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Plant cultivation and forest clearance by prehistoric North Americans: pollen evidence from Fort Ancient, Ohio, USA

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Abstract: Archaeological records show that, as early as 2000–1500 BC, Native Americans in the eastern USA domesticated a group of native plant species with starchy or oily seeds that helped support extensive Woodland societies. Previously, the location and extent of cultivation of these ancient crop plants has been unknown, but was hypothesized to be small clearances on river floodplains. Here, pollen analyses of two 2000-year-old sediment records from Fort Ancient, an upland Hopewell archaeological site in southwestern Ohio, show exceptionally high amounts of pollen from cultigens – *Iva annua*, *Polygonum erectum* and *Chenopodium* – deposited during Hopewell occupation of the site (100 BC to AD 400). It is likely that this earthwork is a site of prehistoric cultivation, not exclusively a ceremonial structure. Pollen spectra indicate the area surrounding the ponds was largely deforested, and the sediment record indicates high rates of erosion during this time. Therefore, North American Woodland societies were likely modifying vegetation more extensively through agriculture and other land-clearing activities than has been assumed previously.

Key words: Human impact, prehistory, cultivation, forest clearance, pollen, cultigens, palaeoecology, archaeology, eastern North America, Fort Ancient, early Holocene.

Introduction

In the United States and Canada, historical sources and archaeological records document extensive Native American activities during historic times that affected vegetation (Day, 1953; Dorney, 1981; Cronon, 1983). These activities included burning, agriculture, forest clearing and selective management of plant resources. Although archaeological records show that prehistoric landscape modification was potentially extensive, there has been little evidence from traditional sediment records to indicate the magnitude or extent of prehistoric activities in eastern North America (McAndrews, 1988). Despite a few promising studies (Delcourt *et al.*, 1986; McAndrews and Boyko-Diakonow, 1989; Clark and Royall, 1995), it has been difficult to conclusively document prehistoric land use in North American sediment records. Consequently, it is often assumed that prehistoric societies in North America, unlike those on other continents, did not have an extensive impact on regional vegetation. If Native American land use was extensive, however, ecological views of climate-vegetation relationships and the composition of 'pristine' landscapes would be altered.

Archaeological records show that, as early as 2000–1500 BC, Native Americans in the eastern USA domesticated a group of native plant species with starchy or oily seeds (Smith, 1989). These plants include goosefoot (*Chenopodium berlandieri* var. *jonesianum*), maygrass (*Phalaris caroliniana*), knotweed (*Polygonum erectum*), sumpweed (*Iva annua* var. *macrocarpa*) and sunflower (*Helianthus annuus*) (Struever and Vickery, 1973; Asch and Asch, 1985; Wymer, 1996; Gremillion, 1997). All are annual plants that grow in disturbed places (Gleason, 1952). Although these cultigens helped support extensive Woodland societies in eastern North America, the degree to which cultivation of these ancient crop plants affected vegetation in eastern North America is unknown, as agriculture was considered to have occurred on naturally disturbed sites, such as river floodplains (Smith, 1992). However, seeds and pollen from Woodland cultigens have been found at upland sites as well (Delcourt *et al.*, 1986). Whether Woodland gardens were of sufficient size and duration to affect regional vegetation remains in question. Although a few pollen records confirm the presence of maize agriculture by Mississippian cultures (Delcourt *et al.*, 1986; McAndrews and Boyko-Diakonow, 1989; Fearn and Liu, 1995), there is little detailed corroborating evidence for the location and extent of land use and vegetation modification by the earlier Woodland cultures.

It may be difficult to detect palaeoecological evidence for the influence of Woodland people on vegetation because most pollen records are from large lakes, reflecting spatial and temporal scales that may be inappropriate for detecting human influences, and

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they may have been obtained in places far from concentrated prehistoric activity. Additionally, North American palaeoecologists have tended to attribute most palaeovegetation changes to climate. To address these issues, I obtained two sediment cores from small basins at the well-documented Middle Woodland archaeological site of Fort Ancient in southwestern Ohio, USA. From these cores, I sampled pollen to reconstruct local vegetation, obtained radiocarbon dates to correlate environmental changes with human activities, and examined magnetic susceptibility and loss-on-ignition to understand other sediment characteristics. To compare the fossil pollen assemblages from this site with modern vegetation types, I obtained 18 surface samples from possible vegetation analogues.

Study site

Fort Ancient, located in Warren County, Ohio (approximately 39.4°N, 84.1°W) (Figure 1), is a concentrated site of prehistoric human activity that has been investigated and excavated by many archaeologists (Moorehead, 1895; Connolly, 1996a). The 50 ha earthworks site is situated on a 50 m high bluff overlooking the Little Miami River. The Middle Woodland people, known locally as the Hopewell, began approximately 100 BC to build earthen walls that enclose Fort Ancient and the small ponds immediately inside the walls (Connolly, 1996b). Extensive modification of the landscape and construction of the site ceased by AD 400 (Connolly, 1996b). Recent excavations at Fort Ancient have revealed evidence of Middle Woodland habitation structures and cultural debris in the northern part of Fort Ancient, known as the North Fort (Connolly, 1997; Lazazzera, 2000). Extensive Middle Woodland villages have not been located, although Middle Woodland society must have exhibited the high degree of social organization necessary to build extensive earthworks (Prufer, 1997).

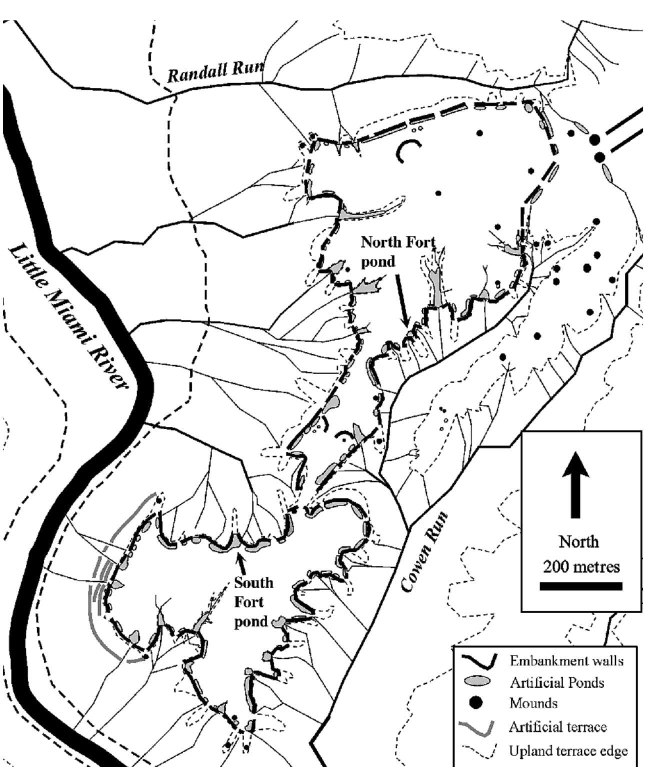

Figure 1 Map of Fort Ancient, Ohio. The earthen walls create the structure of the North Fort and South Fort on a plateau 50 m above the Little Miami River. The small anthropogenic ponds from which sediment cores were obtained are located immediately inside the earthen walls. Reproduced from Cowan *et al.* (2003).

Likewise, the location of Middle Woodland food supply has not been identified on the landscape, although Middle Woodland people certainly cultivated and consumed domesticated plants. Certain characteristics of the Hopewell society, such as an extensive trade network, artwork made of exotic materials, and elaborate earthworks construction have been studied much more than settlement and subsistence patterns (e.g., Kelly, 1979).

Recent archaeological work has revealed that the ponds at Fort Ancient, which occur at regular intervals along the inside edge of the earthen walls, were deliberately constructed by the Middle Woodland people to hold water and were not just pits caused by excavating soil for the construction of the walls (Connolly, 1996a). In addition, the pond sediments contain cultural materials, such as animal bones, charcoal, flint, pottery, fire-cracked rock and tools, which indicate that the ponds were sites for concentrated prehistoric human activity (Connolly, 1996a; Sunderhaus and Blosser, 2000).

Fort Ancient is located a few km south of the maximum advance of the Wisconsinan glaciation. The soils at Fort Ancient developed on Illinoian till and are fined-grained silts and clays (Brockman, 1998). They overlie Ordovician limestone bedrock. The presettlement vegetation of the area was primarily an oak-hickory forest, with patches of beech-maple forest nearby (Gordon, 1969). The current vegetation of Fort Ancient is a mixture of open, maintained grassland and secondary hardwood forest, dominated at various locations by *Quercus* sp., *Fagus grandifolia* and *Carya* sp. Canopy trees also include *Liriodendron tulipifera* and *Fraxinus* sp. *Acer saccharum* and *Asimina triloba* are common in the understorey.

Methods

Coring

Sediment cores were collected in 1998 at Fort Ancient from two of the small anthropogenic ponds. The two ponds are 10 m in diameter and 600 m apart. One pond is in the southern part of the site (South Fort pond) and one is in the northern part of the site (North Fort pond) (Figure 1). The sediment cores were recovered with a piston corer, diameter 10 cm, equipped with teeth on the lower end (see description in Davis *et al.*, 1998). There were approximately 25 cm of standing water in the South Fort pond, and there was no standing water in the North Fort pond although the surface was moist. Upon removal from the ponds and extrusion, the core from the South Fort pond was 132 cm long, and the core from the North Fort pond was 98 cm long. Each core was wrapped in plastic wrap and aluminum foil, transported to the University of Minnesota, sliced in half along its length and stored in a cold room at 8°C.

Radiocarbon dating and age-depth relationship

Sediment was subsampled at 1.0 cm intervals, and terrestrial plant macrofossils were removed from eight sediment subsamples for radiocarbon dates by accelerator mass spectrometry (Table 1). The computer program CALIB 4.0, method A, from the University of Washington Quaternary Isotope Lab was used to calibrate and convert radiocarbon dates to calendar years (Stuiver and Reimer, 1993). I calculated the maximum possible deposition time (the inverse of sedimentation rate) by dividing the greatest difference in calibrated calendar years between two dated levels (upper two-sigma error for the lower date and lower two-sigma error for the upper date) by the amount of sediment deposited in that interval. Deposition time therefore has units of yr cm^{-1}.

Magnetic susceptibility

Magnetic susceptibility measures concentration of primarily ferrimagnetic minerals in sediment, and provides a rapid assessment

Table 1 AMS radiocarbon dates from two sediment cores from Fort Ancient, Ohio. ^{14}C ages were calibrated using CALIB 4.0 (Stuiver and Reimer, 1993)

Lab. number	Core	Depth (cm)	Material	Radiocarbon age (years BP)	Median calibrated age (calendar years BP)	Median calibrated age (years AD)
Beta-130007	South Fort	37–37.5	Charred wood	950 ± 40	840	1110
Beta-137296	South Fort	49–50	Twig and charcoal pieces	850 ± 80	740	1210
Beta-140694	South Fort	59–59.5	*Quercus* (*Lepidobalanus*, white oak subgenus) and *Carya* sp. charcoal	1930 ± 50	1875	75
AA-34437	South Fort	96–96.5	*Carya* cf. *ovata* charcoal	1830 ± 40	1750	200
Beta-130006	South Fort	130–130.5	Charcoal pieces, pine cone scale, and seeds of *Chenopodium*	1870 ± 40	1820	130
Beta-140693	North Fort	16–16.5	*Prunus* sp. charcoal	230 ± 40	290	1660
AA-33654	North Fort	21–23	Unidentified charcoal	1870 ± 40	1820	130
Beta-137297	North Fort	66–66.5	Charcoal pieces	2070 ± 60	2020	70 BC

of a number of environmental variables, especially erosion rates (Verosub and Roberts, 1995). I measured bulk magnetic susceptibility with a Kappabridge KLY-2 by subsampling both sediment cores at contiguous 2 cm intervals and placing samples into plastic boxes 8 cm^2 in volume. Chi (X), a measure of mass magnetic susceptibility with units m^3/kg, was calculated by correcting for the mass of the sediment and the magnetic susceptibility of the plastic box.

Loss-on-ignition

Loss-on-ignition methods followed Dean (1974). Sediment subsamples from the South Fort core were dried in an oven at 105°C, then organic matter was ignited at 550°C in a muffle furnace. The proportion of the sediment sample comprised of ash-free organic matter was calculated by dividing the mass of the organic matter fraction combusted at 550°C by the dry mass of the sediment sample.

Pollen analysis

To each sediment sample, I added a known volume of a concentrated suspension of *Lycopodium* spores, then screened the sediment twice using Nitex™ mesh of 120 μm and 8 μm in diameter to remove some of the inorganic material. Preparation of pollen samples generally followed standard methods from Berglund and Ralska-Jasiewiczowa (1986). I scanned slides of pollen samples until I had identified at least 300 pollen grains. Both arboreal and non-arboreal pollen types are included in the pollen sum, but pollen and spores from aquatic plants are excluded. I identified 57 total pollen and spore taxa in fossil samples from Fort Ancient. Forty-eight of these pollen taxa were included in the upland pollen sum.

Pollen concentration was calculated by the following formula: (number of pollen grains counted in a sample/number of *Lycopodium* grains counted in a sample) (number of grains *Lycopodium*/1mL of *Lycopodium* suspension) (mL of *Lycopodium* suspension added/cc sediment). Pollen concentration has units of number of pollen grains/cc sediment. Pollen-accumulation rates (PAR) were calculated by using the same formula, and then dividing by the number of years represented by 1 cm thickness of sediment. PAR has units of number of pollen grains cm^{-2} $year^{-1}$. Because errors in determining short-term changes in sedimentation rate can lead to inaccurate estimates of PAR, I report my results as minimum PAR, which is calculated by using the maximum possible deposition time.

Surface sample collection and vegetation surveys

Surface samples are modern sediment or soil samples that capture pollen produced by modern vegetation. They provide a way to compare fossil pollen assemblages with pollen produced by modern vegetation types. I collected 18 surface samples from a variety of vegetation types in southern Ohio (Figure 2; Table 2). To obtain a surface sample, I collected a small sample (approximately 20 mL) of sediment or wet soil and humus into a plastic bag. At each surface sample site, I qualitatively assessed the vegetation composition with a relevé of approximately 100 m^2, and assessed the vegetation as either 'open', which meant that there was no tree canopy cover within the relevé, or 'forested', which meant that there was a partially or completely closed canopy of trees. For pollen analysis, I processed nine surface samples from open vegetation and nine surface samples from forested vegetation.

Principal components analysis

A principal components analysis (PCA) was performed using JMP 3.2 (SAS Institute). I computed pairwise correlation coefficients for pollen percentages of all 51 pollen taxa present in fossil or surface samples. These correlations were used in a PCA of the

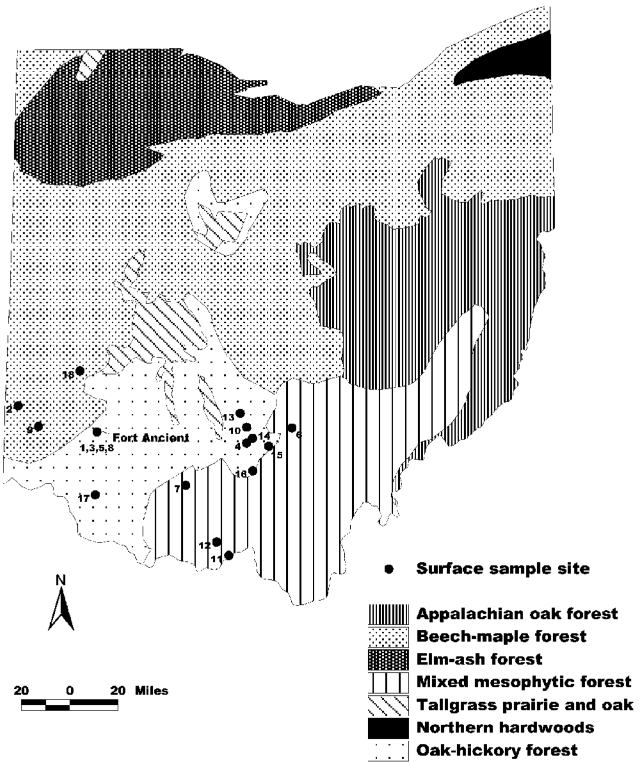

Figure 2 Map of Ohio, USA, showing Fort Ancient and surface sample sites.

Table 2 Surface sample sites in southern Ohio from which pollen samples were obtained, with qualitative vegetation descriptions. 'Forested' indicates a closed tree canopy, while 'open' indicates no trees near the sample site

Sample no.	Sample name	Vegetation type	Common plants	Type of sample
1	North Fort pond	Forested	*Carya, Quercus, Sassafrass albidum*	Surface sediment
2	Hueston Woods	Forested	*Quercus* cf. *Q. muehlenbergii, Fagus grandifolia, Acer saccharum, Prunus serotina*	Wet soil
3	Fort Ancient pond	Forested	*Fagus grandifolia, Fraxinus, Acer saccharum, Quercus, Carya ovata, Asimina triloba*	Surface sediment
4	Backyard pond	Open	*Typha, Poa pratensis, Pinus*	Surface sediment
5	Fort Ancient *Chenopodium* patch	Open	*Chenopodium berlandieri* var. *jonesianum, Ambrosia, Polygonum, Melilotis, Trifolium,* Asteraceae	Moist soil
6	Hocking State Forest pond	Open	*Poa pratensis, Typha, Pinus, Fagus grandifolia, Platanus occidentalis*	Surface sediment
7	Fort Hill pond (a Hopewell hilltop enclosure)	Forested	*Liriodendron tulipifera, Quercus, Acer saccharum, Fraxinus, Asimina triloba*	Surface sediment
8	Fort Ancient *Helianthus* patch	Open	*Helianthus annuus, Ambrosia,* Poaceae	Moist soil
9	Roadside ditch	Open	*Ambrosia, Polygonum,* Apiaceae, Asteraceae, *Bromus, Asclepias, Cichorium intybus*	Moist soil
10	Golf course pond	Open	*Ambrosia, Asclepias, Taraxacum, Typha, Salix, Populus tremuloides*	Surface sediment
11	Ohio River flood plain	Open	*Salix,* Chenopodiaceae, *Polygonum*	Moist soil
12	Shawnee State Forest pond	Forested	*Acer saccharum, Platanus occidentalis, Quercus, Ulmus rubra, Carya, Pinus*	Surface sediment
13	Ditch by cornfield	Open	*Ambrosia, Polygonum*	Moist soil
14	Great Seal State Park	Forested	*Platanus occidentalis, Acer saccharum, Fraxinus, Quercus, Juglans nigra*	Humus sample
15	Tar Hollow State Forest	Forested	*Acer saccharum, Pinus* cf. *P. echinata, Liriodendron tulipifera*	Moist soil
16	Scioto Trail State Forest	Forested	*Quercus* cf. Q. *muehlenbergii, Carya, Acer saccharum*	Humus sample
17	East Fork old field	Open	*Bromus* and other Poaceae, Asteraceae, *Juniperus virginiana, Populus tremuloides*	Moist soil
18	Wegerzyn garden forest	Forested	*Fraxinus, Acer saccharum, Ostrya virginiana*	Moist soil

51 pollen taxa. All pollen taxa were weighted equally in this analysis. I included all 42 fossil samples and 18 surface samples in the analysis. Eigenvectors of the pollen taxa were used to interpret the first two principal axes. I grouped the samples into three groups: Hopewell, post-Hopewell and surface samples, and used a 95% confidence ellipse drawn around each group to determine if a given pollen assemblage was similar to the pollen assemblages of these categories.

Results

Sediment stratigraphy

Both the South Fort core and North Fort core sediment records begin during construction of the site in Hopewell times (AD 130 and 70 BC, respectively) (Table 9.1 in Connolly, 1996a). Gravel with which the Hopewell lined the ponds (Connolly, 1996a) is present at the bases of both cores. Radiocarbon dates indicate rapid deposition of basal sediment during Hopewell times and a sudden transition to slower deposition rates at a time close to the end of the period of occupation by the Hopewell (Figure 3). The basal sediment, contemporaneous with Hopewell occupation, consists of inorganic material (<10% loss-on-ignition), mostly sand and clay minerals containing oxidized iron (Figure 4). Radiocarbon dates from this inorganic layer are not significantly different in age, but the sediment is heterogeneous, indicating that it was not deposited simultaneously, but rather during multiple events. Radiocarbon-based sedimentation rates decreased dramatically between 49 cm and 59 cm in the South Fort core, and between 16 cm and 22 cm in the North Fort core, where there is also a transition to more organic sediments. Because this transition happened so rapidly, determining its exact date was impossible, but it appears to be approximately the same age as Hopewell abandonment of the Fort Ancient site around AD 350.

The sediments deposited during Hopewell occupation, with low organic matter and rapid sedimentation rates, have higher magnetic susceptibility than later sediments (Figure 4). High erosion rates are often linked to high values of magnetic susceptibility (Maher, 1998). At approximately the same level that sedimentation rates decrease and organic matter increases, magnetic susceptibility values decrease.

Sedimentary zones

The sediment record can be divided into two distinct units or zones based on the similarities between the lithology, radiocarbon dated timing of sediment deposition, and pollen stratigraphy in both cores: zone 1, which begins at the start of sediment deposition, during Hopewell times, and ends when arboreal pollen percentages start to rise; and zone 2, which begins when arboreal pollen percentages rise and continues to the surface of the sediment. Radiocarbon dates from zone 1 are contemporaneous with Hopewell cultural occupation, and radiocarbon dates from zone 2 postdate Hopewell abandonment of the site (Figure 3).

Pollen stratigraphy

The pollen assemblages deposited during Hopewell times (zone 1) contain high percentages of several pollen types that are identical to Middle Woodland cultigens (Figure 5). Three taxa represented by pollen types in sediment deposited during Hopewell times are identified as ancient cultivated plants: *Iva annua*-type *Polygonum erectum*-type, and Chenopodiaceae. Zone 1 in both sediment cores contains extremely high percentages of the three

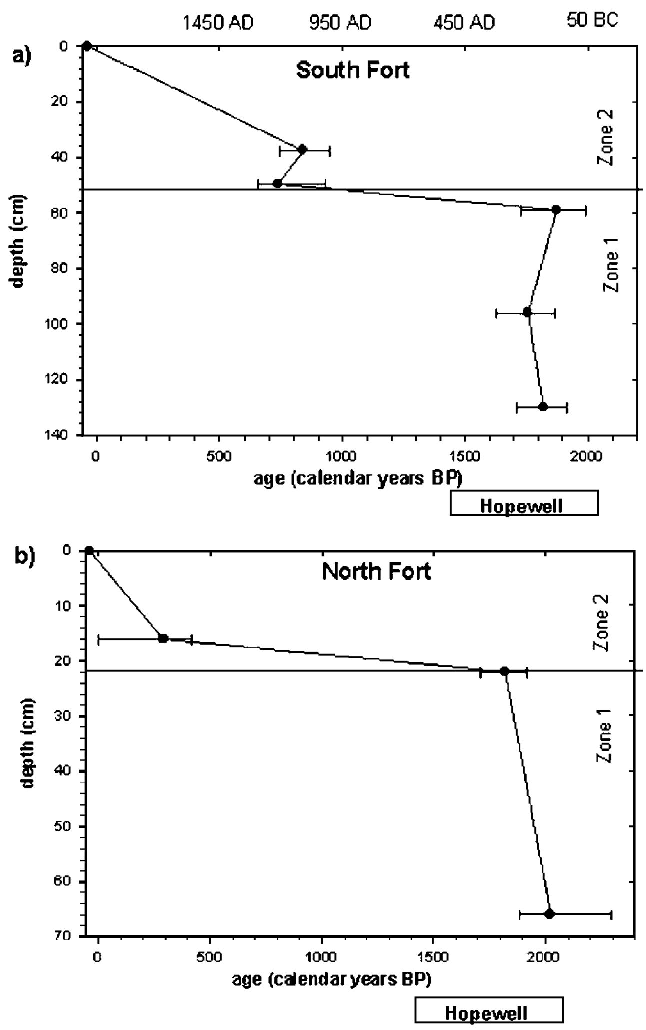

Figure 3 Calibrated AMS radiocarbon age against depth in centimetres from the sediment-water interface for two sediment cores from (a) the South Fort and (b) the North Fort of Fort Ancient, Ohio. The approximate time interval for the Hopewell cultural period and calendar years AD are included. The upper and lower error bars represent two-sigma errors (approximately 95% confidence intervals) for each radiocarbon date. The determination of the boundary between zone 1 and zone 2 is based primarily on pollen stratigraphy and is not well dated because it occurred rapidly. Sedimentation is more rapid in zone 1 than zone 2.

cultigen pollen types – approximately 10%. These pollen percentages are higher than percentages found in other sediment records near Woodland sites (Delcourt *et al.*, 1986; 1998). Pollen from other Middle Woodland cultigens cannot be identified with as much taxonomic resolution, but are included in the pollen types 'Poaceae' and 'Asteraceae undifferentiated', which are common in zone 1 sediments at a combined average of 10%. No morphological changes in pollen associated with domestication of these taxa are documented; pollen from wild types is believed to be identical to pollen from cultivated varieties. The percentages of cultigen pollen in the South Fort core are slightly lower (percentages in individual samples range from 2 to 9%) than in the North Fort core (percentages in individual samples range from 10 to 21%), which may reflect local differences in plant composition immediately surrounding the ponds. In zone 2 in both cores, cultigen pollen types disappear, except for small (under 1%) quantities of Chenopodiaceae pollen grains.

In zone 1, pollen concentrations in sediments are low, with an average of 3780 grains/cc in the North Fort and 2890 grains/cc in the South Fort (Figure 4). The minimum pollen-accumulation rate is 1000 grains cm^{-2} $year^{-1}$ in the South Fort core. In the

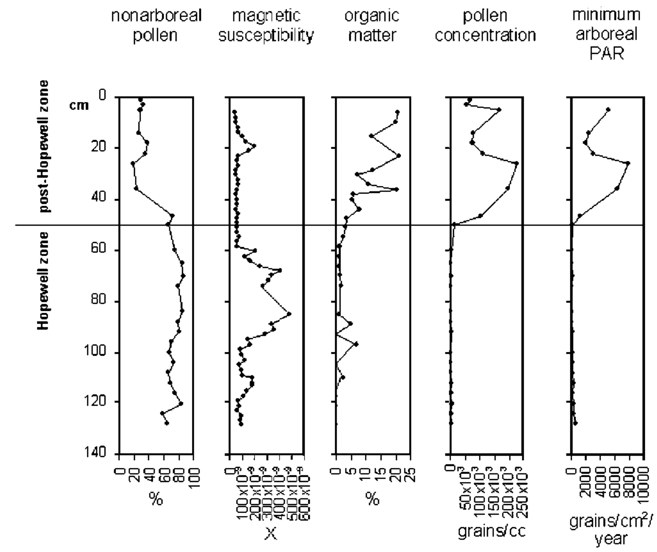

Figure 4 Pollen percentage from non-arboreal plants, magnetic susceptibility, percent organic matter determined from loss-on-ignition, pollen concentration, and minimum arboreal pollen-accumulation rates from the South Fort core at different depths below the sediment-water interface.

North Fort core, minimum pollen-accumulation rates average 280 grains cm^{-2} $year^{-1}$.

The pollen assemblages deposited in zone 1 are uniform over time and are dominated by ragweed (*Ambrosia* spp.) and other herbaceous plants (Figure 5). Fossil samples contain 40–60% *Ambrosia* pollen, similar to percentages of *Ambrosia* observed in sediment deposited in areas with extensive European-style agriculture, annually ploughed soil and road construction (McAndrews, 1988). Even with *Ambrosia* removed from the pollen sum, total non-arboreal pollen percentages in the sediment deposited during the Hopewell period average 43% and are generally comparable to quantities of non-arboreal pollen found in modern surface samples from open landscapes (Gaillard *et al.*, 1998; Hicks, 1998).

In zone 2, after abandonment of the site by the Hopewell, the three cultigen pollen types disappear almost completely, pollen from other herbaceous species declines, and arboreal pollen rises to a maximum of 80% (Figure 5). *Quercus* (35–50%) and *Carya* (10–20%) dominate the pollen assemblages. Minor hardwood taxa, such as *Acer, Fraxinus, Ulmus, Nyssa, Juglans* and *Platanus*, occur during this time period as well. A slight increase in pollen of *Ulmus*, *Fraxinus* and *Acer* occurs toward the top of the pollen diagram.

In zone 2, pollen concentrations are higher than zone 1. Average pollen concentrations during this time are 409970 grains/cc in the North Fort core and 125520 grains/cc in the South Fort core. Zone 2 also exhibits greater pollen-accumulation rates than zone 1, averaging 5890 grains cm^{-2} $year^{-1}$ in the South Fort core and 14000 grains cm^{-2} $year^{-1}$ in the North Fort core (Figure 4).

Macrofossils

Five empty seed coats were found in zone 1 sediments from the South Fort core. Two of these, at 130 cm, were radiocarbon dated at AD 130 (Table 1). The other three seed coats were identified using scanning electron microscopy as a wild variety of *Chenopodium* cf. *C. berlandieri*. Domestication of *C. berlandieri* is determined by the thickness of the testa (Smith, 1984), and these seeds have testas slightly thicker than those of domesticated varieties.

Surface sample analysis

If a modern pollen assemblage is similar to a fossil pollen assemblage from a basin similar in size, the vegetation that produced

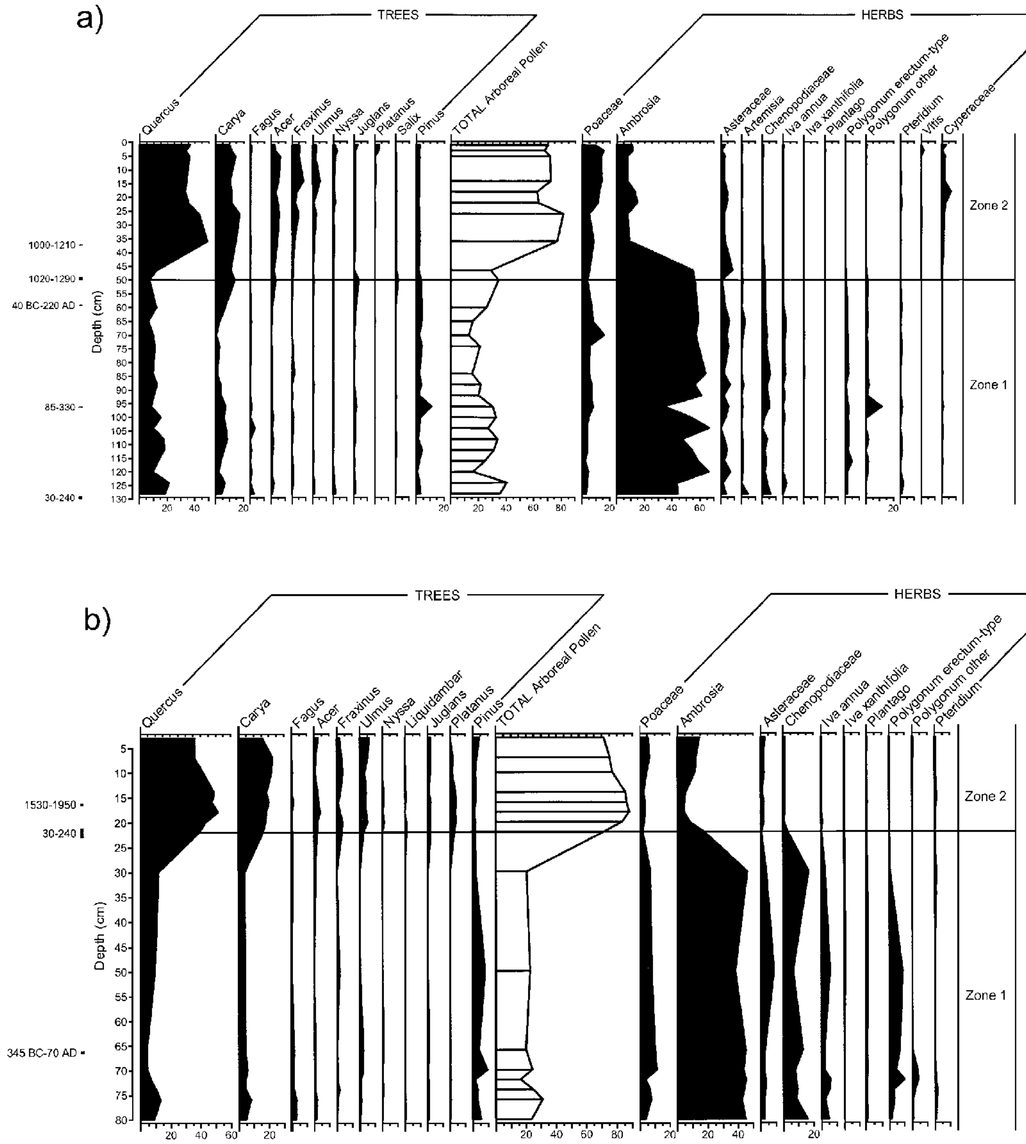

Figure 5 Pollen percentages at depth below the sediment-water interface for cores from (a) the South Fort and (b) the North Fort of Fort Ancient, Ohio. The dates, expressed as range of calibrated calendar years AD, are on the left.

these assemblages is likely to be similar (Overpeck *et al.*, 1985). A principal components analysis (PCA) compares the degree of similarity between pollen assemblages (Figure 6). Axis 1 differentiates pollen assemblages from open and forested vegetation: positive values are due to arboreal pollen taxa, and negative values indicate non-forested vegetation containing the three Hopewell cultigens. Axis 1 explains 12.3% of the explainable variation in the data set (2% expected). Along axis 1, pollen assemblages from Hopewell times are quite distinct from pollen assemblages from post-Hopewell times (Figure 6). Axis 2 is less important than axis 1, explaining 8% of the explainable variation, and generally represents differences between modern and prehistoric vegetation types due to plant species that are more common on modern agricultural landscapes than prehistoric landscapes. Along axis 2, the Hopewell fossil pollen assemblages from zone 1 are indistinguishable from the post-Hopewell fossil pollen assemblages from zone 2.

No surface samples fall within a 95% confidence interval ellipse for Hopewell pollen assemblages (Figure 6). The surface samples most similar to Hopewell pollen assemblages were collected from a reconstructed Hopewell garden containing *Helianthus* and *Chenopodium*, and from a ditch next to an agricultural field (samples 8 and 13, respectively). Thus, the closest analogues to possible Hopewell agricultural fields are open upland areas with several species of cultigens growing together. Three surface samples from modern hardwood forests (samples 1, 7 and 12) are very similar to post-Hopewell samples, suggesting that, after Hopewell abandonment of Fort Ancient, a forest dominated by oak and hickory developed on the site.

Boxplots show that pollen percentages of cultigens in sediment samples from Hopewell times are higher than in any other group of surface or fossil samples (Figure 7). Pollen from *Iva annua*-type, *Polygonum erectum*-type and Chenopodiaceae does occur in surface samples from open places. However, these pollen types in surface samples from open places averages 1%, which is much lower than in fossil assemblages from zone 1. Thus, the percentages of cultigen pollen from fossil samples deposited during Hopewell times does not match any surface sample, even those taken from highly disturbed places where soil has been recently moved.

Discussion

Erosion at the Fort Ancient site

Sediments deposited during Hopewell times (zone 1) display low organic matter, high sedimentation rate and high magnetic susceptibility relative to sediments in zone 2, indicating that there were

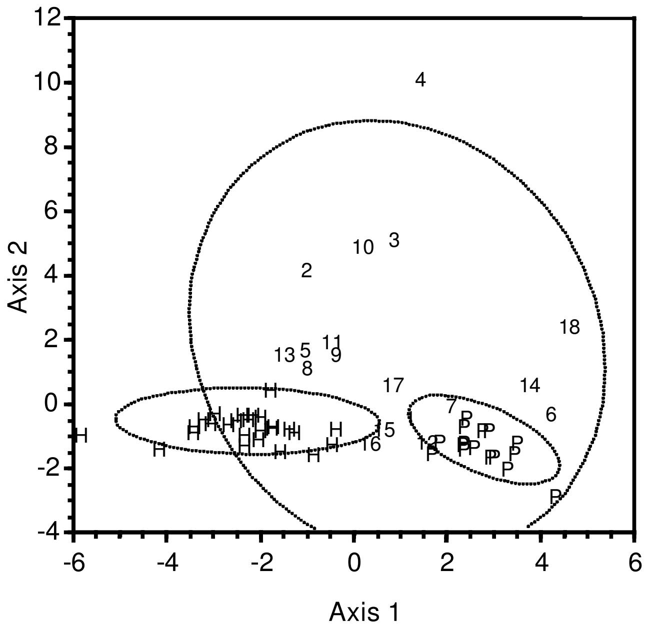

Figure 6 The first two principal axes from a principal components analysis of 42 fossil pollen samples from Fort Ancient, Ohio, and 18 surface pollen samples from southern Ohio. 'H' indicates a fossil sample from zone 1, deposited during Hopewell times. 'P' indicates a fossil sample from zone 2, deposited after Hopewell abandonment of the site. Surface samples are numbered 1–18. A 95% confidence ellipse for each group is shown.

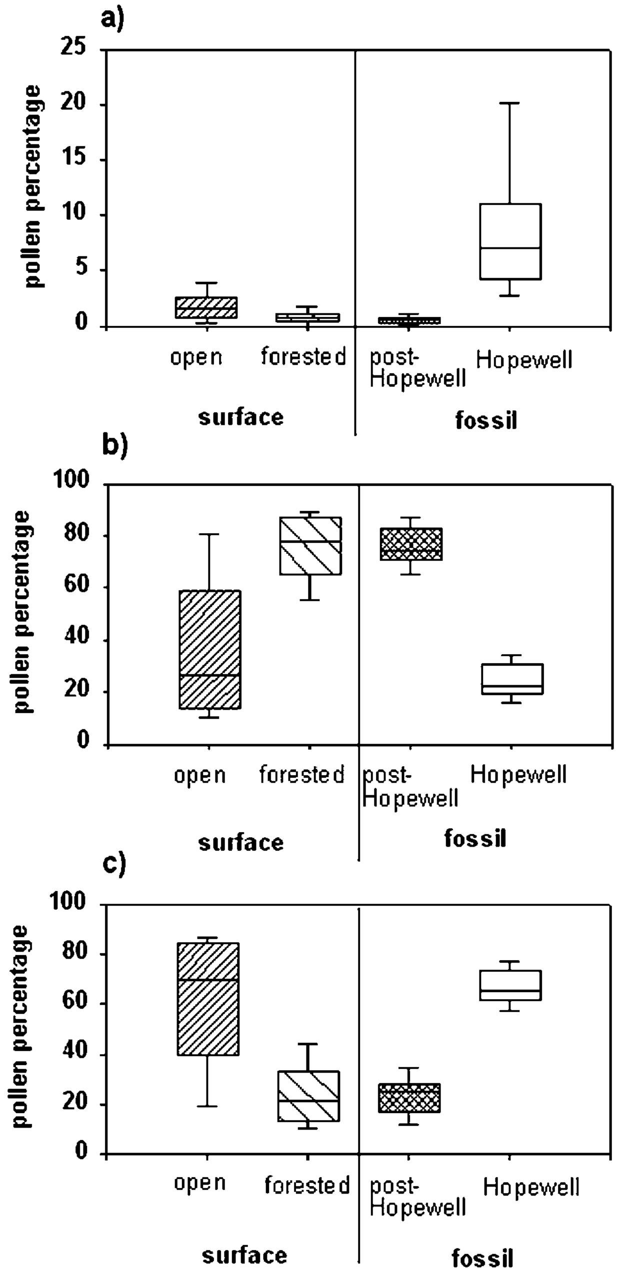

Figure 7 Boxplot of pollen percentages from all fossil and surface pollen samples. Pollen from *Iva annua*-type, *Polygonum erectum*-type and Chenopodiaceae makes up the 'cultigen' category. Fossil samples labelled 'post-Hopewell' are from zone 2, and samples labelled 'Hopewell' are from zone 1. Fossil pollen samples deposited during Hopewell times are different from all other samples because they have higher percentages of cultigen pollen.

high rates of erosion at that time in the watershed of these ponds. The ponds received material presumably eroded from the adjacent earthen walls and also from the small catchment that was constructed by the Hopewell people to supply each pond with water. The high erosion rate and rapid accumulation of sediment suggests discontinuous vegetation cover and frequent disturbance by the Hopewell people at this site. This type of environment might be expected if Hopewell people were practising agriculture at this site at that time.

There are several reasons that magnetic susceptibility indicates erosion. First, most topsoils are magnetically enhanced relative to soils deeper in the soil profile, so when the surface of the soil erodes into a body of water it enhances the magnetic signal in the sediments (Maher, 1998). Second, because the material eroding into the pond during zone 1 is mostly inorganic, there might have been higher inputs of ferrimagnetic minerals relative to organic matter during zone 1. Another possible cause of higher magnetic susceptibility during zone 1 is inputs of natural or anthropogenic charcoal, which has high magnetic susceptibility, into the ponds.

Cultigen pollen

The vegetation around the ponds during zone 1 produced an unusual pollen assemblage, with extremely high amounts of pollen similar to pollen from domesticated weedy taxa – *Iva annua*-type, Chenopodiaceae and *Polygonum erectum*-type. Several lines of evidence indicate that pollen from *Iva annua*, Chenopodiaceae and *Polygonum erectum* deposited during Hopewell times came from cultivated plants rather than their weedy relatives. First, multiple Hopewell cultigens are represented by pollen exclusively during Hopewell occupation. Although there was likely anthropogenic disturbance at the Fort Ancient site during Hopewell times, other plants that indicate disturbance, such as *Plantago*, are conspicuously absent, suggesting that cultivated taxa were favoured over other weedy plants. In addition, *Polygonum erectum* and *Iva annua* are not abundant in Ohio today, despite high levels of disturbance, which indicates that certain conditions are necessary for them to thrive. The final line of evidence is that modern surface samples from weedy areas are not similar enough to the pollen assemblages of zone 1. No surface samples contain large amounts of cultigen pollen, even those from floodplain and other environments where *Iva*, *Chenopodium* and *Polygonum* spp. are growing (Table 2), suggesting that more dense populations than are observed on the modern landscape are needed to produce the levels of cultigen pollen found in zone 1.

A more extensive surface sample collection from disturbed and weedy areas might reveal a modern analogue for the palaeovegetation of Fort Ancient. In particular, an agricultural reenactment of potential Hopewell cultivation regimes occupying a large area would help determine the spatial scale and type of vegetation represented by pollen assemblages deposited during

Hopewell times. Surface samples from river floodplains, especially those where *Iva* and *Chenopodium* are common, might also provide an analogue to the vegetation of Fort Ancient during the Middle Woodland period. In addition, a macrobotanical analysis of the habitation features at Fort Ancient would help in the interpretation of the Middle Woodland fossil pollen assemblages. For example, the macrobotanical assemblages should contain *Iva*, *Chenopodium* and *Polygonum*, and they may also contain *Cucurbita pepo*, whose pollen could not be detected in this sediment record.

The presence of pollen taxa from known Woodland cultigens in sediments deposited during Middle Woodland times at Fort Ancient suggests that these plants grew abundantly near the ponds, presumably in gardens cultivated by Middle Woodland people. The presence of pollen from Middle Woodland cultigens near an upland archaeological site has also been detected in a pond in Kentucky, so Middle Woodland agriculture was probably not restricted to lowland areas (Delcourt *et al.*, 1998). High amounts of non-arboreal pollen, including pollen from *Chenopodium*, *Iva* and *Ambrosia,* were found in a sediment sample deposited during Middle Woodland times at a site in Tennessee, although *Zea mays* also occurs in this sample, which may indicate a different agricultural regime than that of the Middle Woodland people at Fort Ancient (Delcourt *et al.*, 1986).

Open vegetation

The high percentages of non-arboreal pollen and the low pollen-accumulation rates during zone 1 lead me to conclude that the landscape inside both the North Fort and the South Fort was largely deforested at the time of sediment deposition. Low pollen-accumulation rates such as these are found in lateglacial sediments and in modern pollen traps on grasslands (Ritchie and Litchti-Federovich, 1963). While non-arboreal pollen percentages do not straightforwardly reflect landscape openness (Sugita *et al.*, 1999), the zone 1 pollen assemblages at Fort Ancient are dominated by so much non-arboreal pollen (between 60% and 80%) that it is likely that the area immediately surrounding the ponds was deforested.

The pollen diagrams also suggest that these prehistoric people may have maintained a large open area outside the walls of Fort Ancient, as well as a cleared area inside the walls. Tree pollen is ubiquitous in surface samples from open patches within a forest because trees produce abundant pollen, and their pollen travels far, so arboreal pollen can overwhelm a signal from non-arboreal vegetation (Sugita *et al.*, 1997; Hicks, 1998). Low arboreal pollen-accumulation rates at Fort Ancient during Hopewell times clearly indicate that herbaceous plants dominated both local vegetation, which supplies most of the pollen entering small ponds, and background, or regional, vegetation. Although it is not clear how much area of the landscape is represented by pollen in small ponds when the vegetation is open, the clearance at Fort Ancient was probably larger than 200 m diameter. Hicks (1998) has shown that elevated non-arboreal pollen, even in a forested setting, indicates clearances larger than 200 m in diameter. However, the clearance was not so extensive that herbaceous taxa are represented in contemporaneous pollen assemblages in sediments of nearby larger lakes, including Fudger Lake, approximately 60 km to the north (40°06′N, 83°32′W) (Ogden, 1966; Shane *et al.*, 2001).

Post-Hopewell record

During zone 2, the fossil pollen assemblages indicate development of an oak-hickory woodland similar to the one growing at Fort Ancient today, with little change in species composition over time. Sediment-deposition rates slow down considerably, indicating stabilization of the soil surface in the watershed, probably through the development of forested vegetation. Magnetic susceptibility values in zone 2 are lower than values for zone 1, further indicating lower rates of erosion during zone 2. The traditional signal of North American agriculture after European settlement is not apparent in these sediment records. It is quite possible that the disturbance of the ponds during European settlement, including the installation of a limestone wall and drain in the South Fort pond, damaged or removed the post-European sediment horizon.

It is noteworthy that the Mississippian Fort Ancient culture (AD 1000–1500), which had a maize-based subsistence economy, did not leave a clear signal in the sediment record of the ponds, even though there is a Mississippian Fort Ancient village about 1 km away, on the floodplain 50 m below the hilltop enclosure. The ponds from which I obtained my sediment records are 10 m in diameter, located on top of a steep-sided bluff. Thus, they probably do not receive much pollen from the floodplain of the Little Miami River, especially maize pollen which is large and poorly dispersed. Unless agricultural fields were adjacent to the ponds I sampled, it would be very difficult to detect Mississippian influence on the local or regional vegetation once the landscape had reforested (Sugita *et al.*, 1997), although that does not mean that Mississippian environmental impact was negligible.

The pollen signal of prehistoric land use during Hopewell occupation, although it is accompanied by high percentages of *Ambrosia* pollen, is fundamentally different from the pollen signal of European-style agriculture in North America (McAndrews, 1988). The traditional signal of European-style agriculture includes pollen of *Ambrosia*, *Rumex*, *Plantago*, Poaceae and Cyperaceae, but it does not include many crop taxa because many European crops do not produce much pollen (McAndrews, 1988). The disturbance regime associated with Middle Woodland agriculture, although not well characterized, is probably different from either the disturbance regime associated with Native American maize agriculture, which includes the weed *Portulaca*, or European-style agriculture in North America (McAndrews and Boyko-Diakonow, 1989).

Conclusions

This pollen record reveals that prehistoric agriculture in North America was more extensive than previously assumed, and it raises the question of how much impact Native American agriculture had on vegetation in eastern North America. At Fort Ancient, the Hopewell people were not just exploiting small natural clearings within a forested matrix, creating ephemeral clearings, or exclusively modifying river corridors for agriculture, as archaeologists have believed (Prufer, 1997). Rather, the Hopewell cleared the area within and possibly surrounding Fort Ancient, and likely cultivated crops at this site for several hundred years. This evidence causes us to reconsider the nature, extent and geographical distribution of prehistoric human impacts on the North American landscape. Although this sediment record reflects the vegetation history at only one archaeological site, the Woodland people in southern Ohio alone constructed at least seven similar hilltop enclosures and several hundred other earthworks such as geometric earthworks, effigy mounds and burial mounds (Connolly, 1996a; Squier and Davis, 1848). Even if the human impact at each archaeological site was localized to a 2 km radius, over a period of 600 years, the earthmoving activities and agricultural practices of the Middle Woodland people must have substantially affected the vegetation of southern Ohio. Woodland people also modified the forests of eastern North America through the use of fire (Delcourt and Delcourt, 1997; 1998; Delcourt *et al.*, 1998).

In addition, this pollen record reconciles the general problem of discord between the North American archaeological record and the palaeoecological record, clearly demonstrating that prehistoric human activities can be recorded in sediments if the correct conditions are met. These include appropriate basin size to detect human activities of a particular spatial and temporal scale and location of the basin near an archaeological site. Pollen analysis of more sediment cores from upland archaeological sites and river floodplains could help refine our understanding of the extent and location of Woodland agriculture.

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