STABLE ISOTOPE, FOSSIL COLEOPTERA AND POLLEN STRATIGRAPHY IN LATE QUATERNARY SEDIMENTS FROM ONTARIO AND NEW YORK STATE

P. FRITZ, A. V. MORGAN, U. EICHER and J. H. McANDREWS

1Quaternary Sciences Institute; Department of Earth Sciences, University of Waterloo, Waterloo, Ont. N2L 3G1 (Canada)
2Department of Botany, Royal Ontario Museum, Toronto, Ont. M5S 2C6 (Canada) and Departments of Botany and Geology, University of Toronto, Toronto, Ont. M5S 1A7 (Canada)

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Abstract


Stable oxygen isotope contents of marl deposits and molluscs from lakes and ponds in northern New York State (U.S.A.) and southwestern Ontario (Canada) are remarkably uniform for carbonates formed between about 12,600 yr B.P. and 2000 yr B.P. This suggests relatively stable climatic conditions with slowly increasing temperatures throughout this time span, an observation already indicated by fossil beetle data; and re-confirmed by additional data presented in this paper. The variations seen in pollen diagrams probably are related to plant colonization, and climatic parameters such as changing humidities.

This contrasts sharply with observations made in Europe where variations in pollen diagrams are paralleled by changing 18O contents in lacustrine marls and molluscs which clearly reflect climatic/temperature changes during late glacial and early postglacial times (13,500–9000 yr B.P.).

13C contents in marls and molluscs are not directly dependent on climatic change but reflect changing environments with varying aquatic and terrestrial carbon contributions.

Introduction

Stuiver (1968, 1970) suggested that 18O and possibly 13C analyses on freshwater carbonates can be used to obtain paleoclimatic information and subsequent additional research in North America substantiated this earlier suggestion. The European studies also showed through pollen analysis that vegetation succession which parallel climatic trends are normally paralleled by trends in the stable isotope contents of carbonate sediments (Eicher and Siegenthaler, 1976).

This is especially true for data collected from bogs and lake sediments in European alpine environments where changes in pollen and isotopic compositions are clearly related to varying temperatures during late glacial and early postglacial times (Ammann et al., 1983). Data from the British Isles had earlier substantiated this interdependence of climatic information from Coleoptera and flora (Coope et al., 1971; Coope and Brophy, 1972; Coope, 1978).

Fossil insect analyses at a number of sites postdating the maximum ice advance in the mid-continent of North America do not show
evidence of climatic fluctuations such as those seen in Western Europe. Morgan and Morgan (1980) suggest that in the Great Lakes region a stepwise postglacial floral colonization of the deglaciated landscape occurred and temperature changes indicate continuously ameliorating conditions. They further state that "...the evidence derived from the fossil insect faunas indicates that the tundra plant assemblages are not reflecting thermal conditions so much as pioneering communities". It seems likely that modifications in relative humidity may have been responsible for many of the perceived climatic changes reflected in the plant communities, and this has been recently commented upon by Morgan et al. (1982), Edwards et al. (1985) and Godwin (1985).

The apparent disagreement between pollen and beetle data necessitated a closer examination of the isotope records of lake carbonates, especially since isotope changes in molluscs from Lake Erie sediments (Fritz et al., 1975) are largely due to the development of Great Lakes drainage patterns rather than climatic shifts. This paper presents isotope and palynological data which were obtained on marl lakes in northern New York state and southern Ontario.

Field and analytical methods

The Nichols Brook site (northern New York) was cored for pollen and stable isotope samples with a 3 cm diameter Hiller corer. Sample material was collected only from the center of the core so as to avoid contamination. Samples for fossil beetle and radiocarbon determinations were collected in a vertical section dug adjacent to the core site.

Sediments from Inglesby Lake (Ontario) were obtained with a 8 cm Livingstone corer for pollen and stable isotope samples. Organic materials for radiocarbon samples were collected with a 10 cm bucket auger.

The Gage Street site (Kitchener, Ontario) was sampled in an open trench (Schwert, 1978), and is no longer accessible.

Pollen analyses on samples from Nichols Brook and Inglesby Lake were completed by J. McAndrews using standard preparation and analytical procedures. Information on the palynology of the Gage Street site has been summarized from a recent publication by Schwert et al. (1985). All fossil insect studies were conducted at the University of Waterloo using the kerosine separation method described in Coope (1968) and Morgan and Morgan (1979). Fossil insects recovered from the sites in this paper are stored in the Quaternary Entomology Laboratory at Waterloo.

Stable isotope analyses were done at the University of Waterloo by analyzing carbon dioxide produced during the reaction of carbonate with 100% H₂PO₄ at 50°C. Results are expressed as permil deviations from the PDB carbonate standard and have an analytical precision of better than +0.15‰.

Radiocarbon determinations on organic matter and carbonate were performed at Waterloo using benzene synthesis and liquid scintillation counting. Results are presented as conventional ages (τ₁/₂ = 5568 yr) which were calculated using 95% of the activity of the NBS oxalic acid standard as reference.

Stable isotopes in freshwater carbonates

The concepts which underlie the application of stable isotope analyses to paleoclimatic or paleoenvironmental studies have been described in numerous publications. However, because our studies consider organic/biogenic and inorganic material it is necessary to comment on the distribution of both δ¹⁸O and δ¹³C in freshwater lakes, their sediments and molluscs.

Paleoclimatic research in freshwater systems using δ¹⁸O requires a knowledge of the isotopic composition of the precipitation in the drainage basin. This is not easily obtained unless it is assumed that the basic meteorological circulation patterns in the past did not differ from that today and that, therefore, the origin of the vapour masses is similar. Under these conditions changing average annual temperatures will be reflected in changing
average isotope content in the precipitation. Dansgaard (1964) found that globally the temperature coefficient for temperature dependent $\delta^{18}O$ variations was close to 0.7‰, i.e. an increase in average annual temperatures by one degree will cause an increase in $\delta^{18}O$ by 0.7‰.

The data base for central Canada and the northeastern U.S.A. is very limited, but the average annual temperature and $\delta^{18}O$ data for Ottawa (IAEA, 1980) indicate a coefficient of 0.66‰. This confirms Dansgaard (1964), although the correlation coefficients for the regression analyses of data from a single station are not very good because of the small average annual variations in both parameters. The temperature coefficient for the $\delta^{18}O$ fractionation between carbonate and water is close to $-0.2\%_\circ$ which leaves, under the specified conditions, a net dependence of enrichment in the lake water of about 0.45‰ per degree average annual temperature rise, assuming that this temperature increase occurs also during the carbonate precipitation. Eicher and Siegenthaler (1976) quantified the temperature effects for the Gerzensee, a small lake in Switzerland, and demonstrated that non-evaporative enrichment could be as low as 0.1‰ if the precipitation coefficient were lower than assumed by Dansgaard (1964).

A parameter which is very difficult to assess is evaporation because its importance for $\delta^{18}O$ enrichment in lakes depends on climatic as well as hydraulic conditions. However, overall evaporative enrichment is more significant than simple temperature dependent effects and may mask the latter, especially if hydraulic regimes are subject to substantial changes. An understanding of these changes is necessary to interpret isotope data. This is especially true in parts of the Great Lakes basins where glacial meltwater entered many lakes during ice retreat.

Most paleoclimatic studies based on $\delta^{18}O$ analyses assume isotopic equilibrium between water and carbonate and that the temperature dependent isotope effects are known. Such is certainly the case for inorganic carbonates (O’Neil et al., 1969), yet Epstein et al. (1953) as well as Mook and Vogel (1968) showed that also many marine molluscs deposit their shells under equilibrium conditions with the same isotope effects. However, no such experimental data exist for freshwater molluscs nor for the carbonates which precipitate in response to the photosynthetic activity of aquatic plants such as Chara. It is only circumstantial evidence (Fritz and Poplawski, 1974) which suggests that molluscs and probably biogenic precipitates also follow the same rules.

Comparisons of $\delta^{18}O$ concentrations in inorganic marls and molluscs, and comparisons between different mollusc species (bivalves and gastropods), show generally close agreement in any given environment and differences are usually attributed to slight variations in environmental conditions. For example, we have observed that Valvata tricarinata has up to 2.5‰ more $\delta^{18}O$ than associated marl. In part this difference is due to the mineralogies of molluscs and marls, because the aragonitic shells of the former are enriched by at least 0.6‰ over marl calcite formed under the same equilibrium conditions (Tarutani et al., 1969). In addition minor environmental differences between mollusc habitat and loci of marl precipitation can account for some enrichment. Biological effects have not been recognized, but their existence cannot be excluded until detailed laboratory or field experiments have been undertaken.

The situation with respect to the carbon isotopic composition of marl and mollusc shells is less clear. The isotopic makeup of the aqueous carbonate in lake water is the determining parameter for marl and mollusc shell composition, with temperature being of subordinate importance. Aqueous carbon can show rather large variations because constituent isotopes are affected by several processes. It is possible to predict the $\delta^{13}C$ contents in the solid carbonates in lakes where the aqueous carbon is in isotopic equilibrium with the atmosphere provided they precipitate under isotopic equilibrium conditions.

Atmospheric carbon dioxide typically shows
$\delta^{13}C$ values between $-7$ and $-8\%$ and calcite in equilibrium with it would be enriched by approximately $12\%$, i.e. the calcite should show $\delta^{13}C$ values between $+4$ and $+5\%$.

Such values are observed in some marl lakes (Turner et al., 1983) although they are not common. Much more negative values predominate because carbon dioxide of biogenic origin mixes with atmospheric CO$_2$.

Within lakes and ponds $^{12}C$ rich carbon dioxide can be generated either through release of respiration carbon dioxide by aquatic plants or, usually the more likely mechanism, by the aerobic or anaerobic decomposition of organic matter within the water or sediments. The depletions can be significant and values as low as $-18\%$ have been recorded for dissolved inorganic carbon (Killey and Fritz, 1979). In addition, photosynthetic uptake of aqueous carbon can cause isotopic enrichments in the residual carbonate (McKenzie, 1985). This effect can, however, not be distinguished from those due to exchange with atmospheric carbon dioxide.

A third and often very important carbon source is dissolved inorganic carbon which originates in the dissolution of limestones and which is carried by inflowing groundwater. Its effects are similar to those caused by biogenic contributions because limestone dissolution in aquifers usually occurs under the influence of biogenic soil CO$_2$ dissolved in the water. $\delta^{13}C$ values below $-10\%$ are very common for the dissolved inorganic carbon of groundwaters.

Variations in contributions by these different sources can cause very significant variations in the $\delta^{13}C$ contents of the aqueous carbon and thus, potentially, in the precipitating carbonates. Yet the $\delta^{13}C$ contents of marl from any given lake only show very systematic variations through time with clear trends toward increasing or decreasing $\delta^{13}C$ values. Changes appear in response to significant environmental changes (Eicher and Siegenthaler, 1983).

Similarly, mollusc shells from any given lake do not show random variations, and are usually depleted in $\delta^{13}C$ with respect to associated marls. This difference could be attributed to the incorporation of biogenic carbon either through food or local environmental depletion (Chaix et al., 1982). However, we suggest that the explanation for this difference is the isotopic difference between aqueous carbonate and bicarbonate ions. Marl will precipitate in equilibrium with the carbonate ion, whereas molluscs obtain their shell carbon from the total dissolved aqueous carbonate; bicarbonate usually dominates the aqueous carbon of a lake. Depending on temperature this difference varies between 3 and 4\%, a difference frequently observed between marl and molluscs (Fritz, 1984; Karrow et al., 1984). However, at the same time rather significant differences are recognized between different mollusc species (Fritz and Poplawski, 1974; Godwin, 1985). These strongly suggest that the micro-environment in which the molluscs live (or internal biological processes; vital effects), have a significant influence on carbon isotopic compositions. The importance of vital effects has not been fully evaluated although preliminary laboratory experiments suggest that they are small (Fritz and Poplawski, 1974). For this reason and because these differences are rather constant in time it is tentatively assumed that variations reflect modifications in climate or hydraulic regimes (Turner et al., 1983).

Because of these differences in $\delta^{13}C$ contents between mollusc species from the same lake, we compared only data on a single species. Valvata tricarinata was used because it was easily recognized among the most common species and was usually found in all cores over the entire time span considered here.

**Results and discussion**

**Nichols Brook**

The Nichols Brook site ($42^\circ32'41"N$, $78^\circ28'44"W$, elev. 439 m; 1440 ft) is a streambank section near Buffalo, New York (Fig.1). Calkin and McAndrews (1980) reported silt and sand overbank deposits to a depth of 107 cm
and pond marl from 107–250 cm; Pleistocene outwash gravel underlay the marl (Fig. 2).

The section was sampled in 1981 for fossil insect and stable isotope studies. The base of the overbank deposits terminated at 100 cm, where it gave way to calcareous, organic silts and marls. Gravel was encountered at 330 cm. Eight new 14C dates were made in addition to the four published dates (Table I). Pollen and thermal analyses were also done to correlate the new section with that of Calkin and McAndrews (1980).

(a) Pollen analyses

Analyses reported in Calkin and McAndrews (1980) showed the overbank deposits to contain late zone 2 and zone 3 pollen while the marl contained pollen representative of zone 1 and early zone 2. Zone 1 was divided into subzone 1a with relatively abundant Picea and Ostrya in contrast with subzone 1b that has relatively abundant Larix, Pinus, Betula and Nuphar. The subzone boundary is bracketed by a wood date of 11,210 ± 160 yr B.P. and detritus dates of 12,800 ± 250 yr B.P. and 14,900 ± 450 yr B.P. (Table I). However, the isotope data discussed below suggest that hard-water effects influenced the carbon isotopic composition of this pond and, therefore, the oldest 14C data obtained on aquatic moss and detritus derived from it, and reported in Calkin and McAndrews (1980) are not suitable for age calculations.

<table>
<thead>
<tr>
<th>Level (cm)</th>
<th>Lab. no.</th>
<th>Date</th>
<th>Material dated</th>
</tr>
</thead>
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<tr>
<td>100</td>
<td>WAT-914</td>
<td>9050 ± 150</td>
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<td>WAT-891</td>
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<td>WAT-912</td>
<td>9690 ± 370</td>
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</tr>
<tr>
<td>160</td>
<td>WAT-808</td>
<td>10,850 ± 240</td>
<td>wood</td>
</tr>
<tr>
<td>170</td>
<td>WAT-813</td>
<td>11,320 ± 270</td>
<td>wood</td>
</tr>
<tr>
<td>200</td>
<td>WAT-815</td>
<td>11,720 ± 380</td>
<td>wood</td>
</tr>
<tr>
<td>195-205</td>
<td>I-5092</td>
<td>12,800 ± 200</td>
<td>detritus</td>
</tr>
<tr>
<td>205-215</td>
<td>I-6023</td>
<td>11,210 ± 160</td>
<td>wood</td>
</tr>
<tr>
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<td>WAT-844</td>
<td>12,320 ± 240</td>
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<td>WAT-847</td>
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<tr>
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<td>I-4043</td>
<td>13,380 ± 250</td>
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</tr>
<tr>
<td>315-330</td>
<td>I-4216</td>
<td>14,900 ± 450</td>
<td>detritus</td>
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*Dates from Calkin and McAndrews (1980) with levels equivalent to present report.

Thermal analysis (Fig. 2) shows the marl to be 60–80% CaCO3 with values of 25% in the overlying silt. Organic matter is 3–7% below 130 cm and rises to 13% in the upper marl; the silt has 22–28%, indicating that it is peaty.

The new diagram constructed from pollen analyzed from the 1981 samples displays zones 1a, 1b and 2 (Fig. 2). Correlation shows that relative to the earlier collection the latest collection has zone boundaries displaced downward; the zone 1–2 boundary from 115–120 cm is displaced to 120–130 cm and the 1a–1b boundary is displaced from 185–190 cm to 200–210 cm. Thus the zone boundaries are 7.5–17.5 cm lower in the section with the base of subzone 1a at the gravel contact 80 cm lower relative to the earlier collection. This correlation permits the adjustment of the levels for 14C dates (Table I).

The pollen diagram (Fig. 2, Table I), is divided into zone 1 that is dominated by Picea, and zone 2 where Picea is virtually absent. Subzone 1a is distinguished from subzone 1b by low Pinus and Larix and relatively abundant Ostrya and Selaginella. The lowest 30 cm of 1a has peak values of recycled pre-Quaternary spores that correspond with elevated residue values. Pinus (mostly P. banksiana/resinosa
Nichols Brook

Fig. 2. Diagram from the Nichols Brook site showing $\delta^{18}O$ and $\delta^{13}C$, thermal analysis and the most abundant pollen and spores.
type) rises through subzone 1b to a maximum in zone 2. The rise of Pinus is paralleled by an increase in pollen grain density from ca. 10,000 per gram dry weight at the base of zone 1 to 100,000 per gram dry weight at the top of zone 1; zone 2 has over 200,000 per gram dry weight. McAndrews (1981) suggests the mean annual temperature of the boreal woodland of zone 1 was −6 to −3°C, the boreal forest of zone 2 was −3 to +2°C and the mixed forest zone 3 was +5°C. Isotope and Coleoptera data from this site do not support these temperature estimates as discussed below.

A remarkable agreement exists between marl and Chara incrustations which indicates that the photosynthetic activity of this alga is responsible for the formation of marl. The lower-most deposit is an exception since both oxygen and carbon isotopes signal the presence of detrital calcite within the marl component. The $\delta^{18}O$ values for the autochthonous carbonates are close to −11‰ in precipitates found between 265 and 330 cm and then decrease to about −11.8‰. They maintain this composition throughout the remainder of the depositional cycle. The Valvata follow this trend up to about 160 cm but are enriched over the marl by approximately 1.5‰. Between 160 and 100 cm (the top of the marl) a slight increase in the $\delta^{18}O$ values is observed in the molluscs which brings the isotopic difference between marl and molluscs to about 2.5‰.

(b) Oxygen isotopic composition

The oxygen isotopic composition of the marls and molluscs in the Nichols Brook deposit is lower than would be expected under present climatic conditions. Lakes in southern Ontario and New York typically produce marls with $\delta^{18}O$ values greater than −10‰ (Turner et al., 1983). Values as low as those observed in Nichols Brook are only found in northern Ontario where cooler climates prevail. However, all modern marl lakes investigated are subject to some evaporation and thus isotope enrichment. It is revealing to compare Nichols Brook with marl data from Corry Bog, Pennsylvania, which deposited marl about 12,000 years ago. Karrow et al. (1984) find $\delta^{18}O$ values between −8 and −9‰. Although a minor climatic difference may have existed between these two sites, the large isotopic difference indicates that marl deposition at Nichols Brook occurred in a less-evaporitic pond or even in slowly flowing water. The 1‰ decrease in $\delta^{18}O$ values of the Chara incrustations from 310 to 250 cm reflect lowering of the $\delta^{18}O$ contents of the water. A fully flowing water regime was only established in marls found above 250 cm in depth. This is substantiated by the presence of flowing water beetle species (see below). Some evaporation did occur earlier in the sequence. Considering the lower $\delta^{18}O$ contents above 250 cm one can argue that the $\delta^{18}O$ of local precipitations and inflowing groundwater was not very different from today’s. This applies also to average annual temperatures which were close to or just slightly lower than those of the present.

Most remarkable is the observation that the climatic "shifts" indicated by the pollen data and specifically the important zone 1–2 boundary (Picea–Pinus transition) is not visible in the oxygen isotope data. This should be the case if this shift were solely due to major changes in average annual temperatures (Dansgaard, 1964). In this respect, the isotopic information independently verifies observations made from fossil Coleoptera in the lower Great Lakes region and reported by Morgan et al. (1982).

A shift in $\delta^{18}O$ values by several units towards most positive, warmer climate values is recognized in European marl cores at about 10,000 yr B.P. (Eicher, 1980; Siegenthaler et al., 1983) and also exists in isotopic contents of molluscs separated from Lake Erie sediments (Fritz et al., 1975). In the latter case the $\delta^{18}O$ increased by over 10‰ between about 14,000 and 8000 yr B.P. In Europe these shifts are due to climatic improvements in response to a migrating polar front in the Atlantic Ocean off Western Europe (Ruddiman and McIntyre, 1981), but the variations observed in a Lake Erie core (Fritz et al., 1975) are probably due to changing hydraulic regimes (see below).
The divergence of marl and mollusc data in the upper level of the Nichols Brook deposit is not easily explained. Assuming that the growth temperature of molluscs remains constant, then their increasing $\delta^{18}O$ content reflects changing water composition. The marl does not show such an increase; this would be explained if the $^{18}O$ increase in the water was balanced by an increase in marl formation temperatures. The average increase would have to be close to 4°C in order to offset the 1% increase in $^{18}O$. This then would signify that above 130 cm (about 9500 yr B.P.) the climate became dryer and possibly somewhat warmer. The water budget of this pond would have been affected and it would have become slightly more stagnant.

(c) Carbon isotopic composition
Marl and mollusc data show systematic and pronounced changes during the cycles of carbonate formation at the Nichols Brook site (Fig.3). The $\delta^{13}C$ values are low and reflect a strong influence from biogenic carbonate. Isotopic equilibrium with the atmosphere is not established and, therefore, hard-water effects can exist, especially since it is not clear how the isotopically light carbon was added to this system. Calcium carbonate charged groundwater might have been the source in addition

![Nichols Brook Diagram](image-url)

Fig.3. $\delta^{18}C$ and $\delta^{13}C$ analyses at the Nichols Brook site.
to the oxidation of organic allochthonous and/or autochthonous organic matter. Such is the case in modern rivers in southwestern Ontario, for example, where the $\delta^{13}C$ values of the dissolved inorganic carbon are typically between about $-10$ and $-13\%$.

The earliest marl has a detrital component (marine carbonate derived from bedrock) and Chara incrustations begin with $^{13}C$ values of about $-5\%$. Thereafter $^{13}C$ concentrations decrease slowly to values as low as $-8\%$ at about 160 cm depth. A stable period follows up to about 130 cm. Above this horizon the trend reverses and values as high as $-6\%$ are reached. The change appears to accelerate as the spruce–pine transition is approached to reverse somewhat above the transition. As discussed, this change may reflect increasing stagnation of the water. Isotope enrichments are then due to the uptake of isotopically depleted carbon during the photosynthetic activity of aquatic plants and/or increased isotope exchange with the atmospheric carbon dioxide reservoir as would be the case in a more stagnant environment.

The isotope trends seen in the marls are mirrored by the mollusc data. The isotopic difference is remarkably constant and must be a reflection of a geochemically stable environment with well defined habitats as would be expected in a system with running water.

(d) Fossil insects from the Nichols Brook site

A full account of the Coleoptera recovered from the Nichols Brook site will be published elsewhere, but the fauna indicates ecological and climatic conditions which are found in central and southern Ontario today. The assemblage, which contains representatives of 14 families of beetles, is dominated by carabids (ground beetles), staphylinids (rove beetles) and scolytids (bark beetles). Over 200 kg of sediment was washed and examined, but insects were not abundant in the moss and plant detritus. Specimens recovered have been tentatively split into three faunal units, although a few species cross more than one boundary.

Unit A: 325–175 cm (ca. 12,500–11,500 yr B.P.). Coleoptera found in the lower portion of the Nichols Brook section are transamerican species found mainly in the southern half of the boreal forest. Approximately half of the specifically identified beetles range through the boreal ecotone to treeline, but we do not regard this assemblage as indicative of treeline conditions. Indeed the other species from this unit prefer the extreme south of the boreal zone and some range across the international boundary into the northern, and even central, United States. The cold stenotherms associated with such sites as Weaver Drain, Michigan (Morgan, 1982), are absent from even the basal level at Nichols Brook. Furthermore, two thirds of the Coleoptera identified to species level, are represented in the same chronostratigraphic horizon in the Winter Gulf site, approximately 200 m below, and 35 km west of, the Nichols Brook site (Schwert and Morgan, 1980). This indicates that these species were well established in northern New York state prior to 12,000 yr B.P. Pond-marginal habitats are preferred by several carabid and staphylinid species and by the chrysomelid beetle Donacia, which lives on submerged and emergent aquatic vegetation. Open water areas are indicated by the aquatic beetles, Colymbetes, Gyrinus and Hydroporus griseostriatus. At least two genera of elmids (riffle beetles) indicate flowing water at the site (particularly from 255 cm to 125 cm), and this is further substantiated by the stream-bottom resident, Helichus striatus. Representatives of four genera of bark beetles are present; three are transamerican and range throughout the boreal forest.

Unit B: 175–140 cm (ca. 11,500–10,000 yr B.P.). Carabid beetles which appear in this unit can be collected together today in swamps of oligotrophic or mesotrophic type where the vegetation includes carices, Menyanthes and Typha latifolia and where the substrate is frequently covered with mosses. Other species prefer leaf litter in shady areas often occurring on the margins of swamps in stands of Alnus and Betula. This habitat may also have been
occupied by the staphylininids which become more numerous at this level. One carabid, *Carabus sylvosus*, lives exclusively in deciduous woodlands with more or less damp soil (Lindroth, 1961) but scolytids indicate the continued presence of conifers in the area. Another ground beetle, *Metalobus americanus* is xerophilous, and prefers open, sunny substrates. The sedge-eating chrysomelids seen in the lowest unit at Nichols Brook continue to be present, as do the gynuids, dytiscids and hydrophilids which indicate open water. Running water elmids persist, and the stream and marsh edges were occupied by the limnebid, *Hydraena*. The occurrence of beetles in this unit whose modern distribution barely enters southermost Ontario indicates that July temperatures were approaching those seen in the region today.

**Unit C: 140–100 cm (ca. 10,000–9000 yr B.P.).** Carabid beetles include species which reflect environments ranging from shaded deciduous woodland to open fields. The hygrophilous species, *Agonum decentis*, belongs to the first group and is often found under bark and logs near water. *Elaphrus clairvillei* is found on soft, wet organic mud, frequently with sedges (*Carex*) or other vegetation (*Typha* and *Alnus*). The species has also been collected in forest litter where the soil is well-drained (Goulet, 1983). *Myas cyanescens* is a forest-marginal species and has been collected under dead leaves on dry, sandy soil at the edge of a mixed forest. Open substrates were probably occupied by *Metalobus americanus* and *Notiophilus*. The stream or pond marginal habitat at the site was shared by staphylinids, hydrophilids and the chrysomelid *Donacia*. Elmids persist into the early stages of this unit, while a few dytiscids and limnebids indicate the presence of water. However, the disappearance of the gynuids, as well as practically all of the dytiscids and hydrophilids, seems to indicate that by the close of deposition at the Nichols Brook site open water had all but disappeared, and the locality had become quite eutrophic. The only scolytids recovered indicate that the obligate

*Picea* feeders had disappeared before the start of this unit. Conifers are still present, but *Phloeoisinus pini*, which lives on *Picea* and *Pinus*, suggests that the latter grew close to the site.

**Gage Street, Kitchener**

The Gage Street site (43°26'40"N, 80°31'12"W, elev. 342 m; 1122 ft) was a section excavated by backhoe in a drained marl and peat basin in Kitchener, Ontario (Fig.1). The stratigraphy, palynology and paleoentomology of the site has recently been described by Schwert et al. (1985). Deposition is estimated to have commenced prior to 12,500 yr B.P. and continued until about 7000 yr B.P. Because a building has been erected on the site it was not possible to obtain a new core for this study and we analyzed samples collected by Morgan and Schwert in 1975 (Schwert, 1978). The section is composed of 95 cm of peat which overlies about 350 cm marl which becomes increasingly clayey towards the bottom and terminates with 15–20 cm of lacustrine clay. Glacio-fluvial sands and gravels underlie the site to a depth of at least 20 m. Radiocarbon analyses (Fig.4) provide a general time-frame but indicate that the oldest deposits contain substantial amounts of detrital carbonate derived from Paleozoic limestones and dolomites.

(a) Pollen analysis

The pollen diagram (Fig.4) reflects the modern forest composition in its youngest portions. Below this zone between about 90 and 370 cm *Pinus* is dominant with a maximum of over 80% at 170 cm. Between 370 and 470 cm *Picea* dominates but is associated with *Juniperus*, *Fraxinus*, *Quercus* and some *Pinus*. The *Picea* maximum of 80% occurs at 400 cm. By comparing the pollen data with better dated sites elsewhere in southern Ontario palynological boundaries can be assessed to clarify the Gage Street radiocarbon data.

(b) Oxygen isotopic composition

The oxygen isotopic composition of marl in its deepest section (Fig.4) shows a decline of
the $\delta^{18}$O values from close to $-7\%$ at 460 cm to $-10.4\%$ at 370 cm. Between 370 and 320 cm there is a minor increase to about $-9.0\%$, and thereafter it decreases slowly to $-10\%$ with a minimum between 140 and 120 cm. The Valvata curve also shows the maximum at about 300 cm but does not correspond with the isotopic changes noted for the marl in the lowermost part of the section. Instead the $\delta^{18}$O content remains constant between 440 and 360 cm.

This comparison indicates the presence of detrital carbonate in the oldest marl of this section. Sediment deposited during the Picea–Pinus transition does not reveal any major isotopic shifts, an observation already made for the marl and molluscs in the same transitional period from the Nichols Brook site. Thus the $\delta^{18}$O contents observed in the marl and molluscs at the Gage Street site also reflect a relatively constant climate during this time.

However, changes in the profile are recognized when mollusc and marl data are compared. The oldest samples show the "usual" $\delta^{18}$O difference of 1–2% but about 10,000 yr B.P. this difference began to increase. This is similar to what is seen at Nichols Brook, and if the average growth temperature of a given mollusc species remains constant, then the oxygen isotope values of the molluscs reflect increasing $\delta^{18}$O in the water. Such evidence is absent in the marl whose $\delta^{18}$O content decreases during this time span. The increase in $\delta^{18}$O in the molluscs is most probably due to a divergence of environmental conditions between the mollusc habitat on the one hand and the milieu of marl formation on the other. The carbon isotope data discussed below show an even stronger change in differences between marl and mollusc isotopic compositions.

Following the input of isotopically heavy, detrital carbonates the oldest marls at about 370 cm reach $\delta^{18}$O values close to $-10.5\%$. These values are similar or only slightly more positive than those measured in the Nichols Brook sediments. They indicate that evaporation was not significant, i.e. that the water was probably flowing. Thereafter evaporation may have become more important or the inflowing ground and surface waters became slightly enriched due to minor climatic improvements. The very constant values found between about 320 and 140 cm reflect a stable hydraulic regime in which evaporative loss was still only a minor component. The decrease in $\delta^{18}$O at 130 cm could be due to shallowing and increased temperatures or, as possibly suggested by the carbon isotope data, a return to a pond with greater throughput. Shoreline ingrowth could be responsible for this.

As indicated, the marl trends are not paralleled by the mollusc data which, instead show an enrichment expected in a shallowing and more evaporitic pond. This indicates that these molluscs lived in a more stagnant environment, possibly closer to shallow shorelines with abundant aquatic vegetation. The increase is rather continuous and the data available do not reveal any marked and abrupt changes.

(c) Carbon isotopic composition

The radiocarbon and $\delta^{13}$C contents of the deep marls substantiate the presence of significant amounts of detrital carbonate in these horizons. The autochthonous formation and deposition of carbonate dominates sedimentation only above 370 cm. Between 370 and 170 cm the $\delta^{13}$C values of the marl remain rather constant around an average value of $-3.9\%$. Above 160 cm they decrease and reach a low of $-6.2\%$ at about 110 cm.

The $\delta^{13}$C values for Valvata are very different. At 370 cm $\delta^{13}$C values are close to $-12\%$ and increase steadily to about $-7.5\%$ between 340 and about 170 cm. At 170 cm a break occurs and marl and molluscs both show a minor decrease in $\delta^{13}$C values.

Because none of the carbonates reach isotopic equilibrium with the atmosphere; the marl cannot be used for radiocarbon dating. Further, the large isotopic difference between molluscs and marl indicate that, at least in the early history of this pond, the mollusc habitat and loci of marl precipitation did not coincide. However, the rather high $\delta^{13}$C contents of the marl deposited until about 10,000 yr B.P. most
probably reflect formation in a shallow environment in which either exchange with the atmosphere took place or, less likely (Weber and LaRocque, 1964), where carbon dioxide was used by aquatic plants and algae for photosynthesis. The molluscs, instead, must have preferred areas of the pond in which the biogenic production of carbon dioxide was important as would be the case if organic matter provided the substratum of their habitat. A modern example for such a lake would be Little Lake near Cambridge, Ontario, described by Turner et al. (1983) where molluscs show significantly lower δ^{13}C contents than the associated modern or fossil marl.

Thus the Gage Street pond provided initially an environment in which the water was isotopically uniform. However, the δ^{13}C contents of marl and molluscs are so different that one must assume that marl deposition did not occur throughout the lake and that locally organic sediments accumulated whose decomposition provided the isotopically light carbon found in the molluscs. The difference between marls and molluscs decreases throughout the history of the pond and for samples collected above 130 cm the carbon reservoir was apparently uniform since "equilibrium" differences are observed. This agreement is not seen in the oxygen isotope data which suggests that the pond still maintained different micro-environments where one carbon source began to dominate. This could possibly be attributed to the eutrophication of the system in which biological processes (photosynthesis and organic matter decomposition) played a dominant role. It is also important to note, that the increasingly lower δ^{13}C contents in the marls above 170 cm indicate a significant change in the marl depositing environment. However, these changes are not immediately noticeable in the δ^{18}O values which suggest that initially only the carbon budget was affected. The decrease to values as low as −10‰ above 130 cm could then reflect a minor temperature effect. The final isotopic changes seen in the Gage Street pond are similar to those seen in many European lakes, where a minor, not well explained, decrease in δ^{13}C precedes the termination of marl deposition.

(d) Fossil insects from the Gage Street site

The paleoecology of the Gage Street site, including the insects has been well documented elsewhere (Schwert et al., 1985). This section is a summary of some of the findings which are pertinent to this paper. In Schwert et al. (1985) the insect zones were modified slightly to allow better comparison with the pollen zonal boundaries, and pollen zone G6 was subdivided into two insect zones (G6-A and G6-B).

Zone G8: 464–412 cm (ca. 12,600–12,300 yr B.P.). The insects from the bottom of the sequence are typical residents of the boreal forest, ranging north to treeline. The carabids are open ground species which occupy bare sand substrates with grasses but spruce-eating scolytids are present. The aquatic beetles are found typically in shallow, oligotrophic water bodies. There are no obligate tundra or tree-line species in the site, and representatives of other families are dominantly boreal in distribution. The mean July temperatures are estimated at between 15 and 17°C, and as in Morgan and Morgan (1980), the changes in plant sequences are suggested as colonization, rather than being climatically controlled.

Zone G7: 412–328 cm (ca. 12,300–10,700 yr B.P.). The insects from this zone are typical residents of the central and southern boreal forest of Ontario, and a number of species are common to the Nichols Brook site mentioned above. Aquatic species indicate an open water body at the base of the zone which was gradually becoming vegetated near the top, however, isolated elmids show that running water was present at certain times. At least three genera of chrysомelids which inhabit swampy pond margins are represented and this littoral habitat was occupied by representatives of many other families.
Zone G6-A: 328–175 cm (ca. 10,700–8600 yr B.P.). The southern boreal insect assemblages of the previous zone have been replaced by faunal components which are found in southern Ontario today. A coniferous forest which included *Pinus* extended to the edge of the site. Dytiscids (*Liodessus flavicollis*) and a bug (*Marragata hebroides*) in vast numbers testify to extensive algal mats at the pond margin, since both of these species are found on living and decaying filamentous algae in eutrophic waters today. The presence of other dytiscids, gyrinids, hydrophilids and haliplids suggest that open water was also present away from the stagnant margins. Elmids and the dryopid, *Helichus striatus*, indicate some stream flow into, or through, the site. All of the insects in this zone are found in southern Ontario today, and the mean July temperature is postulated to be the same as that found in the area today (21°C).

Zone G6-B: 175–104 cm (ca. 8600–7900 yr B.P.). The open marsh indicated by the insects of Zone G6-A and the lower and middle portions of Zone G6-B, gradually disappeared near the top of Zone G6-B. Terrestrial beetles of many different families suggest moist forest-floor habitats, and scolytids indicate the continued presence of conifers which were dominated by pine. Schwert et al. (1985) point out that at least seven species have southernmost Ontario as the northern limit of their ranges today, and from this they infer mean July temperatures of ca. 22–23°C.

Zone G5: 104–53 cm (ca. 7900–6900 yr B.P.). The insects from Zone 5 are associated with matted moist debris and forest-floor habitats. The Gage Street section terminated with a swamp woodland moving over the depositional site. The presence of warm stenotherms suggests mean July temperatures possibly 2–4°C above those seen in the region today.

**Inglesby Lake**

Inglesby Lake is located 40 km northeast of Belleville, Ontario at the edge of the crystalline rocks of the Frontenac axis (Fig. 1); it is one of numerous marl-depositing lakes in the area. The calcium is largely derived from the dissolution of limestone fragments incorporated in local glacial and glacio-fluvial deposits. The shorelines are shallow marl banks which extend over half of the lake surface.

The Inglesby core site (44°29′N, 77°03′W, elev. 167 m; 548 ft) is located at the south end of the lake; Vreken (1981) obtained a core (Erinsville Station I) from the north end of the same lake. The core was obtained with a 3 cm diameter Hiller borer. The core length was 500 cm and consisting of 415 cm of marl overlying peat to a depth of 470 cm; the basal 30 cm is a dense lacustrine silt (Fig. 5).

Thermal analyses (Fig. 5) show that the marl consists of 80–90% CaCO₃ except for a calcareous gyttja at 30–60 cm. The peat has 60–80% organic matter, whereas the silt has a low carbonate content with virtually no organic carbon.

Three radiocarbon dates on organic matter and peat from the marl-peat transition at 400–420 cm depth indicate an age of approximately 9000 years BP the beginning of marl deposition (Table II). A minor hard water effect

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<td><strong>Radiocarbon dates from Inglesby Lake</strong></td>
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Fig. 4. Diagram from the Gage Street site showing $\delta^{18}O$ and $\delta^{13}C$ and most abundant pollen and spores. Zonation follows McAndrews (1981). Redrawn from Anderson (1982), pollen data modified from Schwert et al. (1985).

Fig. 5. Diagram for Inglesby Lake core showing $\delta^{18}O$ and $\delta^{13}C$, thermal analyses and fossil pollen. For miscellaneous pollen and spores see Table III.
is recognised by the marl date which is approximately 1000 years too old.

(a) Pollen analyses
The pollen diagram (Fig.5) displays three of the four standard assemblage zones for southern Ontario (McAndrews, 1981). Zone 1, confined to the lacustrine silt, is dominated by *Picea* with small but characteristic amounts of Cyperaceae and *Selaginella selaginoides*. Zone 2 is dominated by *Pinus* with small amounts of *Picea*, *Abies*, *Betula*, *Ostrya* and *Quercus*. Subzone 2a occurs in the peat and lower marl. It has over 50% *Pinus banksiana/resinosa* type whereas subzone 2b and zone 3 are dominated by *Pinus strobus*.

The peat has abundant *Myrica*, *Dryopteris* type and small peaks of *Sphagnum* and *Typha latifolia* together with three pollen grains of Ericales (Table III: see p. 202). This indicates a nutrient-rich bog which, due to rising water levels, was succeeded 9000 years ago by a marl-depositing pond. The lower boundary of zone 2 should date 10,000 yr B.P. and the upper boundary of this zone is inferred to be at 7200 yr B.P.

Zone 3 is marked by a relative abundance of mesic tree pollen, especially *Tsuga* and *Fagus*. Subzone 3b spans the *Tsuga* minimum of 5000–4000 yr B.P. The calcareous gyttja at 25–60 cm has peaks of Cyperaceae, *Sparganium* type and *Typha latifolia*, indicating a period of shallow marsh. Zone 4 of the Ontario pollen record, characterized by *Ambrosia* and *Gramineae*, is absent from the Inglesby section because the sediment was too watery to core.

Pollen density varies with lithology and is lowest in the silt and highest in the peat and marl; calcareous gyttja has intermediate values.

(b) Oxygen isotopic compositions

δ18O values in the carbonate display two zones, 415–215 cm and 215–0 cm (two data points obtained on the carbonate in the silt at about 480 cm are not considered because this carbonate has a detrital origin).

Between 415–215 cm the isotope curve is variable but with an average value of −6.2‰; a minimum of −5.4‰ occurs at 275–265 cm. Above 215 cm the isotope curve is more complacent despite the fact that sampling density has been maintained. The average δ18O value of this section is about −7.1‰ and is thus 0.9‰ lower than the average value of the lower zone. The lowest values (−7.4‰) are at 125 cm.

The older marl in this section is about 5‰ richer in δ18O than the time-equivalent deposit from Nichols Brook and about 3.5‰ richer than the Gage Street marl. This is certainly a reflection of differing hydraulic regimes where Inglesby Lake is more evaporitic than the other two. Assuming then that the difference in δ18O between the two zones is primarily evaporation controlled, one can distinguish between an older, warmer or dryer period and a younger, cooler or more humid period. The transition lies close to the first *Tsuga* maximum (ca. 215 cm), but it is not clear whether the two are related, although, similar observations were made by Turner et al. (1983) on samples from Little Lake near Cambridge, Ontario. A decrease in δ18O during this general time span was also recorded by Stuiver (1970) for Pretty Lake, Indiana.

An important observation is that today the average isotopic composition of Inglesby Lake is approximately 5‰ higher than for the average annual precipitation. As discussed this difference is due to evaporation effects that reflect climatic and hydraulic regimes. Because the oxygen isotopic composition of Inglesby Lake sediment is relatively constant for the upper 2 m of marl, it is safe to assume also that the evaporation effects were constant during this time.

(c) Carbon isotopic composition

The basal lacustrine clay contains a minor amount of carbonate (Fig.5) which almost certainly has a detrital origin. The isotope data support this because both oxygen and carbon isotope contents agree with compositions known for Paleozoic carbonates in Ontario (Miles et al., 1984).

The δ13C composition of the marl is rather constant between 415 and 135 cm and averages
dioxide or bicarbonate during photosynthesis does not appear to be important for the carbon isotope budget of these deposits. Thus, the differences in $^{13}$C between the three localities are much more pronounced than differences in $^{18}$O contents, with Inglesby Lake marls being deposited in or close to equilibrium with atmospheric carbon dioxide and Gage Street showing the lowest $\delta^{13}$C values.

A comparison of mollusc and marl data does permit an assessment of the attainment of isotopic equilibrium with the atmosphere and thus the suitability of marl for radiocarbon dating.

Acknowledgements

The Inglesby Lake core site was made accessible through the courtesy of Mr. G. Benn, the owner of the property. The work was partly supported by NSERC grants A7954 to PF, a Team Grant (A8294) to AVM and AM, and A5699 to JHM.

This is Quaternary Entomology Laboratory Contribution no. 80.

References


Ruddiman, W. F. and McIntyre, A., 1981. The mode and
Stuiver, M., 1968. \( \delta^{18} \)O content of precipitation during the last 11K years in the Great Lakes Region. Science, 162: 984–997.

**Note added in proof**

**TABLE III**

Miscellaneous pollen and spores from Inglesby Lake

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</table>

\(^a\) = Larix, 2 = Cupressaceae, 3 = Juglans, 4 = Caryya, 5 = Populus, 6 = Ericales, 7 = Tubuliflorae p.p., 8 = Chenopodiineae, 9 = Botrychium, 10 = Lycopodium, 11 = Osmunda, 12 = Indeterminable, 13 = Unknown.