sample for that particular horizon.

Since two types of samplers with different diameters (the Brown and the Livingstone samplers) were used to sample the sediment, the volume containing the fauna was not constant at all levels (Table 2, p. 315).

It was unnecessary to normalize the volume of wet sediment for each molluscan spectrum as most of the fauna was found within the lower interval (255-400 cm), which was more compressed than the above intervals. Moreover the results expressed in percentage of total count also minimized the discrepancy.

To separate the mollusc shells from the surrounding sediment different methods were used. It was necessary to make sure that the sediment was loosened into a lumpless mud before a sample was run through sieves. Therefore the samples were soaked in water for about twelve hours and then boiled for a few minutes. The sieving was done under a jet of water through a set of four different sized sieves, the largest one (16 mesh) being on top. The shells from each sieve were rewashed in a beaker and the organic sediment left was eliminated by decanting. Then the concentrated shells were transferred to labelled vials and allowed to dry for a minimum of two days at room temperature. The identification and counting of the molluscan assemblage of each sample were done at Westbrooke under the personal guidance of the Reverend H.B. Herrington.

To illustrate the stratigraphic distribution of the molluscan fauna of Atkins Lake, a variation of the pollen diagram method discussed above was used. This presentation of data is similar to a system used by Lozek (1964b), Kovanda (1966), Sparks (1961), and by La Rocque (1966, 1967). These methods, which are all basically the same, are applied according to individual personal preferences.

The malacodiagram (Fig. 17, p.96) is divided into four main parts. The two central and most important parts show the biostratigraphical distribution of the gastropods and pelecypods expressed as a percentage. When the total sum of individuals for one spectrum, shown in the right-hand column, was less than 500, the sample was not considered representative of the molluscan assemblage. In such cases the abundance of the species was expressed by means of one or several crosses.

In the first column on the left and in the last column on the right the stratigraphy and molluscan zones facilitate the interpretation of the molluscan fauna of the deposit.

C. Geochemistry

1. Trace Elements

Qualitative and quantitative stratigraphical distribution of trace elements was determined from the remainder of the samples which had previously been used to construct the pollen diagram of Atkins Lake. These samples were prepared at the Geochemical Laboratory of the Geological survey of Canada, in Ottawa, under the supervision of Christopher C. Durham.

The samples were dried in an oven at 110°C for 48 hours and then grounded to less than 200 mesh, following the procedure of Lavergne (1965). A total energy DC arc semi-quantitative method with a 1.5 meter grating spectrograph was used to determine the elements. A 10 milligram sample of ground sediment was mixed with 20 milligrams of graphite, packed in a carbon electrode, and with a 20 milligram buffer mixture of $CaCO_3$ and graphite. Two drops of a saturated solution of $Mg(NO_3)_2$ in absolute ethyl alcohol were added to promote the smooth burning of the sample. The electrode was then placed under an infrared heat lamp for at least five minutes to evaporate the alcohol. Next, the samples were arced at 12 amps., and the spectra recorded on a 35 millimeter Kodak Spectrum Analysis Film No. 1. Unknown spectra were compared to a synthetically prepared series of spectra ranging from 1 to 10,000 parts per million. The coefficients of variation of this spectrochemical method are smaller than 15 percent.

The elements found in detectable amounts with their respective minimum detection limit, in parts per million, were: Ba(70), B(10), Pb(20), Mn(20), Ti(50), V(20), Zr(10), Cu(3), Ni(2), Sr(70), Cr(10), and Co(10). Elements thought to be present but not found in detectable quantities were: (the number in parenthesis being the lowest detection limit in ppm) Be(1), Bi(20), Mo(5), Nb(10), Cd(200), Ag(1), Sb(100), Sn(10), Zn(1000), and W(1000).

Forty different samples from a four meter core of Atkins Lake and two samples made of carefully cleaned molluscan shells were analyzed using the above procedure. These last two samples were taken from intervals 195-225 and 315-345 centimeters, and their numerical data can be found in table 19 (p. 383).

2. General Chemistry

Three different categories of sediment samples were studied for various general chemical parameters. They are: (a) top recent sediment samples from Meach Lake, (b) samples from several lakes of the Gatineau Area, and (c) fossil samples from the Cataraqui River Marsh, Grady Lake and Atkins Lake deposits.

Eleven sediment samples were taken with an Ekman dredge along a transect from the west to the east shores of Lake Meach (Fig. 19, p.105, 20, p.110) located about 4 kilometers N of Ottawa. The sample from the 8 other lakes, located within the Gatineau area, was taken from the center of each lake, again with an Ekman dredge. All these lakes have been investigated during approximately the last 10 years by the Departement de la Faune Québécoise, Division de Hull. The lakes studied herein were chosen on the basis of the information gathered by the above named agency. Those sampled within the Gatineau Area for this particular study range in hypolimnic oxygen depletion from nil for Lake Simon to high for Lake Vert (Table 14, p.343). Their smallest diameter ranges between 0.5 to 4 kilometers.

A minimum diameter of .5 kilometer was judged necessary to minimize the allochthonous factors which could have affected the data. All the lakes from the Gatineau Area studied for their very recent sediment were sampled in the fall of 1970.

Since all the previous sediment samples had been used for the Atkins Lake mollusc study, the site was resampled on June 19, 1970, with a Brown coring device. Cores from Atkins Lake and the remaining ones from the Cataraqui River Marsh and Grady Lake sites (these latter ones having been stored in a cool room at 3 C since 1966) were divided into intervals of 5 and sometimes 10 centimeters long and placed in numbered plastic bags. Sediment samples from each site marked with an even number, 9 samples from Meach Lake and 1 sample from each of the 8 other lakes of the Gatineau Area, were sent to the Soil Laboratory of the Quebec Department of Agriculture at La Pocatière, where they were analyzed for pH, total N, available P (except for Grady Lake samples) and for the following exchangeable cations Ca, Mg, Na and K.

The pH was determined with a glass electrode and pH meter on a mixture of 1:1 air dry sediment-water in a paper cup. The total N was analyzed by the Kjeldahl method and the available P was determined by the Bray-Arnold method (Jackson, 1958). The exchangeable cations were extracted by a 1 N solution of NH_4OA_c and each determined by flame spectrophotometry.

The odd numbered samples from the three sites of the Kingston Region and subsamples from each site of the lakes of the Gatineau Area were analyzed by the writer for the following variables: density of the wet sediment (for the fossil samples only), percentage water content, percentage dry matter, percentage ignition loss, percentage ash and pH.

In the determination of the density of the wet sediment the volume of each sample was estimated by two techniques: (a) volume was calculated directly knowing the diameter of the coring device used and sample length, (b) the total sample was immersed in a beaker filled with distilled water and the volume of the displaced overflowing water was taken as the volume of the sample. The difference between the two techniques never exceeded 3 per cent. The average of the two readings was taken as the acceptable volume. The weight of each sample was estimated gravimetrically.

The water content of the wet sediment was determined by the weight loss at 110°C during 48 hours while the ignition loss was estimated on the dry oven sediment after having been heated at 550°C during 4 hours. To reduce errors as much as possible about 50 grams of wet sediment were used to determine the water content. The left part of figure 13 (p. 80) shows the steps followed to estimate the percentage dry matter and percentage ignition loss. The left part of table 3 (p. 315) shows the estimated means and standard deviations for water, dry matter and ignitable matter for 12 determinations of one sample.

All the pH determinations done at La Pocatière for the samples from Grady Lake were verified by the writer by using a method similar to the one described above, the only difference being that the glass electrode was directly placed in the plastic bag containing the wet sediment. There was no significant discrepancy between the two sets of data. The percentage errors for the analyses done at La Pocatière vary from 3 to 10.5. The variability was greater for the cations than anions and N. (G. Godbout, personal communication).

Loss on ignition represents an estimate of total carbon and is sometimes abbreviated by the symbol C (Fig. 21C, p. 114, 22C, p. 121, 23C, p.127). Data from Meach Lake are plotted in figures 19 (p. 105), 20 (p. 110), and are listed in table 14 (p. 340). Data from the 9 lakes from the Gatineau Area are shown in table 14 (p. 343). Data along with some important ratios, such as C/N, P/N, Ca/Mg, K/Na, Ca+Mg/K+Na, and total cations are plotted as a function of depth for the Cataraqui River Marsh, Grady Lake and Atkins Lake sites (Fig. 21, p. 114, 22, p. 121, 23, p. 127). Data on the general chemistry of these sites are shown in tables 15 (p. 346), 16 (p. 357), 17 (370). The representation of these results was patterned after the pollen analysis presentation. The numerical scale for each variable plotted is located at the top of each curve. On the extreme right the code number is indicated for each general chemical zone.

3. Sedimentary Chlorophyll Degradation Products (SCDP)

Since the sedimentary chlorophyll degradation products used as a possible index of paleoproductivity of lakes is an important aspect of this work, the 9 lakes from the Gatineau Area were analyzed for sedimentary chlorophyll degradation products (SCDP) content and various wavelength absorbance ratios such as 410/ 350, 410/ 670, 350/ 670, 448/ 670, 448/ 350, 410/ 448. The method used to estimate the SCDP is similar to that of Vallentyne (1955) except that no dimethylaniline was added to the 90 per cent acetone extractive solution and the maximal light absorption for SCDP in the red end of the spectrum was found at the 670 millimicron wavelength on the Gilford 2400 model spectrophotometer.

Figure 12 (p. 78) shows characteristic continuous spectra for a modern 90 per cent acetone chlorophyll extract as well as for a Grady Lake sample of about 10,000 years old.

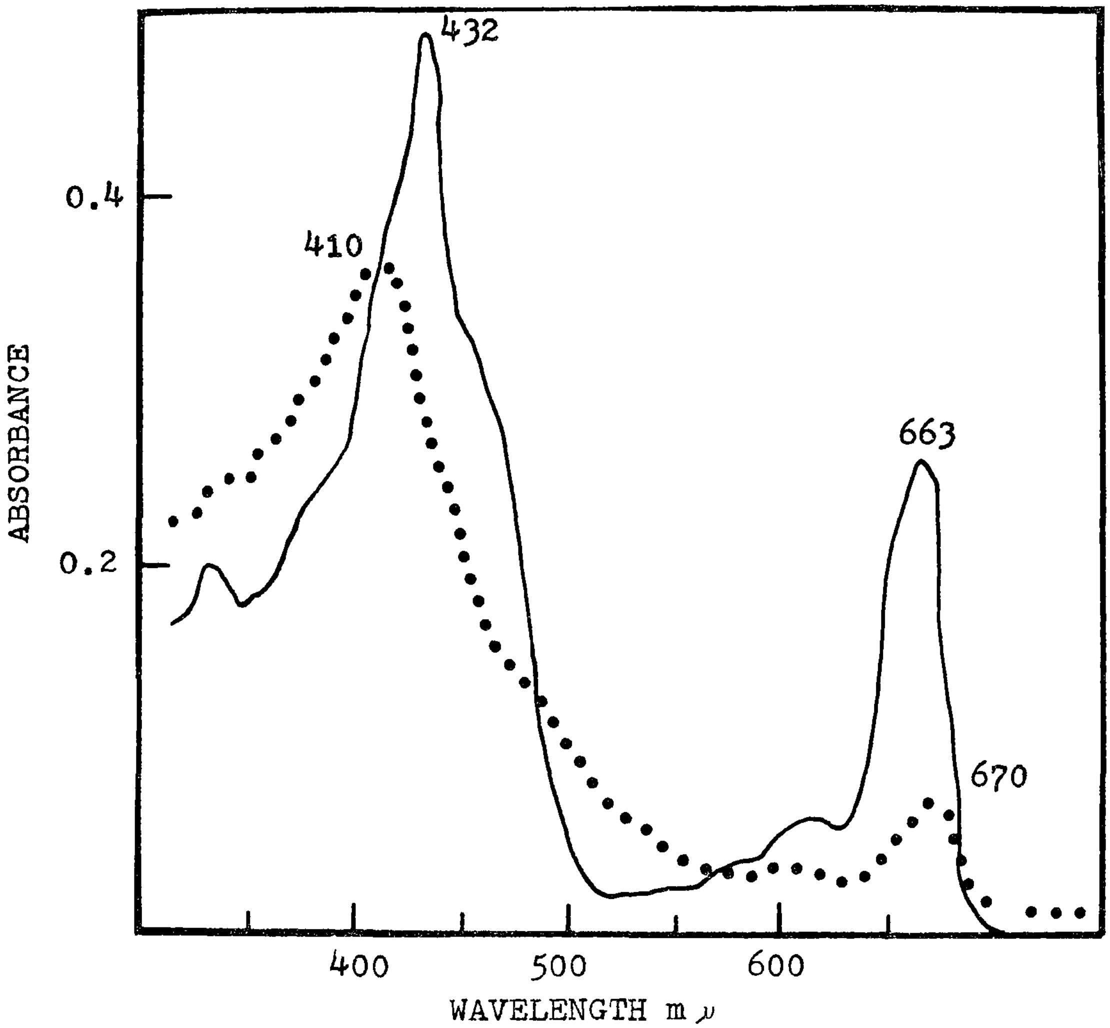


Figure 12. Typical spectra of 90% acetone extracts of <u>Typha</u> from the Cataraqui River Marsh (——) and from a sediment sample of about 10,000 years old from the Grady Lake sediment deposit (•••).

The absorbance of each sample extracted with the 90 per cent acetone solution was read for the following wavelengths: 350, 410, 448 and 670 millimicrons. Numerous workers (Smith and Benitez, 1955; Vallentyne, 1956; Gorham, 1960; Yentsch, 1966; Margalef, 1968 and others) consider these wavelengths as being especially significant in the study of fossil and modern pigments.

Figure 13 (p.80) shows steps followed in the determination of the SCDP along with one computation example. The accuracy of the method was determined before proceeding to the routine analysis of modern and fossil sediment samples. Table 3 (p.315) indicates the means and standard deviations for 12 determinations run simultaneously for the SCDP per gram of dry matter and ignitiable matter on aliquots of a homogeneous sample. Twelve samples were run at the same time for the SCDP analysis and for the absorbance ratios. The last one from each batch of 12 was a control sample which had previously been analyzed several times. Table 4 (p. 316) shows the means and standard deviations of different SCDP parameters of the reference sample for 17 different batches of 12 samples each. The standard deviations of samples run simultaneously were found to be 5 times smaller than those of the reference samples run 17 different times. However the standard deviations for the determinations of SCDP per gram of dry matter and ignitable matter never exceeded 13 and 11 per cent respectively during the whole laboratory process.

SCDP and absorbance ratios were estimated for the 11

SCDP DETERMINATION METHOD

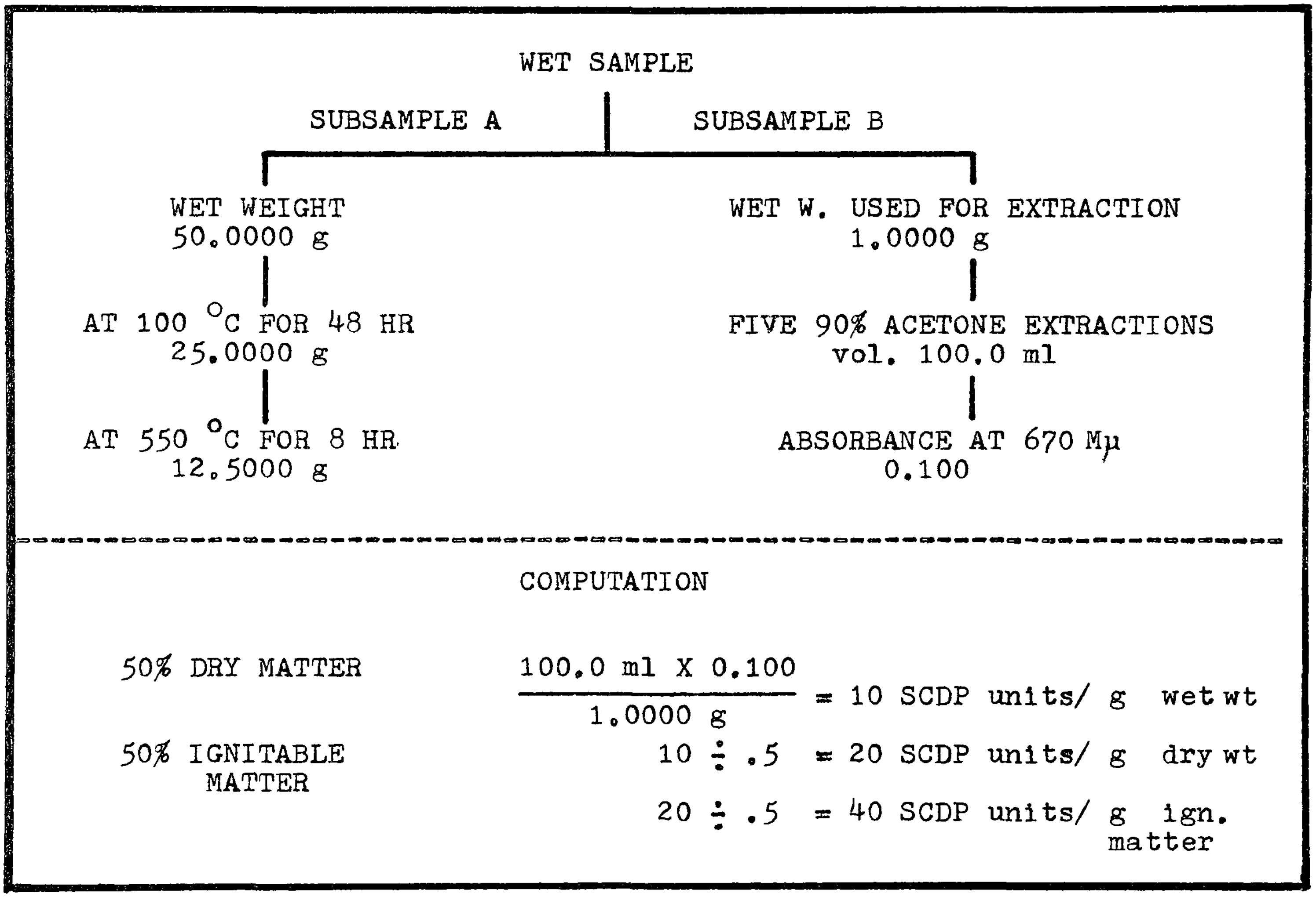


Figure 13. Steps followed in the determination of the sedimentary chlorophyll degradation products (SCDP) along with one computation example.

Meach Lake stations and for the 8 other lakes from the Gatineau Area (Tables 13, p. 340, and 14, p. 343). Fossil sediment samples from the Cataraqui River Marsh, Grady Lake and Atkins Lake deposits (indicated by odd numbers) were analyzed for the same parameters. SCDP and absorbance ratios for the Meach Lake stations are plotted in figure 20 (p. 110). SCDP and absorbance ratios for the three deposits from the Kingston Region are plotted as a function of depth in figures 24 (p. 134), 25 (p. 138), and 26 (p.141) while the data are tabulated in the bottom half of tables 15 (p. 346), 16 (p.357) and 17 (p. 370).

IV. RESULTS

A. The Sediment Cores and C-14 Dates

1. Cataraqui River Marsh

The core described below is 472 centimeters long. It is shown schematically at the left margin of the Cataraqui River Marsh pollen diagram (Fig. 14, p. 83). Two very distinct boundaries dividing three main types of sediments are well defined in this core. Recorded downwards and with the top surface as zero, the following macroscopical description roughly classifies the different types of sediments:

0-260 cm: Coarse to fine sedge-typha peat with wood and twig fragments.

260-425 cm: Silty gray clay with minor plant detritus and wood fragments partly decomposed. Seeds of Nymphaea abundant.

428-472 cm: Stiff gray clay, without visible organic matter.

In figure 21 (p. 114, sections A, B, C) the density, the water content and the ignition loss of the sediments are plotted as functions of depth. The numerical data of these variables are shown in table 15 (p. 346). All data of these three factors are entirely concordant with the above assertion that there are three types of sediments. The top unit (0-260 cm)

FOLD OUT

is characterized by a low density and by a high water content and ignition loss. Moreover these three factors reflect, by sharp quantitative fluctuations, the two inorganic laminae present at levels 183 and 219 centimeters. On the other hand, the lower unit (428-472 cm) has the highest density and the lowest water and ignition loss content in the whole core. In between these top and bottom units, a middle interval (260-428 cm) is characterized by intermediate values of the above named factors.

The basal organic-inorganic transition interval (424-435 cm) which was radiocarbon dated gave an age of 10,200±500 years (I-1223). Assuming that during that time 429.5 centimeters of sediment were deposited above the sampling site, the average rate of sedimentation per year is estimated at 0.42 millimeter.

2. Grady Lake

The length of the core described in the following is 1056 centimeters. Its stratigraphy is briefly illustrated at the left margin of the Grady Lake pollen diagram (Fig. 15, p.85). The core studied was taken under 325 centimeters of water and the stiff silty clay was reached at 1056 centimeters below the mud-water interphase. Recorded downwards with the mud-water interphase as the zero level, the following macroscopic description should classify, at least approximately, the main different types of sediments:

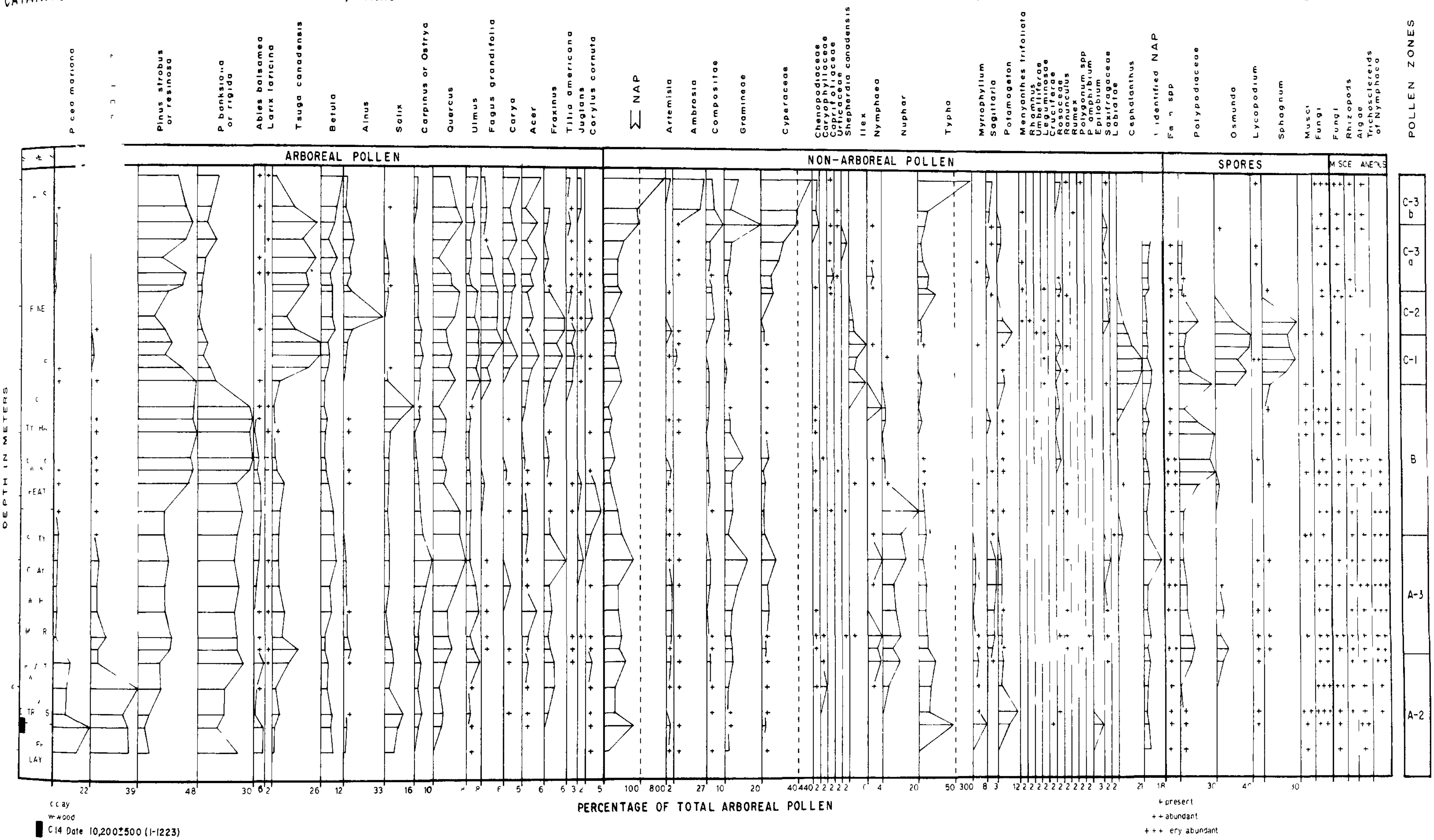
0-256 cm: Fine brown gyttja.

256-556 cm: Fine dark brown gyttja.

Figure 15. Pollen diagram from Grady Lake.

CATARAQUI RIVER MARSH FRONTENAC Co., Ontario

Figure 14. Pollen diagram from Cataraqui River Marsh.



556-1051 cm: Black fine laminated gyttja with individual lamina separating easily from each other. The bottom part of this stratigraphic unit contains a transitional interval (1026-1051 cm) going from organic to inorganic sediments downwards.

1051-1056 cm: Silty, gray clay.

In figure 22 (p.121, sections A, B, C) the density, the water content and the ignition loss are plotted as function of depth. The numerical data of these variables are shown in table 16 (p. 357). Although these three variables fluctuate slightly from one stratigraphic level to another, except for the very bottom part of the core, the density, water content and ignition loss of the sediments reflect fairly well the four major types of sediments. The density and water content of the sediments show gentle fluctuations within the two top units (0-256 and 256-556 cm). However, rapid and gradual changes are very apparent downwards starting more specifically at the 800 centimeter level. As far as the ignition loss of the dry sediments is concerned it decreases slightly but gradually above 556 centimeters and then diminishes very rapidly below that level.

The bottom transitional interval (1021-1032 cm), which changed from inorganic to organic sediment, was dated as having an age of 10,500±180 (GSC-765) years. Based on that date, the average sedimentation rate of Grady Lake deposits per year is estimated at 0.97 millimeter.

3. Atkins Lake

Five cores were necessary for the investigation of this particular lake. One was used for the pollen and trace elements analyses, three were required for the molluscan study and the last one was used for general chemical studies. All these cores are similar and they are each 400 centimeters long. Their stratigraphy is shown schematically at the left margin of figures 16 (p. 88), 17 (p. 96) and 18 (p. 101).

The cores studied were taken side by side over 65 centimeters of water. A brief description of the core follows:

0-6 cm:	Loose, coarse, detrital gyttja with green spherical algae.
6-67 cm:	Black, loose, coarse, detrital gyttja.
67-68 cm:	Shell layer.
68-157 cm:	Dark brown, coarse, detrital gyttja with shells.
157-198 cm:	Dark brown gyttja with high concentration of shells at 181 and 192 centimeters.
198-221 cm:	Transitional zone, change from dark brown gyttja to fine, light brown, detrital, marly gyttja.
221-248 cm:	Light greyish-brown, marly gyttja with numerous shells and fine detritus.
248-343 cm:	Light brown, pinkish to greyish laminated marl with some fine detrital gyttja. Laminae of lighter colour averaging 1 centimeter in thickness

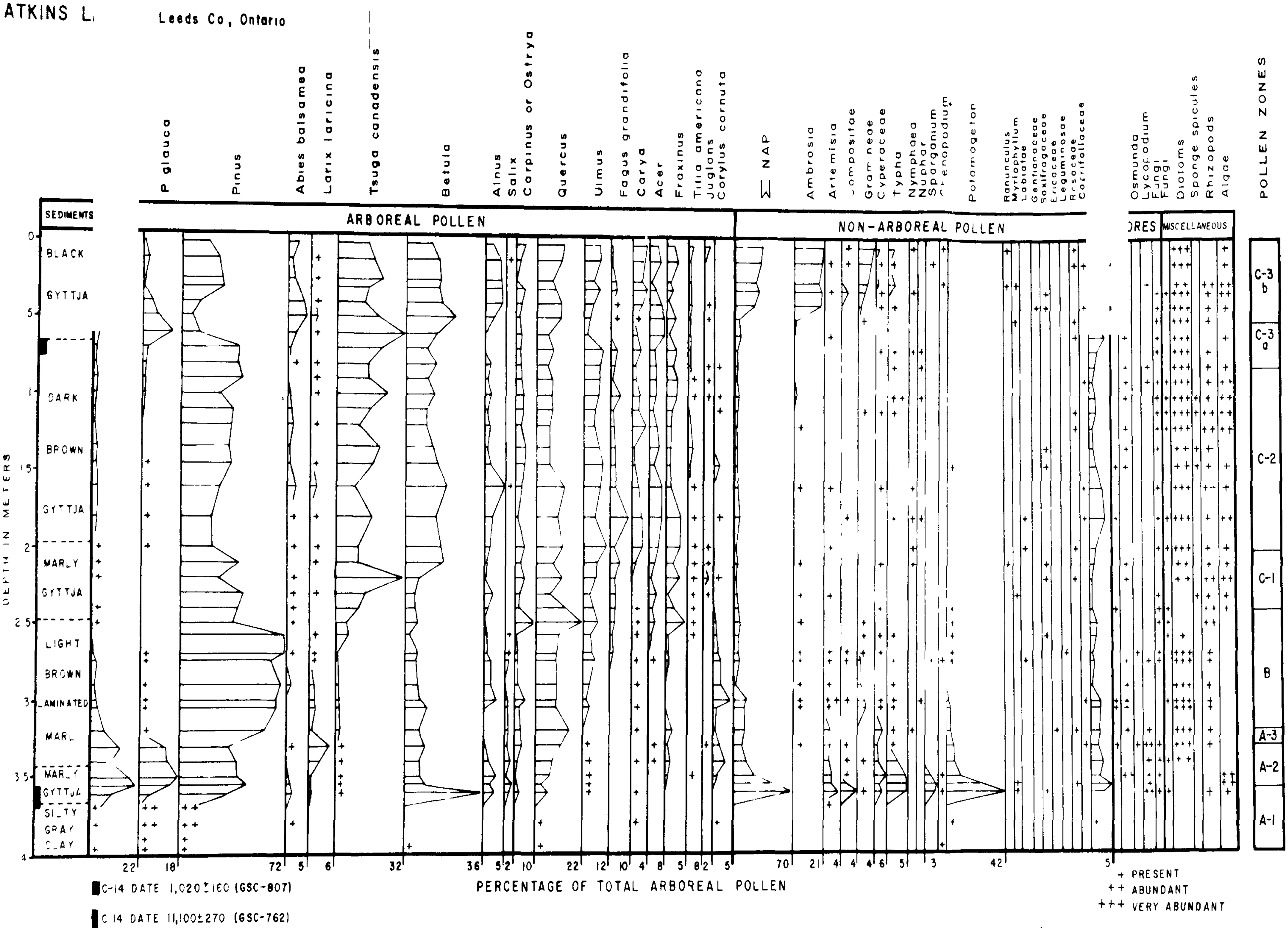


Figure 16. Pollen diagram from Atkins Lake.

with the darker ones averaging about 0.5 centimeter.

343-367 cm: Coarse, detrital, marly gyttja increasing in clay content downwards.

367-377 cm: Clayey, dark gyttja.

377-400 cm: Silty, grey clay.

In figure 23 (p. 127, sections, A, B, C) the density, the water content and the ignition loss are plotted as functions of depth. The numerical data of these variables are listed in table 17 (p. 370).

The density and the water content of the sediments vary drastically only within the two bottom intervals (367-377, 377-400 cm) which reflect an increase in silt and clay. The ignition loss of the dry sediments averages about 65 per cent above the 157 centimeter level but decreases rapidly to approximately 20 per cent within the laminated pinkish-greyish marl unit (240-347 cm). This variable also shows drastic changes in the two bottom inorganic units.

Two samples from this profile were dated by the C-14 method. A basal sample taken between 363 and 376 centimeters gave an age of 11,100±270 (GSC-762) years and an upper sample taken between 65 and 78 centimeters from the upper end of the core was found to be 1020±160 (GSC-807) years old. Based on the oldest date, the average annual sedimentation rate of Atkins Lake deposits is estimated at 0.33 millimeter.

B. Description of the Pollen Diagrams

To describe a pollen diagram it is usually convenient to subdivide it into pollen zones. These zones are biostratigraphical units defined by the American Commission of Stratigraphic Nomenclaturé (1961) as "a body of rock strata characterized by its content of fossils contemporaneous with the deposition of the strata". Defined as such, a pollen diagram is divisible into zones based essentially on observable changes in pollen percentage of the sediment but without any reference to lithologic variations. This type of analysis does not exclude the possibility of using other types of fossil found in the same sediment to construct other systems of zoning. The system used in the present part of this work characterizes each zone as a pollen assemblage zone which is believed to correspond to ecological units contemporaneous in age only within a limited geographical area (see page 241). Minor variations in each pollen zone are attributed to influences in the immediate vicinity of the deposit.

Since the pollen assemblage zones found in the Kingston Region are similar to those already described by previous workers (Deevey, 1951, 1958 Leopold, 1956; Davis, 1965; Beetham and Niering, 1961; Lasalle, 1966; Anderson, 1967) their code of zoning is utilized to avoid confusion.

Zone A-1 (Herbs-*Betula*-*Pinus* pollen assemblage zone)

This zone, characterized by a decline in non-arboreal pollen (NAP) and by an increase in coniferous pollen types, is not present in the Cataraqui River Marsh. In the Atkins and Grady Lakes diagrams the spruces increase while *Pinus*, *Alnus*, *Salix* and NAP are relatively important compared to other palynomorphs. In the Atkins Lake diagram *Betula* reaches a maximum of 35 per cent. *Abies* and *Quercus* are present in minor amounts, whereas *Artemisia*, Compositae, Cyperaceae and *Potamogeton* reach their maximum at both sites within this unit.

Zone A-2 (*Picea* pollen assemblage zone)

In all three diagrams the spruces reach their maximum and the pines are quite high but they do not reach their greatest importance. *Betula*, *Alnus* and *Salix* decrease. *Quercus*, which increases, is the only pollen type of hardwood trees to be present in substantial amount. Terrestrial herbaceous plants, which reach their maximum in the preceding zone, decline rapidly. The aquatic types, such as *Typha*, Sparganiaceae and *Myriophyllum*, decrease in the diagrams. *Potamogeton* increases in the Grady Lake diagram but loses importance in the other two.

Zone A-3 (*Pinus* -*Betula*- *Quercus* pollen assemblage zone)

In all three diagrams the frequency of the spruces declines almost to zero, whereas *Pinus*, *Betula*, *Quercus* and *Carpinus* or *Ostrya* rise. Other types, such as *Ulmus*, *Fraxinus*, *Corylus* and *Acer*, are present in minor amounts. Other deciduous types appear occasionally and are of negligible significance. Some terrestrial non-arboreal types, such as *Artemisia*, Graminaceae and Cyperaceae slightly increase. *Potamogeton* declines in all diagrams but other aquatic types such as *Nymphaea*, *Nuphar*, *Typha*, *Myriophyllum*, *Sagittaria* and trichoscleria of *Nymphaea*, are frequently present in the Cataraqui River Marsh diagram. Moreover, spores of Polypodiaceae and *Osmunda* decrease in this zone.

Zone B (*Pinus* pollen assemblage)

This zone is distinctive because of the high frequency of the *Pinus* pollen and the very low frequency of *Picea* in all diagrams. *Quercus* is the most significant of the broad leaf tree species. *Abies*, *Larix*, *Betula*, *Alnus*, *Salix* and *Corylus* decrease in value.

The top of this zone marks the first continuous appearance of most of the temperate deciduous trees and the minimum percentage of the NAP for all the different zones. In the Cataraqui River Marsh diagram new pollen types such as *Ilex* and *Cephalanthus* make their first appearance, whereas Polypodiaceae reach their maximum of 30 per cent in the middle of this zone. Diatoms of the Grady Lake fade out in the upper part and reappear in the C-1 zone.

Zone C-1 (*Tsuga*-*Quercus*-*Fraxinus* pollen assemblage zone)

This zone is well defined in all three diagrams by the first maximum of *Tsuga canadensis* and by a decline in value of the pines. Here, for the first time, all the deciduous temperate tree pollens have relatively high values. From this zone on, *Betula* pollen becomes more numerous probably due to the establishment of more thermophilous species of this genera in the region. *Quercus* has a slight tendency to decrease, but Fagus does exactly the opposite. The spruces are still very low. The NAP types appear only occasionally except in the Cataraqui River Marsh diagram where Ilex and Cephalanthus reach their maximum. The Polypodiaceae species are still high but they become less important. Osmunda and Sphagnum spore types have high values throughout the entire zone of this diagram.

Zone C-2 (Quercus-Ulmus-Betula pollen assemblage zone)

The C-2 zone is distinctive because of a hemlock minimum present in the three diagrams as well as an increase in Pinus strobus or P. resinosa and a slight increase in the spruces. Most hardwood trees are more abundant at the base than at the top. The NAP of Grady Lake and Atkins Lake are still occasional. In the Cataraqui diagram changes are numerous: Compositae, Cyperaceae and Typha increase, but Ilex, Potamogeton, Cephalantus, Polypodiaceae, Osmunda and Sphagnum decrease in value to almost zero. In the Grady Lake diagram, dinoflagellates disappear completely in the middle of this zone.

Zone C-3a (Tsuga-Betula-Acer pollen assemblage zone)

This zone is primarily delimited in the three diagrams by the second maximum in hemlock and also by a marked reappearance of Picea and Abies. These latter species are especially abundant in Atkins Lake. The Pinus value is lower in the Atkins and Cataraqui diagrams but somewhat higher in Grady Lake. The following deciduous trees: Alnus, Salix, *Carpinus* or *Ostrya*, *Quercus*, *Ulmus*, *Fagus*, *Fraxinus*, *Tilia* and *Corylus* show either low values or a tendency to decline in importance in all diagrams. *Fagus grandifolia* has a relatively high value throughout this zone in the Grady Lake diagram but not in the others. Other types of some importance, such as *Betula*, *Carya* and *Acer*, increase in numbers.

The NAP species are rare or occasional in the Atkins Lake diagram, whereas in the other two diagrams, in particular that from Cataraqui River, there is a steady increase in the following forms: Compositae, Gramineae, Cyperaceae, Chenopodiaceae and *Typha*. In this same diagram, Polypodiaceae, *Osmunda* and *Sphagnum* are quite rare or absent within this zone. In the Grady Lake diagram the middle of this unit indicates a sharp drop in diatoms and a sudden appearance of dinoflagellates.

Zone C-3b (*Ambrosia*-Gramineae pollen assemblage zone)

A sharp increase in non-arboreal pollen types is the chief characteristic of this top zone. *Ambrosia*, *Artemisia*, Compositae, Gramineae, Cyperaceae and *Typha*, which are the main constituents of the NAP, increase in all diagrams. At the top of the Cataraqui River Marsh diagram, the Cyperaceae and *Typha* each reach their maximum of 440 and 300 per cent.

Among the arboreal pollen types, the spruces are particularly noticeable. Pines and hemlock decrease steadily toward the very top, and *Abies* has a high frequency in the Atkins Lake diagram. The deciduous pollen tree types, such as *Betula*, *Alnus* and *Acer*, have a high percentage. *Quercus* and

Fagus decrease while Alnus and Carya increase.

C. Description of the Malacodiagram from Atkins Lake Deposits

The malacodiagram (molluscan diagram) from Atkins Lake (Fig. 17, p. 96) is divided in biostratigraphic zones in accordance with the Code of Stratigraphic Nomenclature. Each zone was characterized, when possible, by a specific assemblage of molluscs. The zones were differentiated on the basis of variations in molluscan taxa, or variations in abundance of taxa, or variations in both of these two elements. It is assumed that such variations are usually attributed to environment, though evolutionary changes may also have an effect over a long period of time.

In the present work a code was used to facilitate the utilization of assemblage zones. The code consists of the letter M followed by a number, the letter symbolizing the molluscan taxon on which these biostratigraphic zones are based. The lowest zone number is found at the top of the diagram just in case other zones should be discovered below the present 4 meter section studied.

A description of each zone of the diagram, starting with the bottom one, follows:

Zone M-8

This bottom unit (360-400 cm) is essentially characterized by the complete absence of molluscs and by the presence of an inorganic type of sediment most of which represents the former oligotrophic stage of the lake.

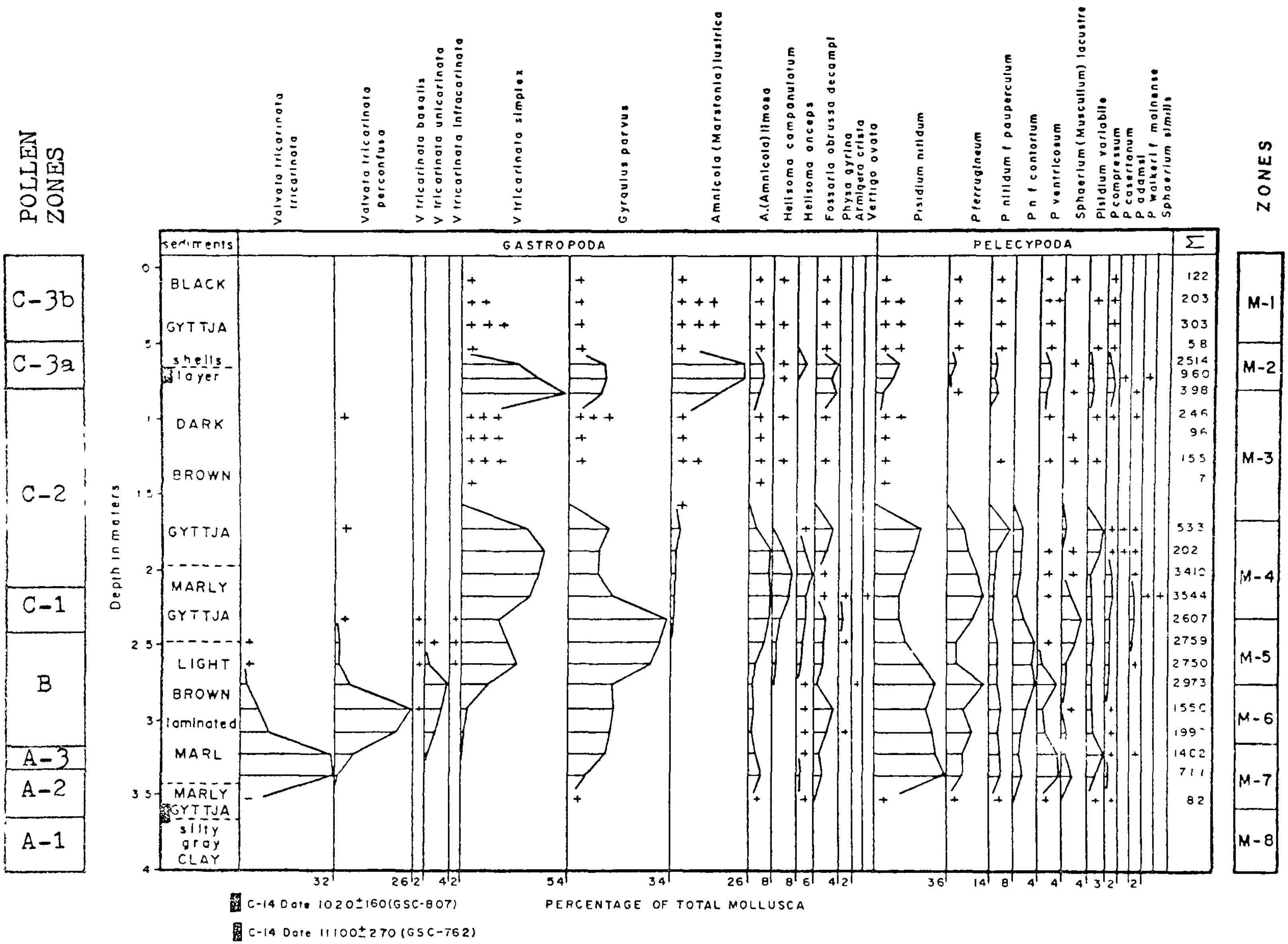


Figure 17. Molluscan diagram from Atkins Lake sediments.
Legend for low abundance of shells: (+)= 1-25, (++)= 26-50, (+++)= 51-75 counted individuals.

Zone M-7 (*Valvata tricarinata tricarinata*-*Pisidium nitidum*-*P. ventricosum* assemblage zone)

This zone (315-360 cm) marks the establishment of 17 of the 27 molluscan taxa found in the whole deposit. *Valvata tricarinata tricarinata*, *Pisidium nitidum* and *P. ventricosum* culminate in the middle part and decrease in the upper part. *Valvata tricarinata perconfusa*, *Gyraulus parvus*, *Pisidium ferrugineum* increase constantly. Other species, such as *Amnicola limosa*, *Sphaerium lacustre*, and *Pisidium variabile*, which are present in small amounts at the base become less abundant toward the upper part of this zone. The increase in the absolute count of individuals per spectrum, which goes from 82 to 1462, shows that the fauna is gradually expanding with time.

Zone M-6 (*Valvata tricarinata perconfusa*-*V. tricarinata infracarinata*-*Pisidium nitidum* assemblage zone)

This biostratigraphic unit (278-315 cm) is characterized principally by *Valvata tricarinata perconfusa* and *V. tricarinata unicarinata* which culminate in abundance and by *Pisidium nitidum* which decreases slightly but constitutes 30 per cent of the whole spectrum. *Valvata tricarinata tricarinata*, *Amnicola limosa*, *Helisoma anceps*, *Pisidium ventricosum*, *Sphaerium lacustre*, *P. variabile*, and *P. compressum* all lose importance at the expense of the dominant taxa. *Valvata tricarinata basalis* and *Physa gyrina*, which are poorly represented all through the diagram, are recorded for the first time in this M-6 zone.

Zone M-5 (Gyraulus parvus-Pisidium nitidum form contortum assemblage zone)

The characteristic dominants within this zone (233-278 cm) are Gyraulus parvus and Pisidium nitidum form contortum. Valvata tricarinata simplex and Pisidium nitidum which decrease, at least in the upper part, are the main associates. Valvata tricarinata tricarinata, V. tricarinata perconfusa, V. tricarinata unicarinata and Pisidium ventricosum, which had previously reached their maximum abundance, are nearly absent in the upper part, whereas Amnicola limosa, Helisoma campanulatum, H. anceps, Fossaria obrussa decampi and Sphaerium lacustre all increase in abundance upward. Pisidium nitidum and P. ferrugineum are negatively correlated with the high occurence of Gyraulus parvus. Finally, this zone is characterized by the first appearance of new taxa such as Valvata tricarinata infracarinata, Helisoma campanulatum and Armiger crista.

Zone M-4 (Valvata tricarinata simplex-Helisoma campanulatum-H. anceps-Amnicola limosa-Pisidium ferrugineum assemblage zone)

The molluscan fauna decreases rapidly in the upper levels after having reached its optimum diversity and abundance at the base of this zone (165-233 cm). Only 16 of the 23 taxa found at the base remain in the upper part, The characteristic taxa of this unit are Valvata tricarinata simplex, Helisoma campanulatum, H. anceps, Amnicola limosa, Pisidium ferrugineum. Gyraulus parvus, Fossaria obrussa decampi, Pisidium nitidum, P. nitidum form pauperculum, P. nitidum form contortum, Sphaerium lacustre and Pisidium variabile all reach a minimum synchronized with the maximum of the dominant representatives. Valvata tricarinata tricarinata, V. tricarinata basalis, V. tricarinata unicarinata, V. tricarinata infracarinata and Physa gyrina disappear above the base of this zone. Vertigo ovata and Sphaerium similis, of which each is recorded only once in the entire diagram, appear toward the base.

Zone M-3

At the base, the molluscan fauna disappears almost completely and only one individual of the Amnicola lustrica species is found at the 165 centimeter level. From the 27 different taxa present in the deposit of Atkins Lake, only 14 are found, more or less sporadically, in this zone (83-165 cm). The total number of individuals counted for the spectrum was believed to be too low to give representative percentage curves. For this reason the relative abundance of these individuals is expressed in the diagram by means of crosses.

Zone M-2 (Amnicola lustrica-Valvata tricarinata simplex assemblage zone)

Within this interval (53-83 cm), 12 taxa reappear in substantial amount. The most characteristic ones are: Amnicola lustrica reaching a maximum of 25 per cent, Valvata tricarinata simplex, Gyraulus parvus, Amnicola limosa, and

Pisidium nitidum. Five other taxa are present in much smaller quantity and ten are not represented at all.

Zone M-1

In this upper unit (0-53 cm) of the diagram the total number of individuals counted for each spectrum is less than 308 and the percentage curves are believed to be unrepresentative. Only 13 of the 27 taxa found in the whole deposit are present.

D. Description of the Trace Elements Diagram from Atkins Lake Deposit

In this diagram (Fig. 18, p. 101) zones were also established on the basis of visible stratigraphic variations in the abundance of the trace elements represented by the curves. The most characteristic elements on which the division into zones of the diagram is based are known collectively as trace elements assemblage zones. Since these zones are not biostratigraphic units, this way of proceeding is not in accordance with the Code of Stratigraphic Nomenclature. The system was adopted since it was similar to the pollen analysis method.

The code used to identify each trace element zone is similar to the one used in the description of the malacodiagram. The letters TE (standing for trace elements) are put before the number of the zone to avoid any confusion with other zoning codes used in the present work or by other workers. As in the mollusc diagram, the zones are numbered consecutively starting

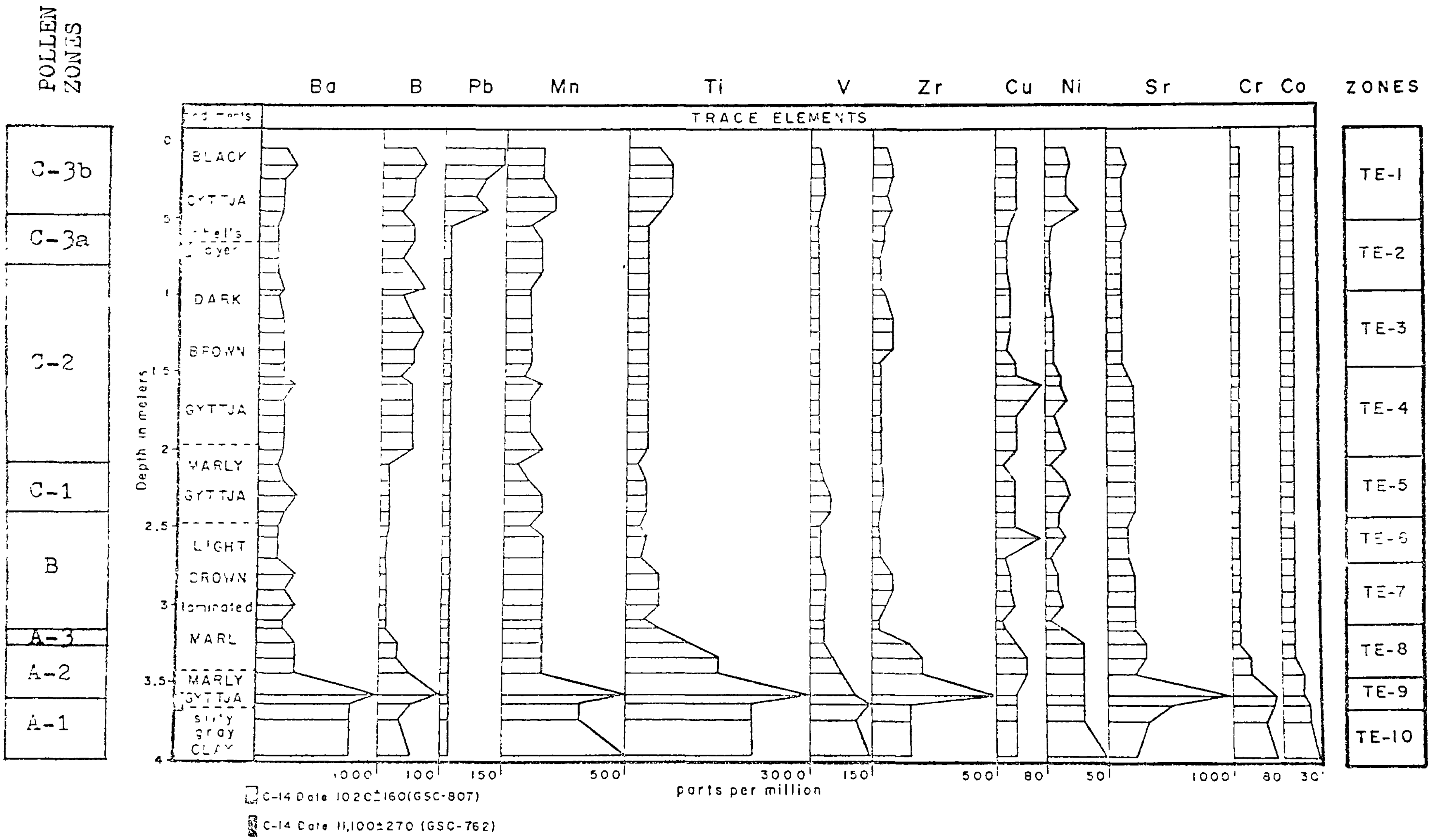


Figure 18. Late-Quaternary stratigraphic diagram of Atkins Lake showing the concentration in parts per million of some trace elements. For each element the arithmetic horizontal scale starts at zero and only the maximum concentration is indicated.

with the one closest to the surface and going downward. The description of the zones begin with the bottom one.

Zone TE-10 (Mn, V, Ni, Cr, Co assemblage zone)

Within this basal trace element zone (368-345 cm), Mn, V, Ni, Cr, and Co reach their maximum abundance and decrease toward the upper part of the core. Only Sr increases substantially. Moreover, two important distinctive features are the low values of Pb (less than 20 ppm) and of Cu (30 ppm).

Zone TE-9 (Ba, B, Ti, Zr, Sr assemblage zone)

This is the smallest and most distinctive zone (345-368 cm) of the whole diagram. Barium, B, Ti, Zr, and Sr, the characteristic elements of the zone, all reach a maximum value at the 360 centimeter level and decrease rapidly toward the upper boundary of this zone. Vanadium, Cr, and Co diminish slowly. Cu is the only element to increase and Pb is the only one that does not show any fluctuation.

Zone TE-8

Although no trace element is dominant within this interval (312-345 cm), the upper boundary corresponds with an important minimum of several elements; for example, Ba less than 200 ppm, B less than 100 ppm, Ti 300 ppm, Zr 20 ppm, Cu 10 ppm and Ni 5 ppm.

Zone TE-7 (Ba, Ti, Zr assemblage zone)

This zone (270-312 cm) is well delimited by several elements, such as Ba, Ti, Zr, Cu, and Ni, which increase for a short time from the bottom of the zone to the middle and then decline up to the upper boundary. Boron, Pb, Cr, and Co remain constant within the unit, but Sr diminishes slightly toward the upper end.

Zone TE-6 (Cu assemblage zone)

This short interval (244-270 cm) is characterized by sustained short reductions in the concentration of Ba, B, Ti, V, Zr, and Sr. On the other hand Cu, and to some extent Ni, are the only elements to reach well-defined peaks in the middle of this zone.

Zone TE-5 (Ba, V, Ni assemblage zone)

Increases in Ba, V, Ni, Mn and Ti toward the middle of this zone (203-244 cm) are the chief characteristics helping to trace the lower and upper boundary of this unit. A small increase in the curve of Sr at level 244 centimeters and a sharp increase in B at level 203 centimeters are other marking points delimiting this zone.

Zone TE-4 (B, Cu, Sr assemblage zone)

Within this TE-4 zone (155-203 cm), B, Cu, Sr and Ni are present in substantial amounts and decrease appreciably toward the upper part. Moreover, small amounts of B and Zr are other important features of this unit.

Zone TE-3 (B, Zr assemblage zone)

The increase in the concentration of B and Zr toward the middle are the most important characteristics of this interval (95-155 cm). Concentrations of Cu, Ni and Sr are all lower than in the zones described above.

Zone TE-2 (Mn assemblage zone)

Mn is the only element delimiting this zone (45-95 cm) by a positive fluctuation but Zr, Cu, and Ni, which decrease in amount toward the middle, also help to characterize the zone.

Zone TE-1 (Pb, Mn, Ti assemblage zone)

The sharp increase in Pb is the most striking feature of this upper zone (0-45 cm). It passes from 20 ppm , which remains constant from the basal zone TE-10, to 150 ppm at the very top of the diagram. There are other remarkable increases in B, Mn, Ti, V, Zr, Cu and Ni which help to distinguish this upper zone from the preceding ones. Cr and Co curves are the only ones which do not show any fluctuation.

E. Bottom Surface Sediment Samples of Lakes from the Gatineau Area

The name, location, hypolimnic oxygen depletion, water depth and results of the various bottom surface sediment samples from the Gatineau Area are tabulated in table 13 (p. 340) and 14 (p. 343).

1. Traverse of Meach Lake

Figure 19A (p. 105) shows a sketch map of Meach Lake and

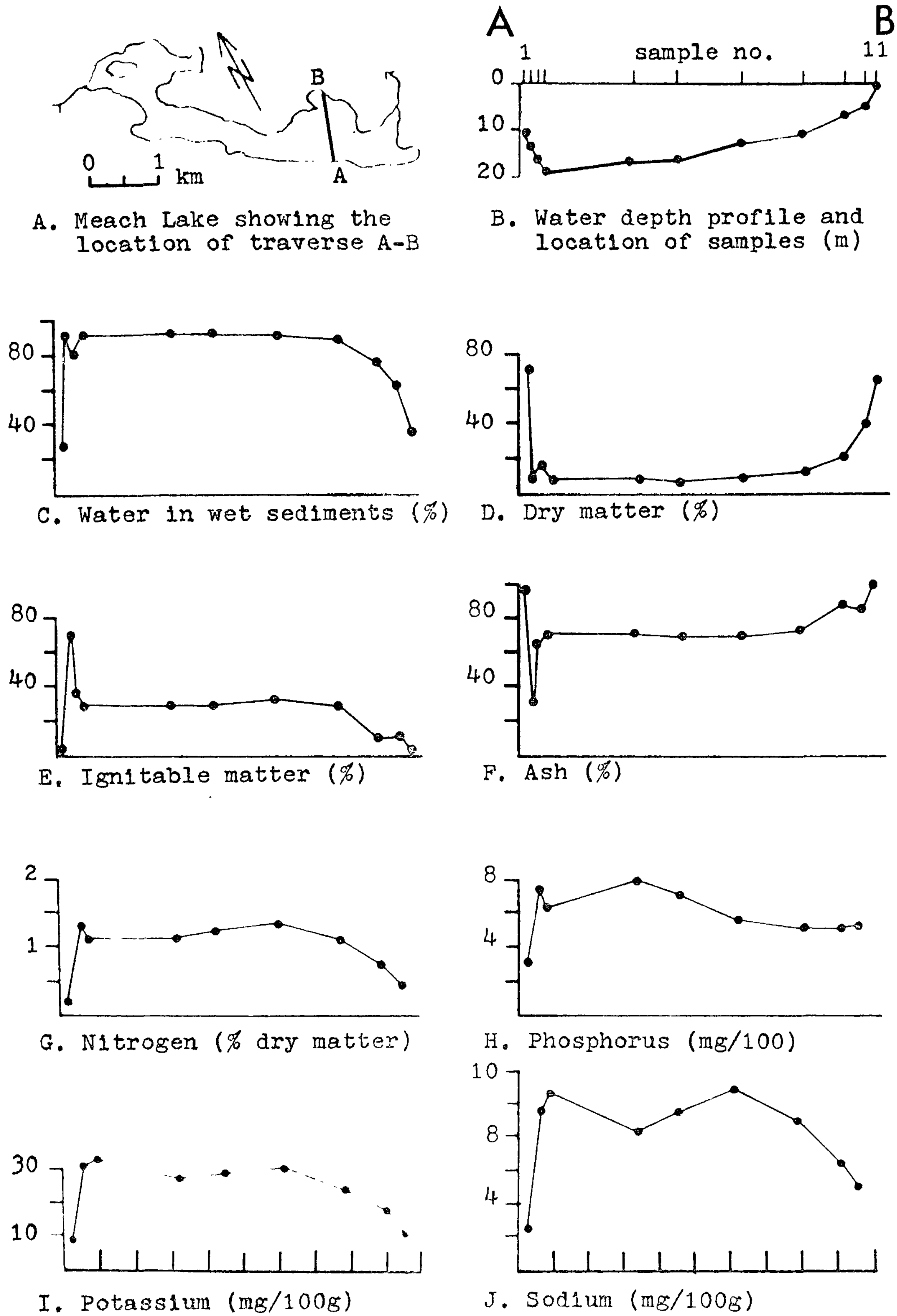


Figure 19(A-R). Distribution of various parameters along traverse A-B of Meach Lake. The horizontal axis is 1 km long.

...K-R

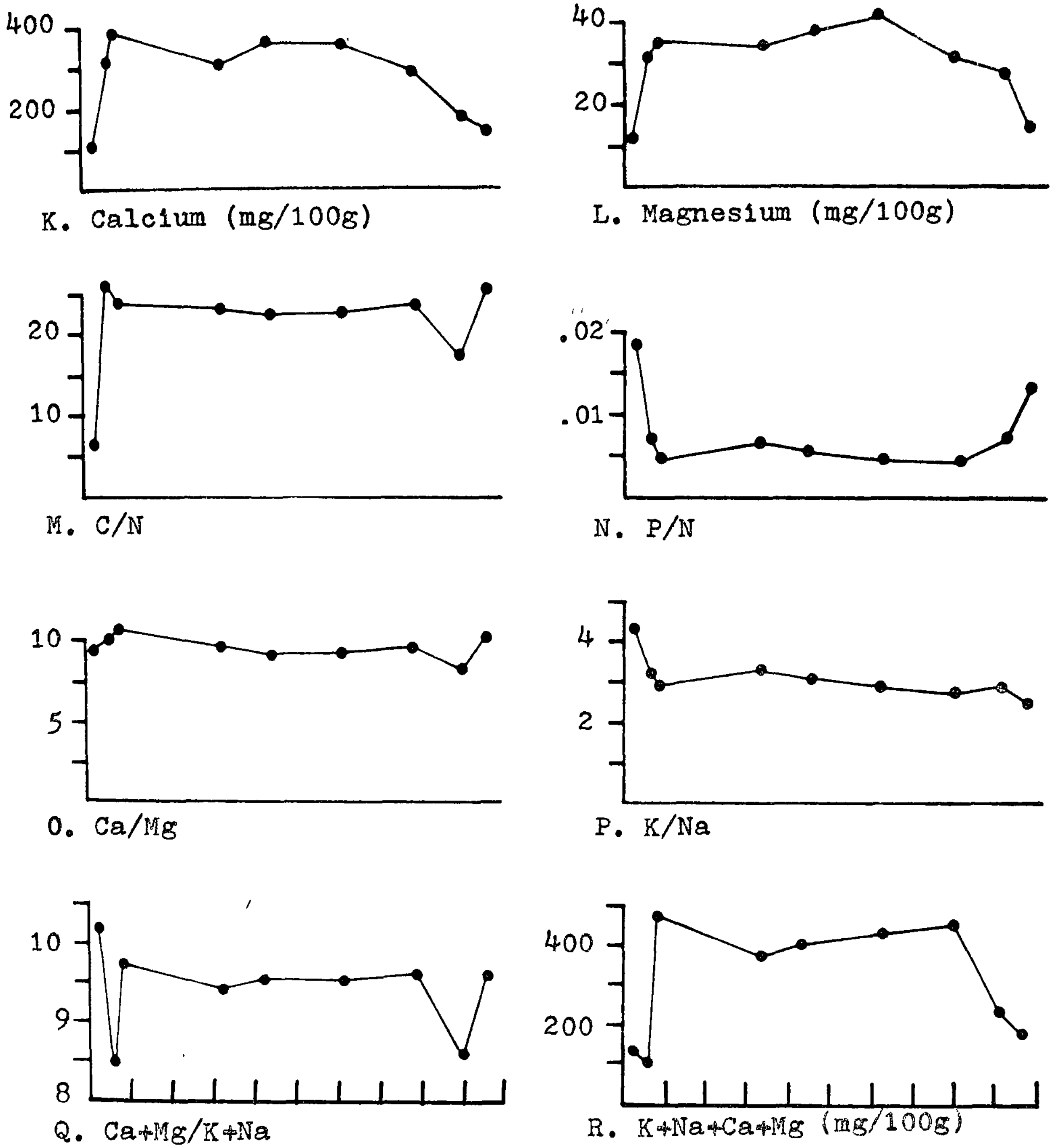


Figure. 19. Cont'd

shows the location of the traverse A-B along which the 11 bottom surface sediment samples were taken. The widest part of the lake (1.0 km) was selected for this traverse so as to reduce the effects of the allochthonous factors as much as possible at the center of the lake.

Figure 19B is a water depth profile of the lake along line A - B. The upper part of this figure shows the location and the number of each of the 11 stations to scale. The mean water depth along traverse A-B is 12.03 meters. At station number 4 the depth is at its maximum (19.5 m) while at station 11 it is only 1.2 meter deep.

a. General chemistry

Figure 19 (graphs C-R) shows the various chemical parameters measured along Meach Lake transect.

The percentage water content of the 11 wet sediment samples (Fig. 19C) is minimal (27.67%) at station number 1, average around 90 per cent for station 2 to 8 and gradually decreases to 35.77 per cent at station 11.

The dry matter (Fig. 19D) is the reciprocal of the percentage water or the wet sediment (100% - water %). The ignition loss of the dry sediment (Fig. 19E) reaches its minimum (1.09%) at the first station and its maximum at the second one (69.74). The curve of the percentage ignition loss for the other 9 remaining stations is quite comparable to the water percentage. It averages around 30 per cent except for the last 3 stations where the lowest value of 3.18 per cent is found at site number 11. The percentage ash of the dry sediment samples is the reciprocal of the ignitable matter (100% - C%) and its curve is similar to that of the percentage dry matter.

The distribution curves for variables N, P, K, Na, Ca, Mg and total cations (Fig. 19, G-L and R) are relatively similar to one another. The lowest value for each of these variables always appears at station number 1 to then rise more or less gradually to a much higher concentration toward the center of the axis. Then the concentration decreases steadily down to the last station. All these quantitative distribution curves are more or less similar to the mirror image of the water depth profile (Fig. 19B).

Figure 19M which represents the distribution of the ratio C/N shows that the first station has a much lower value (6.41) than the other stations which range from 17.82 to 26.61.

The ratio Ca/Mg (Fig. 19o) ranges from 6.4 to 11.8 with a mean of 9.21. The ratio K/Na (Fig. 19P), with a mean of 3.29, is the only variable along the traverse to have a high value near the left shore of the lake. The ratio of cations Ca+Mg/K+Na (Fig. 19Q) has a W-shape like curve. At the first site, this variable reaches its maximum amount of 10.22, to then fall rapidly to a minimum of 8.40 at station 3. The average value for all of the other stations oscillates around 9.5, except for site number 9 where it reaches a low amount of 8.57.

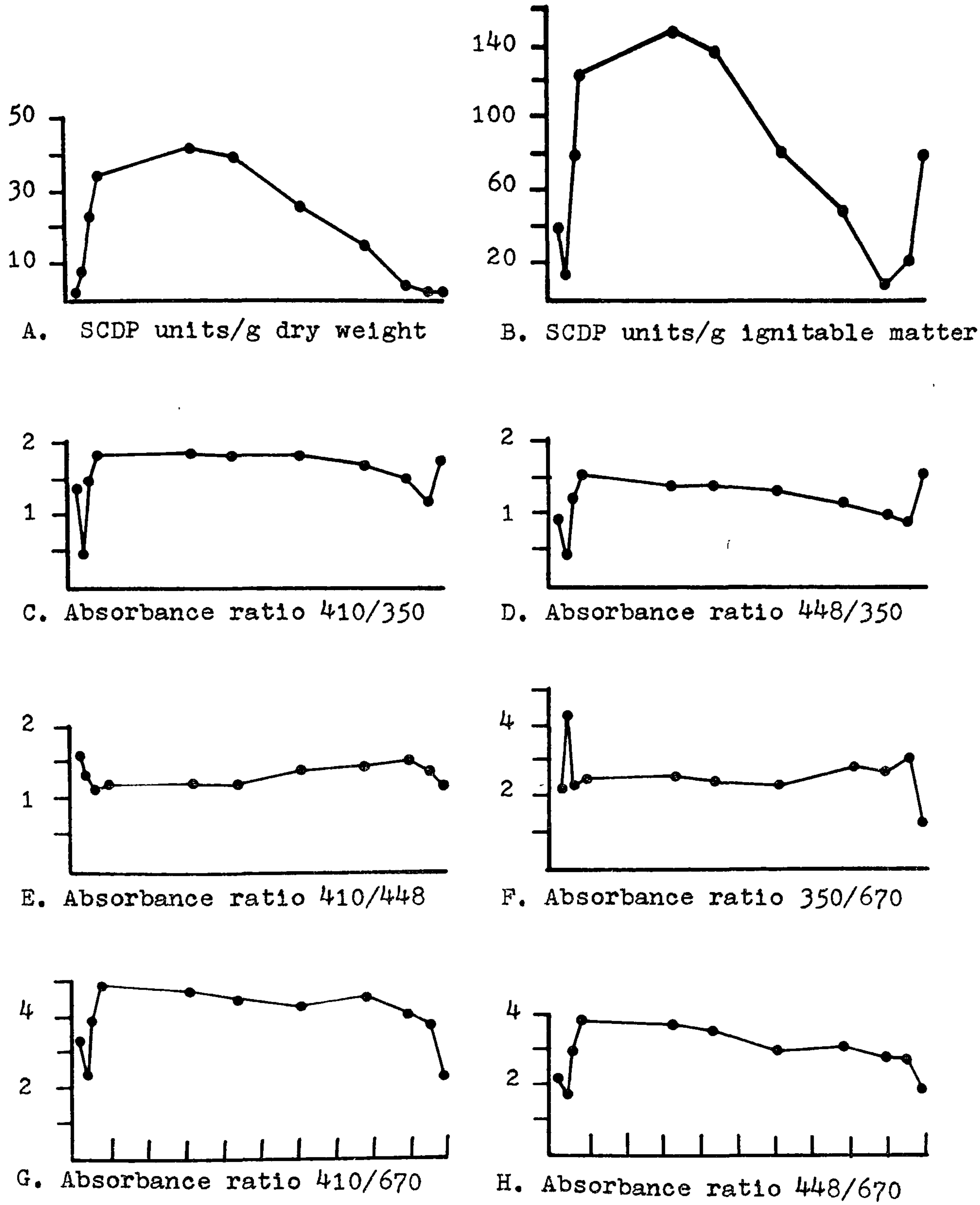
b. Sedimentary chlorophyll degradation products (SCDP)

The amount of the 8 SCDP parameters determined for the bottom surface samples of Meach Lake is plotted as a function of their horizontal distance along the traverse A-B (Fig. 20, p. 110). The SCDP per gram of dry weight has a convex shaped curve. Its two smallest values of 0.41 and 2.31 units are respectively found at stations 1 and 11 and its largest concentration of 43.70 units falls at station number 5. The quantitative distribution of the SCDP per gram of ignitable matter between stations 2 and 9 is similar to the previously described curve. At these two stations minima of 12.16 and 17.07 units per gram of ignitable matter are found while the maximum concentration of these variables reaches 150.87 units at station 5. Intermediate values appear at stations closer to the shores of the lake.

Curves of wavelength absorbance ratios 410/350, 448/350, 410/448, 350/670, 410/670 and 448/670 are quite comparable to one another, at least for stations located away from the extremes of the horizontal axis, where minor quantitative fluctuations are present. Concentrations in the ratios may vary as much as 50 per cent above and below their respective mean at stations closer to the shores of the lake.

2. Sample from the center of the lakes

The sample data from the bottom surface sediment taken at the center of the 9 lakes of the Gatineau Area (Simon, Cayamant, Blue Sea, McGregor, Belisles, Baie de l'Ours, Meach, Perdrix, Vert) are listed in table 14 (p. 343). The lakes are listed



'igure 20. Quantitative distribution of various pigment parameters along traverse A-B of Meach Lake. Horizontal axis is 1 km.

in order of increasing hypolimnic oxygen depletion downward. Since most of these lakes have already been surveyed more than once, at different periods of the year, by the Departement de la Faune Québécoise Division de Hull, terms such as high, medium, low and nil are used here instead of numerical values.

The data from station number 5 of Meach Lake (Table 13, p. 340) also appear in table 14 (p. 343). The former station is the most representative of the whole traverse of Meach Lake. The effects of the allochthonous factors are believed to be minimum for this particular site as well as for the sampling site chosen for the 8 other lakes. The data of station number 5 from Meach Lake are repeated in this table so as to facilitate its comparison with the 8 other lakes studied.

All these lakes are located on the Canadian Shield within a radius of 80 miles north of the city of Ottawa. The water depth of these lakes averages 16.4 meters and ranges from a minimum of 4.9 meters for Cayamant Lake to a maximum of 33.5 meters for Lake Belisles.

a. General chemistry

The percentage dry matter of the wet sediment averaging 19.7, varies from a high of 54.0 for Lake Simon to a minimum of 1.4 for Lake Vert at the bottom of the classified list (Table 14, p. 343). The ignitable matter of the dry sediment exhibits reciprocal distribution. The lowest percentage of 1.5 is found at Lake Simon while the highest one 57.4 appears at Lake Vert. The nitrogen percentage, with a 0.99 per cent average for the 9 lakes, also increases from top (0.15%) to bottom (2.94%).

Potassium, Na, Ca, Mg, total cations, and to a lower extent, ratios Ca+Mg/K+Na and Ca/Mg all have their higher values in lakes listed at the bottom of the table. The ratio P/N with a mean of $13.46X10^{-3}$, has a distribution parallel to the percentage dry matter of the wet sediment and a smaller concentration in lakes appearing at the bottom of the table.

b. Sedimentary chlorophyll degradation products

The SCDP per gram of dry matter and per gram of ignitable matter show parallel trends and increase from Lake Simon to Lake Vert. A minor exception occurs in the SCDP per gram of dry matter of Blue Sea Lake which is lower than the one above (Cayamant) by 4.5 units. The mean value (168.73) of the SCDP per gram of ignitable matter is more than twice the mean (74.86) of the SCDP per gram of dry weight sediment.

As for the various wavelength absorbance ratios of the acetone extracted sediment, there are continuous trends in increases from Lake Simon to Lake Vert in ratios 410/670, 448/670 and 448/350. Their value ranges respectively from 2.14, 1.58 and 0.80 to 5.24, 4.73 and 1.70 with means of 4.11, 3.03 and 1.25. The other 3 ratios 410/350, 350/670 and 410/448 have a smaller range and each average 1.61, 2.44 and 1.43.

F. <u>Description of the General Chemical Diagrams</u>

The same general procedure previously described for the pollen, mollusc, and trace element diagrams is followed here for the presentation of the general chemical data so as to facilitate the comparison of the various types of diagrams included in the present work. The different zones of the 3 general chemical diagrams appearing at the extreme right of figures 21 (p. 114), 22 (p. 121), and 23 (p. 127) were also established on the basis of visible qualitative and quantitative stratigraphic variations of the studied parameters. Within this section (F), the most characteristic factors according to which each diagram is divided into several general chemical zones are collectively known as assemblage zones. The code used to identify each zone consists of 3 capital letters followed by a number. The first letter represents the site since, unlike the pollen zones, the general chemical zones probably reflect environmental factors and have very little interrelationship from one site to the other. The letter C stands for Cataraqui River Marsh, G for Grady Lake and A for Atkins Lake. The 2nd and 3rd letter GC stand for general chemistry. The number following the 3 code letters and increasing from top to bottom identifies the zone number of each site.

1. Cataraqui River Marsh

Zone CGC-8 (Density, P, P/N, Ca/Mg assemblage zone)

This bottom zone (427-472 cm; Fig. 21, p. 114) is highly distinctive. The density ranges from 1.40 to 1.70 grams per milliliter. Such high density does not appear in any of the 7 other overlying zones. Moreover the ratio P/N reaches its highest value (.005) within this basal unit. In contrast with this high distribution, the water percentage of the wet sediment, the ignition loss on dry sediment, N, K, Na,

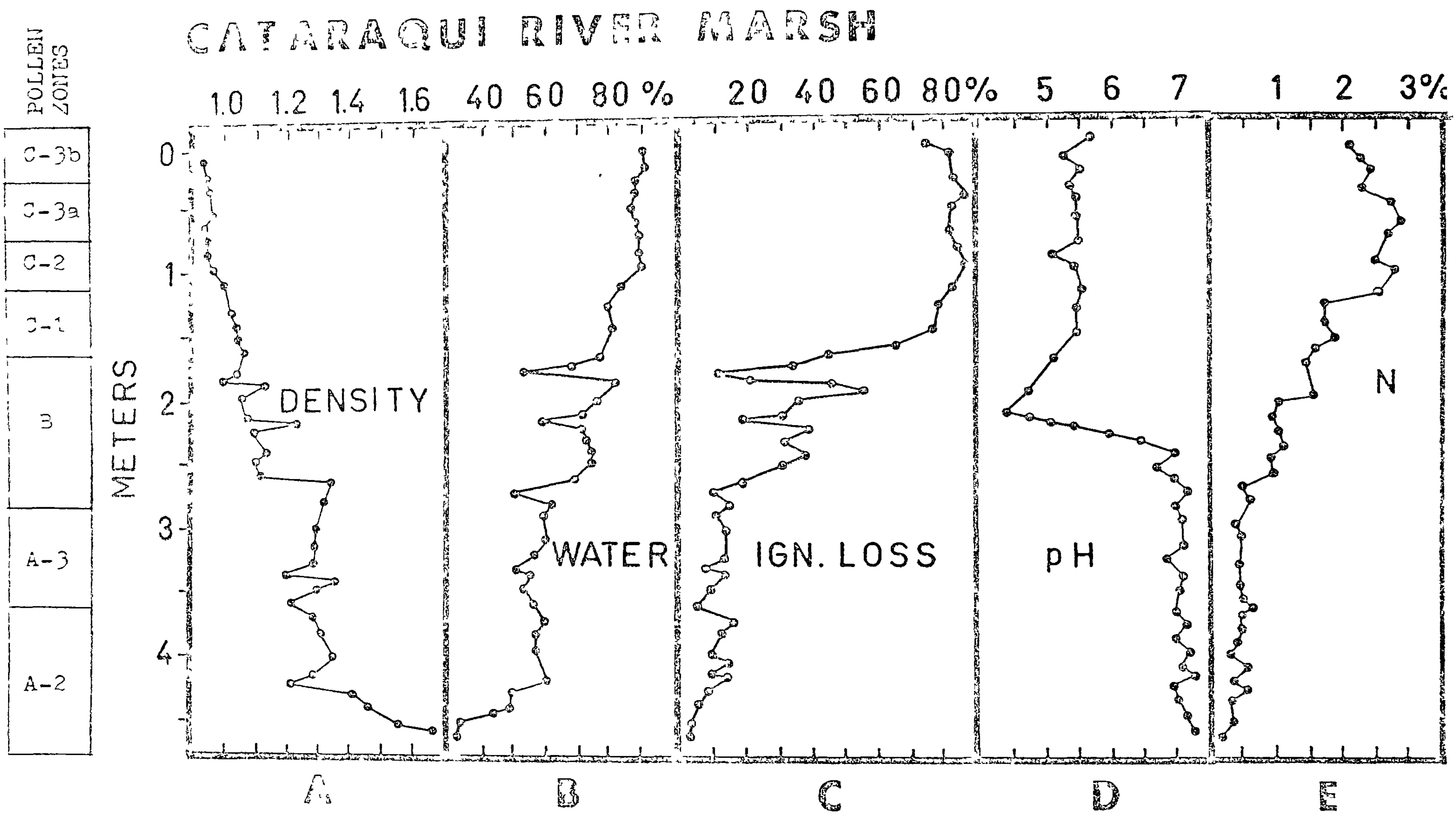


Figure 21. General chemical diagram from the Cataraqui River Marsh deposit. When not indicated the units are in mg per 100 g of room dried sediments.

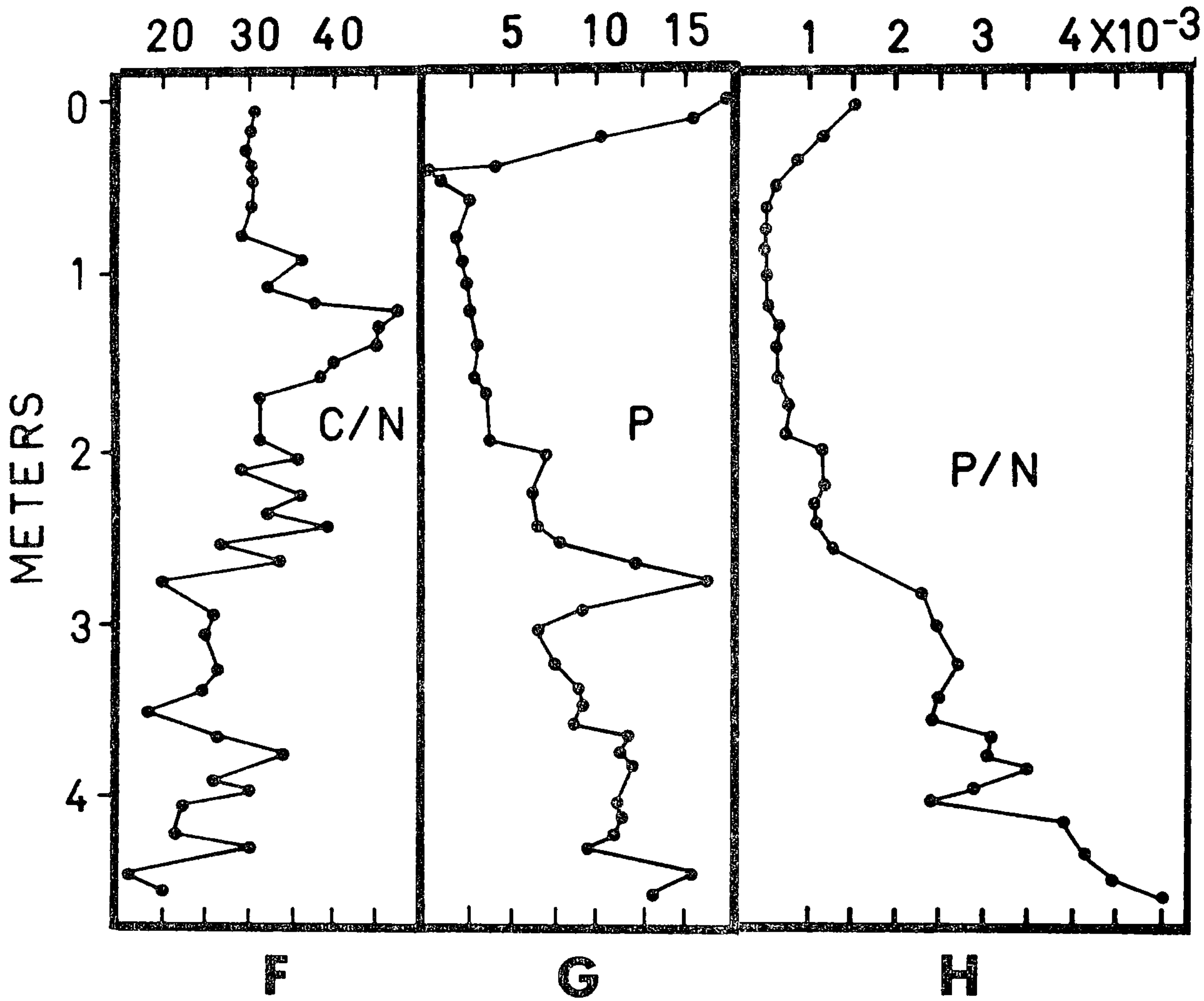
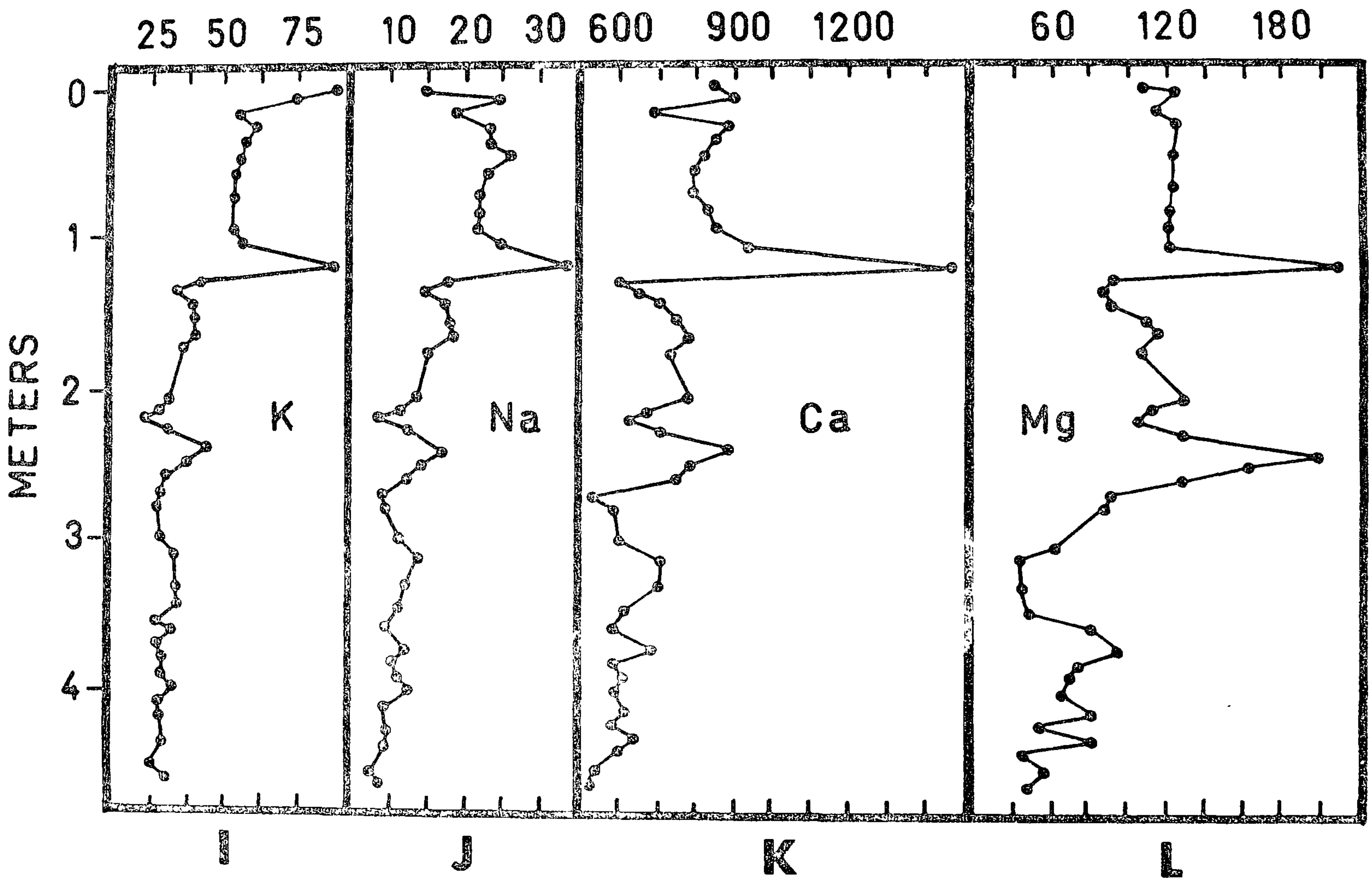


Figure 21. Cont'd



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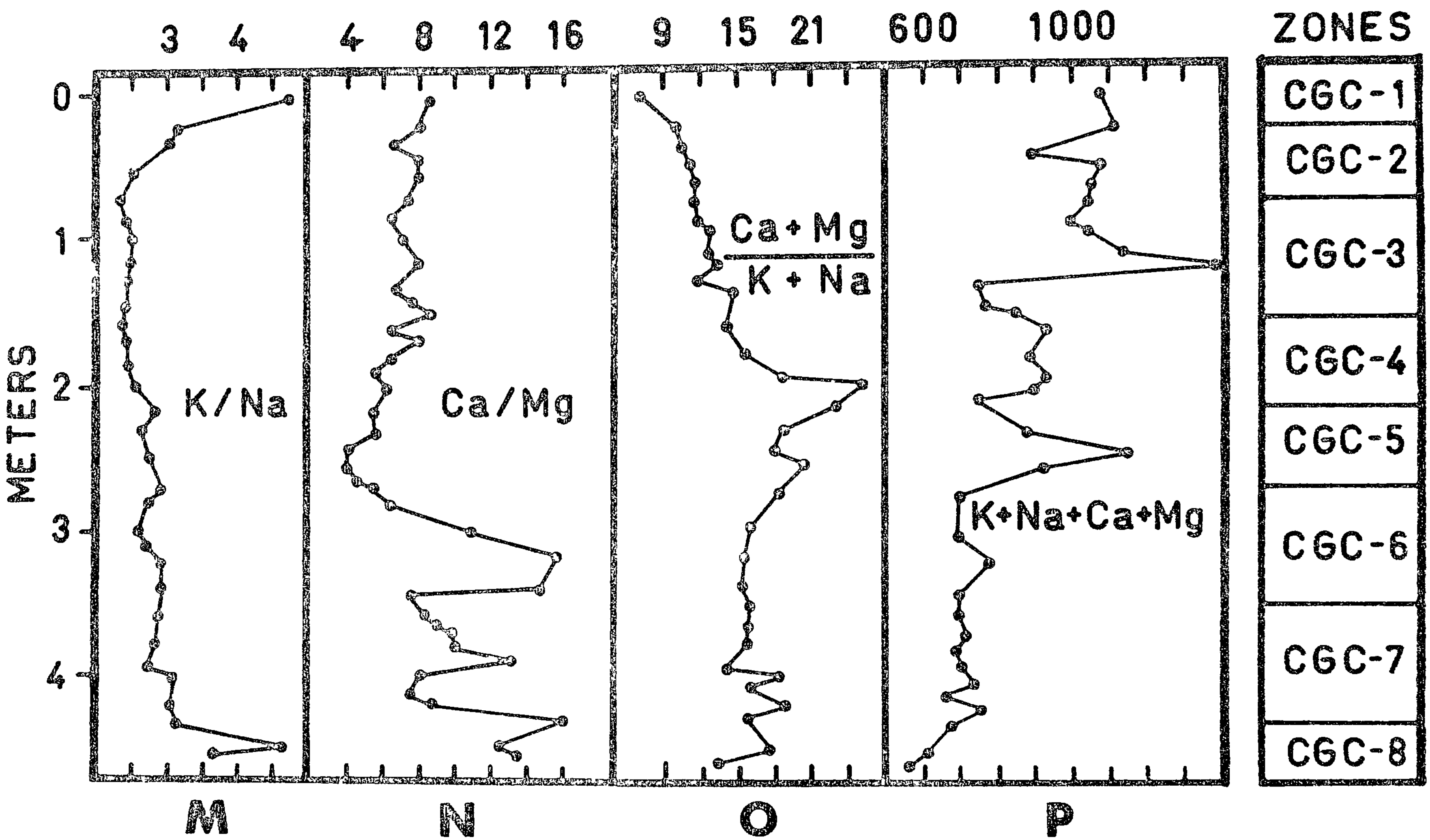


Figure 21. Cont'd

Ca, Mg and the total exchangeable cations all reach their minimum abundance within this stratigraphic interval.

Zone CGC-7 (Density, P assemblage zone)

In this zone interval (342-427 cm) the density, which is still relatively high, averages around 1.3. The water content of the wet sediment has increased by 20 per cent as compared to the preceding zone. The P value (12 mg/100 g) is quite stable all through this zone except at the very top where it falls sharply.

Within this stratigraphic interval the ratios P/N, Ca/Mg and to some extent the density, water content, ignition loss, P, Na, Ca and Mg follow a parallel distribution. Their quantitative curve fluctuates positively from the bottom to the center of the CGC-7 zone, to then decrease in importance toward the upper part.

Zone CGC-6 (Ca/Mg, P/N, minimum Mg assemblage zone)

The density, ignition loss, pH, N, K and K/Na show little quantitative fluctuations within this zone (267-342 cm). On the other hand, the water percentage, C/N, Ca+Mg/K+Na and total exchangeable cations (K+Na+Ca+Mg) increase progressively especially toward the top of the zone, while the Mg declines constantly in the lower part of the same interval.

Zone CGC-5 (pH, total cations, minimum Ca/Mg assemblage zone)

The pH value which was slightly above 7 in the above described zones fluctuates here significantly for the first time. It passes progressively from a value slightly above 7 at the 267 centimeter level to a minimum of 4.4 at the 218 centimeter level. This shift is one of the most striking changes in the whole diagram.

The density and P decline sharply while the individual available cations and their total reach a sustained peak around the middle of this CGC-5 interval zone.

Zone CGC-4 (Ca+Mg/K+Na, pH, P assemblage zone)

This zone (152-215 cm) is characterized by the maximum value for Ca+Mg/K+Na (24) and by the minimum pH value (4.4). The density is close to unity and the water content and ignition loss of the dry sediment exhibit large correlative fluctuations. The water content varies from 81.17 to 52.32 per cent and the ignition loss from 54.55 to 12.64 per cent between levels 186 to 182 centimeters. Here for the first time, the N values are higher than 1 per cent and the K/Na and P/N values reach their minimum.

Zone CGC-3 (total cations, ignition loss, C/N, density assemblage zone)

Within this zone (75-152 cm) the density values of the wet sediment are slightly less than unity for the first time throughout the whole diagram. The ignition loss reaches its highest value of 92.13 per cent at the 95 centimeter level. The ratio C/N and the individual cations and their total also attain their maximum in this CGC-3 zone. The available anion

P and the ratio P/N decrease to their minimum and, at the same time, the ratio Ca+Mg/K+Na which was at its highest level within the previous zone decreases constantly.

Zone CGC-2 (N, P assemblage zone)

In this stratigraphic interval (25-75 cm) the values of the density of the wet sediment are all less than one. The water percentage and the ignition loss both average around 85 per cent. At the 65 centimeter stratigraphic level, N goes up to 2.90 per cent and P declines to 0.68 milligram per 100 grams.

Zone CGC-1 (P, K, K/Na, Ca+Mg/K+Na assemblage zone)

This interval (0-25 cm) is the smallest one and is characterized in general by large fluctuations. Phosphorus fluctuates from its lowest to its highest value (0.68-21.02 mg/100 g) within the top 65 centimeters. Potassium and K/Na both increase sharply while ignition loss, N, Na and Mg decrease substantially at the very top.

2. Grady Lake

Zone GGC-6 (Density, water, ignition loss, N, C/N, K/Na, Ca/Mg, Ca+Mg/K+Na, total cations assemblage zone)

This basal stratigraphic unit (1015-1056 cm) is the most distinctive zone in the chemical diagram of Grady Lake (Fig. 22, p. 121). Density, water, ignition loss, N, C/N, K, Na, Ca, K/Na, Ca/Mg, Ca+Mg/K+Na and total cations reach

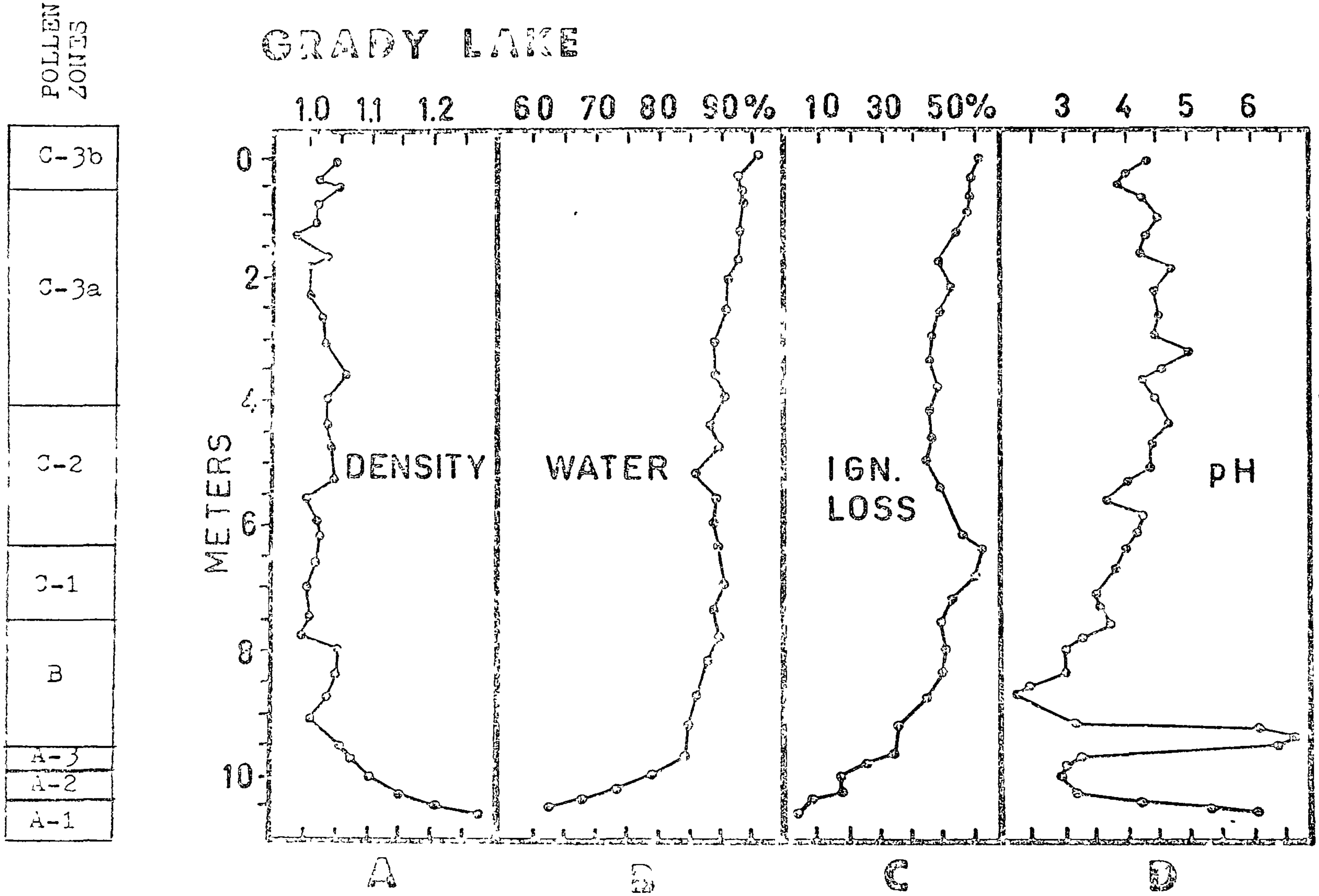


Fig. 22. General chemical diagram from Grady Lake deposit. When not indicated the units are in mg per 100 g of room dried sediments.

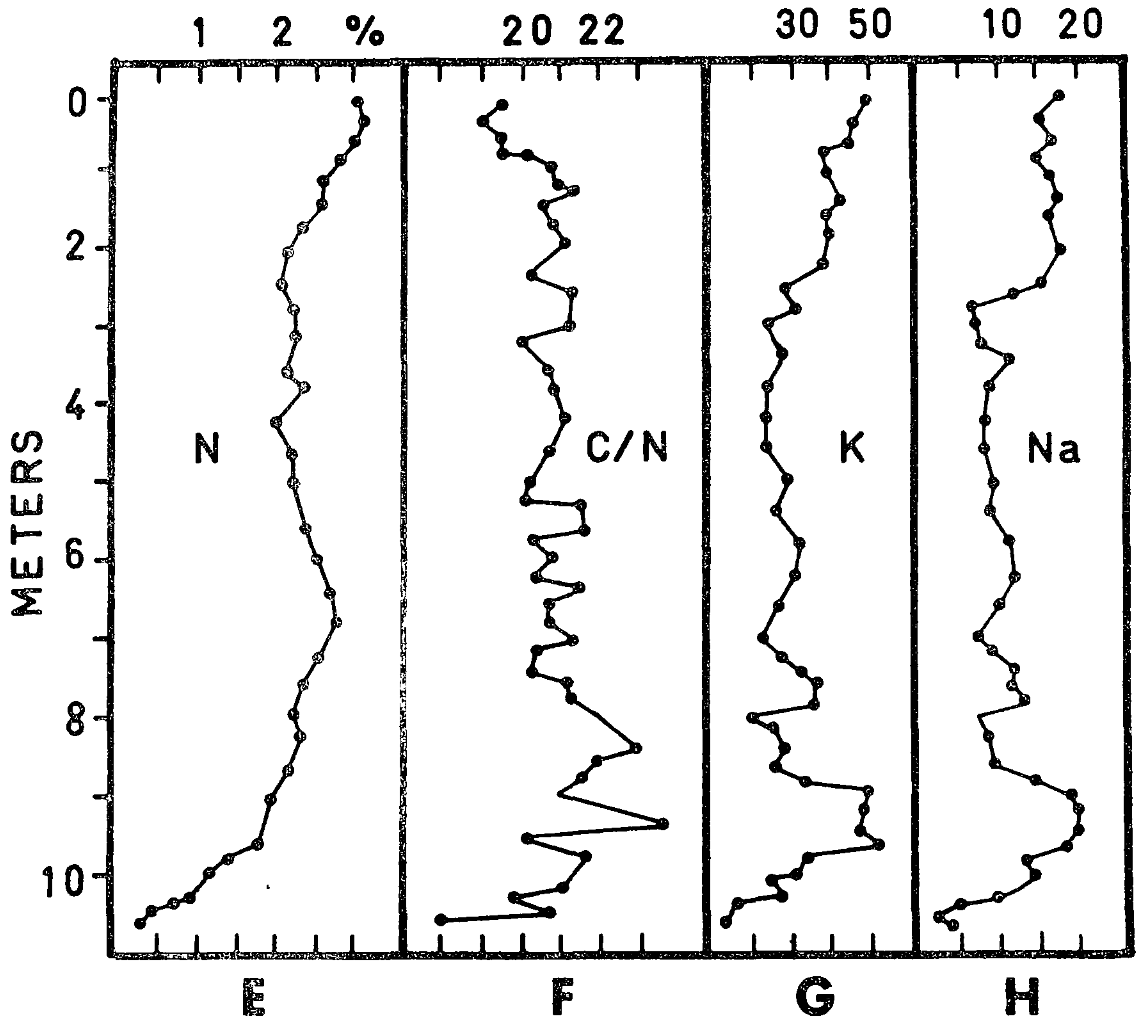
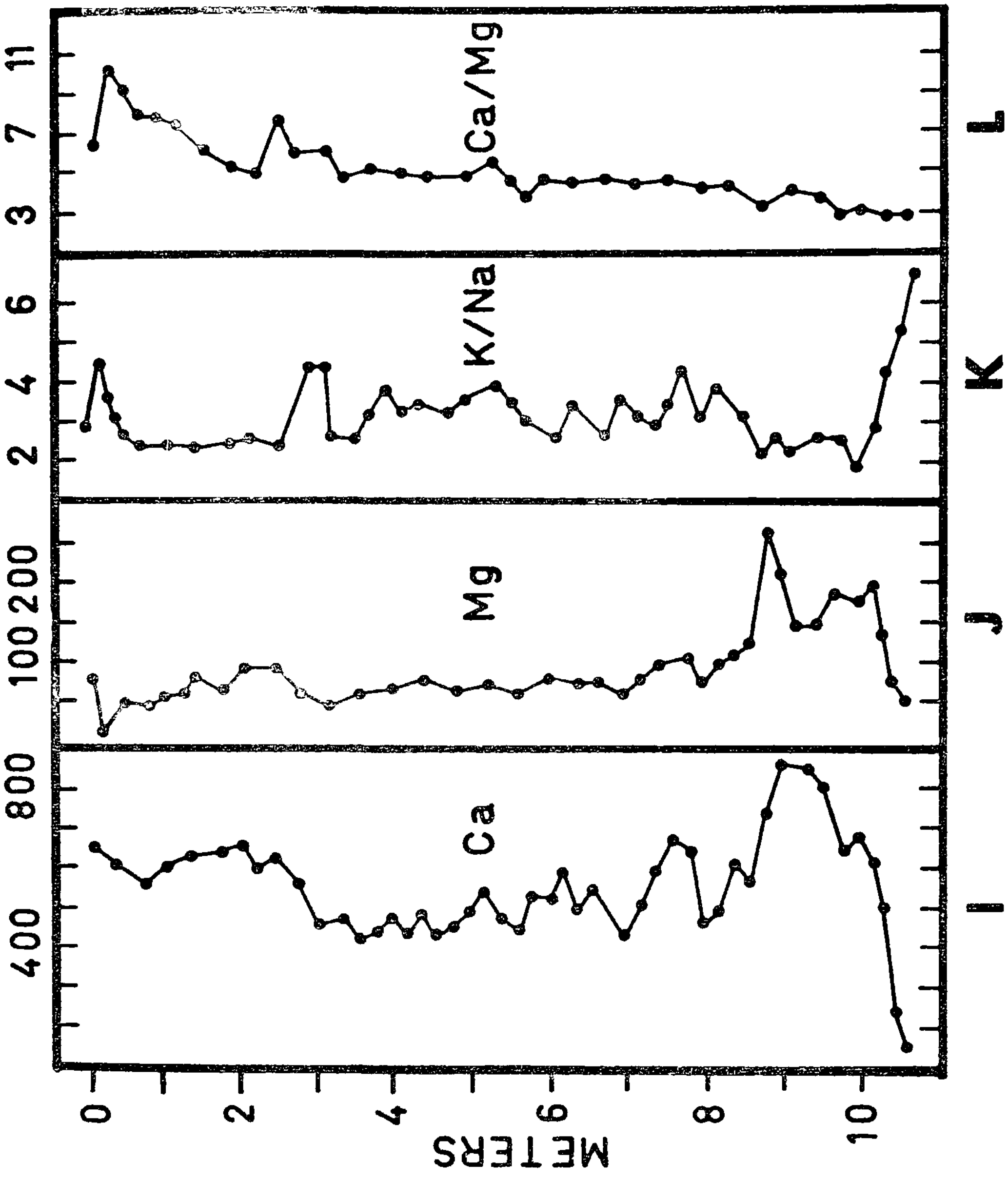


Figure 22. Cont'd



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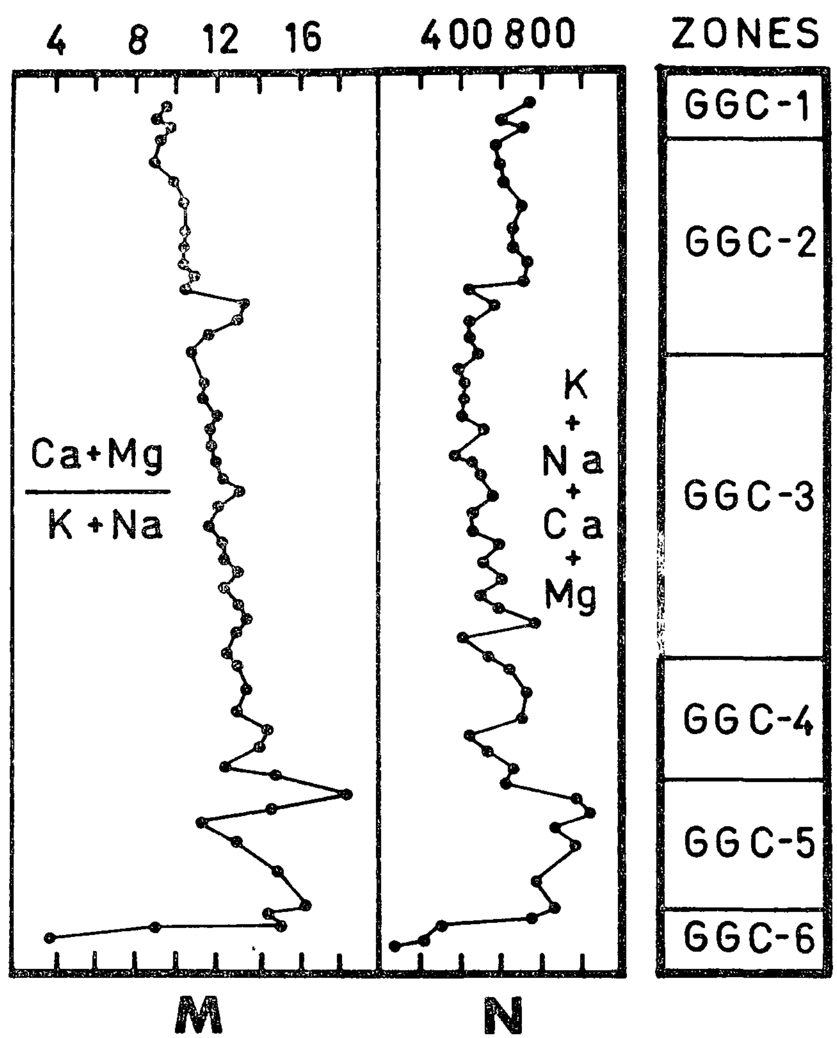


Figure 22. Cont'd

values inferior or superior to any of the other overlying zones.

Zone GGC-5 (pH, K, Na, Ca, Mg, total cations, K/Na, Ca+Mg/K+Na assemblage zone)

In this stratigraphic interval (855-1015 cm), the density of the sediment decreases rapidly while the water, ignition loss and N content tend to become more abundant. The parameters pH, K, Na, Ca, Mg and total cations all increase upward from the lower boundary on to approximately the middle part of this zone, and then fluctuate negatively up to the very top. The variables K/Na and Ca+Mg/K+Na generally show reciprocal trends which help delimit this particular unit.

Zone GGC-4 (K, Na, Ca, total cations assemblage zone)

This unit (705-855 cm) is primarily distinguished by the concurrent maxima exhibited by the cations K, Na, Ca and their total toward the middle and by Mg to a smaller extent. The same trends are found in the GGC-5 zone, but with somewhat slightly higher values.

Zone GGC-3 (Density, water, N, total cations assemblage zone)

The largest unit (315-705 cm) of this diagram is remarkable for the stability of all its variables from the lower to the upper boundary. The ignition loss and the pH are the two parameters showing the greatest fluctuations. From the lower to the upper boundary the percentage ignition loss goes from 60.34 to 46.69 while the pH increases from 3.4 to 5.0.

Zone GGC-2 (C/N, K, Na, Ca/Mg, K, Na, Ca/Mg, Ca+Na/K+Na, total cations assemblage zone)

The lower boundary of this zone (40-315 cm) is delimited by rapid positive fluctuations in the four cations. Variables such as C/N, K/Na, Ca/Mg and Ca+Mg/K+Na also contribute to delimiting this lower boundary. They all show minor maxima within interval 200 to 315 centimeters.

Zone GGC-1 (K/Na, Ca/Mg assemblage zone)

This top unit (0-40 cm) differs considerably from the previous one by its small size and its numerous fluctuations. The pH, C/N, K, Na, Ca, Mg, K/Na and total cations all increase significantly around the 40 centimeter level. The ratio Ca/Mg is the only variable which decreases in importance.

3. Atkins Lake

Zone AGC-7 (Density, water, C/N, P, total cations assemblage zone)

This basal stratigraphic interval (365-400 cm) from the general chemical diagram of Atkins Lake (Fig. 23, p. 117) is mostly distinctive because of its extreme values for several variables. Here the density, C/N, P, P/N and K/Na all reach their minimum value. On the other hand the water content, N, K, Na, Ca, Mg, Ca/Mg and total cations all reach their lowest value in this lower unit.

Zone AGC-6 (Density, water, P, total cations, Ca+Mg/K+Na assemblage zone)

This zone (340-365 cm) is some kind of intermediate

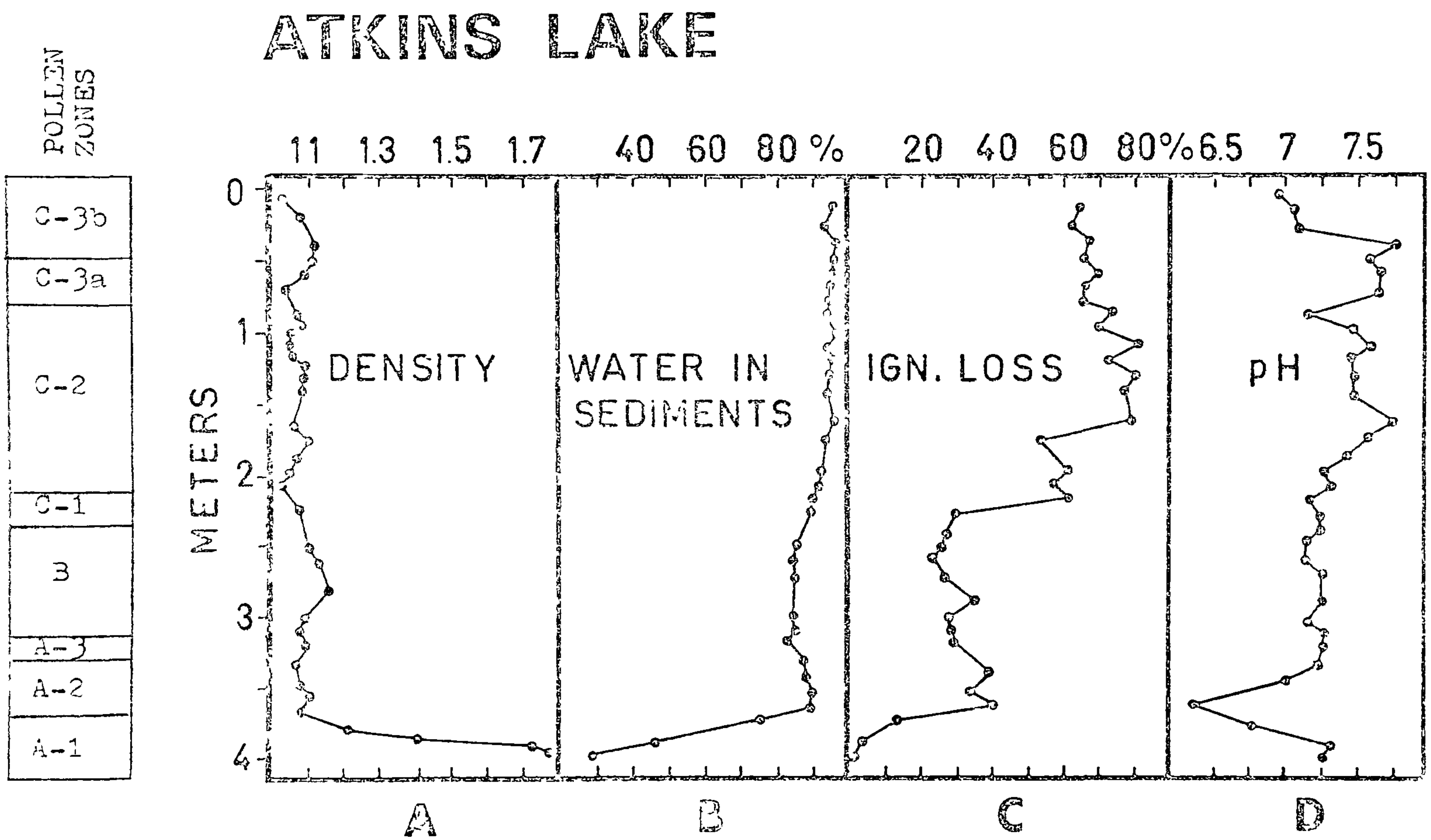
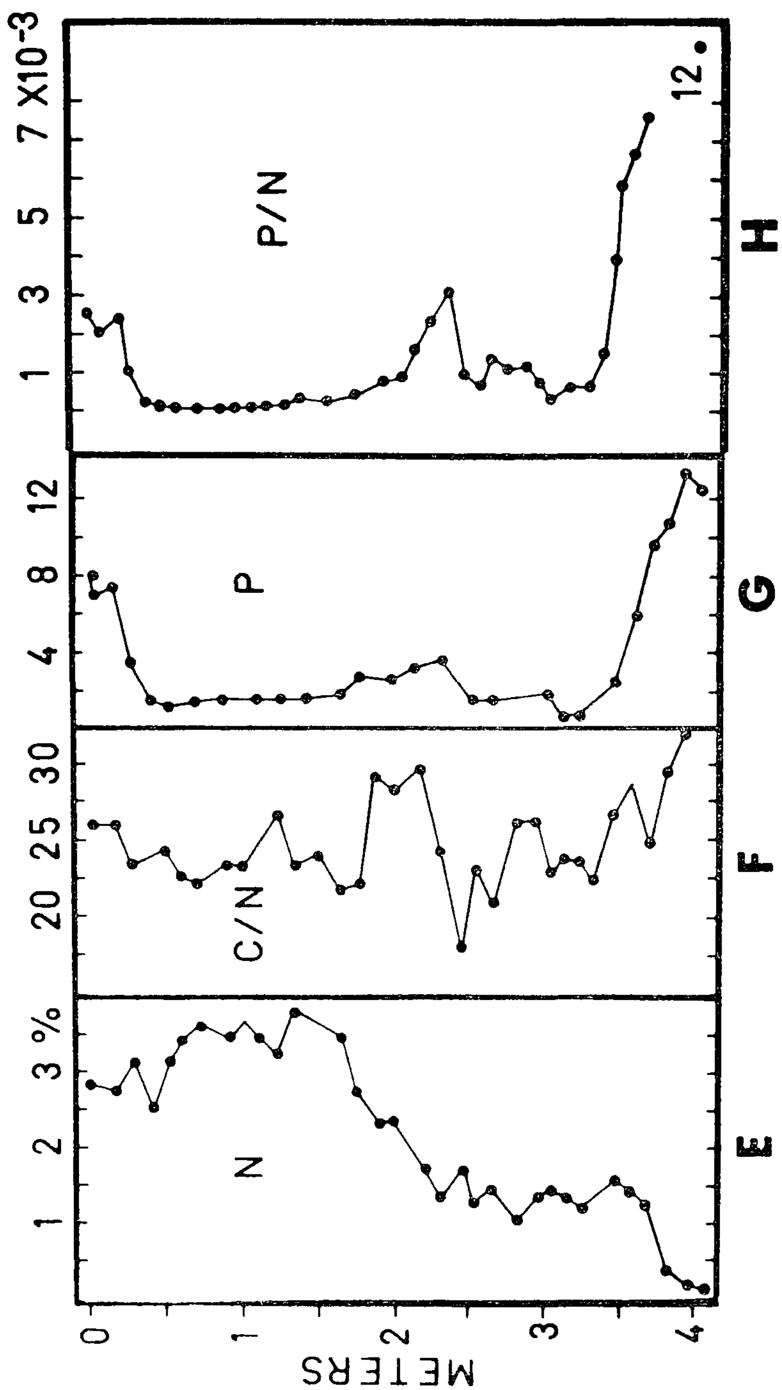


Figure 23. General chemical diagram from Atkins Lake deposit. When not indicated the units are in mg per 100 g of room dried sediments.



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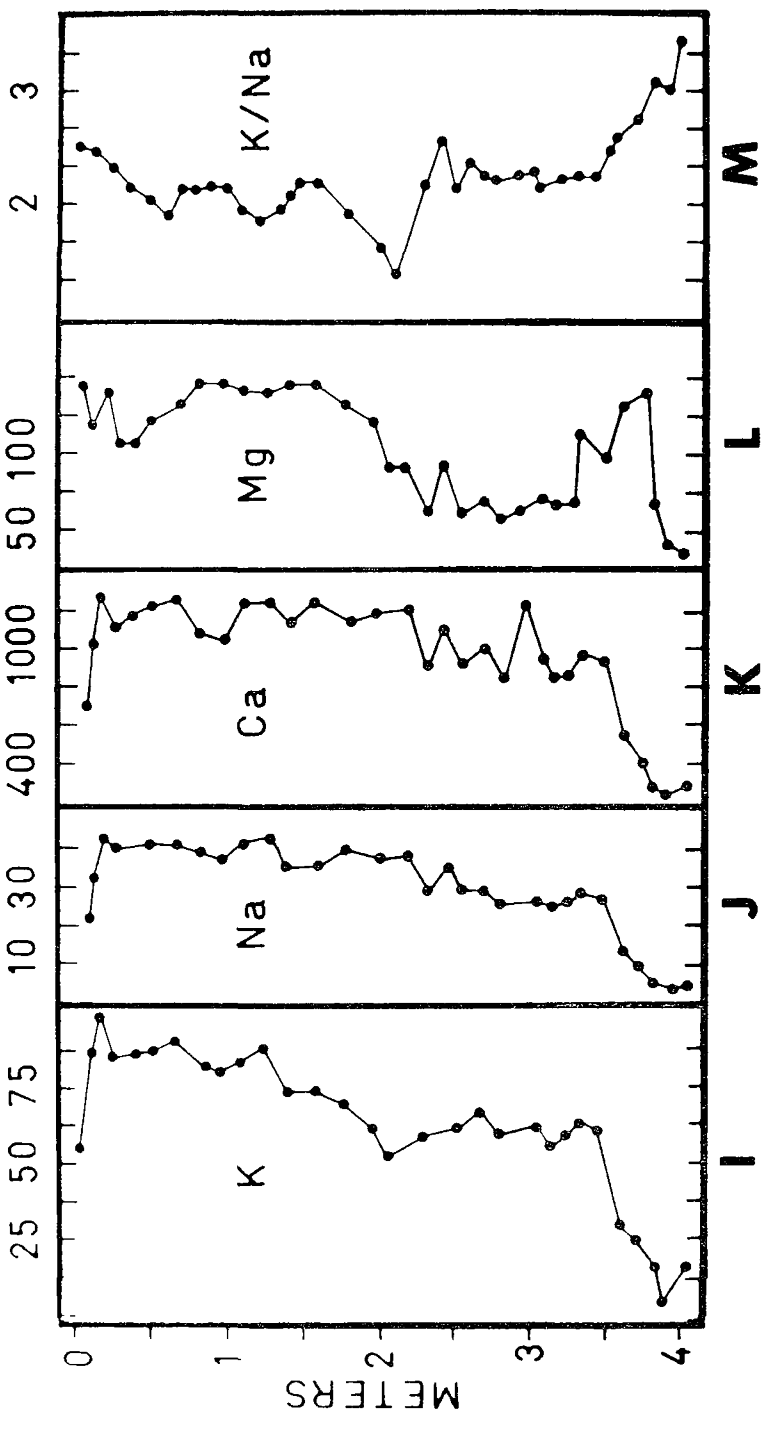

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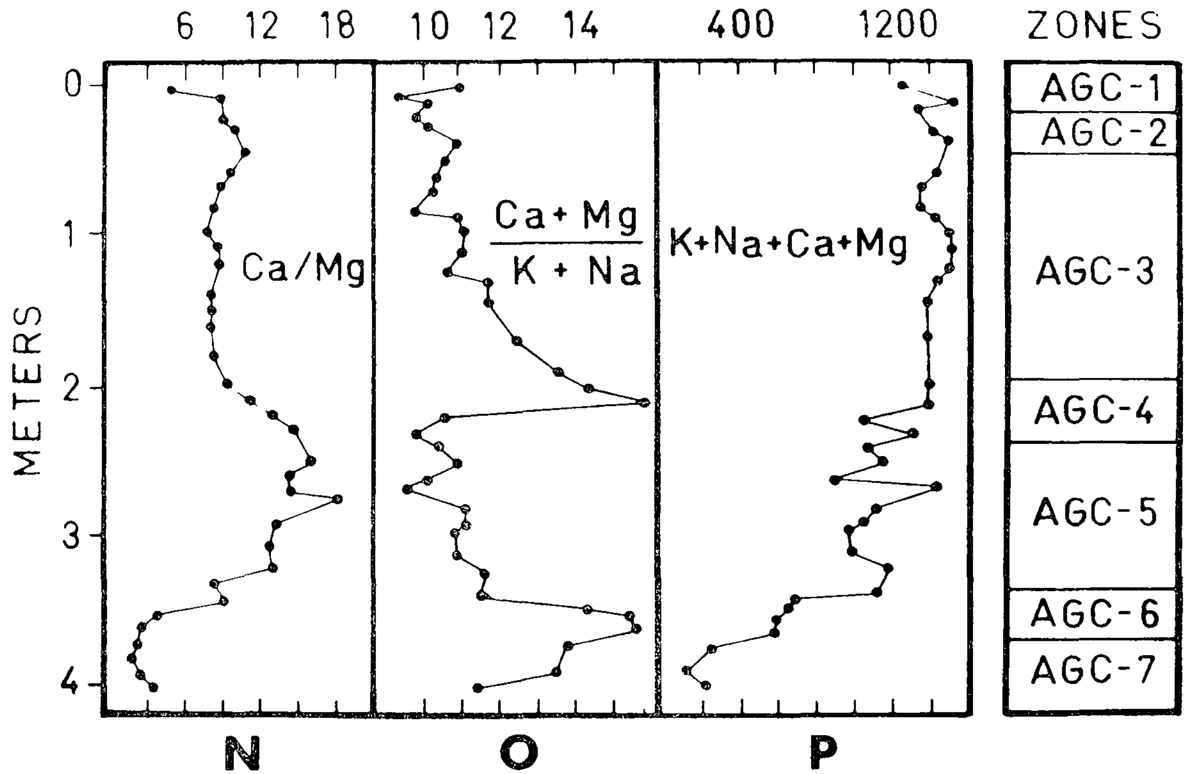


Figure 23. Cont'd

interval between zone AGC-7 and all of the above ones. Many variables in this AGC-6 unit indicate great positive or negative shifts in their concentrations, and then maintain relatively constant values for the rest of the diagram. This tendency is observed in the pH, C/N, P, K, Na, Ca, Mg, K/Na, P/N and total cations. The density and the water content in sediments have already reached values (1.1 and 90%) that remain fairly stable for the rest of the diagram. This unit is also characterized by the ratio Ca+Mg/K+Na which rises considerably at the 360 centimeter level.

Zone AGC-5 (P, Mg assemblage zone)

In this part (240-340 cm) of the profile several variables (ignition loss, pH, N, P, K, Na, Ca, Mg, K/Na and total cations) maintain a constant intermediate value. Phosphorus reaches its lowest amount (0-75 mg/100 g) throughout the entire diagram at the 315 centimeter level. The Mg and the ratio Ca/Mg rise to their maximum. The minimum concentration Ca+Mg/K+Na is highly characteristic of this AGC-5 zone.

Zone AGC-4 (Ignition loss, N, C/N, Mg, K/Na, P/N, Ca+Mg/K+Na assemblage zone)

Several parameters which had a constant value in zone AGC-5 now increase rapidly within this AGC-4 zone (197-240 cm). Ignition loss, N, C/N, Mg, and the ratio Ca+Mg/K+Na show a considerable positive increase and, at the same time, the K/Na, Ca/Mg, and P/N decrease rapidly. Here again the ratio Ca+Mg/K+Na exhibits a sharp peak which greatly contributes to the delimitation of this unit.

Zone AGC-3 (Ignition loss, N assemblage zone)

This zone (52-197 cm) which is the longest of the whole profile (145 cm) has 2 major features and two secondary ones. The ignition loss and N respectively reach their highest percentage value of 81.30 and 3.82 toward the middle of this unit. Most of the other variables each show a distribution curve characteristic, to a certain extent, of the AGC-3 zone.

Zone AGC-2 (pH, P, P/N assemblage zone)

This small unit (25-52 cm) is delimited mainly by a rapid decline in pH and by a considerable increase in P and P/N. All of the other variables have a distribution curve similar to the one described in zone AGC-3.

Zone AGC-1 (K, Na, Ca, Ca/Mg assemblage zone)

This uppermost zone (0-25 cm) is the thinnest in the profile and shows a significant reduction in values of K, Na, Ca, Ca/Mg.

G. Description of the SCDP Diagrams

The same general procedures already described in this chapter are used for the presentation of the SCDP diagrams (Fig. 24, p. 134, 25, p. 138, and 26, p. 141). The code system for the zoning nomenclature is composed of two capital letters followed by a number. The first letter identifies the sites and the second letter P stands for pigment. The term pigment is used in its broader sence to include all sedimentary pigment present in the acetone extracted solution and showing some absorbance at the 350, 410, 448 and 670 millimicron wavelengths. The organic compounds with a maximum absorption at 410 and 670 millimicrons are tentatively identified as being mostly composed of pheophytin a and pheophorbide a (Fig. 12, p. 78).

1. Cataraqui River Marsh

Zone CP-6 (SCDP/g dry weight, SCDP/g ignition loss, absorbance ratios 448/350, 350/670 assemblage zone)

This stratigraphic pigment zone (417-472 cm) from the Cataraqui River Marsh diagram (Fig. 24, p. 134) is characterized by large and rapid fluctuations, generally from lower to higher values, in several variables. The SCDP per gram of dry weight changes from its lowest concentration of 0.01 unit at the 460 centimeter bottom level to a value of 13.45 units at the 417 centimeter level. The SCDP per gram of ignition loss exhibits a parallel fluctuation in the same interval. It passes from its lowest value of 0.61 unit to a high of 95.42 units. The wavelength absorbance ratio 448/350 reaches its maximum in this zone while the ratio 350/670 is at its minimum.

Zone CP-5 (Absorbance ratios 410/350, 448/350, 410/670, 448/670 assemblage zone)

This zone (257-417 cm) covers the greatest stratigraphic interval of the profile. The 8 parameter curves all exhibit important features typical of this unit. However, the SCDP per gram of ignition loss curve decreases substantially from bottom to top. The remaining variables show very few

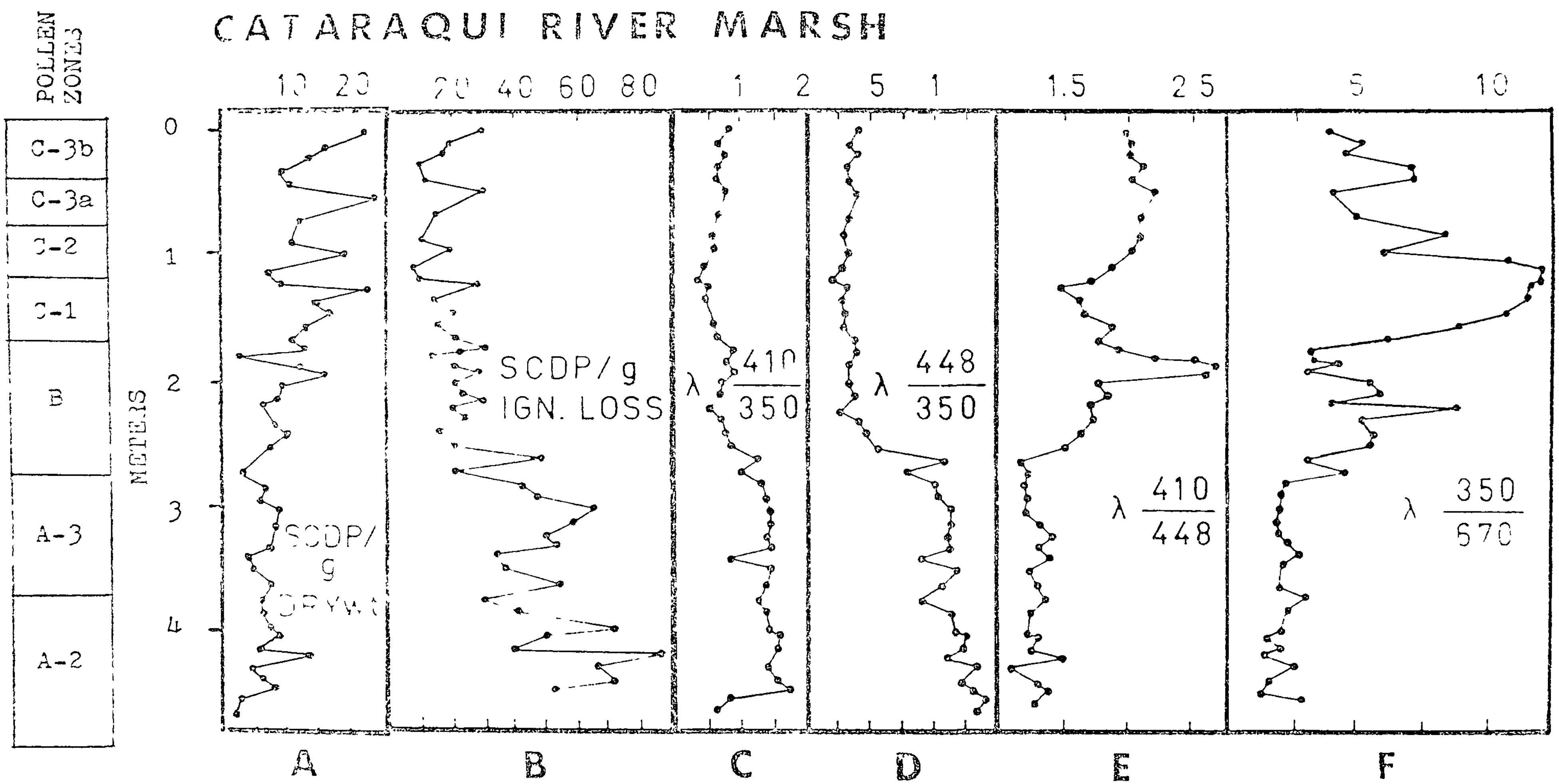


Figure 24. Pigment diagram from Cataraqui River Marsh.

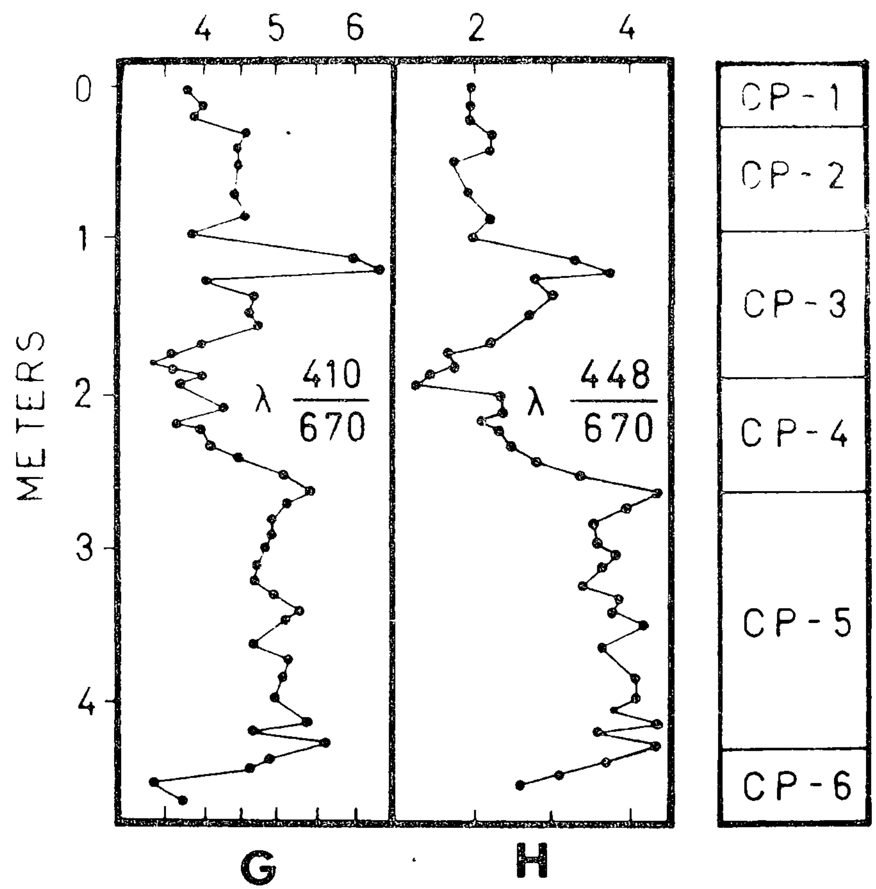


Figure 24. Cont'd

quantitative changes throughout most of the entire unit. Changes appear only at the very top where all the variables lose their quantitative stability.

Zone CP-4 (Absorbance ratios 350/670, 410/448, 410/670, 448/670 assemblage zone)

This zone (192-257 cm) more or less divides the diagram in two distinctive parts. Below and above this transitional zone all the variables are quantitatively inversely proportional. The SCDP per gram of dry weight of sediment along with absorbance ratios 410/448 and 350/670 all have lower values below this zone. The other variables show reciprocal features. The absorbance ratios 410/448 and 350/670 respectively showing a maximum peak at the very top and in the middle of this CP-4 zone also contribute to the delimitation of this unit.

Zone CP-3 (Absorbance ratios 350/670, 410/670, 448/670 assemblage zone)

The wavelength absorbance ratios 350/670, 410/670 and 448/670 all show a similar sustained peak within this pigment zone (95-192 cm). The ratio 410/448 shows an opposite tendency.

Zone CP-2 (SCDP/g ignition loss, absorbance ratio 350/670 assemblage zone)

This stratigraphic interval (32-95 cm) is characterized by low amounts of SCDP per gram of ignitable loss and by a rapid decrease in the wavelength absorbance ratio 350/670.

Zone CP-1 (SCDP/g dry weight, SCDP/g ignition loss assemblage zone)

In this top unit (o-32 cm) the SCDP per gram of dry weight and per gram of ignition loss both increase rapidly while the absorbance ratio 350/670 becomes less important.

2. Grady Lake

Zone GP-8 (SCDP/g dry weight, SCDP/g ignition loss, absorbance ratio 410/350 assemblage zone)

In this bottom interval (1025-1056 cm) of Grady Lake pigment diagram (Fig. 25, p. 138) covering only 31 centimeters, the following variables reach minimum values: SCDP per gram of dry weight of sediment (1.59), SCDP per gram of ignition loss on dry sediment (75.78), and the wavelength absorbance ratio 410/350 (1.06).

Zone GP-7 (SCDP/g dry weight, SCDP/g ignition loss, absorbance ratio 448/670 assemblage zone)

Within this zone (925-1025 cm) the curve of the SCDP per gram of dry weight, that of the SCDP per gram of ignition loss and the curve of the wavelength absorbance ratio 448/670 all show a sustained secondary peak toward the bottom and decrease upward to the 925 centimeter level.

Zone GP-6 (SCDP/g dry weight, SCDP/g ignition loss, absorbance ratios 448/350, 410/448 assemblage zone)

This stratigraphic pigment zone (822-925 cm) is highly distinctive because of large upward increases in the SCDP per gram of dry weight and per gram of ignition loss shifting

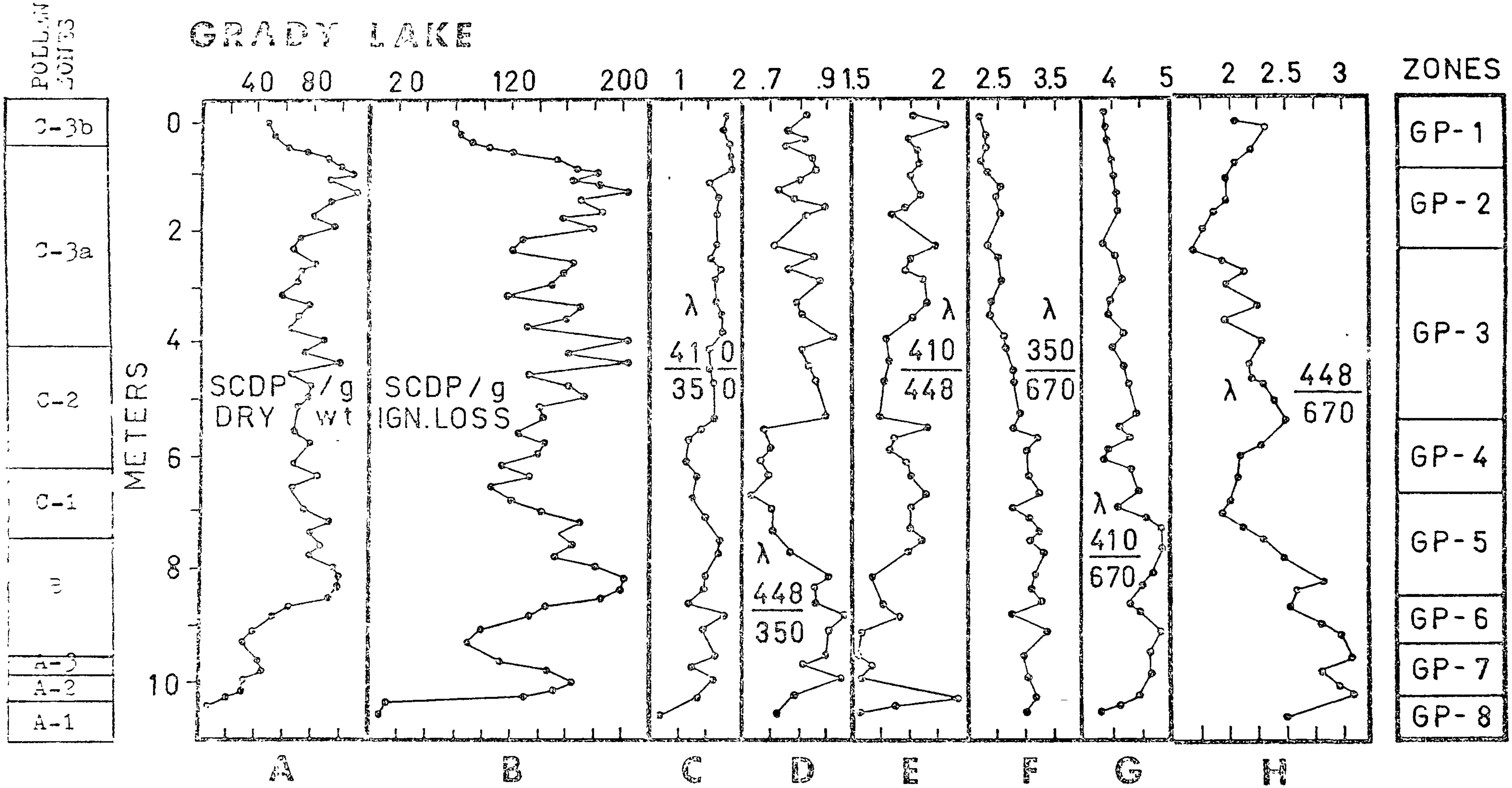


Figure. 25. Pigment diagram from Grady Lake deposit.

respectively from lows of 36.61 and 94.62 to highs of 98.52 and 198.89 units. The sustained high values of the variable 448/350 and the reciprocal trend of the variable 410/448 are other diagnostic features of this GP-6 zone.

Zone GP-5 (SCDP/g dry weight, SCDP/g ignition loss, absorbance ratios 448/350, 448/670 assemblage zone)

The four variables of this assemblage zone (655-822 cm) all decrease steadily up to the upper boundary of this unit. At the same time the variable 410/448 exhibits an opposite fluctuation getting more important from the bottom to the top of this zone.

Zone GP-4 (Absorbance ratios 410/350, 448/350, 410/448, 448/670 assemblage zone)

The upper boundary of this stratigraphic pigment unit (545-655 cm) is delimited by sharp fluctuations in the curve of all of the assemblage zone parameters.

Zone GP-3 (SCDP/g ignition loss, absorbance ratio 448/670 assemblage zone)

This zone (235-545 cm), the most important one relatively to the total length of the core, is delimited at its upper boundary by a secondary minimum in the curve of the SCDP per gram of ignition loss and by an absolute minimum close to 1.65 for the wavelength absorbance ratio 448/670. The other variables all show little significant variability within this large stratigraphic unit.

Zone GP-2 (SCDP/g dry weight , SCDP/g ignition loss, absorbance ratio 448/670 assemblage zone)

In this pigment zone (100-235 cm) the SCDP per gram of dry weight, SCDP per gram of ignition loss and the wavelength absorbance ratio 448/670 gradually increase upward. Moreover the curve of the wavelength absorbance ratio 410/350 exhibits a sharp increase near the 100 centimeter level.

Zone GP-1 (SCDP/g dry weight, SCDP/g ignition loss assemblage zone)

This upper zone, which includes the first meter of the core, is distinct from all others because of the drastic decrease in the SCDP per gram of dry weight and per gram of ignition loss. The wavelength absorbance ratio 350/670 is at its lowest value within this GP-1 zone.

3. Atkins Lake

Zone AP-7 (SCDP/g dry weight, absorbance ratios 410/350, 448/350, 448/670 assemblage zone)

Within this basal pigment zone (375-400 cm) of Atkins Lake (Fig. 26, p. 141), the SCDP per gram of dry weight of sediment is at its minimum concentration of 0.46 unit. The wavelength absorbance ratios 410/350 (0.88), 448/350 (0.65), and 448/670 (2.48) also are at their minimum. The curve of the variable 410/448 reaches its maximum value of 1.94 at the 395 centimeter level.

Zone AP-6 (SCDP/g dry weight, absorbance ratios 410/670, 448/670 assemblage zone)

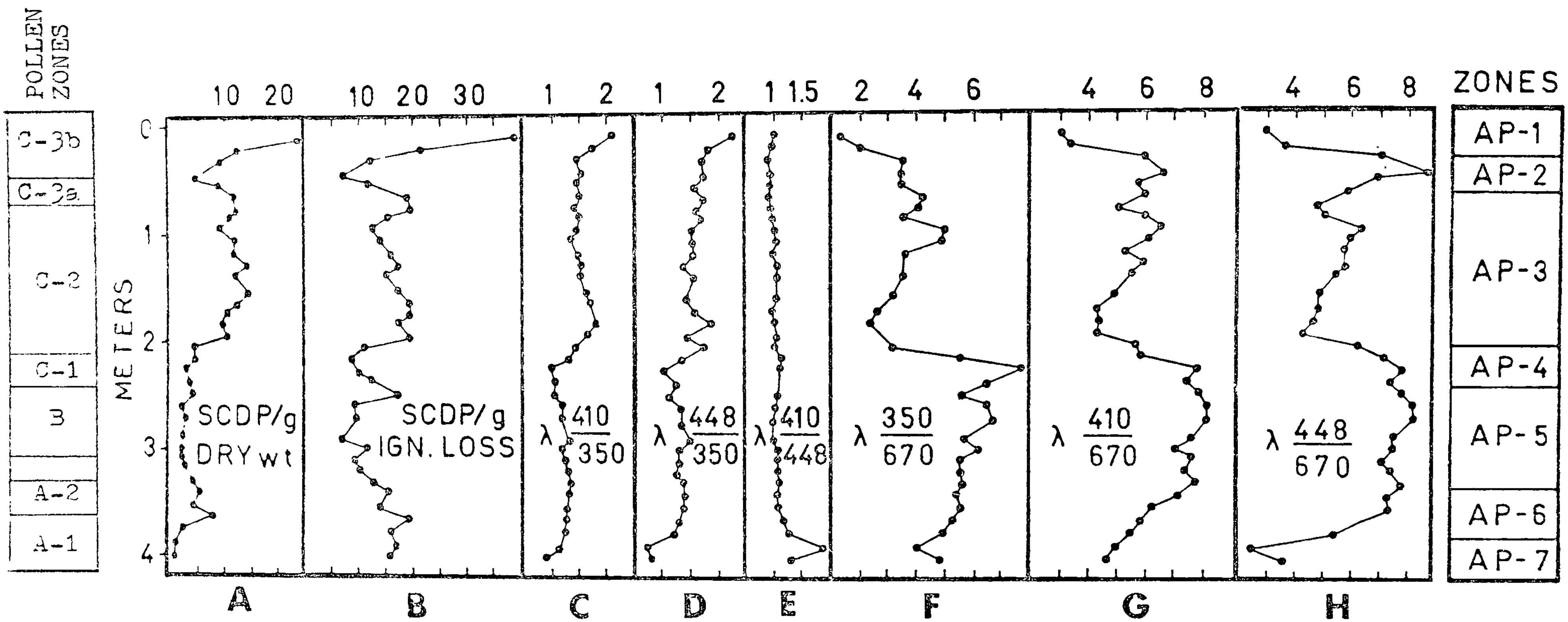


Figure 26. Pigment diagram from Atkins Lake deposit.

In this unit (330-375 cm) the SCDP per gram of dry weight of sediment show a secondary peak of 8.61 units toward the middle. The wavelength absorbance ratios 410/670 and 448/670 exhibit their largest positive fluctuation throughout the entire diagram from the bottom to the very top of this pigment AP-6 zone. On the other hand the SCDP per gram of **ignitable** matter and to a lesser extent the wavelength absorbance ratio 410/448 become less important.

Zone AP-5 (Absorbance ratios 410/670, 448/670, SCDP/g ignition loss assemblage zone)

The most characteristic feature of this stratigraphic zone (245-380 cm) is found in the curve of the wavelength absorbance ratios 410/670 and 448/670 and, to some extent, in that of 350/670, which all reach a maximum sustained peak. However the SCDP per gram of ignition loss and per gram of dry weight have several low values in this interval.

Zone AP-4 (Absorbance ratios 350/670, 410/670, 448/670 assemblage zone)

This AP-4 zone (205-245 cm) is more or less the mirror image of zone AP-6, the latter being a sort of positive transitional interval between zone AP-7 and zone AP-5. It could be opposed to zone AP-4 which is some kind of a negative transition between zones AP-5 and AP-3.

The sharp drop of variables 350/670, 410/670 and 448/670 is the main characteristic feature of this AP-4 interval. Moreover the SCDP per gram of dry weight, SCDP per gram of ignition loss and the wavelength absorbance ratios 410/350 and 448/350 respectively show transitional values below and above the lower and upper boundary of this stratigraphic interval.

Zone AP-3 (SCDP/g dry weight assemblage zone)

This interval (80-205 cm) covering 125 centimeters of the core is delimited by the SCDP per gram of dry weight which has several values. The wavelength absorbance ratios 350/670, 410/670 and 448/670 exhibit a kind of sinusoidal fluctuation.

Zone AP-2 (Absorbance ratio 448/670 assemblage zone)

This short stratigraphic unit (50-80 cm) is distinct from all the others because of its highest peak of 6.45 at the 70 centimeter level of the ratio 448/670. In this unit the SCDP per gram of dry weight and per gram of ignition loss both diminish sharply from the bottom to the top.

Zone A-1 (SCDP/g dry weight, SCDP/g ignition loss, absorbance ratios 350/670, 410/670, 448/670 assemblage zone)

This top stratigraphic pigment unit (0-50 cm) is the most distinctive of the Atkins Lake pigment diagram. The SCDP per gram of dry weight of sediment and the SCDP per gram of ignitable matter of the dry sediment show a more or less expotential increase and both respectively reach their highest value of 27.88 and 42.45 units at the very top. Similar trends are observed in the curve of the wavelength absorbance ratios 410/350 and 448/350. As opposed to these positive features the variables 350/670, 410/670 and 448/670 reach their lowest value throughout the whole diagram at the very top.

V. FACTOR ANALYSIS OF RESULTS

In ecological and geological sciences, and as is the case in the present study, data appear in the form of measurements of several parameters. However, since a large matrix of data is difficult to handle and analyze by means of conventional methods, a digital computer was used to synthesize the data into its most important components by factor analysis.

An R-mode factor analysis groups together variables having a similar behavior, and delimits new independent underlying factors which might be responsible for the dispersion of the variables studied. It also helps identify the principal factors acting on the body of data as well as the magnitude of their influence on each original parameter studied.

Cattell (1952) discusses the place of factor analysis in the scientific method and, more specifically, its advantages in comparison to more elementary statistical analysis. The theories and mathematics involved in factor analysis are treated by Harman (1960), Hadley (1964) and Horst (1965).

Dixon (1969), in the Biomedical Computer Programs, explains the main steps and mathematics involved in a factor analysis computer program. A detailed computer program of an R- and Q-mode analysis with output examples is presented by

Ondrick and Srivastava (1970).

Recently, several authors have applied this statistical method in the fields of geology and biology (Imbrie, 1963; Imbrie and van Andel, 1964; Parks, 1966; Dagnelie, 1960; Yarranton, 1967).

The computer program used for this particular statistical analysis comes from the Scientific Subroutine Package for the IBM System/360. This factor analysis program is performed by calling the following subroutines in sequence:

a) CORRE - to compute means, standard deviations, sum of cross-products of deviations and correlation coefficients.

b) EIGEN - to compute eigenvalues and eigenvectors of the symetric correlation matrix.

c) TRACE - to select the eigenvalues that are greater or equal to the specified controlled value.

d) LOAD - to compute a factor matrix (loading) from eigenvalues and associated eigenvectors.

e) VARMX - to perform orthogonal rotations of a factor matrix.

In the present study, only the R-matrix computed on the covariance between variables gave satisfactory results. Several Q-mode analysis of the data, based on the covariance between the sites or levels, were performed. The grouping, at least that of the stratigraphic analysis from the three sites of the Kingston Region, did not correlate with the various zone types already described.

For the sake of simplicity, only the three most important factors are retained in the following discussion. The variability (standard partial regression coefficient) of each parameter is represented graphically for Meach Lake, for lakes from the Gatineau Area and for the three sites from the Kingston Region studied stratigraphically (Fig. 27, p. 150, 31, p. 156, 35, p. 164, 37, p. 175, 39, p. 184). The interrelationship of these values for factors A, B and C is illustrated in a tridimentional scattergram (Fig. 28, p. 152, 32, p. 159, 36,p. 170, 38, p. 180, 40, p. 189). The reference frames (axes A, B and C) are orthogonal and of unit length. The axis A represents the factor which explains the greatest portion of the variable. Even though it is customary, in factor analysis, to represent a vector by a dot placed at its tip, the coordinates of axis A are represented here by means of a vertical line up or down (depending on its sign) from the tip of the vector to the horizontal plane passing by axes B and C. The negative coordinates of axis A are represented by a dotted line so as to simplify the tridimensional scattergram. The tridimensional scattergram is then an ordination of the standard partial regression coefficients of each parameter on the three most important factors and their spatial relationship is proportional to their interrelationship.

The number at the tip of the coordinates of axis A identifies the variable. The variable studied in more than one site is always represented by the same number. The variable numbers of the 4 main categories of parameters fed to the computer are: 1-38 (percentage pollen types), 48-69 (general chemistry), 75-82 (SCDP), 85-96 (trace elements).

The same equivalent procedures were used for the ordination of the factor scores for Meach Lake and for lakes from the Gatineau Area. The only difference lies in the values of each division of the axis which is equal to 0.1 in the factor loading of the variables, while the division in the tridimensional scattergrams of the factor scores is equal to 1 unit. To compare the maximum number of variables in the fossil samples a number of observations, equal to the number of pollen spectra investigated, was chosen for the statistical analysis of trace elements, general chemistry and SCDP. Since only 25 spectra from the stratigraphic molluscan study of Atkins Lake were available, the writer did not attempt to correlate the molluscan fauna with the other types of variables investigated. Whenever the number of observations for each parameter exceeded that of the pollen spectra, only the stratigraphic equivalent observations of those parameters were retained for the computer program. The number of observations for each fossil parameter studied for the Cataraqui River Marsh, Grady Lake and Atkins Lake are respectively 34, 55 and 40. In the absence of certain data, as was the case for stations 2 and 11 of Meach Lake, the average value between stations 1 and 3 was fed to the computer for station 2, while that of station number 10 was substituted for station 11.

A. Bottom Surface Sediment Samples of Lakes from the Gatineau Area.

1. Meach Lake

The loading of parameters on axes A, B and C are presented schematically in figure 27 (p. 150) and the interrelationship of these parameters is illustrated in the tridimensional scattergram of figure 28 (p.152). Axis A, which explains 51.7 per cent of the total variance of all the parameters, is generally characterized by large positive values for most of the variables. Only the variables P/N (59), Ca+Mg/K+Na (67) and K/Na (68) are associated negatively. The positive end of factor A from Meach Lake can be interpreted in terms of autochthonous environmental effects, while the negative loading on the negative end reflects allochthonous environmental conditions.

Axis B, explaining 17.1 per cent of the variance, is characterized by high negative loading for ignition loss (53), absorbance ratio 350/670 (80), and by high positive loading for absorbance ratios 410/350 (77), and 448/350 (78) and for the SCDP per gram of ignition loss (76). Parameters with a high negative loading exhibit high values at station number 2 and low values at station 11. On the other hand, the parameters with high positive loading tend to show a reciprocal abundance. The fact that, at station number 2, a very high ignition loss has a low quantity of SCDP per gram of ignition loss is probably due to the presence of non-chlorophyllous organic matter such as twigs, branches and roots. Axis B can be interpreted as an environmental gradient associated at its positive end with carbon bound in green pigmented cells,

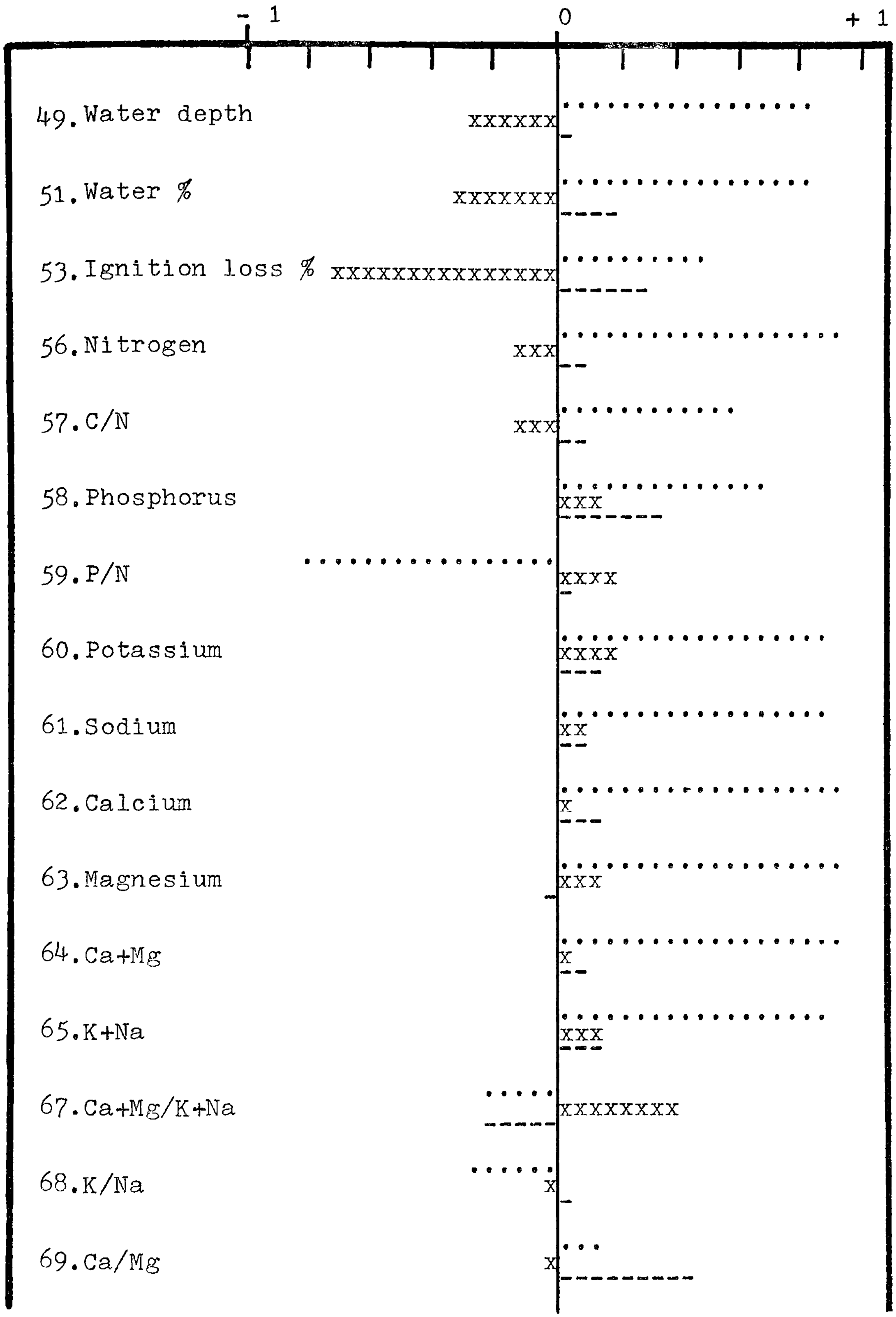


Figure 27. Loading for rotated factors A(...), B(xxx) and C(---) for a R-mode factor analysis of variables from Meach Lake.

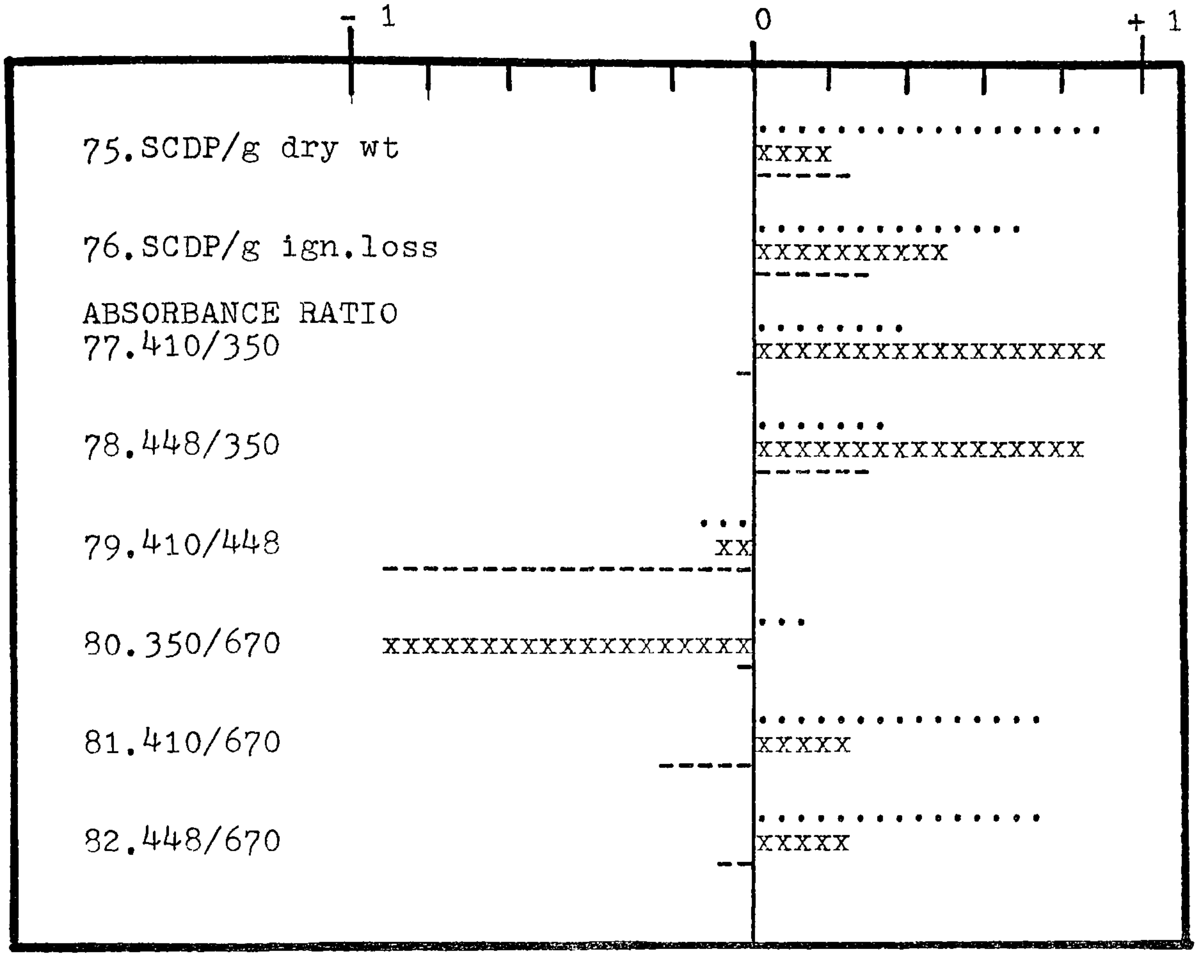


Figure 27. Cont'd

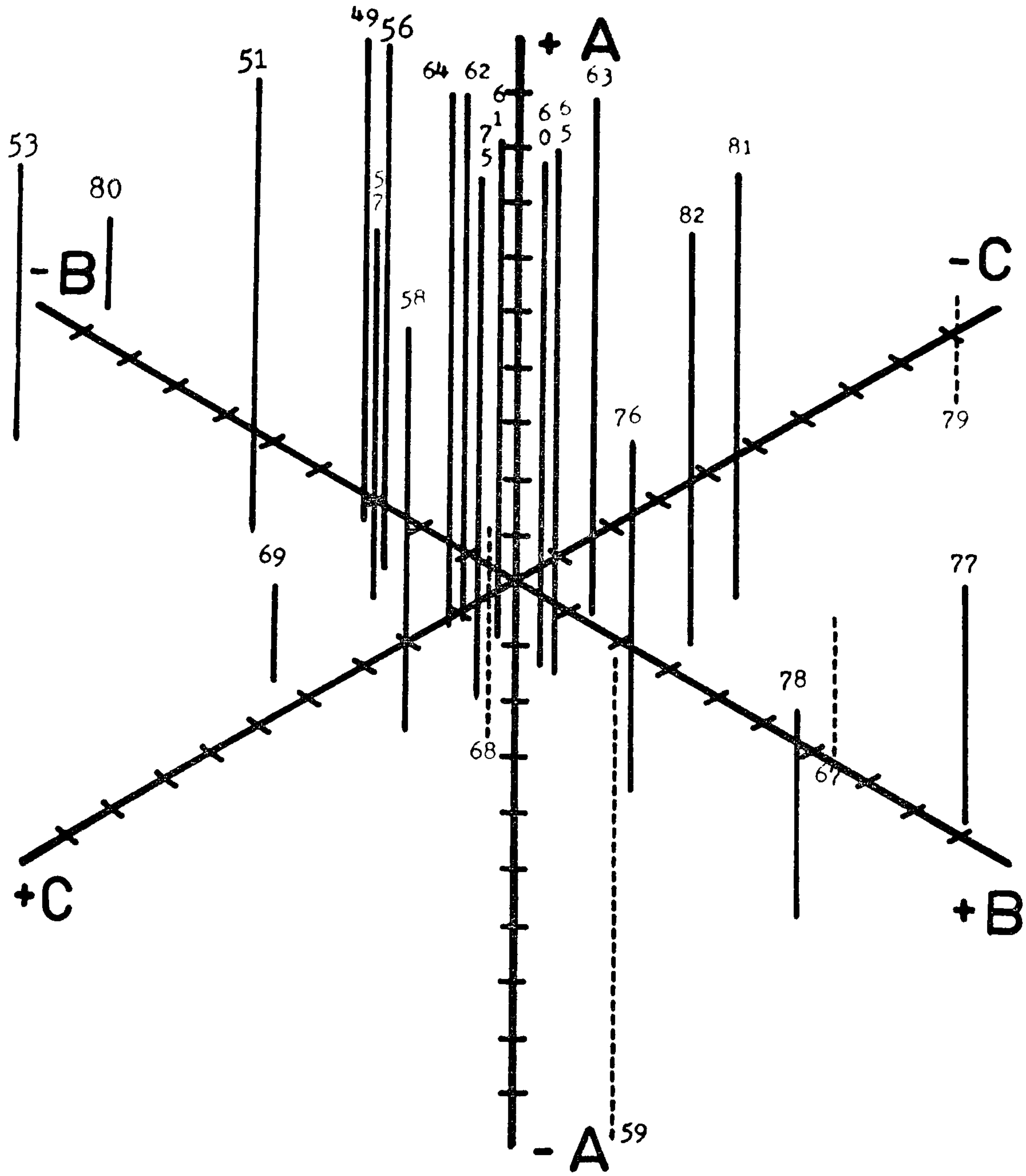


Figure 28. Tridimensional scattergram for the rotated factors A, B and C of a R-mode factor analysis for the bottom surface sediment samples from Meach Lake. The name of each variable is listed in figure 27.

while at its negative end it is associated with non-chlorophyllous cells.

Axis C, which explains only 7.8 per cent of the total variance, has a strong negative loading for the absorbance ratio 410/448 (79). Its quantitative distribution along the Meach Lake traverse correlates negatively with the distribution of ratio Ca/Mg (69). The dispersion of the variables along axis C is not strong enough to detect its underlying factor.

If the factor scores for each site (Fig.29, p. 154) are plotted in a tridimensional scattergram (Fig.30, p. 155), stations with positive values along axis A are found toward the center of the lake while stations with negative values such as 1, 10 and 11 are located near the lakeshores. Station number 2 is highly distinctive from all the others and is the only one to show high negative score along axis B.

2. Gatineau Area Lakes

The 3 most important factors computed from the values of 26 parameters studied in the Gatineau Area lakes explain respectively 56.6, 13.8 and 12.5 per cent of the total variance. The loading of these variables is shown graphically in figures 31 (p. 156) and 32 (p. 159) represents a tridimensional scattergram in which the loading of each variable on each factor illustrates the interrelations of the variables studied.

Axis A is characterized by very high negative loading for most of the variables. Only the dry matter (52),

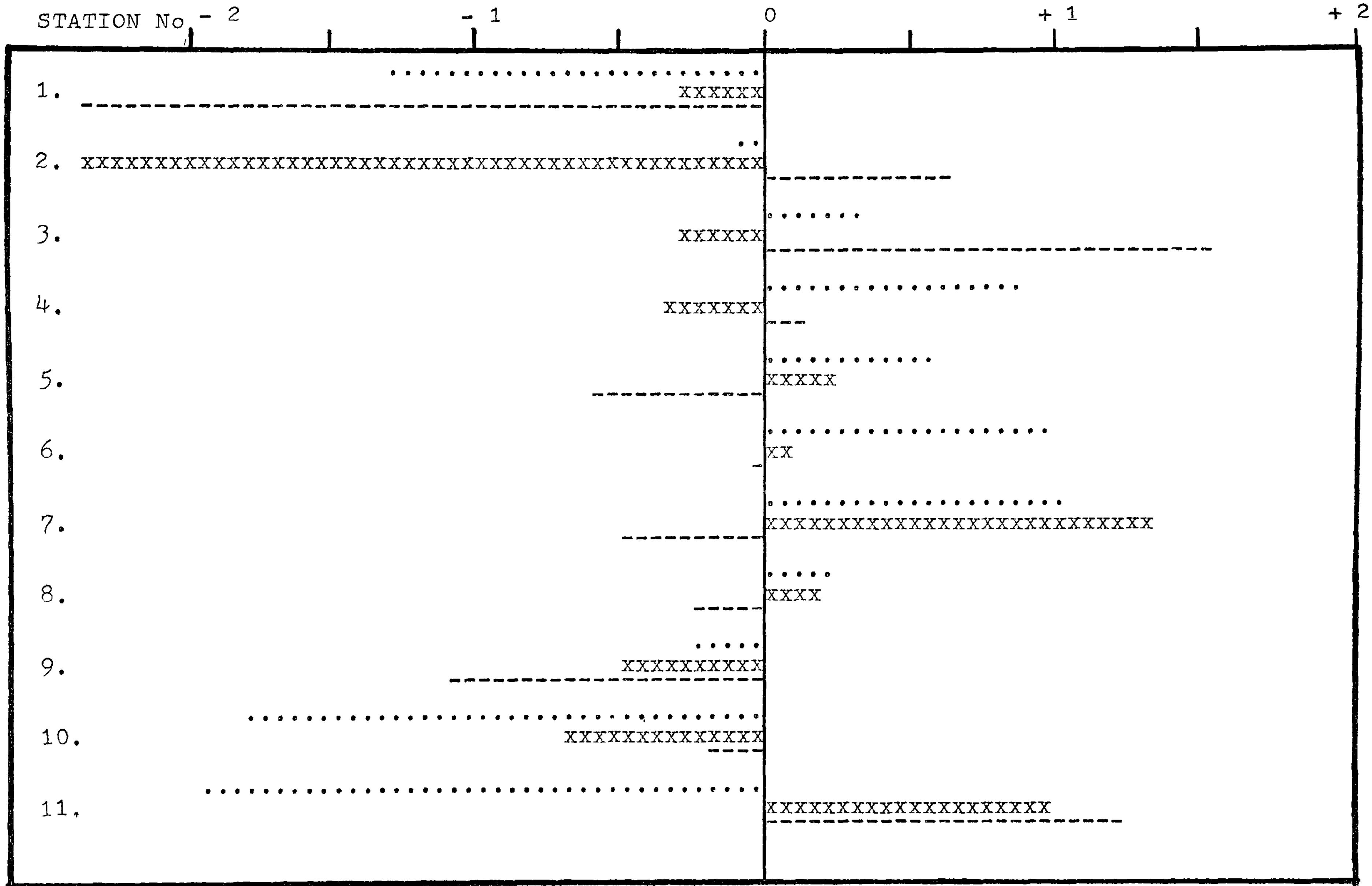


Figure 29. Factor scores for the 11 bottom surface sediment samples from Meach Lake.

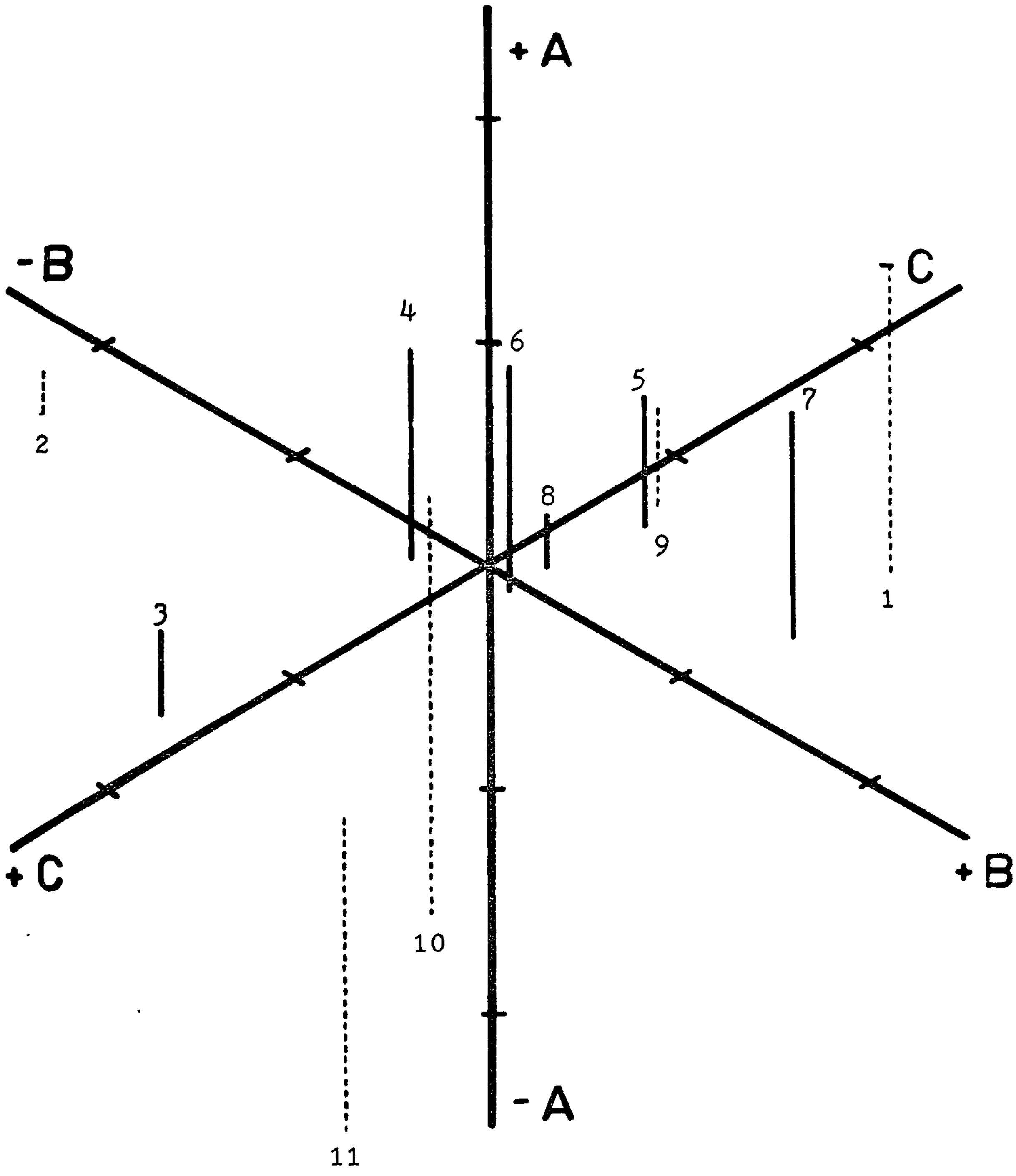
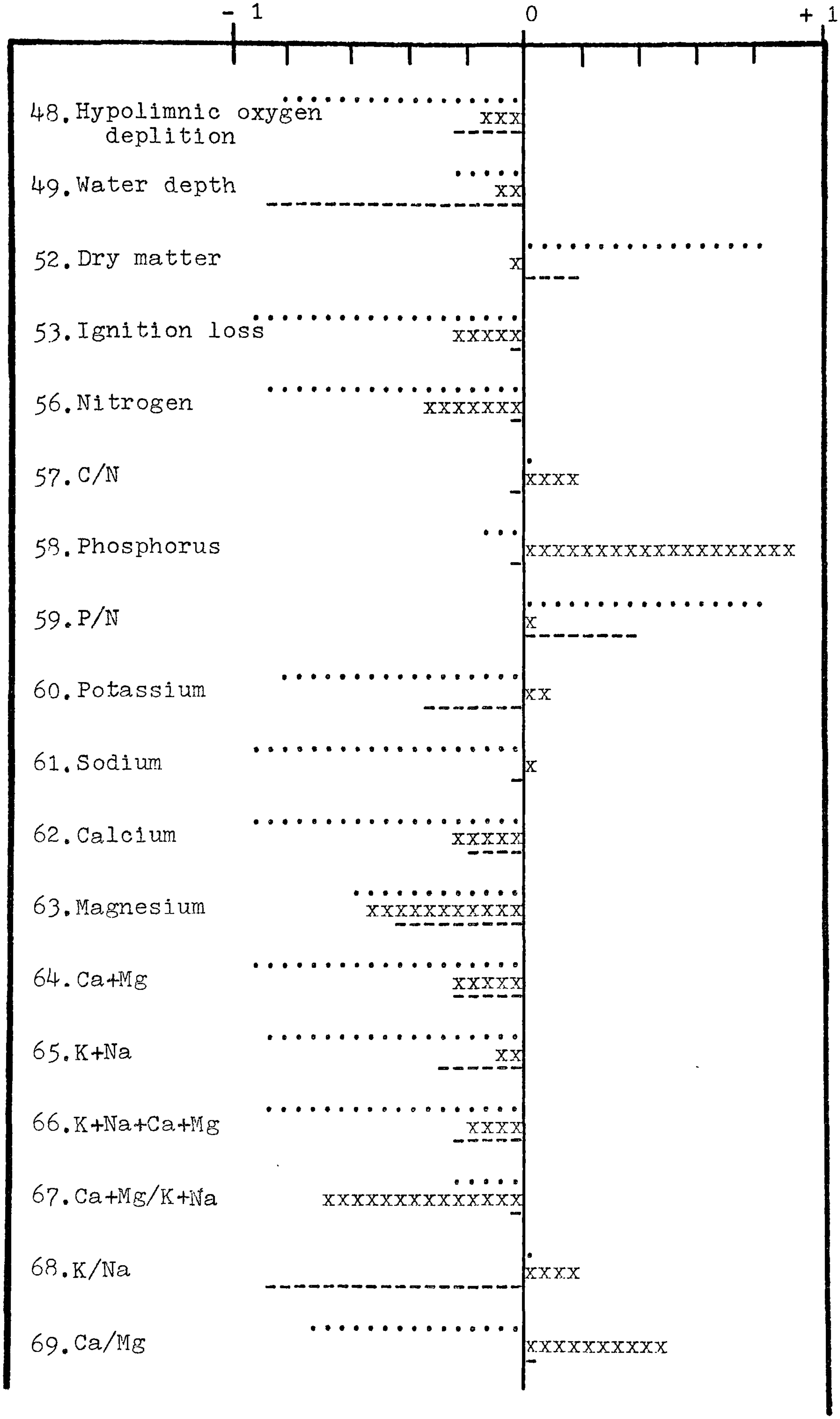


Figure 30. Tridimensional scattergram of the factor scores for the rotated factors A, B and C of a R-mode factor analysis of 24 variables for the 11 stations of Meach Lake.

Figure 31. Loading for the rotated factors A(...), B(xxx) and C(---) for a R-mode factor analysis of the 26 variables studied for each bottom surface sediment sample from the center of the 9 lakes from the Gatineau Area.


- 1
0
+ 1
48. Hypolimnic oxygen deplition
49. Water depth
52. Dry matter
53. Ignition loss
56. Nitrogen
57. C/N
58. Phosphorus
59. P/N
60. Potassium
61. Sodium
62. Calcium
63. Magnesium
64. Ca+Mg
65. K+Na
66. K+Na+Ca+Mg
67. Ca+Mg/K+Na
68. K/Na
69. Ca/Mg

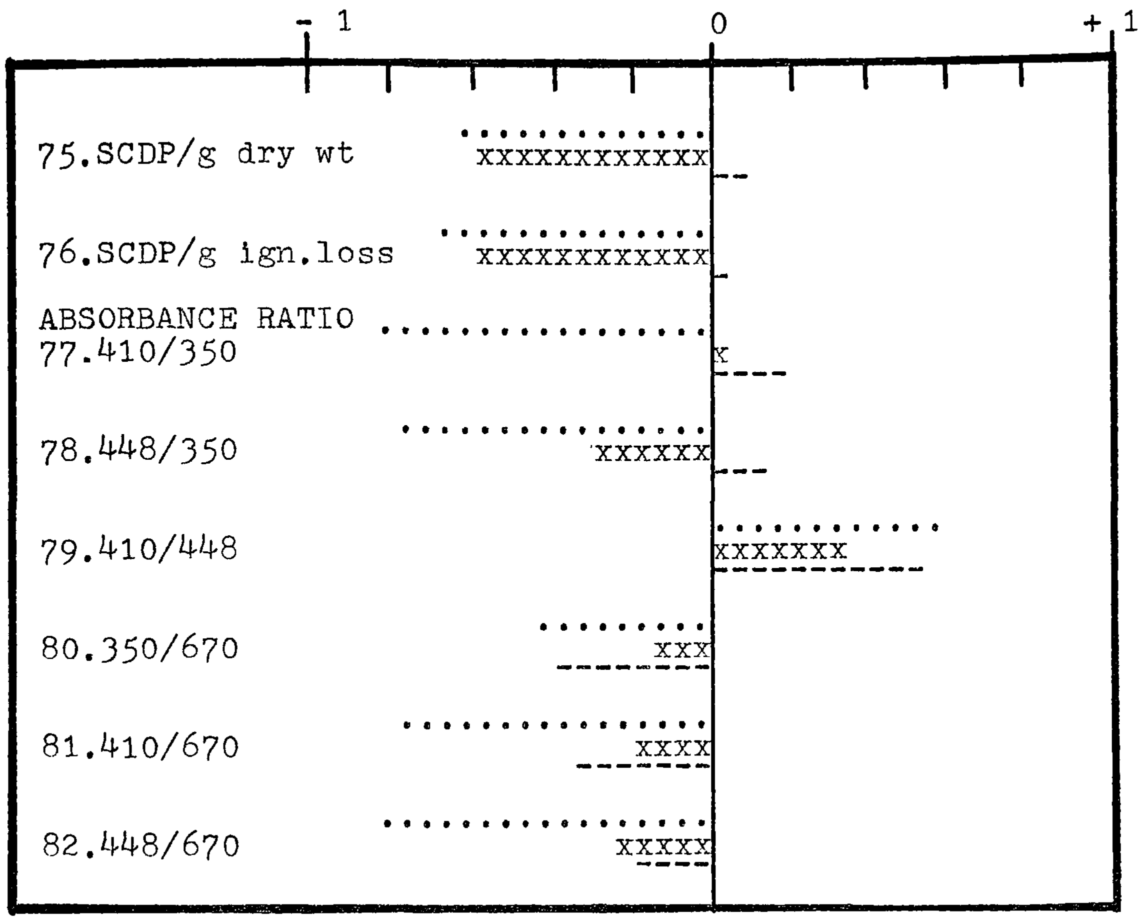


Figure 31. Cont'd

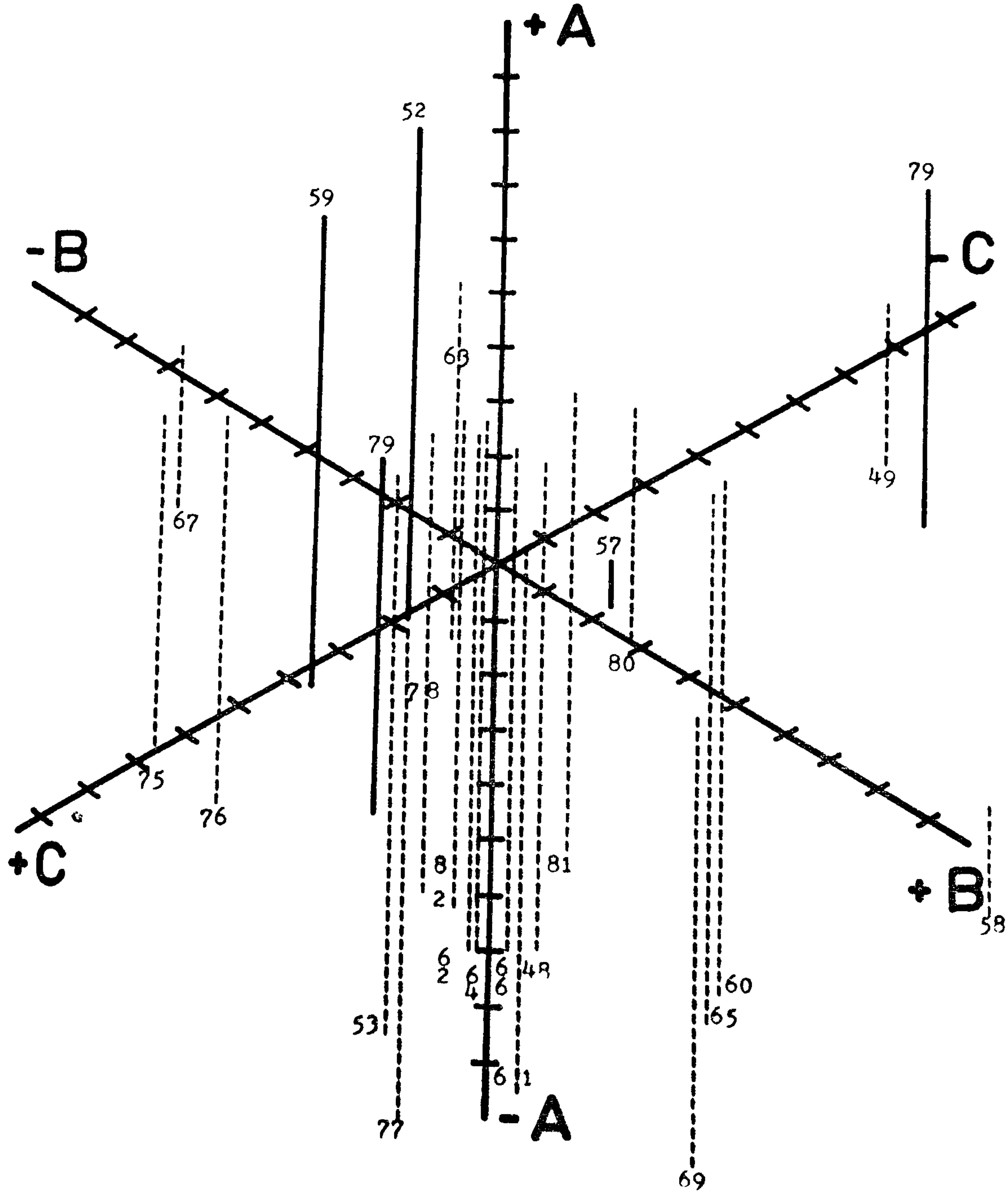


Figure 32. Tridimensional scattergram for the rotated factors A, B and C of a R-mode factor analysis for a bottom surface sediment sample of each lake studied from the Gatineau Area. The name of each variable is listed in figure 31.

ratio P/N (59) and the absorbance ratio 410/448 (79) has a high positive loading on this axis. According to table 14 (p.343) only these 3 variables show a decreasing trend from Lake Simon to Lake Vert. Most of the other variables exhibit increases in values from top to bottom of the table, that is from oligotrophic to eutrophic lakes. Axis A can probably be interpreted as an environmental gradient associated with the lake productivity. Variables associated with the positive end of this axis are characteristic of oligotrophic lakes while those associated with the negative end are more likely to be associated with eutrophic conditions.

Phosphorus (58) and the ratio Ca/Mg (69) have the highest positive loading for axis B. At the other end of axis B, the ratio Ca+Mg/K+Na (67), SCDP per gram of dry weight (75) and SCDP per gram of ignition loss (76) exhibit strong negative loading. The two variables P and Ca/Mg have a parallel quantitative distribution and both reach their higest value at Baie de l'Ours Lake. The variables with a high negative loading tend to have higher values at the top and bottom of the list and lower ones around the center (Table 14, p.343). A reverse quantitative distribution is found for P and for ratio Ca/Mg which have high positive loading values. It is rather difficult to precisely identify the factor controlling these distributions. The factor loading distribution along axis B might suggest that local physical factors such as geomorphology, geology and soil of each lake basin may very well be responsible for these distributions.

Axis C is characterized at its negative end by a high loading for water depth (49), and K/Na (68). These variables tend to have higher quantitative values for lakes McGregor, Belisles and Baie de l'Ours. The positive end of axis C is characterized by moderate loading for ratio P/N (59) and absorbance ratio 410/448 (79). These latter variables tend to have higher quantitative values for lakes Simon, Cayamant and Blue Sea.

In figure 33 (p. 162) the scores of the 3 factors retained are listed. These scores are plotted in a tridimensional scattergram (Fig. 34, p. 163) and their spatial distribution is an index of lake interrelationship. Lakes Simon, Cayamant and Blue Sea, all oligotrophic, show high positive factor scores. At the negative end of axis A lakes Vert, Perdrix and Baie de l'Ours, all representing the eutrophic group, exhibit high scores. An intermediate grouping more or less representing the mesotrophic lakes McGregor, Belisles and Meach shows moderate to low scores along the same axis. These factor scores support fairly accurately the classification of the 9 lakes already established on the bases of several parameters and listed in order in table 14 (p. 343).

B. <u>Fossil Samples of Sites from the Kingston Region</u>

1. Cataraqui River Marsh

Figure 35 (p. 164) shows the loading of factors A, B and C which explain respectively 33.7, 11.8 and 10.8 per cent of the total variance. To avoid the overcrowding of the tridimensional scattergram of the loading of the 66 variables

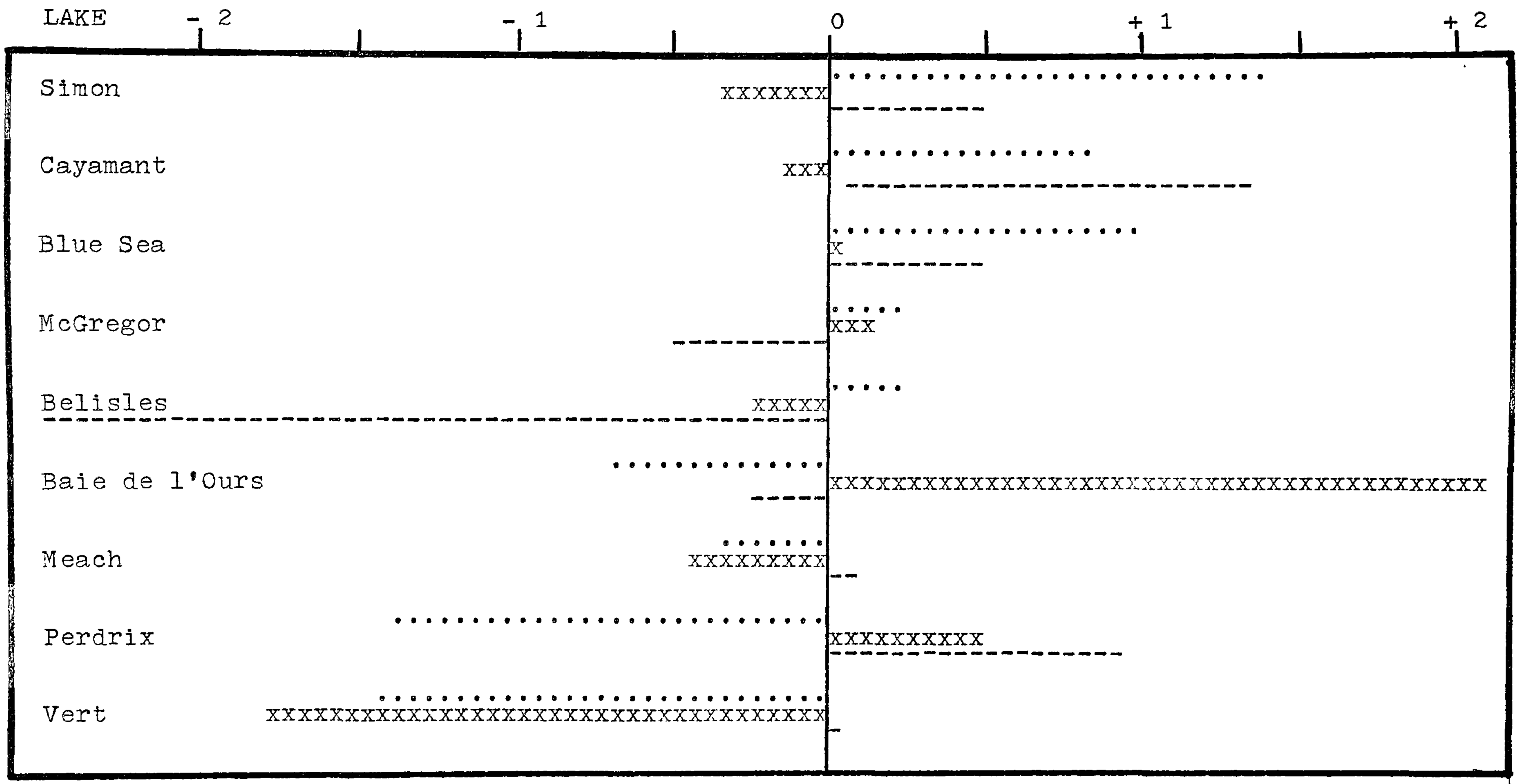


Figure 33. Factor scores of a R-mode factor analysis for the 26 variables studied from each bottom surface sediment sample of the 9 lakes from the Gatineau Area. Factors A(...) B(xxx) and C(---).

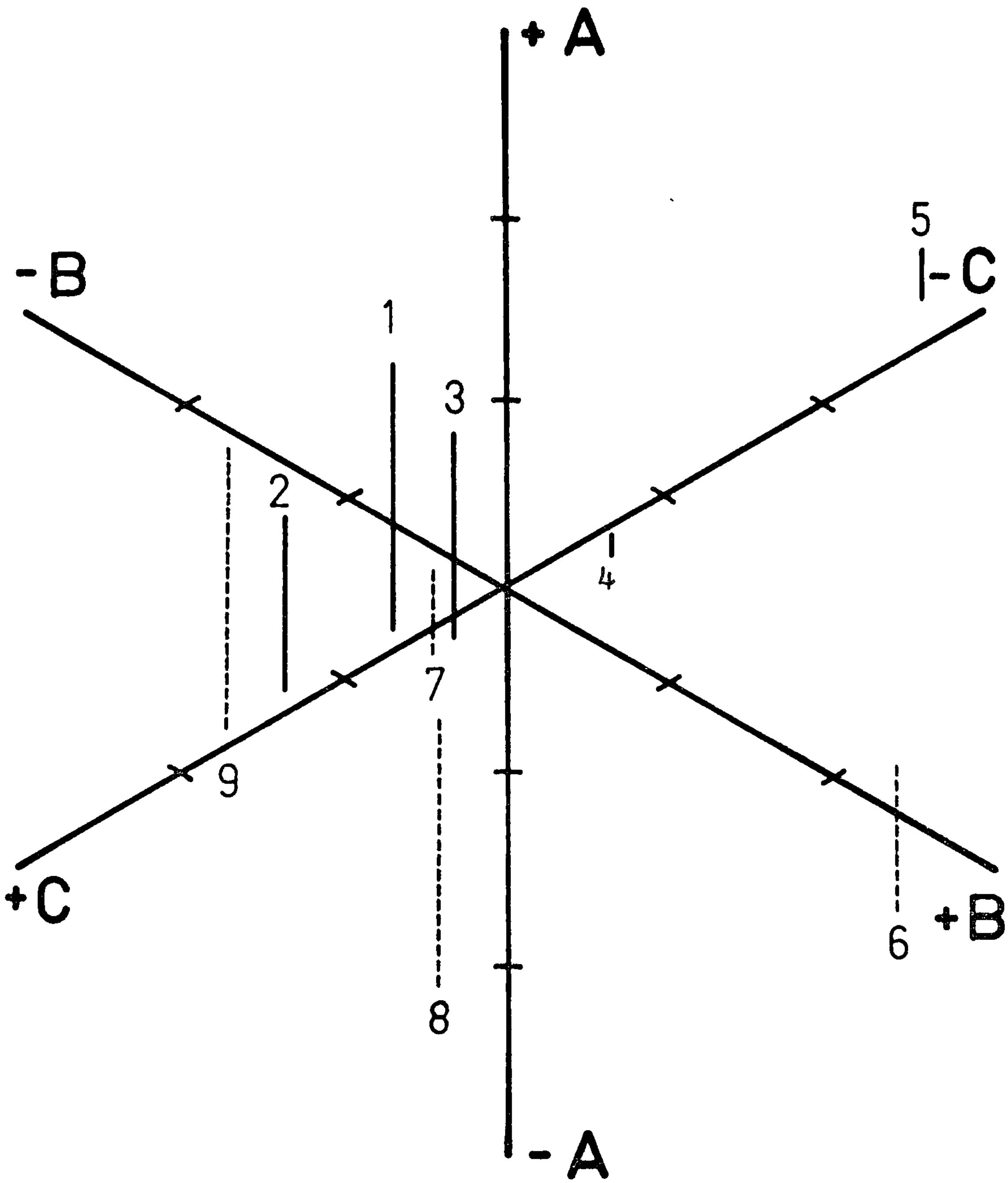
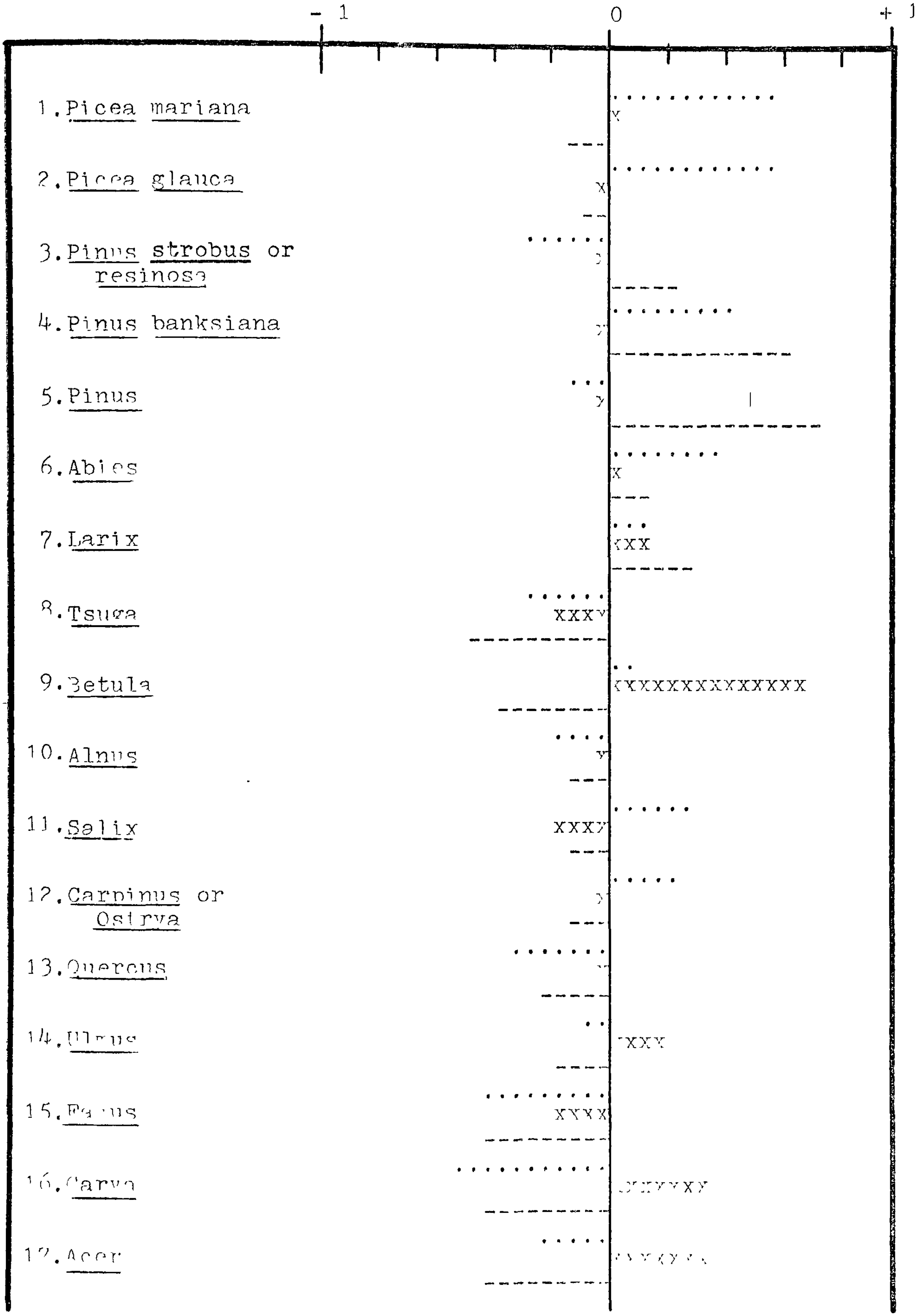


Figure 34. Tridimensional scattergram of the factor scores for the rotated factors A, B and C of a R-mode factor analysis for the 9 lakes from the Gatineau Area. (1) Simon, (2) Cayamant, (3) Blue Sea, (4) McGregor, (5) Belisles, (6) Baie de l'Ours, (7) Meach, (8) Perdrix, (9) Vert.

Figure 35. Loading for rotated factors A(...), B(xxx) and C(---) for a R-mode factor analysis of the 66 variables studied in the Cataraqui River Marsh deposit.


- 1
0
+ 1
1. Picea mariana
2. Picea glauca
3. Pinus strobus or resinosa
4. Pinus banksiana
5. Pinus
6. Abies
7. Larix
8. Tsuga
9. Betula
10. Alnus
11. Salix
12. Carpinus or Ostrya
13. Quercus
14. Ulmus
15. Fagus
16. Carya
17. Acer

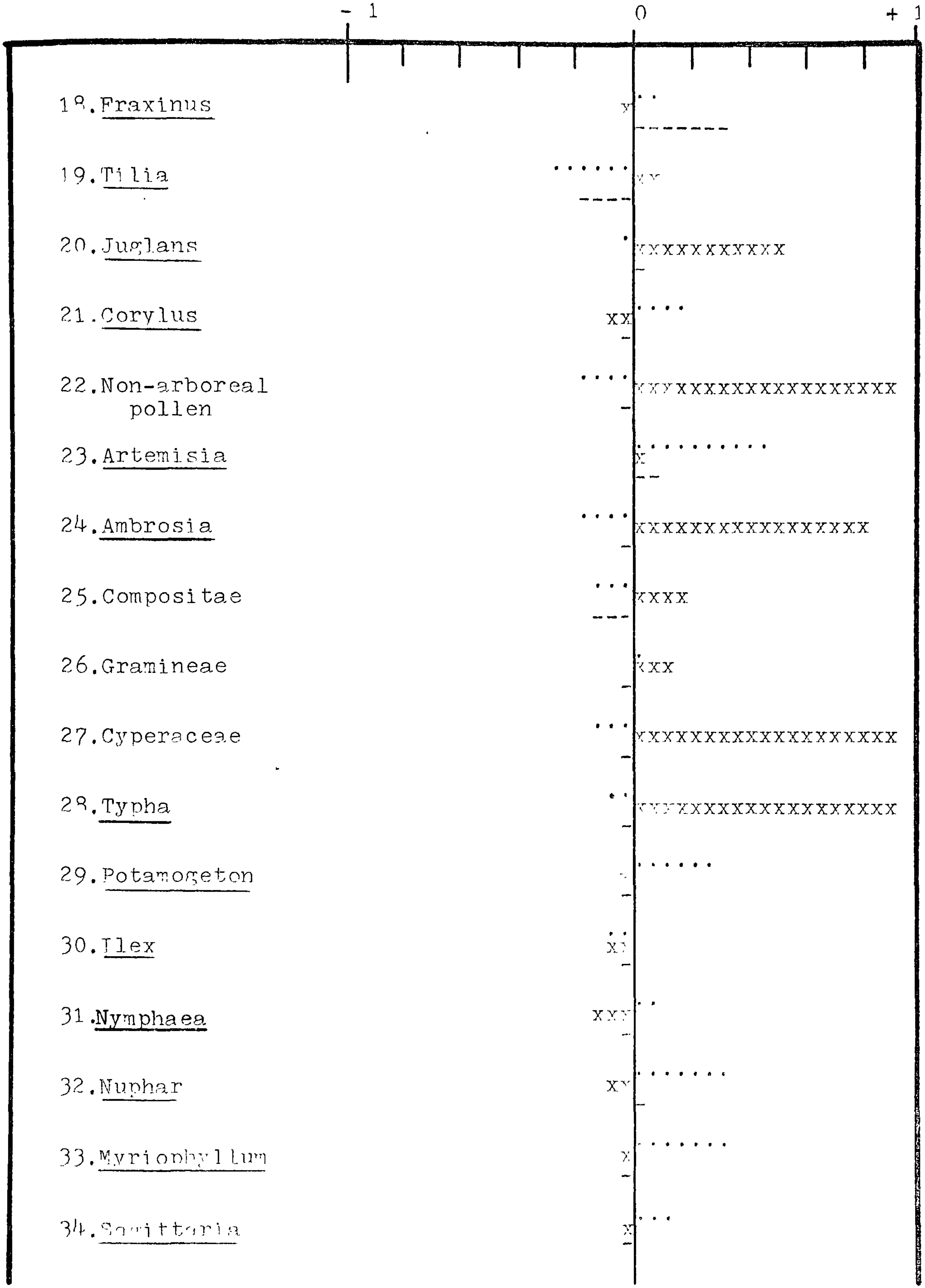


Figure 35. Cont'd

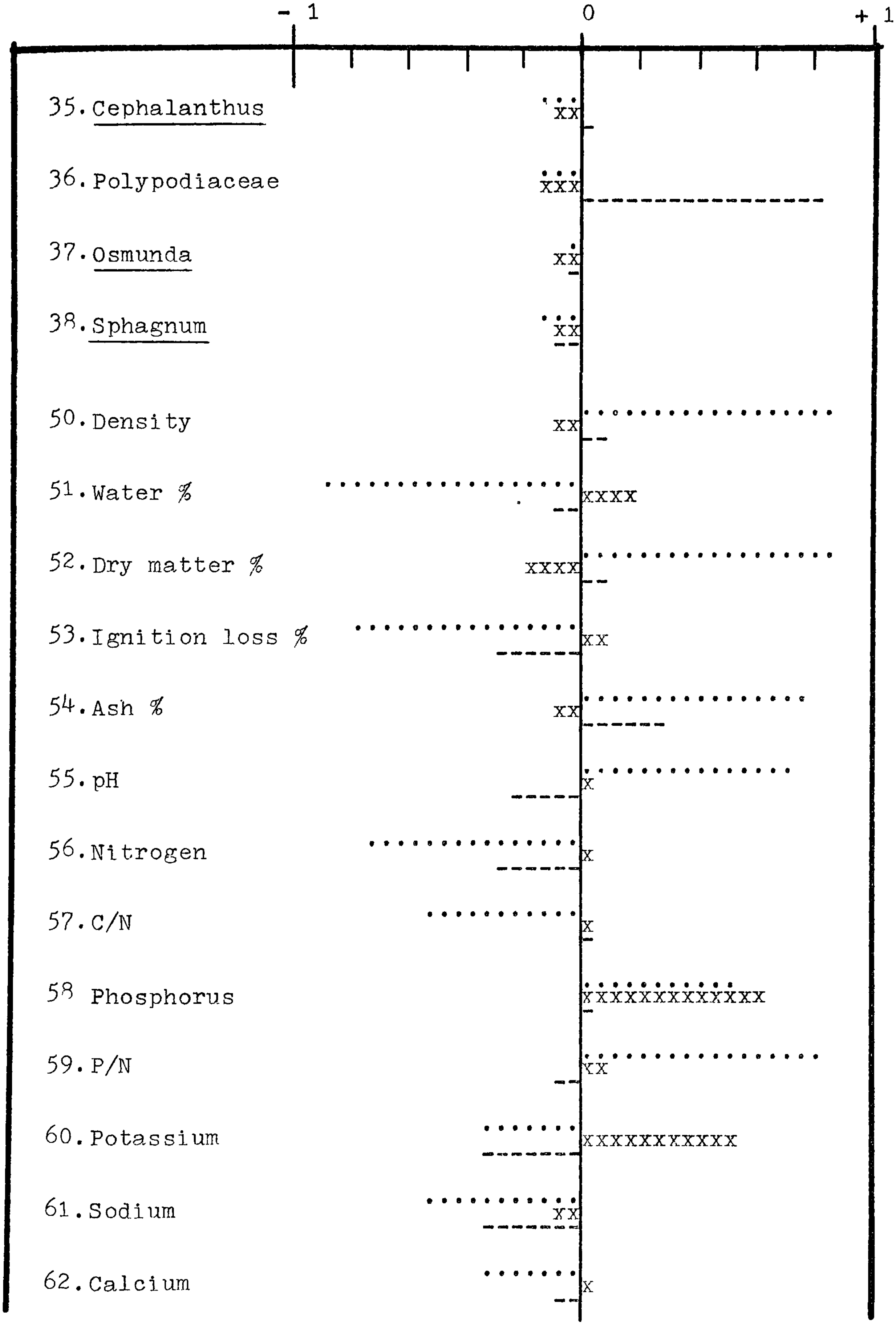


Figure 35. Cont'd

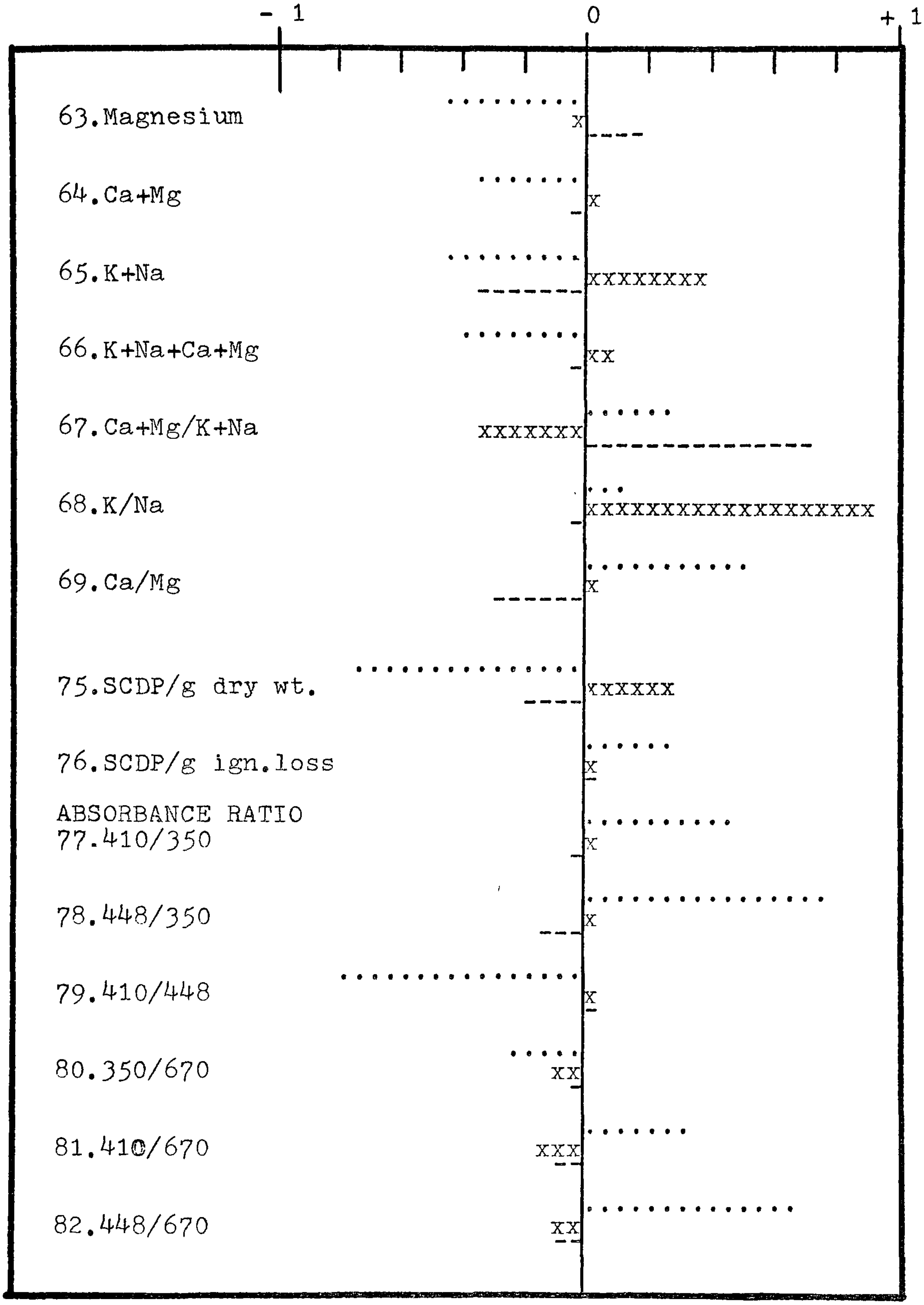


Figure 35. Cont'd

studied in the Cataraqui River Marsh, 3 groups of these variables (1: arboreal pollen and the sum of NAP, no. 1-22; 2: individual NAP, no. 23-38; 3: physico-chemical, no. 50-69 and pigments, no. 75-82) were established and their loading plot on separate pages. The tridimensional scattergram of the arboreal pollen types, non-arboreal pollen types and the general chemistry along with the SCDP variables are shown in figure 36. The first factor loading plotted along axis A in the tridimensional scattergram is characterized by high positive values for the following variables: Picea mariana (1), Picea glauca (2), Pinus banksiana (4), Abies (6), density (50), dry matter (52), ash (54), pH (55), P (58), P/N (59), Ca/Mg (69) and the absorbance ratios 410/350 (77), 448/350 (78) and 448/670 (82). The variables which have a high to medium nagative loading along this axis are: Pinus strobus or resinosa (3), Tsuga (8), Quercus (13), Fagus (15), Carya (16), Tilia (19), water (51), ignition loss (53), N (56), C/N (57), Na (61), Mg (63), Ca+Mg (64), K+Na (65), K+Na+Ca+Mg (66), SCDP per gram of dry weight (75) and absorbance ratio 410/448 (79). It is interesting to see that the pollen types of species associated with the Boreal Forest and the parameters reflecting the inorganic aspect of the sediments are grouped at the positive end of axis A. On the other hand, the pollen types from the Mixed-deciduous Forest species and the parameters reflecting the organic aspect of the sediments are found at the negative end. This factor might be interpreted as an environmental climatic gradient and reflecting a gradual climatic change from colder to warmer downward along the axis.

The following variables are grouped near the positive

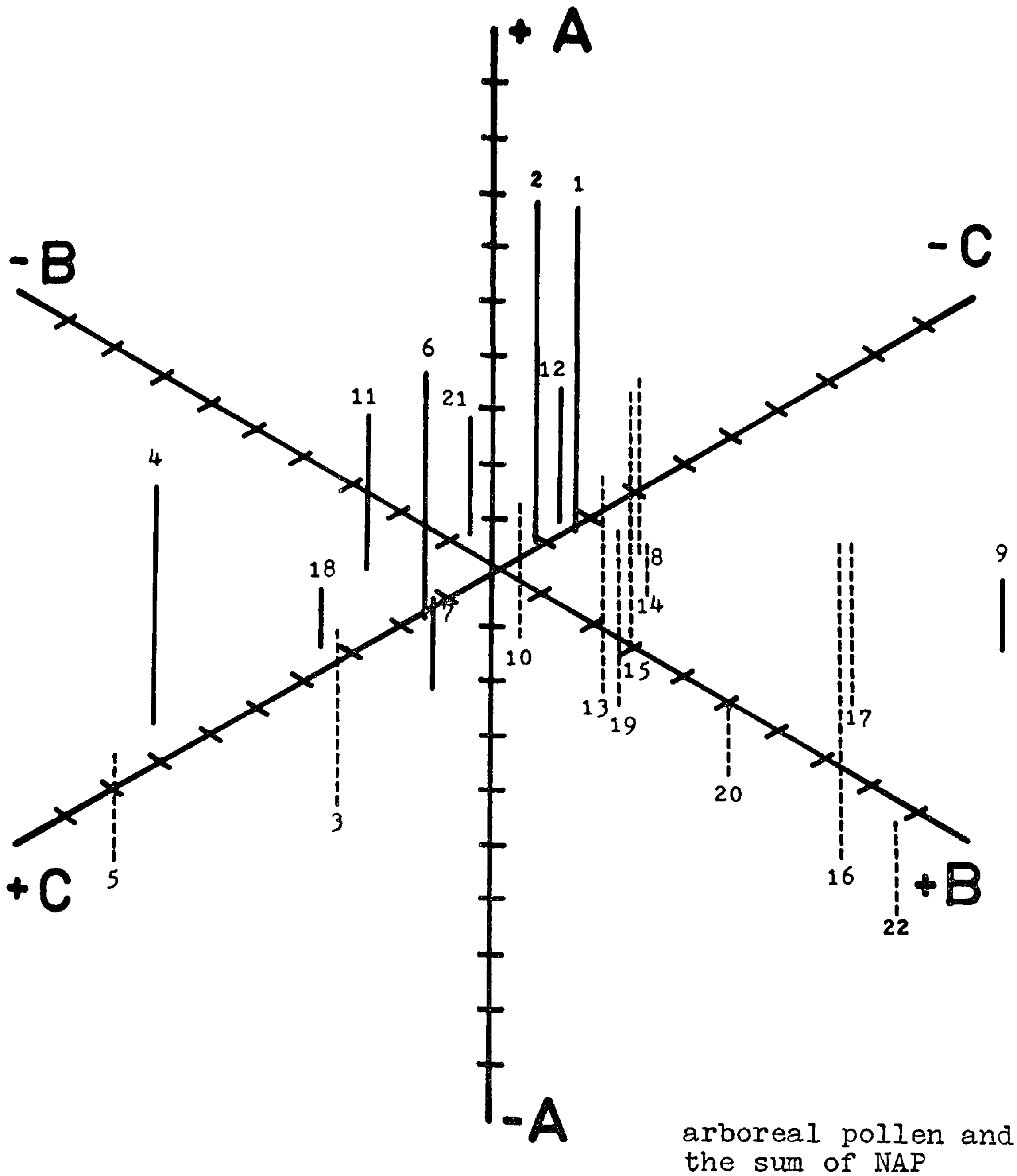


Figure 36. Tridimensional scattergram for the rotated factors A, B and C of a R-mode factor analysis of the 66 variables studied in the Cataraqui River Marsh deposit. The name of each variable is listed in figure 35.

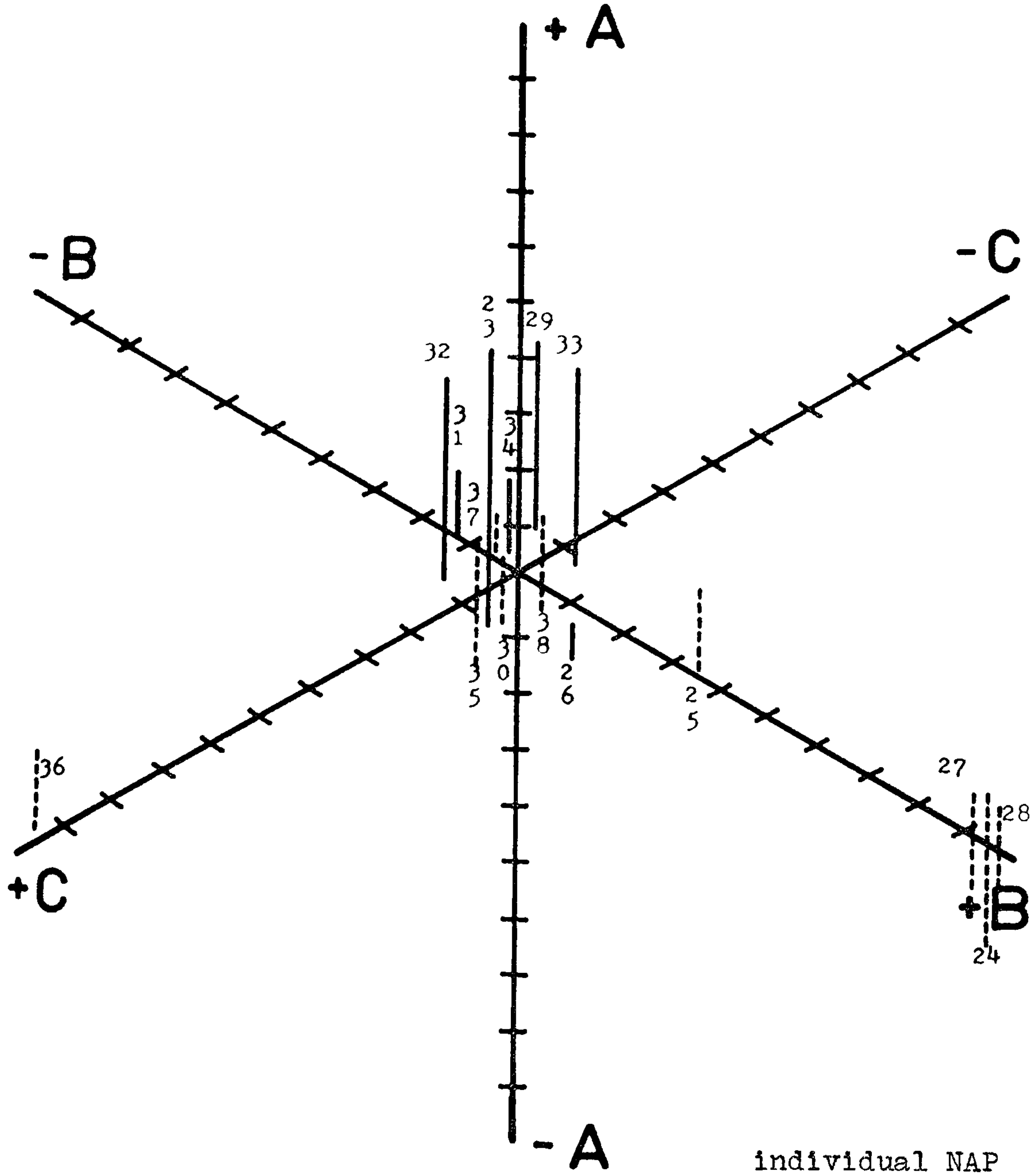
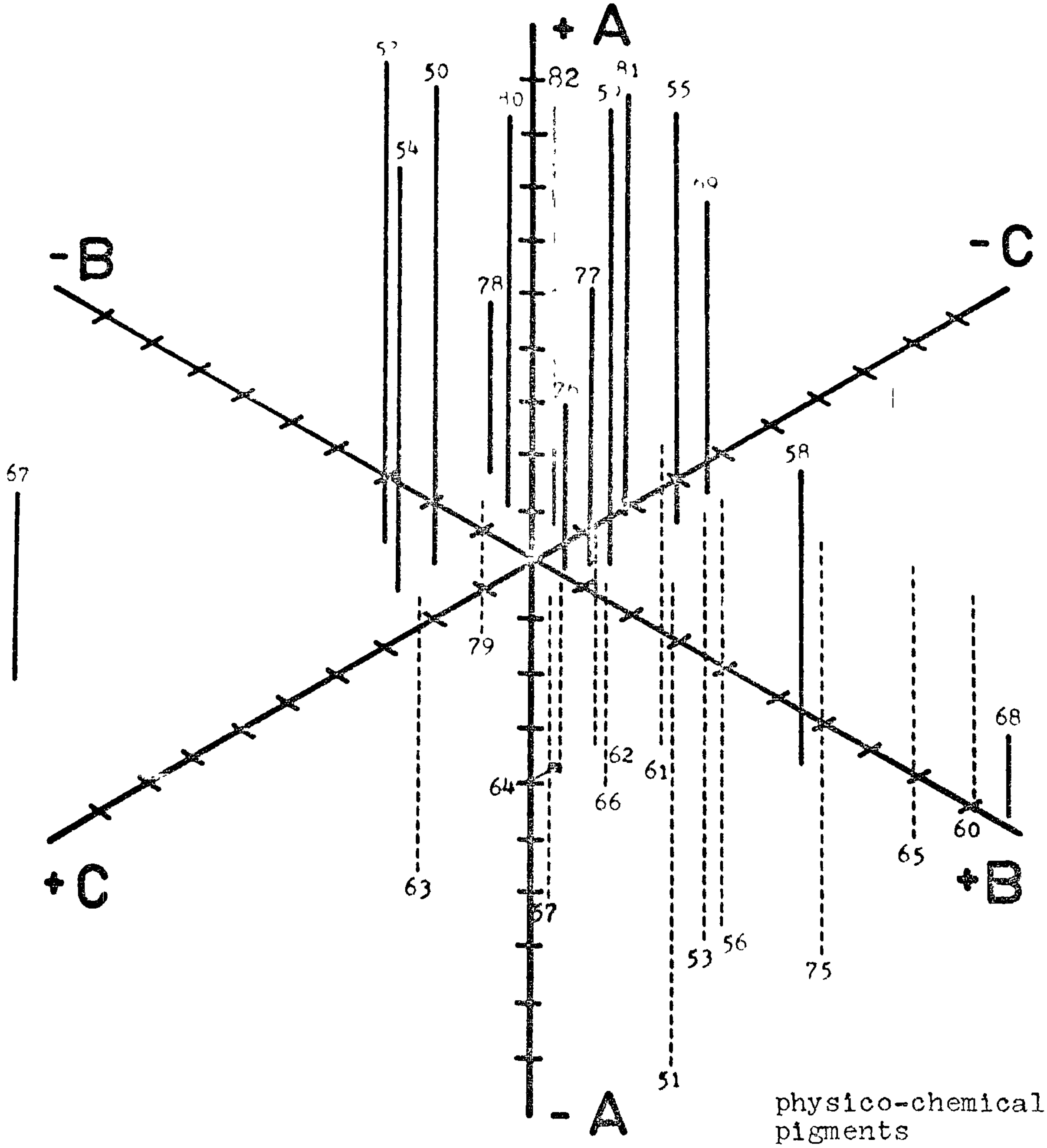


Figure 36. Cont'd



physico-chemical and
pigments

Figure 36. Cont'd

end of axis B. They are *Betula* (9), *Juglans* (20), non-arboreal pollen (22), *Ambrosia* (24), Cyperaceae (27), *Typha* (28), P (58), K (60), K+Na (65) and K/Na (68). All these variables generally tend to be more important either at the very bottom or at the very top or simultaneously at both places. Only the variable Ca+Mg/K+Na (67) showing a moderate loading of - 0.33 appears on the negative side of this axis but its stratigraphic quantitative distribution is reciprocal relative to the variables with high positive loading. Intermediate component values are found for pollen types of boreal and aquatic affinities as well as spores and SCDP variables. This factor is tentatively interpreted as reflecting regional environmental changes. It appears to demonstrate the gradual development of the local marshy environment and later on the deforestation effect by the early settlers.

Axis C shows high positive loading for *Pinus banksiana* (4), *Pinus* sp. (5), Polypodiaceae (36) and Ca+Mg/K+Na (67). Only a few variables such as *Tsuga* (8), *Betula* (9), *Fagus* (15), *Carya* (16), *Acer* (17), and to some extent K+Na (65) show moderate negative loading along this axis. The first group of variables with high positive loading exhibits high stratigraphic quantitative values within the B pollen zone. However, variables with negative loading have a general tendency to exhibit higher values within the C-1 pollen zone. Intermediate component factor loading is found for all the NAP (Polypodiaceae excepted) and for all the SCDP variables. It is rather difficult to positively identify this factor but it could be tentatively interpreted as being an environmental gradient reflecting, from the positive to the negative end of axis C, changes from dry to more humid conditions.

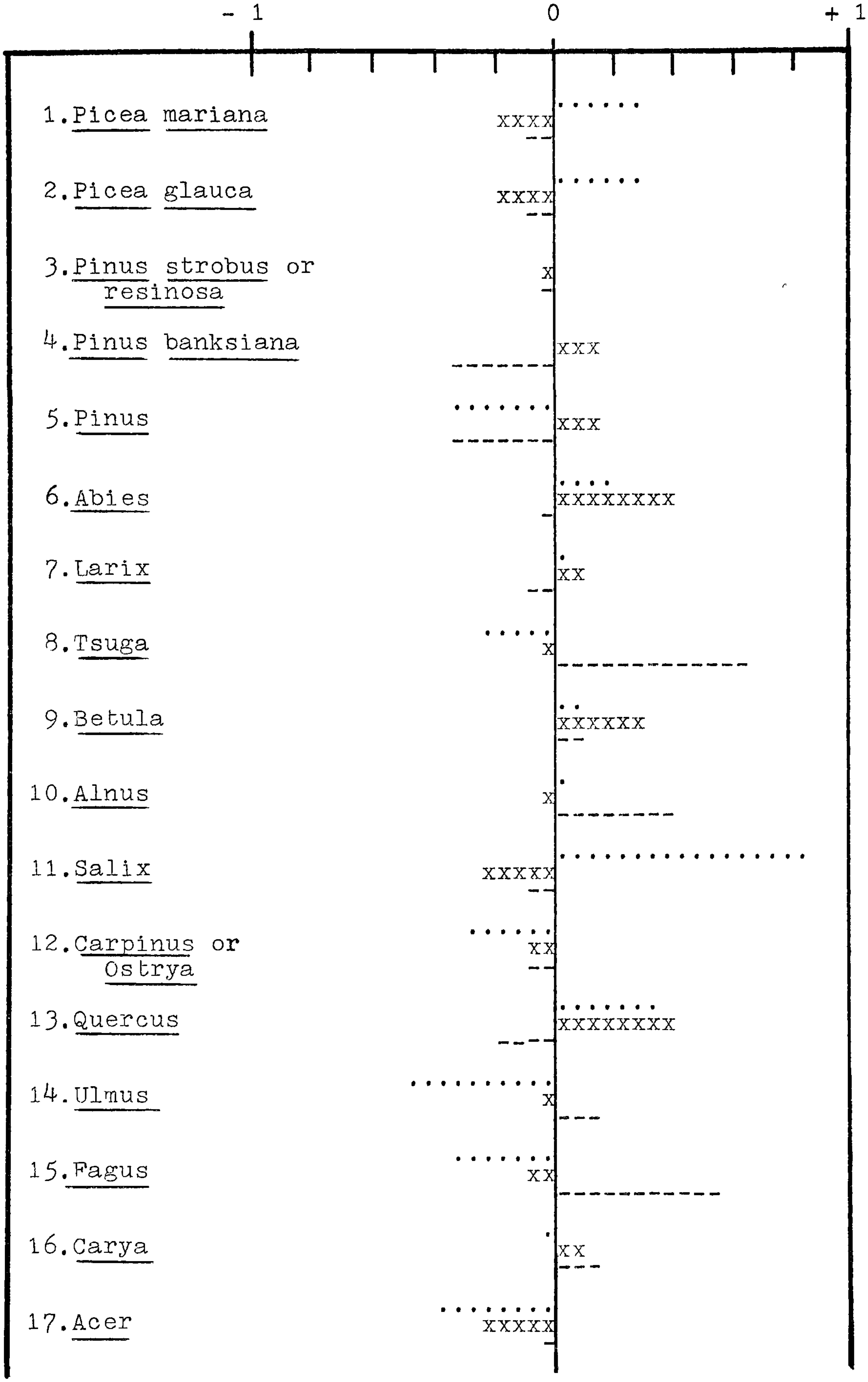
2. Grady Lake

The loading of the 54 variables from the Grady Lake site is represented graphically in figure 37 (p. 175) for the 3 most important factors A, B and C. These factors respectively explain 28.7, 16.5 and 10.2 per cent of the total variance. The interrelationship of the variables studied is illustrated in the tridimensional scattergram (Fig. 38, p. 180) by ordinating the loading of each variable on axes A, B and C.

Axis A is characterized by high positive loading for Pinus banksiana (4), Salix (11), Artemisia (23), Cyperaceae (27), Potamogeton (29), dry matter (52), ratio K/Na (68) and to a lesser extent Picea mariana (1) and Picea glauca (2). All these variables tend to be either restricted or abundant at the very bottom part of the deposit. At the negative end of this axis the following variables exhibit strong loading: Pinus strobus or resinosa (3), Ulmus (4), water (51), N (56), SCDP per gram of dry matter (75), SCDP per gram of ignitable matter (76) and absorbance ratio 410/350 (77). These variables all tend to have very low values at the very bottom of the profile and increase steadily upward. The dispersion of these variables along axis A could be interpreted as a temperature factor and also as a controlling factor for the inorganic aspect of the sediments at the bottom of the profile.

Positive high dispersion along axis B is exhibited by P (60), Na (61), Ca (62), Mg (63), Ca+Mg (64), K+Na (65), K+Na+Ca+Mg (66) moderate negative loading is demonstrated by

Figure 37. Loading for rotated factors A(...), B(xxx) and C(---) for a R-mode factor analysis of the 54 variables studied in the Grady Lake deposit.


- 1
0
+ 1
1. Picea mariana
2. Picea glauca
3. Pinus strobus or resinosa
4. Pinus banksiana
5. Pinus
6. Abies
7. Larix
8. Tsuga
9. Betula
10. Alnus
11. Salix
12. Carpinus or Ostrya
13. Quercus
14. Ulmus
15. Fagus
16. Carya
17. Acer

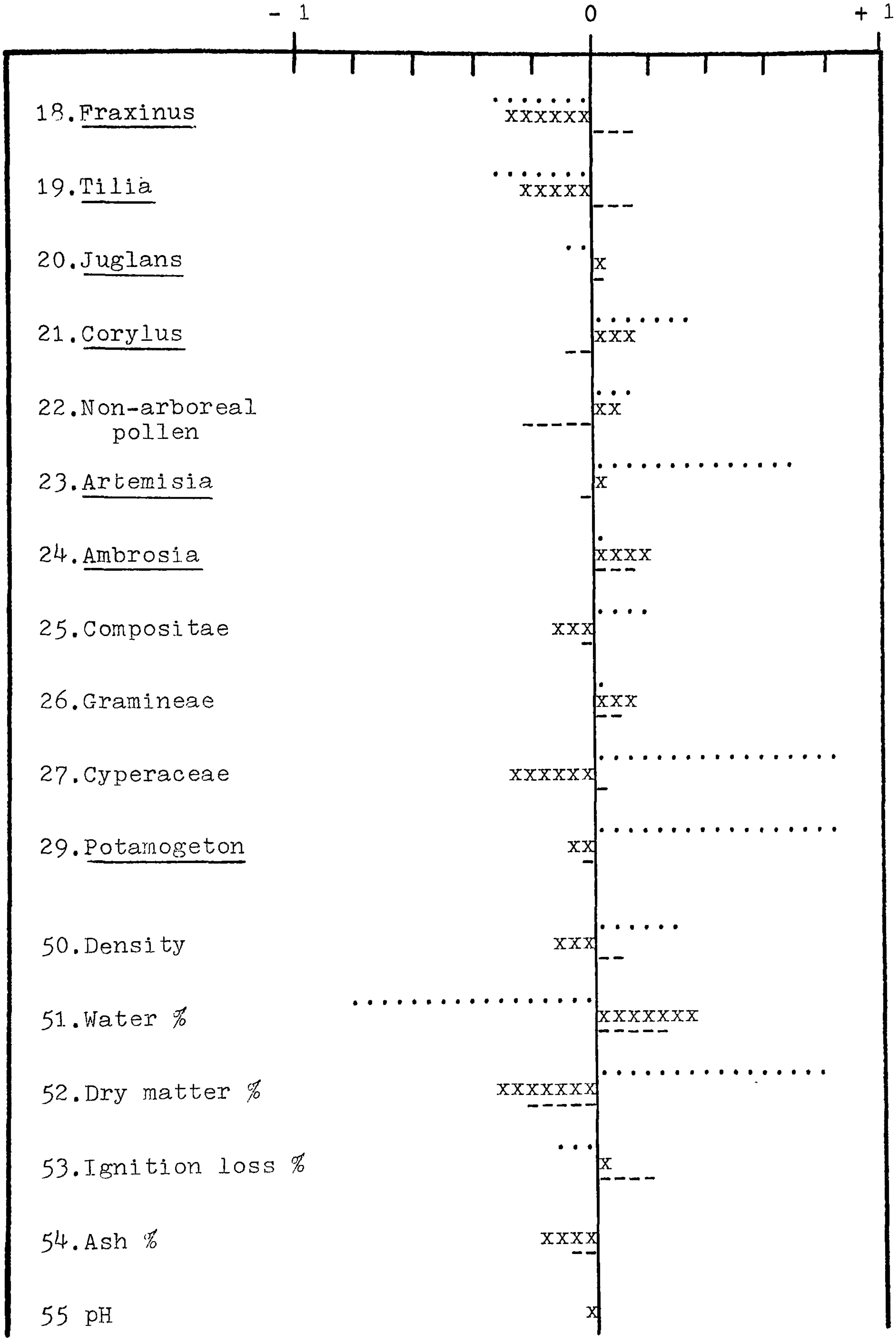
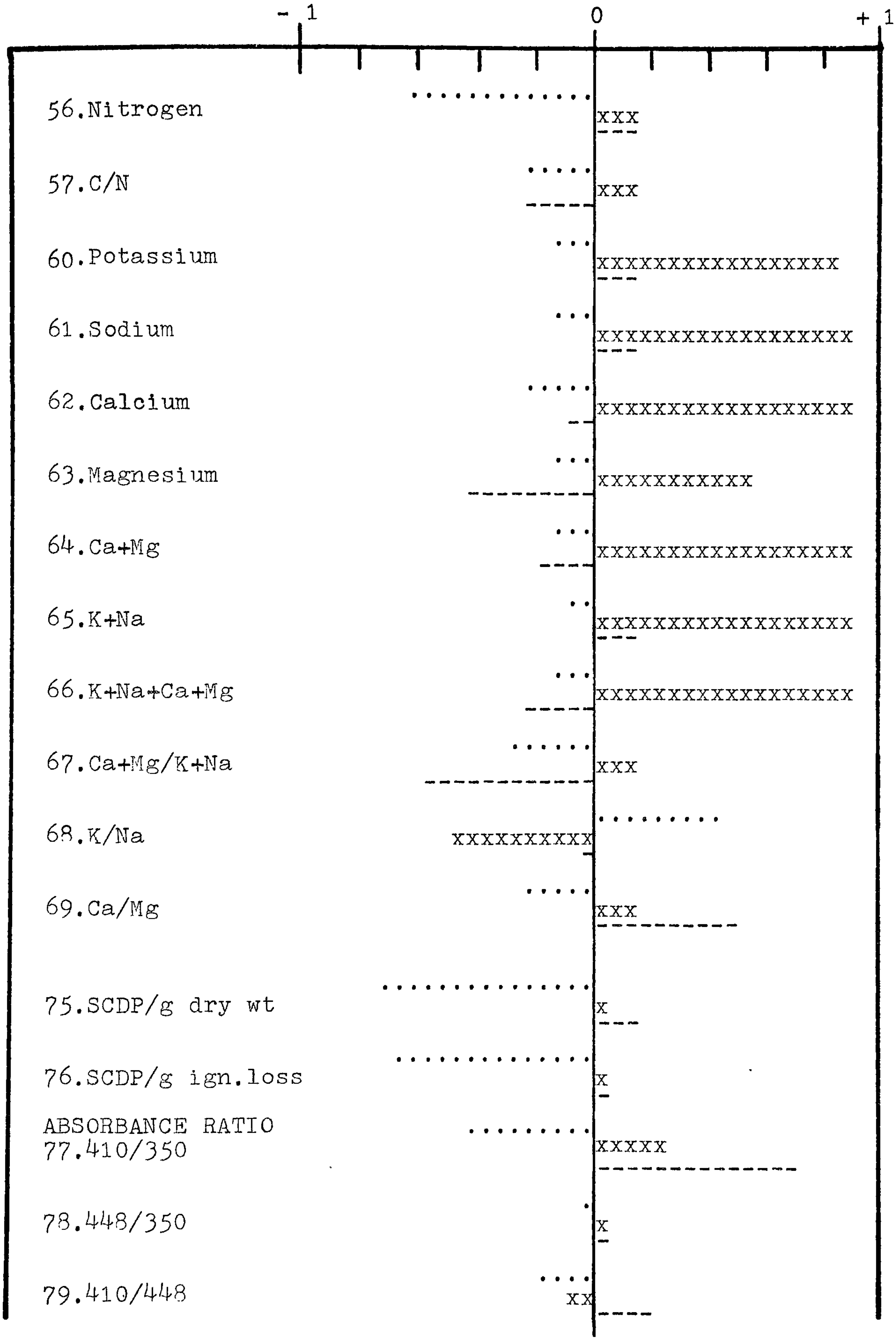


Figure 37. Cont'd



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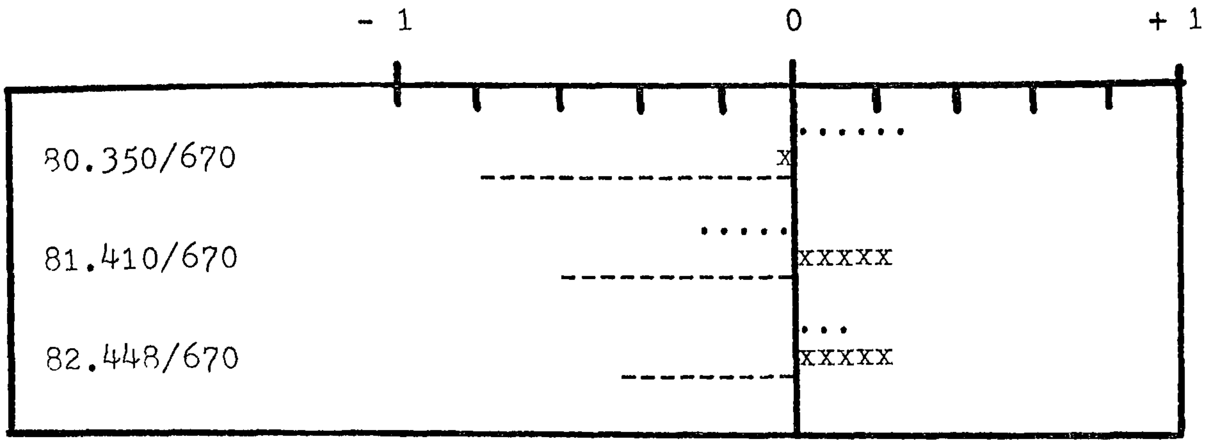

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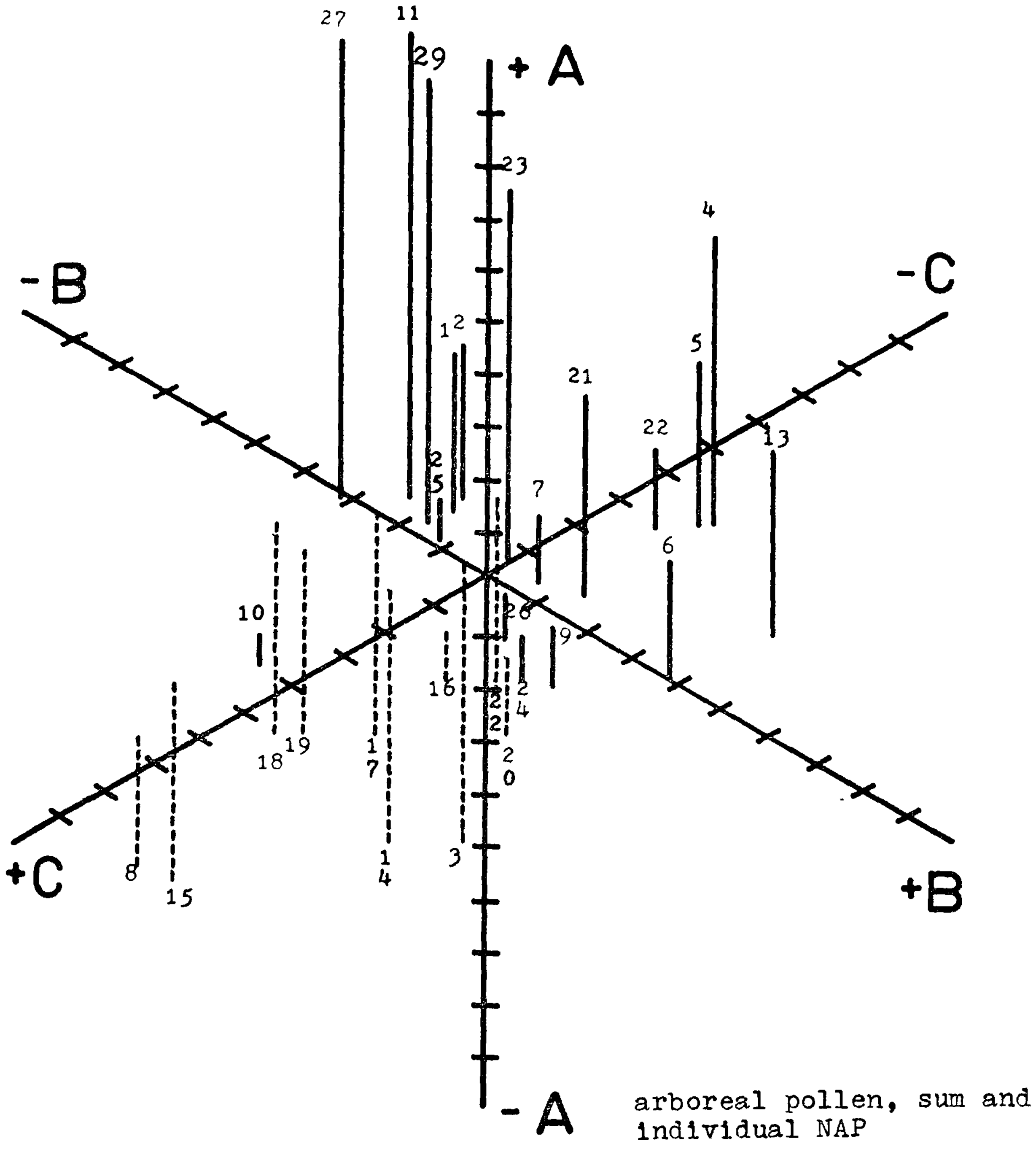
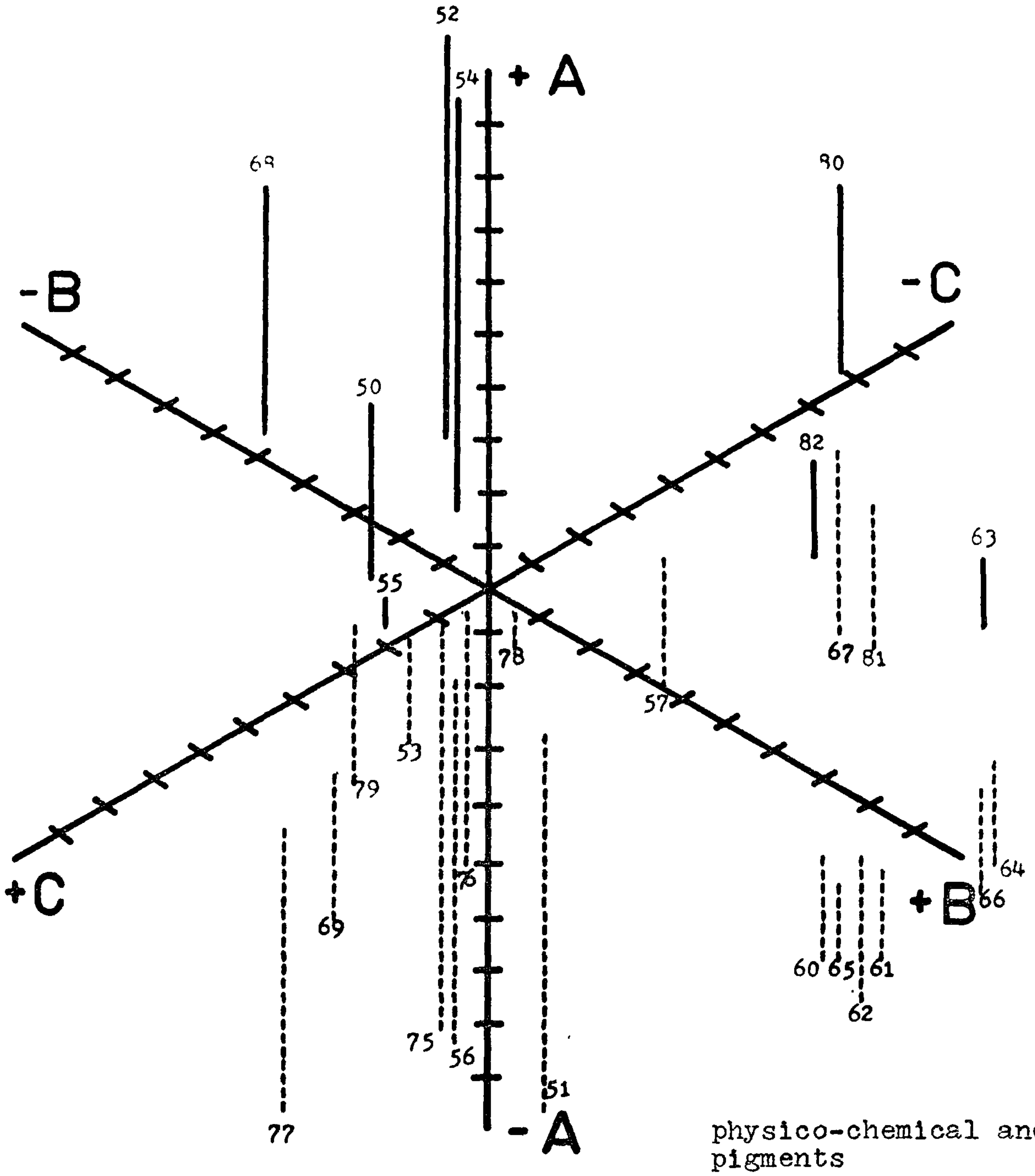


Figure 38. Tridimensional scattergram for the rotated factors A, B and C of a R-mode factor analysis of the the 54 variables studied in the Grady Lake deposit.



physico-chemical and
pigments

Figure 38. Cont'd

the dry matter (52) and the ratio K/Na (68). Factor B, responsible for the dispersion of the variables along axis B, might be regarded as a trophic gradient with values (eutrophic) at the positive end of axis B and low productivity (oligotrophic) at its opposite end.

Axis C shows strong positive covariance for Tsuga (8), Fagus (15), Ca/Mg (69) and absorbance ratio 410/350 (77). All these variables are characterized by a stratigraphic quantitative distribution which is at its minimum at the bottom of the profile and increases constantly toward the top. On the same axis a strong loading is exhibited by Mg (63), Ca+Mg/K+Na (67) and absorbance ratios 350/670 (80), 410/670 (81) and 448/670 (82). All these variables have a reciprocal stratigraphic quantitative distribution relative to the variables grouped at the positive end of the axis. The underlying factor which is responsible for this reciprocal distribution of the variables grouped at both ends of axis C is rather uncertain. It might be attributed to the reduced amount of nutrients entering the aquatic environment due to the power of vegetation over erosive activities or to a greater loss of nutrients through the drainage system.

3. Atkins Lake

The factor analysis of Atkins Lake was done by using data from 66 different variables observed at 40 stratigraphic levels. The loading of each variable for the most important factors A, B and C explains respectively 36.7, 14.4 and 9.8 per cent of the total variance on each factor. It is represented graphically in figure 39 (p. 184). Figure 40 (p. 189) shows the ordination of the loading of the pollen types, physico-chemistry and pigments, and trace elements representing a visual interrelationship among the variables.

Axis A is characterized by high positive loading values for Picea mariana (1), Picea glauca (2), Pinus sp. (5), density (50), dry matter (52), ash (54), P (58), P/N (59), Ca+Mg/K+Na (67), K/Na (68) and all trace elements (B and Pb excepted). The other end of axis A has high negative loading for most of the deciduous pollen types (8-20), water (51), pH (55), N (56), available cations (60-65) and absorbance ratios 410/350 (77), 448/350 (78) and 448/670 (82). Low component values are exhibited by the NAP. The spacial distribution of the variables associated with the inorganic aspect of the sediments is above the horizontal plane passing by axes B and C. The other group of variables is distributed below this plane. The greater quantity of inorganic material washed into the lake at the bottom part of the profile is best attributed to the influence of colder climatic conditions thus preventing the development of a thick forest which would have reduced erosion. The variables with high negative loading on axis A are most likely interpreted as paleoproductivity indexes probably related to warmer climatic conditions.

Axis B has high positive loading values for Pinus sp. (5), Salix (11), Corylus (21), Artemisia (23), ash (54), Ca/Mg (69) and absorbance ratios 350/670 (80), 410/670 (81) and 448/670 (82). On the other hand, the following variables are opposed to these previous ones: Tsuga (8), Betula (9),

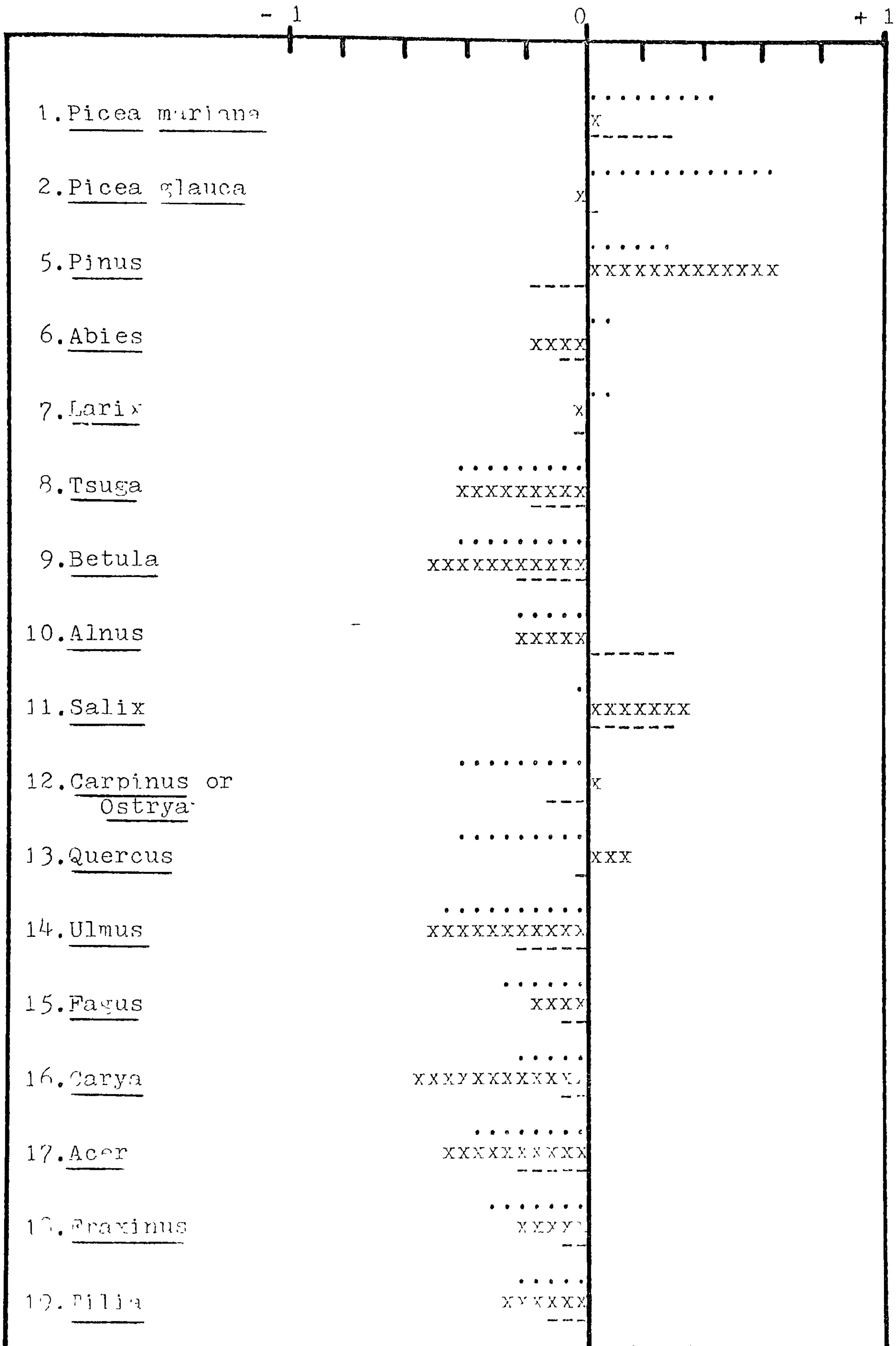


Figure 39. Loading for rotated factor A(...), B(xxx) and C(---) for a R-mode factor analysis of the 66 variables studied in the Atkins Lake deposit.

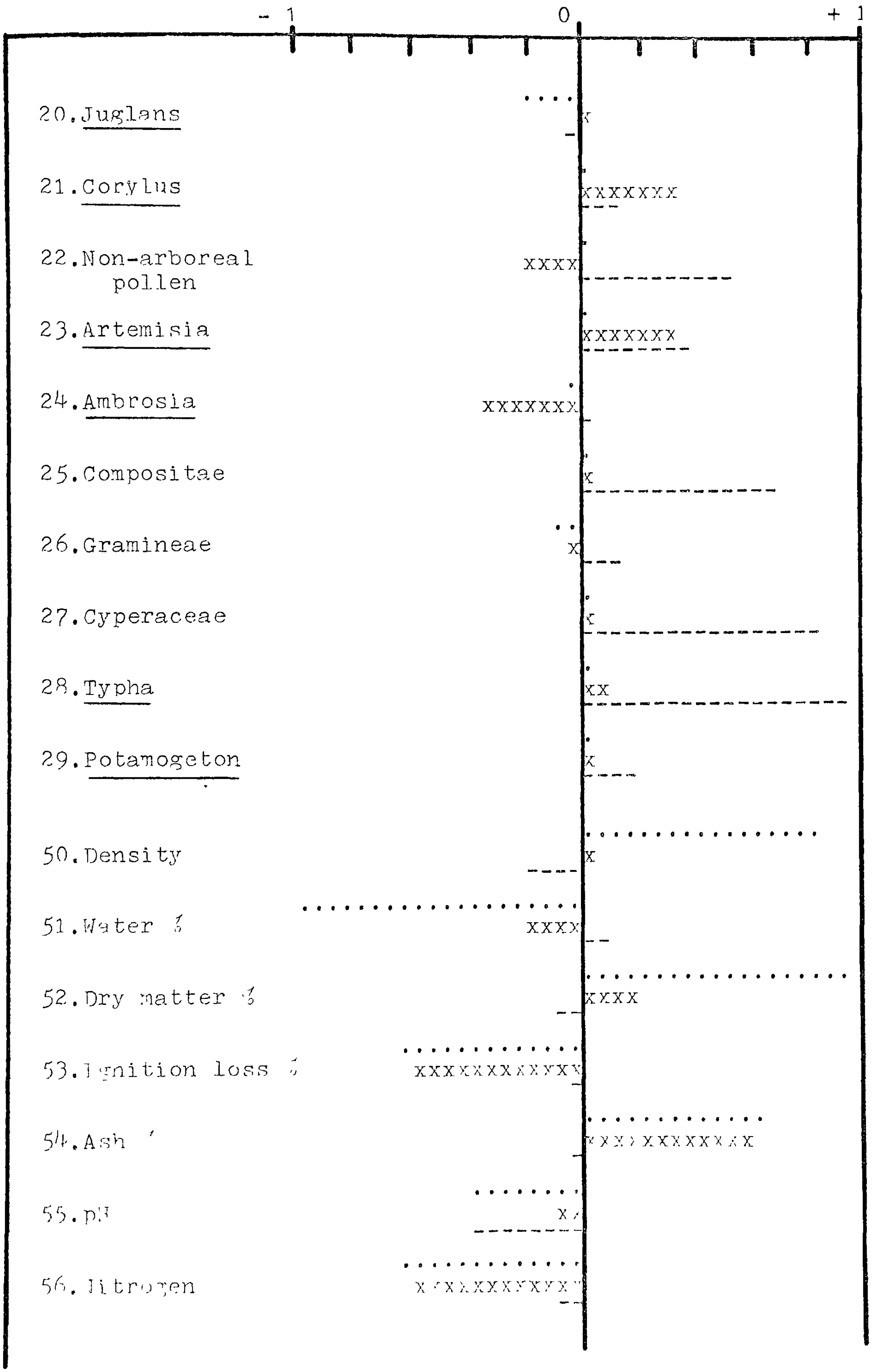


Figure 39. Cont'd

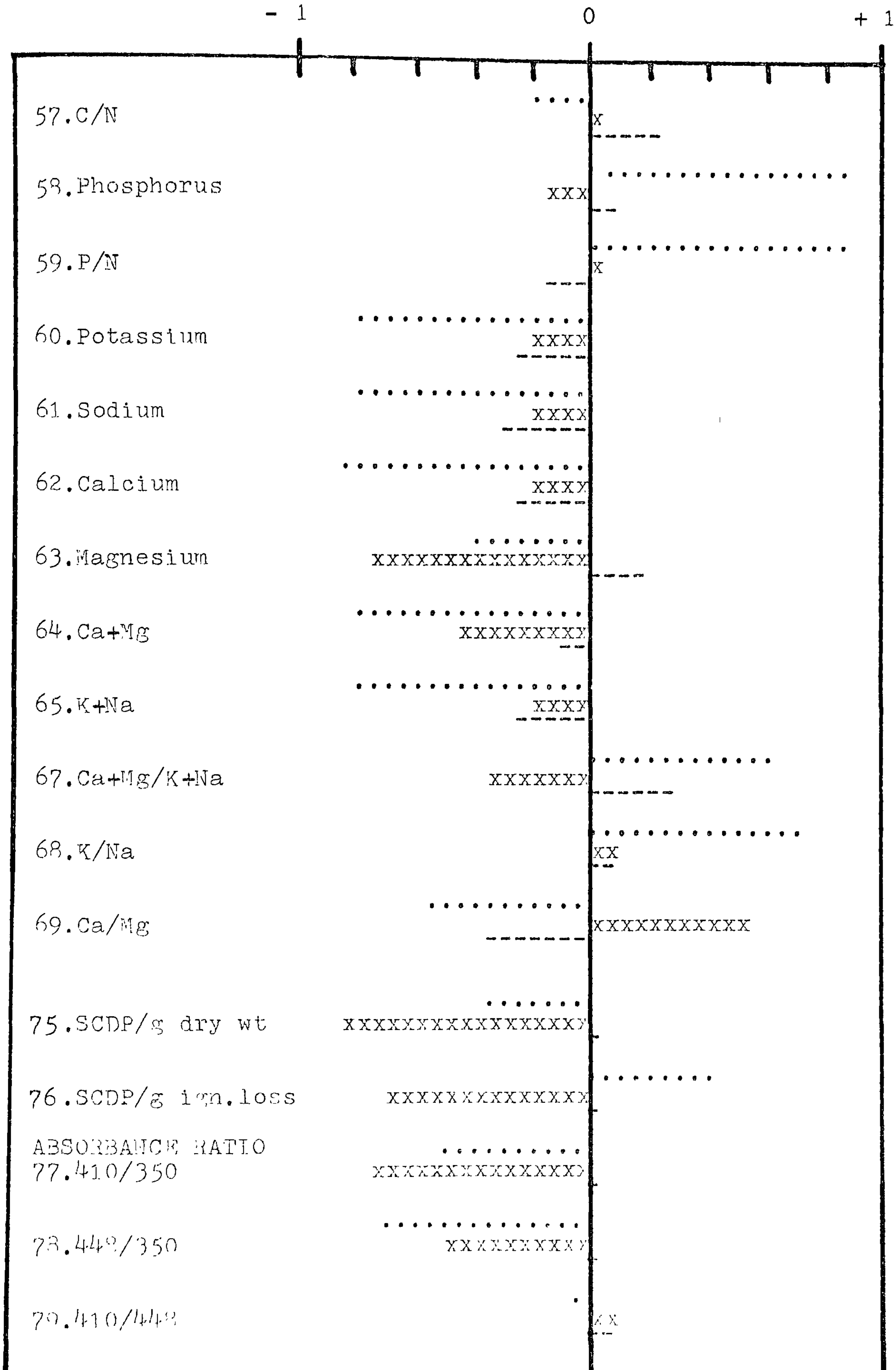


Figure 39. Cont'd

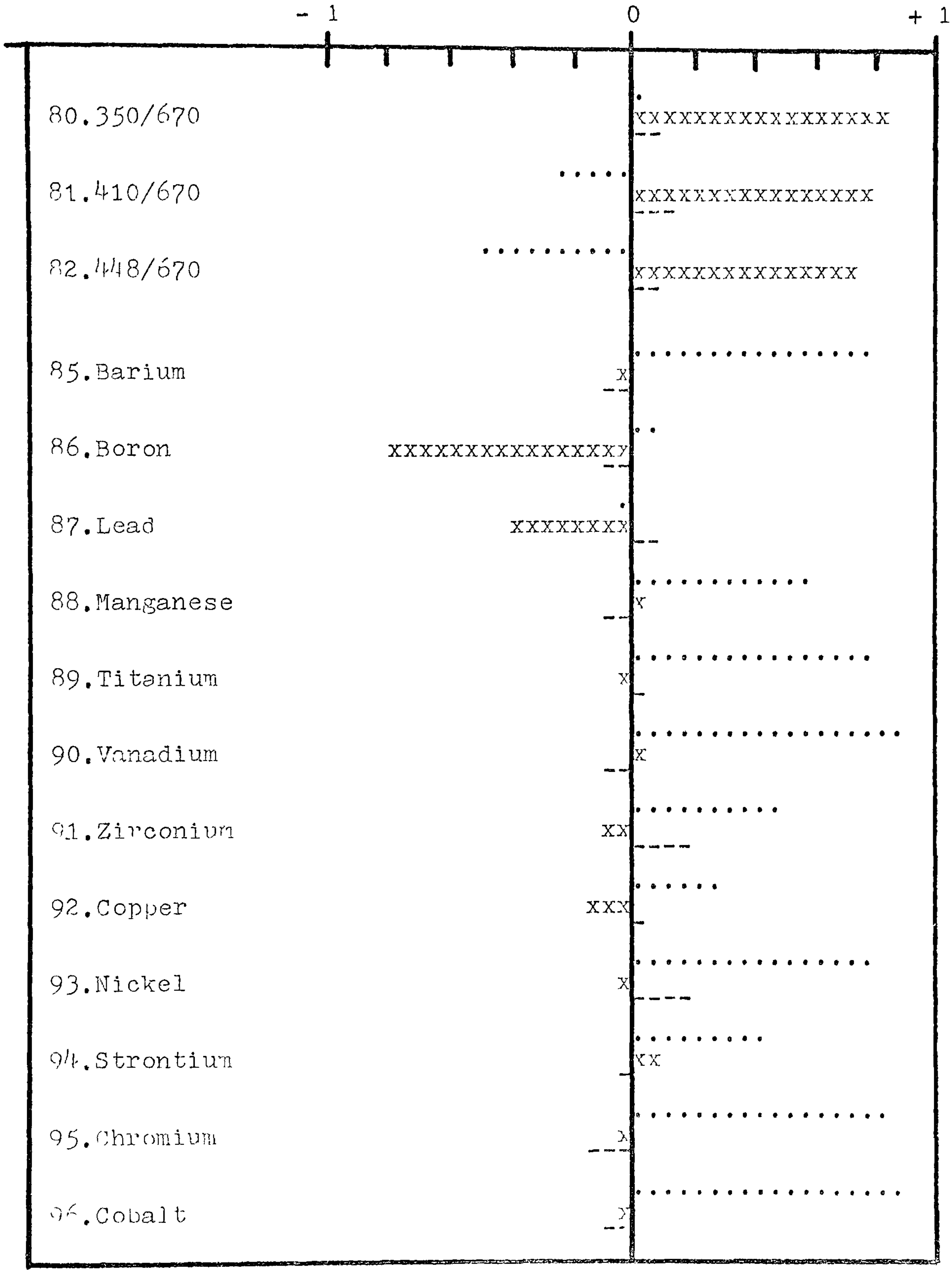


Figure 39. Cont'd

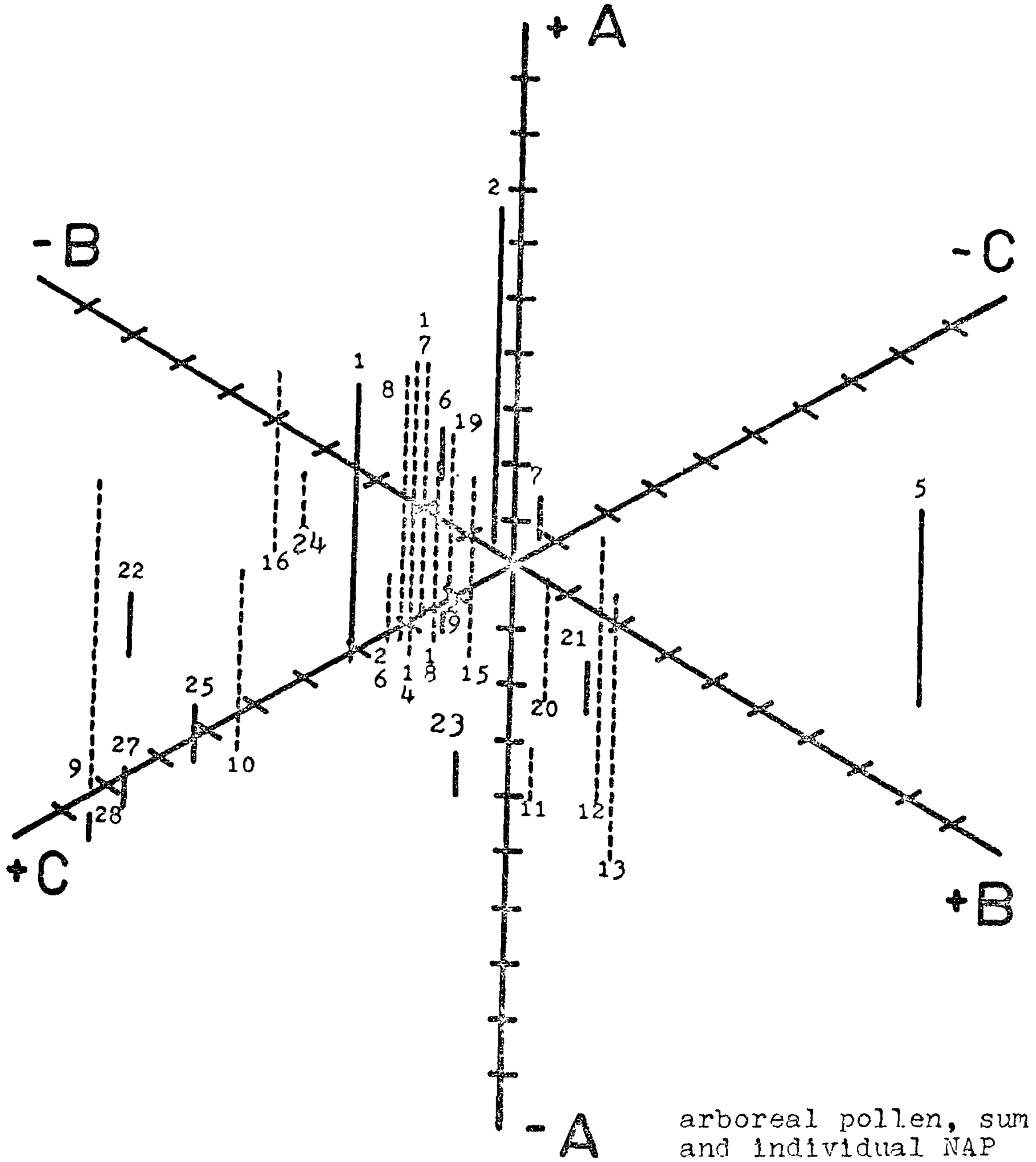


Figure 40. Tridimensional scattergram for the rotated factors A, B and C of a R-mode factor analysis of the 66 variables studied in the Atkins Lake deposit. The name of each variable is listed in figure 39.

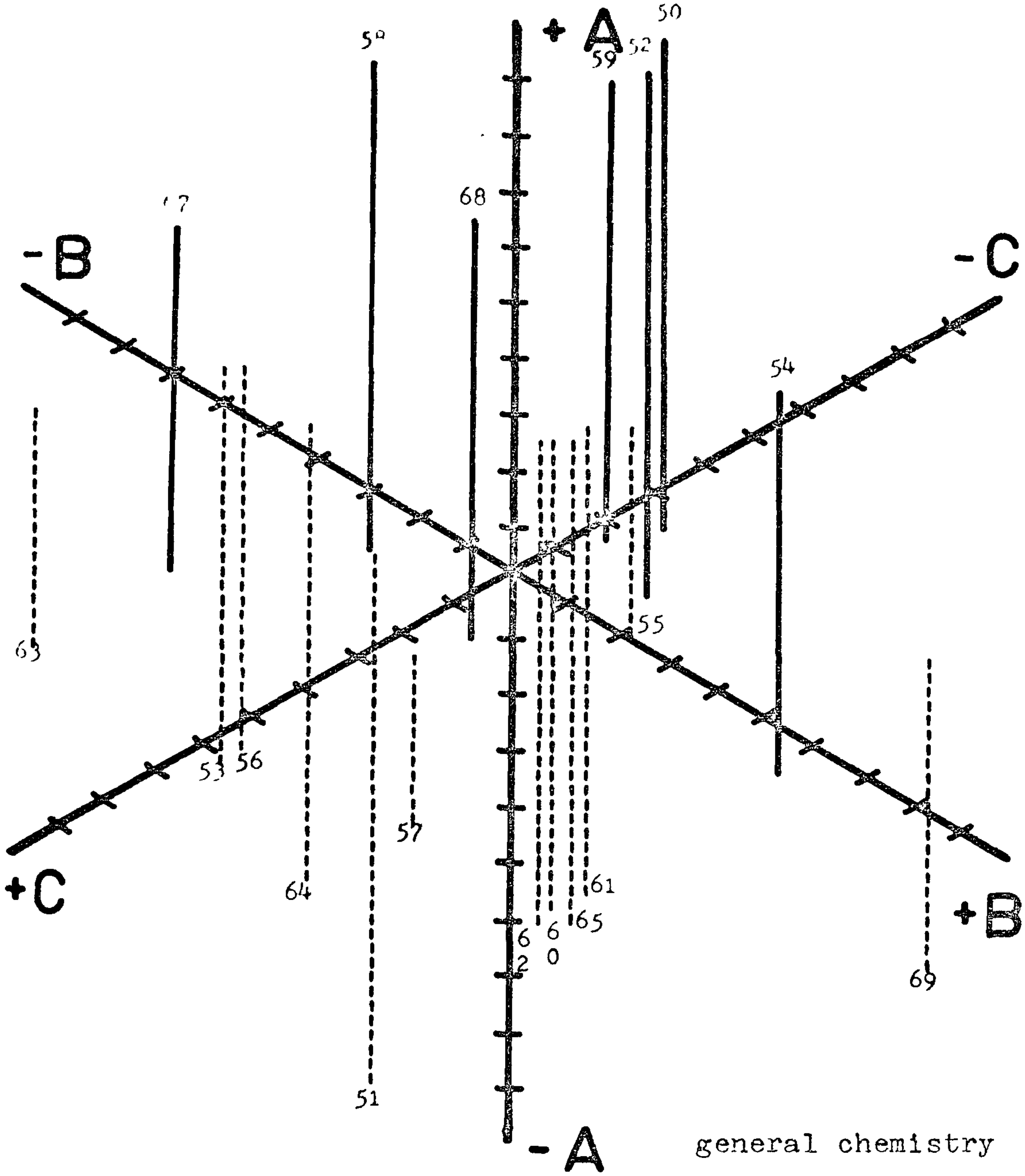


Figure 40. Cont'd

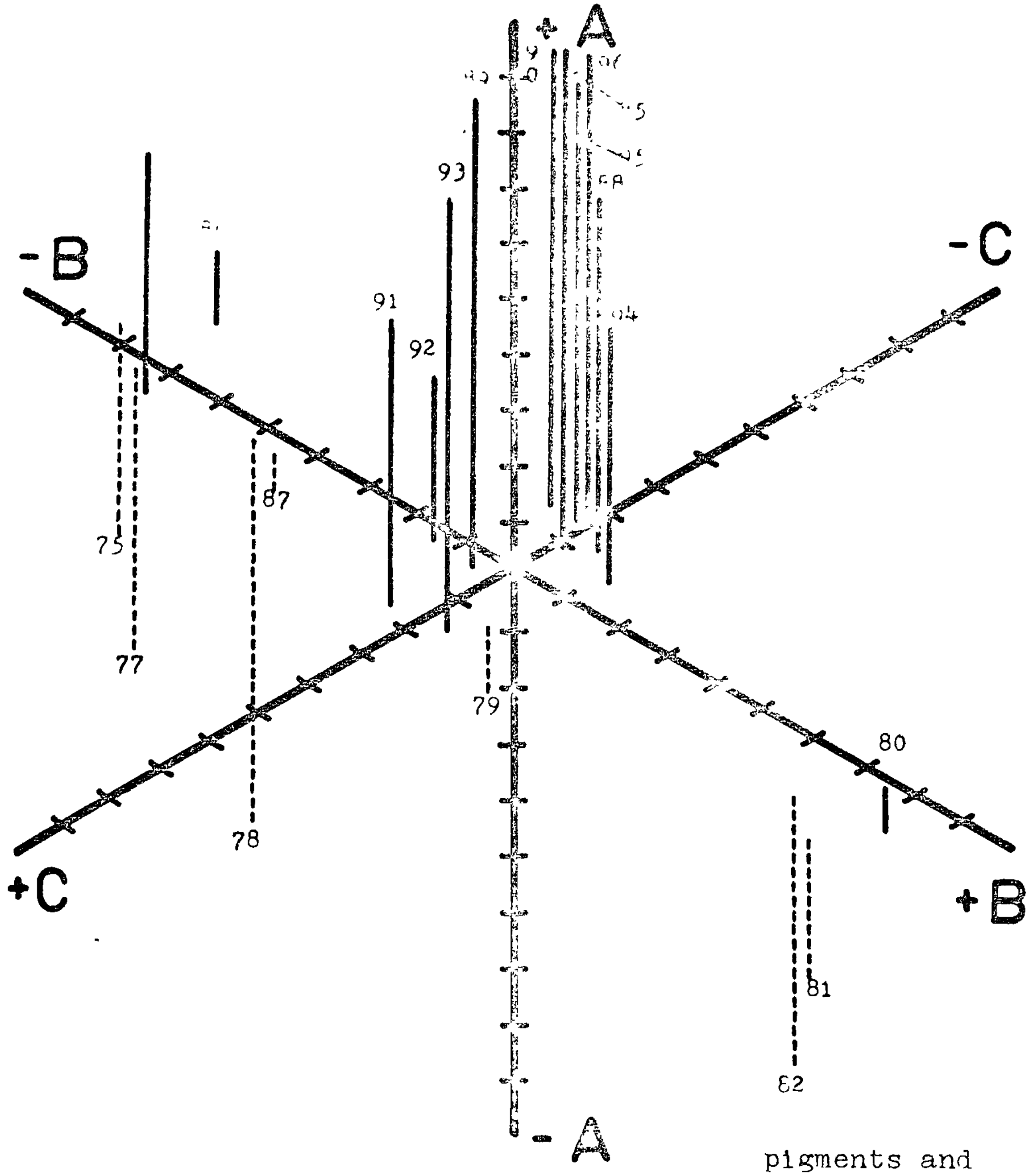


Figure 40. Cont'd

Ulmus (12), Carya (16), Acer (17), Ambrosia (24), ignition loss (53), N (56), Mg (63), Ca+Mg (64), SCDP per gram of dry weight (75), SCDP per gram of ignition loss (76), absorbance ratios 410/350 (77), 448/350 (78) and B. The stratigraphic quantitative distribution of all the variables in the first group are much more important in the bottom half of the profile while the variables belonging to the second group are more significant in the upper half, especially at the very top. The variables with high negative loading belong to two different ecological groups which seem to be affected by the same underlying factor. The deciduous pollen types belonging to the terrestrial ecosystem became more abundant due to more favorable climatic conditions and contributed to increase the terrestrial productivity. Stratigraphic quantitative distribution of the second group of variables, mostly autochthonous to the lacustrine habitat, probably reflects fairly accurately the trophic evolution of Atkins Lake. It is interesting to note that the variables believed to be the best eutrophication indexes (ignition loss, N, Mg, Ca+Mg, SCDP per gram of dry weight, absorbance ratios 410/350 and 448/350) have a general tendency to exhibit high negative loading for axes A and B. This B factor is most easily interpreted as an eutrophic to oligotrophic gradient from the negative to the positive end of axis B.

No interpretation of the variable distribution along axis C is possible since it does not exhibit any strong negative loading.

The factor analysis method used in this study is a much more powerful statistical approach than partial and multiple correlations, variance analyses, and discriminant functions. It requires no supposition as to whether the variables are dependent or independent. The R-mode factor analyses have yielded evidence on every contribution between the variables. They have also indicated the number of variables in action and the magnitude of their interrelationship.

For each set of data the number, nature, and degree of interaction of the factors at work, as well as the magnitude of their influence have been discussed above. The tri-dimensional scattergrams (fig. 28, p. 152, 29, p. 154) for the bottom surface sediment samples from Meach Lake have demonstrated the importance of the underlying factors A and B strongly associated with the geographical location within the lake basin of the variables studied. The statistical treatments (fig. 32, p. 159, 33, p. 162) of the 26 variables investigated from the center of lakes from the Gatineau Area emphasize the importance of morphological characteristics of lakes as important controlling factors of primary productivity of lacustrine ecosystems within small and similar geographical areas.

Factor analyses of variables studied for each of the three fossil deposits from the Kingston Region demonstrated more particularly the effects of Late-Quaternary climatic fluctuations of the terrestrial ecosystem and its interrelationship with lacustrine environments.

VI. DISCUSSION OF RESULTS

A. Modern Sediment Samples from Lakes of the Gatineau Area

1. Meach Lake

The statistical analysis of the variables studied along the traverse of Meach Lake reveals two main reciprocal tendencies. From the 14 variables investigated only 4 (P/N, Ca+Mg/K+Na, K/Na and absorbance ratio 410/448) seem to have been directly affected by the allochthonous factors of Meach Lake. Most of the other variables exhibit higher values toward the center of the lake, probably because of greater algal activities toward the center. This explanation might be acceptable since most of these variables are directly involved in phytoplankton activities. Moreover another factor which has contributed to higher quantities of autochthonous organic matter is the thickness of the water column which supported a greater quantity of phytoplankton toward the center of the lake. On the other hand a greater recycling of the organic matter on the shore could also be partly responsible for the lower values along the shores of most of the variables. Dilution action or trapping of the nutrients by mineral particles near the shores which is a high energy depositional environment are other phenomena which could play an important role in the chemistry of bottom lake sediments.

The general sediment chemistry distribution of Meach Lake is quite comparable to the findings of Kleerekoper and Grenier (1952). Interesting deductions were made even though these workers were mainly concerned with analysis of total major elements. According to their analyses ash, Si, Al, Ca and Mg tend to be more important close to the shores. Water in wet sediments, loss on ignition, total N and P are more important toward the center of the lake because of the more organic aspects of sediments which are largely autochthonous.

One of the most interesting findings from Meach Lake is that pigmented carbon (chlorophyll-linked) could be differentiated to some extent from unpigmented organic matter (xylem, cambium, bark). Of the 11 sites analyzed the highest percentage of organic matter is found at station number 2 which is near the shore. Quite unexpectedly at this station with a very high organic matter content only low amounts of SCDP per gram of ignitable matter and low absorbance ratios 448/350 and 410/350 were detected. The high value of the absorbance ratio 350/670 correlates positively with non-chlorophillous organic matter while absorbance ratios 448/350 and 410/350 might be interpreted as indicators of low amounts of chlorophyllous matter. Gorham (1960) found that the absorbance ratio 410/350 of sediment acetone extracts increased in passing from muds of large, infertile lakes, with waters low in phytoplankton, lime and potash, to muds of smaller and more fertile lakes with abundant phytoplankton, lime and potash. Despite the fact that he was unable to fully explain these correlations, he suspected that the difference in the absorption spectrum of sediment acetone extracts might have been related to the balance between allochthonous and autochthonous organic material and to the length of time spent in an oxidizing environment. For unknown reasons Vallentyne and Craston (1957) were unable to correlate significantly the SCDP with any limnological parameters such as depth of water, hypolimnic oxygen deficit and seston chlorophyll. They suggested that the variability in percentage decomposition of the chlorophyll, initially present in the plankton should be studied more extensively so as to establish relations between SCDP and primary productivity.

The results from Meach Lake demonstrate that in a SCDP study involving several lakes, those with a diameter less than 1 kilometer in length should be avoided so as to quantify, as much autochthonous parameters as possible. As for the representativeness of the stations along the traverse, correlations at the 1 per cent level of significance were found only between stations 3 to 8. These conclusions were considered in sampling the other lakes of the Gatineau Area in order to obtain comparable autochthonous data from one lake to the other.

2. Sample from the Center of Lakes

The main objective of this investigation dealing with the geochemistry of bottom surface sediment samples is to verify the hypothesis that the trophic level of a lake must be reflected by its sediments. Although the chief criteria available for evaluating the present productivity of each lake from the Gatineau Area is the hypolimnic oxygen, the geochemical variables studied correlate to a considerable degree with the original lake classification (Table 14, p. 343). It is rather difficult to reach a final conclusion as to the interpretation of the results since few studies dealing with these problems were found in the literature.

Some of the most outstanding sedimentary geochemical characteristics of the Gatineau Lakes lie in the reciprocal relationship between the inorganic aspects of their sediments and the parameters related to growth of organisms. The less productive lakes such as Simon, Cayamant and Blue Sea have sediments characterized by high percentage of dry matter and ash. Their low amount of dissolved nutrients is probably amplified by the fact that some of them are most likely to be held strongly by the mineral particles. This physico-chemical relationship could possibly explain their long stable oligotrophic stage. As soon as nutrients become available to the lake organisms by changes in the chemical equilibrium of the lake environment or by nutrients being washed in from the surrounding drainage basin, the primary productivity of the water increases and the sedimentation load of autochthonous organic matter gradually dilutes the inorganic composition of its bottom. Recycling of the nutrients probably was more rapid at first especially for shallow lakes because of the greater mixing power of their waters. For the deeper lakes a great part of the nutrients were probably tightly trapped in the sediments. The aerobic, cold oxydizing conditions of the hypolimnion prevailing during a good part of the year, or even meromictic conditions, greatly reduce the recycling of nutrients. Over a relatively long period, if the lost nutrients are not replaced, the productivity decreases.

The erratic variation in the ratio C/N could be explained by the over-estimation of the C and N contents of the highly inorganic samples. Mackereth (1966) discusses this problem extensively and suggests that high inorganic samples might retain some water at 110°C which is estimated as ignition loss. The same author also discusses the problem of glacial clay containing N associated with the inorganic matter. The irregular fluctuation of C/N ratio shows no correlation with any of the other parameters investigated.

Phosphorus distribution which is very sensitive to phytoplankton activities is rather difficult to explain. The fact that P is taken up very rapidly by phytoplankton and that its recycling time is indeed very short could very well explain the low correlation of this available element with the ignition loss and some other parameters.

The results of SCDP from various Gatineau Area lakes are quite comparable to those found by Gorham (1960). Physical and chemical properties of the waters of 5 English lakes of different productivity correlate positively with their content in SCDP per gram of dry weight and with the wavelength absorbance ratio 410/350 of acetone extracted sediments. The results of the study of the Gatineau Area lakes support in general his findings. The extremely high values of SCDP per gram of dry matter (491.6 units) and per gram of ignitable matter (855.7 units) found in the sediments of Lake Vert are close to 5 times greater than any SCDP determinations found by any other author. The highest value of SCDP per gram of ignitable matter ever recorded before was 166.0 units on a sample containing only 23.7 per cent of ignitable matter from Linsley Pond (Vallentyne and Carson, 1957). Based on this fact and the very high content in sedimentary ignitable matter, Lake Vert may very well be a meromictic lake (Dr. S.R. Brown, personal communication). Unfortunately there is no other limnological information available at the moment for Lake Vert. However, even though the order of magnitude of the SCDP per gram of dry matter and per gram of ignitable matter is somewhat higher than data previously recorded by other authors, there are definite trends in these parameters. These are attributed to the fact that the rain of phytoplankton settling down on the bottom of an eutrophic lake is greater than that falling on the bottom of an oligotrophic body of water. From these results it is quite possible that, in most cases, the SCDP from the bottom surface reflects the primary productivity of the overlying column of water. Figure 41 illustrates the logarithmic relations between the SCDP per gram of ignition loss and the percentage in dry weight on ignition of the bottom surface sediments for the 9 lakes from the Gatineau Area and supports the original lake classification based on the hypolimnic oxygen depletion. The oligotrophic lakes are grouped around the lower left end of the curve while the more productive lakes are distributed around the upper right extremity of the curve. A reciprocal logarithmic distribution appears when the SCDP per gram of dry matter is

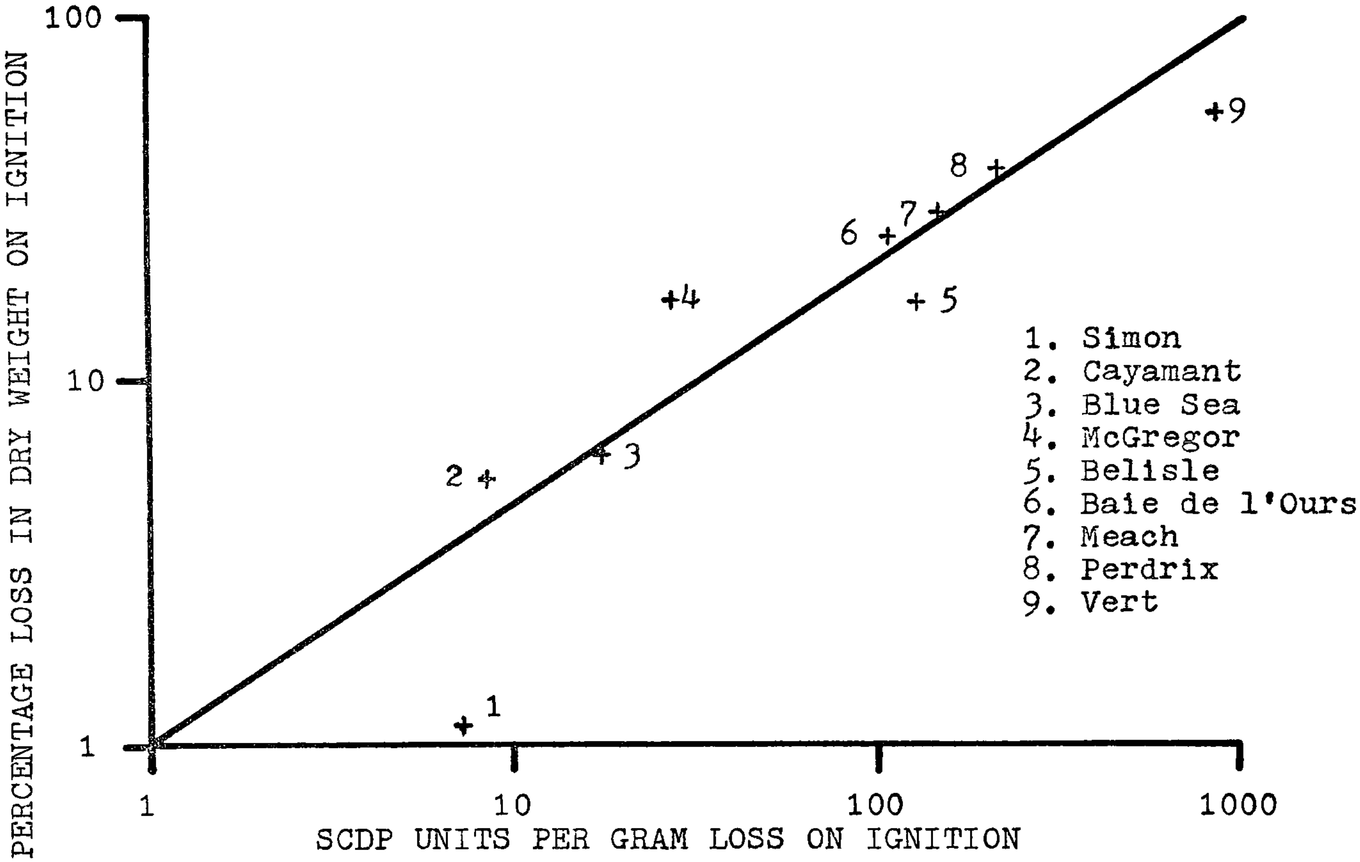


Figure 41. Logarithmic relation between the SCDP per gram of ignition loss and the percentage loss in dry weight on ignition of the bottom surface sediments for the 9 lakes from the Gatineau Area.

plotted against the percentage dry matter of each lake (Fig. 42). These relationships among the above parameters are the best possible indices found in the present study to characterize the trophic level of lakes from their sediments.

The wavelength absorbance ratios 410/350, 448/350, 350/670, 410/670 and 448/670 of sediment acetone extracts all correlate strongly with parameters reflecting the productivity level of the lakes. Gorham (1960) found a similar correlation for the ratio 410/350. However the ratio 410/350 was the only one investigated by Gorham. The range in magnitude for this particular ratio varies from 0.7 for the oligotrophic Lake Wastwater to 1.8 for the eutrophic Lake Priest. The narrower range of this possible productivity index found for the Gatineau Area lakes could be explained by a smaller contribution of allochthonous organic matter to the sediments of the oligotrophic lakes because of their large size.

Gorham (1959) also found that absorption spectra of acetone extracts of woodland mull and mor humus are characterized by strong absorption at wavelength 350 millimicrons which reduces the ratio 410/350. The same author reports a value of about 3 for living Melosira absorbance ratio 410/350. Margalef (1968) found a strong correlation between the absorbance ratio 435/670 and the species diversity of marine phytoplankton.

At the present time it appears that some wavelength absorbance ratios of sediment acetone extracts could be used with caution as indices of past and present lake productivity. However no definite statement as to the strength of correlation between productivity and SCDP can be made without further

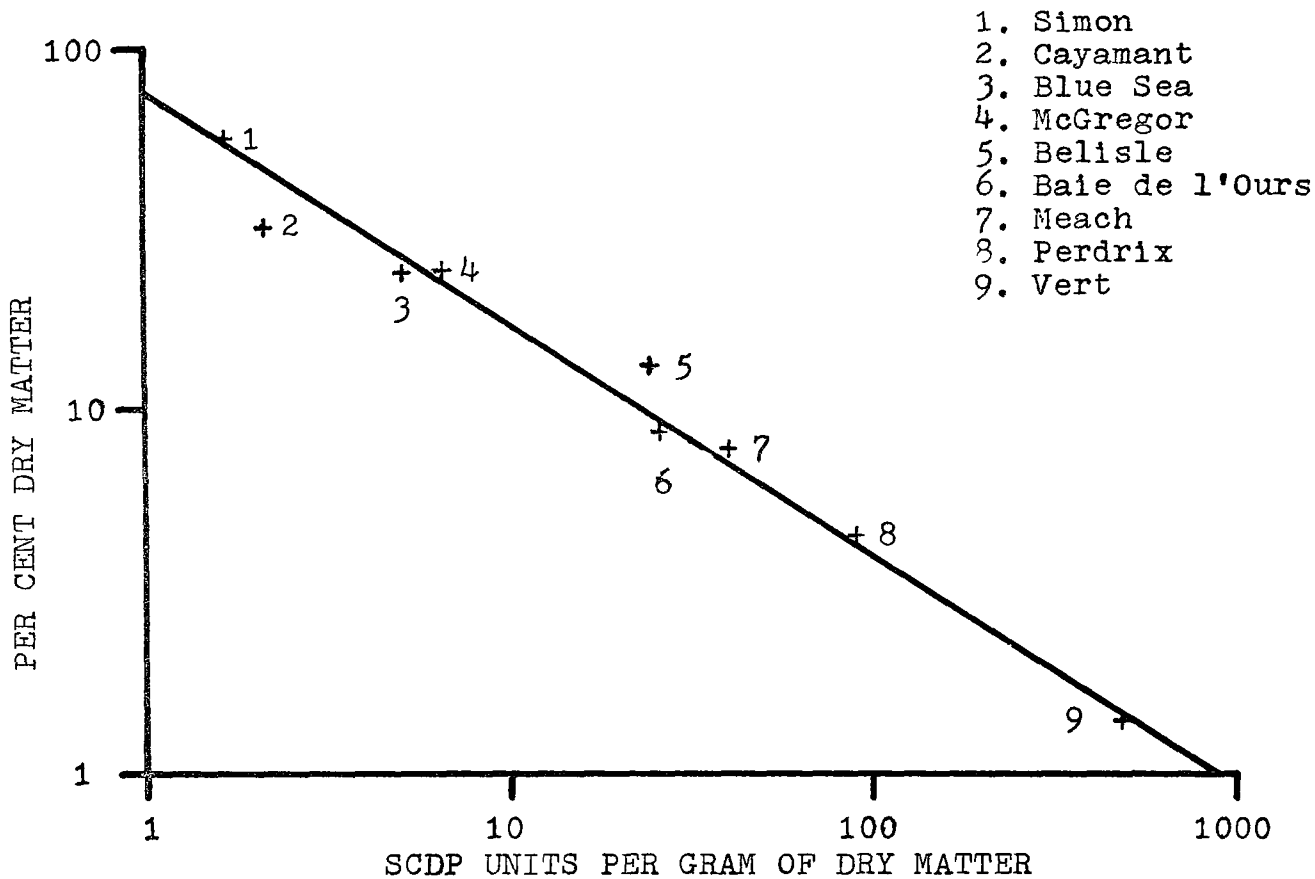


Figure 42. Logarithmic relation between the SCDP per gram of dry matter and the percentage dry matter from the bottom surface sediments of the 9 lakes from the Gatineau Area.

experimental and field research.

B. Fossil Samples from Deposits of the Kingston Region

1. Palynology

In recent years Quaternary paleoecologists have used pollen analysis extensively to reconstruct the paleophytogeography and the paleoclimatology of certain regions. This involves comparing modern pollen rain from a known phytogeographic unit to the fossil pollen assemblages preserved in sediments. As already mentioned in the introductory part of this thesis, several authors have recognized that an essential preliminary to the interpretation of fossil pollen spectra in terms of vegetation is a knowledge of the relationships between contemporaneous pollen assemblages and the prevailing vegetation around the sampling site. Furthermore it has been demonstrated conclusively by several workers referred to in this work that these relationships are complex, mainly because the production, dispersion and preservation of pollen vary widely among plant species. There is no simple, direct relationship between the composition of a forest and its pollen spectrum. Aario (1944), Gregory (1961), Tauber (1965), Janssen (1966), and Lichti-Federovich (1968) have shown that pollen grains can be transported through considerable distances (1000-2000 km) to quite dissimilar landscape regions.

Nevertheless several authors (Wenner, 1947; Martin and Gray, 1962; Bent and Wright, 1963; McAndrews, 1962; Ogden, 1961a;

Lichti-Federovich and Ritchie, 1965, 1969; Davis, 1967; Lichti-Federovich, 1968) have demonstrated that fossil pollen spectra can be correlated with regional landform-vegetation units and they have succeeded in reconstructing past vegetations from pollen diagrams.

Before proceeding to the possible correlation of the pollen zones with modern pollen assemblages, certain assumptions must be made and kept in mind:

a) That the same general species of plants which have existed through Quaternary time in the studied region have not significantly changed their ecological requirements.

b) That during the past, as now, physiological requirements of plants as well as their pollen production, dissemination and preservation stayed constant.

c) That the pollen spectrum counted in the laboratory from a sample is representative of the pollen rain at the time of sedimentation of the sample.

Assuming that the above assumptions are reasonable in Quaternary paleoecology, the basis for the interpretation of paleoclimate from pollen analysis can be stated as follows: Sustained changes within pollen spectra throughout a stratigraphic sequence are the result of changes in the surrounding vegetation in response to climatic oscillations or edaphic successions controlled by normal soil weathering and leaching.

Unfortunately the herb pollen zone, commonly found in most of the recently prepared pollen diagrams from New England, the Maritimes, some of the north-central states and in the Montreal area by Terasmae and Lasalle (1968), was not detected

in the pollen diagrams from the Kingston Region. This late-glacial zone, in which the herbaceous pollen percentage is generally higher than 50 per cent, is commonly interpreted as representing a treeless vegetation similar to the tundra or park-tundra which immediately followed the retreat of the ice between 10,000 to 14,000 years ago (Davis 1965, 1967). The reasons for the absence of this basal herb pollen zone from most of the pollen diagrams of the Great Lakes-St. Lawrence Region could be interpreted in various ways. Several authors have explained this absence by suggesting that warming up of the climate during the Valders retreat was too rapid and did not allow the formation of a wide treeless vegetation belt near the ice margin. The temperature gradient between the Gulf of Mexico and the ice margin during Wisconsin time, which was probably much steeper than today, also undoubtedly contributed to the minimization of this Arctic-Subarctic vegetation type. Even today the temperature gradient from Lake Erie to the Hudson Bay allows the vegetation to pass from a deciduous forest to the tundra within a distance of about 500 miles (800 km). Two other factors which certainly played an important part in the masking of this basal zone are:
a) where there is a cold, short growing season, as in the Arctic today, plants produce little pollen and, b) pollen types such as Pinus, Betula, Quercus, Corylus and others which are carried through considerable distances by wind, greatly reduce the importance of the local NAP producers. All these reasons which could have acted independently or collectively

are more than enough to account for the absence of a well-defined herb pollen zone at the base of the three pollen diagrams for the Kingston Region. This explanation is in accordance with the studies of Wright and Watts (1969) and Craig (1972) who used the more pertinent absolute pollen method to elucidate the vegetation history of Northeastern Minnesota.

Zone A-1

The bottom spruce zone A, subdivided by Deevey (1951) into A-1-2-3, is commonly found in the Great Lakes-St. Lawrence Region near the contact level between the inorganic-organic lake and bog sediments. In the A-1 zone, present only in the Grady Lake and Atkins Lake diagrams, the terrestrial NAP types are considerably inferior to the AP but their presence (18-20%) is of primary importance for paleoclimatologic interpretation. Various pollen and spore types, such as Salix, Alnus, Betula, Cyperaceae, Gramineae, Compositae, Saxifragaceae, Artemisia, Pteridophytes and Lycopodium, are generally all indicators of cold, moist conditions typical of the Subarctic open woodland. Most of these types are more abundant within the A-1 zone than in any of the others. If we maintain that the reasons given above for the absence of the herb pollen zone are correct, it is reasonable to believe that the A-1 zone which contains a high percentage of exotic pollen might represent the tundra or the forest-tundra that existed in the Kingston Region between the time of the ice retreat and 11,000 years ago.

The correlation of pollen zone A-1 with modern pollen spectra is difficult for two main reasons. First, few data are available on modern pollen rain in Northern Canada. The most detailed studies were done by Lichti-Federovich and Ritchie (1965, 1969) in Manitoba and the Northwest Territories. Davis (1967), using published data on modern pollen rain in Northeast America, succeeded in correlating some late-glacial pollen zones from New England with modern spectra from the Canadian Arctic and Subarctic. The second drawback in correlating the A-1 zone of the present study is that this zone is found in two diagrams only, and each zone is based on only two good spectra.

Attempts were made in vain to correlate these fossil pollen assemblages with surface spectra from Labrador, Northwestern Quebec and Central Quebec. Either spruces and NAP types or both were much too high. A more satisfactory correlation was found with the open coniferous landform-vegetation regions (of/2 and of(p)2) of Lichti-Federovich (1968). The characteristic average pollen spectrum of these regions is dominated by Picea (35%), Pinus (25%), Betula (15%), Alnus (20%), Cyperaceae (3%) and Ericaceae (1%). Even though Picea trees are much more common than Pinus at those stations, the latter makes up about half of the spectrum most of which is assumed to be transported through long distances.

Lichti-Federovich's regions correspond to Rowe's Northeastern Transition Section of the Boreal Forest, which he describes (1959) as an open subarctic woodland north of the closed coniferous forest. Within this section, unfavourable climatic conditions, thin soils over glacial drift and frequent fires reduced the distribution, abundance and size of the tree species. Areas of bog, muskeg and barren rocks are intermixed with open stands of dwarfed trees. Higher trees are sometimes found on sheltered soils. Upland sites are occupied by open spruce forests, Picea mariana on heavier textured glacial drift. On sandy sites and outcrop ridges Pinus banksiana is dominant and often associated with Picea glauca. Betula glandulosa, Vaccinium uliginosum, V. vitis-idea and Ledum dominate the ground vegetation. Other accompanying species are Betula papyrifera, Larix laricina, Populus tremuloides and P. balsamifera. The pollen types of these two last species were not present in any pollen diagram from the Kingston Region.

If we assume that the forest described above represents the vegetation which existed in the Kingston Region immediately after the retreat of the ice, it is not unreasonable to believe that the climate which characterizes this northern Manitoba forest at the present also existed then. In table 20 (p. 384) are listed some hypothetical climatic factors which have probably existed during this pollen zone-time. These data were read from climatic maps for the regions with which the fossil pollen assemblages of each zone were correlated (Fig. 43, p. 208).

Zone A-2

The decline in the terrestrial NAP types and shrubs, synchronized with the invasion of Picea mariana and P. glauca from zone A-1 to A-2, suggests a warming up of climate and the development of a closed spruce forest in the Kingston Region about 10,500 years ago. By comparing the fossil pollen spectra from zone A-2 with available surface pollen spectra, they were

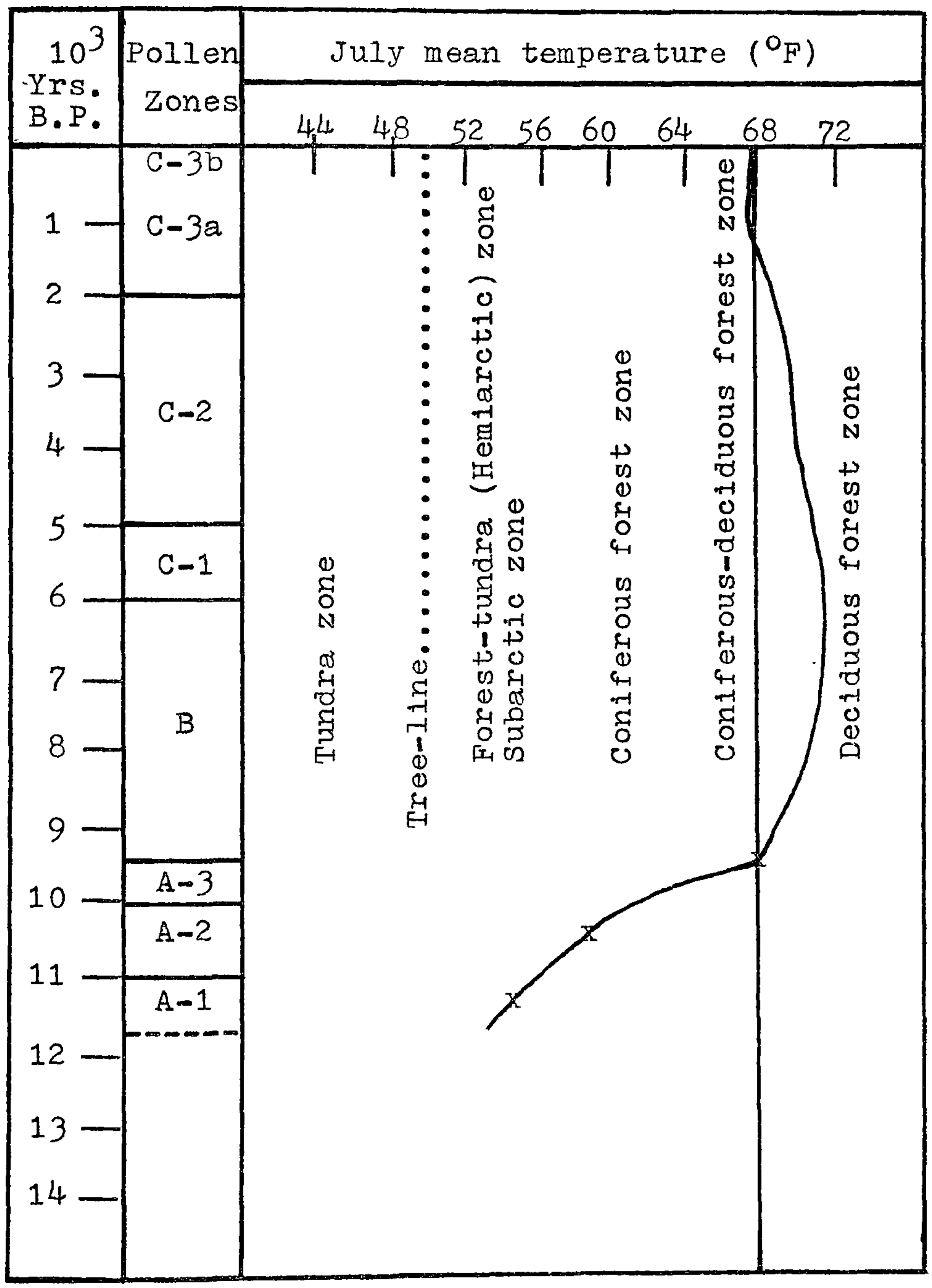


Figure 43. Proposed mean July temperature curve for Late-Quaternary times in the Kingston Region.

found to be similar to samples no. 6,7,8, and 9 of Potzger and Courtemanche (1956a) and sample no. 39 of Lichti-Federovich (1968). These five surface pollen spectra are all from the northern part of the Boreal Forest and close to the northern limit of the black spruce commercial range. The first four samples are all located within the Nottaway River drainage southeast of James Bay. Samples 6, 7 and 8 fall within Rowe's Northern Clay Section of the Boreal Forest (B. 4) and sample no. 9 is included in the Gouin Section (B.3). According to Rowe (1959) the vegetation of the B. 4 section is characterized by seemingly endless stretches of Picea mariana stands which cover the gently rising uplands as well as the lowland flats, alternating in the latter location with extensive sedge and peat bogs. Larix laricina is an infrequent companion of black spruce except in young stands where extensive areas of spruce-cedar swamp occur. Mixed wood stands composed of Populus tremuloides, P. balsamifera, Betula papyrifera, Abies balsamea, Picea glauca and P. mariana are found in the best drained area. Pinus banksiana has a dominant position on many of the drier sites and particularly within the Gouin Section which is similar to the Northern Clay Section in all other characteristics.

The other modern pollen assemblage which resembles the spectra of the A-2 zone is located (55°20'; 97°20') about 200 miles (312 km) northeast of Lake Winnipeg within the closed coniferous forest region of Lichti-Federovich. The characteristic pollen spectrum of this landform-vegetation unit is composed of Picea (42%), Pinus (37%), Betula (7%), Alnus (5%) and less than 1 per cent of all other AP and NAP types. The surrounding vegetation from which this modern pollen assemblage is derived is dominated by Picea mariana occuring on upland and lowland sites. Pinus banksiana, Betula papyrifera and Populus tremuloides are common stand dominants following fire. Well-grown commercially important stands made of Picea glauca, Abies balsamea and Populus tremuloides are found on alluvial deposits and local, heavy-textured soils with drift parent material (Rowe, 1959).

Assuming that similar types of vegetation are produced in similar climates we may conclude that the climate and vegetation now prevailing in these areas must be similar to the climate and vegetation that prevailed during the time the A-2 pollen zone was formed in the Kingston Region. Table 20 (p. 384) shows the important climatic factors which might have existed between 10,000 to 11,000 years ago in the region studied.

Zone A-3

At the end of zone A-2, in the Kingston Region the climate became warmer and drier favouring the introduction of southern species which in turn increased the competition and forced the spruce forest species to migrate North toward more favourable environments. Pines and some hardwood species invaded the region very rapidly. If the rate of sedimentation remained constant for the whole deposit of Grady Lake and Atkins Lake, the total duration of zone A-3 lasted 228 and 347 years respectively. These figures are of the same order of magnitude as the ones obtained by Davis and Deevey (1964) from

Roger Pond in Connecticut and by Farnham and others (1964) from Lake Aitkin in Minnesota. It is evident that the rate of sedimentation of the Cataraqui River Marsh deposit did not stay constant through all this time and no figures could be derived from it. Although the figures given above are tentative, it is not unreasonable to believe that the shift from a dominance of 50 per cent of spruce pollen in the A-2 zone to a dominance of 65 per cent of pine in the B zone reflects a rapid climatic warming approximately 10,000 years ago in the Kingston Region. This rapid climatic change supports Ogden's (1967) idea that a sudden change in climate about 10,000 years ago initiated the retreat of the Valders ice in the Great Lakes Region.

Since the A-3 zone was a very short transitional interval, no attempt was made to correlate it with present vegetation and climate. The ecological conditions probably were intermediate between the vegetation and climate types found in the A-2 and B zones.

Zone B

The typical pine period represented by the B zone is distinguishable in all Eastern North American pollen diagrams and characterized by a marked dominance of *Pinus* pollen. *Quercus* and *Betula* are the most important hardwood pollen types, and *Tsuga*, *Ulmus*, *Fraxinus*, and *Acer* are tree species which are greatly underrepresented in the pollen spectra. Pine species were probably growing abundantly at that time on dry sites of the Frontenac Axis and on sandy Champlain Sea beaches which are quite numerous east of Atkins Lake.

Jack pine, birch, fir and alder appear to have been important elements in the early part of this B zone, whereas white, red and, possibly, pitch pines along with oaks were predominant in the latter part. These results are similar to the ones obtained by Davis (1958, 1960), Whitehead and Bentley (1963) who distinguished a lower B-1 subzone and an upper B-2 subzone on this basis. These results suggest that climatic changes toward warmer and drier conditions during the pine period, which lasted from 9,500 to 6,000 years ago, were not as rapid as in the preceding zone. It also indicates that the oak, which migrates at a slow rate, replaced more typical boreal species at a much later time than pines replaced spruces.

Deevey and Flint (1957) showed that the lower part of the pine zone marks the beginning of postglacial time and recognized an early warmer period prior to our present climate on the basis of pine pollen assemblages. This warmer period was called the hypsithermal and included pollen zones B, C-1 and C-2 (approximately 9,000-2,000 years ago). Results found in the Kingston Region within the B zone are similar to those obtained in other areas of Northeastern North America.

McAndrews (1966) did not succeed in correlating fossil pollen assemblages from the pine period with any modern pollen spectrum and he concluded that no equivalent forest and climate exist today in North America. Davis (1967) was more optimistic and found some resemblance between the B zone assemblages and the modern pollen rain from Central Canada and Northeastern

Minnesota. She matched the early part of the B zone with the modern pollen spectra from the Lake Timagami Region (King and Kapp, 1963) and with the one from the Gatineau Valley (Terasmae and Mott, 1964), all located within the Great Lakes-St. Lawrence Region. The writer believes that better correlations exist with the samples of King and Kapp located between the west part of Lake Ontario and Lake Simcoe. The area is included on the boundary between the Deciduous Forest to the south and the Great Lakes-St. Lawrence Region to the north (Fig. 11, p.37). This matching is more realistic because of the very low values of spruce pollen which are comparable to their values in the B zone. Another possible correlation of the spectrum from the lower part of this zone exists with the modern pollen rain of southeastern Manitoba which was extensively studied by Lichti-Federovich and Ritchie (1965) and Lichti-Federovich (1968). This area falls within section number 12 of the Great Lakes-St. Lawrence Forest Region and within the Whiteshell Forest Area of Manitoba. It is dominated by Pinus banksiana which replaced Pinus strobus and P. resinosa after logging and after forest fires. Poorly drained sites are occupied by Picea mariana, Larix laricina and Thuja occidentalis. Other associated species are Abies balsamea, Populus balsamifera, P. tremuloides, Ulmus americana, Tilia americana, Acer negundo and Quercus macrocarpa.

By referring to the climate of Southeastern Manitoba, where the pine forest described above has been developing and which is believed to resemble the forest type which prevailed in the Kingston Region at least during the first part of the B zone period, it is impossible to conclude that the B zone climate was warmer than the present existing one. The only climatic factor which may partially support this hypothesis is that the average annual precipitation is 254 millimiters less in Southeastern Manitoba and probably favoured the development of a pine forest in that particular area. The distribution of the precipitations during the growing season is quite the same in both regions. All other climatic factors from that area indicate a cooler climate than the one prevailing in the Kingston Region.

The present climate in the area south of Lake Simcoe, where the modern pollen rain is more or less similar to the one which existed during the B zone time, also does not account for the development of an extensive pine forest.

Perhaps we should conclude that no modern forest equivalent to the one that prevailed during the B zone is found today , or that there were frequent fires, diseases, absence of competition from pines, or that the ecological requirements of the pines during this period were not the same as today. It is also possible that Populus and other tree species which have poorly preserved pollen were more important in the former forest. Such species may have contributed to the overrepresentation of pine pollen in the diagram by differential pollen preservation through time. Proposed explanations have not yet been satisfactory.

Zone C-1

In the overlying C-1 zone, which was formed approximately 6,000 to 5,000 years ago in the Kingston Region, hardwood species such as Tsuga, Quercus, Fraxinus, Betula, Acer, Tilia and Ulmus became well-established and replaced most of the pine forest. These changes in the forest components indicate a shift toward a moister climate. This is also corroborated by the abundance of pollen within this zone and by pollen and spore types such as Ilex, Cephalanthus, Osmunda and Sphagnum. The vegetation was not very different from the present one in Southern Ontario and can be compared to that of L. 4c Section of the Great Lakes-St. Lawrence Forest Region described above (Fig.11

Zone C-2

Within zone C-2, which ended about 2,000 years ago, the decline of Tsuga, Ilex, Potamogeton, Cephalanthus, Osmunda and Sphagnum all indicate that this period had the warmest climate in postglacial time. In the Cataraqui River Marsh diagram, the decrease of several aquatic plants and the increase of terrestrial NAP from zone C-2 toward the top of the profile may suggest a lowering of the Lake Ontario water level by 1 to 2 meters or the gradual filling up of the marsh by organic matter.

Zone C-2/C-3 boundary, which is about 2,000 years old, and which shows a change in climate from a warm-dry to a cool-moist condition in the Kingston Region, might coincide with the beginning of the Sub-Atlantic time in Europe estimated at approximately 600 B.C. (Granlund, 1932). This boundary also marks the end of the hypsithermal interval in North America.

Zone C-3

In zone C-3 the return of boreal species such as Abies and Picea are indicators of a deterioration of climate toward cooler and more humid conditions. The presence of Pinus banksiana synchronized with the decline of most thermophilous tree species also indicates this deterioration. Slight increases in Artemisia, Ambrosia, Compositae, Cyperaceae and Typha are other good indicators. For some unexplained reason the dinoflagellates, which disappear completely in the middle of the C-2 zone of Grady Lake, reappear in the middle of the C-3a, and diatoms and algae disappear almost entirely.

A sharp increase in several terrestrial NAP types synchronized with the return of Picea mariana and Alnus and the decline of most other tree species characterizes the C-3b subzone and probably shows the effect of early settlers and present urbanization on the ecosystem. The top (30-50 cm) of the profiles represents sediment accumulation during the last 200 years or so.

2. Malacology

To facilitate the following discussion, the malacological zones will be discussed in respect to the chronology starting with the oldest events (Fig. 17, p. 96).

The complete absence of molluscs within zone M-8 is attributed to unfavourable climatic conditions. As indicated in the discussion of the pollen diagrams, glaciers were melting in the Kingston Region and the climate was of the subarctic type between 11,000-13,000 years ago. Vegetation was poorly established on the glacial sediments, the forest was open, and the runoff carried a heavy load of silt and clay into the lakes. The molluscan migration was probably slower than the retreat of the ice and molluscs may not have colonized the newly deglaciated habitats immediately after this event.

In zone M-7, which is contemporary with the pollen zones A-2, A-3 and with the lower part of the B zone (Fig. 46, p. 230) 17 different molluscan taxa invaded Atkins Lake due to more favourable ecological conditions. The gradual increase in diversity and abundance of fauna within the bottom third of the diagram shows that, even if the climate warmed up very rapidly from pollen zone A-3 to B, the mollusc fauna did not respond to any great extent. It is quite evident from elementary ecology that the aquatic environment, on account of the high specific heat of water, is much more stable than the terrestrial one. The writer believes that a greater abundance of Valvata tricarinata tricarinata, Pisidium nitidum and P. ventricosum within the lower part of the M-7 zone cannot be correlated directly to any regional climatic fluctuation. Several authors (Cornejo, 1961; Roy, 1964; Shallom, 1965; Clowers, 1966; Gibson, 1967; Warner , 1968) studying postglacial fossil aquatic molluscan assemblages have described warmer or colder climatic changes, but they have not specified quantitatively the variation in climate. A cold or warm climate certainly does not mean the same temperature to an Eskimo from the Canadian Arctic and to an Indian from Arizona. It would be illogical to try to interpret minor regional climatic changes over a long period of time by using fossil aquatic molluscan assemblages among which several species have a present distribution covering the whole of North America. Even the combined use of different types of analyses does not make the paleoclimatic method accurate.

Aquatic molluscan assemblages are more closely related to substrate and to water chemistry than to any other factors. This is well illustrated in the molluscan diagram of this study, especially by zones M-4 to M-7 which are based mostly on the stratigraphic abundance of different forms of Valvata tricarinata[1]. The presence of one or several keels is correlated mostly with the marly sediment unit. Presence of marly sediments within the B pollen zone could be explained by an increase in photosynthetic activities of phytoplankton and aquatic macrophytes which in turn have increased their biogenic $CaCO_3$ precipitation during growth in warmer and longer seasons. Ruttner (1953) reported that 100 kilograms of fresh Elodea canadensis precipitated 2 kilograms of $CaCO_3$ in a day with 10 hours of sunlight. Since the removal of CO_2 and HCO_3^- by photosynthesis is greater than the quantity returned

[1]See appendix for systematic discussion Valvata tricarinata forms.

by the respiration of organisms at night, the epilimnion becomes impoverished and precipitation of $CaCo_3$ results. Based on the stratigraphic analysis of the mollusc fauna alone the time period corresponding to the marl unit (248-343 cm) may be interpreted as having a high primary productivity and high pH. According to the stratigraphic geochemical analysis of the sediments (Fig. 23, p. 127, 26, p. 141), an opposed type of paleoenvironment can be deduced for this particular interval. The parameters analyzed such as pH, ignition loss, N and SCDP tend to indicate a low productivity and pH for the paleoenvironment corresponding to the marly unit of Atkins Lake. Recent limnological studies by Wetzel (1965, 1966b) on marly environments strongly support the last hypothesis.

One of the most peculiar findings of this work lies in the great similarity between the stratigraphic distribution curve of total molluscs and that of the wavelength absorbance ratios 448/670, 410/670 and 350/670. All these curves are more or less identical. At present it is impossible to formulate any valuable explanation. A more detailed study of this particular phenomenon oriented toward the diversity index of Margalef (1968) should be considered.

Apart from the water chemistry which influenced the invasion of the lake by molluscs, migration routes also played an important role. It is interesting to note that the molluscs invaded Atkins Lake only after the maximum submergence (Lasalle, 1966; Elson, 1969a,b) of the Champlain Sea. This body of sea water had its western limit just east of Atkins Lake and may have affected the site at least during wind storms. If we analyse the mollusc species distribution and the assemblages found by various authors in postglacial deposits from Quebec, Ontario, Maine and Wisconsin (Table 18, p. 373) we find two distinct groups. Assemblages from Wisconsin and Ontario, including Atkins Lake fauna, have more species in common than those from Quebec and Maine. This is especially true for Amnicola limosa, A. lustrica, Anodonta fragilis, Helisoma anceps striatum, H. campanulatum, H. trivolvis, Physa gyrina, P. heterostrostropha, Pisidium compressum, Sphaerium lacustre, Stagnicola desidiosa and Valvata tricarinata. The particular distribution of these species suggests that the Champlain Sea acted as a post glacial migration barrier and that the species which invaded the lake migrated early from the south and southwest via the Great Lakes water system (La Rocque, 1969b).

The replacement of early invaders by Amnicola campanulatum, Helisoma campanulatum, H. anceps and Fossaria obrussa decampi in zone M-4 indicated a gradual decrease in the water level and luxuriant aquatic vegetation. This resulted in reduction of the pH of the water as well as in the reduction of marl precipitation.

Within zone M-3, the environment was too acid and too poor in calcium carbonate to allow extensive development of molluscan fauna. It is impossible to tell what proportion of the shells, if any, have been dissolved since the death of the molluscs. This eventuality may be overlooked by molluscan paleoecologists and interpreted simply as a drastic change within the environment.

The great numerical increase in most of the taxa within zone M-2 suggests a considerable reduction in the rate of sediment accumulation which concentrated the shells at this particular level. This explanation is also implied primarily by the C-14 date of 1020 years for the middle of the zone, which first appears to be much too old for this depth, and secondly by the compression of pollen zone C-3a. The high percentage of Amnicola lustrica and Fossaria obrussa decampi indicates a firmer lake bottom during that time, whereas the relative low percentage of Gyraulus parvus suggests poor growth of aquatic vegetation.

The zone M-1, including the top 53 centimeters of sediment, which coincides exactly with the C-3a pollen zone (Fig. 46, p. 230) is believed to have started close to 1830 with the arrival of early settlers. Compared to the average rate of sedimentation of the whole organic deposit (0.32 mm/year) the sedimentation rate of this zone is found to be 10 times greater. Although the time-compaction factor is not considered, it is more than enough to explain the low counts per unit volume of the shells in this upper zone; in other words, the molluscs were diluted in a greater volume of sediment.

Cornejo (1961), Roy (1964), Shallom (1965), Clowers (1966), Gibson (1967) and Warner (1968) found a similar reduction in the number of mollusc shells near the top of their section but were unable to correlate it with deforestation by early settlers. In this top zone the molluscan fauna also decreases with the increase of Pb concentration found in the lake sediments (Fig. 17, p. 96). It is a fact that Pb concentration has already reached a critical level for survival of many water birds and that it may affect most of the lake organisms including molluscs. Although ammunition companies have changed the chemical composition of bullets (this could very well explain the concentration of 150 ppm each for the top two chemical spectra) other sources of Pb as gasolines and paints might still contribute to an increase in Pb concentration in the biosphere to a level which is dangerous for several living organisms.

3. Geochemistry

In the following discussion general chemical and pigment results of fossil samples from the 3 Kingston Region sites are treated together and are related to their respective pollen sequences. The advantages of this procedure are not only simplicity and conciseness but also the emphasis on the relationship between the stratigraphic general chemistry of each deposit and its pigment content which are probably controlled by the same general ecological factors.

To maintain objectivity each system of zones was established independently following the basic principles used in the pollen zone system. The pollen stratigraphy is used as the reference system for each site.

a. Cataraqui River Marsh

In the two types of diagrams (Fig. 21, p. 114, 24, p. 134) the basal stratigraphic interval (417-472 cm) reflects an open aquatic environment with high turbidity and very low primary productivity. Within that period which more or less covers the general chemical zone CGC-8 and pigment zone CP-6 (Fig. 44, p. 224), the Boreal Forest was gradually establishing itself in the Kingston Region and was still poorly controlling the erosion of newly deposited sediments. The load of inorganic particles carried down by the river and deposited at the present location of the Cataraqui River Marsh was relatively heavy. Most of the parameters characteristic of a specific type of environment in the study of the bottom surface samples from the Gatineau Area lakes support this paleoenvironmental interpretation. The fact that P and ratio Ca/Mg have high values at the bottom of the Cataraqui River Marsh profile while they are found to correlate positively with the intensity of productivity might be related to their ionic behavior with the clay particles.

The stratigraphic interval (251-417 cm) including zones CGC-6, CGC-7 and CP-5 correlates with the pollen zones A-3 and A-2 which represent an open water environment with about one meter of water and floating aquatic plants. The transport of inorganic particles down the Cataraqui River to Lake Ontario has decreased relative to the previous interval. Some parameters such as ignition loss, ratios C/N, Ca/Mg and Ca+Mg/K+Na characterizing zone CGC-7 suggest that primary productivity was slightly more important as compared to the upper part of zone CGC-6. This increase in productivity is not as

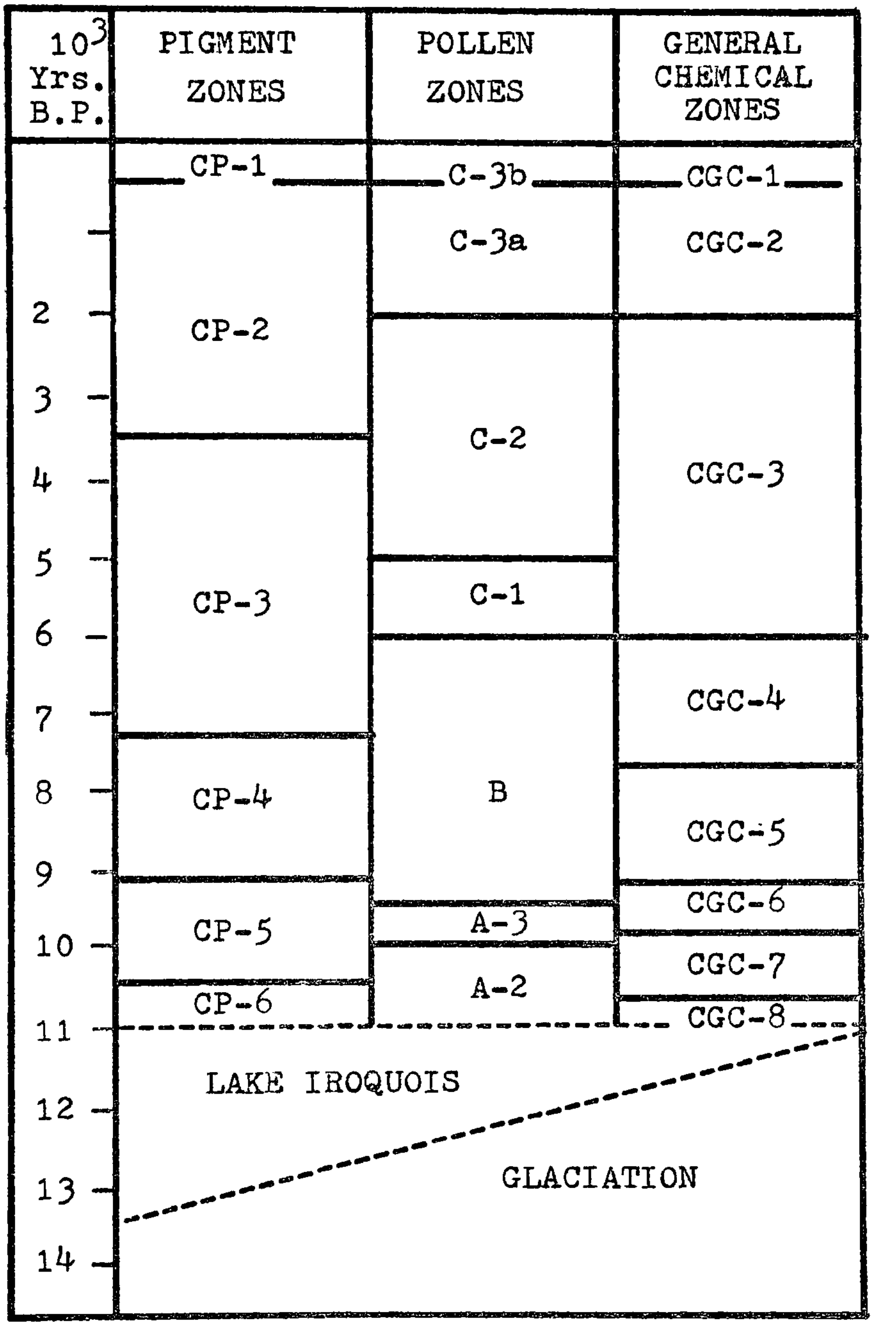


Figure 44. Correlation of the different zone systems of the Cataraqui River Marsh deposit.

evident in the pigment diagram but parameters such as SCDP per gram of dry weight, SCDP per gram of ignition loss, absorbance ratios 410/350 and 448/350 also support this fluctuation. The gradual decrease in primary productivity within zone CGC-6 could be explained by a gradual loss of the nutrients to the sediments as well as to the drainage system. Cowgill and Hutchinson (1970) arrive at similar conclusions in their work on the history of Lago Di Monterosi.

The drastic changes within the general chemical zone CGC-5 and pigment zone CP-4 were probably brought about by a complete filling up of the site by organic sediments. These changes could also be related to a lowering of the water level in Lake Ontario possibly due to the warmer and drier climate which is believed to have prevailed at that time. During this time interval floating plants disappeared and were succeeded by plants such as Polypodiaceae, Osmundaceae and Sphagnum which are characteristic of a more boggy environment. The total biomass of the environment increased substantially while the proportion of the chlorophillous carbon is close to its minimum. The density, water content of the wet sediments and ignition loss of the dry sediments reflect an important general reduction in the sedimentation rate of the inorganic particles. The sharp peaks of these parameters toward the upper part of zone CGC-5 and CGC-4 were probably caused by the flooding of the environment which covered the river bank with mud.

Within zones CGC-4 and CP-3 the environment becomes quite acid and shows some signs of boggy environment. Upward from these zones conditions which reflect the present state of the marsh become more important.

At the very top within zones CGC-1 and CP-1 correlating with pollen zone C-3b the important fluctuations exhibited by many variables are probably the direct result of human disturbance of the ecosystem.

b. Grady Lake

The basal interval of Grady Lake profile, which includes zone GGC-6 of the general chemical diagram (Fig. 22, p. 121) and zone GP-8 of the pigment diagram (Fig. 25, p. 138) both correlating with the A-1 pollen zone (Fig. 45, p. 227), reflects a cold inorganic aquatic environment. Immediately after the retreat of ice from Grady Lake basin about 11,000 years ago, a water body, heavily loaded with clay minerals and supporting minor life activities, existed for close to 1,000 years. The pollen analysis demonstrates that, at that time, the climate was of a subarctic type. Since the growing season during that period probably was very short, the colonization of this aquatic environment must have been relatively short for the different types of organisms.

Several fluctuations occurring within zones GGC-5, GP-7 and GP-6 are particularly interesting. Within zone GGC-5 (855-1015 cm) cations such as K, Na, Ca and Mg reach a high concentration at the 900 centimeter level. All these cations correlate positively with primary productivity in the Gatineau Area lakes studied. At the same time in zone GP-7, the SCDP per gram of dry weight and SCDP per gram of ignition loss

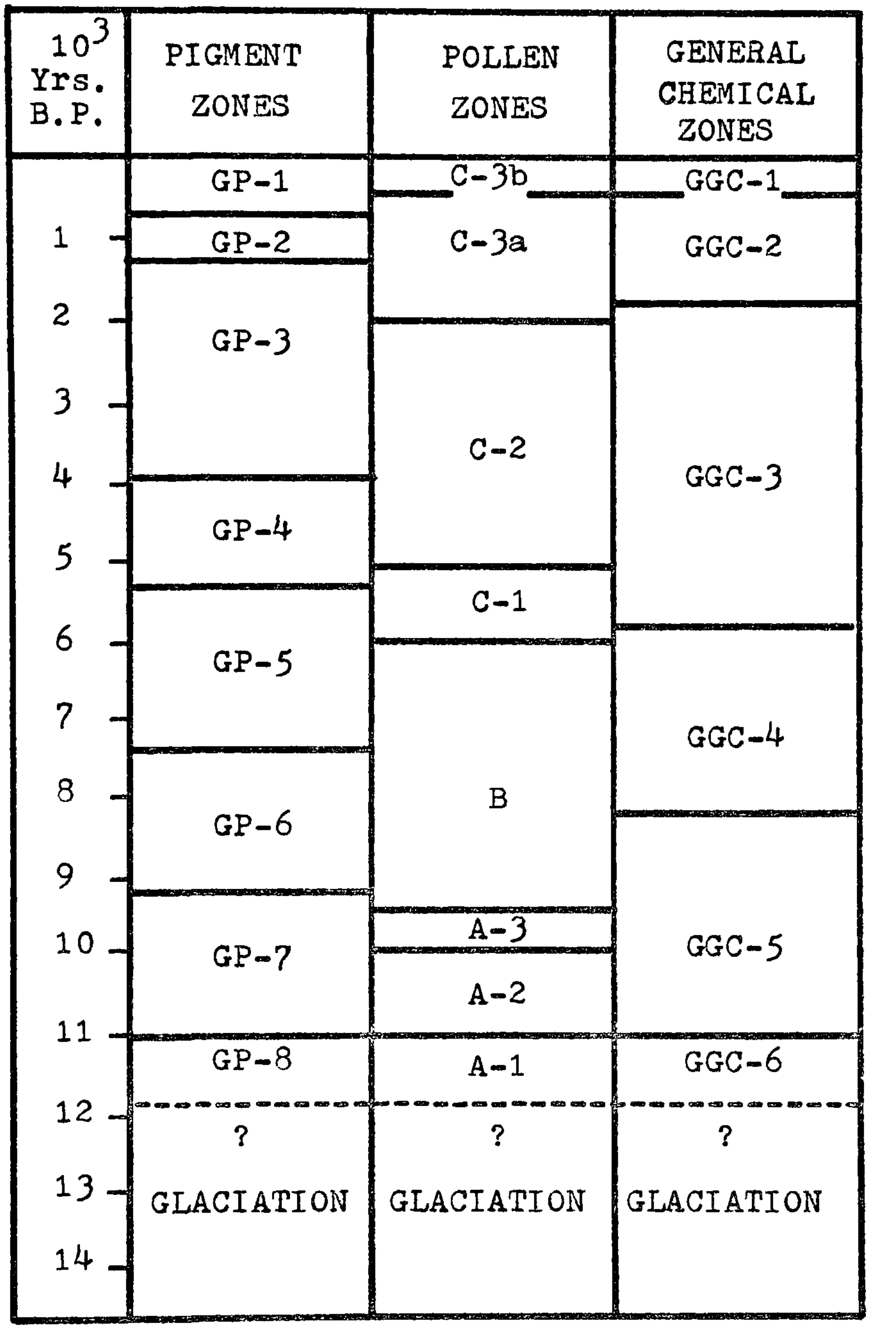


Figure 45. Correlation of the different zone systems of Grady Lake deposit.

seem to indicate a great increase in primary productivity at the 10 meter level which then decreases around the 9 meter level. These fluctuations are quite similar to those previously described in the Cataraqui River Marsh diagram. These geochemical fluctuations tend to suggest an early stage of greater eutrophication because of an abundant quantity of new nutrients washed into the lake during the Boreal Forest period. Later on, the rapid depletion of nutrients by organisms or their gradual loss in sediment or through the drainage system might have reduced the productivity during the B pollen zone interval.

The sharp pH fluctuation curve within zone GGC-5 might be a result of post-sampling bacterial activities. Several parameters such as ignition loss, N, C/N, K, Na, Ca, Mg, SCDP per gram of dry matter, SCDP per gram of ignition loss and absorbance ratio 410/350 suggest another increase of primary productivity around the C-1/B boundary pollen zones followed by a gradual decline down to the lower part of the C-3a pollen zone. The establishment of more deciduous species within the area could be related to this period of higher productivity. At the moment there is no definite acceptable explanation for the increase in importance of several parameters occurring in zones GGC-2 and GP-2. Since the C-3a pollen zone is usually interpreted as a time interval of climatic deterioration, it is difficult to relate this greater productivity period to a more favourable climate. A greater diversity of vegetation caused by the reinvasion of some boreal species from the north is a highly hypothetical explanation for this period of greater organic productivity. The GP-1 zone, which started before the C-3b and GGC-1 zones, could be attributed to the logging industry which preceded deforestation for agricultural purposes. As a result of the removal of some commercial tree species in the vicinity of the lake, the SCDP decreased and more nutrients were washed into that lake because of erosion.

c. Atkins Lake

aa. General chemistry and SCDP

The bottom zones AGC-7 of the general chemical diagram (Fig. 23, p. 127) and AP-7 of the pigment diagram (Fig. 26, p. 141), correlating relatively well with the other zone system of Atkins Lake (Fig. 46, p. 230), are interpreted as a subarctic lacustrine environment low in primary productivity.

Zones AGC-6 and AP-6, corresponding stratigraphically to the period of maximum development of the Boreal Forest within the area, seem to represent a time of rapid increase in primary productivity probably due to greater nutrient abundance. In the overlying period which includes AGC-5 and AP-5, primary productivity of the deposit decreases most probably because of the loss of nutrients to the sediments and through the drainage system. The alkalinotrophic stage of Atkins Lake reflected by the sedimentary marl unit and correlating with the B pollen zone is considered as a relatively low productive period. This low productive alkalinotrophic stage is supported by Wetzel (1965). He shows that the low levels of algae productivity and associated low quantities of dissolved organic matter in extremely calcareous marl lakes are brought about by a circular causal system

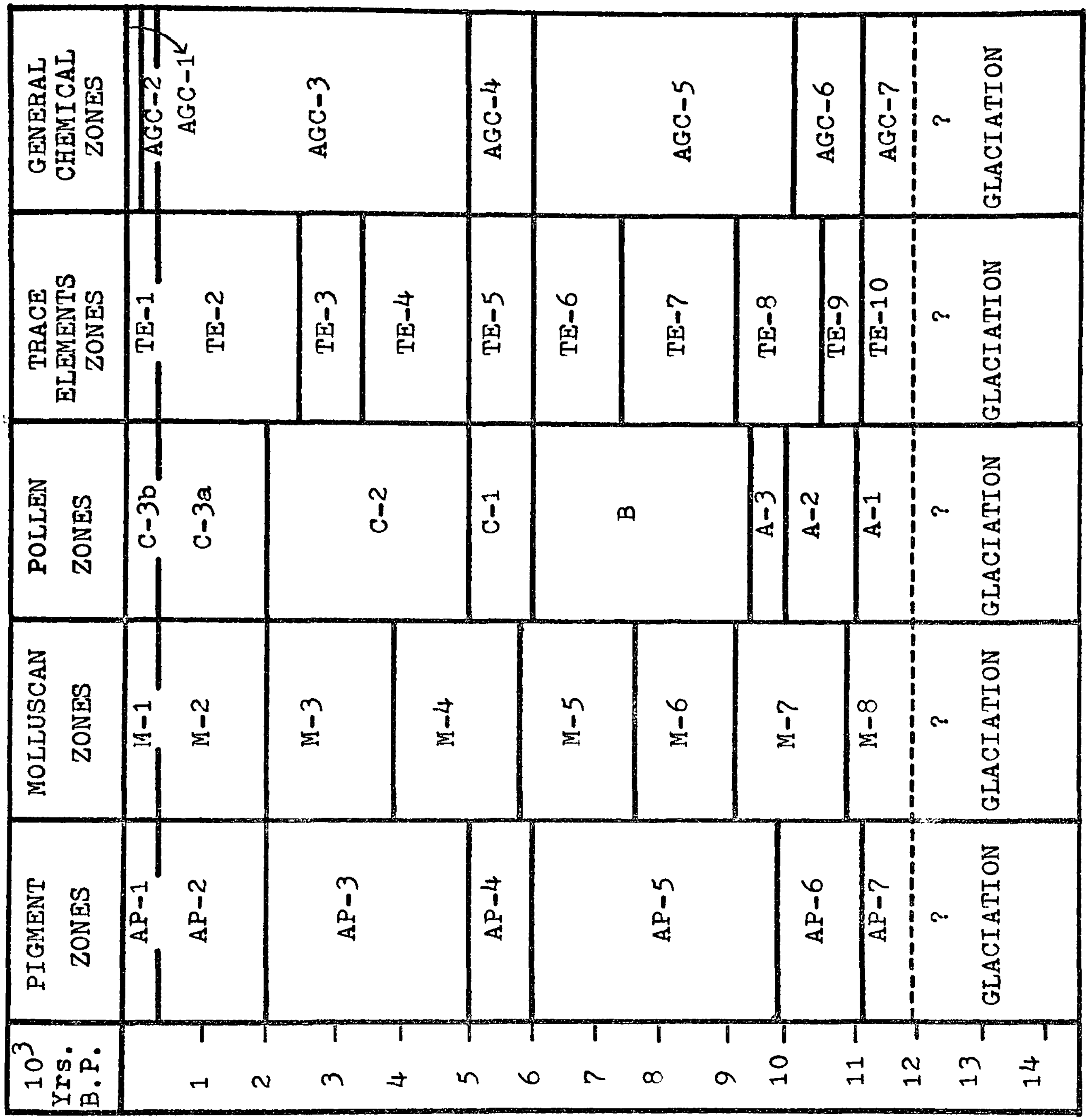


Figure 46. Correlation of different zone systems of Atkins Lake deposit.

perpetuating low rates of growth. This situation was found to be compounded by physiological unavailability of several inorganic nutrients present in insoluble forms throughout most of the year.

Zones AGC-4 and AP-4 marking the end of the alkalinotrophic stage of the lake probably reflect an interval of substantial increase in primary productivity. The fundamental causes of these changes are quite obscure. However, the more humid climate generally accepted as characterizing the C-1 pollen zone might be related to these changes.

In the period represented by zones AGC-3 and CP-3, several variables tend to indicate a higher productivity which would have prevailed during the C-2 pollen zones. This greater rate of growth drops rapidly within zones AGC-2 and AP-2. This lower trophic level is particularly reflected by: (a) high N, Mg, Ca/Mg, Ca+Mg/K+Na, (b) high SCDP per gram of dry weight, (c) high SCDP per gram of ignition loss and (d) high absorbance ratio 448/670. It is interesting to note that the curve of ratio 448/670 and that of 410/670, which correlate positively with the stratigraphic total abundance of molluscs, correlate inversely with the parameters believed to be good indicators of accentuated growth. The drastic changes within zones AGC-1 and AP-1 are attributed to the action of man on the ecosystem. As in the Grady Lake deposit, zone AG-1 of Atkins Lake, stratigraphically equivalent to pollen zone C-3b, correlates with AGC-2 rather than AGC-1. Moreover, erosion probably started to increase significantly only after the clearing up of the area for agricultural purposes rather than immediately after the first cut of some commercial timber species.

bb. Trace Elements

In order to simplify the following discussion of the trace elements diagram (Fig. 18, p. 101) each zone is discussed separately beginning with the lowest one.

Zone TE-10

This zone represents the oligotrophic stage of the lake which followed the melting of the ice in the region and ended about 11,000 years ago. Since vegetation was quite scarce during that time, runoff transported considerable quantities of inorganic sediments into Atkins Lake. High concentrations of most trace elements in this basal zone are related to the physico-chemical relations of the elements with the silicious allochthonous sediments. Perel'man (1967) reports that several Russian workers have shown that the silty and the clay fraction of soils are enriched in Ti, Cu, Zn Co, and that these fractions carry 60 to 80 per cent of the total microelements contained in the underlying rocks. The small amounts of B, Pb, Cu and Sr are probably indicators of their concentration in the underlying dolomitic limestone of the lake drainage basin. Moreover, the high solubility of these elements in a humid climate (Goldschmidt, 1954) suggests their ready loss in ionic form and might account for their reduced abundance in late-glacial sediments.

Zone TE-9

Of 12 trace elements represented in the diagram, 9 reach their maximum concentration within this zone. If the unique spectrum in this zone is representative of the chemical composition of the marly gyttja stratigraphic unit, several possible factors could have contributed to these strikingly high values:

a) The lower part of this zone, corresponding with the A-1/A-2 boundary of the pollen diagram (Fig. 46, p. 230), indicates that 11,000 years ago a dense spruce forest invaded the area and increased the biomass of the region. The spruce forest contributed to a considerable decrease in inorganic lacustrine sedimentation and an increase in organic sedimentation. Mortimer (1942) demonstrated that organic sediments at the bottom of lakes have reducing properties. The presence of dark clay gyttja bands between 367-377 centimeters suggests that a reducing environment existed and favoured precipitation of most of the less soluble ions, possibly producing these maximal concentrations of trace elements.

b) Diffusion and migration of chemical elements both vertically and laterally in the vicinity of a nonporous silty clay sedimentary layer could also have contributed to these maxima.

c) It is interesting to note that this zone, TE-9, correlates with the high water level phase of the Champlain Sea (Elson, 1969a, b; Prest, 1970) which nearly reach the Atkins Lake basin (Fig. 2, p. 18). Keith and Degens (1959) and Goldschmidt (1954) have shown that B, Mn, Ti, V, Zr and Sr are more abundant in marine sediments than in freshwater mud. These trace elements could very well have been brought within the lake drainage during occasional high windstorms. Unfortunately no comparable data are available at the moment. The writer suggests that trace element investigations of the Champlain Sea sediment be undertaken to estimate the paleosalinity distribution of this late-glacial inundation.

Zone TE-8

This transitional zone marks the beginning of the alkalinotrophic stage of the lake. The explanations given above for the previous zone are also valid for the high amount of trace elements found within this zone. The concentration was not, however, high enough to affect the establishment in the lake of a typical freshwater molluscan fauna. The general decreasing trend of the trace element concentration, which was faster for some elements such as Ba, Mn and Sr, is probably related to their biochemical and physico-chemical properties. As shown in the trace element diagram (Fig. 18, p.101), the productivity of autochthonous sediments within this TE-8 zone increased considerably and consequently reduced the relative importance of trace elements typically concentrated by terrestrial plants. Boron is a good example of this type of element.

Zone TE-7

Zones TE-7 to TE-5 inclusively, which correlate with the alkalinotrophic stage of the lake, are delimited by minor oscillations in the element concentration curves and are extremely difficult to interpret as specific paleoecological events. Titanium, Zr, Cu and Ni, which characterize zone TE-7, all show parallel distribution curves, probably produced by similar chemical reactions of the ionic forms of the elements. It is interesting to note that Ti and Zr are quadrivalent positive ions while Cu and Ni are grouped side by side in the periodic table of elements. For the time being, because of the lack of comparable investigations, it is impossible to relate these environmental changes in chemistry directly to the dry-warm climate of the early pollen Pine Period (B-1).

Zone TE-6

Within this interval, contemporaneous with the upper part of the pine pollen zone (B-2) and with the laminated marl unit, several trace elements reached their minimum concentrations. The absence of plant debris, in which several elements are concentrated, could account for these minima. Most of the sediments consist of marl which is biologically precipitated on aquatic plants through photosynthesis activities.

Copper is the only element that reaches a maximum concentration within this zone. Goldschmidt (1954) reported that copper ions were precipitated in a dry climate and carried to the sea in a humid climate. The two copper maxima coincide with the B and C-2 pollen zones which are believed to represent dry-warm interval (Fig. 46, p. 230); on the other hand the C-1 zone represents a more humid climatic interval corresponding to a minimum in the stratigraphic abundance of Cu. If this particular stratigraphic distribution was found to be constant in other deposits, Cu might be used as an index of humidity.

Zone TE-5

This unit reflects the alkalino-eutrophic transitional stage of Atkins Lake and is equivalent to the C-1 pollen zone. The presence of more organic matter in the lake sediments increased the reducing power of the environment and precipitated more Sr, Ni and V. Arnon and Wessel (1953), investigating the micronutrient requirements of algae, found that V was essential for green algae. These authors also demonstrated that 16 other elements, added jointly to the vanadium-deficient cultures, failed to substitute for V. It is possible that the green algae were more numerous in Atkins Lake during this interval and account for V concentration. This hypothesis is supported by the diatoms and algae in the pollen diagram of Atkins Lake. These organisms are more abundant within the C-1 pollen zone contemporaneous with the TE-5 trace element zone (Fig. 46, p. 230). Although there is no actual evidence of the indispensability of V for plants other than green algae, this element is widely distributed in the plant kingdom. Of 62 species analyzed by Bertrand (1942), all contain V.

Zone TE-4

This interval probably indicated the beginning of a more productive eutrophic stage of the lake and is well delimited by fluctuations in the curves of B and Cu. It has been established that B and Cu are essential micronutrients for higher plants. Boron is one of the rare elements which is more abundant in plants than in soil. Wallace (1951) found that B had a concentration of 5,000 parts per million in beech wood, whereas the soil on which it was growing contained only 10 parts pwe million. This accumulation of B by higher plants is well illustrated by its stratigraphic distribution. Its concentration passed from 10 parts per million within the marly units to approximately 60 in the gyttja sediments.

Zone TE-3

This interval is characterized mainly by a small culmination of Zr which is known to be very weakly concentrated by organisms. This zone also corresponds to the molluscan zone M-3 (Fig. 46, p. 230) within which the molluscan fauna declined almost to nil. A more complete chemical analysis of the sediments might have provided possible reasons for this phenomenon.

Zone TE-2

Manganese, the only element to increase while Zr, Cu and Ni exhibit opposite stratigraphic oscillations, characterizes this zone which is contemporaneous with the C-3a pollen zone and the M-2 molluscan zone (Fig. 46, p. 230).

The geochemistry of Mn in fresh waters has been the subject of many important investigations by limnologists. Ruttner (1953) reported that Einsele found that the oxygen produced by autotrophic plants favours precipitation of very insoluble manganese oxides by transferring considerable quantities of Mn from the upper strata of water to bottom muds.

It has also been established that Mn is required for most forms of life and that it is an important catalyst in the oxidation of organic matter. On the other hand Zr, Cu and Ni, which each show a minimum concentration in an oxidizing environment, are dissolved in an aquatic environment and are then carried off to the sea. A higher concentration of oxygen within this zone might explain the return of the molluscan fauna in this interval.

Zone TE-1

This top zone is one of the best defined and corresponds exactly with the C-3b pollen zone and the M-1 mollusc zone discussed previously.

Deforestation of the area for agricultural purposes increased the inflow of allochthonous clay mineral sediments with which trace elements are intimately associated. The burning of logs by early settlers and the use of fertilizers also accentuated the amounts of trace elements in this zone. Recent human activities have also contributed to several other ecological changes already discussed earlier in this work. Man is most likely responsible for the sharp increase in Pb, an element that did not seem to be associated with the clay minerals within zones TE-9 and TE-10 (Fig. 18, p. 101) Thomas (personal communication) has recently found similar results for the mercury increase in the sediments of Lake Ontario.

VII. REGIONAL CORRELATIONS AND LATE-GLACIAL HISTORY

Pollen analysis was originally developed by geobotanists as a stratigraphical tool and has been used extensively with great success. Pollen assemblages which characterize each pollen zone are the basis of correlation. Similarities between pollen zones from different areas are believed to be stratigraphically equivalent. As discussed by Cushing (1964) and Davis (1965) equivalent pollen zones from sites separated by considerable distances may have different pollen spectra and therefore may be different in age and in paleoecological significance. It appears that pollen zones are not always equivalent in time but are formed under similar types of climate.

Since reinvasion of forest after deglaciation (A zones) in the Northeastern United States took place earlier than in the north a time transgression must be taken into account in correlation. The spruce pollen zone is subdivided in many diagrams partly in an attempt to correlate this zone with the Two Creeks-Valders climatic oscillation, one of the best time-markers of the late-Wisconsin glaciation in North America. Broecker and Farrand (1963) have established that the Two Creeks forest existed 11,850±100 years ago. This date has found support among geologists as well as paleoecologists.

The Two Creeks-Valders climatic oscillation has been detected in several pollen diagrams from the Great

Lakes Region (Anderson, 1954; West, 1961; Jelgersma, 1962; Wright and others, 1963). In general these authors divide the spruce pollen zone into a spruce/ash subzone followed by a spruce/birch (or spruce/*Artemisia*) subzone. The increase of *Fraxinus* pollen is associated with the warmer climate of Two Creeks time (zone A-a of Wright and zone 2 of West; Fig. 47, p. 241) whereas the *Artemisia* increase can be correlated with the colder Valders ice advance (zone A-b of Wright and zone 3 of West). Although several radiocarbon dates of the spruce pollen zone fall within the Two Creeks-Valders climatic oscillation, Cushing (1965, 1967) suggested that the *Artemisia* rise could imply a prairie-like opening and thus a warmer climate. This idea seems to be unrealistic since in almost all pollen diagrams from the Midwest, prairie pollen types (*Artemisia*, Compositae, Cyperaceae, Gramineae) are usually associated with the hypsithermal period. In the Kirchner Marsh pollen diagram these prairie pollen types characterize the C-b, believed to have existed approximately 7,100 to 5,100 years ago. In the Disterhaft Farm Bow (West, 1961) the prairie peninsula is reflected in zone 7 and is believed to have lasted from 6,700 to 4,000 years ago.

Correlation of basal pollen zones from the Midwest to New England demonstrates the presence of a tundra, a park-tundra of at least some kind of open spruce vegetation in late-glacial time which formed a belt near the ice front. It is also well established (as discussed previously in this work) that this open vegetation is more evident in pollen

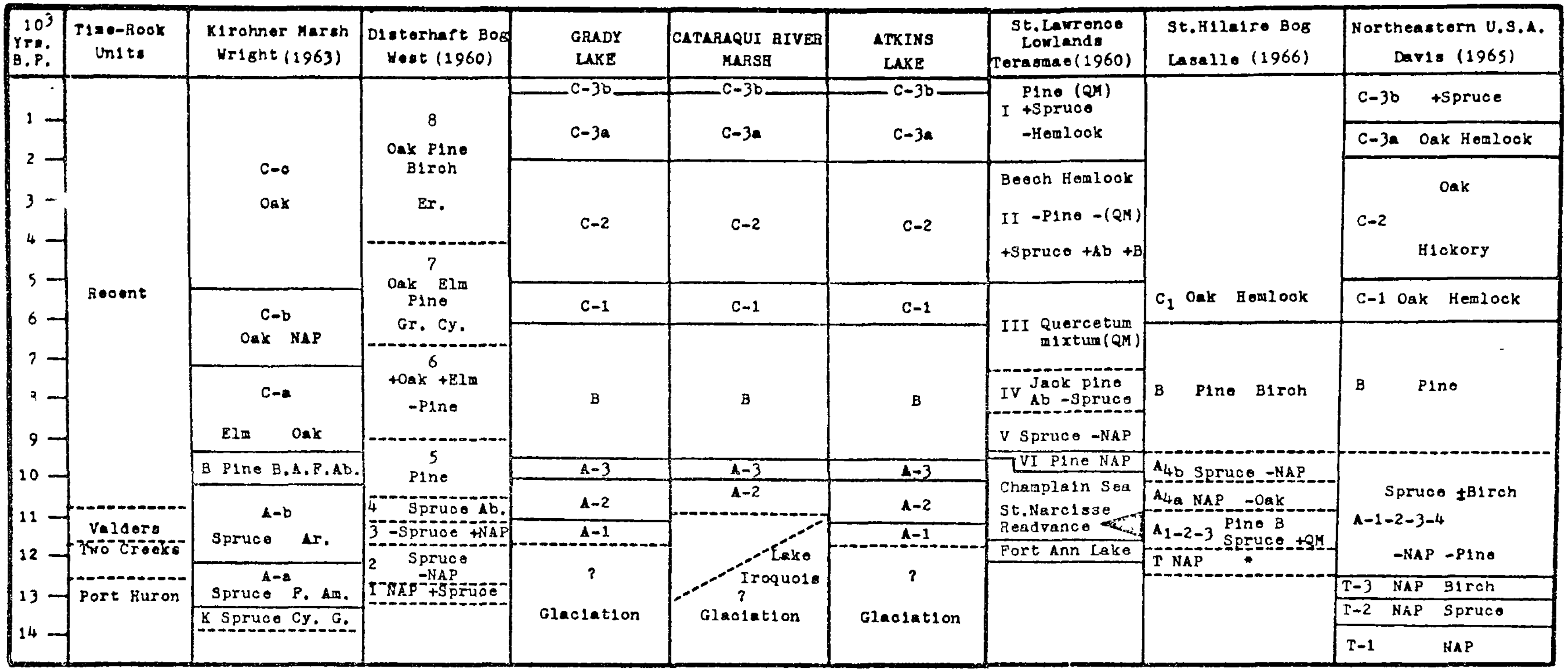


Figure 47. Tentative correlation of different pollen zones and some late and postglacial events.

Legend

A. *Alnus*
Ab. *Abies*
Am. *Ambrosia*
Ar. *Artemisia*
B. *Betula*
Cy. Cyperaceae
Er. Ericaceae
F. *Fraxinus*
Gr. Gramineae
\+ Increasing
\- Decreasing
* Longdistance transport of thermophilous pollen trees

diagrams as we go eastward. The continental Midwest climate allowed the growth of trees near the ice and an oceanic climate in the East favoured the development of a more open forest. This is clearly illustrated today in the Forest Region map of Canada (Rowe, 1959) by a lower latitudinal distribution of the tree line in Newfoundland and Labrador relative to its location in Northern New Quebec.

In the A-1 pollen zone of the Kingston Region the existence of a more or less open arctic type of vegetation, correlative with the Valders retreat, does not necessarily exclude the possibility of discovering older pollen zones in other deposits of that region which would suggest a more typical arctic vegetation. A significant climatic oscillation from warmer to colder in the St.Hilaire Bog has been described by Lasalle (1966). Even if this author believes that this climatic oscillation correlates better with the St.Narcisse advance and the Allerod-Younger Dryas from Europe he has not excluded its possible correlation with the Two Creeks-Valder substage.

The absence of the A-1 pollen zone in the Cataraqui River Marsh is most interesting. It may be explained by the fact that during the A-1 interval Lake Iroquois was at its lowest level known as the Admiralty stage (Coleman, 1922; Mirynech, 1962) and no deposition of sediment occurred on the sampling site. Correlation of the basal pollen zone from the Cataraqui River Marsh with the Grady and Atkins lake diagrams gives an age of about 11,000 years for the earlier pollen record of the site. This suggests a minimum age for Lake Iroquois and a maximum one for the beginning of the present Lake Ontario. Since Karrow, Clark and Terasmae (1961) show that Lake Iroquois which was in existence 11,510±240 (Y-691) years ago was drained between 10,400 to 10,600 years ago, the Fort Ann stand of Lake Vermont (MacClintock, 1958) which occupied the St. Lawrence Lowland before the marine inundation is wholly correlative with Lake Iroquois. Both could then have been, at least at one time, part of the same water body. Taking this possibility into consideration we can conclude that the early phase of the Champlain Sea was approximately synchronous with the last stages of Lake Iroquois and early Lake Ontario. Several new radiocarbon dates (Lowdon and Blake, 1968, 1970) from the Kingston area (Table 22, p. 385) demonstrate that the ice had already retreated north of the Upper St. Lawrence River 11,800 years ago and that the low water level of Lake Iroquois (stand Admiralty) came into existence at that time (Prest, 1970).

The melting of the ice of the St. Antoine moraine (Lee, 1962) and of the Highland Front moraine (Gadd, 1964) was a prerequisite to the beginning of the marine invasion of the St. Lawrence Lowland which ended the Fort Ann stand of Lake Vermont. New radiocarbon dates (Tables 21, p. 385) suggest that the ice existed across the St. Lawrence Valley east of Quebec City around 12,800 to 12,500 years ago (Dyck, Lowdon, Fyles and Blake, 1966). This ice-dam formed during the Port Huron (Mankato) stadial and dated by Hough (1958) at about 13,000 years might have melted during the warm Two Creeks interstadial. If this reasoning is correct, the Champlain Sea must have originated around 12,000 years ago and the St. Narcisse readvance probably was contemporaneous with the Valders ice believed to have reached its maximum 11,500 years ago. These conclusions are in accordance with the recent review of Elson (1969b) and Prest (1970).

The rapid warming of the climate in post-Valders time accelerated the melting of glaciers thus allowing the earth to rise rapidly and bringing the Champlain Sea episode to an end around 9,500 years ago. In post-glacial times the warmer climate gave rise to a pine-deciduous forest in the Kingston Region and in the St. Lawrence Lowlands. Consequently the closed spruce forest was forced to migrate north towards habitats sustaining less competitive vegetation.

VIII. SUMMARY AND GENERAL CONCLUSIONS

I. In understanding the late and postglacial history of North America the Kingston Region occupies a unique geographical position. Since there were different late-glacial water bodies within the Great Lakes-St. Lawrence Lowlands acting as barriers to the migration of terrestrial biota, the Frontenac Axis acted as a migrating bridge between the Adirondacks and the Canadian Shield.

II. The present multi-disciplinary paleoecological work combines palynological, malacological and geochemical investigations so as to lead to a better understanding of the evolution of lakes. Three new pollen diagrams which correlate with the stratigraphic geochemical composition of the radiocarbon dated deposits were obtained. One of these deposits was also studied for its molluscan and trace element compositions.

III. The three new pollen diagrams of the Kingston Region exhibit a striking resemblance to one another and demonstrate the possible existence in late-glacial time of a type of open spruce forest which was rapidly replaced by a dense short-lived spruce forest as the climate became warmer.

IV. In postglacial times an increasingly warm and dry climate gave rise to a pine-hardwood community ending approximately 6,000 years ago. This community was succeeded by a thermophilous deciduous forest.

V. The present climate of the Kingston Region which allowed development of a forest with colder and moister characteristics has existed for the past 2,000 years.

VI. With the arrival of the European settlers around 1830, the environment was highly modified and paleo-ecological environmental reconstruction after that time became rather difficult.

VII. The investigation of the fossil molluscan fauna from Atkins Lake sediments does not demonstrate any correlation between its stratigraphic abundance and paleo-climatic oscillations. The molluscan abundance tends to be inversely proportional to the estimated paleotrophic level of the lake deposits.

VIII. The study of trace elements in Atkins Lake deposits demonstrates their greater abundance in late-glacial and in post-settling times, an observation which is probably linked to periods of greater erosion. In intermediate times biotic factors seem to be directly responsible for the stratigraphic distribution variances. The quantitative stratigraphic distribution of lead shows that the beginning of environmental pollution is correlated with the arrival of European settlers.

IX. Evidence gathered here and from other workers suggests that the beginning of the Champlain Sea episode and consequently the end of the Fort Ann stand of Lake Vermont were correlated with the Two Creeks interstadial (11,850 years ago), whereas retreat of the synchronous St. Narcisse and Valders ices brought Lake Iroquois to its lowest stage and subsequently gave rise to Lake Ontario by allowing an isostatic rebound of the earth's crust about 11,000 years ago.

X. The different pollen zones and some late-glacial events previously described by various North American workers are tentatively correlated with the Kingston Region's late- and postglacial history in figure 47 (p. 241).

XI. The geochemical investigation of several Gatineau Area lakes shows that lake types can be characterized by their bottom sediments. By comparing the findings from the Gatineau Area lakes with the geochemical analysis of the three sedimentary deposits from the Kingston Region good evidence (C, N, Ca, Hg, Na, K, SCDP, absorbance ratio 410/350) is present showing several paleoproductivity fluctuations through the ontogeny of of lakes, thus contradicting the theory of unidirectional evolution.

XII. Correlation of the different zone systems and the factor analysis demonstrate the interrelationships between abiotic and biotic factors operating in an ecosystem. The climate seems to be the most important controlling factor in the ecosystem, at least prior to human interference.

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X. APPENDIX

A. Systematic Paleontology of the Molluscan Fauna from Atkins Lake, Ontario

The following information concerning the classification, description, ecology, geographical and geological distribution of the molluscs found in Atkins Lake sediments represents a summary of facts assembled from articles by various authors. Some of the most important references consulted are: Baker (1920, 1937), Clark, Jr. (in press), Clark (1961), Clowers (1966), Cornejo (1961), Dawson (1875), Gibson (1967), Herrington (1957, 1962), La Rocque (1953, 1962, 1963, 1966, 1967), Ouellet (1967), Provancher (1891), Reynolds (1959), Roy (1964), Taylor and Hibbard (1955), Taylor (1960), Whittaker (1918, 1921, 1922a, 1922b) and Yen (1951)[1].

I hope that this part will give the reader an idea of the restricted and very general source of information available today particularly on the ecology and on the geographical as well as the geological distribution of the species and forms studied. The use of Quaternary molluscan fossils in paleoecological investigations is quite limited on account of this regrettable situation.

1. For a more detailed list of references see La Rocque (1953).

Class GASTROPODA

Freshwater Species

Subclass Prosobranchia

Family VALVATIDAE

Valvata tricarinata (Say) 1817

Pl. 1, fig. 1-12

Cyclostama tricarinata Say 1817, Jour. Acad. Nat. Sci. Phila., vol. 1, p. 13.

Valvata tricarinata simplex Gould 1841, Invert. Mass., p. 222.

Valvata tricarinata unicarinata De Kay 1843, Zoology of N.Y., Pt. 5, p. 118.

Valvata tricarinata Provancher 1891, Moll. Prov. Que., p. 99, pl. III, fig. 13.

Valvata tricarinata basalis Vanatta 1915, Nautilus, vol. 28, p. 105.

Valvata tricarinata infracarinata Vannatta 1915, Nautilus, vol. 28, p. 104.

Valvata tricarinata Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. I, p. 11, pl. I, fig I-3.

Valvata tricarinata unicarinata De Kay. Baker 1928, ibid., p. 16, pl. I. fig. 5.

Valvata tricarinata basalis Vanatta. Baker 1928, ibid., p. 17, pl. I, fig. 8, 9.

Valvata tricarinata infracarinata Vanatta. Baker 1928, ibid., p. 18.

Valvata tricarinata simplex Gould. Baker 1928, Ibid., p. 18, pl. I, fig. 10, 14.

Valvata tricarinata Morrison 1932, Trans. Wis. Acad. Sci. Arts and Letters, vol. 27, p. 366.

Valvata tricarinata Solem 1952, Nautilus, vol. 65, p. 136.

Valvata tricarinata tricarinata La Rocque 1953, Nat. Mus. Can., Bull. 129, p.264.

Valvata tricarinata La Rocque 1956, Nautilus, vol. 70, pp. 13-14.

Valvata tricarinata Hibbard and Taylor 1960, Mus. Paleontol. Univ. Michigan, vol. 16, p. 79, pl. V, fig. 14, 15.

Type locality.—Delaware River.

Diagnosis.—Shell turbinate, thin, translucent, shining; whorls about 4, rapidly enlarging, flattened between the carinae, sloping upward from the carinae to the suture on the upper surface; spire elevated but depressed at the apex; sculpture of coarse growth lines more or less equally spread; sutures distinct and well impressed; body whorl large, with three distinct sharp carinae, one on the shoulder, one on the periphery, and one on the base, which encircles the round deep funnel-shaped umbilicus; aperture circular, modified somewhat by the carinae. (Condensed from Baker 1928, pp. 11-12).

Ecology.—Occupies a wide variety of habitats which include rivers, lakes, and permanent ponds. It occurs on various bottoms such as mud, silt, sand, gravel, mixtures of these materials, and in vegetation. Crawling on algae and aquatic plants as : *Vaucheria*, *Ceratophyllum* and *Elodea*. The species has been found in water of a few centimeters to depths exceeding 9 meters.

General distribution.—Great Slave Lake and the Mackenzie River south and east to New England and Virginia; west to Iowa. Only the collections from the Kingston Region at the National Museum of Canada revealed a few specimens of the form *simplex*. The other samples from all across Canada were of the form *tricarinata*.

Geological range.—*Valvata tricarinata* is a common fossil in deposits of Wisconsin to Recent age and has been recorded by Taylor (1960, p. 33-34) in Nebrascan and early Aftonian deposits.

Remarks.— This species, principally the forms *tricarinata*, *perconfusa* and *simplex*, is one of the most abundant mollusc in many lakes and rivers as well as in Pleistocene deposits (Whittaker 1921, Baker 1928, Clowers 1966). Care should be taken to distinguish the form *perconfusa* from *Valvata bicarinata*, the latter having a depressed spire and a wider umbilicus. It is abundant throughout the deposit, especially in the C-I and base of zone C-2. The form *tricarinata* with three strongly developed carinae is the most important in the basal section; it is soon replaced by the form *perconfusa* and this last one is substituted by the form *simplex* in the rest of the diagram. A few other intermediate forms are also present but in smaller number. Taylor (1960, pp. 48-49) and Clowers (1966, pp. 40-41) noted the presence of various forms of this species in these deposits but did not pay much attention to them. Baker (1928) attributed these variations in the carinae to mutations and environment. Based on my results the first hypothesis is more or less unacceptable. If we assume that he meant genetic variations by using the term mutations this explanation should be rejected. The sharp successions (Fig. 17, p. 96) in the forms of the species Valvata tricarinata do not show any Mendelian ratio among the number of the different forms. If these variations were genetic, according to the Laws of Heredity of Mendel a constant ratio among the numbers of each form should be observable at all the different levels of the diagram.

The second hypothesis of Baker and of Herrington (personal communication) to the effect that the strongly tricarinated form is characteristic of rivers while the variations such as simplex, perconfusa, etc. are confined to lakes, does not explain any of my results. In the mollusc diagram of Atkins Lake most of the strongly carinated forms are found between level 220-350 centimeters and there is nothing within this interval, in the sedimentary column, to indicate a running water habitat. Unfortunately the chemical diagram (Fig. 18, p. 101) showing the vertical distribution of some trace elements did not show any good correlation with these successions. I suggest that more investigations be undertaken in the study of the chemistry of the environment to find better explanations of these variations. I believe that a better correlation should be found between a high concentration of the calcium carbonate in the habitat and the presence of the strongly carinated form.

Family AMNICOLIDAE

Amnicola limosa (Say) 1817

Pl. 1, fig. 13-15

Paludinae limosa Say 1817, Jour. Acad. Nat. Sci. Phila., vol. I, p. 125.

Amnicola limosa Provancher 1891, Moll. Prov. Que., p. 97, fig. 10.

Amnicola limosa Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. I, p. 93, pl. 6, fig. 1-6.

Amnicola limosa porata Baker 1928, Ibid., p. 98, pl. 6, fig. 7-8, 18; pl. 8, fig. 1-3.

Amnicola limosa Morrison 1932, Trans. Wis. Acad. Sci. Arts and Letters, vol. 27, p. 368.

Amnicola limosa porata La Rocque 1953, Nat. Mus. Can., Bull. No. 129, p. 297.

Amnicola limosa limosa La Rocque 1953, Ibid., p. 267.

Amnicola limosa La Rocque 1962, Sterkiana, No. 7, p. 34.

Type locality.—Delaware and Schuylkill rivers, Pennsylvania.

Diagnosis.—Shell small, conical to globose in shape, about 4.4 mm high, 3 mm wide, 4.5 whorls; apex blunt; later whorls round and somewhat shouldered, increasing gradually in size; body whorl round; aperture almost circular, mostly basal; umbilicus deeply perforate. (Modified from Berry, 1943, p. 23).

Ecology.—This species has a wide range in distribution, occurring in creeks, rivers, and fresh and brackish-water lakes. It is generally found in thick beds of Chara, Potamogeton, Vallisneria, Nuphar, and Elodea. These plants are not used for food, but they harbor rich colonies of diatoms on which the snail feeds (Berry, I943, p. 26).

General distribution.— Amnicola limosa is found in New England, New Jersey and Quebec, west to Utah Manitoba, and south to Texas.

Geological range.-- It has been found in many deposits of Wisconsin age and should be considered as ranging fron Late-Pleistocene to Recent.

Remarks.— Amnicola limosa which represents 4.7 per cent of the molluscan assemblage is the third most important species of gastropod in the Atkins Lake deposit. At the base, in pollen zone A-2, its abundance constitutes about 4 per cent of the mollusc fauna; it decreases almost to zero within the B pollen zone and reaches its maximum of 8 per cent within zone interval C-I and the base of C-2. Provancher (I890, p. 97) and Whittaker (I92I, p. 73) respectively noted its common occurence in lakes near Quebec City and in marl deposits of the Ottawa River Valley. Shallom (I965, p. 50) found only one specimen of this species in the upper part of Lac Blanc deposit. Although Clowers (I966) found Amnicola limosa to be abundant only in the upper half of the Box Marl deposit, Gibson (I967) found it sporadically distributed in the Richardson Lake sediments and attributed the very low abundance of this species to the lack of dense beds of algae on which it is feeding. The comparison of the vertical distribution of diatoms and calcareous sediments (Fig.16, p. 88) with the stratigraphic distribution of Amnicola limosa (Fig. 17, p. 96) shows a negative correlation while the decrease of aquatic plants as Potamogeton, Sparganium, Nuphar and Typha, in pollen zone A-2 and A-3, is correlating positively. These results tentatively suggest that the lake at the time of marl accumulation was an open body of water with few aquatic plants but having a rich diatom population. This contradicts Berry (1943) who believes that Amnicola limosa was feeding on diatoms and not on aquatic plants and on such higher algae as Chara.

Amnicola lustrica Pilsbry 1890

Pl. 1, fig. 16

Amnicola lustrica Pilsbry 1890, Nautilus, vol. 4, p. 53.

Amnicola lustrica Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., Pt. I, p. 104, pl, 6, fig. 6, 17, 26, 27, text fig. 45.

Amnicola (Marstonia) lustrica Pilsbry. Berry 1943, Michigan Univ. Mus. Zool. Misc. Publ., No. 57, p. 26, pl. I, fig. 4-6, pl. 3, fig. 3, pl. 5, fig. 6, pl. 7, fig. 4.

Amnicola lacustris Morrisson 1947, Nautilus, vol. 60, p. 86.

Amnicola lustrica La Rocque 1953, Nat. Mus. Can., Bull. 129. p. 268.

Marstonia decepta (Baker) 1928, Taylor 1960, U.S. Geol. Surv. Prof. Paper 337, p. 51, pl. 2, fig. 9.

Type locality.— Not specifically given: New York to Illinois and Minnesota.

Diagnosis.— Shell small, about 4 mm , 5 whorls increasing gradually in size; apex elevated, acute, sutures deeply impressed, whorls shouldered and rounded; aperature ovate umbilicus narrow, perforate. (Condensed from Ferrey 1943, p. 30).

Ecology.— This species lives in rivers and lakes, in water ranging from 3 to 12 meters deep. Cornejo (1961) noted that it is less abundant on marly bottoms and rare on bouldery exposed points. Amnicola lustrica lives commonly on such plants as Vallisneria, Potamogeton, and Chara, and is particularly abundant on filamentous algae. Feeds on aquatic plants and on microscopic organisms and algae.

General distribution.—New York to Minnesota, and southern Ontario.

Geological range.—Late Pleistocene to Recent.

Remarks.—Amnicola lustrica appears in the deposit only in pollen zone C-1 which is much later than Amnicola limosa. Its invasion follows the stage of maximum formation of marl in the lake basin. It is more prolific in the gyttja type of sediments found within pollen zone interval C-3a in which the species reaches its maximum abundance of 25%. Clowers (1966) found similar results in the Box Marsh deposit. Roy (1964) obtained results almost opposed to these. Amnicola lustrica appears usually before Amnicola limosa and is much more common. This is probably due to its optimum geographic distribution which could be located south of Ontario.

Subclass Pulmonata

Order Basommatophora

Family LYMNAEIDAE

Fossaria obrussa decampi (Streng) 1906

Pl. 1, fig. 17

Limnaea desidiosa var. decampi Streng 1906, Nautilus, vol. 9, p. 123.

Galba obrussa decampi Baker 1911, Lymn. N. and Middle Am., p. 289, pl. 32, fig. 15-22.

Fossaria obrussa decampi Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., 70, Pt. I, p. 229, pl. 18, fig. 30-33, pl. 16, fig. 12.

Fossaria obrussa decampi Morrison 1932, Trans. Wis. Acad. Sci. Arts and Letters, vol. 27, p. 371.

Fossaria obrussa decampi La Rocque 1953, Nat. Mus. Can., Bull. 129, p. 285.

Type locality.—Brook's Lake, Newaygo County, Michigan.

Diagnosis.—Shell small, oblong, somewhat inflated, subconic, rather solid; whorls 5, spire whorls convex, distinctly shouldered near the suture, body whorl much flattened in the middle; spire short, broadly conic, turreted, about as long as aperture; sutures deeply impressed; aperture long and narrow, somewhat elliptical, rounded below and forming a prominent shoulder above. (Condensed from Baker, 1928, p. 300).

Ecology.—This species is found in small bodies of water such as creeks, ponds, sloughs, bays, and marshy spots along river banks; living in water less than 3 meters deep, among vegetation, sticks, stones, and any other debris in the water near the edge. It is sometimes seen upon mud flats of small streams and other such places.

General distribution.—Great Lakes drainage; Maine west into Manitoba; northern Michigan south to northern Illinois.

Geological range.—This species is very abundant as a Pleistocene fossil and was associated with Fossaria galbana an extinct species, in the icy waters of Pleistocene time. It was collected in many Pleistocene deposits in the Wisconsin and post-glacial marl deposits in Ontario. (Whittaker, 1921, p. 62).

Remarks.—This species contributes less than 1.5 per cent of the whole mollusc assemblage and is most numerous in the middle of the B (pine) pollen zone. At the top of the C-1 zone *Fossaria obrussa decampi* shows a negative correlation with *Valvata tricarinata simplex*, *Amnicola limosa*, *Helisoma campanulatum*, *Helisoma anceps* and *Pisidium ferrugineum* while at the same time its curve shows similar trends with the one of *Gyraulus parvus*, *Pisidium nitidum* and *Sphaerium lacustre*.

Family PLANORBIDAE

Subfamily Helisomatinae

Helisoma anceps striatum (F. C. Baker) 1902

P. 1, fig. 18-20

Planorbis bicarinatus striatus Baker 1902, Nautilus, vol. 15, p. 120.

Planorbis antrosus striatus Walker 1918, Synopsis and Cat., p. 96.

Helisoma antrosa striata Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. I, p. 328, pl. 19, fig. 28-31.

Helisoma anceps striatum Baker 1945, Moll. Fm. Planorbidae. p. 400.

Helisoma anceps striatum La Rocque 1953, Nat. Mus. Can., Bull. 129, p. 228.

Type locality.—Coldspring Park, Milwaukee, Wisconsin; Pleistocene.

Diagnosis.—Shell small, 3½ whorls, dorsal and ventral carinae distinctly marked, cordlike, elevated; dorsal carina on center of upper side of body whorl; body whorl well rounded; small, deep umbilicus, smoothly concave; surface sculpture of heavy spiral lines which become distinct ridges in many adult specimens; aperture higher than wide. (Condensed from Baker, 1928, p. 328).

Ecology.—Baker (1928, p. 328) stated that this form was a lake dweller, capable of living in cold waters of ice front lakes formed immediately after the ice retreated. This variety or form is found in marl, silt, and peaty marl; studies indicate that it lived in shallow freshwater lakes containing a luxuriant vegetation.

General distribution.—Pleistocene deposits of Wisconsin, Illinois, Michigan, east to Quebec and south to Ohio and Indiana.

Geological range.—*Helisoma anceps striatum* is known from several Pleistocene deposits of the Great Lakes area. Today this living form has a more northern distribution.

Remarks.—*Helisoma anceps striatum* makes up 2.0 per cent of the mollusc assemblage found in Atkins Lake sediments. It is more abundant in the C-1 zone and its stratigraphic distribution shows some similarities with the successions of *Helisoma campanulatum* and also to some extent with *Amnicola limosa*.

Helisoma campanulatum (Say) 1821

Pl. 2, fig. 1-3

Planorbis campanulatus Say 1821, Jour. Acad. Nat. Sci. Phila.

Helisoma campanulatum La Rocque 1962, Sterkiana, No. 7, p. 30.

Type locality.—Caguga Lake, New York.

Diagnosis.—Shell ultra-sinistral, discoidal, more or less rounded; whorls 4½, rounded below and subcarinated above; spire flat; sutures deeply impressed; base of shell rounded, exhibiting 2½ volutions with a deep umbilicus in the middle; aperture lunate. (Condensed from Baker, 1928, p. 346).

Ecology.— *Helisoma campanulatum* is characteristic of lakes, in shallow water with rich, sand, or mud bottom, with or without vegetation. It is also found in quiet parts of rivers and small streams.

General distribution.—Vermont west to North Dakota, south to Ohio and Illinois, north to the Mackenzie drainage.

Geological range.—From Late Wisconsin to Recent.

Remarks.—Like *Helisoma anceps striatum*, *Helisoma campanulatum* constitutes only 2.0 per cent of the whole mollusc assemblage of the deposit. It reaches a maximum of 8 per cent in abundance in the upper part of zone C-1 and its distribution curve is remarkably similar to *Helisoma anceps striatum*.

Subfamily Planorbidae

Gyraulus parvus (Say) 1817

Pl. 2, fig. 4-6

Planorbis parvus Say 1817, Nicholson's Encycl., Ed. II, vol. 2, pl. I, fig. 5.

Planorbis parvus Provancher 1891, Moll. Prov. Que., p. 148, pl. 4, fig 28.

Gyraulus parvus Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. I, p. 374, pl. 23, fig. 27-31, 39.

Gyraulus parvus Morrison 1932, Trans. Wis. Acad. Sci. Arts and Letters, vol. 27, p. 375.

Gyraulus altissimus (F. C. Baker), Baker 1938, Nautilus, vol. 51, pp. 130-131 (not of Baker).

Gyraulus altissimus McGrew 1944, Field Mus. Nat. Hist. Geol. Surv., vol. 9, p. 36.

Gyraulus parvus Baker 1945, Moll. Fam. Planorbidae, pp. 74, 270, 330, 336.

Gyraulus parvus La Rocque 1953, Nat. Mus. Can., Bull. 129, p. 294.

Gyraulus parvus Teskey 1954, Nautilus, vol. 68, p. 27.

Gyraulus parvus Taylor 1960, U.S. Geol. Surv., Prof. Paper 337, p. 58.

Type locality.—Delaware River, near Philadelphia, Pennsylvania.

Diagnosis.—Shell ultra-dextral, depressed, with a rounded periphery; growth lines oblique, crowded, fine; whorls about 3½, rapidly enlarging, rounded below the periphery and somewhat flattened above on the body whorl and all the spire whorls; spire flat, first two whorls sunken below the body whorl; sutures deeply impressed; base slightly concave, umbilical region wide and shallow; aperture long-ovate, nearly in the same plane as the body whorl. (Condensed from Baker, 1928, p. 375).

Ecology.—Usually found in quiet bodies of water of small size, on mud, sandy mud, sand, gravel, or boulder bottoms; on logs and vegetation, in shallow water about a foot to 4 feet. This species is more often found in vegetation than in any other situation (Baker, 1928, p. 377). It is associated with plants such as *Myriophyllum*, *Potamogeton*, *Castalia*, *Nymphea*, and *Clado-*

phora. Also this species has the ability to burrow into the substratum to prevent desiccation and can remain out of the water for long periods of time.

General distribution.—North America east of the Rocky Mountains, from Florida to Alaska and northern Canada.

Geological range.—This species is given a range of Middle Pliocene to Recent by Hibbard and Taylor (1960, p. 100). Eardley and Gvosdetsky (1960) found it in deposits of Yarmouth age. It is a common Pleistocene species which has been recorded from the Nebraskan, Aftonian, Sagamon and Wisconsin.

Remarks.—Variations in the morphology of the adult shells were observed. Most of these shells exhibit an angulation of the body whorl similar to that of *Gyraulus altissimus*. A complete transition was observed from the rounded *Gyraulus parvus* characteristic in the immature specimens to an angulated body whorl in the mature shells. The shells of this species from Atkins Lake are characterized by a lateral flattening of the whorls, by a relatively close coiling, and by a lack in the deflection of the body whorl. This species is also very abundant in many other lakes and deposits examined in the Kingston Region.

Armiger crista (Linnaeus) 1758

Pl. 2, fig. 7

Nautilus crista Linnaeus 1758, Syst. Nat. Ed. 10, p. 709.

Gyraulus (*Armiger*) *crista* Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. I, p. 385, text fig. 164.

Armiger imbricatus Baker 1945, Moll. Fam. Planorbidae, pp. 47, 50.

Gyraulus crista La Rocque 1953, Nat. mus. Can., Bull. 129, p. 293.

Type locality.—Europe.

Diagnosis.—Shell very small, ultra-dextral, depressed, fragile; sculpture of rather coarse lines of growth crossed by very fine, crowded, spiral striae; whorls $2\frac{1}{2}$, rapidly increasing in diameter, flatly rounded below, costate on the periphery where the costae project conspicuously; costae reduced to low ridges on the upper and lower surfaces; spire flat; umbilicus open to apex; aperture ovate. (Condensed from Baker, 1928, p. 385).

Ecology.—This species lives in shallow lakes and temporary ponds; the substrate could be muddy or silty with an abundant vegetation. It has also been reported to occur on dead leaves in stagnant water and in small lakes.

Geographic distribution.—Europe, Asia, North America from Maine west into Alberta, south to California, Utha, Illinois, Indiana and Ohio. Found in Pleistocene deposits as far south as Texas.

Geological range.—It is known from Kansan to Recent deposits.

Remarks.— Only one specimen of this species was observed in the deposit between levels 270-285 centimeters. It should be considered as being brought from a more terrestrial-humid type of habitat.

Family PHYSIDAE

Physa gyrina Say 1821

Pl. 2, fig. 8

Physa gyrina Say 1821, Jour. Acad. Nat. Sci. Phila., vol. 2, p. 171.

Physelia gyrina Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No 70, Pt. I, p. 449, pl. 27, fig. 30-35, 37-40, pl. 28, fig. 1-5-6.

Physa gyrina Morrison 1932, Trans. Wis. Acad. Sci. Arts and Letters, vol. 27, p. 376.

Physa gyrina gyrina La Rocque 1953, Nat. Mus. Can., Bull., 129, p. 298.

Type locality.—Bower Creek, near Council Bluffs, Iowa.

Diagnosis.—Shell sinistral, large, elongated to subcylindrical, rather thick; sculpture of coarse growth lines; whorls 5-6, the last rather, compressed or slightly inflated; spire rather long, acute, whorls well rounded;,aperture generally more than half length of the entire shell.

Ecology.—This species is found in any sort of stagnant or slow-moving body of water.

General distribution.—From the Arctic regions south to Alabama and Texas; mostly east of the Mississippi River.

Geological range.—Taylor (1960, pp. 32, 39) reports this species from deposits of Nebraskan age. It is a common species in Late Pleistocene and Recent deposits.

Remarks.—Only 18 individuals were found in the deposit and they are all within the B and C-1 pollen zone intervals. This vertical distribution is in some ways similar to the one described by Clowers (1966) and Gibson(1967). Although it is much less abundant in Atkins Lake sediments these two authors described the vertical distribution of this species as being more considerable in the middle of the sections and less at the base and at the top. Shallom (1965) found it to be rare and absent from many samples especially at the bottom of the section but the species reaches its maximum abundance at the top of its deposit.

Terrestrial Gastropoda

Subclass Pulmonata

Order Stytommatophora

Family PUPILLIDAE

Vertigo ovata Say 1822

Pl. 2, fig. 9

Vertigo ovata Say 1822, Jour. Acad. Sci. Phila., vol. 2, p. 375.

Vertigo ovata Provancher 1991, Moll. Prov. Que., p. 131, pl. V, fig. 27.

Vertigo ovata McGrew 1944, Field Mus. Nat. Hist. Geol. Surv. vol. 9, p. 343.

Vertigo ovata Pilsbry 1948, Land Moll. N. Am., vol. 2, Pt. 2, p. 952, text fig. 513: 1-3, 4, 7.

Vertigo ovata La Rocque 1953, Nat. Mus. Can., Bull. 129, p. 335.

Vertigo ovata Hibbard and Taylor 1960, Mus. Paleontol. Univ. Michigan, vol. 16, p. 135, pl. II, fig. 8.

Vertigo ovata Taylor 1960, U.S. Geol. Surv. Prof. Paper 337, p. 74.

Type locality.—Philadelphia, Pennsylvania.

Diagnosis.—Shell ovate in outline, about 5 whorls, amber colored, spire convexly conic, apex obtus; whorls increase rapidly in size, body whorl much the largest with strong crest behind apertural lip; peristome thin, aperture semi-circular, sutures impressed; parietal lamella long and strong, columellar lamella strong; angular lamella small; basal fold well developed; upper and lower palatal fold strong.

Ecology.—This species requires high moisture and is commonly found in moist environments provided by shaded slopes near streams and shores of ponds and lakes. It is present in and under plant debris, leaves, grasses, logs, sticks, moss, and in swampy meadows.

General distribution.—Labrador west into British Columbia and north to Alaska; south to Florida, Mexico, and the West Indies.

Geological range.—Recorded from Middle Pliocene by Taylor (1960).

Remarks.— Only one specimen of this terrestrial species was found in the Atkins Lake sediments.

Class PELECYPODA

Freshwater Species

Order Teleodesmacea

Family SPHAERIIDAE

Sphaerium lacustre (Müller) 1774

Pl. 3, fig. 10-11

Tellina lacustris Müller 1774, Verm. Terr. et Fluv., vol. 2,

p. 204.

Cyclas jayenis Prume 1851, Proc. Boston Soc. Nat. Hist., 4, p. 68.

Musculium rosaceum Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. I, p. 358, pl. 99, fig. 19, 20.

Musculium ryckholti Baker 1928, Ibid., Pt. II, p. 359, pl. 99, fig. 6-9.

Musculium lacustre La Rocque 1953, Mus. Nat. Can., Bull, 129, p. 100.

Sphaerium lacustre Herrington 1962, Revis. Sphaeriidae N. Amer., p. 19, pl. 2, fig. 1.

Sphaerium lacustre La Rocque 1967, State Ohio Geol. Surv. Bull. 62, Pt. II, p. 295, pl. 2, fig. 1.

Type locality.—Europe, probably Denmark.

Diagnosis.— Shell small to medium, walls thin, anterior end not so high as posterior; beaks prominent, distinctly raised above the dorsal margin; striae moderately fine to coarse; anterior end rounded, posterior end almost straight; hinge very long; lateral teeth slime but distinct, cardinal teeth weak. (Condensed from Herrington 1962, pp. 19, 20).

Ecology.—Herrington (1962, p. 20) described this species as being plentiful in small lakes and ponds, but also as occurring in large lakes, rivers, and creeks. It appears to prefer a muddy bottom.

General distribution.—Northwest Territories to Florida, and from Nova Scotia to British Columbia and California.

Geological range.—Taylor and Hibbard (1965, p. 12) have found this species in Illinoian deposits of Oklahoma. The form ryckholti has been recorded from Early and Middle Pliocene deposits of Kansas and Oklahoma.

Remarks.—Sphaerium lacustre is moderately to poorly represented in the sediments (1.3 per cent) of Atkins Lake. It reaches a maximum of less than 4 per cent in the C-1 pollen zone and shows a minimum inferior to 1 per cent within the pollen zone B, which one corresponds more or less to the accumulation of the laminated marl unit. This species shows a negative type of correlation with Pisidium nitidum and Pisidium nitidum contortum. This could be due to competition for the same niche.

Sphaerium similis (Say) 1816

Pl. 3, fig. 12-13

Cyclas similis Say 1816, Nicholson's Encycl., vol. 2, pl. I, fig. 9.

Sphaerium simile Prime 1869, Cat. Recent Corbiculadae, p. 158.

Sphaerium sulcatum Sterki 1916, Cat. N. Am. Sphaeriidae, p. 431.

Sphaerium simile Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. II, p. 313, pl. 96, fig. 4-7.

Sphaerium simile Herrington 1950, Nautilus, vol. 63, p. 117, 119 (not synonymous with S. sulcatum).

Sphaerium simile La Rocque 1953, Nat. Mus. Can., Bull. 129, p. 115.

Sphaerium simile La Rocque 1967, State Ohio Geol. Surv. Bull. 62, Pt. II, p. 305.

Type locality.—Delaware River.

Diagnosis.—"Shell suborcular convex, base a little flattened; with nearly equidistant, raised concentric lines, giving a sulcated appearance to the surface, and generally a more conspicuous elevated darker wave, marking the former year's growth of the shell. Epidermis brown or ferruginous; beak nearer central and obtuse; hinge with minute very oblique teeth, lateral ones very distinct, elongated, and considerably resembling those of the next species. (C. dubia)." (Say's original description, with additions by Herrington, 1950, p. 117.)

Ecology.—Sphaerium sulcatum has a preference for a soft bottom in fairly still waters, in eddies of creeks or rivers, along shores, in lakes, and even in lakes filling up with marl. Herrington describes this species as being associated with Pisidium compressum in all these habitats.

General distribution.—East of the Rocky Mountains to Quebec and adjacent Northern States.

Geological range.—La Rocque (1967, p. 305) described this species range as Wisconsin but he also notes that this could be subject to error due to the confusion between this species and Sphaerium sulcatum.

Remarks.—Only six specimens of this species were found in the deposit.

Pisidium adamsi Prime 1851

Pl. 2, fig. 10-11

Pisidium adamsi (Prime) Stimpson 1851, Moll. New England, p. 16.

Pisidium adamsi 1865, Mon. Am. Corbiculadae, p. 63, fig. 63.

Pisidium sargenti Sterki 1916, Cat. N. Am. Sphaeriidae, p. 454.

Pisidium adamsi Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. II, p. 385, pl. 101, fig. 7-9, 19.

Pisidium sargenti Baker 1928, Ibid., p. 387, pl. 101, fig. 5, 6, 18.

Pisidium adamsi La Rocque 1953, Nat. Mus. Can., Bull. 129, p. 102.

Pisidium adamsi Herrington 1962, Revis. Sphaeriidae N. Am., p. 30, pl. 3, fig. 5, pl. 7, fig. 5.

Pisidium adamsi La Rocque 1967, State Ohio Geol. Surv. Bull. 62, Pt. 2, pp.316, 317, pl. 3, fig. 5, pl. 7, fig. 5.

Type locality.—Norway, Maine Holly, Oakland County, Michigan.

Diagnosis.— Shell large and considerably inflated; beaks broad; striae rather heavy and uniformly spaced; periostracum dull; dorsal margin long and curved; anterior end rather steep, the slope slightly curved; posterior truncated and vertical; ventral margin long and gently curved. Hinge long, openly curved and heavy; laterals heavy, cusps broad on top. (Condensed from Herrington, 1962, p. 30.)

Ecology.—It seems to prefer quiet waters, small lakes and slow running streams. (Sterki, 1916). Herrington (1962, p. 31) summarized this species as inhabiting small lakes, ponds, rivers, and (rarely) creeks. It has a preference for muck and decaying vegetal matter.

General distribution.—In North America restricted more or less east of the Mississippi-Missouri river systems from Florida to South Canada.

Geological range.—Wisconsin in age, older occurences are uncertain.

Remarks.—This species constitutes only 0.3 per cent of the total molluscs counted and its stratigraphical distribution in this deposit is restricted chiefly to the C-I pollen zone.

Pisidium casertanum (Poli) 1791

Pl. 2, fig. 12-13

Cardium casertanum Poli 1791, Test. Utr. Sicil. vol. 1, p. 65, pl. 16, fig. I.

Pisidium abditum Haldeman 1841, Acad. Nat. Sci. Phila. Proc., vol. 1, p. 53.

Pisidium abditum Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. II, p. 407, pl. 103, fig. 1-5.

Pisidium complanatum Baker 1928, Ibid., p. 402, pl. 103, fig. 9-11.

Pisidium griseolum Baker 1928, Ibid., p. 412, pl. 104, fig. 25, 26.

Pisidium neglectum Baker 1928, Ibid., p. 390, pl. 105, fig. 7, 8.

Pisidium noveboracense Baker 1928, Ibid., p. 391, pl. 101, fig. 10-12, 20.

Pisidium politum Baker 1928, Ibid., p. 404, pl. 102, fig. 19.

Pisidium politum decorum Baker 1928, Ibid., p. 405, pl. 102, fig. 20-22.

Pisidium roperi Baker 1928, Ibid., p. 400, pl. 102, fig. 23-25.

Pisidium subrotundum Baker 1928, Ibid., p. 409, pl. 101, fig. 21-23.

Pisidium subrotundum pumilum Baker 1928, Ibid., p. 401, pl. 102, fig. 26.

Pisidium superius Baker 1928, Ibid., p. 397.

Pisidium casertanum Adam 1947, Mém. Mus. Roy. Hist. Nat. Belgique, No. 106, p. 200.

Pisidium casertanum van der Schalie 1953, Nautilus, vol. 66, p. 84.

Pisidium casertanum 1955, Okla. Geol. Surv. Circ. 37, p. 12.

Pisidium casertanum Hibbard and Taylor 1960, Mich. Univ. Mus. Paleontol. Contrib., vol. 16, No. 1, p. 77.

Pisidium casertanum Herrington 1962, Revis. Sphaeriidae N. Am., pp. 33, 14, fig. 1, pl. 7, fig. 7.

Pisidium casertanum La Rocque 1967, State Ohio Geol. Surv. Bull. 62, Pt. II, pp. 342, 243, pl. 4, fig. 1, pl. 7, fig. 7.

Type locality.—Sicily.

Diagnosis.— Rather long shell of moderate weight; beaks subcentral not high; striae fine; dorsal and ventral margins parallel and gently curved; posterior end truncated; hinge plate moderately long, laterals distinct; cusps on laterals rather sharp. (Condensed from Herrington, 1962, p. 33).

Ecology.—Pisidium casertanum has succeeded in adapting itself to a wide variety of habitats. One finds it in bog ponds, ponds, swamps that dry up for several months of the year swamp-creek , creeks with considerable current, rivers, and lakes including the Great Lakes. This is by far the most common Pisidium. (Herrington 1962, p. 34). Zimmerman (1962, p. 62) reported this species from sandy or muddy bottoms, in shallow water, from 0.5 m to 3.0 m in depth.

General distribution.—Almost cosmopolitan: Eurasia, New Zealand, and Australia; in the Western Hemisphere from Patagonia to the Arctic Circle. (Herrington and Taylor, 1958, p. 14).

Geological range.—This species is common in Wisconsin deposits and has a range from Pliocene to Recent.

Remarks.—Only four shells of this species have been found in Atkins Lake sediments.

Pisidium compressum Prime 1851

Pl. 2, fig. 14-15

Pisidium compressum Prime 1851, Boston Soc. Nat. Hist. Proc., vol. 4, p. 164.

Pisidium compressum Sterki 1907, Ohio Acad. Sci. Proc., vol. 4, p. 396, 402.

Pisidium compressum Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. II, p. 370, pl. 100, fig. 9-13.

Pisidium compressum van der Schalie 1953, Nautilus, vol. 66, p. 84.

Pisidium compressum La Rocque 1953, Nat. Mus. Can., Bull. 129, p. 103.

Pisidium compressum Taylor 1960, U. S. Geol. Surv., Prof. Paper 337, p. 47.

Pisidium compressum Herrington 1962, Revis. Sphaeriidae N. Am. p. 35, pl. 5, fig. 2, pl. 7, fig. 14.

Pisidium compressum La Rocque 1967, State Ohio Geol. Surv. Bull. 62, Pt. II, pp. 329-332, pl. 5, fig. 2, pl. 7, fig. 14.

Type locality.—Fresh pond near Cambridge, Massachussets.

Diagnosis.—Shell medium sized, heavy, shape varies from short and high to moderately long; beaks prominent, far back, narrow and with ridges; growth lines coarse to moderately fine. (Modified from Herrington, 1962, p. 35).

Ecology.— *Pisidium compressum* is found in many habitats but prefers rivers and small creeks (Sterki 1916, p. 447). Herringtom (1962, p. 34) reports this species to be most common in shallow water, with sand substrate and vegetation. Taylor (1960, p. 47) states that this form inhabits only perennial waters with some current and never swamps of ponds. Reynolds (1959, p. 47) states that the species is a burrowing form, feeds on detritus and plankton, and inhabits those environments with a firm substrate. Cornejo (1961, p. 41) reports this species to be frequently associated with **such plants as *Scirpus*,** *Pontederia*, *Castalia*, *Nymphaea*, and *Potamogcton*.

General distribution.—From the Arctic Circle to Mexico, Pacific Coast to the Atlantic.

Geological range.—*Pisidium compressum* is known from the Middle Pliocene to the Recent.

Remarks.—*Pisidium compressum* forms only 0.87 per cent of the mollusc assemblage of Atkins Lake sediments and reaches a maximum stratigraphical distribution which is inferior to 2 per cent within the C-1 pollen zone.

Pisidium ferrugineum Prime 1851

Pl. 2, fig. 16-17

Pisidium ferrugineum Prime 1851, Boston Soc. Nat. Hist. Proc., vol. 4, p. 162.

Pisidium ferrugineum Sterki 1916, Cat. N. Am. Sphaeriidae, p. 467.

<u>Pisidium ferrugineum</u> Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No 70, Pt. II, p. 426, pl. 104, fig. 3-5.

<u>Pisidium ferrugineum</u> Herrington 1954, Nautilus, vol. 67, p. 133.

<u>Pisidium ferrugineum</u> La Rocque 1959, Sterkiana, No. I, p. 30.

<u>Pisidium ferrugineum</u> Herrington 1962, Revis. Sphaeriidae N. Am., p. 39, pl. 4, fig. 6, pl. 7, fig. 12.

<u>Pisidium ferrugineum</u> La Rocque 1967, State Ohio Geol. Surv. Bull. No. 62, Pt. II, p. 340-342, pl. 4, fig. 6, pl. 7, fig. 12.

<u>Type locality</u>.—Cambridge, Massachusetts.

<u>Diagnosis</u>.—Shell small, usually much inflated, walls thin; beaks subcentral; striae coarse to faint; periostracum glossy, dorsal margin rounded length variable; ventral margin rounded much as dorsal, but longer; laterals short with rather pointed cusps; cardinals straight or slightly curved, very small and near anterior cusps. (Condensed from Herrington, 1962, p. 39).

<u>Ecology</u>.—<u>Pisidium ferrugineum</u> lives in mud, sand, or marly clay bottoms of ponds, lakes, and in some rivers; usually in water less than 3 m deep. Herrington (1962, p. 40) reported this species as preferring cool climate.

<u>General distribution</u>.—In North America from the Atlantic to the Pacific Coast, between latitudes 35° to 65° . It is also found in Europe.

<u>Geological range</u>.—This species has not been found in deposits older than Wisconsin in age.

<u>Remarks</u>.—<u>Pisidium ferrugineum</u> is the second most important species of the family sphaeriidae in Atkins Lake sediments. It constitutes 7.0 per cent of the assemblage and shows a negative correlation with <u>Pisidium nitidum</u> which is the most important bivalve of the deposit.

Pisidium nitidum Jenyns 1832

Pl. 2, fig. 18-19

Pisidium nitidum Jenyns 1832, Cambridge Phil. Soc. Trans., vol. 4, p. 304, pl. 20, fig. 7-8.

Pisidium splendidulum Sterki 1907, Ohio Acad. Sci. Proc., vol. 4, p. 392.

Pisidium glabellum Sterki 1913, Nautilus, vol. 26, p. 137.

Pisidium tenuissimum Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull. No. 70, Pt. II, p. 418, pl. 104, fig. 29- 33.

Pisidium nitidum Germain 1931, Faune de France, vol. 22, p. 706.

Pisidium glabellum La Rocque 1953, Nat. Mus. Can., Bull. 129, p. 105.

Pisidium nitidum Herrington 1954, Nautilus, vol. 67, p. 132.

Pisidium nitidum Herrington 1962, Revis. Sphaeriidae N. Am., p. 45, pl. 5, fig. 6, pl. 7, fig. 17.

Pisidium nitidum La Rocque 1967, State Ohio Geol. Surv., Bull. 62, Pt. II, pp. 333, 334.

Type locality.—Great Britain.

Diagnosis.—Shell moderately small, walls thin, rhomboid; beaks subcentral, broad; striae moderately fine; anterior end with a rounded slope joining ventral margin below in a rounded point; posterior end vertical or undercut; hinge long, laterals of moderate length, cardinals subcentral. (Condensed from Herrington, 1962, p. 45).

Ecology.—Herrington (1962, p. 46) described this species as being typical of large ponds, bog ponds, lakes, creeks, and rivers with a preference for shallow water. Germain (1931, p. 706) stated that it lives in large lakes as deep as 25 meters; ponds, brooks, and ditches, preferably in clear or fairly clear water but with aquatic plants (rare or absent in marshes).

General distribution.—Eurasia and North Africa; in North America, from Northwest Territories to Mexico except for Southeastern United States and from Newfoundland to British Columbia.

Geological range.—It has been recorded from early Pliocene by Herrington (1962, p. 46) in the Laverne formation of Oklahoma and by Taylor (1960, p. 48) in different Pleistocene deposits. It is common in Postglacial and living assemblages.

Remarks.—*Pisidium nitidum* is the most common pelecypod of the deposit (18.8 per cent) and the only one with *Pisidium ventricosum* to reach its maximum abundance as early as the pollen zone A-2. With the increase in competition in the above B and C-I zones *Pisidium nitidum* decreases substantially. Although it starts to increase at the base of C-2 it drops sharply and is not found in the collection between 150-165 centimeters.

(*Pisidium nitidum* form *pauperculum* Sterki 1896)

Pl. 3, fig. 2-3

Pisidium pauperculum Sterki 1896, Nautilus, vol. 10, p. 64.

Pisidium pauperculum Sterki 1916, Cat. N. Am. Sphaeriidae, p. 473.

Pisidium pauperculum Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. II, p. 420, pl. 100, fig. 22-25.

Pisidium pauperculum La Rocque 1953, Nat. Mus. Can., Bull. 129, p. 108.

Pisidium nitidum pauperculum La Rocque 1959, Sterkiana, No. 1, p. 31.

Pisidium nitidum pauperculum Herrington 1962, Revis. Sphaeriidae N. Am., p. 45.

Pisidium nitidum pauperculum La Rocque 1967, State Ohio Geol. Surv. Bull. 62, Pt. II, pp. 334, 335, 336.

Type locality.—Not given.

Diagnosis.—Herrington (1962) described the ecological form pauperculum as follows: "It is rather short, high, heavy, with dorsal margin much curved; beaks sometimes more prominent than in the typical form; anterior end steep below the cusps; hinge-plate and teeth heavier; the cardinals more nearly central."

Ecology.—Much the same as the typical form of this species.

General distribution.—Ontario to Maine, south to South Dakota, Minnesota, Wisconsin, Indiana, Ohio, and New Jersey.

Geological range.—This form has **not yet been recorded in deposits older than Wisconsin.**

Remarks.—Although the form pauperculum has an adult potential of reproduction much inferior to Pisidium nitidum both show a similar stratigraphic distribution. This could possibly be due to the common behavior of these two forms toward environmental changes.

(Pisidium obtusale form ventricosum Prime 1851)

Pl. 3, fig. 4-5

Pisidium ventricosum Prime 1851, Proc. Boston Soc. Nat. Hist., vol. 4, p. 68.

Pisidium rotundatum Prime 1851, Ibid.

Pisidium vesiculare Sterki 1896c, Nautilus, vol. 10, No. 2, pp. 20, 21.

Pisidium ventricosum Dall 1905a, Harriman Alaska Exped., vol. 13, p. 143.

Pisidium ventricosum Sterki 1916, Ann. Carn. Mus., vol. 10, p. 466.

Pisidium ventricosum La Rocque 1953, Cat. Recent Moll. Canada, p. 112.

Pisidium obtusale ventricosum Herrington 1962, Revis. Sphaeriidae N. America, p. 46, pl. 4, fig. 4, pl. 7, fig. 10.

Pisidium obtusale ventricosum La Rocque 1967, State Ohio Geol. Surv. Bull. 62, Pt. II, p. 329.

Type locality.—Fresh Pond, Cambridge, Massachusetts.

Diagnosis.—Pisidium obtusale form ventricosum looks like a Pisidium obtusale form rotundatum with a heavier hinge-plate, and with the ventral margin pushed forward, making the posterior end not vertical but undercut. What Sterki called Pisidium vesiculare is found in specimens in which the process is not carried as far. Pisidium obtusale form ventricosum sometimes has a slight angle at the anterior end, and some specimens are greatly inflated. (Herrington, 1962, p. 47).

Ecology.—This form is found principally in lakes and large rivers.

General distribution.— It was collected from the Northwest Territories to the Northern States, and from California, Alberta to the Atlantic Coast. **Also recorded from Ireland to Japan.**

Geological range.—Pleistocene: late Wisconsin. Marl beds near Ottawa (Herron, 1880, p. 40). Fossil: Maine, Michigan Sterki, (1916, p. 466). Wabash, F. C. Baker, (1920a, p. 385). Souder Lake, Cornejo, (1961), Oakhurst Aukeman, (1960, p. 42), and Aultman Sheatsley, (1960) deposits, Ohio.

Remarks.—Pisidium obtusale ventricosum contributes by less than 2 per cent to the total fauna of the deposit. Its stratigraphical distribution shows some degree of correlation with Pisidium nitidum.

Pisidium variabile Prime 1851

Pl. 3, fig. 6-7

Pisidium variabile Prime 1851, Boston Soc. Nat. Hist. Proc., vol. 4, p. 163.

Pisidium mirabile (Whittermore) Clessin 1879, Cycladeen, p. 49, pl. 6, fig. 1-3, 19-21.

Corneocyclas variabilis Dall 1905, Harriman-Alaska Exped., vol. 13, p. 142, fig. 114.

Pisidium Sterki 1916, Cat. N. Am. Sphaeriidae, p. 453.

Pisidium variabile Baker 1920, Jour. Geol. vol. 28, p. 446.

Pisidium variabile Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. II, p. 381, pl. 101, fig. 1-4.

Pisidium variabile La Rocque 1953, Nat. Mus. Can., Bull. 129, p. 111.

Pisidium variabile Herrington 1962, Revis. Sphaeriidae N. Am., p. 50, pl. 3, fig. 4, pl. 7, fig. 4.

Pisidium variabile La Rocque 1967, State Ohio Geol. Surv., Bull. 62, p. 338, pl. 3, fig. 4, pl. 7, fig. 4.

Type locality.—Fresh Pond, near Cambridge, Massachusetts.

Diagnosis.—Shell heavy, varying from short and high to moderately long; beaks prominent, far back and broad; striae coarse to fine; dorsal margin short and round; anterior end begins near beaks without angle, has a steep straight slope; ventral margin long and curved; posterior end rounded, vertical or undercut. (Condensed from Herrington 1962, p. 50).

Ecology.—Herrington (1962, p. 50) described this species as being an inhabitant of creeks, rivers, and lakes usually with still water and soft bottom sediments. Reynolds (1959, p. 162) summarized the ecology of *Pisidium variabile* as follows: "It is found in rivers and lakes, frequently in water 1-13 feet deep, burrowing in gravel, sand, clay, and mud, but is more abundant in mud where the water is 4-11 feet deep. It has been collected in waters with pH 5.72-8.37, fixed carbon dioxide 1.72-30.56 p.p.m. It feeds on detritus and plankton and is eaten by numerous varieties of fish."

General distribution.— In North America from coast to coast between latitudes 36-55 degrees.

Geological range.—This species was recorded in several deposits of Yarmouth, Sangamon and Wisconsin age.

Remarks.—This species shows a bimodal type of curve in its vertical distribution which correlates roughly with the *Pisidium nitidum* curve. In the bottom part of the diagram a maximum appears in zone A-3 and C-2 with a minimum abundance between these two peaks.

(*Pisidium walkeri* form *mainense* Sterki 1898)

Pl. 3, fig. 8-9

Pisidium walkeri var. *mainense* Sterki 1898, Nautilus, vol. 12, p. 79.

Pisidium walkeri Sterki 1907, Ohio Acad. Sci. Proc., vol. 4, p. 397.

Pisidium mainense Sterki 1907, Ibid.

Pisidium walkeri Baker 1928, Wis. Geol. Nat. Hist. Surv. Bull., No. 70, Pt. II, p. 394, pl. 102, fig. 12-14.

Pisidium mainense Baker 1928, Ibid., p. 396, pl. 105, fig. 12, 13.

Pisidium mainense La Rocque 1953, Nat. Mus. Can., Bull. 129, p. 106.

Pisidium walkeri La Rocque 1953, Ibid., p. 112.

Pisidium mainense Herrington 1954, Nautilus, vol. 67, p. 136.

Pisidium walkeri form *mainense* 1962, Revis. Sphaeriidae N. Am., p. 51, pl. 6, fig. 4.

Type locality.—Kent County, Michigan.

Diagnosis.—The species type has a shell of medium size, long, moderate diameter, thin walls; beaks far back, rather prominent; striae medium to somewhat heavy, uniformly spaced; dorsal margin tilted back, short; anterior end a long slightly curved slope, joining ventral margin quite low with rounded angle; ventral margin very long and not much curved; posterior end vertical. The form *mainense* is smaller with finer striae, the anterior slope a little more rounded and usually beginning a little closer to the beaks. The shell is relatively shorter and therefore appears to be higher in outline. (Condensed from Herrington 1962, p. 51).

Ecology.—This form is found in creeks, rivers, and small lakes having a soft bottom.

General distribution.—The form *mainense*, according to Herrington (1962 p. 51), has been found in Alberta, Saskatchewan, and the southern parts of Ontario; Maine, Massachusetts, Rhode Island, New York, Ohio, Michigan, and Illinois.

Geological range.—The form *mainense* is restricted to Late Wisconsin deposits.

Remarks.—Only 3.5 individuals were found in the whole deposit.

B.

Table 1

Summary of important climatic factors in the Cataraqui River Marsh area (C.R.M.a.) and in the Gready Lake area (G.L.a.) read from maps by Putnam and Chapman (I938), Sanderson (I950) and Brown and others (I968).

climatic factor	C.R.M.a.	G.L.a.
Mean annual temperature	44.9°F	42.0°F
Winter temperature	20°F	I6°F
Summer temperature	67°F	66.5°F
July mean temperature	69°F	67.9°F
January mean temperature	I8°F	I4°F
Annual absolute minimum temperature	-35°F	-39.5°F
Annual absolute maximum temperature	96°F	I03°F
Mean annual frost free period	I54 days	I30 days
Mean date of last frost	May I2	May 20
Mean date of first frost	Oct. 5	Sept. 27
Start of growing season	April I3	April I5
End of growing season	Nov. 3	Oct. 30
Mean annual length of growing season	204 days	I98 days
Mean annual growing degree-days	3600	2400
Annual precipitation	899 mm	864 mm
Annual snowfall	1550 mm	1775 mm
Potential evapotranspiration	614 mm	584 mm
Average annual water surplus	297 mm	267 mm
Average annual water deficiency	76.2 mm	63.5 mm

Table 2

Volume of wet sediment from which the molluscan spectra were calculated at various depths from the mud-water interface.

Depth cm	Volume ml
0-90	885
90-150	760
150-255	635
255-400	510

Table 3

Statistics for a group of twelve determinations of water content, dry matter, ignitable matter and sedimentary chlorophyll on aliquots of an homogenous sediment sample taken from the upper part of Grady Lake core.

	H_2O (%)	Dry matter (%)	Ignitable matter (%)	SCDP (Units/g dry matter)	SCDP (Units/g ignitable matter)
$\bar{X}$	93.792	6.211	55.494	102.522	184.750
S.D.	.060	.062	.124	2.758	5.221

Table 4

Statistics of the control sample from Meach Lake for several determinations used in the pigment study.

	Ignitable matter (%)	SCDP (Units/g Dry matter)	SCDP (Units/g Ignitable matter	Absorbance ratios of various wavelengths					
				410/350	410/670	350/670	448/670	448/350	410/448
N	5	17	17	17	17	17	17	17	17
$\bar{X}$	26.238	36.528	133.473	1.764	4.394	2.484	3.385	1.343	1.309
S.D.	.097	4.386	13.610	.084	.222	.105	.286	.094	.089

DEPTH IN CENTIMETERS	0	25	38	50	63	75	85	90	110	120	130	140	150	160	180	190	200	220
POLLEN TYPES																		
Picea mariana		1	3	2	3	...	3	...	...	...	...	...	1	1	...	...	...	...
Picea glauca		...	...	...	...	...	...	...	...	1	...	4	...	3	...	1	21	2
Pinus strobus/resinosa	61	77	77	75	58	93	90	68	28	38	63	41	77	85	90	77	118	87
Pinus banksiana	22	14	9	20	10	9	5	8	3	5	12	6	13	16	56	52	65	56
Abies balsamea	1	1	...	...	1	1	...	...	...	1	...	...	...	1	1	1	...	3
Larix laricina	2	...	...	1	...	1	...	...	...	...	...	...	...	...	1	...	1	2
Tsuga canadensis	4	25	41	30	54	43	55	46	17	22	58	53	41	6	2	1	2	4
Betula	42	23	17	11	13	18	21	25	21	20	12	12	13	5	5	8	8	6
Alnus	6	4	9	15	9	14	8	11	75	10	5	5	3	...	32	1	2	...
Salix		1	...	...	4	6	1	7	...	...	...	...	2	...	...	14	7	4
Carpinus/Ostrya	5	3	...	...	6	4	5	5	6	10	8	10	6	6	1	6	...	2
Quercus	17	24	29	17	37	26	24	39	26	13	18	21	17	22	6	12	15	9
Ulmus	12	6	8	5	9	3	7	17	11	21	15	14	11	15	1	4	3	3
Fagus grandifolia	2	3	2	1	7	10	13	13	11	7	14	7	4	4	...	...	...	...
Carya	9	4	5	7	3	8	10	6	5	1	5	8	4	...	...	1	...	...
Acer	11	2	7	3	9	5	8	5	7	5	7	10	7	3	2	...	...	2
Fraxinus		3	2	...	3	...	2	4	13	19	7	10	7	3	...	...	2	3
Tilia americana	2	1	2	1	1	1	2	4	2	4	3	5	4	3	...	...	...	...
Juglans	3	2	...	...	...	1	...	1	1	...	...	1	...	1	...	...	...	...
Corylus cornuta		...	...	1	...	1	3	...	5	...	...	1	1	...	...	...	1	...
TOTAL	199	194	171	189	230	244	257	265	231	176	222	203	210	173	197	176	228	183

Table 5. Records of arboreal pollen types from Cataraqui River Marsh sediments.

DEPTH IN CENTIMETERS	230	240	260	280	300	320	340	360	370	380	390	400	410	420	430	450	460
POLLEN TYPES																	
Picea maria..........	1	1	2	6	4	4	6	3	3	17	1	16	4	13	31	23	...
Picea glauca.........	2	4	1	2	8	9	10	25	12	12	10	75	2	46	48	53	...
Pinus strobus/resinosa	92	76	36	46	30	40	63	57	46	32	...	36	9	17	8	14	...
Pinus banksiana......	54	39	43	38	25	40	43	42	38	46	9	27	10	26	17	36	...
Abies balsamea.......	2	4	11	8	5	2	2	2	1	5	...	2	...	...	4	4	...
Larix laricina.......	2	...	...	2	1	1	3	...	1	1	...	...	1	...	...	...	...
Tsuga canadensis.....	5	12	8	5	4	6	14	11	24	16	1	3	2	8	2	2	...
Betula..............	1	12	19	18	15	14	18	9	10	11	3	7	2	16	10	17	...
Alnus...............	1	4	...	...	2	3	2	5	1	2	1	...	1	3	4	3	...
Salix...............	5	5	3	4	3	5	3	4	8	6	...	4	6	17	10	8	...
Carpinus/Ostrya......	5	4	7	8	11	11	8	5	3	6	4	3	1	7	3	...	...
Quercus.............	14	10	26	25	26	25	16	16	19	12	2	7	3	10	6	...	...
Ulmus...............	4	4	7	3	3	9	16	5	8	13	1	1	...	4	1	1	...
Fagus grandifolia....	...	2	...	...	1	1	1	1	2	2	...	...	...	...	...	...	...
Carya...............	2	1	1	...	...	4	...	...	3	2	...	...	...	1	...	...	...
Acer................	1	1	3	3	1	1	10	3	1	3	1	2	1	1	1	...	...
Fraxinus............	...	1	1	3	7	2	5	2	3	5	...	5	2	2	...	...	...
Tilia americana......	...	1	1	...	...	...	...	2	1	1	...	...	...	...	...	...	...
Juglans.............	...	2	...	1	2	...	...	2	...	...	...	...	...	...	...	...	...
Corylus cornuta......	1	5	8	3	...	1	...	1	...	3	2	1	...	2	1	1	...
TOTAL	196	188	177	175	118	178	220	195	181	184	35	189	44	174	143	162	...

Table 5. Cont'd

DEPTH IN CM	0	25	38	50	63	75	85	90	110	120	130	140	150	160	180	190	200	220
Pollen types																		
Artemisia	1	...	...	...	...	...	...	1	...	1	...	2	...	...	...	1	...	...
Ambrosia	51	39	2	2	1	1	...	...	...	...	2	5	1	2	...	1	2	...
Compositae	6	8	...	4	6	1	10	8	1	3	...	...	3	3	4	2	1	3
Gramineae	15	5	34	9	7	4	6	2	5	...	1	...	1	...	1	6	9	17
Cyperaceae	832	78	63	49	45	26	38	39	...	...	1	...	3	8	4	...	8	16
Chenopodiaceae	3	2	4	...	...	...	1	...	...	...	...	...	...	...	1	1	1	...
Caryophyllaceae	....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
Caprifoliaceae	1	...	1	1	...	5	1	1	...	...	...	...	...	...	...	...	...	...
Urticaceae	....	1	1	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Shepherdia canadensis	....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Ilex	....	...	...	...	...	...	...	...	...	4	24	9	7	17	...	...	...	...
Nymphaea	....	...	1	...	2	3	2	4	...	...	1	...	...	...	8	...	...	...
Nuphar	....	...	...	5	...	...	...	...	...	...	...	1	...	...	4	3	1	2
Typha	575	27	18	6	18	35	30	71	4	...	1	...	...	7	...	16	7	5
Myriophyllum	....	...	...	...	1	...	...	...	...	...	1	...	...	...	...	...	...	...
Sagittaria	....	2	1	1	...	3	...	1	...	...	...	...	...	...	...	2	...	...
Potamogeton	....	...	4	7	...	...	...	...	7	17	1	...	5	7	...	2	1	1
Menyanthes trifoliata	....	1	...	...	1	...	1	...	1	...	...	...	...	...	...	...	...	...
Rhamnus	....	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...
Umbelliferae	....	...	...	...	...	...	...	...	...	1	...	...	...	...	...	1	...	...
Leguminosae	....	...	...	...	...	...	...	...	...	...	...	...	...	4	...	...	...	...
Cruciferae	....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Rosaceae	3	...	...	...	...	2	4	1	1	...	3	...	4	3	2	...	...	3
Ranunculaceae	1	...	...	...	...	...	...	1	...	...	1	...	1	1	...	...	...	...
Rumex	....	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Polygonum sp	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
P. amphibium	....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Epilobium	....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Saxifragaceae	1	...	2	...	1	2	1	...	4	...	...	...	...	1	3	...	...	...
Labiatae	....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...
Cephalanthus	....	...	...	...	...	...	...	1	...	15	26	36	46	28	...	...	...	...
Unidentified	3	8	17	15	12	12	14	7	11	13	12	8	15	11	4	8	3	4
Spores Types																		
Polypodiaceae	....	8	5	7	5	1	7	1	38	9	12	8	20	45	9	25	97	44
Osmundaceae	....	...	...	...	...	...	...	...	47	73	85	50	73	40	...	...	...	...
Sphagnum	....	...	...	...	...	...	1	...	67	19	49	58	36	7	1	...	...	...
TOTAL	1508	182	171	109	99	97	115	139	181	155	220	177	215	184	41	68	131	96

Table 6. Records of non-arboreal pollen types from Cataraqui River Marsh sediments.

DEPTH IN CM.	230	240	260	280	300	320	340	360	370	380	390	400	410	420	430	450	460
Pollen types																	
Artemisia	3	1	2	1	1	3	4	3	1	2	-	1	-	-	2	1	-
Ambrosia	-	-	-	1	1	2	-	2	-	3	-	1	-	-	1	1	-
Compositae	2	4	1	3'	3	4	3	3	3	3	-	2	2	2	-	1	-
Gramineae	8	7	8	22	15	13	9	7	8	8	-	4	-	1	2	4	-
Cyperaceae	4	7	4	11	17	12	20	4	7	5	2	1	3	1	7	6	-
Chenopodiaceae	1	-	1	-	-	-	1	2	1	-	-	1	-	-	-	-	-
Caryophyllaceae	-	-	-	-	-	-	-	1	-	1	-	4	-	-	-	-	-
Caprifoliaceae	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Urticaceae	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Shepherdia canadensis	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Ilex	-	2	-	-	-	-	-	1	3	3	1	-	-	-	-	-	-
Nymphaea	-	2	-	-	5	-	-	8	5	6	-	2	-	-	-	-	-
Nuphar	3	1	36	17	16	12	17	19	10	33	-	5	-	-	-	-	-
Typha	2	3	11	18	-	17	20	23	23	39	10	30	4	24	65	-	-
Myriophyllum	-	1	-	-	2	2	-	1	1	4	1	1	-	2	12	-	-
Sagittaria	1	-	1	-	13	5	4	4	2	1	-	-	-	-	-	-	-
Potamogeton	1	-	1	2	3	4	2	4	1	6	3	3	4	19	10	-	-
Menyanthes trifoliata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rhamnus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Umbelliferae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Leguminosae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cruciferae	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Rosaceae	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	-
Ranunculaceae	-	1	3	-	-	-	3	1	2	-	-	-	1	-	-	-	-
Rumex	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polygonum sp.	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
P. amphibium	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Epilobium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-
Saxifragaceae	-	-	-	1	3	-	3	3	-	1	-	-	1	2	-	-	-
Labiatae	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
Cephalanthus	-	2	5	4	-	-	-	-	1	-	-	-	-	-	-	-	-
Unidentified	8	10	-	6	19	5	8	9	4	9	1	6	5	4	7	9	-
Spores types																	
Polypodiaceae	59	29	5	5	3	-	13	20	21	16	-	-	-	3	3	1	-
Osmundaceae	-	8	-	-	-	1	17	6	21	10	-	-	-	-	-	-	-
Sphagnum	-	-	-	-	1	-	2	3	1	-	-	-	-	-	-	-	-
TOTAL	93	78	81	93	102	80	123	127	116	150	18	61	20	79	119	23	0

DEPTH IN CM.	15	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340
Pollen types																		
Picea mariana	1	2	2	...	2	3	2	2	5	1	2	1	1	1	1	...	1	2
Picea glauca	2	5	1	...	...	...	...	...	3	...	2	...	1	...	1	...	1	...
Pinus strobus/resinosa	34	54	58	77	74	38	38	45	29	33	32	40	35	44	35	34	25	37
Pinus banksiana	9	10	21	11	11	11	13	9	8	12	9	21	32	32	15	20	31	20
Abies balsamea	1	...	1	...	1	...	1	1	...	...	1	...	1	...	...	...	...	1
Larix laricina	...	1	1	2	...	1	1	...	...	...	2	1	...	...	...	...	1	2
Tsuga canadensis	15	16	35	43	34	39	38	49	55	44	39	36	31	18	18	27	53	51
Betula	31	39	40	29	40	41	47	37	24	38	21	23	24	18	22	30	27	30
Alnus	27	25	10	10	6	21	10	9	11	7	13	2	13	19	17	7	16	9
Salix	...	1	...	...	...	...	...	...	...	...	...	...	3	...	...	...	...	1
Carpinus/Ostrya	12	6	13	7	7	13	6	6	7	6	8	12	17	11	14	6	8	13
Quercus	14	17	15	16	25	23	13	29	29	29	24	46	30	22	39	29	23	24
Ulmus	18	16	10	8	7	18	12	17	6	12	11	17	9	15	12	15	20	25
Fagus grandifolia	10	14	15	21	28	17	25	22	38	17	20	19	28	11	19	31	26	30
Carya	2	1	4	2	6	...	...	1	5	4	4	1	3	...	2	6	1	1
Acer	6	5	11	10	18	5	8	9	7	3	18	12	12	11	8	22	11	10
Fraxinus	6	8	5	3	4	5	3	11	6	5	7	16	18	14	9	14	14	10
Tilia americana	...	...	2	1	4	5	3	1	1	1	3	3	3	1	3	2	1	1
Juglans	3	1	...	...	1	...	...	1	...	1	...	...	1	...	2	...	...	1
Corylus cornuta	3	1	1	...	...	...	2	...	...	...	...	...	1	...	...	...	...	...
TOTAL	228	222	245	243	273	241	220	249	244	213	226	246	263	217	217	243	267	268

Table 7. Records of arboreal pollen types from Grady Lake sediments.

DEPTH IN CM.	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700
<u>Pollen types</u>																		
<u>Picea</u> <u>mariana</u>	...	...	2	1	...	...	...	...	...	...	1	...	1	4	...	1	1	1
<u>Picea</u> <u>glauca</u>	1	1	2	1	...	1	...	...	...	...	...	...	...	2	...	...	1	...
<u>Pinus</u> <u>strobus/resinosa</u>	54	55	53	41	61	84	79	60	107	60	91	60	53	60	30	45	35	25
<u>Pinus</u> <u>banksiana</u>	18	22	24	33	18	23	25	16	12	16	25	29	13	20	12	26	12	15
<u>Abies</u> <u>balsamea</u>	...	...	...	...	...	1	...	1	...	...	2	...	...	...	1	...	...	1
<u>Larix</u> <u>laricina</u>	...	...	...	...	2	...	1	...	...	1	...	...	1	...	...	...	1	...
<u>Tsuga</u> <u>canadensis</u>	59	41	25	21	15	27	7	14	8	3	19	15	8	8	7	30	37	21
<u>Betula</u>	32	15	22	39	24	16	29	19	31	28	32	32	40	27	30	27	24	19
<u>Alnus</u>	7	3	10	12	9	12	7	6	7	15	9	7	15	7	8	5	8	11
<u>Salix</u>	...	...	1	...	...	...	...	...	...	...	...	...	1	1	2	1	...	2
<u>Carpinus</u>/<u>Ostrya</u>	13	9	14	24	17	20	10	19	8	8	6	20	14	13	21	13	6	17
<u>Quercus</u>	24	24	39	23	30	18	27	42	50	65	52	40	78	70	43	40	43	56
<u>Ulmus</u>	17	14	8	14	9	10	15	6	9	10	6	9	13	21	19	14	18	8
<u>Fagus</u> <u>grandifolia</u>	31	14	21	33	21	13	16	14	6	10	21	16	10	18	20	18	6	16
<u>Carya</u>	1	3	...	1	...	...	...	...	2	2	3	4	3	3	4	2	2	1
<u>Acer</u>	11	8	8	5	12	12	10	11	5	11	13	18	20	13	16	16	9	8
<u>Fraxinus</u>	9	4	4	7	13	5	10	1	8	5	4	9	8	6	6	5	10	9
<u>Tilia</u> <u>americana</u>	4	3	2	...	2	1	...	2	3	5	4	2	3	3	2	2	2	1
<u>Juglans</u>	2	...	1	...	1	...	...	1	...	1	1	1	1	5	1	...	...	...
<u>Corylus</u> <u>cornuta</u>	...	...	...	...	...	...	1	1	...	2	1	...	...	...	...	...	1	1
TOTAL	283	219	236	267	234	243	237	213	268	249	290	262	282	281	238	245	216	218

Table 7. Cont'd

DEPTH IN CM.	720	740	760	780	800	820	840	860	880	900	920	940	960	980	990	1000	1020	1040	1055
Pollen types																			
Picea mariana	...	...	...	2	1	1	...	1	1	...	1	1	8	3	14	37	43	19	4
Picea glauca	...	...	...	1	...	...	1	1	...	1	1	4	1	2	16	56	64	13	16
Pinus strobus/resinosa	39	30	53	42	51	72	66	72	70	43	33	42	44	7	25	7	19	20	9
Pinus banksiana	29	18	52	81	78	84	82	127	97	97	97	134	159	100	57	61	59	105	131
Abies balsamea	...	...	...	...	1	...	...	1	...	2	...	4	1	1	2	2	....	1	....
Larix laricina	...	...	...	...	1	...	1	...	1	...	...	4	3	2	2	....	1	1	....
Tsuga canadensis	27	36	10	9	3	1	...	1	2	3	1	2	5	...	...	2	5	5	6
Betula	17	17	10	6	8	12	17	13	40	14	36	34	53	51	21	10	24	33	6
Alnus	7	7	9	3	1	6	1	...	2	1	6	3	2	...	1	....	1	19	6
Salix	...	...	...	...	...	...	...	...	4	...	...	...	...	5	1	2	3	10	7
Carpinus/Ostrya	18	18	11	16	9	24	17	10	14	4	4	2	3	9	13	11	....	2	3
Quercus	38	50	34	51	45	40	44	15	43	47	52	13	20	41	27	20	4	1	4
Ulmus	25	13	26	9	5	13	8	6	3	7	4	6	4	3	7	4	1	2	....
Fagus grandifolia	12	14	9	6	8	5	1	1	3	...	...	2	1	...	...	....	....	....	....
Carya	2	...	1	...	...	1	...	...	...	...	...	...	...	1	...	....	....	....	1
Acer	16	16	8	6	9	2	3	1	2	1	2	1	1	1	2	3	3	....	....
Fraxinus	8	6	9	3	4	4	8	5	2	1	2	1	1	2	8	....	1	....	1
Tilia americana	2	3	...	2	3	...	1	...	...	1	...	...	1	1	...	....	....	....	....
Juglans	1	...	...	...	...	...	...	1	1	...	...	...	...	...	...	....	....	....	....
Corylus cornuta	...	...	1	...	1	2	1	2	...	...	...	1	1	4	9	3	2	4	....
TOTAL	241	228	233	237	229	262	251	257	285	222	239	254	307	233	205	219	230	235	195

Table 7. Cont'd

DEPTH IN CM:	1.5	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300	320	340
Pollen types																		
Artemisia.....	1	1	4	...	3	1	1	...	1	...	1	...	...	...	...	...	...	...
Ambrosia......	35	29	1	6	2	2	1	...	...	...	1	...	...	...	1	1	...	...
Compositae....	1	1	...	1	...	...	...	...	...	...	...	...	1	...	1	2	...	1
Gramineae.....	7	31	4	8	2	1	2	...	...	1	2	5	2	2	3	1	1	...
Cyperaceae...	...	1	1	...	...	...	1	...	...	1	...	...	...	...	...	1	...	1
Chenopodiaceae	1	...	...	2	...	...	...	...	1	...	...	...	1	...	...	...	...	...
Leguminosae...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Plantago......	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Saxifragaceae.	...	3	4	2	...	...	...	...	...	1	...	...	...	...	...	...	...	...
Nemopanthus...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Ilex.........	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Scheuchzeria..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Ericaceae.....	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...
Nuphar........	...	...	...	1	...	...	1	...	...	...	1	...	...	...	...	...	...	...
Typha.........	2	1	...	1	...	1	...	...	1	...	...	...	...	...	...	1	...	...
Potamogeton...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Myriophyllum..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Sparganium....	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Rosaceae......	1	4	6	2	...	1	1	...	...	...	...	...	...	...	...	...	...	...
Caprifoliaceae	...	2	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...
Cruciferae....	...	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Ranunculaceae.	...	3	2	3	...	...	...	...	...	...	...	...	...	...	...	2	...	...
Malvaceae.....	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
Cornus.......	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...
Polygonaceae..	...	...	...	...	...	...	...	...	...	1	1	...	1	...	...	...	...	...
Labiatae......	...	1	...	...	1	...	...	...	...	...	...	...	...	...	...	...	1	...
Unidentified..	7	6	6	7	3	...	...	1	3	2	5	4	7	2	2	2	15	3
TOTAL:	55	88	29	34	11	6	7	1	7	6	11	9	12	5	7	10	19	6

Table 8. Records of non-arboreal pollen types from Grady Lake sediments.

DEPTH IN CM:	360	380	400	420	440	460	480	500	520	540	560	580	600	620	640	660	680	700
Pollen types																		
Artemisia	...	...	1	...	...	...	...	...	...	...	...	...	...	2	...	...	...	...
Ambrosia	...	...	...	2	...	1	1	1	...	...	...	1	...	1	2	...	1	...
Compositae	1	...	...	...	...	...	1	1	1	1	...	1	...	...	...	1	...	...
Gramineae	...	1	...	...	...	...	2	...	2	...	...	...	...	...	...	...	...	...
Cyperaceae	...	...	...	...	...	...	...	1	...	...	...	...	...	1	1	1	1	...
Chenopodiaceae	...	...	...	...	...	...	...	...	...	...	1	...	2	...	...	...	1	...
Leguminosae	...	...	...	...	...	...	1	...	1	...	...	...	...	...	...	...	...	...
Plantago	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Saxifragaceae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Nemopanthus	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Ilex	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Scheuchzeria	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...
Ericaceae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Nuphar	...	...	...	...	...	...	...	...	4	...	...	...	...	...	...	...	...	1
Typha	...	1	1	...	...	1	1	...	...	...	...	...	...	1	...	...	...	...
Potamogeton	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Myriophyllum	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	2	2	...
Sparganium	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...
Rosaceae	...	...	1	...	...	...	...	...	...	...	1	...	...	...	...	...	2	...
Caprifoliaceae	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...
Cruciferae	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...
Ranunculaceae	...	...	...	...	...	...	...	...	...	...	...	3	...	...	...	...	...	1
Malvaceae	...	1	...	...	1	1	...	...	...	1	1	...	...	...	...	...	...	...
Cornus	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Polygonaceae	...	...	...	...	...	2	2	1	...	1	...	...	...	...	...	...	...	...
Labiatae	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	1	...
Unidentified	1	3	2	2	3	3	2	5	2	5	...	2	3	3	6	3	5	3
TOTAL:	3	6	5	4	4	8	10	9	10	11	5	7	5	8	11	7	14	5

Table 8. Cont'd

DEPTH IN CM:	720	740	760	780	800	820	840	860	880	900	920	940	960	980	990	1000	1220	1040	1055
Pollen types																			
Artemisia	1	1	...	...	...	...	1	...	2	...	1	2	1	5	7	8	2	13	3
Ambrosia	2	...	...	...	1	...	1	1	1	3	6	2	3	1	1	1	....	....	6
Compositae	1	...	...	...	...	1	...	...	1	...	...	1	...	...	...	2	....	....	2
Gramineae	...	...	...	...	...	...	...	...	4	1	1	4	4	12	7	....	3	1	2
Cyperaceae	...	...	...	...	...	...	...	...	...	...	...	...	1	1	4	1	3	9	12
Chenopodiaceae	1	...	1	...	...	...	...	...	...	1	...	1	...	...	...	....	....	1	1
Leguminosae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	....	....
Plantago	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	....	....
Saxifragaceae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	1	....
Nemopanthus	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	....	....	....	....
Ilex	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	....	....
Scheuchzeria	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	....	....
Ericaceae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	1	....
Nuphar	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	....	....
Typha	...	...	...	1	...	...	...	...	1	...	...	...	...	...	...	4	3	....	....
Potamogeton	...	...	...	...	...	...	...	...	...	...	154	1500	182	182	551	610	939	19	12
Myriophyllum	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	1	....
Sparganium	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	....	....	....	....
Rosaceae	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	....	....
Caprifoliaceae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	....	....
Cruciferae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	....	....
Ranunculaceae	...	...	...	...	1	...	...	...	...	...	...	...	...	...	1	....	....	....	....
Malvaceae	...	...	...	...	1	...	...	...	...	...	...	...	...	...	1	....	....	....	....
Cornus	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	....	....	....
Polygonaceae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	....	....	....	....
Labiatae	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	....	....	....	....
Unidentified	4	4	4	1	1	1	2	1	1	4	4	...	2	4	5	2	2	5	6
TOTAL:	12	7	5	3	3	2	4	2	10	9	167	1511	193	207	186	629	952	51	44

Table 8. Cont'd

DEPTH IN CM.	1.5	11	25	30	40	50	60	70	80	90	100	110	120	135	140	145	160	180	200	210	220
Pollen types																					
Picea mariana ...	32	3	2	-	20	16	6	1	3	5	2	3	3	5	-	1	6	6	2	-	1
Picea glauca	5	7	2	1	9	4	31	-	2	2	2	5	2	-	2	1	1	1	3	-	-
Pinus	67	51	61	57	14	20	27	80	98	120	61	109	93	86	24	70	67	51	67	95	59
Abies balsamea ..	8	1	3	1	7	12	3	1	1	-	2	2	3	1	-	1	6	1	1	-	-
Larix laricina ..	-	1	1	2	1	4	1	-	1	3	1	1	2	1	1	2	4	2	3	1	3
Tsuga canadensis.	58	35	49	30	51	54	70	43	41	44	58	45	29	65	20	33	22	42	37	25	74
Betula	69	25	37	30	32	67	22	19	47	30	31	29	25	36	28	29	50	35	56	40	16
Alnus	9	8	8	7	8	6	-	-	4	2	3	-	4	1	3	3	13	5	4	1	-
Salix	-	-	-	-	-	-	-	-	-	-	-	2	-	-	-	-	1	-	-	-	-
Carpinus/Ostrya..	9	6	1	9	5	6	7	4	5	8	10	16	8	15	-	9	10	4	16	9	13
Quercus	48	23	15	25	22	33	12	16	12	18	17	22	16	17	14	12	36	26	44	17	28
Ulmus	40	16	9	15	8	10	4	17	16	22	15	16	15	19	8	18	21	14	36	16	14
Fagus grandifolia.	2	-	5	5	1	2	-	7	6	3	12	2	6	6	2	3	8	21	10	12	6
Carya	14	6	5	7	5	2	3	5	3	3	4	5	10	1	-	2	5	7	8	3	-
Acer	14	11	3	7	12	19	19	3	12	10	8	5	4	13	5	5	16	15	17	8	4
Fraxinus.........	7	5	2	3	1	6	1	5	5	6	5	4	4	3	-	4	5	9	11	4	8
Tilia americana....	9	2	1	-	3	3	3	1	3	2	1	2	3	7	-	1	1	2	5	2	4
Juglans	1	-	-	-	2	1	-	-	1	1	1	-	2	-	-	-	-	-	1	1	1
Corylus cornuta....	-	1	-	1	1	-	-	-	2	-	1	2	-	-	-	3	1	2	-	-	1
TOTAL	379	207	234	202	198	282	215	202	264	280	234	309	266	276	117	197	260	243	321	234	232

Table 9. Records of arboreal pollen types from Atkins Lake sediments.

DEPTH IN CM.	230	240	250	257	270	275	290	300	305	320	330	340	350	355	360	370	380	390	400
Pollen types																			
Picea mariana	...	1	1	...	2	10	3	...	7	13	31	22	36	32	21	3	2	...	1
Picea glauca	...	...	...	...	1	3	3	2	4	2	27	34	35	22	11	6	6	3	
Pinus	131	118	94	139	232	174	184	140	172	140	71	96	78	71	60	16	8	3	4
Abies balsamea	1	2	2	...	1	...	3	...	1	2	1	...	1	...	2	...	1	...	...
Larix laricina	1	...	...	1	...	2	3	3	4	2	11	7	2	...	1	...	...	...	...
Tsuga canadensis	32	28	14	16	4	3	6	4	6	4	2	2	2	1	1	...	...	...	...
Betula	9	11	17	5	21	16	17	14	25	16	20	17	13	13	70	...	...	...	...
Alnus	4	3	...	1	3	5	5	6	1	...	...	4	6	2	6	...	...	...	...
Salix		1	...	1	2	3	...	1	3	2	2	4	1	3	3	...	...	...	...
Carpinus/Ostrya	8	7	23	3	7	7	4	11	6	9	8	5	2		2	...	...	...	...
Quercus	16	38	55	28	31	32	28	22	26	42	27	22	15	5	13	...	1	...	...
Ulmus	7	13	18	10	14	16	8	1	8	...	3	2	1	2	1	...	...	...	...
Fagus grandifolia	8	9	4	3	6	...	...	...	3	...	...	...	...	...	...	...	...	...	...
Carya		2	5	1	...	1	1	...	1	...	...	1	...	...	1	...	...	...	...
Acer	11	7	8	1	...	4	...	...	2	1	2	...	...	...	...	...	...	...	...
Fraxinus	2	5	12	2	3	4	...	...	...	5	5	3	2	...	...	...	...	...	...
Tilia americana	3	1	2	2	...	...	...	...	4	...	...	...	...	...	...	...	...	...	...
Juglans	2	1	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...
Corylus cornuta		...	2	3	5	6	6	9	3	1	4	8	2	...	3	...	1	...	...
TOTAL	245	242	257	255	331	286	270	214	274	238	214	249	196	151	294	25	19	6	5

Table 9. Cont'd

DEPTH IN CM.	1.5	11	25	30	40	50	60	70	80	90	100	110	120	135	140	145	160	180	200	210	220
Pollen types																					
Ambrosia	84	41	38	46	34	3	...	...	...	...	3	...	1	...	...	...	1	...	...	...	...
Artemisia	...	...	...	1	...	...	1	...	...	...	...	...	...	...	...	...	1	...	1	2	...
Compositae	1	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...
Gramineae	14	6	...	3	2	1	...	...	...	...	...	1	...	...	...	...	...	1	...	...	...
Cyperaceae	9	1	3	1	1	...	...	1	...	...	...	1	...	...	...	...	1	...	...	1	...
Typha	5	1	3	...	1	...	...	...	2	...	4	1	...	...	...	...	...	1	...	...	...
Nymphaea	1	...	...	1	...	...	...	1	...	...	...	...	...	...	...	...	2	2	1	1	...
Nuphar	...	...	...	...	...	...	...	1	2	...	1	...	...	...	...	...	...	...	...	...	...
Sparganium	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Chenopodiaceae	2	...	1	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Potamogetonaceae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...
Ranunculaceae	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Myriophyllum	...	...	...	...	...	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Labiatae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	...
Gentianaceae	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Saxifragaceae	...	...	...	1	1	...	...	...	...	...	...	...	...	1	...	1	...	...	...	1	1
Ericaceae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Plantaginaceae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Leguminosae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Rosaceae	1	2	...	...	...	1	1	...	...	...	...	3	2	...	...	...	1	...	1	...	2
Caprifoliaceae	...	3	...	1	1	...	...	...	...	1	...	...	...	...	...	...	...	1	...	...	...
Unidentified	2	5	4	6	3	6	8	3	3	2	4	4	1	3	2	3	8	8	5	3	1
TOTAL	120	61	50	62	43	13	10	6	7	3	12	10	4	4	2	5	14	15	9	9	4

Table 10. Records of non-arboreal pollen types from Atkins Lake sediments.

DEPTH IN CM.	230	240	250	257	270	275	290	300	305	320	330	340	350	355	360	370	380	390	400
Pollen Types																			
Ambrosia.........	1	...	1	...	3	3	1	1	1	...	2	...	...	...	...	...	...	...	...
Artemisia........	1	...	...	...	4	1	1	7	2	4	4	3	4	...	6	1	...	...	...
Compositae.......	...	...	...	...	1	1	...	2	...	...	2	1	1	2	8	...	...	...	...
Gramineae........	...	...	...	1	2	3	3	5	6	1	...	1	...	...	1	...	...	...	...
Cyperaceae.......	...	1	1	2	1	...	...	2	2	1	3	5	12	2	8	...	...	...	...
Typha............	...	...	...	1	...	...	1	3	2	2	2	6	9	...	10	...	...	...	...
Nymphaea.........	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...
Nuphar...........	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...
Sparganium.......	...	...	...	...	...	...	...	...	...	...	...	...	...	4	2	...	...	...	...
Chenopodiaceae....	...	...	...	...	...	1	...	...	...	...	...	...	1	...	1	...	...	...	...
Potamogetonaceae..	...	1	6	1	1	2	...	3	10	8	3	6	8	38	83	...	1	...	...
Ranunculaceae.....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Myriophyllum.....	1	...	...	...	...	...	...	...	...	...	...	...	...	1	2	...	...	...	...
Labiatae.........	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...
Gentinaceae......	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Saxifragaceae.....	...	...	...	1	...	...	...	...	...	...	...	...	...	11	...	...	...	...	...
Ericaceae.........	...	...	...	...	...	...	...	...	...	...	...	...	...	3	...	...	...	...	...
Plantaginaceae....	...	...	...	...	...	...	...	...	...	2	...	...	...	...	...	...	...	...	...
Leguminosae......	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Rosaceae.........	...	...	...	...	...	...	...	...	...	3	1	...	...	1	...	...	...	...	...
Caprifoliaceae....	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...
Unidentified......	5	1	6	4	2	3	1	...	5	5	4	7	4	8	6	1	1	...	...
TOTAL	8	3	14	10	15	15	7	25	28	27	21	29	39	56	141	2	2	0	0

Table 10. Cont'd

DEPTH IN CENTIMETERS GASTROPODA	0-15	15-30	30-45	45-60	60-67	67-75	75-90	90-105	105-120	120-135	135-150	150-165	165-180	180-195	195-210
Valvata tricarinata tricarinata	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..
V. tricarinata perconfusa	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
V. tricarinata basalis	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
V. tricarinata unicarinata	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
V. tricarinata infracarinata	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
V. tricarinata simplex	22	37	70	11	775	372	212	125	74	73	3	..	179	873	1377
Gyraulus parvus	3	6	9	1	338	122	44	54	7	8	..	..	74	214	309
Amnicola limosa	4	7	19	1	134	53	15	1	..	14	3	..	10	168	268
Amnicola lustrica	22	73	80	16	650	225	70	9	9	38	..	1	16	3	40
Helisoma campanulatum	1	..	2	..	8	2	..	6	..	1	..	..	18	79	228
Helisoma anceps	..	..	..	..	3	..	..	..	..	..	..	..	1	19	213
Fossaria obrussa decampi	2	5	25	3	101	31	15	10	..	3	..	..	..	2	2
Physa gyrina	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Armigera crista	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Vertigo ovata	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

PELECYPODA															
Pisidium nitidum	35½	32	45	18	285½	86½	15½	25	4	12½	1	..	124½	384½	494½
P. ferrugineum	18½	23	9	1	55	12	1½	..	..	..	..	..	31½	127½	316
P. pauperculum	1½	3½	17	2	64	12	10½	..	..	1½	..	..	37½	47½	48½
P. nitidum contortum	..	..	..	..	..	..	..	..	..	..	..	..	8	23	30½
P. obtusale ventricosum	9½	16	20½	2½	61½	20½	3½	6½	..	3	..	..	..	3	½
P. variabile	..	2	..	1	29½	9½	3½	1	..	1	..	..	15½	25½	22½
P. compressum	2	5½	..	2	28	11	5½	3	..	..	..	..	6½	24½	25½
P. casertanum	..	..	..	..	..	1	..	..	..	..	..	..	½	½	..
P. adamsi	..	..	..	..	..	..	1½	½	..	..	..	..	3½	10½	24½
P. walkeri mainense	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..
Sphaerium lacustre	1	..	..	..	2	..	½	..	2	½	..	..	4½	17½	21
S. simile	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..
TOTAL	122	203	303	58	2514	959	398	246	96	155	7	1	533	2021½	3410

Table 11. Molluscan records from Atkins Lake sediments.

DEPTH IN CENTIMETERS / GASTROPODA	210-225	225-240	240-255	255-270	270-285	285-300	300-315	315-330	330-345	345-360	M	%
Valvata tricarinata tricarinata	..	..	10	8	61	109	162	44	228	21	1061	3.7
V. tricarinata perconfusa	..	15	30	45	143	410	364	82	1	..	1095	3.8
V. tricarinata basalis	..	2	3	4	..	4	..	..	..	..	13	.04
V. tricarinata unicarinata	..	..	8	17	118	39	20	2	..	..	204	.6
V. tricarinata infracarinata	..	4	8	1	..	..	..	..	..	..	13	.04
V. tricarinata simplex	1212	483	652	781	412	45	27	7	..	..	7322	23.3
Gyraulus parvus	544	870	864	726	433	240	236	177	34	10	5333	16.9
Amnicola limosa	281	184	130	62	14	21	22	27	28	7	1485	4.7
Amnicola lustrica	27	17	..	..	..	..	..	..	..	..	1296	4.1
Helisoma campanulatum	193	72	19	6	..	..	..	..	1	..	676	2.1
Helisoma anceps	138	98	68	39	12	14	8	1	8	5	627	1.9
Fossaria obrussa decampi	13	56	37	37	41	54	35	10	1	..	483	1.5
Physa gyrina	3	11	3	..	..	..	1	..	..	..	18	.05
Armiger crista	..	..	..	..	1	..	..	..	..	..	1	.003
Vertigo ovata	..	..	..	..	..	..	..	..	..	..	1	.003

PELECYPODA

Pisidium nitidum	397½	337½	434½	672	946½	373½	476	454	268	16½	5852½	18.6
P. ferrugineum	449	210½	91	88½	404½	81½	141½	83	40	7½	2192	6.9
P. nitidum pauperlum	59	39½	66	80½	74½	68½	41½	53½	28½	5	764	2.4
P. nitidum contortum	18½	48	112	85	128½	34½	17½	7	12½	..	525	1.6
P. obtusale ventricosum	0½	..	1½	21½	93	14	25½	54	32	2½	401½	1.2
P. variabile	27	20	27½	16½	22½	6½	9½	58½	8	5½	311½	.9
P. compressum	55½	21	24½	25½	21½	1	2	1	6	1	271½	.8
P. casertatanum	..	..	..	..	..	..	..	..	..	..	1	.003
P. adamsi	24	23	8	1	..	..	..	1	..	..	98½	.3
P. walkeri mainense	2½	..	..	..	..	..	..	..	..	..	3½	.1
Sphaerium lacustre	59½	85½	58½	14½	13½	4½	17½	4½	13	..	427	1.3
S. simile	2	..	2	1	..	..	..	..	..	..	6	.2
TOTAL	3544	2607	2759	2750½	2973½	1550	1690	1462½	711	82	31442	100%

Table 11. Cont'd

Table 12

Trace elements concentrations from Atkins Lake sediments in ppm.

DEPTH IN CM.	5.5	17	25	35	45	55	65	75
ELEMENTS								
Barium	200	300	200	200	200	150	150	150
Boron	50	70	50	50	30	50	50	30
Lead	150	150	100	70	100	<20	<20	<20
Manganese	150	150	150	200	200	100	150	150
Titanium	500	700	700	700	500	300	300	300
Vanadium	20	30	30	30	20	<20	<20	20
Zirconium	50	70	70	50	70	30	30	20
Copper	30	30	30	30	30	20	15	15
Nickel	15	20	15	15	30	5	3	3
Strontium	100	150	100	100	100	150	100	100
Chromium	<10	<10	<10	<10	<10	<10	<10	<10
Cobalt	<10	<10	<10	<10	<10	<10	<10	<10
Beryllium	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<20	<20	<20	<20	<20	<20	<20	<20
Molybdenum	<5	<5	<5	<5	<5	<5	<5	<5
Niobium	<10	<10	<10	<10	<10	<10	<10	<10
Cadmium	<200	<200	<200	<200	<200	<200	<200	<200
Silver	<1	<1	<1	<1	<1	<1	<1	<1
Antimony	<100	<100	<100	<100	<100	<100	<100	<100
Tin	<10	<10	<10	<10	<10	<10	<10	<10
Zinc	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
Tungsten	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000

DEPTH IN CM.	85	95	100	115	125	135	145	155
ELEMENTS								
Barium	150	200	150	200	200	200	200	200
Boron	50	70	30	50	70	50	50	30
Lead	<20	<20	<20	<20	<20	<20	<20	<20
Manganese	150	100	100	100	100	100	100	70
Titanium	300	300	300	300	300	300	300	300
Vanadium	<20	<20	<20	20	<20	20	20	20
Zirconium	30	30	50	70	70	70	30	30
Copper	15	20	20	20	20	15	30	30
Nickel	5	3	3	5	5	5	5	10
Strontium	100	100	100	100	100	100	100	150
Chromium	<10	<10	<10	<10	<10	<10	<10	<10
Cobalt	<10	<10	<10	<10	<10	<10	<10	<10
Beryllium	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<20	<20	<20	<20	<20	<20	<20	<20
Molybdenum	<5	<5	<5	<5	<5	<5	<5	<5
Niobium	<10	<10	<10	<10	<10	<10	<10	<10
Cadmium	<200	<200	<200	<200	<200	<200	<200	<200
Silver	<1	<1	<1	<1	<1	<1	<1	<1
Antimony	<100	<100	<100	<100	<100	<100	<100	<100
Tin	<10	<10	<10	<10	<10	<10	<10	<10
Zinc	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
Tungsten	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000

Table 12. Cont'd

DEPTH IN CM.	160	170	180	190	200	210	220	230
ELEMENTS								
Barium	300	200	200	200	300	150	200	300
Boron	50	50	70	50	50	<10	10	15
Lead	20	20	<20	<20	<20	<20	<20	<20
Manganese	150	100	100	100	150	50	200	150
Titanium	300	300	300	300	300	150	300	300
Vanadium	20	20	<20	<20	20	20	30	50
Zirconium	30	30	30	30	30	20	30	30
Copper	75	50	30	30	30	7	30	30
Nickel	10	15	7	10	15	3	15	20
Strontium	200	200	200	200	200	200	200	200
Chromium	<10	<10	<10	<10	<10	<10	<10	<10
Cobalt	<10	<10	<10	<10	<10	<10	<10	<10
Beryllium	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<20	<20	<20	<20	<20	<20	<20	<20
Molybdenum	<5	<5	<5	<5	<5	<5	<5	<5
Niobium	<10	<10	<10	<10	<10	<10	<10	<10
Cadmium	<200	<200	<200	<200	<200	<200	<200	<200
Silver	<1	<1	<1	<1	<1	<1	<1	<1
Antimony	<100	<100	<100	<100	<100	<100	<100	<100
Tin	<10	<10	<10	<10	<10	<10	<10	<10
Zinc	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
Tungsten	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000

Table 12. Cont'd

DEPTH IN CM.	240	250	257	270	280	290	300	310
ELEMENTS								
Barium	200	150	150	150	300	200	300	200
Boron	15	10	10	<10	10	10	10	<10
Lead	<20	<20	<20	<20	<20	<20	<20	<20
Manganese	150	100	150	150	150	150	150	150
Titanium	300	200	300	200	500	500	500	300
Vanadium	30	20	20	20	30	30	30	30
Zirconium	30	20	30	30	70	70	50	20
Copper	30	30	70	15	20	20	30	10
Nickel	10	10	15	5	10	10	15	5
Strontium	200	150	150	150	200	200	200	200
Chromium	<10	<10	<10	<10	<10	<10	<10	<10
Cobalt	<10	<10	<10	<10	<10	<10	<10	<10
Beryllium	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<20	<20	<20	<20	<20	<20	<20	<20
Molybdenum	<5	<5	<5	<5	<5	<5	<5	<5
Niobium	<10	<10	<10	<10	<10	<10	<10	<10
Cadmium	<200	<200	<200	<200	<200	<200	<200	<200
Silver	<1	<1	<1	<1	<1	<1	<1	<1
Antimony	<100	<100	<100	<100	<100	<100	<100	<100
Tin	<10	<10	<10	<10	<10	<10	<10	<10
Zinc	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
Tungsten	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000

Table 12. Cont'd

DEPTH IN CM.	315	325	335	345	360	365	375	395
ELEMENTS								
Barium	200	300	300	300	1000	700	700	700
Boron	10	30	30	50	100	50	30	50
Lead	<20	20	20	20	20	20	20	20
Manganese	150	150	150	150	500	300	300	500
Titanium	500	1000	1500	1500	3000	2000	3000	2000
Vanadium	30	20	50	70	100	150	100	150
Zirconium	30	150	200	300	500	150	150	150
Copper	20	30	50	50	30	30	30	30
Nickel	15	30	30	30	30	30	30	50
Strontium	200	300	300	200	1000	500	300	200
Chromium	<10	10	30	30	70	70	50	70
Cobalt	<10	<10	10	15	20	20	20	30
Beryllium	<1	<1	<1	<1	<1	<1	<1	<1
Bismuth	<20	<20	<20	<20	<20	<20	<20	<20
Molybdenum	<5	<5	<5	<5	<5	<5	<5	<5
Niobium	<10	<10	<10	<10	<10	<10	<10	<10
Cadmium	<200	<200	<200	<200	<200	<200	<200	<200
Silver	<1	<1	<1	<1	<1	<1	<1	<1
Antimony	<100	<100	<100	<100	<100	<100	<100	<100
Tin	<10	<10	<10	<10	<10	<10	<10	<10
Zinc	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000
Tungsten	<1000	<1000	<1000	<1000	<1000	<1000	<1000	<1000

Table 12. Cont'd

Table 13

Records of the general chemistry and the sedimentary chlorophyll degradation products (SCDP) of the bottom surface sediment samples of Meach Lake. The station numbers along traverse A-B (Fig. 19B, p. 105) are shown at the top. Exchangeable ions are in milligrams per 100 grams of dried sediment.

STATION NO	1	2	3	4	5	6
Depth m	11.0	15.0	16.5	19.5	16.5	16.5
Water %	27.63	91.10	88.30	91.46	91.81	92.19
Ignition loss %	1.09	69.74	31.20	28.95	28.96	29.35
Nitrogen %	0.17	...	1.21	1.16	1.19	1.28
Phosphorus	3.18	...	7.37	6.19	8.06	7.22
Potassium	9.4	...	32.9	33.0	27.5	29.1
Sodium	2.13	...	9.54	10.60	8.35	9.34
Calcium	107.	...	325.	390.	305.	329.
Magnesium	12.	...	32.	33.	33.	37.
C/N	6.41	...	25.82	24.94	23.42	22.71
P/N	18.72	...	6.10	5.34	6.78	5.64
Ca+Mg	119.	...	357.	423.	338.	366.
K+Na	11.63	...	42.44	43.60	35.85	38.44
Ca+Mg/K+Na	10.22	...	8.40	9.74	9.43	9.54
K+Na+Ca+Mg	130.6	...	99.4	466.6	373.8	404.4
Ca/Mg	8.9	...	10.1	11.8	9.2	8.8
K/Na	4.41	...	3.29	3.11	3.29	3.11
SCDP/g dry wt.	0.41	8.48	24.30	36.52	43.70	40.68
SCDP/g ign.loss	38.13	12.16	73.88	126.15	150.87	138.56
ABSORBANCE RATIO						
410/350	1.38	0.54	1.53	1.88	1.83	1.82
448/350	0.85	0.43	1.25	1.50	1.42	1.44
410/448	1.62	1.27	1.22	1.25	1.28	1.26
350/670	2.33	4.36	2.61	2.57	2.60	2.49
410/670	3.23	2.38	4.01	4.85	4.78	4.54
448/670	2.00	1.87	2.33	3.87	3.71	3.59

Table 13. Cont'd

STATION NO	7	8	9	10	11
Depth m	12.8	11.0	7.5	4.9	1.2
Water %	90.57	87.87	74.34	62.08	35.77
Ignition loss %	33.12	29.18	13.53	11.19	3.18
Nitrogen %	1.39	1.18	0.76	0.42	...
Phosphorus	5.64	5.16	5.26	5.42	...
Potassium	31.5	24.0	18.0	11.8	...
Sodium	10.85	8.85	6.19	4.84	...
Calcium	355.	285.	179.	146.	...
Magnesium	41.	31.	28.	14.	...
C/N	23.81	24.63	17.82	26.61	...
P/N	4.05	4.38	6.93	12.89	...
Ca+Mg	396.	316.	207.	160.	...
K+Na	41.35	32.85	24.19	16.64	...
Ca+Mg/K+Na	9.58	9.63	8.57	9.64	...
K+Na+Ca+Mg	437.3	348.8	231.1	176.6	...
Ca/Mg	8.6	9.2	6.4	10.4	...
K/Na	2.93	2.71	2.91	2.44	...
SCDP/g dry wt.	26.51	15.36	4.77	2.32	2.31
SCDP/g ign.loss	80.04	52.63	11.07	20.72	72.94
ABSORBANCE RATIO 410/350	1.83	1.67	1.52	1.20	1.88
448/350	1.30	1.15	1.00	0.89	1.62
410/448	1.41	1.46	1.53	1.35	1.16
350/670	2.36	2.73	2.67	3.00	1.20
410/670	4.26	4.57	4.06	3.62	2.26
448/670	3.03	3.12	2.66	2.68	1.94

Table 14

Records of general chemistry and sedimentary chlorophyll degradation products of bottom surface samples from 9 lakes of the Gatineau Area. The lakes are classified in order of increasing hypolimnic oxygen depletion downward. Meach Lake data are from station number 5 of traverse A-B (Fig. 19B, p. 105. Exchangeable ions are in milligrams per 100 grams of dried sediment.

HYPOLIMNIC OXYGEN DEPLETION	Lake	Lat ° '	Long ° '	Depth m	Dry matter %	Ign. matter %	N %	P	K	Na	Ca	Mg	C/N
Nil	Simon	45 58	75 05	7.5	54.0	1.5	0.15	5.32	8.5	2.87	109	13.7	10.0
	Cayamant	46 06	76 17	4.9	24.4	5.6	0.18	5.38	11.8	3.92	117	19.8	31.5
	Blue Sea	46 13	76 03	17.0	33.0	6.8	0.25	5.42	11.4	4.00	400	17.2	27.2
Low	McGregor	45 38	75 39	17.0	27.7	17.6	0.70	5.59	22.4	7.04	254	28.4	25.1
	Belisles	46 02	75 00	33.5	14.1	17.4	0.68	5.25	24.2	5.64	258	37.2	25.6
Medium	Baie Ours	45 53	75 08	16.5	10.0	26.5	1.10	9.86	26.5	7.35	255	19.0	25.3
	Meach	45 58	75 05	16.5	8.1	28.9	1.19	8.06	27.5	8.35	305	33.0	23.4
	Perdrix	45 35	75 41	16.7	4.8	41.3	1.56	6.58	27.8	9.90	358	27.6	20.1
High	Vert	46 09	76 17	18.5	1.4	57.4	2.94	3.73	27.0	9.20	430	42.0	19.5

P/N $X10^{-3}$	$\frac{Ca+Mg}{K+Na}$	Total cations	Ca/Mg	K/Na	SCDP/g dry matter	SCDP/g ign. matter	WAVELENGTHS ABSORBANCE RATIO					
							$\frac{410}{350}$	$\frac{410}{670}$	$\frac{350}{670}$	$\frac{448}{670}$	$\frac{448}{350}$	$\frac{410}{448}$
35.42	11.72	132.0	7.95	2.96	0.6	7.2	1.36	2.14	1.30	1.58	1.18	1.41
29.22	8.67	152.5	5.91	3.03	6.6	8.0	1.54	3.20	2.20	2.35	1.17	1.83
21.70	9.58	162.6	7.56	2.84	2.1	18.4	1.36	3.62	2.58	2.04	0.80	1.77
8.00	9.61	311.8	8.95	3.19	5.1	28.9	1.49	4.29	2.98	3.05	1.01	1.45
7.73	9.88	325.0	6.95	4.30	23.1	134.9	1.45	4.86	2.84	3.42	1.16	1.20
8.92	8.07	307.8	13.41	3.62	26.1	116.0	1.62	3.87	2.26	2.68	1.16	1.50
6.78	9.43	373.8	9.25	3.29	43.7	150.8	1.83	4.78	2.60	3.71	1.42	1.28
4.22	10.22	423.3	12.96	2.81	82.1	198.7	2.06	5.01	2.50	4.08	1.65	1.33
1.92	13.02	508.2	10.22	2.94	491.6	855.7	1.79	5.24	2.71	4.37	1.70	1.12

Table 14. Cont'd

Table 15

Records of the general chemistry and sedimentary chlorophyll degradation products from Cataraqui River Marsh sediments. Exchangeable ions in milligrams per 100 grams of **dried sediment.**

DEPTH CM	0	5	10	15	20	25	30	35	40	45
Density	0.92		0.93		0.93		0.93		0.95	
Water %	96.49		89.80		88.91		86.30		86.87	
Ignition loss %	75.80		79.61		80.72		82.53		88.07	
pH		5.7		5.2		5.4		5.3		5.3
Nitrogen %		2.05		2.25		2.44		2.28		2.77
Phosphorus		21.02		14.41		9.03		3.58		1.55
Potassium		112.0		75.0		57.5		62.5		58.5
Sodium		15.6		23.7		19.3		23.3		24.5
Calcium		855.		900.		695.		875.		855.0
Magnesium		109.0		120.0		114.0		120.0		120.0
SCDP/g dry wt.	22.29		15.70		14.33		8.06		9.60	
SCDP/g ign.loss	29.40		19.73		17.75		9.77		10.90	
ABSORBANCE RATIO										
410/350	0.77		0.63		0.72		0.61		0.59	
448/350	0.39		0.31		0.35		0.32		0.29	
410/448	1.95		2.03		2.04		2.10		2.02	
350/670	4.93		6.25		5.41		7.60		7.62	
410/670	3.84		4.00		3.91		4.68		4.53	
448/670	1.96		1.96		1.91		2.22		2.24	

Table 15. Cont'd

DEPTH CM	50	65	75	85	90	95	100	105	110	115
Density	0.93		0.95	0.96		0.94	0.99	0.99	1.00	0.96
Water %	86.22		88.36	88.72		89.27		83.68		80.96
Ignition loss %	85.56		80.35	88.53		92.13		84.88		81.93
pH		5.4	5.4		5.1		5.3		5.5	
Nitrogen %		2.90	2.68		2.49		2.79		2.46	
Phosphorus		0.68	0.81		1.72		1.83		2.18	
Potassium		58.5	55.0		54.8		58.0		89.6	
Sodium		26.7	23.8		22.2		24.9		36.3	
Calcium		835.	795.		848.		936.		1464.	
Magnesium		125.0	125.0		120.8		120.8		208.0	
SCDP/g dry wt.	25.97		18.42	11.47		9.35		18.88		6.16
SCDP/g ign.loss	30.35		22.27	14.28		10.56		20.49		7.26
ABSORBANCE RATIO										
410/350	0.78		0.71	0.67		0.53		0.60		0.45
448/350	0.34		0.33	0.32		0.26		0.30		0.24
410/448	2.28		2.08	2.07		2.02		1.87		1.71
350/670	5.07		5.86	8.63		6.33		13.80		18.34
410/670	3.96		3.94	4.65		3.83		6.25		6.46
448/670	1.72		1.89	2.25		1.95		3.34		3.76

Table 15. Cont'd

DEPTH CM	120	125	130	135	140	145	150	155	160	165
Density	0.98	1.01	1.02	1.03	0.97	1.03	1.00	1.05	1.08	1.08
Water %		79.13		79.05		80.01		81.45		75.36
Ignition loss %		78.95		76.16		76.71		71.49		45.36
pH	5.5		5.4		5.5		5.4		5.5	
Nitrogen %	1.70		1.69		1.70		1.86		1.53	
Phosphorus	2.27		2.15		2.59		2.92		2.92	
Potassium	40.0		32.8		38.8		41.6		42.4	
Sodium	17.6		15.2		17.2		18.8		18.2	
Calcium	596.		636.		708.		748.		772.	
Magnesium	90.4		88.0		90.4		109.6		104.0	
SCDP/g dry wt.		22.26		13.42		16.28		12.01		9.56
SCDP/g ing.loss		28.29		17.61		21.22		16.80		20.90
ABSORBANCE RATIO										
410/350		0.44		0.40		0.44		0.53		0.59
448/350		0.30		0.25		0.26		0.28		0.33
410/448		1.45		1.60		1.67		1.86		1.74
350/670		8.93		11.71		10.41		8.94		6.76
410/670		4.01		4.77		4.63		4.79		4.04
448/670		2.76		2.97		2.76		2.57		2.30

Table 15. Cont'd

DEPTH CM	170	176	180	182	184	186	190	195	200	205
Density	1.08	1.03	1.01	1.34	1.12	1.08	1.04	1.07	1.12	1.12
Water %		74.35	75.47	52.32	56.64	81.17	81.11		74.37	71.34
Ignition loss %		42.70	44.17	12.64	19.19	54.55	56,21		36.89	31.94
pH	5.0		5.0			4.7			4.7	
Nitrogen %	1.41		1.43			1.47		1.50		0.97
Phosphorus	3.38		4.37			5.52		3.69		6.87
Potassium	37.4		35.7			32.8		31.2		29.0
Sodium	15.88		15.07			14.32		13.48		11.88
Calcium	724.		732.			749.		772.		668.
Magnesium	114.0		119.5			121.7		128.8		109.6
SCDP/g dry wt.		12.81	10.73	1.41	3.39	11.20	16.29		8.07	
SCDP/g ign.loss		30.00	24.31	11.22	17.69	20.53	28.98		21.89	
ABSORBANCE RATIO										
410/350		0.82	0.77	0.76	0.74	0.75	0.85		0.63	
448/350		0.36	0.37	0.39	0.30	0.27	0.30		0.36	
410/448		2.22	2.04	1.94	2.44	2.73	2.78		1.72	
350/670		4.45	4.34	4.50	5.04	5.33	4.29		6.33	
410/670		3.66	3.35	3.44	3.77	4.01	3.66		4.01	
448/670		1.64	1.64	1.77	1.54	1.46	1.34		2.32	

Table 15. Cont'd

DEPTH CM	210	215	218	220	225	230	237	240	245	250
Density	1.06	1.04	1.23	1.08	1.13	1.09	1.06	1.12	1.09	1.09
Water %	71.34		57.93	70.93		72.59		73.83		73.44
Ignition loss %	31.94		19.23	38.25		31.47		37.52		29.95
pH			4.4		5.35				6.9	
Nitrogen %		0.89			0.97		1.09		0.86	
Phosphorus		6.24			5.98		6.19		6.40	
Potassium		23.6			32.0		44.0		37.6	
Sodium		8.04			12.68		17.08		14.08	
Calcium		620.			700.		896.		772.	
Magnesium		104.0			128.8		193.4		160.0	
SCDP/g dry wt.		7.61	5.58	6.94		7.32		5.86		5.93
SCDP/g ign.loss		23.82	29.02	18.14		23.26		15.63		19.79
ABSORBANCE RATIO										
410/350		0.63	0.71	0.43		0.69		0.70		0.80
448/350		0.34	0.42	0.25		0.40		0.43		0.54
410/448		1.82	1.67	1.73		1.72		1.60		1.60
350/670		6.75	5.12	9.38		6.00		6.42		6.31
410/670		4.31	3.67	4.07		4.14		4.54		5.1
448/670		2.35	2.19	2.34		2.40		2.82		3.42

Table 15. Cont'd

DEPTH CM	258	260	265	270	275	280	285	290	295	300
Density	1.11	1.10	1.32	1.35	1.22	1.30	1.30	1.32	1.22	1.27
Water %		68.73		48.12		61.10		58.83		60.84
Ignition loss %		18.96		8.73		13.04		10.33		11.43
pH			6.95		7.1				7.05	
Nitrogen %	0.94		0.41		0.56				0.42	
Phosphorus	7.72		11.99		10.19				8.77	
Potassium	31.6		26.6		26.6				29.0	
Sodium	12.08		9.34		9.44				11.8	
Calcium	748.		524.		572.				596.	
Magnesium	128.8		90.4		87.2				60.4	
SCDP/g dry wt.		8.97		1.66		5.49		4.82		7.20
SCDP/g ign.loss		47.30		19.03		42.01		46.67		63.00
ABSORBANCE RATIO										
410/350		1.26		0.92		1.35		1.38		1.41
448/350		1.11		0.74		0.97		1.01		1.12
410/448		1.14		1.24		1.38		1.37		1.25
350/670		4.29		5.55		3.68		3.58		3.41
410/670		5.44		5.13		4.98		4.97		4.85
448/670		4.77		4.11		3.59		3.61		3.86

Table 15. Cont'd

DEPTH CM	305	310	315	320	325	330	335	338	340	345
Density	1.27	1.21	1.27	1.21	1.27	1.31	1.19	1.35	1.30	1.29
Water %		61.45		56.65		48.27	55.74	55.06		52.83
Ignition loss %		12.46		12.80		9.54	11.25	11.32		9.24
pH			7.05						7.0	
Nitrogen %	0.47				0.42				0.42	
Phosphorus	6.17				9.32				8.77	
Potassium	34.6				33.2				32.0	
Sodium	13.28				12.08				11.48	
Calcium	700.				692.				612.	
Magnesium	43.6				43.6				47.6	
SCDP/g dry wt.		7.02		6.19		5.21	3.82	2.18		3.40
SCDP/g ign.loss		56.39		48.37		54.68	33.97	19.26		36.84
ABSORBANCE RATIO 410/350		1.41		1.32		1.41	1.21	0.75		1.42
448/350		1.09		0.95		1.10	0.87	0.95		1.16
410/448		1.29		1.38		1.27	1.38	1.38		1.22
350/670		3.36		3.54		3.50	4.01	4.02		3.64
410/670		4.78		4.70		4.94	4.87	5.30		5.21
448/670		3.68		3.39		3.86	3.50	3.83		4.23

Table 15. Cont'd

DEPTH CM	350	355	360	365	370	375	380	385	390	395
Density	1.25	1.20	1.23	1.27	1.21	1.29	1.29	1.30	1.25	1.35
Water %			57.66		60.94		57.80		57.09	
Ignition loss %			5.54		16.91		12.01		7.92	
pH		7.0				7.0		6.9	7.10	
Nitrogen %	0.49	0.54		0.43		0.42		0.39		0.27
Phosphorus	9.61	8.77		11.58		11.19		11.96		6.63
Potassium	28.2	32.8		29.0		30.2		29.0		33.8
Sodium	9.74	11.88		10.48		10.88		10.48		12.68
Calcium	572.	684.		580.		604.		580.		612.
Magnesium	80.0	95.2		73.6		68.4		64.4		52.0
SCDP/g dry wt.		6.33			4.75		4.73		5.75	
SCDP/g ign.loss		54.01			28.13		39.41		72.58	
ABSORBANCE RATIO										
410/350			1.36		1.16		1.37		1.40	
448/350			1.07		0.87		1.11		1.17	
410/448			1.26		1.31		1.22		1.19	
350/670			3.43		4.46		3.70		3.52	
410/670			4.80		5.17		5.08		4.93	
448/670			3.68		3.92		4.13		4.14	

Table 15. Cont'd

DEPTH CM	400	405	410	415	417	420	425	430	435	440
Density	1.32	1.22	1.28	1.37	1.21	1.24	1.40	1.46	1.45	1.37
Water %	57.22		54.69		61.84		48.77		48.36	
Ignition loss %	14.91		10.46		14.09		8.63		6.96	
pH		7.1		7.2		6.9		6.9		
Nitrogen %		0.57		0.32		0.52		0.25		
Phosphorus		10.84		11.19		10.84		9.31		
Potassium		28.6		27.8		28.2		29.8		
Sodium		9.54		9.14		9.34		9.94		
Calcium		612.		572.		644.		588.		
Magnesium		81.8		49.6		80.0		42.0		
SCDP/g dry wt.	7.25		4.17		13.45		3.68		5.01	3.41
SCDP/g ign.loss	48.64		39.87		95.42		66.55		71.95	53.27
ABSORBANCE RATIO										
410/350	1.54		1.53		1.53		1.48		1.32	1.70
448/350	1.19		1.27		1.05		1.06		1.19	1.26
410/448	1.28		1.20		1.45		1.23		1.28	1.34
350/670	3.19		3.52		3.02		3.24		3.20	2.92
410/670	4.92		5.41		4.65		5.20		4.89	4.96
448/670	3.82		4.50		3.20		4.22		3.81	3.69

Table 15. Cont'd

DEPTH CM	445	450	455	460
Density	1.41	1.67	1.70	1.65
Water %		32.44		31.33
Ignition loss %		3.25		2.87
pH	7.1		7.2	
Nitrogen %	0.32		0.15	
Phosphorus			13.16	
Potassium			31.2	
Sodium			8.44	
Calcium			508.	
Magnesium			45.2	
SCDP/g dry wt.	0.07			0.01
SCDP/g ign.loss	2.35			0.61
ABSORBANCE RATIO				
410/350	0.76			0.50
448/350	1.62			1.33
410/448	1.25			0.66
350/670	4.33			8.00
410/670	3.33			4.00
448/670	2.66			6.00

Table 16

Records of the general chemistry and sedimentray chlorophyll degradation products from Grady Lake sediments. Exchangeable ions in milligrams per 100 grams of **dried sediment.**

DEPTH CM	0	5	10	15	20	25	30	35	40	45	50
Density	1.04		1.04		1.03		1.03		1.11		1.05
Water %		96.23		94.48		91.71		93.48		92.89	
Ignition loss %		60.42		59.90		59.19		58.96		59.44	
pH	4.5		4.3		4.2		3.9		3.7		3.8
Nitrogen %	3.04		3.32		3.15		3.13		3.10		3.00
Potassium	50.0		70.0		58.0		46.0		46.0		46.0
Sodium	17.35		16.70		15.45		14.20		14.20		15.70
Calcium	555.		630.		570.		510.		510.		540.
Magnesium	77.0		38.0		37.0		36.0		36.0		41.0
SCDP/g dry wt.		46.63		49.39		48.53		50.80		60.12	
SCDP/g ign.loss		77.17		82.44		81.99		86.15		101.13	
ABSORBANCE RATIO											
410/350		1.73		1.72		1.74		1.68		1.76	
448/350		0.83		0.73		0.77		0.83		0.76	
410/448		2.07		2.35		2.24		2.01		2.31	
350/670		2.22		2.12		2.18		2.32		2.19	
410/670		3.85		3.66		3.81		3.91		3.87	
448/670		1.85		1.55		1.70		1.94		1.64	

Table 16. Cont'd

DEPTH CM	55	60	65	70	75	80	85	90	95	100	105
Density		1.03		1.09		1.00		1.01		1.00	
Water %	94.89		94.47		94.34		92.41		94.25		92.28
Ignition loss %	59.29		58.40		57.96		57.40		57.92		55.22
pH		4.0		4.2		4.3		4.4		4.5	
Nitrogen %		3.06		3.03		3.00		2.88		2.83	
Potassium		46.0		42.0		39.0		39.0		40.0	
Sodium		17.20		15.70		15.92		16.08		16.20	
Calcium		570.		470.		495.		510.		530.	
Magnesium		46.0		46.0		49.0		52.0		58.0	
SCDP/g dry wt.	69.57		88.69		84.25		98.28		104.57		102.67
SCDP/g ign.loss	117.33		151.86		145.36		171.20		180.52		185.02
ABSORBANCE RATIO											
410/350	1.77		1.78		1.82		1.74		1.73		1.70
448/350	0.81		0.86		0.89		0.87		0.92		0.81
410/448	2.17		2.06		2.01		1.99		1.88		2.08
350/670	2.28		2.17		2.17		2.23		2.36		2.34
410/670	4.03		3.80		3.96		3.89		4.09		4.00
448/670	1.85		1.85		1.93		1.95		2.17		1.91

Table 16. Comt'd

DEPTH CM	110	115	120	125	130	136	156	160	165	170	180
Density	1.01		0.96		1.01		1.03		1.06		0.99
Water %		93.04		93.59		94.63		93.61		93.01	
Ignition loss %		53.62		54.42		56.07		50.48		48.58	
pH	4.2		3.8		4.3		3.5		4.2		4.7
Nitrogen %	2.68		2.61		2.57		2.55		2.43		2.25
Potassium	42.0		44.0		42.0		40.0		40.0		45.0
Sodium	17.20		17.70		16.45		16.20		15.85		17.60
Calcium	570.		555.		530.		540.		560.		510.
Magnesium	81.0		77.0		70.0		57.0		93.0		83.0
SCDP/g dry wt.		97.62		110.88		90.24		91.36		74.07	
SCDP/g ign.loss		182.05		203.74		165.82		180.99		152.45	
ABSORBANCE RATIO											
410/350		1.56		1.56		1.63		1.58		1.62	
448/350		0.73		0.79		0.91		0.82		0.89	
410/448		2.11		1.97		1.79		1.91		1.81	
350/670		2.51		2.54		2.46		2.43		2.50	
410/670		3.93		3.99		4.02		3.87		4.06	
448/670		1.85		2.01		2.24		2.01		2.24	

Table 16. ConT'd

DEPTH CM	190	200	208	210	220	230	240	250	260	265
Density	1.00	1.02	1.00	1.15	0.98	0.95	0.93	0.99	1.04	1.13
Water %	95.57		93.12		89.05		87.04		91.35	
Ignition loss %	51.43		52.52		53.22		52.62		48.15	
pH		5.2			4.9		4.0		4.4	4.5
Nitrogen %		2.14			2.27		2.72		2.63	
Potassium		39.5			41.0		26.0		23.0	
Sodium		15.35			15.35		9.63		11.1	
Calcium		510.			530.		206.		385.	
Magnesium		83.0			93.0		26.0		40.0	
SCDP/g dry wt.	81.83		93.57		67.66		62.31		79.28	
SCDP/g ign.loss	159.02		178.14		127.12		118.42		164.65	
ABSORBANCE RATIO										
410/350	1.65		1.66		1.64		1.64		1.58	
448/350	0.82		0.73		0.72		0.72		0.78	
410/448	1.97		2.21		2.25		2.26		2.02	
350/670	2.60		2.44		2.51		2.28		2.50	
410/670	3.92		3.87		3.75		3.74		3.96	
448/670	2.06		1.75		1.75		1.65		1.96	

Table 16. Cont'd

DEPTH CM	270	280	290	300	310	320	330	340	350	360	370
Density	1.16	1.13	1.01	1.03	1.07	1.00	1.02	0.98	1.10	1.05	1.03
Water %	89.72		90.23		92.78		89.36		89.59		89.42
Ignition loss %	43.22		46.08		46.69		45.03		45.04		47.61
pH		4.3		4.8		5.0		4.5		4.2	
Nitrogen %		2.33		2.30		2.24		2.13		2.36	
Potassium		25.2		27.2		29.4		25.5		25.4	
Sodium		6.84		7.34		11.2		8.6		8.4	
Calcium		557.		537.		374.		322.		334.	
Magnesium		48.5		46.5		68.4		59.5		54.8	
SCDP/g dry wt.	69.32		67.28		72.96		75.66		71.31		79.47
SCDP/g ign.loss	160.36		146.00		156.40		168.01		158.31		166.78
ABSORBANCE RATIO											
410/350	1.64		1.62		1.65		1.63		1.65		1.64
448/350	0.87		0.77		0.78		0.79		0.82		0.89
410/448	1.88		2.10		1.75		1.53		2.01		1.94
350/670	2.44		2.52		2.50		2.37		2.33		2.48
410/670	4.03		4.10		3.95		3.89		3.87		3.97
448/670	2.14		1.95		2.16		2.53		1.92		2.17

Table 16. Cont'd

DEPTH CM	380	390	400	410	420	430	440	450	460	470	480
Density	1.11	1.03	1.03	0.98	1.03	1.04	1.05	1.07	1.03	1.00	1.04
Water %		91.10	89.	89.63		88.88		90.08		90.21	
Ignition loss %		43.22		45.21		49.11		46.13		47.69	
pH	4.4		4.3		4.5		4.7		4.3		4.1
Nitrogen %	2.31		2.04		2.02		2.25		2.37		2.25
Potassium	29.2		24.6		29.8		25.0		26.6		29.2
Sodium	9.05		7.84		9.44		7.84		8.74		9.05
Calcium	382.		334.		386.		330.		354.		397.
Magnesium	65.0		57.2		80.0		60.4		68.4		68.5
SCDP/g dry wt.		87.64		70.59		99.18		59.56		74.77	
SCDP/g ign.loss		202.77		156.14		201.95		129.11		156.78	
ABSORBANCE RATIO											
410/350		1.63		1.52		1.52		1.51		1.52	
448/350		0.93		0.81		0.83		0.80		0.87	
410/448		1.74		1.88		1.82		1.87		1.75	
350/670		2.54		2.59		2.50		2.71		2.74	
410/670		4.16		3.95		3.94		4.11		4.18	
448/670		2.38		2.10		2.16		2.19		2.39	

Table 16. Cont'd

DEPTH CM	490	500	510	520	530	540	550	560	570	580	590
Density	1.05	1.03	0.97	1.04	1.00	1.01	0.99	1.10	0.99	1.00	1.01
Water %	87.82		86.04		90.26		89.67		89.26		89.15
Ignition loss %	44.77		49.70		49.39		52.49		52.80		56.31
pH		4.3		3.8		3.7		4.2		4.2	
Nitrogen %		2.31		2.25		2.29		2.56		2.58	
Potassium		29.8		27.0		26.6		31.7		31.7	
Sodium		9.34		8.54		8.44		11.18		9.55	
Calcium		448.		374.		354.		337.		422.	
Magnesium		73.6		57.2		57.2		85.5		80.5	
SCDP/g dry wt.	71.77		68.78		69.81		63.31		75.17		78.03
SCDP/g ign.loss	160.12		138.38		141.33		120.61		142.37		138.56
ABSORBANCE RATIO											
410/350	1.52		1.54		1.54		1.46		1.31		1.28
448/350	0.88		0.89		0.90		0.68		0.71		0.71
410/448	1.73		1.72		1.70		2.14		1.84		1.80
350/670	2.78		2.76		2.80		2.73		3.18		2.98
410/670	4.21		4.27		4.32		4.00		4.20		3.84
448/670	2.42		2.48		2.53		1.86		2.27		2.12

Table 16. Cont'd

DEPTH CM	600	610	620	630	640	650	660	670	680	690	700
Density	1.03	1.02	1.01	1.01	0.99	1.01	1.03	1.05	1.06	0.99	1.03
Water %		89.36		90.28		89.83		90.17		91.01	
Ignition loss %		56.79		56.37		55.48		60.34		52.20	
pH	4.1		3.6		3.8		3.7		3.6		3.4
Nitrogen %	2.75		2.70		2.79		2.79		2.58		2.58
Potassium	32.0		28.2		30.2		38.1		23.2		28.6
Sodium	12.08		9.24		10.00		14.16		7.05		9.64
Calcium	500.		391.		460.		600.		335.		400.
Magnesium	80.0		73.6		73.6		111.8		62.0		80.0
SCDP/g dry wt.		79.94		81.85		62.50		70.84		72.22	
SCDP/G ign.loss		140.52		131.22		112.64		117.39		138.36	
ABSORBANCE RATIO											
410/350		1.32		1.41		1.41		1.37		1.49	
448/350		0.70		0.70		0.69		0.63		0.71	
410/448		1.91		2.01		2.01		2.16		2.07	
350/670		2.92		2.97		2.95		3.18		2.67	
410/670		3.97		4.22		4.16		4.37		3.99	
448/670		2.10		2.09		2.06		2.02		1.92	

Table 16. Cont'd

DEPTH CM	710	720	730	740	750	760	770	780	790	800	810
Density	1.01	0.99	1.03	1.00	1.05	1.00	1.03	1.03	1.05	1.11	1.04
Water %	89.49		88.90		90.14		90.01		89.15		88.29
Ignition loss %	53.69		47.99		49.32		50.92		51.44		49.40
pH		3.5		3.5		3.6		3.1		2.6	
Nitrogen %		2.44		2.34		2.32		2.27		2.39	
Potassium		32.8		37.0		36.6		21.6		26.2	
Sodium		11.68		11.88		12.88		7.44		8.34	
Calcium		492.		508.		548.		350.		386.	
Magnesium		99.2		99.2		109.6		73.6		99.2	
SCDP/g dry wt.	91.00		73.68		80.14		74.38		92.49		98.27
SCDP/g ign.loss	169.47		153.53		162.50		146.07		179.79		198.89
ABSORBANCE RATIO											
410/350	1.47		1.49		1.56		1.53		1.51		1.49
448/350	0.96		0.71		0.74		0.77		0.80		0.92
410/448	1.53		2.09		2.11		1.97		1.87		1.62
350/670	3.04		3.28		3.04		3.28		3.18		3.09
410/670	4.50		4.90		4.78		4.98		4.78		4.63
448/670	2.92		2.34		2.26		2.52		2.75		2.85

Table 16. Cont'd

DEPTH CM	820	830	840	850	860	870	880	890	900	910	920
Density	1.01	1.01	1.03	1.01	1.03	1.03	1.01	1.01	1.00	1.05	1.04
Water %		88.64		86.72		87.20		87.69		85.60	
Ignition loss %		49.82		50.35		45.80		37.59		36.03	
pH	2.7		2.9		2.2		2.5		2.1		6.8
Nitrogen %	2.07		2.21		2.18		1.97		1.97		1.48
Potassium	29.4		27.4		35.0		50.8		49.2		49.2
Sodium	23.36		9.34		14.68		19.48		19.88		19.68
Calcium	516.		460.		652.		780.		636.		708.
Magnesium	109.6		120.8		209.2		208.0		147.2		147.2
SCDP/g dry wt.		98.52		92.16		62.37		49.95		35.61	
SCDP/g ign.loss		197.72		183.01		136.17		132.88		98.84	
ABSORBANCE RATIO											
410/350		1.48		1.53		1.58		1.66		1.43	
448/350		0.86		0.87		0.89		1.06		0.91	
410/448		1.72		1.75		1.68		1.56		1.57	
350/670		3.05		2.95		3.25		2.67		3.31	
410/670		4.52		4.52		4.49		4.46		4.76	
448/670		2.62		2.57		2.76		2.85		3.02	

TAble 16. Cont'd

DEPTH CM	930	940	950	960	970	980	990	1000	1010	1015	1020
Density	1.05	1.04	1.07	1.05	1.05	1.11	1.10	1.08	1.16	1.09	1.14
Water %	85.44		85.25		84.16		79.31		77.98		71.62
Ignition loss %	39.74		35.07		26.37		18.72		19.12		17.89
pH		6.6		3.2		2.7		2.5		2.8	
Nitrogen %		1.83		1.39		1.27		0.87		0.93	
Potassium		50.8		35.8		33.8		27.4		27.0	
Sodium		18.88		13.28		13.48		12.88		10.00	
Calcium		700.		540.		572.		508.		400.	
Magnesium		190.4		190.4		183.8		208.0		136.8	
SCDP/g dry wt.	37.26		38.92		42.24		30.46		28.90		22.28
SCDP/g ign.loss	94.62		110.98		160.16		162.74		151.16		124.56
ABSORBANCE RATIO											
410/350	1.48		1.57		1.35		1.54		1.41		1.39
448/350	0.88		1.07		0.82		0.98		0.91		0.83
410/448	1.65		1.46		1.63		1.57		1.54		1.57
350/670	2.97		2.29		3.42		2.98		3.42		3.15
410/670	4.67		4.57		4.62		4.60		4.83		4.56
448/670	3.08		3.11		2.83		2.93		3.12		2.21

Table 16. Cont'd

DEPTH CM	1025	1030	1035	1040	1045	1050
Density	1.15	1.17	1.19	1.20	1.23	1.26
Water %		65.27		62.69		55.96
Ignition loss %		9.46		8.20		4.80
pH	3.05		4.1		5.15	
Nitrogen %	0.69		0.42		0.37	
Potassium	16.2		12.2		15.1	
Sodium	4.43		2.82		3.07	
Calcium	207.		125.		14.	
Magnesium	80.5		49.1		54.8	
SCDP/g dry wt.		2.86		2.11		1.59
SCDP/g ign.loss		30.28		25.78		33.18
ABSORBANCE RATIO						
410/350		1.37		1.36		1.06
448/350		0.55		0.73		0.73
410/448		2.47		1.86		1.44
350/670		3.09		2.95		3.46
410/670		4.27		4.04		3.70
448/670		1.72		2.16		2.56

Table 17

Records of the general chemistry and sedimentary chlorophyll degradation products from Atkins Lake sediments. Exchangeable ions in milligrams per 100 grams of dried sediment.

DEPTH CM	5	10	15	20	25	30	35	40	45	50	60
Density		1.03		1.12		1.08		1.12		1.11	
Water %	96.50		96.00		94.01		97.03		96.60		96.63
Ignition loss %	65.04		64.42		62.95		67.56		66.48		69.25
pH	7.0			7.1		7.1		7.8		7.6	
Nitrogen %	2.88	2.81		2.60		2.71		2.53		2.96	
Phosphorus	7.61	6.58		7.16		3.32		1.29		1.19	
Potassium	55.6	84.8		98.0		84.5		85.5		85.5	
Sodium	21.36	32.18		42.00		38.70		40.50		40.50	
Calcium	700.	1016.		1290.		1120.		1170.		1250.	
Magnesium	143.2	116.0		138.0		105.0		105.0		120.0	
SCDP/g dry wt.	27.88		24.90		14.98		9.32		5.25		10.21
SCDP/g ign.loss	42.45		38.64		23.98		13.80		7.90		14.74
ABSORBANCE RATIO											
410/350	1.83		2.13		1.71		1.49		1.52		1.45
448/350	1.70		2.22		1.80		1.67		1.67		1.54
410/448	1.05		1.07		0.95		0.89		0.91		0.94
350/670	1.76		1.38		1.91		3.50		3.40		3.47
410/670	3.23		2.95		3.29		5.36		5.20		5.05
448/670	3.00		3.09		3.45		6.00		5.70		5.35

Table 17. Cont'd

DEPTH CM	65	70	75	80	85	90	95	100	105	110	115
Density	1.08		1.02		1.04	1.06		1.08		1.04	
Water %		95.15		94.68	95.46		96.38		95.41		96.45
Ignition loss %		66.04		65.86	74.46		70.03		81.30		73.77
pH	7.7	7.7	7.2		7.2	7.2		7.5		7.6	
Nitrogen %	3.39		3.57		3.50	3.46		3.64	3.70	3.43	3.18
Phosphorus	1.22		1.35		1.35	1.35			1.20		1.09
Potassium	86.8		88.5		85.0	82.5			81.5		83.5
Sodium	40.50		40.50		39.10	38.20			36.70		41.50
Calcium	1220.		1190.		1190.	1190.			1150.		1250.
Magnesium	126.0		132.0		138.0	145.0			145.0		139.0
SCDP/g dry wt.		12.58		13.03	12.17		9.23		11.99		12.05
SCDP/g ign.loss		19.06		19.07	16.34		13.18		14.74		16.33
ABSORBANCE RATIO											
410/350		1.54		1.47	1.53		1.21		1.48		1.82
448/350		1.72		1.57	1.64		1.47		1.49		1.58
410/448		0.89		0.94	0.93		0.98		0.98		0.92
350/670		4.31		4.05	3.59		5.00		4.90		3.58
410/670		6.68		6.00	5.50		7.27		7.27		5.20
448/670		7.45		6.38	5.90		7.36		7.31		5.62

Table 17. Cont'd

DEPTH CM	120	125	130	135	140	150	155	160	165	170	175
Density	1.09		1.08		1.07		1.06		1.05		1.13
Water %		95.71		94.21		96.70		95.74		94.67	
Ignition loss %		81.25		78.41		78.50		65.82		53.15	
pH	7.5		7.5		7.5		7.6		7.8		7.6
Nitrogen %	3.19	3.82	3.47		3.37		3.41		3.46		2.76
Phosphorus	1.09	1.09	1.35		1.43		1.62		1.77		1.69
Potassium	85.0	87.5	84.2		81.0		78.5		74.5		68.7
Sodium	42.20	43.00	38.10		35.50		33.20		34.5		33.92
Calcium	1250.	1250	1185.		1155.		1220.		1150.		1170.
Magnesium	139.0	139.0	142.0		145.0		132.0		138.0		140.0
SCDP/g dry wt.		15.11		11.98		15.47		13.28		11.09	
SCDP/g ign.loss		18.11		15.28		19.71		19.41		20.87	
ABSORBANCE RATIO											
410/350		1.54		1.50		1.62		1.70		1.79	
448/350		1.30		1.50		1.36		1.42		1.49	
410/448		1.04		1.00		1.01		0.98		0.93	
350/670		3.90		3.62		3.55		3.34		3.14	
410/670		5.92		5.44		4.95		4.67		4.39	
448/670		5.66		5.43		4.85		4.77		4.70	

Table 17. Cont'd

DEPTH CM	180	185	190	195	200	210	220	225	230	235	240
Density		1.06		1.04		1.02		1.07		1.08	
Water %	94.89		94.66		93.31		90.32		90.26		87.71
Ignition loss %	56.75		66.18		57.22		61.06		30.82		26.22
pH		7.5		7.3		7.4		7.2		7.3	
Nitrogen %		2.29		2.32		3.00		1.70		1.31	
Phosphorus		2.20		2.50		3.00		3.25		5.49	
Potassium		61.3		52.7		44.25		62.4		87.2	
Sodium		35.2		36.7		35.2		28.1		34.5	
Calcium		1180.		1200.		1210.		896.		1112.	
Magnesium		119.0		105.0		92.0		60.4		99.2	
SCDP/g dry wt.	9.78		11.77		5.75		5.25		3.17		3.68
SCDP/g ign.loss	17.24		19.53		10.06		8.59		10.28		14.06
ABSORBANCE RATIO											
410/350	1.65		1.62		1.48		1.00		1.17		1.07
448/350	1.81		1.37		1.64		0.98		1.15		1.04
410/448	0.91		1.02		0.90		1.02		1.02		1.01
350/670	2.38		2.64		3.17		5.55		7.84		6.31
410/670	4.33		4.31		5.61		7.89		7.43		7.40
448/670	4.76		4.19		6.21		7.73		7.31		7.27

Table 17. Cont'd

DEPTH CM	245	250	255	260	265	280	285	290	295	305	308
Density	1.09		1.13		1.15		1.18		1.08		1.06
Water %		86.27		85.27		85.33		97.21		84.81	
Ignition loss %		26.33		24.02		26.90		35.93		26.94	
pH	7.3		7.2		7.2		7.3		7.3		7.2
Nitrogen %	1.71		1.22		1.40		1.04		1.33		1.39
Phosphorus	1.38		1.37		1.62		1.69		1.77		1.25
Potassium	64.8		68.4		68.8		75.7		63.2		59.7
Sodium	29.7		28.9		25.7		42.5		27.7		26.1
Calcium	920.		981.		800.		1247.		936.		882.
Magnesium	57.2		68.4		54.8		66.7		73.6		67.2
SCDP/g dry wt.		5.19		2.22		2.55		2.67		3.67	
SCDP/g ign.loss		19.71		9.25		9.50		7.44		13.62	
ABSORBANCE RATIO											
410/350		1.21		1.22		1.36		1.25		1.23	
448/350		1.25		1.28		1.48		1.30		1.25	
410/448		1.03		0.97		0.95		0.92		0.96	
350/670		6.10		6.48		6.62		4.28		6.11	
410/670		7.87		8.13		5.85		7.69		6.48	
448/670		8.12		8.48		6.35		7.97		6.61	

Table 17. Cont'd

DEPTH CM	310	315	320	325	330	335	340	345	350	360	370
Density		1.07		1.09		1.02		1.07		1.10	
Water %	85.72		84.27		83.32		88.85		88.48		87.29
Ignition loss %	28.79		28.78		29.35		35.02		40.00		34.30
pH		7.3		7.3		7.3		7.2		6.7	
Nitrogen %		1.39		1.38		1.21		2.05		1.55	
Phosphorus		0.75		0.98		1.68		2.39		5.68	
Potassium		56.4		58.8		64.8		61.2		30.2	
Sodium		25.36		25.76		28.16		26.76		12.98	
Calcium		834.		848.		965.		920.		516.	
Magnesium		64.4		64.4		114.4		95.2		128.8	
SCDP/g dry wt.	2.68		2.61		2.88		5.43		6.17		4.83
SCDP/g ign.loss	9.30		9.08		9.84		12.48		16.29		14.08
ABSORBANCE RATIO 410/350	1.25		1.28		1.31		1.37		1.36		1.37
448/350	1.25		1.26		1.24		1.34		1.35		1.32
410/448	0.98		1.01		1.01		1.06		1.08		1.10
350/670	5.26		5.81		5.78		5.73		5.37		5.54
410/670	6.97		7.46		7.59		7.85		7.36		7.60
448/670	6.82		7.34		7.28		7.74		7.28		7.26

Table 17. Cont'd

DEPTH CM	375	380	385	390	395	400
Density	1.27		1.78		1.81	
Water %	89.61	82.63	75.66	48.16	29.20	29.20
Ignition loss %	41.83	27.38	12.94	4.36	2.19	1.88
pH	6.5		7.4		7.1	
Nitrogen	1.25		0.32		0.11	0.13
Phosphorus	9.61		10.84		13.16	12.38
Potassium	25.4		14.1		8.5	13.1
Sodium	9.44		4.67		2.82	3.92
Calcium	396.		189.		113.	145.
Magnesium	147.2		73.6		40.0	49.6
SCDP/g dry wt.	8.61	5.38	2.17	1.25	0.59	0.46
SCDP/g ign.loss	20.59	19.68	16.78	28.78	27.03	24.82
ABSORBANCE RATIO						
410/350	1.39	1.33	1.27	1.25	0.91	0.88
448/350	1.26	1.18	1.10	0.65	0.72	0.70
410/448	1.14	1.15	1.15	1.34	1.34	1.26
350/670	5.02	4.92	4.82	3.80	4.86	4.74
410/670	7.00	6.57	6.14	4.79	4.44	4.07
448/670	6.35	5.84	5.33	2.48	3.53	3.23

Table 18. Molluscan assemblages found by various workers in marl deposits from Eastern Quebec, Maine, both living and fossil, Wisconsin, and Eastern Ontario including Atkins Lake deposit. When available the figures are percentages of the relative abundance of each species found in the whole deposit. X: species present; X*: reported abundant.

1-Bonaventure marl deposit, north of Chaleur Bay, Quebec.
2-Houlton marl deposit, Aroostook Co., Maine.
3-Fossil Mollusca from Barren Brook, Aroostook County, Maine.
4-Living Mollusca from Barren Brook, Aroostook County, Maine.
5-Fossil Mollusca from Lovely Brook, Aroostook County, Maine.
6-Living Mollusca from Lovely Brook, Aroostook County, Maine.
7-Nadeau Lake, Fort Fairfield, Aroostook County, Maine.
8-Lac Blanc deposit, Matapedia County, Quebec.
9-White Lake deposit, Langlade County, Wisconsin.
10-Spur Lake deposit, Mariette County, Wisconsin.
11-Mountain deposit, Oconto County, Wisconsin.
12-Waupaca deposit, Waupaca County, Wisconsin.
13-Harmony deposit, Mariette County, Wisconsin.
14-McKay Lake marl deposit, Ottawa, Ontario.
15-White Lake marl deposit, Renfrew and Lanark counties, Ontario.
16-Marsh adjacent to Colton Lake outlet, Renfrew County, Ontario.
17-Colton Lake marl deposit, Renfrew County, Ontario.
18-Box Marsh marl deposit, Renfrew County, Ontario.
19-Richard Lake deposit, Pontiac County, Ontario. (Section G)
20-Richardson Lake deposit, Pontiac County, Ontario. (Section GG)
21-Atkins Lake deposit, Leeds County, Ontario.

Name of species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Amnicola limosa	..	..	..	..	..	..	..	X	10.55	.26	3.65	7.46	.01	X*	18.3	27.2	10.0	10.52	..	.07	4.72
A. lustrica	..	..	..	..	..	..	..	.	38.9	1.36	.64	1.82	..	X*	20.2	5.2	5.6	4.78	..	..	4.10
Anodonta fragilis	..	..	X	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Aplex hypnorum	..	..	..	..	..	..	..	..	..	..	..	..	.01	..	..	..	..	..	..	..	..
Armiger crista	..	..	X	X	..	..	..	..	.01	..	..	.01	.01	..	..	..	..	..	..	.01	.01
Carychium exile	..	..	..	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Deroceras sp.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.02	..	..
Euconulus fulvus	..	..	..	X	..	..	..	..	..	..	.01	..	..	..	..	..	..	..	.02	..	..
Ferrissia loma/retusa	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0.9	..	..	..
F. parallela	..	..	X	..	..	..	..	..	.03	.02	..	.01	.01	..	..	..	..	..	.08	0.1	..
Fossaria obrussa	..	..	..	..	..	..	..	..	.01	.11	.02	..	.04	X	..	3.6	9.6	2.02	..	..	..
F. obrussa decampi	..	X	..	..	..	..	X	X	2.83	2.57	11.81	23.7	49.6	X*	2.3	6.0	13.2	6.40	10.70	10.1	1.53
F. umbilicata	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Gastrocopta contracta	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0.14	..	..
G. pentodon	..	..	..	X	..	..	..	..	..	..	..	.41	..	..	..	..	..	..	..	..	..
Gyraulus hirsutus	..	..	..	X	..	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
G. parvus	X	X	X	X	X	..	X	X	10.80	53.70	16.70	32.9	46.40	X"	15.4	11.2	17.6	27.8	37.80	48.8	16.94

Table 18. Cont'd

Name of species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Helicodiscus parallelus	..	..	..	..	..	..	..	..	..	..	..	..	.01	X	..	1.2	..	..	..	..	..
Helisoma anceps	..	X	X	..	..	..	..	..	..	..	..	..	..	X	..	..	..	..	..	..	1.99
H. aneps striatum	..	..	..	..	..	..	..	X	2.31	4.47	5.05	5.86	.20	..	1.8	11.6	7.6	..	4.42	9.13	..
H. campanulatum	..	..	..	..	..	..	..	..	.87	.13	3.1	.30	.01	X	1.2	..	0.6	..	.03	.81	2.09
H. trivolvis	X	X	X	X	..	..	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Lymnaea stagnalis	..	X	..	..	..	..	..	..	.02	..	..	..	..	X	..	..	..	..	.01	.01	..
Nesovitrea binneyana	..	..	..	..	..	..	..	..	..	.01	..	..	..	..	..	..	..	..	..	..	..
Oxyloma decampi gouldi	..	..	X	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Physa gyrina	..	..	..	..	..	..	..	X	2.98	.03	4.56	1.5	.01	X*	0.5	3.2	0.3	..	.10	5.60	.06
P. heterostropha	..	X	X	X	X	X	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Pisidium sp.	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
P. adamsi	..	..	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
P. casertanum	..	..	..	X	X	..	..	X	..	21.20	26.5	9.41	2.64	X*	10.1	1.6	2.9	1.70	23.70	12.0	.01
P. compressum	..	..	X	X	..	..	..	..	..	..	..	..	..	..	3.4	1.6	7.1	9.80	3.17	1.64	.86
P. ferrugineum	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1.8	0.4	0.6	.34	..	..	..
P. nitidum	..	..	..	X	X	..	..	..	14.80	..	..	..	..	..	..	..	..	..	..	..	18.6
P. nitidum contortum	..	X	X	..	X	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1.67
P. nitidum pauperculum	..	..	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2.43
P. lilljeborgii	..	..	X	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..

Table 18 Cont'd

Name of species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Pisidium obtusale	...	...	X	X	...	...	...	...	....	....	...	....	...	...	...	...	...	...	....	....	....
P. obrusale ventricosum	...	X	X	X	X	X	...	...	....	....	...	....	...	...	...	...	...	...	....	....	1.27
P. seminulum	...	...	...	X	...	...	...	...	....	....	...	....	...	...	...	...	...	...	....	....	....
P. variabile	...	X	X	X	X	X	X	X	3.42	3.19	.32	6.96	...	...	...	...	...	...	....	....	..99
P. walkeri mainense	...	...	X	X	...	...	...	...	....	....	...	....	...	...	...	...	...	...	....	....	..10
Planorbula armiger	...	...	...	...	...	...	...	...	....	..01	.02	..01	...	...	...	...	...	...	....	....	....
Promenetus exacuous	...	...	...	...	...	...	X	...	....	..07	.04	..01	...	...	...	...	...	...	2.06	..80	....
Pseudosuccinea columella	...	...	...	...	...	...	...	...	....	....	...	....	...	...	...	...	...	.02	....	....	....
Retinella identata	...	...	...	...	...	...	...	...	....	....	...	....	...	...	...	...	...	...	..03	....	....
R. rhoadsi	...	...	...	...	...	...	...	...	....	....	...	....	...	...	...	...	...	...	..05	....	....
Sphaerium lacustre	...	...	...	...	...	...	...	...	..09	...8	.87	..06	.01	...		0.4		0.3	3.05	3.46	1.35
S. nitidum	...	...	...	...	...	...	...	...	....	....	...	....	...	...	...	...	8.9	.65	....	..32	....
S. partumeium	...	...	...	...	...	...	...	X	....	....	...	....	...	...	...	...	...	...	....	....	....
S. rhomboideum	...	X	X	X	...	...	X	...	....	....	...	....	...	...	...	...	...	...	....	....	....
S. securis	...	...	X	...	...	...	...	...	....	....	...	....	...	...	...	...	...	...	....	....	....
S. simile	...	...	X	X	...	...	...	...	....	....	...	....	...	...	...	...	...	...	....	....	..02
S. sulcatum	X	X	...	...	...	...	X	...	0.11	..05	.02	0.12	...	...	3.8	0.4	-	1.67	3.98	..17	....
Stagnicola sp.	...	...	...	...	...	...	...	...	....	....	...	....	...	...	...	...	...	...	..03	..05	....

Table 18. Cont'd

Name of species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Stagnicola desidiosa	..	..	X	X	X	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
S. palustris	..	..	..	..	..	..	..	X	..	..	..	..	.01	..	..	..	..	..	..	..	..
Striatura exigua	..	..	..	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Strobilops labyrinthica	..	..	..	X	..	..	..	..	..	.02	..	.01	..	..	..	..	..	..	..	..	..
Succinea avara	..	..	..	X	..	..	..	X	.01	.48	..	.38	.34	..	..	..	..	..	..	..	..
S. grosvenori	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.01	..
S. ovalis	..	..	X	X	..	..	..	..	..	..	..	..	..	X	..	..	..	..	.03	..	..
Valvata lewisii	..	X	..	..	..	..	X	..	.02	..	..	..	..	..	..	..	..	..	.68	0.18	..
V. sincera	..	..	X	..	..	..	..	X	.26	.48	1.52	.54	.01	..	6.2	..	..	2.90	..	..	..
V. tricarinata	..	..	..	..	..	..	..	X	12.40	9.87	24.70	8.24	.14	X*	13.2	25.2	23.8	19.60	9.80	6.49	32.53
Vertigo sp.	..	..	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
V. ovata	..	..	..	..	..	..	..	X	..	..	..	..	..	..	..	..	..	.90	.05	..	.01
V. tridenta	..	..	..	..	..	..	..	..	..	.24	..	.07	.01	..	..	..	..	..	..	..	..
V. ventricosa	..	..	..	X	..	..	..	X	..	..	..	..	..	..	..	..	..	..	..	..	..
Zonitoides arboreus	..	..	..	X	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Z. nitidus	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	.01	..	..

Table 19

Trace elements concentrations found in shells of Valvata tricarinata simplex (V.t.s.) and Valvata tricarinata tricarinata (V.t.t.) extracted from Atkins Lake sediments respectively between levels 195-225 and 315-345 centimeters. (*) indicates possible contamination due to lead sulphide in the laboratory.

ELEMENTS	V.t.s.(ppm)	V.t.t.(ppm)
Barium	300	100
Boron	<10	<10
Lead	150*	70*
Manganese	30	20
Titanium	70	70
Vanadium	20	20
Zirconium	<10	<10
Copper	7	3
Nickel	<2	<2
Strontium	200	200
Chromium	<10	<10
Cobalt	<10	<10
Beryllium	<1	<1
Bismuth	<20	<20
Molybdenum	<5	<5
Niobium	<10	<10
Cadmium	<200	<200
Silver	<1	<1
Antimony	<100	<100
Tin	<10	<10
Zinc	<1000	<1000
Tungsten	<1000	<1000

Table 20

Summary of hypothetical important climatic factors which existed in the Kingston region during the late-glacial pollen zones A-1 and A-2 compared with the present existing ones (Kr).

CLIMATIC FACTOR	A-1	A-2	Kr
Mean annual temp.(°F)	18	31	44.9
July mean temp.(°F)	55	61	69
January mean temp.(°F)	-19	-7	18
Mean annual min. temp.(°F)	-49	-46	-35
Start growing season	June 12	May 11	April 13
End growing season	Sept.10	Oct.5	Nov.3
Degree-days above 42°F	832	1750	3600
Mean spring frost date	June 23	June 12	May 5
Mean fall frost date	Sept.1	Sept 4	Oct.5
Mean frost free period (days)	75	83	154
Mean annual pptn.(mm)	381	611	889
Average May-Sept. pptn.(mm)	254	387	356

Table 21

Radiocarbon dates suggesting the maximum age of the Champlain Sea. (After Lowdon and Blake, 1968, 1970)

Number	Age	Location
GSC-936	12,000±230	L'Avenir, Que.
GSC-505	11,880±180	L'Avenir, Que.
GSC-1013	11,800±210	Maitland, Ont.
GSC-842	11,600±150	Meach Lake, Que.
GSC-475	11,530±160	St.Christine, Que.

Table 22

Radiocarbon dates suggesting the Upper St.Lawrence River free of ice. (After Lowdon and Blake, 1968)

Number	Age	Location
GSC-626	11,760±310	Biddy Lake, Ont.
GSC-625	11,350±260	Ross Lake, Ont.
GSC-649	11,180±180	Little Round Lake, Ont.
GSC-762	11,100±270	Atkins Lake, Ont.
GSC-679	11,020±170	Oak Lake, Ont.

PLATE 1

Gastropod shells from Atkins Lake sediments.

FIGURE PAGE

1-3. *Valvata tricarinata tricarinata*, X8............

4-6. *Valvata tricarinata perconfusa*, X8.............

7-9. *Valvata tricarinata simplex*, X8................

10-12. *Valvata tricarinata infracarinata*, X8..........

13-15. *Amnicola limosa*, X8...........................

16. *Amnicola lustrica*, X8.........................

17. *Fossaria obrussa* form *decampi*, X8..............

18-20. *Helisoma anceps*, X8...........................

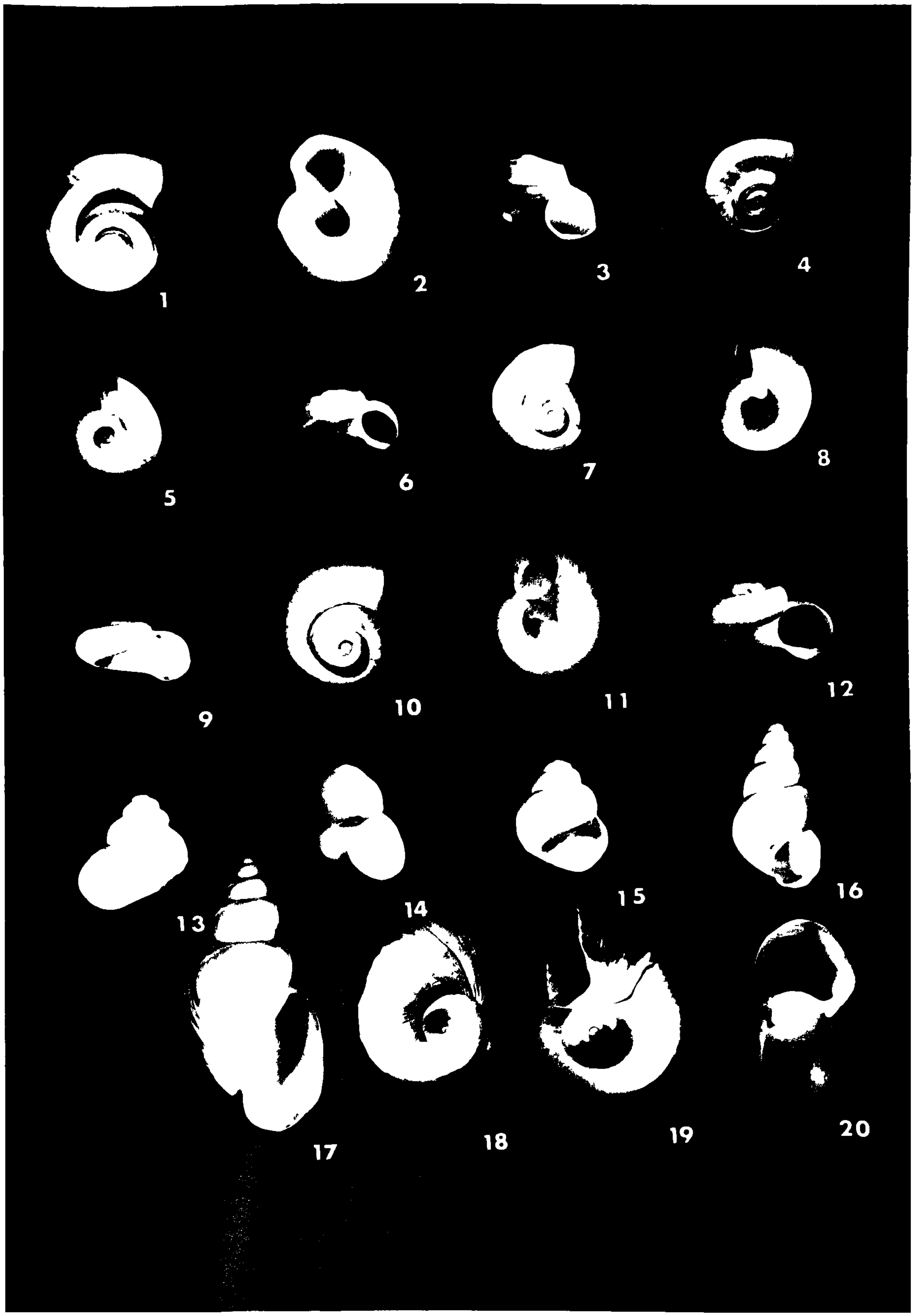
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PLATE 2

Gastropod and pelecypod shells from Atkins Lake sediments.

FIGURE PAGE

1-3. *Helisoma campanulatum*, X3.....................

4-6. *Gyraulus parvus*, X8.........................

7. *Armiger crista*, X15.........................

8. *Physa gyrina*, X3............................

9. *Vertigo ovata*, X8...........................

10-11. *Pisidium adamsi*, X8.........................

12-13. *Pisidium casertanum*, X8.....................

14-15. *Pisidium compressum*, X8.....................

16-17. *Pisidium ferrugineum*, X8....................

18-19. *Pisidium nitidum*, X8........................

20. *Pisidium nitidum* form *contortum*, X8...........

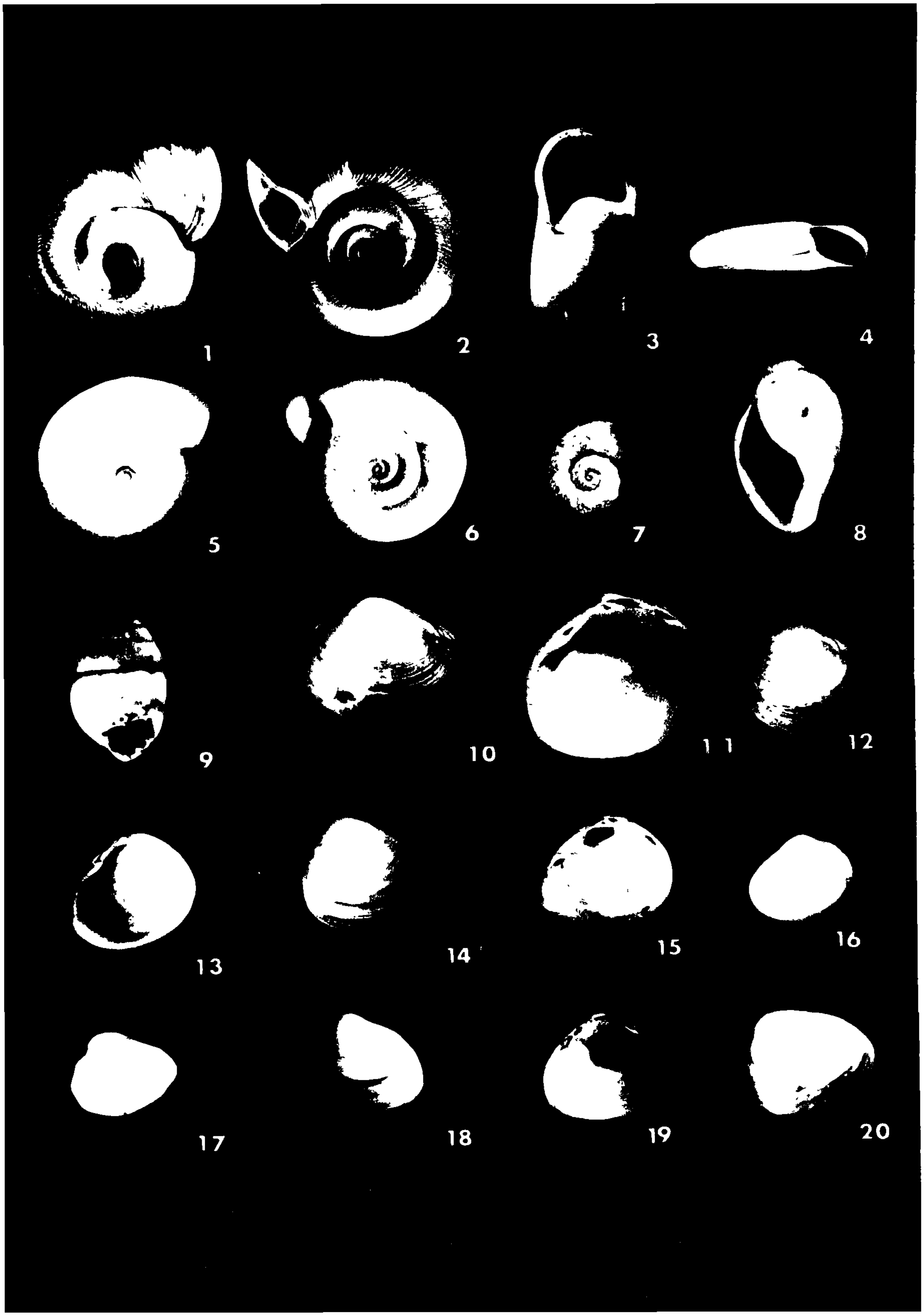
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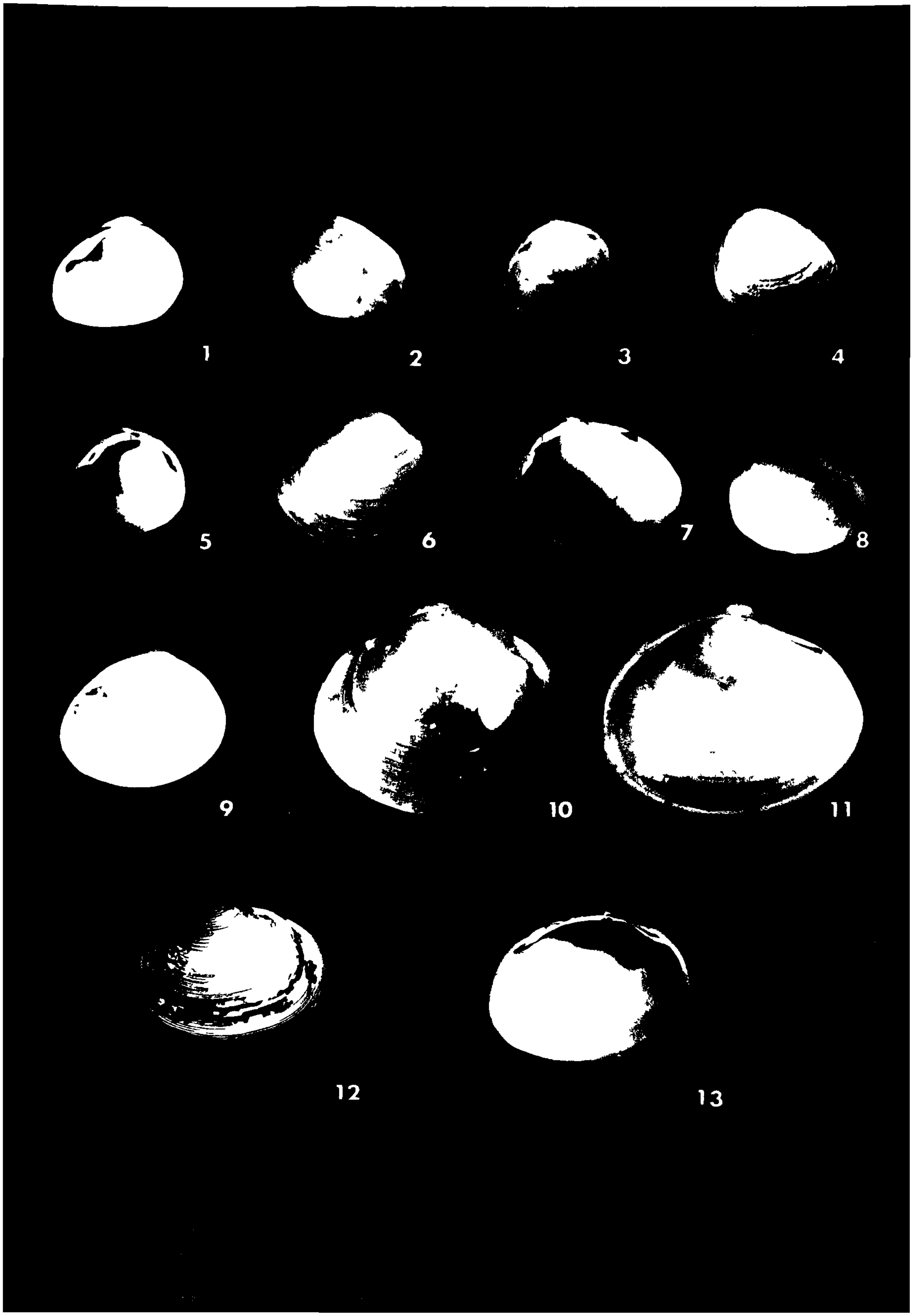
PLATE 3

Pelecypod shells of the Sphaeriidae family from Atkins Lake sediments.

FIGURE PAGE

1. Pisidium nitidum form contortum, X8............
2-3. Pisidium nitidum form pauperculum, X8..........
4-5. Pisidium obtusale form ventricosum, X8.........
6-7. Pisidium variabile, X8.........................
8-9. Pisidium walkeri form mainense, X8.............
10-11. Sphaerium lacustre, X8.........................
12-13. Sphaerium simile, X8...........................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