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I.M. Kettles, M. Garneau, and H. Jetté

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MACROFOSSIL, POLLEN, AND GEOCHEMICAL RECORDS OF PEATLANDS IN THE KINOSHEO LAKE AND DETOUR LAKE AREAS, NORTHERN ONTARIO

Abstract

The macrofossil and pollen records from two cores in the Detour Lake and Kinosheo Lake peatlands in northeastern Ontario cover more than 7000 years and 4000 years of vegetation history, respectively, and record a succession of peatland environments. The Detour Lake pollen record includes the vegetation successions associated with two major climatic shifts, the Mid-Holocene warm period and Late Holocene cooling trend. From 4000 BP, the vegetation successions derived from pollen analysis correlate well with respect to the evolution of the peatland and surrounding upland vegetation. Similar patterns of change were also noted in the pollen and macrofossil stratigraphies from other parts of northern Ontario. Patterns of trace element distribution reflect major changes in the peatlands. The most notable is the decrease in most trace elements as the peatland evolved from minerotrophic to ombrotrophic conditions. Levels of many elements are enriched in the near-surface peat horizons. Based on the data from this study, it is not possible to identify which part of the surface enrichment reflects airborne anthropogenic pollutants, inputs from naturally occurring atmospheric sources, or the relocation of inorganic constituents by physical, chemical, or biological processes.

Résumé

Les macrofossiles et pollens provenant de deux carottes prélevées dans les tourbières des lacs Detour et Kinosheo, dans le nord-est de l'Ontario, couvrent respectivement plus de 7 000 ans et 4 000 ans d'histoire végétale et documentent une succession de milieux de tourbière. Les pollens du lac Detour proviennent de successions végétales associées à deux périodes majeures de changement de climat, soit le réchauffement de l'Holocène moyen et le refroidissement de l'Holocène supérieur. À compter de 4 000 ans BP, les successions végétales reconnues grâce à l'analyse pollinique montrent une bonne corrélation avec l'évolution de la tourbière et de la végétation des terres environnantes. On a également noté des variations similaires dans la stratigraphie des pollens et des macrofossiles ailleurs dans le nord de l'Ontario. La répartition des éléments traces reflète des changements importants survenus dans les tourbières. Le changement le plus important est la diminution de la concentration de la plupart des éléments traces alors que la tourbière passait d'un milieu minérotrophe vers un milieu ombrotrophe. Les concentrations de nombreux éléments sont plus élevées dans les horizons de tourbe sous la surface actuelle. Avec les données de cette étude, il n'est pas possible de savoir quelle portion de l'enrichissement est attribuable à des polluants aéroportés anthropiques, à des intrants provenant de sources atmosphériques naturelles, ou à la relocalisation de constituants inorganiques par des processus physiques, chimiques ou biologiques.

SUMMARY

Peat cores were collected from three peatlands in northeastern Ontario — one near Kinosheo Lake (51°33.00´N, 81°48.85´W) and two near Detour Lake (49°56.42´N, 80°02.57´W; 49°59.58´N, 79°53.97´W). The research, conducted in two phases, was designed to study remote peat bogs as repositories of naturally occurring and anthropogenic metals. In the first stage, cores were collected through the peat sequence to mineral sediment and analyzed to gather baseline data on the geochemical and paleoecological variations associated with the different stages of peatland development. In the second stage, detailed work was undertaken on selected cores to characterize metal distribution in different components of organic matter and to investigate further metal sources. In this paper, results from the first phase of research are reported.

SOMMAIRE

On a prélevé des carottes de tourbe dans trois tourbières dans le nord-est de l'Ontario — une près du lac Kinosheo (51°33,00´N, 81°48,85´W) et deux près du lac Detour (49°56,42´N, 80°02,57´W; 49°59,58´N, 79°53,97´W). Cette recherche, exécutée en deux phases, a été conçue pour étudier les tourbières dans les régions éloignées en tant que sites d'accueil de métaux d'origine naturelle et d'origine anthropique. Lors de la première phase, on a carotté les dépôts de tourbe depuis la surface jusqu'au sédiment minéral, et on a analysé les carottes afin d'obtenir des données de base sur les variations géochimiques et paléoécologiques associées aux divers stades de développement de la tourbière. Dans la deuxième phase, on a poursuivi des travaux plus détaillés sur des carottes choisies afin de caractériser la répartition des métaux dans les différentes composantes de la matière organique et d'examiner plus à fond les sources des métaux. On présente ici les résultats de la première phase de la recherche.

The first stage objectives were accomplished by 1) integrating microfossil, macrofossil, and geochronological data for one peat core from the Kinosheo Lake and one of the Detour Lake peatlands to establish the vegetation assemblage successions from which past peatland environments were interpreted, 2) interpreting geochemical data for the same two cores within the context of the past peatland environments, and 3) examining geochemical data only for cores from the other Detour Lake peatland and two other sites within the same peatland at Kinosheo Lake for comparison purposes. In addition to providing baseline data on geochemical variation in peat sequences, results from this study provide some information on the history of the boreal forest in the area south of James Bay. Regional-scale information on past climate history gleaned from interpretations of past vegetation assemblages may be used in some cases as an analogue to assess the potential effects of the projected climate warming (Guiot, 1985, 1991; COHMAP Members, 1998).

On a atteint les objectifs de la première phase de la recherche 1) en intégrant les données sur les microfossiles, les macrofossiles et la géochronologie provenant d'une carotte de tourbe prélevée dans la tourbière du lac Kinosheo et d'une autre prélevée dans la tourbière du lac Detour afin d'établir les successions végétales à partir desquelles on a interprété les milieux passés des tourbières, 2) en interprétant les données géochimiques des mêmes carottes en tenant compte de la chronologie des milieux des tourbières et 3) en examinant uniquement les données géochimiques, à des fins de comparaison, provenant de carottes prélevées dans l'autre tourbière du lac Detour et à deux autres sites dans la même tourbière du lac Kinosheo. En plus de fournir des données de base sur la variation géochimique des séquences de tourbe, les résultats de cette étude ont fourni de l'information sur l'histoire de la forêt boréale de la région au sud de la baie James. Dans certains cas, on peut utiliser l'information sur l'histoire climatique à l'échelle régionale, qui a été recueillie à partir de l'interprétation des anciens assemblages végétaux, comme analogue pour évaluer les effets du réchauffement climatique prévu (Guiot, 1985, 1991; COHMAP Members, 1998).

Results show that peat accumulation began at the Detour Lake peatland around 7200 years ago and at the Kinosheo Lake peatland around 4000 years ago. At Detour Lake the early-stage peatland evolved from a wet, rich fen to a tree-covered fen. In contrast, there is no evidence of an aquatic, rich fen stage in the early development of the Kinosheo Lake peatland, and it is likely that this part of the peatland formed by paludification. Peat which accumulated after 4000 BP at both sites has similar paleoecological records and upland vegetation succession and is thought to have accumulated under ombrotrophic conditions. The records of vegetation succession can be associated with two major climatic shifts. The high content of *Pinus* pollen in peat which formed after 6800 years at Detour Lake corresponds to the mid-Holocene warm period (Richard, 1979, 1980, 1995; McAndrews et al., 1982; Richard et al., 1989; Garalla and Gajewski, 1992; Gajewski et al., 1993; Klinger and Short, 1996) whereas the decrease of spruce pollen and high concentration of *Sphagnum* spores in peat which accumulated over the last 2500 years at Kinosheo Lake is consistent with the cooling trend observed further east in subarctic Quebec (Payette, 1988; Gajewski et al., 1993).

Les résultats indiquent que l'accumulation de tourbe a commencé il y a environ 7 200 ans à la tourbière du lac Detour et il y a environ 4 000 ans à la tourbière du lac Kinosheo. Au lac Detour, la tourbière initiale a évolué depuis une tourbière minérotrophe riche et saturée en eau vers une tourbière minérotrophe boisée. À la tourbière du lac Kinosheo, on n'a pas trouvé d'indication d'une phase de tourbière minérotrophe riche et saturée en eau au stade initial de l'évolution de la tourbière, et il est probable que cette partie de la tourbière a été formée par paludification. Aux deux sites, la tourbe qui s'est accumulée depuis 4 000 ans BP présente une histoire paléoécologique et une succession végétale des terres avoisinantes similaires et se serait accumulée dans des conditions ombrotrophes. On peut associer l'histoire des successions végétales à deux changements de climat. Au lac Detour, la forte concentration de pollen de *Pinus* dans la tourbe qui s'est formée après 6 800 BP correspond à la période chaude de l'Holocène moyen (Richard, 1979, 1980, 1995; McAndrews et al., 1982; Richard et al., 1989; Garalla et Gajewski, 1992; Gajewski et al., 1993; Klinger et Short, 1996), alors que la diminution de la concentration de pollen d'épinette et la forte concentration de spores de *Sphagnum* dans la tourbe qui s'est accumulée au lac Kinosheo au cours des derniers 2 500 ans concordent avec la tendance au refroidissement qui a été reconnue plus à l'est, au Québec subarctique (Payette, 1988; Gajewski et al., 1993).

There is more variation in the content of trace and other elements in peat from the two Detour Lake peatlands which formed on the Canadian Shield than in the Kinosheo Lake peatland which formed in Paleozoic sedimentary terrain. At Detour Lake bog #2 and the Kinosheo Lake peatland, elements are most enriched in the lowermost part of the peat sequence which formed under minerotrophic conditions. As the peatlands evolved from minerotrophic peatlands to ombrotrophic bogs, the levels of some elements (e.g. Pb and Zn) decreased abruptly with decreasing depth from the surface and others decreased gradually (e.g. Ca, Mg, and Sr). There was no obvious correspondence between these changes and the spectrum of species forming similar types of

Les concentrations des éléments traces et d'autres éléments varient plus dans la tourbe provenant des deux tourbières du lac Detour, qui se sont formées sur le Bouclier canadien, que dans la tourbe de la tourbière du lac Kinosheo, qui s'est formée en terrain sédimentaire paléozoïque. À la tourbière n^{o} 2 du lac Detour et à la tourbière du lac Kinosheo, c'est la partie la plus profonde du dépôt de tourbe, formé dans des conditions minérotrophes, qui présente le plus important enrichissement en éléments. Alors que les tourbières évoluaient de minérotrophes à ombrotrophes, les concentrations de certains éléments (p. ex. Pb et Zn) diminuaient rapidement vers la surface tandis que pour d'autres éléments (p. ex. Ca, Mg et Sr) les concentrations diminuaient lentement. Il n'y a pas de correspondance évidente entre ces changements et la peat (i.e. minerotrophic or ombrotrophic) or between the degree of humification of organic materials and the elemental signatures of the peat.

composition des espèces qui forment des tourbes (minérotrophes ou ombrotrophes) ou entre le degré d'humification de la matière organique et la réponse des éléments dans les dépôts tourbeux.

At Detour Lake bog #2 and the Kinosheo Lake peatland, there are higher levels of many elements in the uppermost 35–50 cm of peat which formed in an ombrotrophic environment. Surface enrichment in bogs has been noted in many other studies (e.g. Parkarinen and Tolonen, 1976; Damman, 1978; Hvatum et al., 1983; Shotyk et al., 1996) and there are a number of potential sources. Bogs are nourished primarily by precipitation and dry deposition, the metals in which are derived from naturally occurring sources such as wind blown particles, volcanic emissions, venting from faults, and local soil degassing in snow and rain (Clymo, 1983; Rasmussen, 1994), or from anthropogenic pollutants. In addition, changes at the bog surface are rapid and the biological and physico-chemical processes occurring are markedly different than those occurring lower in the peat sequence (Clymo, 1983). On the basis of the data from the first phase of this study, it is not possible to discern which part of this surface enrichment reflects airborne anthropogenic pollutants, inputs from naturally occurring atmospheric sources, or the physical, chemical, or biological processes affecting decaying organic materials within the peat sequence.

À la tourbière n° 2 du lac Detour et à la tourbière du lac Kinosheo, il y a des concentrations élevées de plusieurs éléments dans les 35 à 50 cm supérieurs de la tourbe qui s'est formée dans un contexte ombrotrophe. On a noté un tel enrichissement en surface dans les tourbières lors de nombreuses études (p. ex. Parkarinen et Tolonen, 1976; Damman, 1978; Hvatum et al., 1983; Shotyk et al., 1996) et il existe un certain nombre d'origines possibles. Les tourbières sont surtout alimentées par les précipitations et les poussières atmosphériques et les métaux sont dérivés de sources d'origine naturelle, p. ex. les particules entraînées par le vent, les émissions volcaniques, le dégazage des failles et le dégazage des sols locaux dans la neige et la pluie (Clymo, 1983; Rasmussen, 1994), ou encore ils proviennent des polluants anthropiques. De plus, les changements à la surface de la tourbière sont rapides et les processus biologiques et physico-chimiques qui s'y déroulent sont très différents des processus qui agissent plus en profondeur dans le dépôt de tourbe (Clymo, 1983). Il n'est pas possible, avec les données obtenues dans la phase I de cette étude, de déterminer quelle partie de cet enrichissement de surface est attribuable à des polluants anthropiques apportés par le vent ou à des intrants apportés par des sources atmosphériques naturelles, ou encore à des processus physiques, chimiques ou biologiques agissant sur la matière organique en décomposition à l'intérieur de la séquence de tourbe.

INTRODUCTION

Information on the distribution of metals from naturally occurring and anthropogenic sources in surficial materials in remote areas is needed to provide a perspective to emissions of toxic metals from major point sources of industrial pollution. Peat from ombrotrophic peatlands is often used as a surficial sample media in airborne pollution studies because it is virtually isolated from the direct effects of minerotrophic groundwater (Glooschenko, 1986). In addition, the plant remnants preserved in the peat deposits provide a sequential record of past vegetation and related environments (Clymo, 1983).

As part of the Industrial Partners Program at Geological Survey of Canada, peat cores were collected from remote peatlands in northeastern Ontario to study peat bogs as repositories of naturally occurring and anthropogenic metals. Research on these peatlands was conducted in two phases. In the first stage, cores were collected through the peat sequence to mineral sediment and analyzed to gather baseline data on the geochemical variation associated with the different stages of peatland development. In the second stage, detailed work is being undertaken on selected cores to characterize metal distribution in different components of organic matter using sequential phase leaching techniques and to investigate sources of lead and other metals through the use of lead isotope ratio measurements. In this paper, results from the first phase of research are reported.

The first stage objectives were accomplished by 1) integrating microfossil, macrofossil, and geochronological data for one peat core from each of two peatlands (Kinosheo Lake and Detour Lake bog #2) to establish the vegetation assemblage successions from which past peatland environments were interpreted, 2) interpreting geochemical data for the same two cores within the context of the past peatland environments, and 3) examining geochemical data only for cores from another Detour Lake peatland and two other sites at Kinosheo Lake for comparison purposes.

In addition to providing baseline data on geochemical variation in peat sequences, results from this study provide some information on the history of the boreal forest in the Kinosheo Lake and Detour Lake regions. By using pollen data in combination with macrofossil and geochronological data, it was possible in many cases to evaluate the regional significance of changes in peatland environments determined from the two local paleoenvironmental reconstructions. Regional-scale information on past climate history gleaned from interpretations of past vegetation assemblages may be used in some cases as an analogue to assess the potential effects of the projected climate warming (Guiot, 1985, 1991; COHMAP Members, 1998).

A pollen stratigraphy developed previously for another part of the Kinosheo Lake peatland focused on testing hypotheses for vegetation successional sequences (Klinger and Short, 1996). More than 400 km south of James Bay, Liu (1982) interpreted the early postglacial history of the boreal forest, and around 200 km north of the present study sites, in the Sutton Ridge area, McAndrews et al. (1982) determined the vegetation history, both based on pollen and macrofossil stratigraphies in lake sediment cores. In the eastern Hudson Bay and James Bay regions of Quebec, there have also been studies on vegetation successions and species dynamics associated with the offlap of marine waters between 4000 BP and the present (Richard, 1979, 1980, 1995; Payette, 1988; Richard et al., 1989; Richard and Larouche, 1989; Garalla and Gajewski, 1992; Gajewski et al., 1993).

The Kinosheo Lake peatland (51°33.00´N, 81°48.85´W) was an important site for a wetland ecosystems project (Jeglum and Cowell, 1982) and the Northern Wetlands Study (NOWES) (Glooschenko et al., 1994) (Fig. 1). The two other sites, Detour Lake bog #1 (49°56.42´N, 80° 02.57´W) and Detour Lake bog #2 (49°59.58´N, 79°53.97´W), are located 200 km southeast of Kinosheo Lake. The Detour Lake bogs lie along the only road in the area which leads to a small gold mine opened in 1983.

STUDY AREA

The underlying bedrock at Kinosheo Lake bog is flat-lying Devonian limestone, while at Detour Lake bog #1 it is Precambrian granodiorite and at Detour Lake bog #2 Precambrian metasedimentary bedrock (Fig. 1; Ontario Geological Survey, 1991). Overlying the bedrock at the three sites is calcareous silty till, derived primarily from Paleozoic carbonate bedrock in the Hudson Bay and James Bay regions (Dredge and Cowan, 1989). Aerial photographs show that the peatlands developed in low-lying areas in fluted till plains; peatlands dominate the Kinosheo Lake area but form only a minor component of the landscape near Detour Lake (Tarnocai et al., 2000).

Glacial sediments underlying the sites were deposited during the late Wisconsinan stage of glaciation or deglaciation (Dredge and Cowan, 1989). During the deglaciation the study sites were covered by glacial Lake Ojibway which expanded northward against the retreating ice margin. Late glacial reconstructions show that the Detour Lake area was inundated by glacial Lake Ojibway between approximately 9500 and 8500 BP but after 8500 BP it was covered again by the glacial ice associated with the Cochrane readvance (Veillette, 1997). After 8000 BP, a break up of ice in southern Hudson Bay caused glacial Lake Ojibway to drain and the Tyrell Sea to invade the Hudson Bay and James Bay areas where it reached almost as far south as Detour Lake. The Tyrell Sea occupied coastal areas below approximately 150 m a.s.l. until after 5000 BP (Vincent, 1989; Dredge and Cowan, 1989). Although late glacial waterbodies inundated the three study sites, no waterlain sediments were observed at the base of the peat cores; all sites are underlain by glacial till.

The peatlands studied are located in the humid, high boreal forest ecoclimatic region (Fig. 1; National Wetland Working Group of the Canada Committee on Ecological Land Classification, 1986). This area is characterized by cold winters, warm to moderately cool summers, and moderate to high precipitation. Peat cores were collected at Kinosheo Lake between 400 m and 500 m from the lake shore in a peatland covered at its margins by stunted black spruce. Towards the centre the peatland becomes more open, being covered with sparse sedges and ericaceous shrubs (Fig. 2).

Figure 1.

Location of study sites. Also shown are areas covered by Canadian Shield and Paleozoic sedimentary bedrock (Ontario Geological Survey, 1991) and wetland regions (National Wetland Working Group of the Canada Committee on Ecological Land Classifications, 1986).

Figure 2.

The Kinosheo Lake peatland near site #6. Photograph by Stephen Robinson. GSC 1999-038

The two Detour Lake sites were both small and forested, dominantly by stunted black spruce. Permafrost occurs sporadically in peatlands in the vicinity of Kinosheo Lake but is absent in the Detour Lake area (French, 1989).

METHODS

Cores were collected using a peat corer similar to the one described by Jowsey (1966) on the flat surface of the peatland at the two Detour Lake sites and at three locations at the Kinosheo Lake site. These cores, referred to as the long cores, ranged in length from 100 cm to 264 cm and in most cases reached the mineral sediment. At Kinosheo Lake, one site (site #1) was forested, mainly by black spruce, while the other two (sites #2 and #6) were open, having a dominant *Sphagnum* cover with intermittent sedges and ericaceous shrubs. Two cores less than 35 cm long were collected from peat hummocks within a metre of the long cores at Detour Lake bog #2 and at site #6 in the Kinosheo Lake peatland; these are referred to as the short cores.

The Detour Lake bog #2 long core (150 cm) was analyzed for its content of macrofossils, pollen, and ash, and bulk density at 10 cm intervals to 120 cm (the contact with mineral sediment). The ash content was determined from loss-on-ignition data (500°C). In the same core, peat between 30 cm and 40 cm was radiocarbon dated at Beta Analytic, Florida (Beta-79045) and between 92 cm and 100 cm at Geological Survey of Canada (GSC-5694). Wood collected at 118 cm was dated using accelerator mass spectroscopy techniques (AMS) at Beta Analytic, Florida (Beta-70113). Geochemical analysis of peat and the underlying mineral sediments in the long cores from the bog #2 site, as well as the bog #1 site, were undertaken at 10 cm intervals.

In the bog #2 short core, peat from the uppermost 20 cm was dated at 0.5 cm intervals using ^{210}Pb dating techniques (Turner and Kettles, 2000) and between 33 cm and 35 cm (GSC-5764) using radiocarbon methodology. In the same core, bulk density, ash content, and geochemical determinations were also undertaken at 0.5 cm intervals to a depth of 22 cm.

The Kinosheo Lake site #6 long core (264 cm) was analyzed for its content of macrofossils, pollen, and ash, and also bulk density, at 10 cm intervals to 254 cm. Wood at 251 cm was radiocarbon dated at Isotrace Laboratory, Toronto (TO-4318), and wood at 67 cm at Geological Survey of Canada (GSC-5672). Peat and mineral sediments from long cores at sites #1, #2, and #6 were analyzed geochemically at 10 cm intervals. In the Kinosheo Lake site #6 short core, peat in the uppermost 21 cm was dated using ^{210}Pb dating techniques (Turner and Kettles, 2000), and analyzed geochemically for selected element levels at approximately 0.5 cm intervals.

For macrofossil analysis, subsamples with a constant volume of 20 cm^3 were collected at 10 cm intervals. The material was heated in a 5% KOH solution, washed, and sieved through a 0.180 mm screen (Garneau, 1993). Macrofossils remaining on the screen were hand-picked using a stereoscopic microscope (10x and 40x) and some plant parts (e.g. plant epidermis) were identified using a photonic microscope (400x and 1000x). Fossil plant remnants were either individually counted or their contents estimated as percentages of the total volume of screened material. Volumes of mineral particles and charcoal fragments were estimated as percentages of the total sample volume.

For pollen analysis, 1 cm^3 subsamples were mixed with a known quantity of *Eucalyptus globulus*, the concentration of which was predetermined using a hematocytometer (Benninghoff, 1962). Subsamples were then processed using a method modified from Erdtman (1960) and the following reagents — 10% potassium hydroxide, 49% hydrofluoric acid, 50% hydrochloric acid, and acetone. The residues were dehydrated with butanol and preserved with silicone oil. The identification and counting of pollen, spores, and microfossils were carried out using a photonic microscope. Wherever possible, 100 grains of *Eucalyptus globulus* and

300 grains of pollen were counted. Results of both pollen and macrofossil analysis were compiled and plotted using the TILIA (version 2) computer program (Grimm, 1993).

The less than 0.063 mm fraction of the underlying sediments was extracted by dry sieving and the less than 0.002 mm fraction by sieving, centrifuging, and decanting, using a methodology described by Lindsay and Shilts (1995). Peat and mineral sediments were analyzed by Chemex Ltd., Mississauga, for selected trace minor, and major elements, excluding mercury, by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) following an aqua regia partial extraction. Peat samples were analyzed for Hg using cold vapour atomic absorption spectroscopy techniques.

Descriptions of the peat and sediment in the long cores from the Kinosheo Lake peatland and Detour Lake bog #1 and bog #2 are presented in Appendix 1. For both the long and short cores, bulk density data are listed in Appendix 2, loss-on-ignition data in Appendix 3, and geochemical data in Appendix 4.

RESULTS

Detour Lake bog #2

The bog #2 long core (150 cm) was composed of peat between depths of 0 cm and 100 cm, mineral sediment of unknown origin between 100 cm and 116 cm, an organic horizon between 116 cm and 120 cm, and till below 120 cm (Appendix 1). Levels of trace elements are generally higher in the underlying glacial sediments than in the peat in the bog #2 core, as well as in the other long cores analyzed for this study (Appendix 4). Within the underlying till, there are higher concentrations of most elements in the clay-sized fraction, dominated by phyllosilicates, compared to the silt+clay-sized fraction (<0.063 mm) which contains larger quantities of metal-poor feldspar and quartz (Shilts, 1984).

Results of pollen and macrofossil analysis show three biozones within the bog #2 long core (Fig. 3, 4). Biozone 1 (120.5–90 cm) has a low concentration of pollen composed predominantly of *Pinus banksiana*, and herbs — Cyperaceae (sedges), *Artemisia*, *Ambrosia*, Compositae Tubuliflorae and Gramineae (grass) — accompanied by *Picea mariana*, *Salix* (willow), and *Alnus* (alder). Identification of angiosperm wood remnants at this depth support the presence of these shrubs at the site. In this biozone, the assemblage of tree pollen and macrofossil remnants, marked by a limited number of species, is associated with the early stages of boreal forest development (Ritchie, 1987). The abundance of *Pinus banksiana* (jack pine) with *Betula* (birch) and *Larix* (larch) pollen suggests that upland sites were occupied by these species.

Biozone 1 is subdivided into biozone 1a (120.5–108 cm) and biozone 1b (108–90 cm). At the base of biozone 1a, the presence of mosses *Calliergonella cuspidata* and *Drepanocladus vernicosis* suggest minerotrophic conditions. Sedges are present locally and seeds of *Carex exilis*, *C.* cf. *canescens*, and *C. oligosperma* were identified. The presence of seeds and pollen of *Typha latifolia* (cattail) and coenobium of *Pediastrum* indicate that the site was inundated by standing water. This interpretation is reinforced by the abundance of Cladocera shells, head capsules larva of Chironomids, ephippium of *Daphnia*, and oogonia of *Chara* in the sediment. Wood at 118 cm was dated at 7280 ± 70 BP (Beta-70113).

There are relatively high levels of many elements (Al, Ba, Co, Cr, Fe, K, Mg, Mn, Na, Ni, V, and Zn) in the organic layer (116–120 cm) in biozone 1a compared to the rest of the peat sequence (Appendix 4; Fig. 5, in pocket). Because the differences in values are very large for many elements, the geochemical data for the basal organic layer (116–120 cm) and glacial sediments were not plotted on Figure 5.

Biozone 1b overlies the interpeat sediment layer and has a macrofossil assemblage which suggests a mesotrophic environment. Pollen percentages of *Typha* and Cyperaceae increase as does the abundance and variety of seeds. An increase in the volume of woody remains (mainly *Larix laricina*) shows that the site was forested while a decrease in number of aquatic invertebrate fragments reveals drier conditions locally. The peat in this biozone is enriched in As, Ca, Cu, Fe, Mg, Mn, Ni, Sr, V, and Zn, in some cases by approximately an order of magnitude, compared to the overlying central part of the sequence. Peat collected between 92 cm and 100 cm was dated at 6880 ±110 BP (GSC-5694).

Biozone 2 (90–20 cm), characterized by assemblages of pollen and macrofossils dominated by Gymnospermae and *Sphagnum*, has been subdivided into three subzones — 2a, 2b, and 2c. Near the base in biozone 2a (90–70 cm), the percentage of black spruce pollen (*Picea mariana*) rises and that of tamarack (*Larix laricina*) reaches its highest values. Macrofossil analysis confirms the prominence of these two taxa at this stage of peatland development. The dominance of wood fragments, remnants of sedges, and the presence of *Sphagnum* sect. *Acutifolia* in the macrofossil assemblage suggest that mesotrophic conditions existed at that time. The microfossil and macrofossil assemblages indicate slightly drier conditions than those associated with biozone 1. There are two intervals in this biozone with charcoal fragments (50–45 cm and 40–35 cm). Concentrations of some elements (Ca, Cu, Fe, Mg, Mn, Ni, and V) begin to decrease over this biozone, while Hg increases from biozone 1.

Biozone 2b (70–40 cm) is characterized by a high concentration of pollen where the percentages of *Pinus banksiana* decreases relative to *Picea mariana*, and those of *Betula* and *Alnus* pollen increase. This assemblage suggests that the site had evolved into a tree-covered bog with similar vegetation to that associated with the present-day peatlands in the boreal forest (Hosie, 1969). The decrease in *Larix* pollen and the prevalence of bryophyte remains, dominated by *Sphagnum magellanicum*, suggest that the site had evolved from mesotrophic to ombrotrophic conditions. The herbs assemblage in this biozone is less diverse than in biozone 2a, and only a few seeds of *Carex* (mainly *Carex trisperma*) were counted. The evolution of the peatland to an ombrotrophic bog in biozone 2b coincides with a gradual decrease in the concentrations of Al, Ba, Ca, Cu, Fe, Hg, Mg, Mn, Ni, Sr, and

V with decreasing depth in the sequence. Over the same biozone, levels of As, Cr, and Zn remain low while levels of P increase slightly.

In biozone 2c (40–20 cm), there is a high percentage of *Picea mariana* pollen while the representation of *Pinus banksiana* and *Pinus strobus* pollen decreases from biozone 2b. Macrofossils of *Picea mariana* are abundant near the base but diminish considerably towards the top of this subzone. The decrease in *Picea mariana* fragments, combined with an increase in *Betula* (birch), *Alnus*, and Ericaceae pollen, indicate a change in the local forest cover. These changes in the pollen assemblage suggest an opening of the forest cover, also expressed by the marked increase in the percentage of *Sphagnum* spores indicating its abundance locally. Increased volumes of Pteridophytae, herbs, and sedge remnants confirm a more open herb-dominated environment. Seeds of *Carex trisperma* and *C. disperma* indicate wet and ombrotrophic conditions. The combination of the above characteristics suggest that a low-shrub, tree-covered bog dominated by *Picea mariana* was the dominant local environment. In addition, the assemblages of invertebrates (Cladocera shells, Chironomidae head capsules larvae) at the top of the subzone indicate that the site became wetter with time. Peat between 40 cm and 30 cm was dated at 3230 ± 80 BP (Beta-79045).

In biozone 2c, the pattern of decrease persists upwards from biozone 2b for some elements (Al, Ba, Ca, Cu, Fe, Hg, Mg, Ni, Sr, and V) while there are consistently low levels of others (As, Co, Mn, and Pb). Concentrations of Cu, Fe, Mg, Mn, Ni, and Zn reach their lowest levels, though the levels of Zn increase slightly near the top of the biozone. In contrast, levels of K and P increase.

The macrofossil and pollen assemblages in biozone 3 (20–0 cm) indicate that the peatland site had evolved to an ombrotrophic environment where *Sphagnum magellanicum*, *Picea mariana*, and ericaceous shrubs were prevalent. The marked decrease in the content of woody remnants and an increase in bryophyte (mainly *Sphagnum magellanicum*) and herbaceous remnants are consistent with an open bog vegetation cover. The presence of thecamoebians such as *Amphitrema flavum*, *Assulina muscorum*, *Assulina siminulum*, and *Hyalosphenia subflava*, as well as the Rotifera *Habrotrocha*

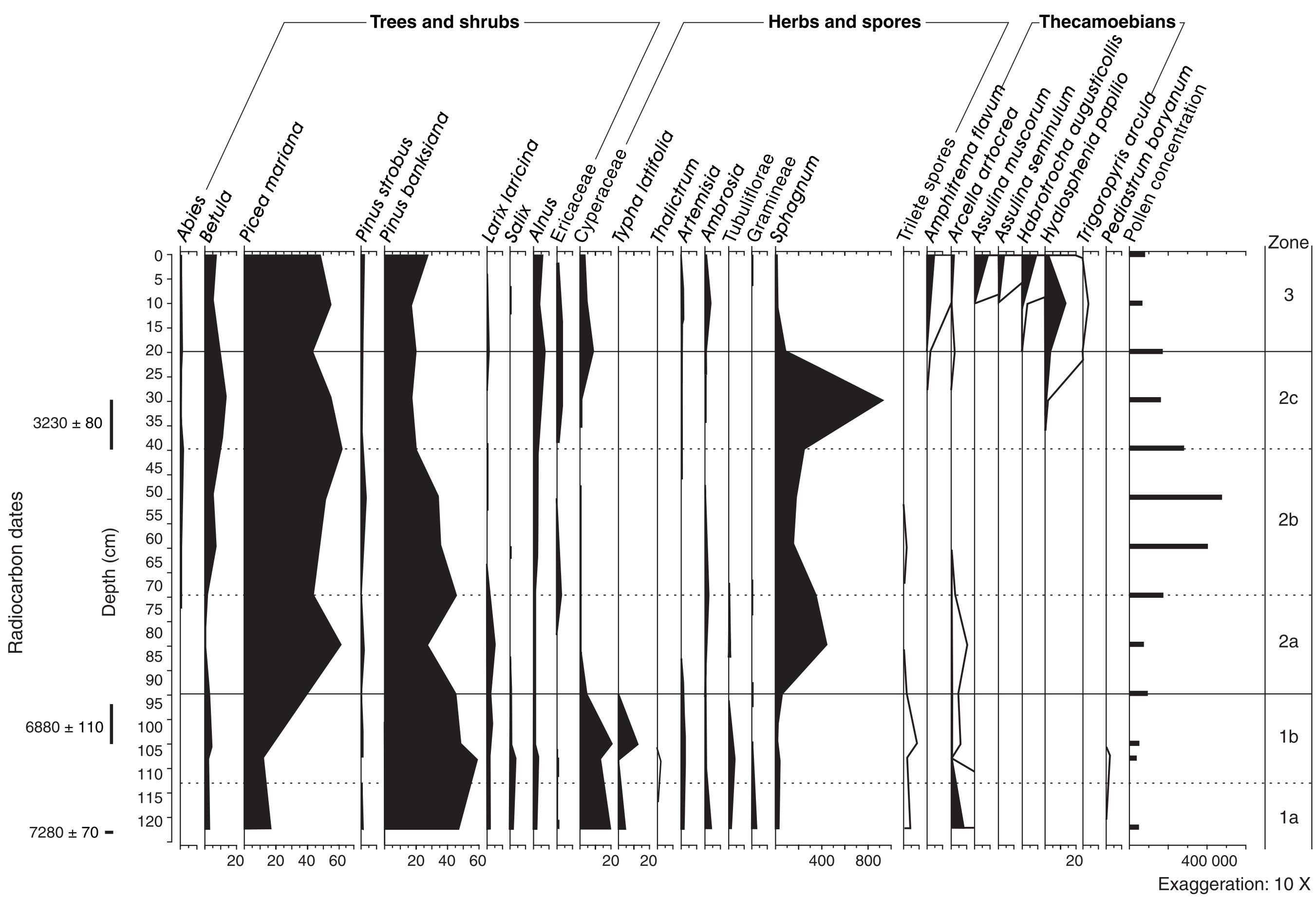

Figure 3. *Pollen diagram for Detour Lake bog #2 long core.*

angusticollis, Cladoceran shells, and Chironomid head capsules larvae suggest saturated soil conditions. Despite these indications, there is also an increase in the level of the thecamoebian *Hyalosphenia papilio*, which indicates that the water table fluctuated at the site.

There are marked differences in the geochemical composition of peat between biozone 2 and biozone 3, although both accumulated in an ombrotrophic environment. Biozone 3 is characterized by increases in Cd, Co, Cu, Fe, K, Mg, Mn, and Ni and especially in Pb, As, and Zn, compared to biozone 2. Between biozone 3 and biozone 2, Pb increases to 26 ppm from 2 ppm, As to 6 ppm from 2 ppm, and Zn to 32 ppm from 6 ppm. Although concentrations of most elements increase, levels of Al and Ba continue to decrease upwards within biozone 3 while levels of Ca, Sr, V, and Hg are generally low.

In peat from the bog #2 short core, there are various patterns of geochemical variation. Levels of many elements (Al, Co, Cr, Cu, Fe, Mn, Mg, Ni, and V) are relatively low below 5 cm and increase markedly in the uppermost 5 cm. In most cases, element concentrations are similar to those which characterize the one sample from the uppermost 10 cm of peat in the bog #2 long core. Above 5 cm in the short core, high concentrations of the elements listed above coincide generally with a high levels of ash (12% or greater). Above 22 cm, levels of Hg and Sr decrease gradually upwards in the sequence and also, P to a depth of 2 cm, while Zn increases gradually. Lead levels increase from 8 ppm at 22 cm to 42 ppm at 10 cm, then decrease again to 8 ppm at the surface. The distribution patterns of Pb and Cd correspond positively while Pb and Ca correspond negatively in the calcium-poor peat (0.4–0.7%) composing the short core.

Detour Lake bog #1

In the bog #1 long core (133 cm), the boundary between peat and glacial till was intercepted at 116 cm. Samples from this core were analyzed for selected element abundances for

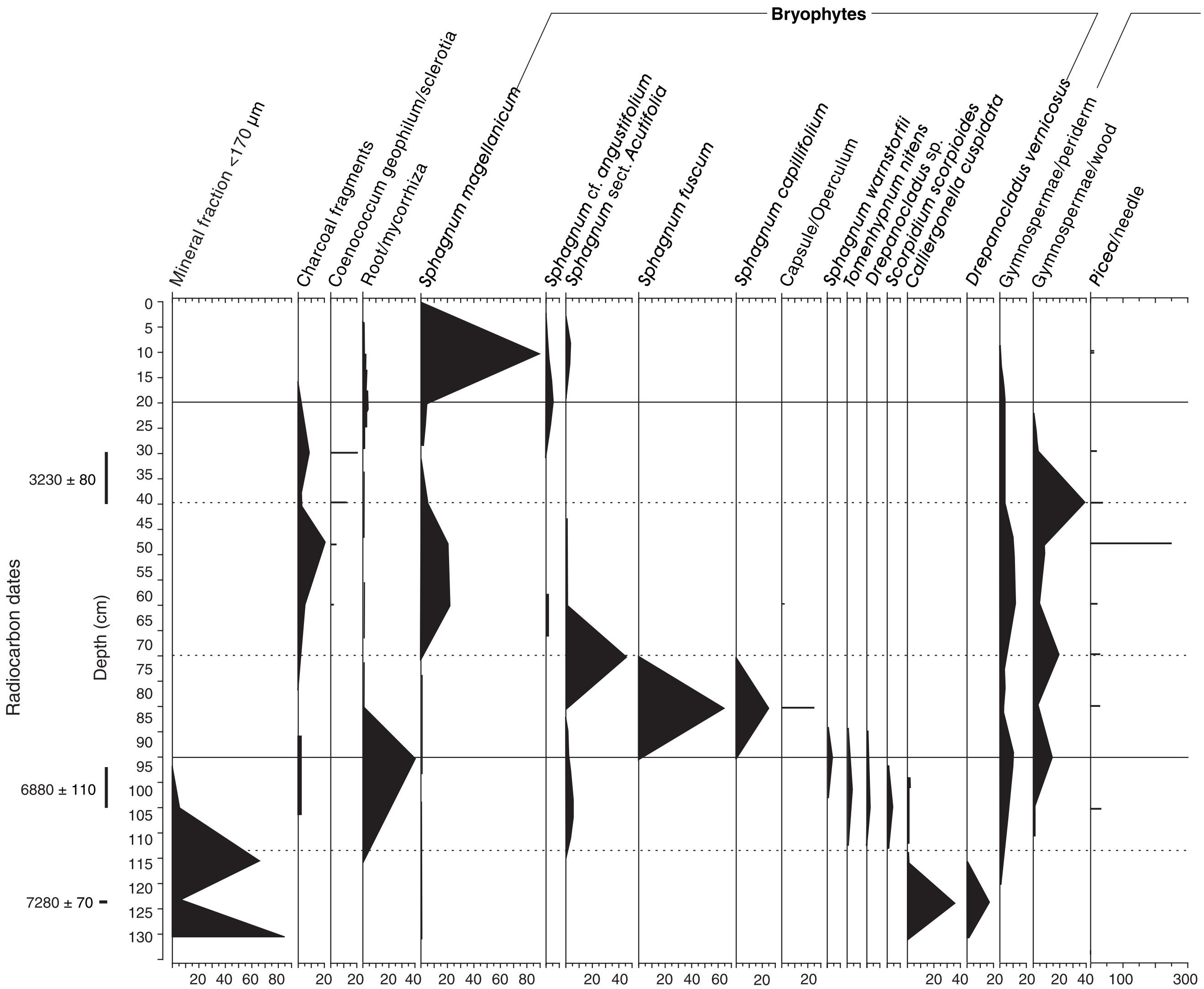

Figure 4. *Macrofossil diagram for Detour Lake bog #2 long core.*

comparison purposes with the Detour Lake bog #2 long core peat sequence (Appendix 4, Fig. 5). Results show that the distribution patterns of Ca, Cd, Co, Cu, Fe, Hg, K, Mg, Mn, Ni, P, Pb, Sr, and Zn in the long cores are similar generally for both bogs. In bog #1, there is the same pattern of element enrichment in peat near the surface compared to peat in the central part of the sequence for Pb, Cd, Fe, Mg, Mn, Ni, and Zn, but in bog #1 the increases for most of these elements are even more pronounced. Unlike the bog #2 long core, however, there is no increase in the As content in the near-surface peat horizons of bog #1 core.

Kinosheo Lake peatland site #6

In the long core (264 cm), the peat-glacial till boundary was reached at 254 cm. Three biozones have been identified in the peat sequence (Fig. 6, 7), biozone 1 (254–245 cm), biozone 2 (245–50 cm), and biozone 3 (50–0 cm). Wood at the base of peat (251 cm) was dated at 4000 ± 80 BP (IsoTrace, TO-4318) which corresponds to a date of 4110 ± 80 BP obtained for basal peat in the same bog in an earlier study (Klinger et al., 1994).

In biozone 1, peat immediately overlying till contains abundant lignous macrofossil remnants (*Picea mariana*) and Gymnospermae pollen (*Picea* and *Pinus*). These are accompanied by Cyperaceae and Ericaceae pollen and macrofossil remnants which reflect minerotrophic conditions. Although pollen concentration is low, the presence of freshwater algae *Pediastrum* shows that the site was saturated. The occurrence of *Sphagnum fuscum* suggests that the peatland was evolving gradually to a nutrient-poor environment. There are relatively high levels of most trace elements in peat at the base, with Zn having 40 ppm, Hg 80 ppb, Cu 32 ppm, Fe 0.4%, and

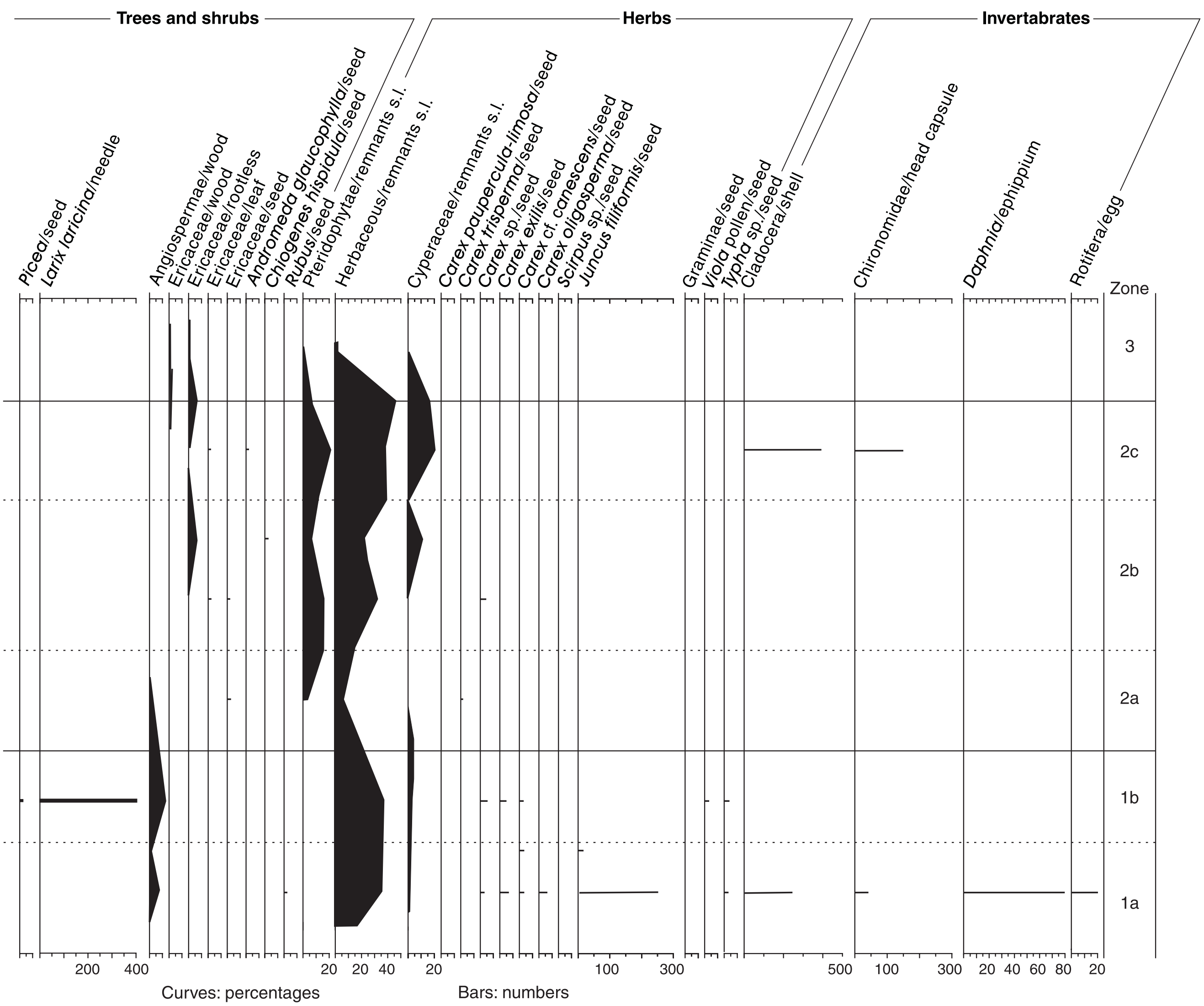

Figure 4. *(cont.)*

Pb 6 ppm (Fig. 5). In the peat at the top of the biozone, there is a decrease in the concentrations of many elements (Al, Ba, Cr, Cu, Fe, K, Mg, Mn, Ni, P, Pb, V, and Zn). Zinc, for example, decreases to 14 ppm, Pb to undetectable levels, and Cu to 12 ppm.

In biozone 2 (245–50 cm), fewer species are present in the assemblages of pollen and macrofossils. The macrofossil assemblage is dominated by *Sphagnum fuscum*, accompanied by Ericaceae species and a decreased volume of *Picea mariana* fragments while spruce remains foremost in the pollen assemblage. Wood at 67 cm was dated at 1720 ± 70 BP (GSC-5672).

In biozone 2a (245–220 cm), the high content of sweet gale (*Myrica gale*) pollen indicates moist conditions, further reinforced by the presence of thecamoebians — *Amphitrema flavum*, *Assulina muscorum*, and *Assulina seminulum*. The large content of *Sphagnum fuscum* fragments and the paucity of black spruce and ericaceous remnants characterize an environment transitory between a tree-covered and a more open environment. Herbaceous remnants are scarce and the presence of *Eriophorum spissum* epidermis fragments is consistent with a wet and nutrient-poor environment.

Biozone 2b (220–50 cm) has abundant spruce pollen and remnants of *Sphagnum fuscum*, Ericaceae species, and black spruce. The presence of thecamoebians such as *Arcella artocrea* and *Assulina muscorum*, accompanied by small amounts of *Typha* and *Thalictrum* pollen, show that site was saturated locally. The occurrence of *Sphagnum capillifolium* and *Chamaedaphne calyculata* in peat which accumulated about 2000 BP indicate that the site was more open as well as wetter. The assemblage at this level is also associated with a slight decrease in spruce macrofossil remnants as well as a small rise in the volume of charcoal fragments (1–2% of the screened sample). An equivalent pattern was noted at the base of biozone 2b (195–175 cm) but there were no other indications of change in the ecological conditions locally. Kuhry (1994) noted that surface fires do not influence the long-term vegetation development of *Sphagnum*-dominated boreal peatlands. Vegetation response such as species composition changes in moss cover, if any, is generally limited to a few decades after the fire event.

Biozone 2a and 2b are characterized by decreasing concentrations of many elements and consistent low levels of others. Calcium, Cr, Cu, Fe, Mg, Mn, Ni, Sr, and Zn decreased over biozone 2a. In biozone 2b, concentrations of

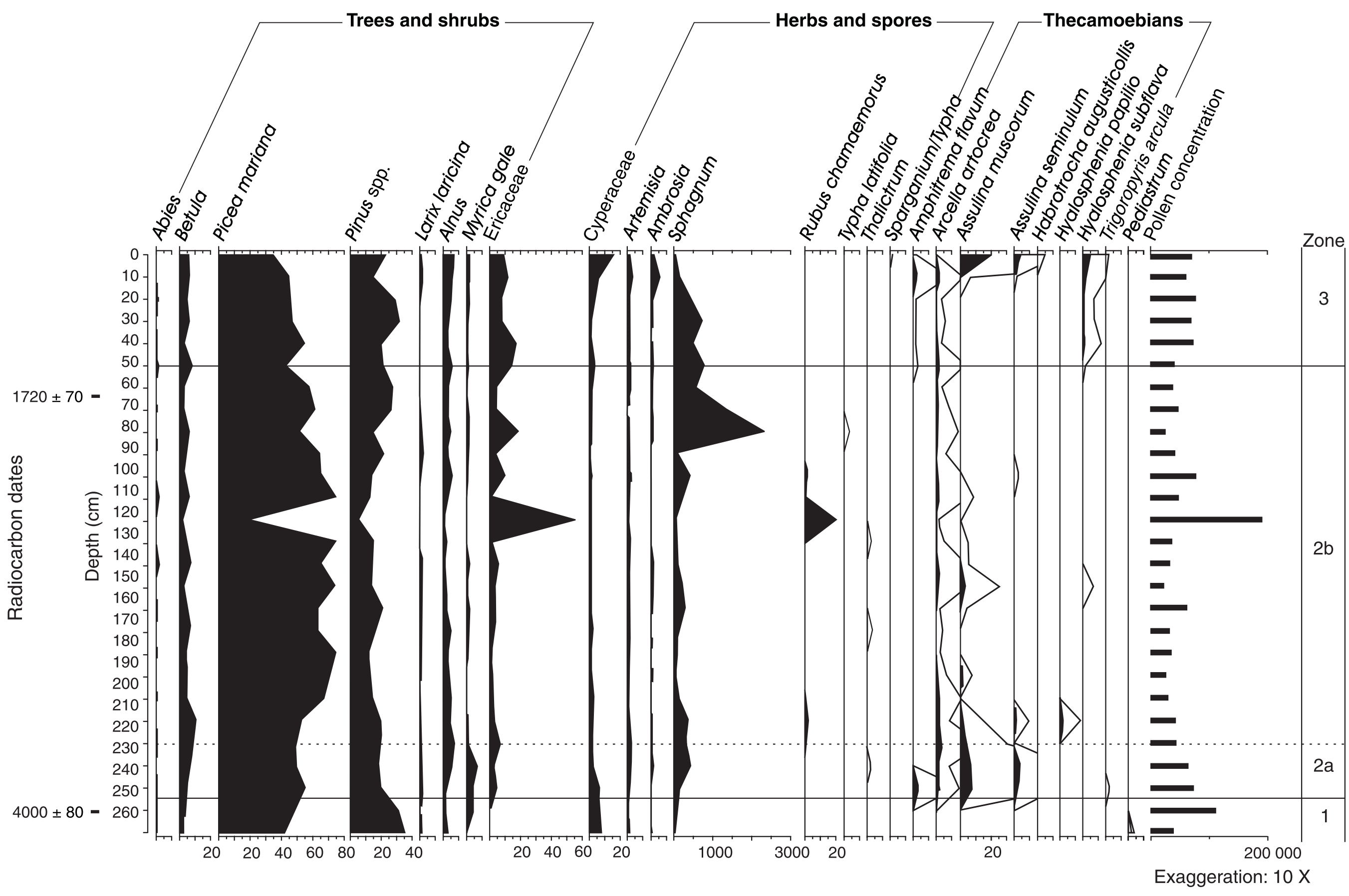

Figure 6. *Pollen diagram for Kinosheo Lake site #6 long core.*

Ca, Mg, Mn, and Sr continue to diminish upwards while levels of most others are consistently low. For example, over biozone 2b, levels of Ca drop from 1.9 % to 0.4% and Mg from 0.13% to 0.07%. Above 150 cm in biozone 2b, there are small increases in the concentrations of Hg and Zn.

The pollen and macrofossil assemblages in biozone 3 (50 cm to surface) reflect persistent humid conditions. The increased volume of *Sphagnum capillifolium* remnants in the lower part of biozone 3 shows that the site was open and saturated. It is likely, however, that the peatland became drier during the last century because there is an increase in *Hyalosphenia subflava* which indicates soil disturbances and water-level fluctuations (Garneau, 1998). In biozone 3 there are low concentrations of most elements but levels of Hg increase from 50 ppm at the top of biozone 2a to 110 ppm, at the top of biozone 3 P from 150 ppm to 300 ppm, and Zn from 14 ppm to 28 ppm.

In the site #6 short core, levels of many elements are consistently low (Al, As, Ba, Ca, Cd, Co, Cu, Mg, Sr, and V). Manganese and potassium levels increase systematically with decreasing depth from the surface, with the increases in K content being more pronounced in the uppermost 2 cm. Concentrations of Cr, Ni, and, to a lesser extent, P increase in the uppermost 1 cm of the sequence. Lead increases systematically with decreasing depth from 2 ppm at 22 cm to 28 ppm at 5 cm then decreases to 2 ppm at the surface. Iron levels also increase systematically from 0.04% at 22 cm to 0.10% at 11 cm, then decrease upwards to 0.03% at the surface. Zinc decreases gradually from 36 ppm to 18 ppm between 22 cm and 17 cm, then increases gradually to 44 ppm at the surface. Mercury concentrations vary between 40 ppb and 140 ppb but decrease generally with decreasing depth from 120 ppb to 90 ppb. In most cases, element levels in the short core are similar to those which characterize the one sample composed of the uppermost 10 cm of peat from the site #6 long core.

Kinosheo Lake peatland sites #1 and #2

Kinosheo Lake site #1 and site #2 long cores (128 cm and 200 cm, respectively) were collected through peat to the frost table. Mineral sediments were not intercepted. Again for purposes of comparison with Kinosheo Lake site #6, peat from sites #1 and #2 were analyzed for selected element

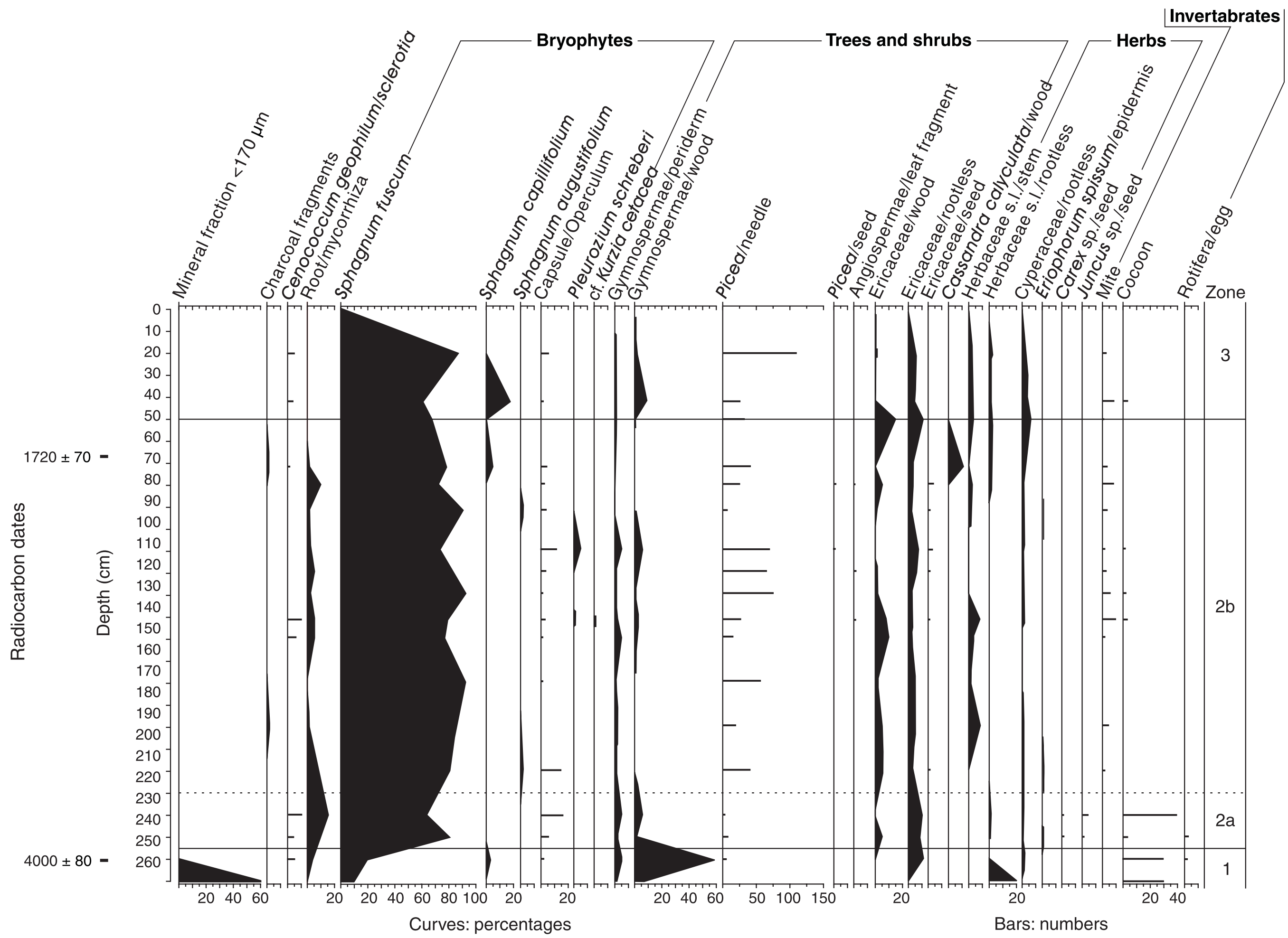

Figure 7. *Macrofossil diagram for Kinosheo Lake site #6 long core.*

abundances (Appendix 4). There is basal enrichment of fewer elements in the latter two cores (Fig. 5). The distribution of Al, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Ni, Pb, Sr, V, and Zn are generally similar over the central parts of the site #1, #2, and #6 long cores but there are differences in the distribution of some of these elements in the uppermost horizons of the three cores. In the uppermost horizons of the site #1 and #2 cores, there are markedly higher levels of Pb (18 ppm and 22 ppm compared to 4 ppm in the site #6 core) and Mn (120 ppm and 45 ppm compared to 10 ppm in the site #6 core), and there is 4 ppm As in the site #1 core compared to undetectable levels in the other two cores. In the site #6 and #2 cores, Hg levels are low in the central part of the peat sequence increasing slightly with decreasing depth from the surface while concentrations are variable in the site #1 core.

DISCUSSION

Most interpretations of late glacial history of northeastern Ontario indicate that proglacial waters or glacial ice persisted in the Detour Lake area until after 8000 BP (Veillette, 1997). The radiocarbon age of 7230 ±70 BP on a piece of wood at the base of peat (118 cm) at Detour Lake bog #2 indicate a minimum age for the beginning of peat formation. The peatland was first a wet, rich fen with brown mosses (*Calliergonella cuspidata* and *Drepanocladus vernicosus*), sedges (*Carex exilis*, *C. canescens*, and *C. oligosperma*), *Juncus filiformis*, and *Typha*. Upland vegetation was dominated by shrub communities including *Betula* and ericaceous species as described in initial successional stages by McAndrews et al. (1982). The local vegetation cover was disturbed at approximately 7000 BP by the deposition of mineral sediment. This interpeat sediment is thought to have been deposited by infilling or by local changes in the drainage system as there is no other evidence in the Quaternary record in the Hudson Bay Lowlands of a glacial readvance this late in time (Dredge and Cowan, 1989; Vincent, 1989; Thorleifson et al., 1993).

After the sediment layer was deposited, a tree-covered fen developed at the site where *Larix*, sedges, and *Typha* were nourished by mineral-rich soil waters, as reflected by the high levels of many elements associated with the peat in this part of the sequence. This phase of development corresponds chronologically to the mid-Holocene warm period when forest species such as pine expanded northward (Terasmae and Anderson, 1970; Ritchie, 1987; Liu, 1990). Liu (1990) described a pollen assemblage dominated by *Pinus banksiana/resinosa* at approximately 7000 BP. He noted percentages of *Pinus banksiana/resinosa* pollen greater than 30% which correspond to the high percentages in the Detour Lake bog #2 core (up to 60%). McAndrews et al. (1982) also recorded an increase in *Pinus*, *Salix*, and sedge pollen between 7500–6500 BP. The macrofossil assemblage at the bog #2 site was characterized by angiosperm wood fragments, herb remnants, and moss fragments. In contrast to Liu's (1990) findings, no pine needles were found. This suggests that the occurrence of *Pinus* pollen corresponds only to upland vegetation and not to the bog #2 site where the local environment was an herb-shrub fen. This initial stage of development has been described in several studies of Holocene peatland dynamics (Aaby and Tauber, 1974; Zoltai and Tarnocai, 1975; Aaby, 1976; Tolonen et al., 1985; Barber, 1987).

After 6000 BP, *Sphagnum* started to accumulate on the site with *Sphagnum capillifolium* and *Sphagnum fuscum* being identified in the macrofossil assemblage. In subarctic Quebec, Payette (1988) and Lavoie and Payette (1995) recorded minimal ages of 5050 years for basal peat overlying mineral sediments. Although the Quebec sites are 100 km north of the boreal forest limit, they record the beginning of peat accumulation in northern latitudes. Inception of peatlands occurred at this time (5050–4000 BP), associated with particularly moist conditions (Payette, 1984). At the same time, the upland vegetation assemblage was replaced by one dominated by spruce, larch, and *Sphagnum*, all of which are species typically found in the boreal forest at that time and also at present (Liu, 1990).

In northern Ontario and Quebec, the climate cooled at approximately 4000 BP, influencing the pattern of peatland expansion (Richard, 1979, 1980, 1995; McAndrews et al., 1982; Richard et al., 1989; Garalla and Gajewski, 1992; Gajewski et al., 1993; Klinger and Short, 1996). The higher content of *Picea mariana* pollen and lower content of *Pinus* spp. in peat which accumulated around 3200 BP, as well as the assemblage of botanical remnants, suggest postxerothermic cooling. Other changes in the macrofossil and pollen assemblage indicate an opening of the forest cover, also consistent with a cooling climate and autogenic succession processes. The low levels of many elements in the peat from this part of the sequence likely reflect the loss of influence from minerotrophic groundwater on the peatland.

At Kinosheo Lake, which was covered by marine waters, the basal peat began to accumulate approximately 3000 years later than at Detour Lake bog #2 which lies around 100 km to the south. In contrast to Detour Lake bog #2, there is no evidence of an aquatic, rich fen stage in the early development of the Kinosheo Lake peatland, and it is likely that this part of the peatland formed by paludification processes. A similar succession was described by Klinger and Short (1996) in the same peatland. Payette (1988) also studied subarctic peatlands where ombrotrophic peat accumulated directly over free-drained lacustrine deposits and where *Sphagnum fuscum* dominated under cooler conditions. Even if external factors such as hydrology and the presence or absence of permafrost have to be considered when interpreting local vegetation successions, in many cases major changes in the paleoecological records reflect regional-scale change in climate (Payette, 1984, 1988; Ovenden, 1990; Garneau, 1992, in press; Gajewski, et al., 1995). In this study major changes in the records are related to Holocene climate shift dynamics and compared to interpretations based on other studies undertaken east and west of James Bay and Hudson Bay (Sjors, 1959; Tarnocai, 1982; Jeglum and Cowell, 1982; Glooschenko and Martini, 1983; Klinger et al., 1994).

Peat which accumulated after 4000 BP at Kinosheo Lake peatland and Detour Lake bog #2 have generally similar stratigraphic records and upland vegetation succession. Between 4000 and 2500 BP, pollen assemblages become less diverse suggesting species reduction in response to the development of a *Sphagnum*-dominated peatland. A similar pattern of development elsewhere in northern Ontario was described by McAndrews et al. (1982). The decrease in the content of spruce pollen found in peat at Kinosheo Lake during the last 2500 to 2000 years (wood in peat at 67 cm was dated at 1720 ± 70 BP) indicates that the forest cover was more open. This decline of spruce, combined with the high concentration of *Sphagnum* spores is consistent with the regression of the forest cover associated with the cooling trend, observed further east in subarctic Quebec (Payette, 1988; Gajewski et al., 1993). There is a decrease in the volume of tree remnants in the macrofossil assemblage in this part of the Detour Lake and Kinosheo Lake peat sequences suggesting an opening of the bogs. In the Detour Lake bog #2 core, recurrent charcoal horizons do not coincide with any important shifts in the composition of vegetation identified in the macrofossil record.

There are large differences in age between the uppermost 35 cm of peat in the short core from the hummock and the long core from the flat part of the bog from Detour Lake bog #2. Peat between 33 cm and 35 cm in the hummock core were dated at 180 ± 50 years (GSC-5764, conventional), whereas peat found at similar depths in the complete core is more than 3000 years old. The young age of the hummock peat is further supported by ^{210}Pb dates which suggest that peat at 22.5 cm in the same core formed about 108 years from 1994 (Turner and Kettles, 2000). No near-surface peat from the Kinosheo Lake site #6 long core was dated but the surface peat in the hummock is also young, with peat above 17 cm, having accumulated in the 104 years before 1994 (Turner and Kettles, 2000).

There is more variation in the content of trace and other elements in peat from the two Detour Lake bogs which formed on the Canadian Shield than in the Kinosheo Lake peatland which formed in Paleozoic sedimentary terrane. Tills and related sediments derived from Paleozoic metasedimentary lithologies are generally metal-poor compared to sediments derived from Precambrian lithologies. Similar to peatlands in other areas, however, the biggest differences in geochemical composition are between deposits which formed from vegetation which grew under the influence of mineral soil water (a fen environment) and those formed from vegetation which was dependent primarily on precipitation (a bog environment) (Clymo, 1983). Changes in the distribution of most elements in the basal parts of the Detour Lake bog #2 sequence and the Kinosheo Lake site #6 core mirrors the gradual change from minerotrophic to ombrotrophic conditions in the peatland. Elements are most enriched in the lowermost peat which formed under the most strongly minerotrophic conditions. As the peatlands evolved from fens to ombrotrophic bogs, the levels of some elements in peat dropped off abruptly with decreasing depth, while others decreased gradually. In peat which formed in the early ombrotrophic stages (70–20 cm in Detour Lake bog #2 core and 220–50 cm in Kinosheo Lake site #6 core), levels of Al, Ba, Ca, Cu, Fe, Mg, Sr, and V continued to decline at Detour Lake bog #2 as did Ca and Sr in Kinosheo Lake site #6 core while the levels of many others remained at consistently low levels.

Two other factors affecting the levels of inorganic substances in peat are the nature of the original plant material and the nonselective increase in concentration of all inorganic materials due to the decay of organic matter (Clymo, 1983). Some plant species are known to preferentially accumulate metals (Brooks et al., 1995). In the Detour Lake bog #2 core and Kinosheo Lake site #6 core, however, there was no obvious correspondence between changes in the spectrum of species forming similar types of peat (i.e. minerotrophic or ombrotrophic) and changes in the elemental signatures (Fig. 3, 5). Similarly there was no correspondence between the element abundances and the degree of humification of organic materials as indicated by the descriptions of the peat composing the cores and, in some cases, the content of ash and bulk density of the peat (Fig. 5).

In both the long and short cores, there are higher levels of many elements in the uppermost 35 cm to 50 cm of peat which formed in an ombrotrophic environment. Surface enrichment in bogs has been noted in many other studies (e.g. Parkarinen and Tolonen 1976; Damman, 1978; Hvatum et al., 1983; Shotyk et al., 1996) and there are a number of potential sources. Bogs are nourished primarily by precipitation and dry deposition, the metals in which are derived from naturally occurring sources such as wind blown soils, volcanic emissions, venting from faults, and local soil degassing in snow and rain (Clymo, 1983; Rasmussen, 1994), or from anthropogenic pollutants. In addition, changes at the bog surface are rapid and the biological and physico-chemical processes occurring are markedly different than those occurring lower in the peat sequence (Clymo, 1983). High concentrations in the surface peat may reflect relocation of inorganic constituents by diffusion, mass flow, or biocycling (e.g. roots, micro-organisms) from the peat substrate or within the near-surface peat layer, all of which are affected by changes in temperature, pH, oxygen concentration, position of the water table, and the presence of sulphides (Clymo, 1983; Brooks et al., 1995).

Preliminary work on lead isotope determinations on peat from the Detour Lake bog # 2 show that Pb has been derived from a variety of sources (Kettles and Bell, 1996). In the very young peat from the short (hummock) core, there is a systematic decrease in $^{206}Pb/^{204}Pb$ ratio values where lead levels increase and decrease, with decreasing depth. This regular pattern of change in the lead isotopic composition would not be expected if surface enrichment in lead concentrations in this remote area, reflected mainly atmospheric lead inputs from anthropogenic sources. Below 50 cm, where lead levels are consistently low, the lead isotopic composition is most variable. The $^{206}Pb/^{204}Pb$ lead isotope ratios for the basal layers of peat in the long core, which formed in an minerotrophic environment, are intermediate between ratios for the underlying glacial till and those for peat in the overlying part of the sequence which formed in the early-stage ombrotrophic environment. Ratios are highest in peat which formed between 6800 and 3200 years ago, a time period which includes the episode of postglacial warming which affected most environmental systems.

The complex nature of surface element enrichment is also indicated by the variability in the patterns of element distribution in the near surface peat horizons from the Detour Lake and Kinosheo Lake peatlands. Enrichment levels for some elements are not uniform in cores from the same peatland. For example, Pb levels are markedly higher in the long cores from site #1 and site #2 at Kinosheo Lake but are only slightly elevated in peat from the site #6 long core. Concentration of As is elevated in the surface of the Detour Lake bog #2 long core but is low in the Detour Lake bog #1 long core collected about 10 km away.

CONCLUSIONS

Combination of pollen, plant macrofossil, and geochemical data for peatlands provides an opportunity to study past plant communities and the Holocene environmental conditions associated with them. External factors such as topography, hydrology, and the presence or absence of permafrost influence peatlands' ecology and development. Even if the composition of plant communities during peatland development varies greatly from place to place (Moore and Bellamy, 1974), there is the same general pattern of shift from minerotrophic peatland to ombrotrophic bog. The macrofossil and pollen record from Detour Lake bog #2 covers more than 7000 years of vegetation history and records the peatland change from fen to a bog. This long record includes the vegetation successions associated with two major climatic shifts, the Mid-Holocene warm period and Late Holocene cooling trend.

High percentages of *Picea* and *Pinus* pollen in peat at the base of the Detour Lake bog #2 core may reflect warmer climate conditions but they may also reflect the relatively low influx of pollen from local vegetation into the early-stage peatland. Hence, it is important to separate external factors from internal ones before concluding that species migration was influenced by climate change.

From 4000 BP, the vegetation successions in the Kinosheo Lake and Detour Lake bog #2 correlate well, with respect to the evolution of wetland and upland vegetation successions. Similar patterns were also noted in the pollen and macrofossil stratigraphies from other parts of northern Ontario as reported by McAndrews et al. (1982) and Liu (1990).

Peatland development in northern Ontario expanded in response to cooler, wetter climate conditions. In this case, the Detour Lake bog #2 and Kinosheo Lake peatlands evolved into *Sphagnum*-Ericaceae bogs. Most changes in plant assemblages in these bogs have been interpreted as responding to climatic variations, even if ecological successions over time also influence peatland dynamics as expressed by the changes in the peat geochemical data.

Patterns of trace element distribution reflect major changes in peatlands. Although hydrology, which is a reflection of climate, is the limiting factor in peatland development (Moore and Bellamy, 1974), nutrient availability and chemico-edaphic conditions are additional factors influencing the biota. The decline in influence of the minerotrophic groundwater as the peatland evolved from a fen to a bog is the strongest control on the trace elements signatures of peat below 30 cm to 50 cm from the surface. Levels of some elements decrease gradually in peat which formed in the fen and early bog environment while others decrease abruptly and remain consistently low. Levels of many elements are enriched in peat near the surface. On the basis of the data from this study, it is not possible to discern which part of this enrichment reflects airborne anthropogenic pollutants, inputs from naturally occurring atmospheric sources, or the physical, chemical, or biological processes affecting the decaying organic materials within the peat sequence.

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APPENDIX 1

Long core descriptions

Depth (cm)	Description
Kinosheo Lake peatland site # 6 (51°32.98´N, 81°48.89´W)	
0–44	Bryophyte peat; brown; poorly decomposed; contains herbaceous rhizomes
44–74	Bryophyte peat; poorly decomposed; white herbaceous rhizomes incorporated
74–120	Bryophyte peat; fibrous, few herbaceous rhizomes
120–144	Bryophyte peat; reddish; fibrous
144–194	Bryophyte peat; brown; poorly decomposed; better decomposed layers between 148–150 and 186–194 cm
194–223	Bryophyte peat; mesic
223–234	Bryophyte peat; wood fragments
234–240	Bryophyte peat; moderately well decomposed; contains wood fragments
240–254	Woody peat; humic; contains few bryophytes
254–264	Till; sandy; clayey; some pebbles
Kinosheo Lake peatland site #1 (51°33.01´N, 81°48.83´W)	
0–114	Peat; predominantly fibrous; some mesic layers
114–128	Peat; mesic; contains white herbaceous rhizomes
Kinosheo Lake peatland site #2 (51°33.03´N, 81°48.85´W)	
0–62	Peat; light brown; fibrous
62–63	White inclusions of unknown origin
63–186	Peat; brown; fibric; contains wood between 81–84 cm.
186–200	Peat; black; well decomposed.
Detour Lake bog #1 (49°56.42´N, 80°02.57´W)	
0–38	Peat; brown; fibrous
38–50	Peat; dark brown; mesic
50–116	Peat; black; mesic; contains wood fragments between 68 and 87 cm.
116–133	Till; grey; clayey
Detour Lake bog #2 (49°59.58´N, 79°53.97´W)	
0–22	Bryophyte peat; moderately decomposed peat
22–50	Woody peat; brown; mesic
50–60	Woody peat with alternating layers of bryophyte peat; fibric
60–90	Woody peat with alternating layers of bryophyte peat; humic to fibric
90–108	Woody peat with herbaceous remnants
108–116	Sediment; fine-grained
100–108	Peat; black; well decomposed
108–116	Diamicton; grey; some pebbles including some composed of Paleozoic limestone
116–120.5	Bryophyte peat with herbaceous and woody remnants; mesic
120.5–150	Till; grey; clayey; some pebbles including some composed of Paleozoic limestone

APPENDIX 2

Bulk density data

Kinosheo Lake peatland				Detour Lake bog #2			
Long core (flat surface)		Short core (hummock)		Long core (flat surface)		Short core (hummock)	
Segment (cm)	Bulk density (g/cm^3)	Segment (cm)	Bulk density (g/cm^3)	Segment (cm)	Bulk density (g/cm^3)	Segment (cm)	Bulk density (g/cm^3)
0.0–5.0	0.03	0.0–0.2	0.05	0.0–4.0	0.04	0.0–0.6	0.09
5.0–10.0	0.04	0.2–0.6	0.06	4.0–8.0	0.04	1.0–1.5	0.05
10.0–15.0	0.10	0.6–1.3	0.05	8.0–12.0	0.08	2.0–2.4	0.07
15.0–20.0	0.10	1.3–1.9	0.04	12.0–16.0	0.10	3.5–4.0	0.06
20.0–25.0	0.08	1.9–2.5	0.04	16.0–20.0	0.10	5.0–5.5	0.06
25.0–30.0	0.09	2.5–3.1	0.04	20.0–24.0	0.10	5.5–6.0	0.05
30.0–35.0	0.08	3.1–3.7	0.04	24.0–28.0	0.14	6.0–6.3	0.05
35.0–40.0	0.05	3.7–4.3	0.04	28.0–32.0	0.17	6.3–7.1	0.03
40.0–44.0	0.06	4.3–4.9	0.05	32.0–36.0	0.17	7.1–7.6	0.05
50.0–55.0	0.06	4.9–5.7	0.04	36.0–40.0	0.14	8.6–9.1	0.05
55.0–60.0	0.07	5.7–6.6	0.04	40.0–44.0	0.17	9.1–9.6	0.06
60.0–65.0	0.09	6.6–7.3	0.05	44.0–47.0	0.21	9.6–10.1	0.06
65.0–70.0	0.07	7.3–8.0	0.04	50.0–54.5	0.17	10.1–10.6	0.06
70.0–75.0	0.06	8.0–8.5	0.05	54.5–59.5	0.11	10.6–11.1	0.05
75.0–80.0	0.10	8.5–9.0	0.05	59.5–64	0.15	11.1–11.5	0.07
80.0–85.0	0.07	9.0–9.7	0.05	64.0–69.0	0.13	11.8–12.5	0.09
85.0–90.0	0.06	12.4–13.0	0.06	69.0–73.0	0.14	13.3–14.0	0.09
90.0–95.0	0.05	13.0–13.5	0.03	73.0–78.0	0.11	14.7–15.3	0.07
95.0–100.0	0.04	13.5–14.1	0.05	78.0–84.0	0.13	17.9–18.4	0.07
100.0–105.0	0.07	14.1–14.6	0.05	84.0–89.0	0.14	18.4–18.9	0.08
105.0–110.0	0.07	14.6–15.2	0.03	89.0–93.0	0.10	18.9–19.4	0.06
110.0–115.0	0.07	15.2–15.9	0.07	93.0–96.0	0.12	20.5–21.0	0.07
115.0–120.0	0.09	15.9–16.6	0.06				
120.0–125.0	0.06	16.6–17.5	0.06				
125.0–130.0	0.08	17.5–18.3	0.05				
130.0–135.0	0.06	18.3–18.9	0.07				
135.0–140.0	0.07	18.9–19.5	0.09				
140.0–145.0	0.04	19.5–20.1	0.07				
145.0–150.0	0.04	20.1–20.7	0.06				
150.0–155.0	0.06	20.7–21.4	0.05				
155.0–160.0	0.07	21.4–22.2	0.06				
160.0–165.0	0.09	22.2–23.0	0.08				
165.0–170.0	0.08						
170.0–175.0	0.06						
175.0–180.0	0.07						
180.0–185.0	0.08						
185.0–190.0	0.07						
190.0–195.0	0.07						
195.0–200.0	0.07						
200.0–205.0	0.07						
205.0–210.0	0.07						
215.0–220.0	0.11						
220.0–225.0	0.07						
225.0–230.0	0.14						
230.0–235.0	0.10						
235.0–240.0	0.14						
240.0–244.0	0.11						

APPENDIX 3

Loss-on-ignition (500°C) data

Kinosheo Lake peatland				Detour Lake bog #2			
Long core (flat surface)		Short core (hummock)		Long core (flat surface)		Short core (hummock)	
Segment (cm)	Remaining ash (%)	Segment (cm)	Remaining ash (%)	Segment (cm)	Remaining ash (%)	Segment (cm)	Remaining ash (%)
1–10	6.21	0–0.2	2.57	4.0–8.0	6.81	0–0.6	12.22
10–20	3.62	0.6–1.3	2.23	12.0–16.0	5.75	1.5–2.0	14.68
20–30	2.38	1.9–2.5	2.08	20.0–24.0	6.71	2.0–2.4	17.95
30–40	1.82	3.1–3.7	2.35	28.0–32.0	5.32	3.5–4.0	5.91
40–50	2.76	4.3–4.9	2.03	32.0–36.0	4.97	5.0–5.5	11.90
50–60	2.13	5.7–6.6	2.06	36.0–40.0	11.53	6.3–7.1	2.07
60–70	2.10	7.3–8.0	2.09	40.0–44.0	9.00	8.6–9.1	2.59
70–80	2.82	8.5–9.0	2.61	44.0–47.0	9.33	10.1–10.6	3.03
80–90	2.15	9.7–10.4	1.93	47.0–54.5	9.04	11.1–11.5	1.20
90–100	2.75	11.0–11.7	3.12	54.5–59.5	9.57	12.5–13.3	5.11
100–110	2.82	12.4–13.0	2.00	64.0–69.0	12.45	14.7–15.3	4.63
110–120	2.2	13.5–14.1	2.44	73.0–78.0	11.70	16.9–17.4	3.96
120–130	3.04	14.6–15.2	2.36	84.0–89.0	8.04	18.4–18.9	3.76
130–140	3.25	15.9–16.6	2.16	93.0–96.0	12.48	19.9–20.5	3.19
140–150	4.81	17.5–18.3	3.25			22.0–22.7	0.70
150–160	3.75	18.3–18.9	3.42				
160–170	3.55	18.9–19.5	1.94				
170–180	3.74	19.5–20.1	3.16				
180–190	3.89						
190–200	4.32						
200–210	4.95						
210–220	5.88						
220–230	8.48						
230–240	10.97						

APPENDIX 4

Geochemical data for peat and underlying sediments

Depth (cm)	Material	Al (%)	As (ppm)	Ba (ppm)	Ca (%)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	K (%)	Mg (%)	Mn (ppm)	Na (%)	Ni (ppm)	P (ppm)	Pb (ppm)	Sr (ppm)	V (ppm)	Zn (ppm)
Detour Lake bog #1 long core																					
0–10	peat	0.13	<2	20	0.63	1	1	17	26	0.38	70	0.09	0.19	45	0.01	10	560	54	18	9	50
10–20	peat	0.09	2	20	0.6	0.5	<1	5	23	0.15	110	0.04	0.07	10	0.01	3	770	16	16	2	32
20–30	peat	0.14	2	20	0.89	<0.5	<1	5	32	0.20	180	0.02	0.08	10	0.01	3	860	6	21	2	28
30–40	peat	0.16	<2	20	1.2	<0.5	1	5	11	0.23	150	0.01	0.11	10	0.01	2	480	2	26	2	12
40–50	peat	0.15	2	30	1.62	<0.5	<1	4	7	0.24	120	0.02	0.18	20	0.01	2	340	2	32	2	8
50–60	peat	0.16	<2	30	1.89	<0.5	<1	3	7	0.21	140	<0.01	0.14	15	0.01	1	310	2	38	2	6
60–70	peat	0.15	<2	30	1.99	<0.5	<1	2	6	0.23	110	<0.01	0.13	20	0.01	1	320	2	37	2	4
70–80	peat	0.2	<2	20	2.21	<0.5	<1	7	8	0.28	160	0.01	0.13	30	0.01	1	410	2	37	3	4
80–90	peat	0.22	<2	20	2.67	<0.5	<1	4	7	0.38	140	<0.01	0.15	40	<0.01	1	270	2	41	4	2
90–100	peat	0.35	<2	20	3.19	0.5	1	7	12	0.49	160	0.01	0.18	55	<0.01	3	390	<2	47	8	4
90–100D	peat	0.36	2	30	2.55	0.5	1	9	13	0.49	130	0.02	0.21	55	0.01	4	390	2	39	8	8
100–106	peat	0.79	4	40	2.62	<0.5	2	17	16	0.72	100	0.08	0.29	75	0.01	7	340	4	41	21	14
116–120	till <2µm	3.62	<2	120	0.56	0.5	19	100	23	3.97		0.65	1.63	395	3.50	50		6	33	71	94
120–126	till <2µm	3.69	<2	130	0.94	<0.5	19	117	31	4.49		0.69	2.05	465	1.55	54		14	36	78	108
125–133	till <2µm	3.58	<2	140	1.26	<0.5	19	116	32	4.37		0.76	2.19	495	2.07	53		14	38	76	108
116–120	till <63µm	1.59	<2	100	0.55	<0.5	8	42	16	1.64		0.31	0.64	170	0.09	20	530	8	30	33	36
120–126	till <63µm	1.29	<2	80	1.14	<0.5	6	36	15	1.43		0.23	0.96	155	0.07	16	510	6	26	28	32
126–133	till <63µm	1.23	<2	70	5.33	<0.5	4	37	20	1.41		0.27	2.65	245	0.07	15	380	12	41	28	34
Detour Lake bog #2 long core																					
0–10	peat	0.11	6	10	0.67	0.5	1	5	19	0.36	110	0.07	0.11	10	0.01	3	650	26	15	2	32
10–20	peat	0.15	1	20	0.59	<0.5	<1	3	8	0.28	100	0.06	0.06	5	0.01	2	1090	4	13	2	14
20–30	peat	0.25	2	20	0.75	<0.5	<1	7	7	0.17	140	0.04	0.04	2.5	<0.01	1	570	2	16	3	6
30–40	peat	0.29	2	20	1.14	<0.5	<1	6	8	0.17	140	0.01	0.07	5	<0.01	1	310	2	22	4	2
40–50	peat	0.4	1	30	1.7	<0.5	1	8	13	0.24	170	0.01	0.09	5	<0.01	2	360	4	33	6	6
50–60	peat	0.49	1	40	2.04	<0.5	1	8	10	0.30	180	0.01	0.10	10	<0.01	2	480	2	38	4	4
60–70	peat	0.48	1	40	2.9	0.5	1	8	15	0.40	200	0.01	0.15	15	<0.01	6	320	<2	50	6	6
70–80	peat	0.51	1	60	3.6	<0.5	<1	9	20	0.53	140	0.01	0.20	25	<0.01	5	280	2	60	7	10
80–90	peat	0.49	1	50	3.8	<0.5	<1	9	23	0.57	150	0.01	0.22	35	0.01	6	260	2	60	10	4
90–100	peat	0.44	4	40	3.74	<0.5	1	8	37	0.59	100	<0.01	0.22	40	<0.01	7	250	2	57	14	30
100–110	till <2µm	3.05	<2	110	0.77	<0.5	19	89	23	3.60		0.62	1.62	370	5.00	43		8	31	65	86
116–120	peat	1.64	2	80	1.63	<0.5	8	51	31	1.92		0.30	1.05	190	0.03	22	520	6	33	45	64
110–116	till <2µm	2.51	<2	90	0.73	<0.5	15	71	18	3.06		0.52	1.42	315	5.00	35		6	25	52	76
120–130	till <2µm	3.18	2	120	1.79	<0.5	16	109	29	3.79		0.69	2.31	435	3.01	49		14	38	66	102
130–140	till <2µm	3.45	<2	130	1.33	<0.5	19	118	35	4.43		0.71	2.20	520	1.78	54		12	38	78	116
140–150	till <2µm	3.21	8	130	1.56	<0.5	17	106	33	3.97		0.75	2.09	460	2.46	50		14	43	73	106
100–110	till <63µm	1.59	<2	100	0.98	<0.5	9	46	19	1.70		0.32	0.93	190	0.07	22	590	10	31	36	40
110–116	till <63µm	1.97	<2	110	1.9	<0.5	10	61	31	2.31		0.36	1.58	255	0.05	27	550	10	34	44	66
120–130	till <63µm	0.84	<2	40	4.81	<0.5	2	27	12	0.95		0.18	2.80	180	0.04	12	370	6	33	19	24
130–140	till <63µm	0.81	<2	40	7.71	<0.5	1	26	12	0.96		0.19	3.19	235	0.04	11	360	4	47	20	22
140–150	till <63µm	0.76	<2	40	8.71	<0.5	1	25	12	0.97		0.18	3.13	240	0.04	11	340	4	54	20	22

APPENDIX 4. (cont.)

Depth (cm)	Material	Al (%)	As (ppm)	Ba (ppm)	Ca (%)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	K (%)	Mg (%)	Mn (ppm)	Na (%)	Ni (ppm)	P (ppm)	Pb (ppm)	Sr (ppm)	V (ppm)	Zn (ppm)
Detour Lake bog #2 short core (hummock)																					
0.0–0.6	peat	0.29	<2	10	0.64	<0.5	5	30	85	0.66	100	0.19	0.31	135	0.01	14	550	8	6	11	54
0.6–1.0	peat	0.34	<2	10	0.62	<0.5	4	38	111	0.83	100	0.11	0.33	115	0.02	14	410	12	6	13	38
1.0–1.5	peat	0.4	<2	10	0.66	<0.5	6	46	122	0.97	120	0.09	0.37	115	0.01	15	400	14	6	15	38
1.5–2.0	peat	0.32	<2	10	0.64	<0.5	4	35	90	0.71	110	0.09	0.30	95	0.01	13	360	14	6	12	36
2.0–2.4	peat	0.25	<2	10	0.62	<0.5	3	22	65	0.53	110	0.08	0.24	75	0.01	10	300	14	6	9	34
2.4–2.9	peat	0.17	<2	10	0.59	<0.5	2	13	31	0.35	90	0.08	0.19	60	0.01	9	290	12	6	6	34
2.9–3.5	peat	0.17	<2	10	0.62	<0.5	2	11	28	0.32	90	0.08	0.19	55	0.01	8	290	12	7	5	36
3.5–4.0	peat	0.13	<2	10	0.65	0.5	1	7	13	0.22	70	0.07	0.17	45	0.01	7	280	8	7	3	32
4.0–4.5	peat	0.15	2	10	0.59	0.5	1	8	9	0.24	70	0.08	0.17	40	0.01	6	260	12	7	4	36
4.5–5.0	peat	0.14	<2	10	0.53	<0.5	1	7	8	0.23	80	0.07	0.15	30	<0.01	3	270	14	7	4	32
5.0–5.5	peat	0.1	<2	10	0.52	0.5	<1	4	4	0.16	80	0.07	0.14	20	<0.01	2	270	18	7	3	30
5.5–6.0	peat	0.08	<2	10	0.53	0.5	<1	2	4	0.11	80	0.07	0.14	15	0.01	2	280	22	7	2	32
6.0–6.5	peat	0.07	2	10	0.51	0.5	<1	2	4	0.10	100	0.07	0.13	15	0.01	1	280	26	7	2	32
6.5–7.1	peat	0.06	2	10	0.47	0.5	<1	1	4	0.08	120	0.08	0.12	10	<0.01	1	320	28	7	2	34
7.1–7.6	peat	0.07	2	10	0.48	0.5	<1	17	4	0.09	100	0.07	0.12	10	<0.01	6	320	32	8	2	36
7.6–8.1	peat	0.06	2	10	0.48	0.5	<1	1	4	0.09	120	0.07	0.12	10	<0.01	1	320	32	9	1	34
8.1–8.6	peat	0.06	<2	10	0.48	1	<1	1	4	0.10	130	0.06	0.11	10	<0.01	2	370	36	10	1	38
8.6–9.1	peat	0.06	<2	10	0.48	1	<1	1	3	0.09	130	0.06	0.11	10	0.01	2	340	36	9	1	36
9.1–9.6	peat	0.05	<2	10	0.45	1	<1	1	3	0.10	100	0.06	0.10	5	<0.01	1	370	38	10	1	36
9.6–10.1	peat	0.07	2	20	0.5	1.5	<1	2	6	0.16	110	0.07	0.10	15	0.01	2	390	42	12	2	42
10.1–10.6	peat	0.06	2	20	0.52	2	<1	1	4	0.16	130	0.07	0.11	10	<0.01	2	480	40	13	2	42
10.6–11.1	peat	0.07	<2	20	0.52	3	<1	2	4	0.18	130	0.08	0.11	10	0.01	2	520	36	13	2	44
11.1–11.5	peat	0.07	<2	20	0.47	3	<1	2	3	0.21	100	0.07	0.10	5	<0.01	1	510	34	12	2	38
11.5–11.8	peat	0.08	<2	20	0.48	3	<1	2	4	0.25	130	0.06	0.09	5	<0.01	2	510	36	12	2	38
11.8–12.5	peat	0.1	2	20	0.57	3.5	<1	2	3	0.27	130	0.08	0.10	5	<0.01	2	610	34	14	2	38
12.5–13.3	peat	0.12	2	20	0.53	3	<1	2	3	0.22	140	0.07	0.10	5	0.01	2	610	34	14	2	32
13.3–14.0	peat	0.12	2	20	0.55	3	<1	2	3	0.24	140	0.07	0.10	5	<0.01	2	630	30	14	2	30
14.0–14.7	peat	0.13	2	20	0.6	1.5	<1	2	3	0.16	150	0.06	0.10	5	<0.01	2	620	24	15	2	40
14.7–15.3	peat	0.12	4	20	0.53	2.5	<1	2	3	0.23	140	0.06	0.09	5	<0.01	2	620	26	14	2	28
15.3–15.9	peat	0.11	<2	20	0.57	1	<1	2	2	0.12	130	0.05	0.08	5	<0.01	1	580	18	15	1	38
15.9–16.5	peat	0.13	<2	20	0.63	0.5	<1	2	2	0.13	120	0.05	0.08	5	<0.01	1	600	16	15	2	74
16.5–16.9	peat	0.11	<2	20	0.56	0.5	<1	26	2	0.13	110	0.05	0.07	5	0.01	12	520	14	15	2	52
16.9–17.4	peat	0.09	<2	20	0.54	0.5	<1	1	2	0.11	110	0.04	0.07	<5	<0.01	<1	550	12	14	1	26
17.4–17.9	peat	0.08	<2	20	0.53	0.5	<1	1	2	0.12	120	0.04	0.07	<5	<0.01	1	610	12	13	1	22
17.9–18.4	peat	0.09	<2	20	0.53	<0.5	<1	1	1	0.13	140	0.04	0.07	<5	<0.01	<1	600	8	14	1	18
18.4–18.9	peat	0.08	<2	20	0.55	<0.5	<1	1	2	0.13	130	0.04	0.06	<5	<0.01	<1	640	12	14	1	18
18.9–19.4	peat	0.08	<2	20	0.59	0.5	<1	<1	2	0.13	140	0.04	0.07	<5	<0.01	<1	690	12	15	1	16
19.4–19.9	peat	0.07	<2	20	0.56	<0.5	<1	1	2	0.12	140	0.04	0.07	5	0.01	1	770	6	14	1	28
19.9–20.5	peat	0.08	2	20	0.6	0.5	<1	1	2	0.13	110	0.04	0.07	5	0.01	<1	770	8	15	1	22
20.5–21	peat	0.08	<2	20	0.55	<0.5	<1	<1	1	0.14	150	0.04	0.06	5	0.01	1	790	6	14	1	26

APPENDIX 4. (cont.)

Depth (cm)	Material	Al (%)	As (ppm)	Ba (ppm)	Ca (%)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	K (%)	Mg (%)	Mn (ppm)	Na (%)	Ni (ppm)	P (ppm)	Pb (ppm)	Sr (ppm)	V (ppm)	Zn (ppm)
Detour Lake bog #2 short core (hummock) (cont.)																					
21–21.5	peat	0.08	<2	20	0.56	<0.5	<1	<1	2	0.13	70	0.04	0.06	<5	<0.01	1	760	14	14	1	26
21.5–22	peat	0.09	<2	20	0.58	<0.5	<1	1	2	0.14	160	0.05	0.06	5	<0.01	1	910	8	14	1	28
22–22.5	peat	0.08	6	20	0.54	<0.5	<1	1	1	0.14	150	0.04	0.06	<5	0.01	1	750	8	13	1	28
Kinosheo Lake site #1 long core																					
0–10	peat	0.1	4	20	0.28	<0.5	<1	4	7	0.19	110	0.1	0.07	120	0.01	2	410	18	13	1	28
10–20	peat	0.05	<2	10	0.3	<0.5	<1	4	5	0.15	60	0.06	0.07	50	0.01	2	490	18	10	<1	22
20–30	peat	0.06	<2	10	0.34	<0.5	<1	3	2	0.18	110	0.02	0.06	45	0.01	1	410	4	9	<1	14
30–40	peat	0.08	<2	10	0.4	<0.5	<1	5	3	0.20	90	0.01	0.06	30	0.01	1	360	4	9	<1	6
40–50	peat	0.06	2	10	0.36	<0.5	<1	3	2	0.15	90	0.01	0.05	30	<0.01	1	320	4	8	<1	8
50–60	peat	0.08	<2	10	0.56	<0.5	<1	2	2	0.06	110	<0.01	0.04	15	<0.01	<1	290	<2	10	<1	4
60–70	peat	0.05	<2	10	0.62	<0.5	<1	1	1	0.08	180	<0.01	0.05	15	<0.01	<1	210	<2	9	<1	4
70–80	peat	0.03	2	<10	0.78	<0.5	<1	3	1	0.08	50	<0.01	0.06	15	<0.01	<1	150	<2	10	<1	4
80–90	peat	0.04	<2	<10	0.98	<0.5	<1	4	1	0.09	60	0.01	0.07	20	<0.01	1	180	<2	11	<1	4
90–100	peat	0.03	<2	<10	1.16	<0.5	<1	2	15	0.07	40	0.01	0.08	20	0.01	<1	180	2	12	<1	14
100–110	peat	0.03	<2	10	1.34	<0.5	<1	1	6	0.07	80	<0.01	0.08	25	0.01	<1	250	<2	12	<1	6
110–120	peat	0.09	<2	10	1.95	<0.5	<1	2	4	0.10	110	<0.01	0.09	40	<0.01	<1	320	2	18	1	8
120–128	peat	0.08	<2	10	2.82	<0.5	<1	1	5	0.16	200	<0.01	0.12	55	<0.01	<1	180	<2	23	1	8
Kinosheo Lake site #2 long core																					
0–10	peat	0.08	<2	20	0.34	0.5	<1	3	7	0.15	140	0.05	0.08	45	0.01	2	410	22	14	1	50
10–20	peat	0.05	<2	10	0.28	<0.5	<1	3	14	0.10	110	0.02	0.07	10	0.01	1	350	6	11	<1	34
20–30	peat	0.06	<2	10	0.29	<0.5	<1	1	4	0.06	90	<0.01	0.07	5	0.01	1	320	2	11	<1	22
30–40	peat	0.09	<2	10	0.27	<0.5	<1	<1	6	0.04	70	<0.01	0.06	5	0.01	<1	370	2	9	<1	32
40–50	peat	0.08	<2	10	0.3	<0.5	<1	1	4	0.04	50	<0.01	0.05	5	<0.01	<1	280	<2	9	<1	12
50–60	peat	0.06	<2	10	0.34	<0.5	<1	4	2	0.03	60	<0.01	0.06	5	0.01	1	180	<2	10	<1	12
60–70	peat	0.04	<2	10	0.4	0.5	<1	3	3	0.03	60	<0.01	0.07	5	0.01	<1	130	<2	10	<1	10
70–80	peat	0.03	<2	<10	0.46	0.5	<1	2	2	0.03	30	<0.01	0.07	5	0.01	<1	110	<2	10	<1	8
80–90	peat	0.05	<2	<10	0.54	0.5	<1	2	3	0.03	60	<0.01	0.07	10	<0.01	<1	170	<2	10	<1	8
90–100	peat	0.04	<2	<10	0.62	<0.5	<1	1	2	0.04	60	<0.01	0.07	10	<0.01	<1	150	<2	10	<1	6
100–110	peat	0.03	<2	<10	1.46	<0.5	<1	2	2	0.06	40	<0.01	0.11	20	0.01	<1	120	<2	14	<1	4
110–120	peat	0.06	<2	<10	1.21	<0.5	<1	1	1	0.05	60	<0.01	0.09	15	0.01	<1	120	<2	13	<1	4
120–130	peat	0.02	<2	<10	0.91	<0.5	<1	2	4	0.04	20	<0.01	0.09	15	0.01	<1	90	<2	10	<1	6
130–140	peat	0.04	<2	<10	0.85	<0.5	<1	2	1	0.04	40	<0.01	0.08	10	0.01	<1	110	<2	11	<1	6
140–150	peat	0.04	<2	<10	0.63	<0.5	<1	3	3	0.04	50	<0.01	0.07	15	0.01	1	150	<2	10	<1	10
150–160	peat	0.05	<2	<10	1.52	<0.5	<1	2	1	0.07	50	<0.01	0.10	20	0.01	<1	110	<2	15	<1	16
160–170	peat	0.03	<2	<10	1.72	<0.5	<1	1	1	0.08	40	<0.01	0.12	25	0.01	<1	110	<2	15	<1	6
170–180	peat	0.04	<2	<10	2.01	<0.5	<1	3	2	0.12	40	<0.01	0.12	30	0.01	<1	140	<2	16	<1	4
180–190	peat	0.08	<2	10	3.15	<0.5	<1	2	1	0.21	60	<0.01	0.17	50	0.01	<1	150	<2	24	1	6
190–200	peat	0.13	<2	10	4.1	<0.5	<1	3	5	0.34	60	<0.01	0.20	70	0.01	2	180	<2	31	2	6
Kinosheo Lake site #6 long core																					
1–10	peat	0.06	<2	<10	0.24	<0.5	<1	6	2	0.08	110	0.02	0.04	10	0.02	<1	300	4	6	<1	28
10–20	peat	0.08	<2	10	0.22	<0.5	<1	2	2	0.07	100	0.01	0.05	5	0.01	1	270	2	9	1	16
20–30	peat	0.07	<2	10	0.31	<0.5	<1	4	4	0.09	70	<0.01	0.06	5	0.01	1	160	2	11	1	16
30–40	peat	0.05	<2	10	0.31	<0.5	<1	6	2	0.08	50	<0.01	0.06	15	0.01	1	150	2	12	<1	14
40–50	peat	0.06	<2	10	0.29	<0.5	<1	4	11	0.06	50	<0.01	0.06	<5	0.02	1	160	2	11	<1	20
50–60	peat	0.05	<2	10	0.35	<0.5	<1	3	4	0.06	60	<0.01	0.07	<5	0.01	<1	150	<2	13	<1	14

APPENDIX 4. (cont.)

Depth (cm)	Material	Al (%)	As (ppm)	Ba (ppm)	Ca (%)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	K (%)	Mg (%)	Mn (ppm)	Na (%)	Ni (ppm)	P (ppm)	Pb (ppm)	Sr (ppm)	V (ppm)	Zn (ppm)
Kinosheo Lake site #6 long core (cont.)																					
60–70	peat	0.05	<2	10	0.37	<0.5	<1	2	2	0.04	50	<0.01	0.07	<5	0.01	<1	140	<2	11	<1	10
70–80	peat	0.07	<2	10	0.43	<0.5	<1	2	2	0.04	40	<0.01	0.07	<5	0.01	<1	140	<2	12	<1	8
80–90	peat	0.04	<2	<10	0.38	<0.5	<1	4	3	0.04	40	<0.01	0.07	<5	0.01	1	120	<2	9	<1	8
90–100	peat	0.04	<2	10	0.42	<0.5	<1	3	3	0.04	40	<0.01	0.07	<5	0.01	<1	130	2	9	<1	10
100–110	peat	0.04	<2	<10	0.5	<0.5	<1	2	3	0.03	20	<0.01	0.07	<5	0.01	<1	100	<2	9	<1	6
110–120	peat	0.08	<2	10	0.61	<0.5	<1	2	3	0.04	30	<0.01	0.07	<5	0.01	<1	140	<2	11	<1	6
120–130	peat	0.03	<2	<10	0.63	<0.5	<1	3	2	0.03	30	<0.01	0.08	<5	0.01	<1	90	<2	10	<1	6
130–140	peat	0.03	<2	<10	0.68	<0.5	<1	1	1	0.03	20	<0.01	0.08	<5	0.01	<1	90	<2	9	<1	6
140–150	peat	0.03	<2	<10	0.55	<0.5	<1	3	2	0.03	30	<0.01	0.06	<5	<0.01	1	90	<2	8	<1	4
150–160	peat	0.03	<2	<10	0.82	<0.5	<1	3	1	0.04	40	<0.01	0.08	5	0.01	<1	100	<2	10	<1	4
160–170	peat	0.03	<2	<10	1.05	<0.5	<1	2	2	0.05	20	<0.01	0.10	5	0.01	<1	100	2	12	<1	6
170–180	peat	0.02	<2	<10	1.16	<0.5	<1	2	4	0.04	20	<0.01	0.10	10	0.01	<1	100	2	12	<1	6
180–190	peat	0.03	<2	<10	1.23	<0.5	<1	2	3	0.05	30	<0.01	0.11	10	0.01	<1	100	<2	12	<1	6
190–200	peat	0.04	<2	<10	1.28	<0.5	<1	3	4	0.06	20	<0.01	0.10	10	0.01	1	140	<2	13	<1	10
200–210	peat	0.07	<2	10	1.65	<0.5	<1	3	2	0.07	30	<0.01	0.11	10	0.01	<1	150	<2	15	1	6
210–220	peat	0.04	<2	<10	1.85	<0.5	<1	3	1	0.07	30	<0.01	0.13	15	0.01	<1	110	2	15	<1	8
220–230	peat	0.07	<2	10	2.87	<0.5	<1	0.5	3	0.14	60	<0.01	0.18	20	0.01	1	160	<2	22	1	8
230–240	peat	0.07	<2	10	3.46	<0.5	<1	2	5	0.21	60	<0.01	0.20	30	0.01	1	170	<2	25	1	14
240–250	peat	0.19	<2	10	4.34	0.5	<1	3	12	0.31	90	<0.01	0.23	40	<0.01	2	200	<2	32	5	14
250–254	peat	0.5	<2	20	3.32	<0.5	1	18	32	0.40	80	0.04	0.25	50	0.01	5	310	6	27	17	40
260–265	till <2µm	3.23	<2	110	1.74	<0.5	18	94	24	4.00		0.68	2.12	400	4.27	43		14	35	70	104
254–260	till <63µm	1.15	<2	40	6.32	<0.5	1	32	10	1.44		0.20	3.76	195	0.03	14	390	4	32	27	34
260–265	till <63µm	1.01	2	30	6.38	<0.5	1	31	11	1.26		0.18	3.66	180	0.03	13	370	6	33	25	28
Kinosheo Lake site #6 short core (hummock)																					
0.0–0.2	peat	0.02	<1	10	0.17	<0.5	<1	8	3	0.03	80	0.42	0.06	65	0.03	4	300	2	4	<1	44
0.2–0.6	peat	0.07	<1	10	0.17	<0.5	<1	22	3	0.06	60	0.31	0.07	60	0.03	10	280	4	4	1	34
0.6–1.3	peat	0.04	<1	10	0.18	<0.5	<1	1	3	0.04	70	0.23	0.07	65	0.02	1	220	4	5	1	32
1.3–1.9	peat	0.03	<1	10	0.18	<0.5	<1	1	2	0.03	70	0.16	0.08	65	0.01	<1	180	10	5	1	34
1.9–2.5	peat	0.03	<1	<10	0.18	<0.5	<1	<1	2	0.03	60	0.11	0.07	65	0.01	<1	140	12	5	<1	32
2.5–3.1	peat	0.04	<1	<10	0.18	0.5	<1	4	2	0.04	60	0.09	0.07	60	0.01	1	130	18	5	1	32
3.1–3.7	peat	0.04	<1	<10	0.19	0.5	<1	1	1	0.04	70	0.08	0.08	70	0.01	1	130	22	6	1	32
3.7–4.3	peat	0.04	2	<10	0.19	<0.5	<1	1	1	0.04	80	0.07	0.08	50	0.01	2	120	28	6	1	32
4.3–4.9	peat	0.04	<1	<10	0.2	<0.5	<1	1	1	0.04	80	0.07	0.08	45	0.01	<1	130	28	7	1	32
4.9–5.7	peat	0.04	<1	<10	0.19	0.5	<1	1	1	0.05	100	0.07	0.08	45	0.03	<1	130	24	7	<1	30
5.7–6.6	peat	0.04	2	10	0.21	<0.5	<1	1	1	0.06	60	0.07	0.08	45	0.01	<1	150	28	7	1	34
6.6–7.3	peat	0.04	<1	10	0.18	<0.5	<1	1	1	0.06	90	0.06	0.07	30	0.01	<1	140	24	7	1	32
7.3–8.0	peat	0.04	<1	<10	0.18	<0.5	<1	1	1	0.06	40	0.07	0.08	20	0.01	<1	140	26	7	1	32
8.0–8.5	peat	0.05	<1	10	0.21	<0.5	<1	1	2	0.08	150	0.09	0.09	20	0.06	2	160	18	9	1	36
8.5–9.0	peat	0.04	2	10	0.2	<0.5	<1	1	1	0.09	80	0.06	0.08	50	0.01	1	160	22	8	1	34
9.9.7	peat	0.05	<1	10	0.19	<0.5	<1	1	1	0.08	130	0.06	0.08	15	0.01	1	150	20	8	1	34
9.7–10.4	peat	0.06	2	10	0.2	<0.5	<1	1	1	0.09	100	0.05	0.08	10	0.01	<1	160	20	8	1	36
10.4–11.0	peat	0.06	2	10	0.19	<0.5	<1	2	2	0.10	110	0.05	0.08	15	0.01	2	150	16	8	1	36
11.0–11.7	peat	0.05	<1	10	0.2	<0.5	<1	1	1	0.08	110	0.05	0.09	10	0.01	<1	160	20	8	1	38
11.7–12.4	peat	0.05	<1	10	0.19	<0.5	<1	4	1	0.08	70	0.04	0.08	10	<0.01	2	160	20	8	1	32
12.4–13.0	peat	0.06	<1	10	0.17	<0.5	<1	1	1	0.07	80	0.04	0.07	10	<0.01	1	160	16	7	1	30

APPENDIX 4. (cont.)

Depth (cm)	Material	Al (%)	As (ppm)	Ba (ppm)	Ca (%)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Hg (ppb)	K (%)	Mg (%)	Mn (ppm)	Na (%)	Ni (ppm)	P (ppm)	Pb (ppm)	Sr (ppm)	V (ppm)	Zn (ppm)
Kinosheo Lake site #6 short core (hummock) (cont.)																					
13.0–13.5	peat	0.05	<1	<10	0.15	<0.5	<1	1	1	0.06	140	0.04	0.06	5	0.01	<1	150	12	7	1	28
13.5–14.1	peat	0.04	<1	10	0.15	<0.5	<1	1	1	0.07	120	0.04	0.06	5	<0.01	<1	160	14	7	<1	28
14.1–14.6	peat	0.04	<1	10	0.16	<0.5	<1	1	1	0.06	140	0.03	0.07	5	0.01	<1	170	18	7	1	28
14.6–15.2	peat	0.05	2	10	0.16	<0.5	<1	1	1	0.06	100	0.03	0.07	5	0.01	1	180	14	7	1	26
15.2–15.9	peat	0.06	<1	10	0.18	<0.5	<1	1	1	0.06	120	0.03	0.07	5	<0.01	<1	190	16	8	<1	28
15.9–16.6	peat	0.04	<1	<10	0.16	<0.5	<1	2	1	0.04	100	0.02	0.07	<5	<0.01	1	200	12	7	<1	26
16.6–17.5	peat	0.06	<1	10	0.19	<0.5	<1	1	1	0.04	130	0.02	0.07	<5	<0.01	<1	230	10	9	<1	28
17.5–18.3	peat	0.05	<1	<10	0.14	<0.5	<1	1	<1	0.03	90	0.01	0.06	<5	<0.01	<1	200	6	7	<1	20
18.3–18.9	peat	0.04	<1	<10	0.14	<0.5	<1	<1	1	0.03	100	0.01	0.05	<5	<0.01	<1	160	4	7	<1	18
18.9–19.5	peat	0.06	<1	10	0.16	<0.5	<1	1	1	0.04	100	0.01	0.06	<5	<0.01	<1	180	6	8	1	22
19.5–20.1	peat	0.04	<1	10	0.15	<0.5	<1	<1	1	0.04	110	0.01	0.05	<5	0.01	<1	150	4	8	<1	20
20.1–20.7	peat	0.04	<1	10	0.16	<0.5	<1	<1	1	0.04	90	0.01	0.05	<5	0.01	<1	170	4	8	<1	22
20.7–21.4	peat	0.05	<1	10	0.17	<0.5	<1	1	1	0.04	90	0.01	0.06	<5	<0.01	<1	210	4	8	<1	26
21.4–22.2	peat	0.05	<1	10	0.17	<0.5	<1	1	1	0.04	100	0.01	0.05	<5	<0.01	<1	220	2	8	1	28
22.2–23.0	peat	0.06	<1	10	0.19	<0.5	<1	1	1	0.05	120	0.01	0.06	<5	<0.01	<1	250	2	9	1	36
Detection limit		0.01	2	10	0.01	0.5	1	1	1	0.01		0.01	0.01	5	0.01	1	10	2	1	1	1