Géographie physique et Quaternaire

Evidence for Stagnation of the Harvard Sublobe (Lake Michigan Lobe) in Northeastern Illinois, U.S.A., from 24 000 to 17 600 BP and Subsequent Tundra-Like Ice-Marginal Paleoenvironments from 17 600 to 15 700 BP

Indices de la stagnation du sous-lobe glaciaire de Harvard (lobe du lac Michigan) dans le Nord-Est de l’Illinois, États-Unis, de 24 000 à 17 600 BP et paléoenvironnements des toundras marginales entre 17 600 et 15 700 BP

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Résumé de l'article
Les sédiments glaciaires associés au sous-lobe de Harvard, dans le Nord-Est de l’Illinois, sont intercalés dans des sédiments dont la matière organique peut être datée. Des fragments de Picea sp. sont présents dans les couches sous-jacentes et remontent au plus à 24 000 ± 270 BP. La matière organique sus-jacente est disséminée dans les limons laminés et les sables fins de dépôts de lacs de barrage glaciaire perchés. Cette matière organique livre des âges 14C qui sont de 2500 à 1300 ans plus vieux que la matière organique de la base des sédiments des marmites glaciaires (kettles). Les âges 14C de quatre sites perchés vont de 17 610 ± 270 à 16 120 ± 80 BP. Notre révision du diagramme distance-temps du sous-lobe de Harvard traduit l'existence d'une période de stagnation glaciaire entre 24 000 et 17 600 BP. Le limon lacustre sus-jacent contient des assemblages macrofossiles de toundra, avec Salix herbacea et Dryas integrifolia. Ces plantes croissaient dans des milieux proches des glaces. Le contexte géomorphologique et l'écologie des ostracodes (Cytherissa lacustris et Limnocythere friabilis) indiquent que certains lacs supraglaciaires étaient étayés par plus de 17 m de glace.
ABSTRACT Glacial deposits of the last glaciation associated with the Harvard sublobe (Lake Michigan lobe) in northeastern Illinois, U.S.A., occur between sediment with dateable organics. The lower organics include fragments of *Picea* sp. as young as 24 000 ± 270 BP. The supraglacial organics occur sparsely in laminated silt and fine sand in landforms that are positioned relatively high on the landscape, such as deposits from ice-walled lakes. These terrestrial organics yield ages that are 2500 to 1300 14C years older than organics at the base of sediment successions in nearby kettle basins. Basal 14C ages from four upland sites range from 17 610 ± 270 to 16 120 ± 80 BP. Our revised time-distance diagram of the Harvard sublobe now reflects a period of stagnation from 24 000 to about 17 600 BP. The supraglacial lacustrine silt yielded plant macrofossil assemblages of primarily tundra plants, including *Salix herbacea* and *Dryas integrifolia*. These plants likely grew in supraglacial and ice-marginal environments. The ostracode fauna include *Cytherissa lacustris* and *Limnocythere frivaldii*. Geomorphic relations and ostracode ecology indicate that more than 17 m of ice buttressed some of the supraglacial lakes.

ÉVIDENCE DE STAGNATION POUR LE SOUS-LOBE DE HARVARD (LOBE DU LAC MICHIGAN) DANS LE NORD-EST DE L’ILLINOIS, ÉTATS-UNIS, DE 24 000 À 17 600 BP ET ENVIRONNEMENTS TUNDRA-LIKE ICE-MARGINAL PALEOENVIRONMENTS DE 17 600 À 15 700 BP

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INTRODUCTION

The advance and retreat of the southern margin of the Laurentide Ice Sheet has been attributed to either climatic forcing factors associated with long-term ENSO cyclicity of about 800 years (Wang et al., 2000, 2003) or to internal glacial mechanisms (Mickelson et al., 1983; Dyke and Prest, 1987; Lowell et al., 1999). Testing hypotheses such as these requires well-dated deposits associated with both glacier advances and retreats. Pollen diagrams, used to illustrate dynamic ice margins, are often hampered by a few unverified, and in some cases, unreliable radiocarbon ages, especially those obtained from bulk lake sediments (Grimm and Maher, 2002). Inaccuracies will eventually be resolved as key sites are dated by newer techniques such as accelerator mass spectrometry (AMS).

Terrestrial plant and faunal remains are present in deglacial sediments in northeastern Illinois. The aim of this investigation is to describe the sedimentary successions in these settings, describe the flora and fauna, and discuss the significance of the inferred palaeoenvironments. The reconstructions indicate that the Harvard sublobe of the Lake Michigan lobe stagnated from about 24 000 to 17 600 BP. Probably the most significant feature of this research is the discovery of terrestrial materials in material not previously known to yield reliable radiocarbon ages, and the potential to more accurately date deglacial successions.

The sites described herein were discovered during mapping of surficial glacial deposits in the urban areas west of Chicago, Illinois (Curry et al., 2001; Grimley and Curry, 2001; Curry, 2005, in review). Most of these sites have been subsequently obliterated by land development and reclamation.

THE LAST GLACIATION IN NORTHEASTERN ILLINOIS

During the last glaciation in northeastern Illinois (the Michigan Subepisode of the Wisconsin Episode), the Lake Michigan lobe was comprised of the Harvard, Princeton, and Joliet sublobes (Fig. 1A; Willman and Frye, 1970). During the Marengo Phase of Hansel and Johnson (1996), the Harvard sublobe formed the Burlington and Marengo Moraines (Fig. 2A). Later, flow of the active portion of the southern Lake Michigan lobe was diverted west by interaction with the Huron-Erie lobe (Fig. 2A). The Princeton sublobe formed the Gilberts drift (Fig. 2C) although its continuity with the aforementioned moraines associated with the Livingston Phase was obliterated by fluvial erosion during the subsequent Woodstock Phase.

During the Woodstock Phase, the Harvard and Joliet sublobes formed the Woodstock Moraine and basal portion of the West Chicago Moraine, respectively (Fig. 2D). The Woodstock Moraine is incised by a relatively steep-walled channel eroded by the Fox River, the primary drainage in the eastern half of the study area. Downstream of this breach are several large point bars and an abandoned oxbow-like channel formed by initial erosion of the Woodstock Moraine and subsequent aggradation in the Fox River valley. These features were attributed to the Fox River Torrent by Alden (1994) and Curry (2005) and possibly formed at about the same time as the Kankakee Torrent described by Ekblaw and Atty (1925), Brete (1940) and Willman and Payne (1942). Deposition that may be associated with the Kankakee/Fox River torrents have been radiocarbon dated at about 16 000 to 15 600 BP (Hajc and Johnson, 1989; Hansel and Johnson, 1996). The last glaciation (Michigan Subepisode) in Illinois ended with the Crown Point Phase (not shown) and formation of the Valparaiso, Tinley, and Lake Border Moraines. Ice finally retreated from Illinois by about 14 000 BP (Hansel and Johnson, 1992).

SITES AND METHODS

Radiocarbon ages of materials collected from our sites and other sites in northeastern Illinois are listed in Table I. Uncalibrated 14C ages are used for discussion purposes; the calibrated values are also given in Table I. Plant macrofossils, ostracodes, and pelecypods were systematically analyzed from monoliths sampled at the Fox River Stone Company (FRSC) and Prairie Hill (PP) sites. Unless otherwise noted, the other sites were cored. Sediment sample volumes of 500 cm³ were sieved for plant macrofossils and insects (nested screens with 425 and 212 μm mesh openings). Pollen samples (1 cm³) were also collected, but poor condition and low concentration of pollen grains resulted in only a representative subsample being analyzed.

Standard procedures were used for the analysis of plant macrofossils (Birks, 1980) and pollen (Faegri and Iversen, 1975). Plant macrofossils were identified with the aid of a collection of seeds, fruits, leaves and other plant organs from modern plants. Species represented in this collection include all those which today inhabit arctic, subarctic, boreal forest, deciduous parkland, and grassland environments. Plant taxonomy and habitat information are based on Welsh (1974), Edlund (1986), Gleason and Conquest (1991), and Aiken et al. (2003).

Samples that were sieved for ostracodes and 14C-dateable material were pretreated following Forster (1988). Ostracodes were identified by referring to Delorme (1970a, 1970b, 1971). Pelecypod shells were also picked and identified.

1. The Burlington moraine is the informal name given to an arcuate ridge in northeastern DeKalb and northeastern Kane County. The moraine is formed of the Tiskilwa Formation, and was previously mapped as part of the Elburn Complex by Willman and Frye (1970). The village of Burlington is located near the centre of the moraine.
GLACIAL SEDIMENT SUCCESSION

OLDER ORGANICS
Throughout northeastern Illinois, proglacial lake sediment, outwash, and loess of the last glaciation overlie an organic-rich silt loam to silty loam diamicton known as the Robein Member of the Roxana Silt (Fig. 3). The unit is leached of carbonate minerals and weathered, and is the upper part of the Farmdale Soil, which is typically welded to the Sangamon Soil developed in glacial sediment of the Glasford Formation (Curry, 1989; Curry and Pavich, 1996; Curry et al., 1999). At sites 13, 14, and 15 in northeastern Illinois (Fig. 2A; Table I), tree trunks in growth position and other wood fragments in silt of eolian or lacustrine origin yield ages as young as 23,320 to 24,000 BP (Table I). This age, which marks the end of the Athens Subepisode (a period of primarily loess deposition) and the beginning of the Michigan Subepisode (the last period of glacier activity in northeastern Illinois), is about 1000 14C years younger than what is reported in Hansel and Johnson (1996: Fig. 10). In some places these sediments yield valves of the ostracodes Limnocythere friabilis and Cytherissa lacustris. Fossil plants from these deposits are locally abundant (especially at the Feltes site) (Curry et al., 1999), but have not been identified.

SEDIMENT SUCCESSION OF THE LAST GLACIATION IN NORTHEASTERN ILLINOIS
Hansel and Johnson (1996) subdivided the glacial succession deposited by the Lake Michigan lobe into two groups. The Wedron Group includes three formations with several members comprised of glaciogenic diamicton (typically fl) that intertongue with layers of sorted sediment (typically outwash and lake sediment) of the Mason Group, including the aforementioned Roxana Silt (Fig. 3; Hansel and Johnson, 1996; Curry et al., 1999).

OLDER ORGANICS
Supraglacial deposits of fossiliferous, bedded silts and fine sand classified as the Equality Formation occur throughout northeastern Illinois. Here, we describe the stratigraphy and environment of deposition of sediment successions at five main sites with radiocarbon ages (Fig. 4), and provide a brief overview of key additional sites in the region with radiocarbon ages.

Hampshire Quadrangle Ice-Walled Lake Deposits
Several core samples from the Hampshire Quadrangle (Curry, in review) indicate that most, if not all, of the circular to subcircular features known as the De Kalb mounds (Flemal et al., 1973) are sediment that were deposited in ice-walled lakes (Iannicelli, 2003; Konen et al., 2005). The genesis of these landforms had been attributed to the disintegration of pingos (Flemal et al., 1973), but new evidence including abundant deep-water ostracodes (described below) and geomorphic associations indicate that some of the deposits were in contact with as much as 17 m of glacial ice (Konen et al., 2005). The loess-mantled ice-walled lake sediment successions include discontinuous layers of sand and gravel that lie between fossiliferous, rhythmically bedded silts and very fine sand (Fig. 4; Curry, in review). Flemal et al. (1973) limited their occurrence in the region to low-lying areas between the
Bloomington Morainic System and the Shabonna Moraine (Fig. 2A-B), but they are probably present on the gently sloping up-ice slopes of most of the moraines.

Fox River Stone Company Site (FRSC)

Exposures along a quarry wall revealed a succession of clayey glacial diamicton and fossiliferous lake sediment mantled by layers of sand and gravel (Fig. 4). The rhythmically bedded lacustrine silt and very fine sand contained abundant plant macrofossils, ostracodes, and fingernail clams. The site was near the crest of the St. Charles Moraine (Fig. 2C) which is formed of the Yorkville Member of the Lemont Formation. The surficial sand and gravel is associated with an outwash fan-delta that was built westward from the Minooka Moraine (Curry et al., 1999).

Prairie Pit #94 Site

An exposure in a quarry just northeast of the Fox River Stone Company revealed a succession of rhythmically bedded silt to medium sand (Fig. 4). The fossiliferous lake sediment is present above silty clay diamicton of the

FIGURE 2. Location of study sites and features noted in text. (A) Landforms associated with the Marengo Phase and sites with pre-glacial organics and the supra-glacial ice-walled lake site (H-3). (B) Landforms associated with the Putnam Phase (black lines) and features identified in Figure 2A (white lines). The Fox River valley is shown, although it was eroded primarily during the Woodstock Phase. (C) Landforms associated with the Livingston Phase (black lines) and older features (white lines). The sites occur on diamicton of the Yorkville Member, Lemont Formation. (D) Landforms associated with the Woodstock Phase (black lines) and older features (white lines). The sites occur on outwash associated with the Haeger Member except for the Randall Road and Sleepy Hollow sites which are associated with aggradation after the Fox River Torrent.
EVIDENCE FOR STAGNATION OF THE HARVARD SUBLOBE (LAKE MICHIGAN LOBE)

TABLE I

<table>
<thead>
<tr>
<th>Site no.</th>
<th>Lab number</th>
<th>14C age</th>
<th>1σ</th>
<th>2σ</th>
<th>Material assayed</th>
<th>Depth (m)</th>
<th>Stratigraphic association</th>
<th>Calibrated age</th>
<th>1σ</th>
<th>Upper</th>
<th>Lower</th>
</tr>
</thead>
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<td>1</td>
<td>ISGS-5865</td>
<td>14 130</td>
<td>70</td>
<td>25.1</td>
<td>wood</td>
<td>22.7</td>
<td>Equality Fm (silt)</td>
<td>16 850</td>
<td>N.A.</td>
<td>16 647</td>
<td>17 063</td>
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<td>2</td>
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<td>60</td>
<td>N.D.</td>
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<td>16 317</td>
<td>16 726</td>
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<tr>
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<td>22.4</td>
<td>Haeger Mbr.</td>
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<td>N.A.</td>
<td>15 838</td>
<td>16 331</td>
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<td>1.0</td>
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<td>70</td>
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<td>above</td>
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<td>15 558</td>
<td>15 948</td>
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<td>40</td>
<td>N.D.</td>
<td>needles</td>
<td>15.3</td>
<td>Batelast Mbr.</td>
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<td>N.A.</td>
<td>16 467</td>
<td>16 860</td>
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<td>90</td>
<td>-25.5</td>
<td>needles</td>
<td>6.9</td>
<td>above Haeger Mbr.,</td>
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<td>N.A.</td>
<td>15 802</td>
<td>16 236</td>
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<td>110</td>
<td>-27.7</td>
<td>Pseudotsuga</td>
<td>7.8</td>
<td>Woodloch</td>
<td>17 630</td>
<td>N.A.</td>
<td>17 444</td>
<td>17 941</td>
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<tr>
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<td>-26.4</td>
<td>flower bract</td>
<td>8.4</td>
<td>Moraine</td>
<td>18 150</td>
<td>N.A.</td>
<td>17 949</td>
<td>18 232</td>
</tr>
<tr>
<td>10</td>
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<td>150</td>
<td>N.D.</td>
<td>needle</td>
<td>15.1</td>
<td>above Yorkville Mbr.,</td>
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<td>N.A.</td>
<td>17 650</td>
<td>18 470</td>
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<td>1.3</td>
<td>St. Charles, Moraine</td>
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<td>N.A.</td>
<td>18 533</td>
<td>18 774</td>
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<td>170</td>
<td>-26.5</td>
<td>Dryas leaves</td>
<td>2.3</td>
<td>above Yorkville Mbr.,</td>
<td>18 950</td>
<td>N.A.</td>
<td>18 655</td>
<td>19 069</td>
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<td>Dryas leaves</td>
<td>3.0</td>
<td>Minooka, Moraine</td>
<td>19 690</td>
<td>N.A.</td>
<td>19 554</td>
<td>19 813</td>
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<td>130</td>
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<td>Salix leaves and seeds</td>
<td>4.0</td>
<td>above Yorkville Mbr.,</td>
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<td>N.A.</td>
<td>20 141</td>
<td>20 444</td>
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<tr>
<td>15</td>
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<td>130</td>
<td>-25.4</td>
<td>Dryas leaves</td>
<td>5.4</td>
<td>St. Charles, Moraine</td>
<td>20 700</td>
<td>N.A.</td>
<td>20 480</td>
<td>20 881</td>
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<td>80</td>
<td>-27.1</td>
<td>twigs</td>
<td>1</td>
<td>above Batelast Mbr.</td>
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<td>N.A.</td>
<td>18 931</td>
<td>19 093</td>
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<td>80</td>
<td>-26.8</td>
<td>Dryas leaves</td>
<td>1</td>
<td>above Yorkville Mbr.,</td>
<td>19 300</td>
<td>N.A.</td>
<td>19 833</td>
<td>20 033</td>
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<tr>
<td>18</td>
<td>Oxa-W-9172-13</td>
<td>16 770</td>
<td>90</td>
<td>-27.0</td>
<td>Salix and Dryas leaves</td>
<td>3.4</td>
<td>above Tikilewa</td>
<td>19 930</td>
<td>N.A.</td>
<td>19 207</td>
<td>19 426</td>
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<td>19</td>
<td>Oxa-W-9172-9</td>
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<td>270</td>
<td>-28.2</td>
<td>Vaccinium leaves</td>
<td>4.3</td>
<td>Formation</td>
<td>20 810</td>
<td>N.A.</td>
<td>20 430</td>
<td>21 144</td>
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<td>ISGS-3021</td>
<td>23 230</td>
<td>550</td>
<td>fine, unidentified organics</td>
<td>7.0</td>
<td>above Tikilewa Formation</td>
<td>28 080</td>
<td>770</td>
<td></td>
<td></td>
<td></td>
</tr>
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N.D. = not determined; N.A. = not applicable

Sites:
(1) Mastodon Lake, Phillips Park, Aurora, NW NW Section 35, T. 38 N., R. 8 E.; (2) Brewer Creek, Excavation pit near boring BC-1, Section 6, T. 40 N., R. 9 E. (Curry et al., in prep.); (3) Crystal Lake, NW Section 6, T. 40 N., R. 8 E.; (4) Sleepy Hollow meander scar, NW NW Section 29, T. 42 N., R. 8 E.; (5) Bridge boring, Randall Road over Tyler Creek, NW Sect, 9, T. 42 N., R. 8 E.; (6) Nancy Drive, Crystal Lake, SE Section 3, T. 43 N., R. 8 E.; (7) Nelson Lake, NE Section 29, T. 39 N., R. 7 E.; (8) NEU-123, NE SW Section 22, T. 39 N., R. 8 E. (Spranger and Flemal, 1981); (9) Prairie Pit #94, NW Section 2E, T. 41 N., R. 8 E. (Curry et al., 1999); (10) Fox River Stone Company, NW Section 4, T. 40 N., R. 8 E. (Curry et al., 1999); (11) Sleepy Hollow substation flood retention pond, SW Section 1, T. 40 N., R. 8 E. (12) Remodelled lake deposit, S. 1/2 Section 34, T. 40 N., R. 8 E. (13) Weldon substation (temporary exposure at retention pond); NE Section 12, T. 42 N., R. 7 E.; (14) BuR City mine portal, NE SE Section 30, T. 41 N., R. 7 E. (15) Felix sand and gravel pit, NE Section 19, T. 39 N., R. 7 E. (Curry et al., 1999)

Radiocarbon ages >21,000 BP were calibrated using CALPAL (http://calpal.qub.ac.uk/calpal.html); a sigma-one value is given

Radiocarbon ages <21,000 BP were calibrated using CALIB5 (http://calib.qub.ac.uk/calib.html)

The site is located in a hydrologically closed kettle depression with about 8 m of relief (Figs. 2C, 4). A core from the site includes about 2.3 m of fossiliferous lacustrine silt and silty clay intercalated with thin beds of sandy loam diamicton. The fossiliferous sediment overlies sand and gravel as well as sandy, boulder diamict of the Haeger Member. The plant macrofossils from this site were analyzed for 14C dating prior to identification.

The primary difference between the sites is the diamicton was that of the Batestown Member (Lemont Formation). The site is located on an eroded portion of the Bartina Moraine (Curry, 2005).
Randall Road bridge over Tyler Creek

A core from this site revealed a thick succession of fossiliferous slackwater lake sediment (>15 m) in a valley tributary to the Fox River (Fig. 2D). Analysis of the core indicates that the sediment accumulation rate was very high with the two dated intervals separated by approximately 700 years and 9.3 metres of sediment. The fossiliferous lake sediment is present above the Batestown Member.

Sleepy Hollow meander channel

A sediment core from along the channel of a prominent abandoned meander channel revealed thin, fossiliferous lake sediment at a depth of about 1 m, lying above pebbly outwash (Fig. 2D). The radiocarbon ages from this and the Randall Road bridge site (Table I) provide minimum ages for aggradation of outwash in the Fox River valley following the Fox River Torrent.

Nelson Lake and Crystal Lake, Brewster Creek, and Mastodon Lake

Each site occurs in a kettle basin (Fig. 2C-D). Nelson Lake and Mastodon Lake occur on the flanks of the St. Charles and Minooka moraines, respectively. Crystal Lake and the Brewster Creek site are located on outwash plains associated with the Woodstock Moraine. The radiocarbon ages obtained from fossils in sediments associated with aforementioned ice-marginal environments are from about 1000 to 2750 14C years older than fossils from the kettle sites (Table II).

FOSSILS

PLANT MACROFOSSILS

The plant macrofossils from all the sampled sites are well preserved though some leaves have fungal deterioration. A representative selection of these macrofossils is illustrated in Figure 5. In contrast, most of the pollen is extremely degraded (mainly crumpled) and found in low numbers, except for certain samples collected from the PP #94 site where some grains are recognizable and in good condition. The poor pollen recovery precludes quantitative analysis and these data are merely described in the text.

The plant macrofossil assemblages of both the FRSC and PP #94 sites are very similar (Fig. 6) and are considered here as one flora. Plant macrofossils of the primary taxa, described below, were also identified from the sites shown on Fig. 4, with the exception of the Nancy Drive site (where the fossils were not studied).

Arctic Tundra Plants

The most abundant macrofossils are leaves of *Dryas integrifolia* (Arctic dryad, white dryad and Arctic avens) (Fig. 5A), *Vaccinium uligonosum* spp. alpinium (bog bilberry or arctic blueberry) (Fig. 5C), and *Salix herbacea* (snowbed willow, herb-like willow and dwarf willow). Floral bracts of the latter are shown in Figure 5B. All three species are prostrate dwarf shrubs that form creeping mats. These taxa today inhabit gravelly outwash, wet meadows, and scree slopes in the Arctic (north of 55° N) and in alpine tundra habitats. The range of *Vaccinium uligonosum* spp. alpinium extends further south than the other two species into the boreal forest. All three taxa can tolerate both wet and dry soil conditions, but their requirements for soil chemistry differ. *Dryas integrifolia* and *Salix herbacea* prefer neutral or alkaline soils, whereas *Vaccinium uligonosum* spp. alpinium favours acidic soils.

Leaf fragments tentatively identified as those of *Rhododendron lapponicum* (Lapland rosebay) were only recovered from the FRSC site. This evergreen dwarf shrub has a similar ecology (including soil preference) and geographic range as...
Vaccinium uligonosum spp. alpinum. Both of these species can not tolerate dense shade, but are found more commonly in open areas or under partial shade in open woodlands.

Several taxa of arctic herbs were identified from macrofossils. Seeds of a member of Rosaceae (rose family) (Fig. 5D), tentatively identified as Sibbaldia procumbens (sibbaldia) are rare. Like the dwarf shrubs, this ground-hugging perennial herb requires a moist, gravelly soil, and is distributed today across the low (southern) Arctic.

A few calyces of Armeria maritima (sea thrift and sea pink) were also recovered (Fig. 5E). This species is a perennial cushion plant with pink flowers and long, narrow fleshy evergreen leaves (not found as fossils). Armeria maritima exists today in dry sand and gravel, such as found along the coast of oceans and lake shores, and on river terraces. This species is not found under heavy shade.

Seeds of Silene (Fig. 5F), tentatively identified as Silene acaulis (moss campion), are common in the FRSC and PP #94 samples. This is a perennial cushion plant with a woody taproot that forms an extensive moss-like carpet. It colonizes well-drained sandy gravelly and till soils, and inhabits river terraces and shorelines, barrens, and slopes. Silene acaulis has a circumpolar and circumboreal distribution and is found in alpine habitats as far south as New Hampshire. Also identified were other species which have modern distributions in both the low arctic and boreal forest. An achene of Ranunculus cf. aquatilis (white water-crowfoot and white water-buttercup) (Fig. 5H) was recovered just at the PP #94 site. This annual or perennial plant requires moist or wet soil and can grow in shallow water (<1 m deep), hence it is found today along the edges of streams, ponds and lakes. Although Ranunculus aquatilis is fairly common in Arctic lakes and ponds, it may be occasionally found as far south as the Midwest U.S.A. and New England.

A few drupes of Potamogeton filiformis (slender-leaved pondweed, and filiform pondweed) were found. This species inhabits still or flowing eutrophic fresh water in streams, lakes, and ponds in water depths up to 1 m. It is the only species of...
Youth (PP #94) site only. One needle of black spruce, were recovered in low abundance from the West and Pettit, 2000). Recovered from both sites were pondweed found in the Canadian Arctic Archipelago today (white spruce), pegs (for attachment of leaves) identified (Birks, 1980; Gajewski found (Fig. 5I) as were several stem fragments with woody plants being poor pollen producers, since many are insect-pol- lination. A seed of a boreal forest-type plant, variety of habitats and have primarily a circumboreal distribu- tion. A species of Caryophyllaceae (pink/chickweed family), pollen grains within sediment pores (Cushing, 1967; Hall, 1981).

**POLLEN**
Most of the samples contain few pollen grains that are extremely degraded (particularly crumpled), especially from the FRSC site. Even samples of black lamiaceae from the PP #94 section contained pollen too degraded for quantitative analy- sis. Maher et al. (1998), Baker et al. (1999) and Heusser et al. (2002) all reported preservation of pollen of full-glacial age in some sediment samples, but not in others, even though they were all collected from the same moraines. Observations for poor pollen recovery in these sites include: pollen concentra- tions being diluted during times of rapid loess deposition and other glaciogenic sediment (e.g. Heusser et al., 2002); tundra plants being poor pollen producers, since many are insect-poli- liminated (Birks, 1980; Gajewski et al., 1995); and oxidation of pollen grains within sediment pores (Cushing, 1967; Hall, 1981).

Pollen grains of a few taxa, those of Picea glauca-type (white spruce), Abies (fir), and Ambrosia-type (reaped), are moderately well preserved. But only those of spruce are com- mon, suggesting that spruce, probably Picea glauca, was present somewhere in the region during this time. Considering the low pollen counts of this taxa per microscope slide, it is doubtful that white spruce existed in the local area. Abies prob- ably also existed in the region (though not in the immediate area), since experimental studies of modern pollen deterio- ration in soils indicate that grains of this taxon deteriorate read- ily after deposition (Hall, 1981).

**OSTRACODES**
Ostracodes were recovered from most sites described above except for the Nancy Drive and PP #94 sites. Their absence from these sites may be attributed to the low total dissolved solid content of the host water in tandem with slow sediment accumulation rates. Alternatively, methanogenesis may be invoked as a cause for shell dissolution (Jones et al., 1982; Curty et al., 1997a). 

Limnocythere friabilis (Fig. 7A, D) was the most abundant ostracode identified in the ice-marginal and supraglacial lake sediment. This species is among the smallest in North America (Delorme, 1971) with the average valve length reach- ing about 55 µm. Only females were observed, suggesting that in these extreme ice-marginal environments the species reproduced via parthenogenesis. Only three of more than 5 500 modern freshwater aquatic sites in Canada yielded Limnocythere friabilis (Denis Delorme, personal communica- tion). The species is also present in Lake Michigan at water depths between 30 and 75 m (Buckley, 1975), and in Lake Erie at depths below about 15 m (Benson and MacDonald, 1963). Limnocythere friabilis is also abundant in Pleistocene lake sediments of Lake Michigan (Staplin, 1963; Forester et al., 1994) and early postglacial kettle successions in Illinois such as the one described at Nielson Lake (Curry, 2003).

Cytherissa lacustris (Fig. 7B, E) was also abundant, particu- larly in the ice-walled lake deposits. This species prefers living in relatively dilute water ranging in total dissolved solids from about 10 to 250 mg/L (Delorme, 1978, 1989). Cytherissa lacus- tris is found commonly throughout Canada in waters greater than 3 m depth surrounded by boreal vegetation. Its upper tem- perature tolerance is about 23 °C. Like Limnocythere friabilis, Cytherissa lacustris is found in the profundal zone of the mod- ern Great Lakes at water depths ranging from 15 to 45 m (Benson and MacDonald, 1963; Buckley, 1975, Delorme, 1978).

### TABLE II

| Ice-marginal site | Site                                      | Basal date, large kettles | Underlying lithostratigraphic unit (associated moraine) | Difference in Age
<table>
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<tbody>
<tr>
<td>14 860 ± 110</td>
<td>Nancy Drive</td>
<td>Crystal Lake</td>
<td>Haeger Member</td>
<td>1330</td>
</tr>
<tr>
<td>13 530 ± 130</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 870 ± 90</td>
<td>Breezler Creek</td>
<td></td>
<td>Haeger Member (Woodstock Moraine)</td>
<td>900</td>
</tr>
<tr>
<td>17 540 ± 130</td>
<td>Fox River Stone</td>
<td>14 780 ± 150</td>
<td>Yorkville Member (St. Charles Moraine)</td>
<td>2760</td>
</tr>
<tr>
<td>16 540 ± 120</td>
<td>Prairie PI #94</td>
<td>14 130 ± 70</td>
<td>Yorkville Member (Mincotta Moraine)</td>
<td>2410</td>
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</table>

<table>
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<th>Site</th>
<th>130 ± 110</th>
<th>80 ± 70</th>
<th>Nancy Drive</th>
<th>Crystal Lake</th>
<th>Haeger Member</th>
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<td>Difference in Age</td>
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EVIDENCE FOR STAGNATION OF THE HARVARD SUBLOBE (LAKE MICHIGAN LOBE)  

**Figures 5.** Scanning Electron Microscope (SEM) micrographs of selected plant macrofossils. Note the reference scales (white line) are of various lengths.

- A) *Dryas integrifolia*
- B) *Salix herbacea*
- C) *Vaccinium uligonosum spp. alpinium*
- D) *Sibbaldia procumbens*
- E) *Armeria maritima*
- F) *Silene cf. S. acaulis*
- G) *cf. Cardamine bulbosa*
- H) *Ranunculus cf. R. aquatilis*
- I) *Picea mariana*
Limnocythere herrickii (Fig. 7C, F, I) is present in freshwater lakes located in the northern boreal forest and tundra of northeastern Canada north of 65° N latitude. This species is tolerant of high salinity, but it cannot tolerate sustained temperatures above 15°C (Forester et al., 1987a).

Candona rectangulata (Fig. 7H) is present in freshwater environments (Borror et al., 1989). Also recovered were cocoons of Turbellaria (flatworm), which today inhabit laminated lake sediments (Borror et al., 1989). Shells of Pisidium sp. (fingernail clams) also were found in certain stratigraphic positions and indicate sediment was deposited in relatively quiet water.

Other Invertebrates

Arthropod remains are uncommon and limited to two types. Thoracic segments of Caddisfly (Order Trichoptera) larvae were recovered. These larvae are known to live in cases on the underside of rocks in streams and along lake shores (Borror et al., 1989).

Discussion

Paleoenvironments of Northeastern Illinois

In the ice-walled lake environments studied in Illinois, plants grew on sandy and gravelly soils that developed directly on the glacial ice and were washed or collapsed into the lakes as the underlying ice melted. The slackwater lake and proglacial lake environments represented at the FRSC and PP #94 sites, respectively, contain many ostracodes and plant fossils common to the ice-walled lakes. Other environments, such as relatively ice-free outwash deposits or silty abandoned strand deposits, were likely available for colonizing by plants. Only a few taxa, such as Petalomesotritus formosus (slender-leaved pondweed) and possibly Ranunculus cf. aquatilis (white water-crowfoot), occupied the shallow water along the lakes. The absence of an aquatic-emergent flora and the limited suite of submerged aquatic plants suggest that the lakes were oligotrophic.
FIGURE 7: Scanning Electron Microscope (SEM) micrographs of selected ostracodes.

A) Limnocythere friabilis, female, left valve
B) Cytherissa lacustris, left valve
C) Limnocythere herricki, male, left valve
D) Limnocythere friabilis, female, right valve
E) Cytherissa lacustris, right valve
F) Limnocythere herricki, male, right valve
G) Heterocypris incongruens, female, left valve
H) Candona subtriangulata, female, right valve
I) Limnocythere herricki, male, right valve

Sélection de photographies d’ostracodes obtenues à partir d’un microscope électronique à balayage.
The abundance of Vaccinium uligonosum spp. alpinum and Salix herbacea (snowbed willow) leaves in the region may not just be attributed to the commonness of these dwarf shrubs, but also because they are deciduous. Leaves of Dryas integrifolia (Arctic dryad), in contrast, are evergreens and hence may be under-represented in the fossil record. These and most other species identified are found in recent fluvial deposits of the Canadian Arctic (West and Pettit, 2000). Thus, the deposition of modern plant remains is not spatially uniform and some species are over- or under-represented in the fossil record relative to their actual abundance (West and Pettit, 2000).

Ecological studies also reveal that both Salix herbacea and Dryas integrifolia are pioneers on stony and gravelly habitats, such as recently exposed river flats and lake shores, where they stabilize the substrate with long taproots and fix nitrogen via the ectomycorrhizal nodules attached to their roots. Dryas integrifolia can not endure competition from other plants for space, so its abundance at the study sites further substantiates our interpretation of a tundra-like environment. Dryas integrifolia is also commonly found today with Silene acaulis (moss campion), which is a perennial cushion plant that has been tentatively identified at our sites. Both of these taxa are reported in ecological studies to withstand open-tundra and drying alpine winds on mountain tops. Sibbaldia procumbens (sibbaldia) is another pioneer tentatively identified in our study. Today, this perennial herb is commonly found with Salix herbacea under snow patches that persist late into the Arctic summer.

We interpret the paleovegetation as “tundra-like” rather than “tundra”, because of the presence in the fossil assemblage of a few taxa which today have ranges south of the tree-line. Species which are found in the boreal forest and the Arctic today include Silene acaulis, Ranunculus cf. aquatilis (white water-crowfoot), and Potamogeton Willmorms (slender-leaved pondweed) (Porsild and Cody, 1980). The remainder of the flora, Picea mariana (black spruce), cf. Cardamine bubosa (spring cress), Saxifraga sp. (saxifrage), and Viola sp. (violets), are presently restricted to the boreal forest zone.

The rare occurrence of Picea mariana macrofossils, and absence of pollen of this taxon suggest that black spruce was probably a minor constituent of this flora. Moreover, these fossil silts were only recovered from the younger PP #94 site, suggesting that black spruce arrived in the study area after 16 500 BP. In addition to climate, the organic-poor soils, as indicated by the shrub and herb taxa, would also have limited the range of Picea mariana (black spruce) which requires richer soils. Also, Birks (1976) suggested that strong winds during the full-glacial may have been more effective than low temperatures in limiting tree growth. Black spruce probably grew on moist soils once summer temperatures warmed above the July 10 °C isotherm that today delineates tree-line (Pitcher and Harrison, 1993), and when high winds diminished. Even though well-preserved pollen grains of Picea glauca-type (white spruce) were recovered, the biased pollen assemblages, low pollen concentrations, and the absence of Picea glauca macrofossils suggest that white spruce was not present in the immediate area.

COMPARISON WITH OTHER COEVAL FOSSIL LOCALITIES

The ages assigned to many sites with tundra-like vegetation are probably inaccurate because the 14C chronologies are based on the dating of bulk organic sediment (gyttja and marl) (e.g. Baker, 1965; Birks, 1976). These sediments are now known to provide ages that are erroneously older by at least a millennium, because of the “hard-water effect” (MacDonald et al., 1991). For example, pollen and plant macrofossils from the Wolf Creek site in central Minnesota were interpreted as indicative of a full-glacial tundra environment from 20 000 to 14 000 BP (Birks, 1976). While the interpretations regarding paleovegetation are reasonable, the chronology is too old and predates the now accepted deglaciation chronology for this part of Minnesota. Our 14C chronology, based on terrestrial plant macrofossils, provides a more accurate determination of the timing of deglacial events and vegetation changes. With reference to other studies, we reject all ages derived from sediment and other aquatic materials and only report those obtained from terrestrial plant macrofossils.

Most researchers who interpret interstadial and late-glacial vegetation from pollen stress the importance of long-traveled...
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pollen in the records. McAndrews (1984) reported current deposition of deciduous tree pollen on a glacier in the Canadian Arctic and determined that these grains had traveled over 1 000 km. Birks (2003) stressed the importance of studying plant macrofossils when reconstructing interstadial and late-glacial vegetation and climate because of the problems of long-distance dispersal of pollen and over-representation of tree pollen in Arctic environments. Our results support this conclusion since we recovered Picea mariana needles of local origin, but pollen grains, tentatively identified as those of Picea glauca, were likely far-traveled. Similarly, pollen grains of Picea (spruce) and deciduous trees were found associated with “Arctic” macrofossils, such as Salix herbacea and Dryas integrifolia, at both Spider Creek (Baker, 1965), and Wolf Creek (Birks, 1976) in Minnesota, and at the Valders Quarry in Wisconsin (Maher et al., 1998). Likewise, they interpreted that the pollen grains were derived from distal sources. The nearest site comparable in age to ours is that of the Conklin Quarry in southeastern Iowa, which dates from 18 000 to 16 700 BP (Baker et al., 1986). The site is located 250 km west of the study area. The pollen assemblage is dominated by Picea (spruce), Pinus (pine), and Cyperaceae (sedge family) pollen and associated with macrofossils of spruce with those of dwarf shrubs and tundra herbs (Baker et al., 1986).
were already present in the immediate area. By the time active ice had retreated, white spruce trees (Picea glauca) (tamarack), and Poaceae (grass). A site in south-eastern Minnesota revealed that Arctic (e.g. Dryas integrifolia and Salix cf. herbacea) and subarctic vegetation existed on a treeless or nearly treeless landscape at about 18 700 BP (Baker et al., 1999). The pollen spectrum of this site included Picea (spruce), Pinus (pine), and Cyperaceae (sedge family), which was interpreted as allochthonous.

To the north of our study area, similar open-tundra vegetation was established in eastern Wisconsin (Valders Quarry) after the retreat of the Green Bay lobe at about 14 500 BP (Maher et al., 1998). Interestingly, the ostracode fauna are also nearly identical, with only the addition of the deep-water cryophyllic ostracode Candona subtriangulata. This is the only site from the southern Great Lakes region with a well-described interstadial ostracode fauna. At the Two Creeks site in northeastern Wisconsin, Kaiser (1994) indicated that the Two Creekian Interstadial persisted from 12 050 to 11 750 BP. During this time Picea mariana (black spruce) occupied the swampy soils along the shore of glacial Lake Chicago when the lake was at or just below the present level of Lake Michigan (Kaiser, 1994). These ages are comparable to the date of 12 050 BP obtained from Salix sp. (willow) stems, associated with several mosses and leaves of Dryas integrifolia and Salix herbacea, at the Cheboygan Bryophyte Bed in northern Lower Michigan (Larson et al., 1994).

Tundra localities outside the upper Midwest

Comparison of tundra-like fossil localities in eastern North America with those from the upper Midwest provide valuable insight into deglacial environmental conditions along the southern margin of the Laurentide Ice Sheet. No tundra-like fossil sites dating to the full- or late-glacial have yet been found on the northern Great Plains west of Wolf Creek, Minnesota. Yansa (2006) attributed this to the late deglaciation of this region; by the time active ice had retreated, white spruce trees were already present in the immediate area.

Tundra fossils have been reported at several sites in Ontario (e.g. Terasmae et al., 1966; Morgan and Morgan, 1979; Anderson, 1982; McAndrews and Jackson, 1988; Warner et al., 1988; Karrow, 1990), but most of these have poor chronologically control. One exception is Yu (2003) recent study of macrofossil assemblages from the base of cores from Crawford Lake and Tweed Marsh Pond in southern Ontario. He reported initial colonization by sparse tundra vegetation comprised of Alinus (alder), Dryas integrifolia, Salix herbacea, and Cyperaceae (sedge family) with some boreal plants at an estimated age of 13 000 BP (extrapolated down core from a date of 10 920 BP). By about 12 000 BP, the vegetation was dominated by Picea, suggesting that the oldest parts of the macrofossil records at these sites represent a transition from tundra (or tundra-like) vegetation to boreal forest.

Macrofossil analysis indicates that Dryas integrifolia, Salix sp. (willow) and Carex sp. (sedge) inhabited south-central Pennsylvania by 14 400 BP where they are assumed to be coeval with local periglacial features (Delano et al., 2002). In Quebec, New York, and New England there are scattered fossil localities bearing full-glacial and late-glacial assemblages of tundra plants with a minor component of boreal vegetation, such as Picea and/or Populus balsamifera (balsam poplar) (e.g. Argus and Davis, 1962; Miller and Thompson, 1979; Richard, 1979; Davis and Jacobson, 1985; Miller and Spear, 1999). Only about half of the taxa that we identified at our sites were also found at these eastern sites. This suggests that during the full-glacial and late-glacial a fairly uniform tundra-like flora existed within the upper Midwest and that it shared some characteristics with a coeval flora that existed in eastern North America. Dryas integrifolia, of note, is found at all of these sites, which agrees with Porsild (1947) that this species was common and widespread in postglacial time.

Revised time-distance diagram for the Harvard sublobe

Curry et al. (1997a) used a radiocarbon age from the Wedgewood site of 23 230 ± 550 BP (Fig. 2A; Table I) to document the interstadial Wedgewood Phase (Fig. 3A). The age was obtained on bulk, fine organics washed from a lacustrine deposit that was present above diamicton of the Tiskilwa Formation, and below outwash associated with the Haeger Member. The deposit also contained abundant Cyperus lacustris and Limnocharis triangulata. With the new AMS dates obtained from plant macrofossils from the ice-walled lake deposits, it seems likely that the age from the Wedgewood site is contaminated with old carbon.

The new radiocarbon ages suggest that the Harvard sublobe stagnated for about 4000 14C years. The onset of stagnation began at an unknown point (about 21 000 BP) when ice activity in Harvard sublobe stopped after formation of the Marengo Moraine (Fig. 3B). The Harvard sublobe was starved for new ice at this time because the direction of ice flow was diverted by interaction of the Lake Michigan lobe with the Huron-Erie lobe (Wickham et al., 1988). Ice activity in the Harvard sublobe resumed at about 18 000 BP when the St. Charles and possibly Barlina moraines began to form. The similarity in the basal ages of four sites with tundra plant macrofossils indicate that the Harvard sublobe melted fairly uniformly across an area comprising the Burlington Moraine, Marengo Moraine, Gilberts Drift, the eastern parts of the Shabonna, Arlington, and Mendota moraines, as well as the Elburn Complex and St. Charles Moraine. The age at the Fox River Stone Company of 17 540 ± 130 14C years suggests that the Harvard sublobe reactivated and the initial activity of

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the Joilet sublobe. The orientation of the southern part of the St. Charles Moraine (Fig. 2C) suggests its formation was influ-
enced by interaction with the Huron-Erie lobe. By contrast, the ori-
entation of the younger Minooka Moraine indicates that inter-
action between the Lake Michigan and Huron-Erie lobes had ceased.

The age of the large glaciofluvial landforms in the Fox River valley, and hence, the age of the Fox River Torrent during the
Milwaukee Phase, is limited by the age from the Nancy Drive
site on the Woodstock Moraine at about 14 900 BP and the
ages from the Sleepy Hollow subdivision and Prairie Pit #94
sites at about 15 700 BP. The Fox River Torrent may have occurred at about the same time as the Kankakee Torrent
(Willman and Payne, 1942).

CONCLUSIONS

From about 21 000 to 18 000 BP, the Harvard sublobe stagn-
ated in northeastern Illinois. In the latter stages of melting, slackwater and ice-walled lake environments preserved fossils
of tundra vegetation and lacustrine organisms. Such environ-
ments are ubiquitous in continentally-glaciated areas (Menzies
and Shilts, 1996). For example, there are more than 500 ice-
walled lake deposits in northeastern Illinois (the De Kalb
Mounds of Fremal et al., 1973), and each one examined so far
has yielded plant macrofossils. Younger fossiliferous ice-walled
lake deposits dating from the Younger Dryas occur in North
Dakota (Clayton, 1967; Tuftil et al., 1964). We hope that these
and the previous results encourage others to examine deglacial landforms in other areas not only for paleoecological reconstruc-
tions, but for their potential for unraveling deglacial histories.

The oldest ages marking the onset of deglaciation in north-
eastern Illinois are from terrestrial fossils preserved in the sed-
iment of ice-walled lakes and slackwater lakes. These deposits often occur in areas relatively high on the landscape. Prior to
this study, the oldest reliable deglacial ages came from fossils
preserved in the base of kettle successions. We have found
that such ages are from 1000 to 2500 14C years younger than
dated material from ice-walled lakes and slackwater lake deposits located on the same moraines or their outwash plains
(Table II). The difference is attributed to the relatively rapid
downwasting of surficial ice that formed the ice-walled and
slackwater lake environments preserved fossils
reconstructions, but for their potential for unraveling deglacial histories.

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From 17 500 to 15 700 BP, the supraglacial and ice-mar-
ginal terrestrial environments in northeastern Illinois were dry
and windy, as suggested by plant macrofossils of dwarf tundra
shrubs and low Arctic herbs, such as Salix herbacea, Dryas
integri folia, Vaccinium uligonosum ssp. alpinum, and
Silene cf. acuclus. A few plants with boreal forest affinities also
were identified, resulting in our interpretation of an anomalous “tundra-like” environment, rather than “tundra”. Many, if not all
sites were devoid of trees judging from the general absence of
needles and twigs, and the presence of tundra plants that can’t
live under a forest canopy such as Armeria maritima.

Deposits in northeastern Illinois dating from about 17 500 to
14 200 BP do not contain wood fragments, but a few
millimetres in diameter that are representative of the deposit’s age; radiocarbon ages of larger wood fragments from such
deposits invariably yield dates >24 000 BP, indicating rework-
ning of fossils from the Robein Silt.

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