JOURNAL OF QUATERNARY SCIENCE (2002) **17**(8) 773–780
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Published online 22 July 2002 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/jqs.688

Late Wisconsin periglacial environments of the southern margin of the Laurentide Ice Sheet reconstructed from pollen analyses

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Heusser, L., Maenza-Gmelch, T., Lowell, T. and Hinnefeld, R. 2002. Late Wisconsin periglacial environments of the southern margin of the Laurentide Ice Sheet reconstructed from pollen analyses. *J. Quaternary Sci.,* **Vol. 17** pp. 773–780. ISSN 0267-8179.

Received 21 June 2001; Revised 20 March 2002; Accepted 25 April 2002

ABSTRACT: Full-glacial pollen assemblages from four radiocarbon-dated interstadial deposits in southwestern Ohio and southeastern Indiana imply the presence of herbaceous vegetation (tundra or muskeg with subarctic indicator *Selaginella selaginoides*) on the southern margin of the Miami lobe of the Laurentide Ice Sheet ca. 20 000 ^{14}C yr BP. Scattered *Picea* (spruce) and possibly *Pinus* (pine) may have developed regionally ca. 19 000 ^{14}C yr BP, and ca. 18 000 ^{14}C yr BP, respectively. Spruce stumps in growth position support a local source of pollen. Prior to the ca. 14 000 ^{14}C yr BP glacial advance, small amounts of *Quercus* (oak) and other deciduous pollen suggest development of regional boreal (conifer–hardwood) forests. Copyright © 2002 John Wiley & Sons, Ltd.

KEYWORDS: pollen analysis; Laurentide Ice Sheet; Ohio; Indiana; vegetation history.

Introduction

The increased resolution and temporal and spatial coverage of palaeoclimate records from ice cores and ocean sediments from the last glacial cycle require recovery of similar records from the terrestrial sector in order to develop a holistic view of Earth. Unfortunately, most terrestrial records by their very nature are of a complex and fragmentary nature. In glaciated terrain, for example, environmental reconstructions generally derive from pollen contained in lacustrine or bog sequences lying above or beneath glacial sequences. This obviously yields little insight to conditions during glacial maxima. Stratigraphical records from the margin of the Laurentide Ice Sheet leading to, through and after the Last Glacial Maximum are spatially and temporally limited; therefore, the nature of periglacial environments is not well known (Péwé, 1983). This reflects not only a lack of appropriate sites, but also the limitations of the biological and sedimentological components of available sites.

To address this problem and reconstruct periglacial environments of part of Southern Great Lakes Lobes, we investigated the pollen content of interstadial sediments deposited between ca. 20 000 and ca. 14 000 ^{14}C yr BP in a small geographical area (southwestern Ohio and southeastern Indiana).

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Background

Allochthonous material in Ohio River terraces and erratics ('foreign and adventitious debris') in drift were recognised ca. 200 yr ago, and a fossil forest bed near Cincinnati provided early evidence of multiple glaciations in America (reviewed in Lowell and Brockman, 1994). More recently, using aerial mapping, detailed lithostratigraphical analyses, and multiple, reliable radiocarbon ages from a sequence of units, four climatically induced fluctuations in late Wisconsin advances and retreats of the Miami sublobe between 22 000 and 14 000 ^{14}C yr BP were documented, pulses that occurred in unison with those of several sublobes across the southern margin of the Laurentide Ice sheet (Ekberg *et al.*, 1993; Lowell and Brockman, 1994; Lowell and Teller, 1994; Lowell, 1995).

Pollen-based reconstructions of ice-marginal environments in the contiguous USA range from extensive tundra or narrow forest–tundra to open coniferous park tundra (Goldthwait, 1958; Kapp and Gooding, 1964; Berti, 1975; Delcourt and Delcourt, 1981; Baker and Waln, 1985; Shane, 1987; Wright, 1987). In western Illinois, the demise of boreal forest and advance of Late Wisconsinan glaciers after 22 700 ^{14}C yr BP was reconstructed from the decrease in *Picea* pollen and increase in *Selaginella selaginoides* (Baker *et al.*, 1989a,b). Beetle assemblages from Ohio, Indiana and Illinois also reflect the replacement of coniferous communities by open ground (Morgan, 1987). In Ohio and Indiana, well-dated exposures of upright, bark-covered spruce stumps that were overridden by ice (Lowell and Brockman, 1994) indicate the presence

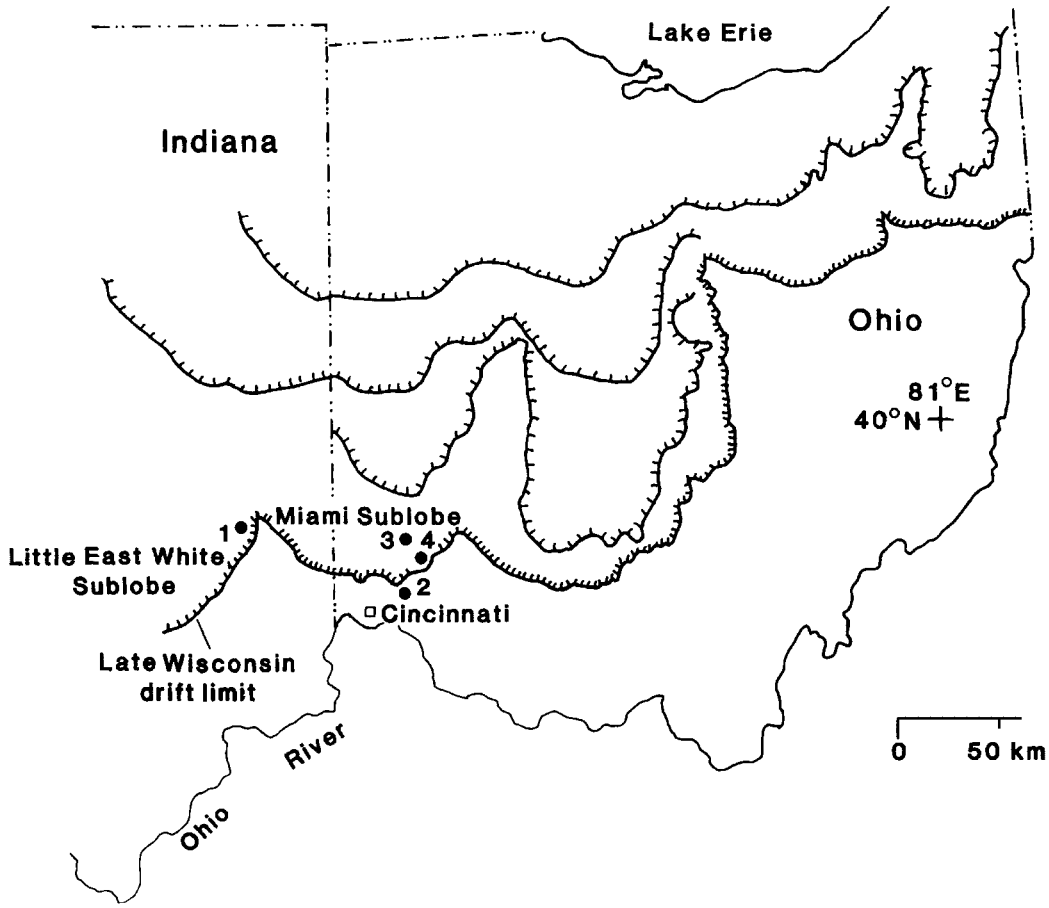


Figure 1 Location map showing study sites (1. Snyder Creek; 2. Creek Creek; 3. Gregory Creek; 4. Bunnel) and position of major late Wisconsin moraines in southwestern Ohio and southeastern Indiana

of spruce (spruce parkland) near the glacial margin between ca. 16 680 and ca. 13 500 ^{14}C yr BP. South of the ice margin in central Kentucky, upland vegetation of spruce forest was present between ca. 20 000 and ca. 16 000 ^{14}C yr BP (Wilkins *et al.*, 1991). To the east, in Pennsylvania and Maryland, spruce and pine pollen and macrofossils, together with high percentages of grass and/or sedge pollen, were interpreted as evidence of grass–dwarf-shrub tundra close to tundra–forest border, whereas coeval spruce- and pine-dominated pollen spectra with low herb percentages implied proximal forest (Maxwell and Davis, 1972; Watts, 1979).

Methods

Our interstadial sites are located in the area of the Miami Sublobe of the Laurentide Ice Sheet on the low-lying (≤300 m elevation) Till Plains of southwestern Ohio and adjoining Indiana (Fig. 1) (Lowell and Brockman, 1994; Hinnefeld, 1996). The Miami lobe lies at the southern limit of the Laurentide Ice Sheet and near the eastern limit of the central USA loess cover. One of our sites (Snyder Creek) lies at the intersection of the Miami and Little East White lobes and may be part of either, although the drainage suggests that the Miami lobe had the major impact (Lowell and Brockman, 1994).

Exposures in creek beds (Snyder Creek, Creek Creek, Gregory Creek; Figs 2–4) were sampled for pollen at centimetre intervals. Cores from a drained palaeolake basin (Bunnel) were sampled for pollen at variable intervals that ranged between 10 and 50 cm (TL and RH). The creek-site sediments are basically silty colluvial material derived from Wisconsinan loess or other glacigenic parent material and deposited on pre-existing landscapes (Lowell and Brockman, 1994) (T. V. Lowell, personal communication, 1999). At the Bunnel Site, glaciolacustrine clays are overlain by several metres of dark lacustrine silt that is regarded as loess topped by lake marls (Hinnefeld, 1996).

Laboratory procedures that were developed for processing marine sediments were used to extract pollen from these relatively inorganic sediments. After adding a known amount of an exotic tracer to calculate pollen concentration, sediments were boiled in KOH and sieved through 120 μm and 7 μm screens prior to chemical dissolution of carbonates and silica followed by acetolysis. The residue was again sieved through 7 μm screens (Stanley, 1966; Heusser and Stock, 1984). Macrofossils were not observed in the >120 μm fraction of any of the ca. 200 samples processed. Pollen identifications were based on pollen reference collections and descriptive keys (Kapp, 1969; McAndrews *et al.*, 1973). Although many samples yielded little or no pollen, ≥300 pollen grains were counted in samples from the Bunnel site. Those samples from the creek sites that yielded counts of ca. 100 grains are shown in Figs 5–7. For intersite comparison, selected pollen data from the four sites are shown as percentages based on the sum of all terrestrial pollen excluding Cyperaceae (Figs 5–8). Pollen data from Bunnel are also shown in Fig. 9 as percentages based on the sum of all pollen taxa including Cyperaceae. Cryptogams are shown as percentages of all pollen and spores, and the relative amount of redeposited pollen (pollen differentiated from well-preserved, apparently autochthonous

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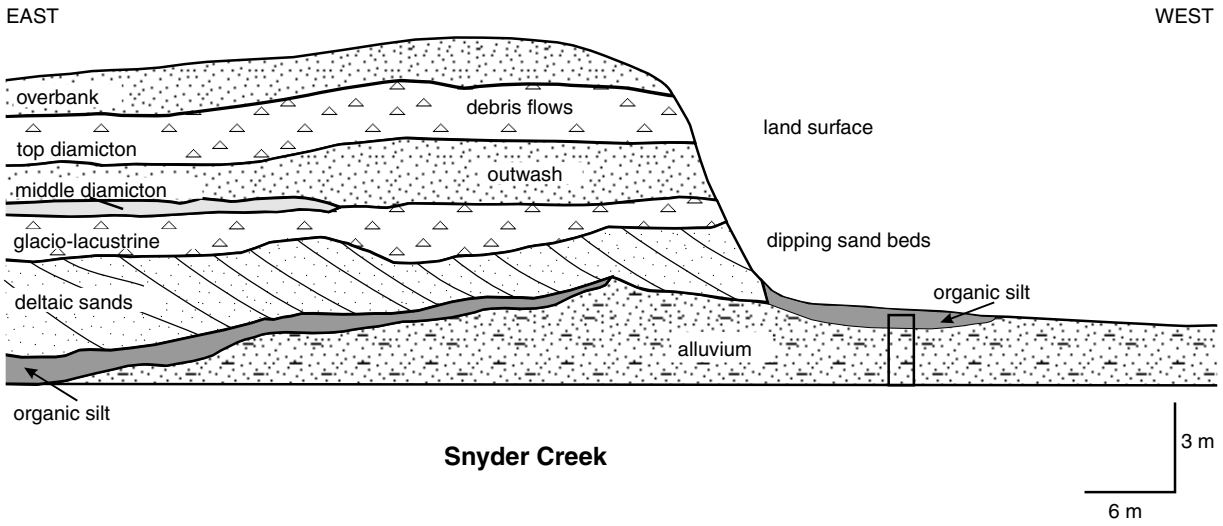


Figure 2 Stratigraphical sketch of stream-cut at Snyder Creek showing location of section sampled for pollen analysis (Lowell and Brockman, 1994)

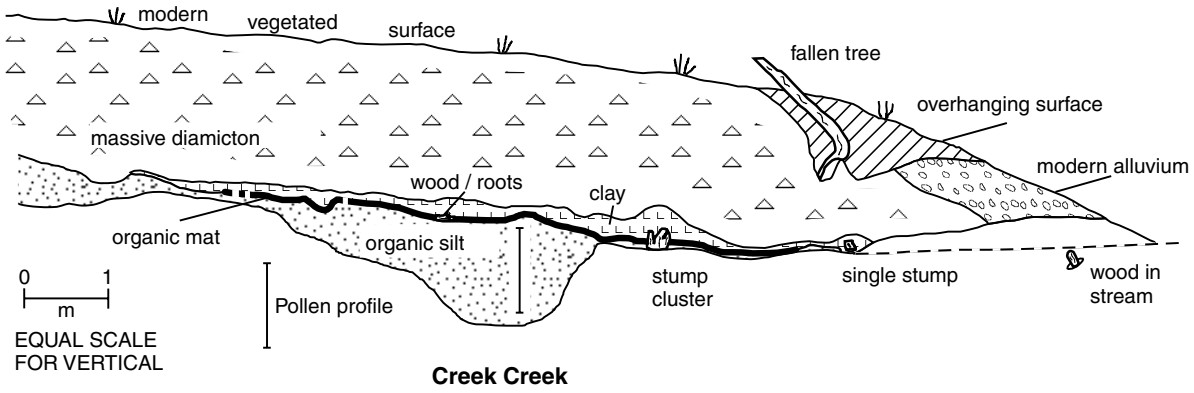


Figure 3 Sketch of the outcrop on Creek Creek showing location of the section sampled for pollen analysis (Lowell and Brockman, 1994)

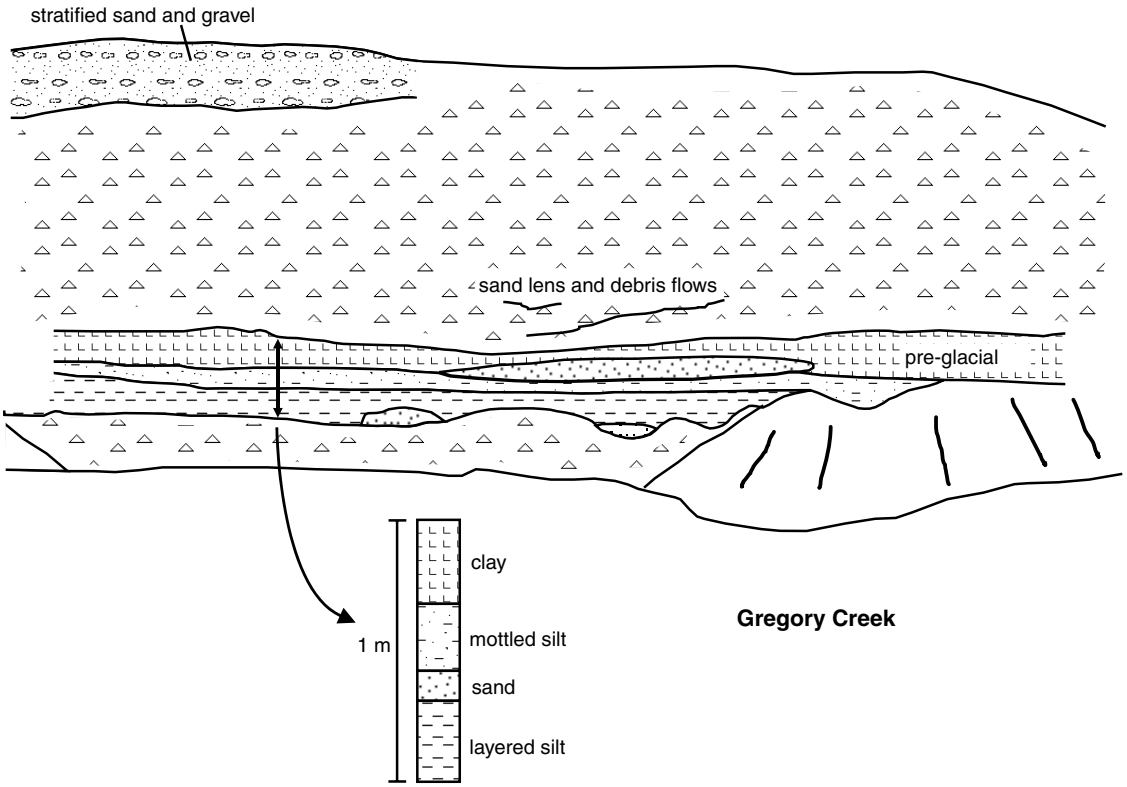


Figure 4 Sketch of the Gregory Creek exposure showing location of the section sampled for pollen analysis (Lowell and Brockman, 1994)

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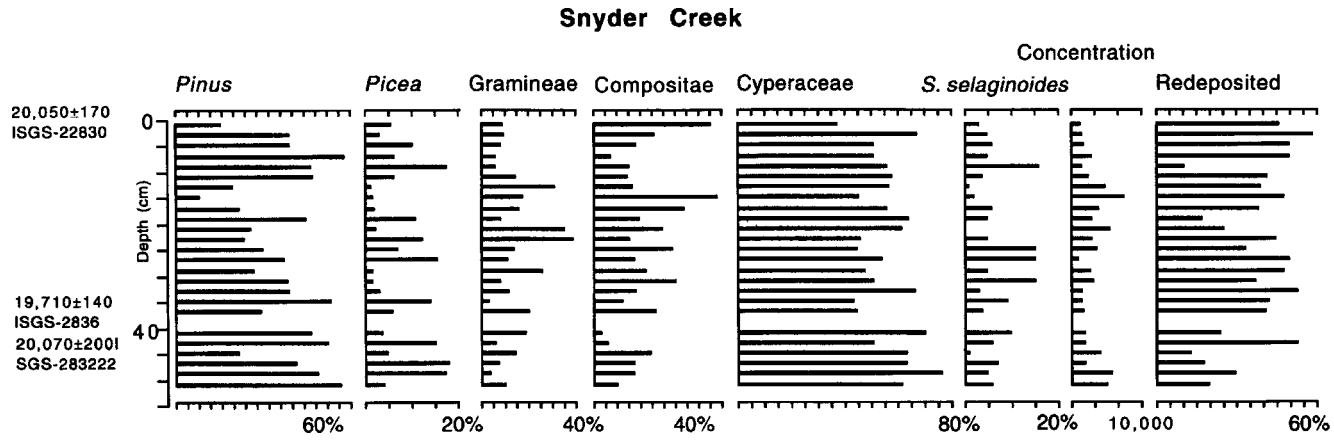


Figure 5 Relative abundance of selected pollen and spores, total pollen concentration (grains per gram dry weight sediment), and relative abundance of redeposited pollen from Snyder Creek, Indiana (Lowell and Brockman, 1994: Hinnefeld, 1996)

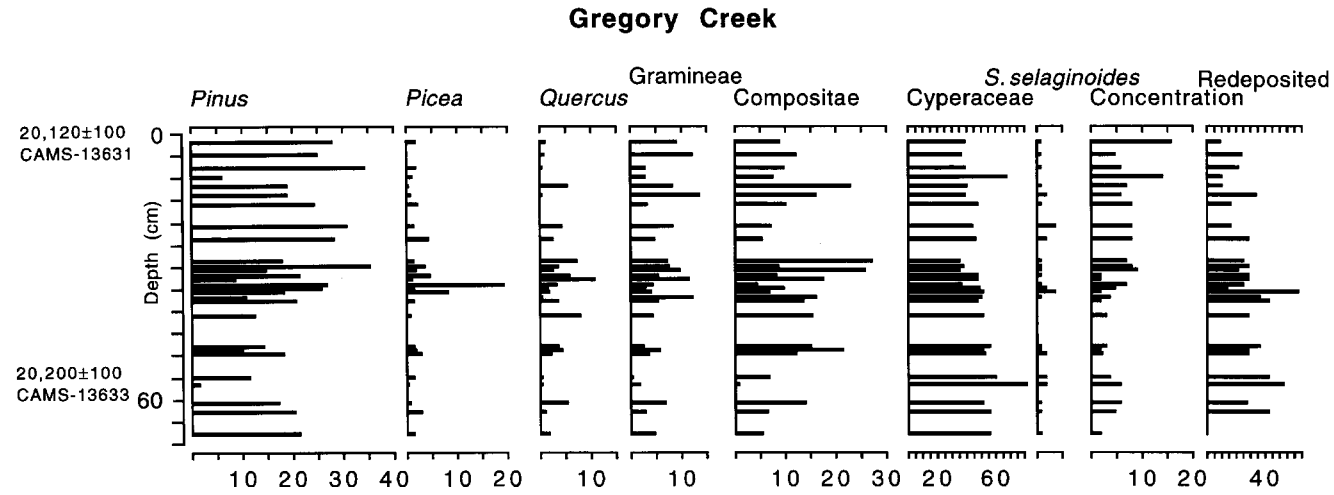


Figure 6 Relative abundance of selected pollen and spores, total pollen concentration (grains per gram dry weight sediment), and relative abundance of redeposited pollen from Gregory Creek, Ohio

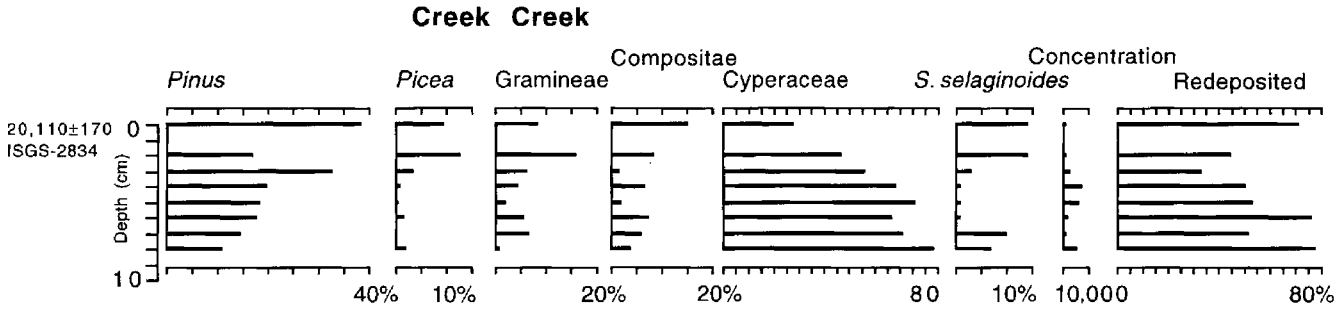


Figure 7 Relative abundance of selected pollen and spores, total pollen concentration (grains per gram dry weight sediment), and relative abundance of redeposited pollen from Creek Creek, Ohio

pollen by morphology or staining by Safranin O) is based on the sum of pollen plus redeposited palynomorphs. Pollen concentration is based on the number of pollen grains per gram dry weight sediment.

Chronology

Three dates bracket the polleniferous levels from Snyder Creek (20 070 ± 200 ^{14}C yr BP and 19 710 ± 140 ^{14}C yr BP at ca. 35 cm depth and 20 050 ± 170 ^{14}C yr BP at the top (T. V. Lowell, personal communication, 1999) (Fig. 5). Radiocarbon dates from Gregory Creek (basal date of 20 200 ± 100 ^{14}C yr BP, and upper date of 20 120 ± 120 ^{14}C yr BP) imply that the ca. 1-m section represents a virtual instant in geological time (T. V. Lowell, personal communication, 1999) (Fig. 6). The age of the overlying diamicton is believed to be the same as that of the Creek Creek site (ca. 19 500 ^{14}C yr BP). At the Creek Creek locality (Fig. 7), radiocarbon dates from the base and top of the ca. 60 cm section sampled for pollen are 22 800 ± 330 ^{14}C yr BP, and 20 110 ± 170

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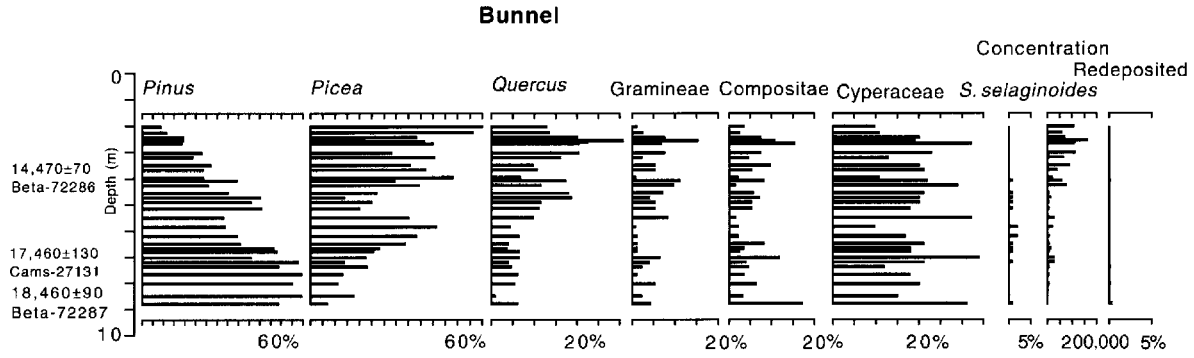


Figure 8 Relative abundance of selected pollen and spores, total pollen concentration (grains per gram dry weight sediment), and relative abundance of redeposited pollen from Bunnel, Ohio

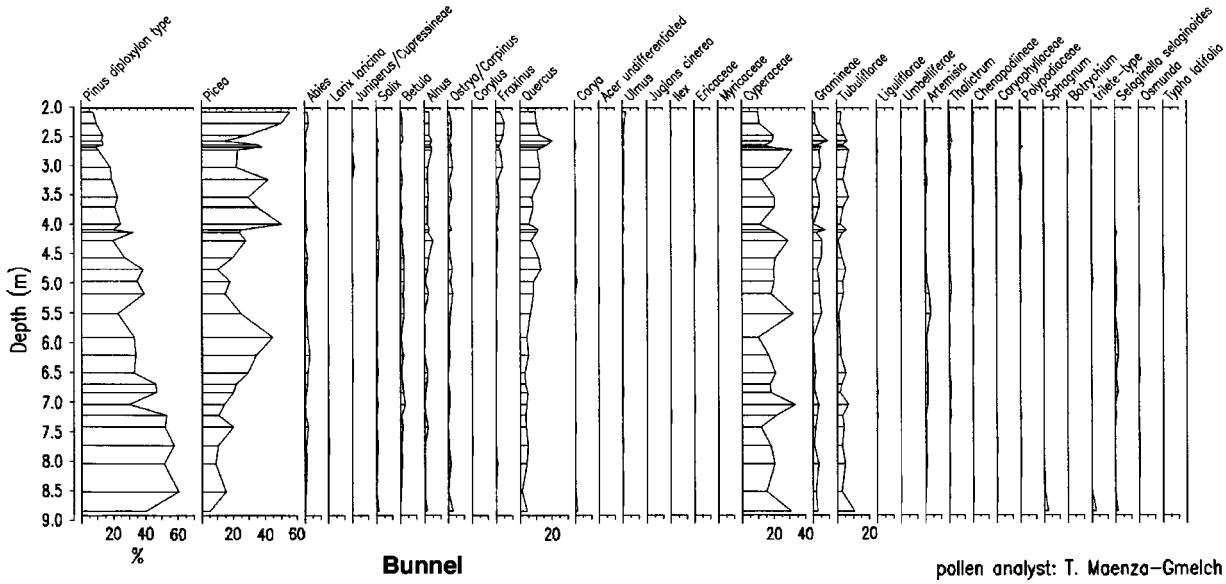


Figure 9 Relative abundance of pollen and spores from Bunnel, Ohio

^{14}C yr BP, respectively. The dates suggest that deposition of the productive samples from the upper ca. 8 cm probably occurred around ca. 20 000 to ca. 21 000 ^{14}C yr BP (T. V. Lowell, personal communication, 1999). Thus, it would appear that the pollen spectra from the creek sites are basically contemporaneous. The age model for the rapidly deposited sediments from the younger Bunnel site (Figs 8 and 9) is based on linear interpolation of three dates (14 470 ± 70 ^{14}C yr BP at 3.11 m, 17 460 ± 130 ^{14}C yr BP at 6.83 m and 18 460 ± 90 at 7.15 m (Hinnefeld, 1996). This site rests on material deposited during the recession from the ca. 19 500 ^{14}C yr BP advance (T. V. Lowell, personal communication, 1999).

Results and discussion

Pollen concentration

Less than half the samples processed and analysed for pollen from the creek sites yielded counts of ca. 100 pollen grains. Concentration in the productive samples ranged between ≤20 000 to ≤80 000 pollen grains per gram dry weight sediment (Figs 5–8). Pollen concentration in samples from the Bunnel cores was higher by a factor of ten, reaching values comparable to those found in interstadial peats and organic-rich lenses in Iowa (Hallberg *et al.*, 1980; Baker *et al.*, 1986). The large difference in pollen concentration between sediments from the three creek sections and the lake site may reflect differences in sedimentation and/or post-depositional processes, e.g. lower oxidation at Bunnel and higher oxidation in the overbank deposits of the creek sites. An overall upward increase in pollen concentration and organic carbon (T. V. Lowell, personal communication, 1999) in sediments deposited at the Gregory Creek site and in pollen concentration and influx at the Bunnel site supports the notion that oxidation was a factor in pollen concentration at these sites.

Variations in the quantity of loess deposited at our sites undoubtedly affected pollen concentration, with higher amounts of wind-blown material diluting full glacial pollen input. The general anticorrelation between the relative amount of redeposited pollen and pollen concentration (Figs 5–8) may reflect dilution by redeposited pollen derived from loess as well as from other glacigenic sediment. In ice-marginal environments, it is reasonable to assume deposition of older polleniferous material acquired from up flowline during ablation (Lowell, 1995).

Decreased loess availability associated with soil stabilisation by vegetation may be reflected in the increased pollen abundance in the younger sediments deposited at the Bunnel site. Assuming that pollen abundance in our sites is also a

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function of the pollen production of, and dispersal from, the plant communities from which the pollen was derived, the low pollen concentrations of samples from the full-glacial sediment may reflect the low pollen production of tundra-like plant communities. Similarly, the increased pollen concentrations in the younger samples from Bunnel would reflect the development and proximity of boreal forest communities that produce larger amounts of pollen.

Pollen assemblages

Pollen diversity, like pollen abundance, is low at the creek sites. Representation of the five dominant taxa—*Pinus* diploxylon-type (probably *P. banksiana* or jack pine), *Picea* (spruce), Gramineae, Compositae and Cyperaceae—is essentially the same at each of the sites, reflecting similar sources of pollen and of depositional environments ca. 20 000 ^{14}C yr BP (Figs 5–7). *Selaginella selaginoides* is continuously present, contributing as much as 20% of the sum of pollen and spores at the Snyder Creek site. The composition of the dominant pollen taxa (excluding Cyperaceae) and the low pollen abundance in the lower four samples from the Bunnel site are not unlike those of the creek sites. This suggests that the vegetation and evironmental conditions immediately prior to and after the local ca. 19 500 ^{14}C yr BP ice advance were similar.

The lack of diversity in pollen spectra from the creek sites may reflect sampling errors owing to low pollen counts (Faegri and Iversen, 1975); however, this is less likely in the Bunnel samples because all pollen counts from this site are all ≥300. We suggest that the limited pollen diversity in full-glacial samples reflects limited plant diversity, e.g. plant communities such as shrub and herb tundra that are dominated by few taxa (Anderson *et al.*, 1991). The presence of microspores of *S. selaginoides* (a species found in moist habitats from boreal forest to northern tree limit) and the substantial contributions of herbs coupled with the abundance of Cyperaceae (up to 80% of the total pollen sum at the creek sites) suggests wetland deposition in a cool, open environment. *Pinus and Picea* pollen in such an assemblage have been interpreted as evidence of open spruce forest (Knollenberg and Huber, 1994), as small, scattered clumps of trees in tundra, or as evidence of long-distance aeolian transport and/or reworking (Ritchie, 1969; Berti, 1975; Davis and Webb, 1975; Ritchie and MacDonald, 1986; Baker *et al.*, 1986). Non-forested boreal environments, referred to as tundra–park-tundra, were reconstructed from similar Late Wisconsin pollen and faunal assemblages deposited elsewhere in the mid-west (Mundt and Baker, 1979; Morgan, 1987; Baker *et al.*, 1989a)

Pollen diversity is higher in the younger Bunnel sediments (Figs 8 and 9) in which *Quercus* (oak) becomes a significant component. *Abies* (fir), *Salix* (willow), *Betula* (birch), *Alnus* (alder), *Fraxinus* (ash), *Ulmus* (elm) and herbs other than Compositae occur occasionally, as do trace amounts of Polypodiaceae, Lycopodiaceae, *T. latifolia*, *Sphagnum* and the freshwater green alga *Pediastrum*. Between ca. 19 700 and ca. 16 500 ^{14}C yr BP (8.85 m to 5.51 m) *Pinus* decreases from 60 to 22%, *Picea* increases from 5 to 45%, and Cyperaceae, accompanied by Gramineae (<3.5%) and Tubuliflorae (<10%), fluctuates between 10% and 30% (Figs 5 and 6). *Quercus* is present in low values (<5%), and *S. selaginoides* is relatively common. Between ca. 16 500 and ca. 15 400 ^{14}C yr BP (5.51 to 4.0 m), *Quercus* increases (≤13%), *Pinus* values re-expand to 39% and *Picea* decreases to 10%. Cyperaceae remain high, and *S. selaginoides* is no longer present.

In the rapidly deposited sediment of the upper ca. 2 m (ca. 15 000 to ca. 14 000 ^{14}C yr BP), *Picea* expands to 55% and *Pinus* declines to minimal values. *Quercus* pollen reaches highest levels in this interval (20%), as do other hardwoods (≤5%) (e.g. *Fraxinus*, *Alnus* and *Ulmus*). The *Picea* and *Quercus* assemblage suggests the development of forest communities. Pollen and spores indicative of local wet environments (Polypodiaceae, *Sphagnum*, *T. latifolia, Pediastrum, Isoetes*) occur sporadically throughout. The absence of *S. selaginoides* and the increase of deciduous trees appear to reflect a regional response to global warming.

Comparison of the Bunnel pollen record with modern pollen spectra (Ritchie and Lichti-Federovich, 1967; Davis and Webb, 1975; Webb and McAndrews, 1976; Anderson *et al.*, 1991) suggests that on the southern margin of the Miami lobe of the Laurentide Ice Sheet between ca. 20 000 and 14 000 ^{14}C yr BP, boreal communities similar to tundra and tundra–parkland of northern Canada were replaced by plant communities like those of the modern southern boreal forest. Shane (1987) interpreted percentages of spruce (<25%) and sedge-dominated non-arboreal pollen (≥25%) from four sites in the Ohio and Indiana Till Plains as indicative of late-glacial transition from open vegetation to spruce forest. The overall increase in *Picea* at the Bunnel site seems to lead up to the high percentages of spruce (ca. 75 to ca. 80%) observed in sediments in Ohio and Indiana deposited between ca. 15 000 to ca. 11 000 ^{14}C yr BP (Garrison, 1967; Bailey, 1972, Williams, 1974; Whitehead *et al.*, 1982; Shane, 1987). At a site in the Yukon similar changes in pollen composition and concentration have been interpreted as the succession from tundra-like vegetation to northern boreal forest (Ritchie *et al.*, 1982). An alternative interpretation of high proportions of *Picea* pollen and the relative absence of *Artemisia* and other herbs is as parkland with patches of closed forest or as open parkland with continuous stands of well-spaced trees (Ritchie and DeVries, 1964; Ritchie and MacDonald, 1986).

Although our interpretation of the pollen spectra at our sites may be valid, the physical relationship between the late Wisconsin plant communities from which the pollen was derived and our depositional sites may be open to question. The issue is whether pollen derives from local vegetation, from extra-local vegetation, or from pollen reworked from loess or other glacial parent material (Faegri and Iversen, 1975). In those samples from the creek sites in which the abundance of pre-Quaternary palynomorphs is greater than, or similar to, that of Quaternary pollen, without corroborating evidence it is difficult to prove that most of the pollen was not redeposited. In the Bunnel samples, however, reworked pollen are insignificant or absent and pollen concentrations are sufficient (average 68 000 g^{-1}) to obtains counts of ≥300 grains; therefore, it is not unreasonable to assume that the pollen data represent regional pollen rain and that most of the pollen grains are not redeposited.

Thus, the high percentages of diploxylon-type pine pollen in the basal Bunnel samples, like those in sites from the southern midwest and central east coast of the USA (Maxwell and Davis, 1972; Davis and Webb, 1975; Delcourt. 1979; Watts, 1979; Wilkins *et al.*, 1991; Kneller and Peteet, 1993), would imply the presence of jack pine at or near the depositional site during full-glacial time. If jack pine was present, then the periglacial environment of the Miami lobe was less severe than that of the northern midwest where jack pine was absent from about ca. 20 000 to ca. 10 000 ^{14}C yr BP (Wright, 1987).

Because both *Picea* and *Pinus* pollen are presently recorded in relatively high values well beyond treeline (Ritchie and Lichti-Federovich, 1967), it is possible that some of the pine and spruce grains deposited in our full-glacial sediments were

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transported from *Pinus* and *Picea* forests elsewhere (Grüger, 1972; King, 1973; Berti, 1975; Delcourt, 1979; Meyers and King, 1985; Ritchie and MacDonald, 1986; Baker *et al.*, 1989a,b; Wilkins *et al.*, 1991). Although pine pollen may have been transported from the southeast, where pine was well-represented in the full-glacial pollen rain (Delcourt and Delcourt, 1981), the very high percentages of pine (60–80%) in our sites seems to imply local pine populations. The low values of spruce pollen (<20%) in sediments deposited between ca. 20 000 and ca. 17 000 ^{14}C yr BP are not usually interpreted as evidence of local presence (Shane, 1987); however, spruce was present (Lowell and Brockman, 1994; Lowell, 1995), supporting Shane's (1987) observations that the rapid northward migration of spruce in Ohio ca. 15 000 ^{14}C yr BP reflected at least some spruce survival in unglaciated parts of the Ohio Plateau during the Late Wisconsin.

Summary

Assuming that the pollen spectra represent regional vegetation of the southern margin of the Miami lobe of the Laurentide Ice Sheet, we conclude the following:

1 sedge-dominated herbaceous muskeg-like vegetation with *S. selaginoides* (vegetation consistent with boreal conditions similar to those of northern Canada) was present immediately before and after the ca. 19 500 ^{14}C yr BP ice advance;
2 at the same time, *Picea* was present on the southern margin of the Miami lobe of the Laurentide Ice Sheet, even though pollen percentage values do not reach levels that indicate the local presence of spruce before ca. 17 500 ^{14}C yr BP;
3 high values of *Pinus* pollen suggest that pine may have been present, however, corroborating macrofossil evidence has not been found;
4 climatic amelioration inferred from the development of spruce parkland with oak ca. 15 000 was terminated by the ca. 14 500 ^{14}C yr BP ice advance.

Acknowledgments This study arose from the 41st Annual Meeting of the Midwest Friends of the Pleistocene. We would like to thank the Friends—including C. Scott Brockman, Cal Heusser and Linda Shane—and acknowledge some others who pioneered research in the region, particularly Dick Baker, Ron Kapp, Donald Engelhardt, Jane Forsyth, Jim King and Richard Goldthwait.

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