HOPEWELL BLADELETS: A BAYESIAN RADIOCARBON ANALYSIS

G. Logan Miller

Hopewell bladelets may be the most common diagnostic artifact of the Hopewell Interaction Sphere. As such, they are often recognized as a Middle Woodland "index fossil" and a key materialized indication of Hopewell ceremonialism. However, few formal analyses of their occurrence across space and time exist. Drawing on published reports, as well as an extensive review of the unpublished gray literature, I present a Bayesian analysis of radiocarbon-dated, bladelet-bearing features from across Ohio. The Bayesian model provides insight into previously unrecognized temporal variation in this element of Hopewell material culture. Results indicate that bladelets are present from around the BC/AD switch to nearly AD 500 in certain portions of the state. Analysis by major drainages indicates that bladelets occur earliest in southern and central Ohio before subsequently spreading north to the Lake Erie region. Understanding the spatial and temporal variation in artifact classes such as Hopewell bladelets is essential to explaining prehistoric cultural processes.

Las navajillas Hopewell pueden considerarse el artefacto de diagnóstico más común de la esfera de interacción Hopewell. Como tal, a menudo se les reconoce como "fósil índice" del Silvícola medio y un indicador material clave del ceremonialismo Hopewell. Sin embargo, existen pocos análisis formales de su ocurrencia a través del espacio y el tiempo. Con base en informes publicados y en una extensa revisión de la literatura gris inédita, se presenta un análisis bayesiano de rasgos contenientes navajillas y fechados por radiocarbono a lo largo del estado de Ohio. El modelo bayesiano revela una variación temporal no anteriormente reconocida en este elemento de la cultura material Hopewell. Los resultados indican que las navajillas estuvieron presentes en ciertas partes del estado entre el primer y quinto siglo dC. Tomando en cuenta su distribución alrededor de los drenajes principales, el análisis revela que las navajillas ocurren primero en Ohio meridional y central y luego se difunden hacia la región del Lago Erie en el norte. Un entendimiento preciso de la variación espacial y temporal de clases de artefactos como las navajillas Hopewell es esencial para explicar los procesos culturales prehistóricos.

Understanding the spatial and temporal distribution of patterns in material culture has always been of central importance to archaeological inference (Binford 1965; Dunnell 1971; McKern 1939; Thomas 1894; Willey and Phillips 1958; Willey and Sabloff 1993). Since the mid-twentieth century, radiocarbon dating has played a vital role in building archaeological chronologies worldwide (Libby 1955), and accelerator mass spectrometry dates and Bayesian modeling have led to what many describe as a continuing radiocarbon revolution (Bayliss 2009). As a baseline for the explanation of variation in material culture, one must first establish a detailed understanding of the spatiotemporal distribution of material culture. This issue is particularly important in cases where large-scale regional similarities may mask local variation. In these cases, archaeologists often downplay local variation by focusing on shared regional material culture. Such is the case with Hopewell ceremonialism in eastern North America, while similar arguments can be made for the archaeology of Clovis, Adena, or Mississippian. As Charles recently lamented, there is a widely held "conception (or at least presentation) of Hopewell as a uniform and singular entity in which any temporal and spatial variation in the manifestations of the phenomenon is largely ignored" (2012:471). Although studies of Hopewell variation exist (e.g., Charles 1995; Clay 2014; Emerson et al. 2013; Struever 1964;

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Wright 2014), we should pay more attention to what could have been a dynamic and ever-changing process of Hopewell ceremonialism. To do so, I analyze temporal and spatial variation in one element of Hopewell material culture, chipped-stone bladelets. Drawing on published reports, as well as on an extensive review of unpublished survey reports, I present a Bayesian analysis of radiocarbon-dated, bladelet-bearing features from across Ohio in order to examine spatiotemporal variation in the use of this diagnostic artifact. Results highlight previously unrecognized variation in the timing of bladelet use throughout Ohio.

Hopewell

The term *Hopewell* refers to an archaeological horizon during the Middle Woodland period of eastern North America, one characterized by dispersed settlements, horticultural subsistence, earthwork construction, elaborate mortuary ceremonialism, and long-distance exchange networks known as the Hopewell Interaction Sphere (Abrams 2009; Caldwell 1955; Charles 2012; Dancey 2005; Sieg and Hollinger 2005; Struever 1964). While Hopewellian manifestations were present throughout the Eastern Woodlands, the core area of cultural expression was along the major rivers of south and central Ohio. Through extensive trade networks, groups along these rivers obtained materials such as copper from the Lake Superior region, marine shells from the Gulf Coast, obsidian from the Yellowstone Plateau of Wyoming, and mica from the Appalachian Mountains (Abrams 2009; Bernardini and Carr 2005; Boulanger et al. 2017; Dancey 2005). These materials were crafted into elaborate display objects and used in ceremonial gatherings at earthworks and mound centers. The earthworks were often constructed in geometric shapes such as circles, squares, octagons, or combinations of the three. Hilltop enclosures, which appear to follow the natural contour of elevated ridges but which may have been built upon anthropogenically modified terrain, are also common (Connolly 1996). Outside of the earthworks, groups lived in small dispersed settlements subsisting by hunting, gathering, and cultivating seed crops (Dancey and Pacheco 1997; Kanter et al. 2015; Pacheco, Burks, and Wymer 2005, 2009; Pacheco and Dancey 2006).

Hopewell Bladelets

In addition to exotic raw materials and monumental constructions, a distinctive and widespread Hopewell artifact is the bladelet (Greber, Davis, and DuFresne 1981; Pi-Sunyer 1965). However, despite their frequency and importance for recognizing the Hopewell horizon, few formal analyses of their spatial and temporal distribution exist.

Hopewell bladelets have a length-to-width ratio of at least two to one, roughly parallel margins, and a triangular, trapezoidal, or prismoidal cross section (Greber, Davis, and DuFresne 1981; Miller 2015; Pi-Sunyer 1965). They are produced from high-quality, colorful, and often heat-treated cherts. In Ohio, these often include Flint Ridge chert from central Ohio, Harrison County chert (also known as Indiana Hornstone or Wyandotte) from southern Indiana, and Knox chert from Tennessee. Bladelets of Flint Ridge chert from central Ohio not only are found throughout the state but have been recovered far into the Southeast from sites in Tennessee, North Carolina, and Georgia (Kay and Mainfort 2014; Keith 2013; Kimball 1992; Wright 2014). Numerous Flint Ridge bladelets have also been recovered in the Havana Hopewell heartland of the Illinois River valley (Emerson et al. 2013; Farnsworth and Atwell 2015; Nolan and Bainter 2004). After examining metric variation and production errors among the bladelet assemblage at the Turner Workshop, Nolan, Seeman, and Theler (2007) concluded that bladelets were not made by specialists. Ohio Hopewell bladelets were rarely retouched, and even more rarely hafted, while used for a wide range of tasks (Miller 2014a, 2015). Functional analysis indicates that bladelets in Ohio were used in a generalized manner as butchery, cutting, scraping, perforating, drilling, and incising tools (Miller 2014a, 2015; Yerkes 1990, 1994, 2009). Essentially, archaeologists have documented their use in nearly all productive tasks expected of stone tools outside of heavy-duty woodworking and projectile use. They have also documented their

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generalized nature at both earthworks and habitation sites, although bladelets were employed in craft production at some earthworks (Miller 2015). Thus, use for a wide range of tasks and manufacture by nonspecialists characterize the Ohio Hopewell bladelet industry as a standardized, but not a specialized, one (Miller 2014a; Nolan, Seeman, and Theler 2007; Yerkes 1994).

Many argue that the function of Hopewell bladelets extended beyond their use as processing or manufacturing tools to elements of reciprocal exchange (Braun 1986; Hofman 1987; Reid 1976; Yerkes 2002, 2003) or mortuary preparation (Jefferies 2006; Odell 1994; Seeman 1979; Walthall 1985). For example, Odell (1994) argues that differences in the use-wear on bladelets between Smiling Dan and Napoleon Hollow in the lower Illinois River valley indicate that bladelets were used in mortuary preparation at Napoleon Hollow and took on special symbolic meaning in the process. Byers (2006, 2011, 2015) expands this reasoning to argue that bladelets were preferred over flakes in ritual contexts within earthworks and elsewhere. In these contexts, cultural belief prescribed that bladelets could only be used for one task, according to Byers. To Byers, outside of the ritual context, bladelets could have been used interchangeably with expedient flake tools because bladelets lost their symbolic significance. On the other hand, use-wear evidence indicates that while bladelets were often used for one task, there are examples of bladelets being reused for additional activities (Miller 2014a, 2015; Yerkes 1994). In addition, testing the symbolic reasoning behind someone choosing a bladelet or a flake 2,000 years ago will prove difficult. Although based on a small sample, the fact that bladelets were more often associated with female burials at four mound centers in the lower Illinois River valley (Leigh 1988:202–203) suggests that bladelet use was gendered.

Two morphologically distinct types of Hopewell bladelets have been identified in the archaeological record. Centered in the Illinois River valley, Havana Hopewell bladelets tend to be longer and wider and have larger platforms than Ohio bladelets (Greber, Davis, and DuFresne 1981; Pi-Sunyer 1965). The variation is likely due to differences in production technique. Montet-White (1968) argued that the direct predecessor of Hopewell blade core technology emerged from an Archaic period bifacial technique in the Illinois River valley. This so-called Cobden technique was a flexible technology used through the Early Woodland period to produce blades, flakes, and preforms resulting in irregular cores (Montet-White 1968:28). With the beginning of the Middle Woodland period, Montet-White saw the Cobden technique replaced by the distinctive Fulton technique in the central and lower Illinois Valley. The Fulton technique is a highly inflexible technology used to produce bladelets from large, loaf-shaped prepared cores. Harkness (1982) describes Ohio Hopewell bladelet cores as largely conical Goslin cores from which knappers removed bladelets through soft hammer or pressure flaking. Similar to the bladelets themselves, Ohio Hopewell bladelet cores tend to be smaller than Havana Hopewell bladelet cores.

The timing of the emergence and decline of the Hopewell bladelet industry generally coincides with the larger Hopewell horizon or Hopewell Interaction Sphere, which spread throughout the Eastern Woodlands sometime between 200 BC and AD 400. However, after examining bladelets from Twenhafel, a mound center and habitation site in the Mississippi Valley of southern Illinois, Morrow (1998) argued that a bladelet industry existed before and after the introduction and decline of Hopewell pottery at the site. Other studies in Illinois (e.g., Fortier 2000; Odell 1994:117) failed to replicate this, finding direct correlation between the rise and fall of Hopewell Interaction Sphere items and Hopewell bladelets. No similar studies currently exist in Ohio. As most explanations for the rise and decline of bladelet technology place the tool's purpose in some aspect of Hopewell ceremonialism (i.e., craft production, exchange, or mortuary preparation), a fine-grained chronology of relevant dates for the technology is essential.

Methodology

While blade industries were present at various times throughout the prehistory of eastern North America (Parry 1994), the distinctive style and

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materials used for Hopewell bladelets make them readily identifiable. As such, archaeologists use them to identify Middle Woodland Hopewell components at surface-collected sites (e.g., Dancey and Pacheco 1997). But no formal examination of the temporal span of the bladelet industry in Ohio has been undertaken to verify this relationship. Here I present a Bayesian radiocarbon analysis examining the rise and fall of bladelets in Ohio. While modern political boundaries obviously did not exist in prehistory, Ohio's state boundaries are marked by physiographic features that would have been important in prehistory. On the southern border is the Ohio River; Hopewellian remains rarely occur to the south in Kentucky. Much of the northern portion of the state is bounded by Lake Erie. In between, the major river valleys examined here (Little Miami, Licking, Muskingum, Scioto, Huron, and Cuyahoga) are all contained within the state's boundaries.

The Bayesian analysis utilizes the software OxCal version 4.2 (Bronk Ramsey 2009a; Bronk Ramsey and Lee 2013) and the IntCal 13 ^{14}C calibration curve (Reimer et al. 2013). Bayesian analysis calculates the posterior probability distributions of a sequence of dates in conjunction with some level of prior, or a priori, knowledge input from the researcher (Bronk Ramsey 2009a). After defining the parameters and inputting the data, the OxCal software calculates the start and end date ranges for each sequence or phase at 68.2% and 95.4% confidence intervals, as well as a median age for each range based on the assumption that the ^{14}C dates are drawn from a sample within a normal distribution. A further strength of the analysis is that it can identify dates as outliers and minimize their impact through outlier modeling (Bronk Ramsey 2009b). Individual dates and overall models with an Agreement Index (A_{model}) greater than 60 are generally assumed to be unproblematic.

The two most widely used Bayesian models are sequences and phases (Bronk Ramsey 2009a). Sequence analysis applies to dates excavated in stratigraphic order or other events that presumably proceed in a chronological series. Sequence analysis determines the degree to which the dates form a chronological progression while also reducing the error range of each date. A phase analysis assesses the relationship between dates for which no internal order or stratigraphy can be assumed, such as a group of dates within the same depositional level. However, assessment of the temporal relationships between two or more phases is sometimes possible based on the occurrence of certain a priori parameters. Phases may be contiguous, sequential, or overlapping. The boundaries between contiguous phases directly adjoin one another with no temporal gap in between. Sequential phases occur one after the other but with a potential chronological gap in between. In overlapping phases, their order is not known, and one may start before the other ends.

It would be ideal to directly date bladelets from carbonized residue deposited on the artifacts, as is often applied to ceramics (e.g., Berstan et al. 2008; Nakamura et al. 2011; Taché and Hart 2013). While some stone tools may retain protein residues or starch grains, the organic material necessary for accelerator mass spectrometry ^{14}C dating is rarely present. One feasible approach to generating a ^{14}C database would be to use all dates from sites that contain bladelets in their assemblage. However, we obtain a more accurate picture by using dates obtained from discrete features that contain bladelets within their fill. This approach addresses the potential for dating the reoccupation of sites by groups without bladelets (including the possibility of non-bladelet-producing Hopewell groups) or the circular logic of only selecting Middle Woodland dates from these sites. After identifying dates meeting these criteria, I conservatively applied chronometric hygiene protocols (e.g., Nolan 2012; Pettitt et al. 2003; Wilmhurst et al. 2011). These protocols included two criteria: the rejection of dates with error ranges >100 years as well as those obtained prior to 1970. Due to this sample selection procedure, I assume that any remaining anomalous dates, or outliers, are of the t-type, in which the sample dated is unrelated to the event intended to be dated (Bronk Ramsey 2009b), such as more recent carbonized material introduced into older deposits through bioturbation. Dates fitting this description are examined individually below.

The statewide database of ^{14}C dates includes those published in articles, books, theses,

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dissertations, and compliance survey reports on file at the State Historic Preservation Office in Columbus, Ohio. Features that included a ^{14}C date and contained one or more bladelets in their artifact inventory were included in this analysis. I evaluated photos or line drawings in the original reports to confirm the analyst's ability to identify Hopewell bladelets. Application of this procedure identified 62 ^{14}C dates from 57 features at 31 sites throughout Ohio (Table 1). The calibrated 2σ range of all dates obtained from features with Hopewell bladelets spans from 1123 cal BC to cal AD 1387 (Supplemental Table 1). This date range is highly incongruent with the current understanding of the timing of the rise and fall of the Hopewell Interaction Sphere and other technological developments in the Eastern Woodlands, which raises two possibilities. Either there is a need to drastically revise the current understanding of the technological and related cultural elements of Ohio and probably eastern North American prehistory, or simply plotting the calibrated distributions of radiocarbon dates associated with Hopewell bladelets yields unsatisfactory results that seemingly greatly overestimate the span during which this technology was in use. Occam's razor suggests that the latter is far more likely, as several outliers are undoubtedly present in this large collection of dates from many different sources.

Defining the Model and Identifying Outliers

Radiocarbon dates were grouped into phases based on their occurrence within different watersheds (Figure 1). The 62 ^{14}C dates came from 31 sites located in the watersheds of six different rivers (Table 1). Only three dates were identified from the Hocking River valley. These dates are widely separated in time and therefore do not provide an informative picture of bladelet use in the area. Thus, the Hocking Valley is omitted from the current analysis. Due to a similarly small sample, ^{14}C dates from the Cuyahoga River valley were combined with those from the Huron River valley into one Lake Erie watershed phase. Therefore, the analysis contains four phases. An overlapping phase model was used in this case so that no prior assumption about the spread of the technology from one region to another was included; this allows for the possibility that bladelets were introduced into new regions before their use in other regions ended.

A model that includes all ^{14}C dates sorted into four phases, as described above, produced an acceptable Agreement Index score of 80.0 (see Supplemental Text for R code). Only one ^{14}C date, from the Scioto Valley (Beta-48081, A = 19.7), was flagged as an outlier. The excavators also identified this date as "spurious" (Aument and Gibbs 1991:83). The material was recovered from a pit with an "irregular oval shape" in plan view (maximum dimensions 140 × 68 cm), 22 cm in depth, with a "squared basin" shape in profile (Aument and Gibbs 1991:78). Numerous bladelets, including 20 complete specimens made from Flint Ridge chert, represent the only temporally diagnostic artifacts recovered from the feature. Other materials recovered from this feature were fire-cracked rock, burned bone, ceramics, and chipped stone debitage. The ceramics were all grit-tempered body sherds, too small and eroded to be further evaluated. The carbon sample submitted for radiocarbon dating was composed of "scattered charred wood fragments" (Aument and Gibbs 1991:80). In retrospect, Aument and Gibbs note that some of the wood may actually have been "recent corn plant remains" (1991:83). Thus, multiple lines of evidence suggest that Beta-48081 is an outlier and should be removed from the model. The removal of Beta-48081 results in the next most recent date (Beta-109964, A = 43.7) being flagged as an outlier.

The stepwise identification and removal of outliers results in the six most recent ^{14}C dates being omitted from the model before a result with no outliers is produced. The resulting boundary end (68% probability: cal AD 250 to 330; 95.4% probability: cal AD 170 to 380; median: cal AD 290) is substantially earlier than the original modeled result (see Table 2). In each case, the A_{model} value is well above 60, indicating that "there is no problem with the model as a whole (and therefore no samples need be rejected)" (Bronk Ramsey 2009b:1025). Several issues may be at play here in the Scioto Valley. One is that several of the dates may be spurious, as Beta-48081 was determined to be. Another potential confounding factor is that there may have been

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Table 1. Radiocarbon Data.

Sample ID	Material	^{14}C BP	Site	Feature	Drainage	Reference
Beta-15011	Wood charcoal	1650 ± 60	33SU138 (Stanford Knoll)	1	Cuyahoga (Lake Erie)	Finney 2002
Beta-15012	Charcoal	1780 ± 60	33SU138 (Stanford Knoll)	11	Cuyahoga (Lake Erie)	Volf 2000
Beta-147367	Nutshell	1600 ± 40	33SU434 (Szalay)	22	Cuyahoga (Lake Erie)	Richner and Bauermeister 2009
Beta-215829[a]	Charcoal	1670 ± 50	33AT980	04:54.7	Hocking	Pecora and Burks 2006
Beta-216729[a]	Charcoal	1890 ± 40	33AT980	62	Hocking	Pecora and Burks 2006
Beta-95832[a]	Charcoal	2300 ± 70	33PE361	16	Hocking	Schweikart, Church, and Ericksen 1997
Beta-276822	Charcoal	1780 ± 50	33ER14 (Heckelman)	09-36	Huron (Lake Erie)	DeMuth et al. 2016
Beta-290291	Wood	1770 ± 40	34ER14 (Heckelman)	21	Huron (Lake Erie)	Redmond and Scanlan 2011
Beta-290293	Nutshell	1730 ± 40	35ER14 (Heckelman)	34	Huron (Lake Erie)	Redmond and Scanlan 2011
Beta-332683	Charcoal	1640 ± 30	36ER14 (Heckelman)	12-06	Huron (Lake Erie)	Boatman 2014
Beta-335374	Nutshell	1780 ± 30	37ER14 (Heckelman)	12-34	Huron (Lake Erie)	Redmond and Scanlan 2013
Beta-28609	Charcoal	1780 ± 40	38ER14 (Heckelman)	09-37	Huron (Lake Erie)	DeMuth et al. 2016
Beta-315578[a]	Nutshell	2210 ± 30	33ER557 (Metz site)	1	Huron (Lake Erie)	DeMuth et al. 2016
Beta-429898[a]	Charcoal	2220 ± 30	33ER85 (Seaman's Fort)	2	Huron (Lake Erie)	DeMuth et al. 2016
Beta-16620	Wood	1760 ± 60	33LI212 (Murphy)	100A	Licking/Muskingum	Dancey 1991
Beta-36272[a]	Charcoal	2360 ± 90	33LI311 (Murphy III)	2	Licking/Muskingum	Pacheco 1991
Beta-36274[a]	Nutshell	2235 ± 60	33LI311 (Murphy III)	1	Licking/Muskingum	Pacheco 1991
Beta-36277[a]	Charcoal	2310 ± 70	33LI311 (Murphy III)	1	Licking/Muskingum	Pacheco 1991
Beta-295845	Charcoal	1920 ± 50	33LI1767	18	Licking/Muskingum	Brown 2011
Beta-28062	Charcoal	1845 ± 60	33LI252 (Hale's House)	15	Licking/Muskingum	Lepper and Yerkes 1997
Beta-37356	Charcoal	1560 ± 60	33MU304	18	Licking/Muskingum	Church, Cremeens, and Ericksen 1991
Beta-?[a]	Charcoal	2790 ± 70	33WN425	1	Licking/Muskingum	Pecora, Kener, and Burks 2005
Beta-26468	Charcoal	1660 ± 60	33HA588	1	Little Miami	Kozarek, Myers, and Connolly 1993
Beta-111467	Charcoal	1850 ± 60	33WA2 (Fort Ancient)	316/95	Little Miami	Connolly 2004
Beta-111468	Charcoal	1750 ± 60	34WA2 (Fort Ancient)	483/95	Little Miami	Connolly 2004
UGAMS-13478[b]	Nutshell	1840 ± 30	35WA2 (Fort Ancient)	52/96	Little Miami	Miller 2014b
UGAMS-13479[b]	Nutshell	1790 ± 25	36WA2 (Fort Ancient)	52/96	Little Miami	Miller 2014b
UGAMS-13481[b]	Nutshell	1750 ± 25	33WA362 (Smith)	37-01	Little Miami	Miller 2014b
UGAMS-13480[b]	Nutshell	1750 ± 30	33WA765 (Circle Overlook)	Test Unit 1, Level 2	Little Miami	Miller 2014b
Beta-251620[b]	Oak	1950 ± 40	33WA2 (Moorehead Circle)	08-80	Little Miami	Riordan 2011
Beta-147063	Wood, hickory nutshell	1820 ± 40	33FA156-158 (Strait)	4	Scioto	Burks 2004

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Table 1. Continued

Sample ID	Material	^{14}C BP	Site	Feature	Drainage	Reference
Beta-147184	Hickory nutshell	1960 ± 50	33FA156-158 (Strait)	4	Scioto	Burks 2004
Beta-??[b]	Charcoal	1750 ± 40	33FR1521	1	Scioto	Weller, Burks, and Burcham 1999
Beta-235190	Charcoal	1870 ± 40	33FR561	3	Scioto	Weller 2008
Beta-235191	Charcoal	1850 ± 50	34FR561	4	Scioto	Weller 2008
Beta-235192	Charcoal	1610 ± 40	35FR561	7	Scioto	Weller 2008
Beta-48081[a]	Wood	770 ± 60	33FR895 (Walmart site)	Anomaly 107	Scioto	Aument and Gibbs 1991
Beta-109963[a]	Charcoal	1900 ± 50	Redwing site	3	Scioto	Ruby and Lynott 2009
Beta-109964[a]	Charcoal	1150 ± 40	Redwing site	3	Scioto	Ruby and Lynott 2009
Beta-231668[b]	Hickory nutshell	1900 ± 40	33RO1059	7	Scioto	Bauermeister 2010
Beta-231669[b]	Hickory nutshell	1850 ± 40	34RO1059	8	Scioto	Bauermeister 2010
Beta-220008	Wood	1880 ± 50	33RO1090	106	Scioto	Baltz and Picklesimer 2007
Beta-213557	Wood	1940 ± 60	33RO1090	12	Scioto	Baltz and Picklesimer 2007
Beta-220009	Wood	1910 ± 50	33RO1090	106	Scioto	Baltz and Picklesimer 2007
Beta-181497	Honey locust	1820 ± 80	33RO110 (Overly Tract)	8	Scioto	Dancey 2009
Beta-181499	Hickory nutshell	1890 ± 80	33RO110 (Overly Tract)	21	Scioto	Dancey 2009
Beta-181500	Honey locust	1810 ± 60	33RO110 (Overly Tract)	23	Scioto	Dancey 2009
Beta-181501	Honey locust	1720 ± 60	33RO110 (Overly Tract)	31	Scioto	Dancey 2009
Beta-206205	Wood	1750 ± 60	33RO1104 (Brown's Bottom #1)	38	Scioto	Pacheco, Burks, and Wymer 2005
Beta-210517	Composite wood	1890 ± 50	33RO1104 (Brown's Bottom #1)	135	Scioto	Kanter et al. 2015
UGAMS-28067[b]	Tuber fragment	1780 ± 23	33RO1104 (Brown's Bottom #1)	196	Scioto	Nolan, Seeman, and Hill 2017
Beta-242883	Nutshell	1650 ± 60	33RO1105 (Lady's Run)	421	Scioto	Pacheco, Burks, and Wymer 2009
Beta-242885[b]	Bark	1800 ± 40	33RO1105 (Lady's Run)	403	Scioto	Pacheco, Burks, and Wymer 2009
Beta-293457[b]	Nutshell	1780 ± 30	33RO1105 (Lady's Run)	673	Scioto	Kanter et al. 2015
UGAMS-28069[b]	Hazelnut	1720 ± 23	33RO1105 (Lady's Run)	358	Scioto	Nolan, Seeman, and Hill 2017
UGAMS-28070[b]	Black walnut shell	1810 ± 24	33RO1105 (Lady's Run)	421	Scioto	Nolan, Seeman, and Hill 2017

Table 1. Continued

Sample ID	Material	^{14}C BP	Site	Feature	Drainage	Reference
DIC-860	Charcoal	1500 ± 50	33RO22 (Harness Mound)	53A	Scioto	Greber 1983
Beta-159033	Charcoal	1740 ± 50	33RO26 (Hopeton)	6	Scioto	Lynott 2014
Beta-176578	Charcoal	1900 ± 50	33RO26 (Hopeton)	9	Scioto	Ruby and Lynott 2009; Weymouth, Bevan, and Dalan 2009
Beta-176579	Wood	1900 ± 40	33RO26 (Hopeton)	14	Scioto	Lynott and Mandel 2009
Beta-177507	Charcoal	1990 ± 70	33RO26 (Hopeton)	6	Scioto	Lynott 2014
Beta-147064	Charcoal	1650 ± 50	Triangle site	64	Scioto	Lynott 2009

[a]Eliminated from the final analysis. See the text for reasoning.
[b]Accelerator mass spectrometry.

variation in the termination of the use of bladelets throughout the river valley.

Given the obvious issues with Beta-48081, it seems safe to assume that this is an outlier and should be removed. The next most recent date, Beta-109964, was run on a sample of wood charcoal from a midden feature at the Redwing site outside of the Hopeton earthworks in Ross County. Another sample of wood charcoal from this midden feature (Beta-109963) returned a date of 1900 ^{14}C BP (Table 1). These two samples are significantly different as calculated in Calib 7.0.4. It is unclear why two significantly different dates were obtained from the same feature. The excavators Ruby and Lynott (2009:113) note that while the midden contained only diagnostic Middle Woodland artifacts (bladelets and ceramics), Late Woodland Jack's Reef points were recovered from the site during surface survey. Thus, they attribute the more recent date to the intrusion of materials related to the later occupation. Rather than rejecting Beta-109964 and retaining Beta-109663 simply because the former does not fit the accepted range for "the construction and use of Hopewellian earthworks in the Scioto region" (Ruby and Lynott 2009:113), I eliminated both dates until this issue can be resolved. Since there are so many dates from the Scioto River valley, if one or both of these are part of a larger pattern, similar dates will emerge at other sites.

Because no similarly obvious material or contextual issues are associated with the other four most recent dates in the Scioto phase, they are retained and produce an improved Agreement Index ($A_{model} = 87.1$). The results of this analysis are presented in Table 2 and Figure 2 (see Supplemental Figures 1–4 for plots of all probability distributions associated with each phase).

Further Refinements

In their current state, these phases suggest that a drastic revision of the temporal range of bladelet use in Ohio is necessary. However, while the OxCal Agreement Index is useful for identifying outliers through statistical analysis, it cannot take context or material dated into account. Due to the nature of the analysis in which features, rather than Ohio Hopewell bladelets directly, are dated, I undertook further analysis to identify additional potential t-type outliers in the database before making such a grand claim. I took a pragmatic approach to this process by examining the probability plots of ^{14}C dates in each phase. The majority of ^{14}C dates in each phase overlapped substantially at 2σ, generally covering the first several centuries AD. Dates that were substantially older or more recent, whose probability distributions did not overlap with the core group of ^{14}C dates at 2σ, were flagged for further analysis (as seen in Supplemental Figures 1–2). This procedure resulted in the identification of four older ^{14}C dates from the Licking/Muskingum phase (Beta-?, Beta-36272, Beta-36274, and Beta-36277) and two older ^{14}C dates from the Lake Erie phase (Beta-429898, Beta-315578). Recall that more recent ^{14}C dates from the Scioto phase (Beta-109964 and Beta-

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Table 2. Results of the Four-Phase Bayesian Analysis.

Phase	68.2% Probability	95.4% Probability	Median
Lake Erie start	390 to 245 BC	540 to 210 BC	330 BC
Lake Erie end	AD 415 to 565	AD 390 to 725	AD 515
Licking/Muskingum start	1165 to 860 BC	1595 to 810 BC	1050 BC
Licking/Muskingum end	AD 425 to 725	AD 340 to 1170	AD 600
Little Miami start	AD 5 to 210	70 BC to AD 225	AD 80
Little Miami end	AD 275 to 400	AD 245 to 510	AD 350
Scioto start	AD 15 to 80	25 BC to AD 100	AD 45
Scioto end	AD 420 to 475	AD 390 to 530	AD 445

Note: Dates are rounded to the nearest five years; two outliers from the Scioto Valley were removed.

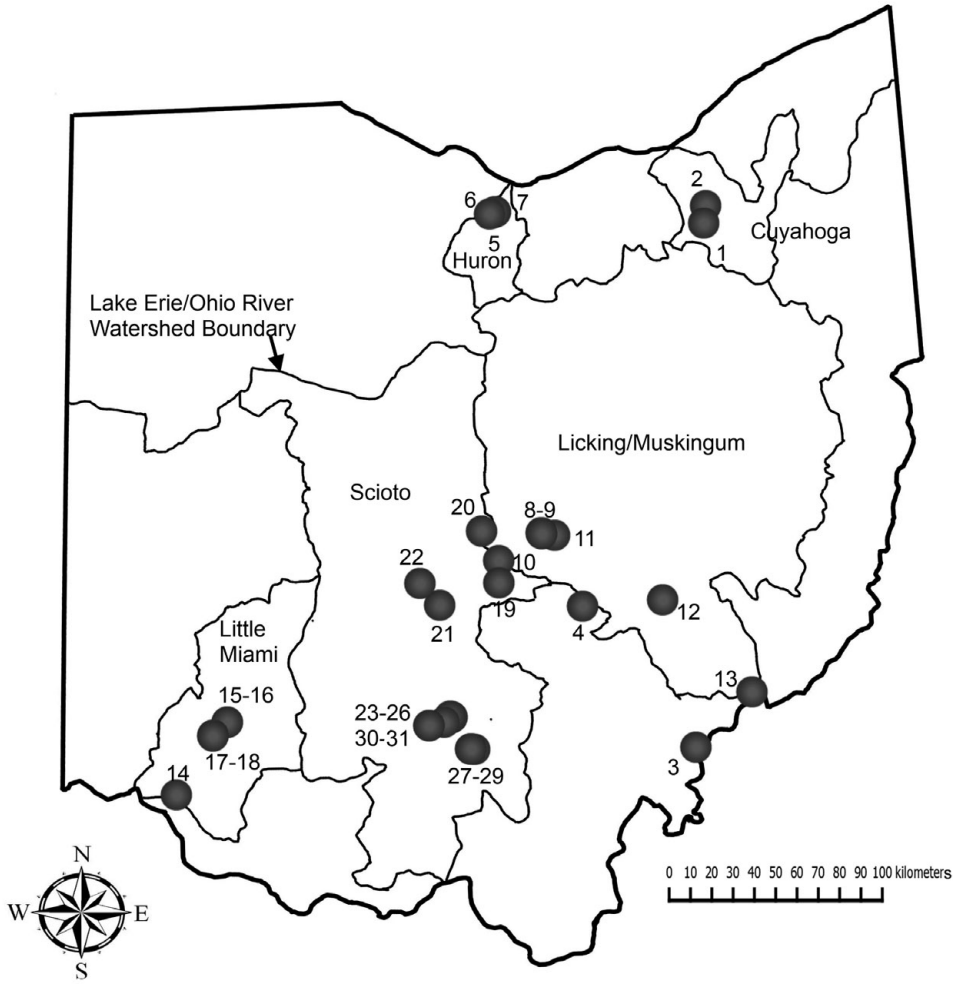


Figure 1. Map of Ohio showing watersheds and sites containing dated features with Hopewell bladelets: (1) 33SU138; (2) 33SU434; (3) 33AT980; (4) 33PE361; (5) 33ER14; (6) 33ER557; (7) 33ER85; (8) 33LI212; (9) 33LI311; (10) 33LI1767; (11) 33LI252; (12) 33MU304; (13) 33WN425; (14) 33HA588; (15) 33WA2; (16) Moorehead Circle; (17) 33WA362; (18) 33WA765; (19) 33FA156-158; (20) 33FR1521; (21) 33FR561; (22) 33FR895; (23) Redwing; (24) 33RO1059; (25) 33RO1090; (26) 33RO110; (27) 33RO1104; (28) 33RO1105; (29) 33RO22; (30) 33RO26; (31) Triangle.

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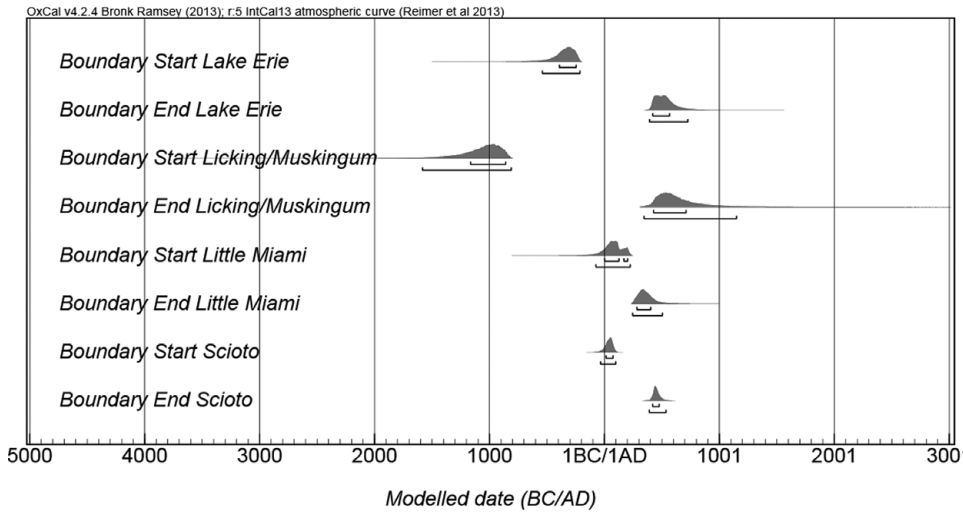


Figure 2. Plot of the start and end ranges (with median date [+] and 68% and 95% confidence intervals) for each of the four phases in the initial Bayesian analysis.

48081) have already been identified as outliers. None was identified in the Little Miami phase.

In the Licking/Muskingum phase there is a gap in the 2σ calibrated ranges from about 140 to 40 cal BC that produces two distinct groups of four ^{14}C dates each that do not overlap at 2σ (Supplemental Figure 2). The more recent group of dates more closely conforms to traditional conceptions of the temporal span of Hopewell. The early group of dates cannot be rejected simply because they fall outside of this time frame. However, several lines of evidence call these dates into question and invite caution before using these to drastically rethink the temporal position of Hopewell bladelet technology. Careful reading of the stratigraphy of features at Murphy III suggests that the dates and bladelets are actually from different features. Pacheco (1991) notes that there is an Early Woodland component (lacking bladelets) at the site with a similar footprint to the Middle Woodland component (with bladelets). Charcoal was collected "from the bottom" of Features 1 and 2, while bladelets were recovered from the upper fill (Pacheco 1991:5). In other words, "Early Woodland features were partially filled with the trash of the later more extensive Middle Woodland occupation" (Pacheco 1991:5). This later (Hopewell) material is likely associated with Feature 5, a cylindrical flat-bottomed pit that overlaps Feature 2 (Pacheco 1996:27). With these dates (Beta-36272, Beta-36274, and Beta-36277) eliminated, the oldest date, Beta-?, a wood charcoal sample (Pecora, Kener, and Burks 2005), is an obvious outlier. Along with Hopewell bladelets and a Middle Woodland projectile point (Lowe cluster), 33WN425 yielded Late Archaic (Motley cluster), Early Woodland (Kramer), and Late Woodland/late prehistoric (Madison) points along with substantial historic overburden. The site is intriguing, but the high probability of contamination with older charcoal casts enough doubt on the date to warrant its elimination from consideration until further evidence suggests otherwise.

Outside of the four early dates from the Licking/Muskingum Valley, only two radiocarbon ages from the entire state are earlier than 2000 ^{14}C BP. These are from Metz (Beta-351578) and Seaman's Fort (Beta-429898) in the Huron River valley, included in the Lake Erie phase (Table 1 and Supplemental Figure 1). Once again, these two dates may signal an early use of Hopewell bladelets. Overall, 11 ^{14}C dates from the Lake Erie watershed are included in this analysis. Outside of the two dates from Metz and Seaman's Fort, the oldest radiocarbon age is 1780 ^{14}C BP (Table 1). The probability curves of these nine other dates all substantially overlap with one another, yet there is no overlap with the two early

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dates from Metz and Seaman's Fort (Table 1 and Supplemental Figure 1). In other words, there is a gap of about 300 years between the extreme ends of the 2σ ranges (Beta-315578 and Beta-15012) of these two groups of dates (Supplemental Table 1). Pairwise comparison of each of the Lake Erie phase dates with the next most recent or older date (see Supplemental Figure 1 for the time-progressive order of dates) using the "Test Sample Significance" tool in Calib 7.0.4 indicates that the only significant difference occurs between Beta-315578 and Beta-15012. All of the other dates are statistically the same as the next older or more recent date in the sequence.

Several possibilities may account for this. One is that the two early dates are t-type outliers, where the deposition of the dated material is unassociated with the deposition of the bladelets. A second possibility is that bladelet use occurred at these sites quite early, with the radiocarbon gap due to the abandonment of bladelet technology for around 300 years before it came into use again during the Middle Woodland. This would mean that bladelet technology originated in northern Ohio before the groups there abandoned bladelet use at the time groups in the southern half of the state adopted the technology, only for bladelets to be readopted by their originators in northern Ohio a few centuries later. Alternatively, bladelet use may have continued throughout this time, with no dated samples obtained from this era. This possibility also seems unlikely given that, of all four phases, the Lake Erie phase contains the second-highest number of dates. The most parsimonious explanation is that these two early dates are simply outliers. Both of these sites have substantial Early Woodland components. For example, based on diagnostic ceramic types recovered from feature fill, 48 Early Woodland features have been excavated at Metz, in comparison to just two Middle Woodland features (DeMuth et al. 2016:Table 1). This is not to say that bladelets cannot occur in Early Woodland contexts, only that there is a (probably greater) chance for comingling of remains through repeated construction and the associated disturbance at the sites. This interpretation is more in line with directly dated human bone recovered from burials in Hopewell mounds in the Lake Erie region (Redmond 2007), none of which returned radiocarbon ages prior to 1950 ^{14}C BP (Figure 3). Similarly, gaps of this magnitude in other regions (Scioto and Licking/Muskingum) all resulted from radiocarbon outliers. As noted earlier, it would be ideal to directly date bladelets via adhered carbonized residue, as is often done with ceramics. In the absence of this possibility, the next best alternative is to date features with bladelets in their fill. A potential pitfall of this approach is that sometimes not all carbonized material in a feature's fill will be related to the period in which bladelets were used. That is what likely occurred at Metz and Seaman's Fort. Further support for this interpretation is presented below.

Results

The results of the four modified phases are presented in Table 3 and Figure 4 (see Supplemental Figures 5–8 for plots of all probability distributions associated with each phase). A comparison of the modeled start ranges and median start dates for each phase suggests that bladelets may occur earliest in the Licking/Muskingum Valley. However, interpretation is hampered by the wide error ranges, due to low numbers of ^{14}C dates, associated with the Licking/Muskingum phase. Ultimately, more dates are needed from this region to create a more compact chronology. The large sample from the Scioto Valley provides strong evidence that bladelets were present by the early first century AD. Bladelets were present in the Little Miami Valley at this time or soon after. The start date for the Lake Erie watershed is clearly later than for the other phases, perhaps by as much as a couple of centuries.

The end of bladelet use may have occurred first in the Little Miami Valley. The modeled end dates for the Scioto Valley and the Lake Erie watershed are similar. In the Licking/Muskingum, bladelets use may have continued after declining everywhere else in the state, but again, interpretation of this phase is hindered by large error ranges. Thus, I interpret the general progression of bladelet technology as beginning in the Licking/Muskingum, Scioto, and Little Miami Valleys, with the possibility for the earliest appearance in the Licking Valley. After a lull of as many as 200 modeled years,

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Table 3. Results of the Revised Four-Phase Bayesian Analysis.

Phase	68.2% Probability	95.4% Probability	Median
Lake Erie start	AD 185 to 300	AD 95 to 325	AD 230
Lake Erie end	AD 385 to 485	AD 340 to 570	AD 435
Licking/Muskingum start	120 BC to AD 165	655 BC to AD 230	5 BC
Licking/Muskingum end	AD 410 to 700	260 to 1210 AD	AD 570
Little Miami start	AD 5 to 210	70 BC to AD 225	AD 80
Little Miami end	AD 275 to 400	AD 245 to 510	AD 350
Scioto start	AD 15 to 80	30 BC to AD 105	AD 45
Scioto end	AD 420 to 480	AD 390 to 530	AD 450

Note: Dates are rounded to the nearest five years.

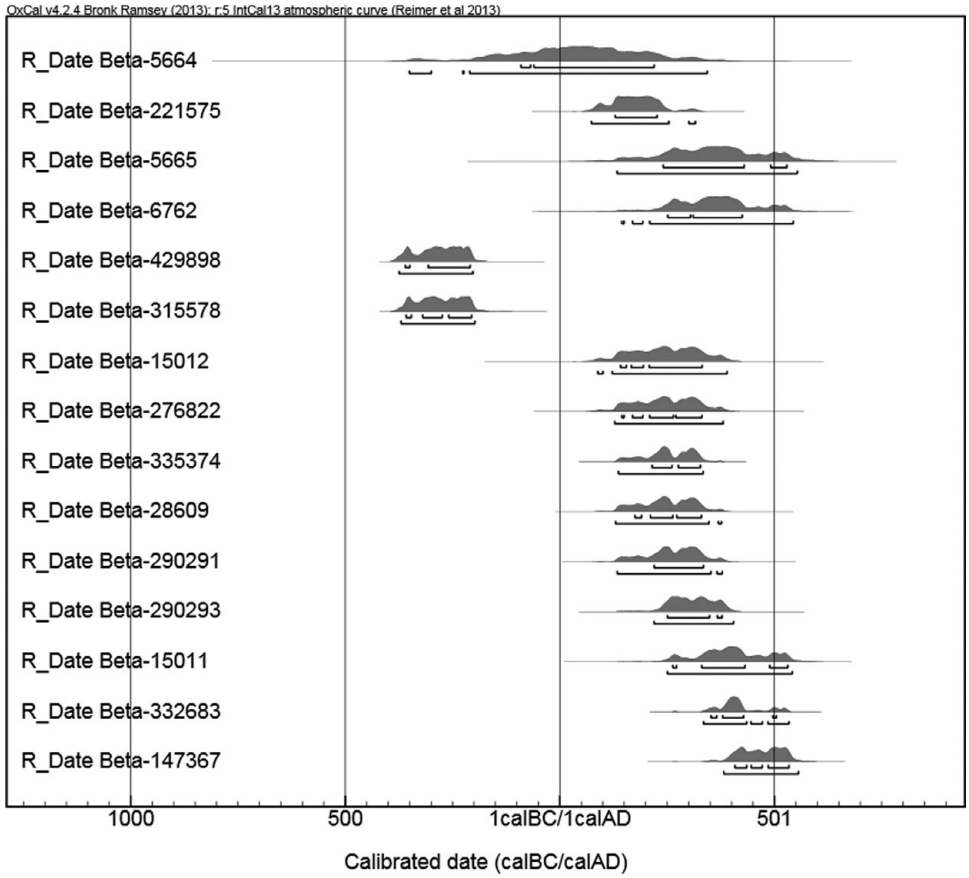


Figure 3. Plot of probability distributions obtained on human bone from Hopewell burials in the Lake Erie region (data from Redmond 2007) and those from features containing bladelets.

bladelets were in use by groups in northern Ohio. Bladelet use may have ended earliest in the Little Miami, followed by the Scioto and Lake Erie basin. Bladelet use may have extended the longest in the Licking/Muskingum Valley.

Discussion

Determining the timing of Ohio Hopewell bladelet use is not an easy task. One interpretation of the dates and the Bayesian analysis

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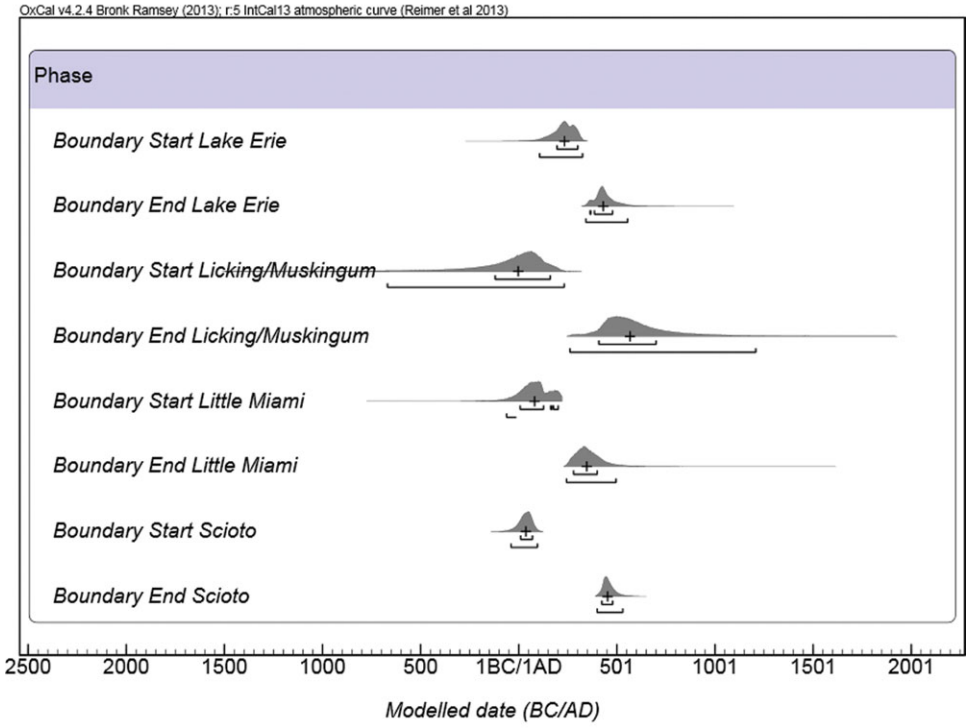


Figure 4. Plot of the start and end ranges (with median date [+] and 68% and 95% confidence intervals) for each of the four phases in the final Bayesian analysis. (Color online)

is that bladelets were in use for ~1,500 years, from approximately 500 cal BC to cal AD 1000 (95.4% probability). However, scrutiny of the dated materials and their contexts suggests that many abnormally early or more recent dates are problematic. The removal of these dates from the final Bayesian ^{14}C analysis provides a clearer and more reliable view of bladelet use in Ohio.

At one level, the results indicate that Hopewell bladelets in Ohio are indeed diagnostic of the Middle Woodland period, approximately cal AD 1–450 or 500 (95.4% probability), as has long been assumed (but see below for variations in how the temporal boundaries of Hopewell and Middle Woodland have been defined). More importantly, the Bayesian analysis provides insight into previously unrecognized temporal variation in Hopewell material culture. In the Licking/Muskingum and Scioto Valleys, bladelet technology was in use essentially through the entirety of the Middle Woodland. Small variations in modeled start ranges for these two regions reflect a quick spread of this technology after its introduction. There is evidence that the period of bladelet use in the Little Miami Valley may have begun later and ended earlier than in the two watersheds to the east. The most striking result is the late initial appearance of bladelets at sites in northern Ohio. If this modeled gap of a century or two is an accurate reflection of prehistoric reality, then it presents some interesting questions about the time-transgressive relationship between the northern and southern portions of the state.

When paired with previous research about the construction of Hopewell earthworks, the results have important implications for refining our understanding of the spread of Hopewell ceremonialism. In Ohio, few Hopewell earthworks have been investigated to allow accurate understanding of the timing of their construction and use (Greber 2003). Part of the issue is that it is difficult to obtain carbonized material associated with specific construction events for these earthen monuments. Thus, start dates for Ohio Hopewell ceremonialism range from 200 cal BC

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(e.g., Griffin 1967), to 100 cal BC (e.g., Byers 2004; Charles 2012; Griffin 1983; Stothers, Pratt, and Shane 1979), to cal AD 1 (e.g., Abrams 2009; Lynott 2014; Seeman 1996). The end of Ohio Hopewell is variously cited as cal AD 300 (e.g., Griffin 1983), cal AD 350 (e.g., Seeman 1996), cal AD 400 (e.g., Byers 2004; Charles 2012), cal AD 500 (e.g., Stothers, Pratt, and Shane 1979), or cal AD 600 (i.e., 1470 BP; Greber 2003). However, the Bayesian results presented here are part of a growing body of evidence that 50 cal BC to cal AD 1 may be the most likely start for Ohio Hopewell. For example, Emerson et al. note that the "earliest known example of Scioto Hopewell mound ceremonialism" (2013:56) occurs at the Tremper mound and enclosure in the lower Scioto Valley, which they have dated to 1990 ± 70 BP (60 cal BC–cal AD 85 at 1σ; Emerson et al. 2005). The two most thoroughly dated Hopewell earthwork construction sequences—Hopeton and Pollock—were built well after 100 BC. Based on analysis of 22 ^{14}C dates from contexts associated with earthwork construction at Hopeton, Lynott (2014:112) favors a weighted average of cal AD 91–259 for the span of the initial to final stages of construction of the earthwork. At Pollock, a hilltop enclosure in the Little Miami Valley, Riordan (1995) identified a construction sequence that began in the first half of the first century cal AD and concluded in the late second century cal AD based on 15 ^{14}C dates. In fact, Riordan (1996:250) questions whether any Ohio hilltop enclosures were constructed prior to 100 cal BC and, in fact, posits that the construction of all Ohio hilltop enclosures most likely postdates cal AD 1. Finally, Greber (2003:97) notes that the "majority" of all Ohio Hopewell–affiliated dates fall within ±280 years of 1750 ^{14}C BP, placing the start of Ohio Hopewell at about 30 cal BC.

The above discussions focus on Hopewell in the southern half of Ohio. While Stothers, Pratt, and Shane (1979) placed the beginning of Hopewell in northern Ohio at 100 cal BC, Greber notes that the majority of dates from northeastern Ohio fall "toward the latter end of the Hopewell era" (2003:100). After spending six seasons investigating Heckelman, one of the major Woodland hilltop enclosures in northern Ohio, Redmond has concluded that the Early Woodland non-Hopewell occupation ended by 3 cal BC and the site was not reoccupied again until "after cal AD 200 by one or more social groups marked by a material culture closely resembling Ohio Hopewell" (2016:47). Both Greber's regional overview and Redmond's site chronology conform to the final results presented above, in which bladelets were not in the Lake Erie region until after cal AD 200. Taking them as a whole, it is interesting to note that the earliest dates from Hopewell mounds and earthworks largely correlate with the beginning of the phases presented here.

If earthwork construction and bladelet production in Ohio began in the period between 50 cal BC and cal AD 1, then the correlation with important developments along the Illinois River at this time cannot be ignored. There is strong evidence that the group of materialized practices archaeologists now identify as Hopewell emerged in the central Illinois River valley between 200 and 100 cal BC and subsequently spread to the lower Illinois River valley, via human migration, by 50 cal BC (Buikstra and Charles 1999; Charles 2012; Griffin 1967; King, Buikstra, and Charles 2011). One defining characteristic of the early Hopewell occupations in the lower Illinois River valley is evidence for "direct contact with Ohio Hopewellian communities" (Farnsworth and Atwell 2015:208). This material evidence includes copper ear spools, Altamaha shell pendants, expanded-center bar gorgets, copper axes, and a copper-cone-decorated costume, in addition to Hopewell bladelets made of Ohio Flint Ridge chert recovered at lower Illinois River valley sites (Farnsworth and Atwell 2015). Numerous bladelets and bladelet cores of Ohio Flint Ridge chert have been reported from ritual staging areas near the Bedford, Montezuma, and Elizabeth Mounds along the western bluff line of the lower Illinois River valley (Emerson et al. 2013:62; Farnsworth and Atwell 2015:201). Farther north in the central Illinois River valley, Flint Ridge bladelets occur at the Whitnah Village site associated with the Sister Creeks mounds (Nolan and Bainter 2004). At essentially this same time in Ohio, numerous effigy pipes made of Sterling pipestone from near the Rock River in northwestern Illinois were deposited at Tremper

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Mound in the Scioto Valley (Emerson et al. 2013).

Conclusion

The results presented here place the earliest bladelets at sites in Ohio at about the same time as the early Hopewell sites containing Flint Ridge chert bladelets in the lower Illinois River valley. A further point of interest is that the earliest median start date for the phases is in the Licking/Muskingum Valley, home to the Flint Ridge quarries, and not the traditionally defined core area of Ohio Hopewell in the Scioto Valley. It is possible, then, that the desire for Flint Ridge chert by groups in the lower Illinois River valley may have played a role in spreading Hopewell ceremonialism to Ohio.

Dating the end of Hopewell in Ohio proves to be more problematic. Part of the reason is that it is possible that Hopewell earthworks continued to be used even after the final stages of wall construction. However, the issue extends beyond the earthworks, as demonstrated by the issues with outliers at the end of the Scioto phase presented above. Greber's (2003) upper boundary of 1470 ^{14}C BP is later than the median end date of most of the phases presented here, although the Licking/Muskingum phase is comparable. While there is considerable overlap at 95%, the median end dates for the phases presented here are separated by more than 200 modeled years (Table 3). Thus, any of the dates from cal AD 300 to 500 may be acceptable for the end of Hopewell. Perhaps this can be explained by Dancey's (1996) assertion that a great deal of variation in lifestyles was present in Ohio at this time. It may be necessary to examine dates at a finer scale than the overall watershed to thoroughly understand this variation.

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Data Availability Statement. The OxCal programming code is included in the Supplemental Materials. Further information on the Ohio Archaeological Inventory and the survey reports cited here can be obtained from the State Historic Preservation Office–Ohio History Connection.

Supplemental Materials. Supplemental materials are linked to the online version of this article, which is accessible via the Society for American Archaeology member log-in at https://doi.org/10.1017/aaq.2017.64.

Supplemental Text. Code for OxCal Models.

Supplemental Figure 1. Plot of probability distributions for all dates from the Lake Erie phase.

Supplemental Figure 2. Plot of probability distributions for all dates from the Licking/Muskingum phase.

Supplemental Figure 3. Plot of probability distributions for all dates from the Little Miami phase.

Supplemental Figure 4. Plot of probability distributions for dates from the Scioto phase, with those from Redwing and 33FR895 excluded as noted in the text.

Supplemental Figure 5. Plot of probability distributions for dates from the final version of the Lake Erie phase.

Supplemental Figure 6. Plot of probability distributions for dates from the final version of the Licking/Muskingum phase.

Supplemental Figure 7. Plot of probability distributions for the final version of the Little Miami phase.

Supplemental Figure 8. Plot of probability distributions for the final version of the Scioto phase.

Supplemental Table 1. Calibrated ^{14}C dates from Table 1.

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