HOPEWELL ARCHAEOASTRONOMY IN THE PAINT CREEK VALLEY: AN ANALYSIS OF THE CALENDRICAL SIGHTLINES AT THE BAUM SQUARE AND SEIP SQUARE, ROSS COUNTY, OHIO

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Abstract

Some two millennia ago, Native Americans in present day Ohio constructed monumental earthworks that remain perplexing today. Since circa 1980, research has shown that these Hopewell geometric enclosures index rising and setting sightlines for both the sun and moon, evidencing a prehistoric calendar. This paper examines such calendrical sightlines as found at the Baum and Seip square earthworks. Both Baum and Seip are in the Paint Creek Valley west of Chillicothe, the core of Ohio Hopewell. The arrays of sightlines emanating from these two earthworks span the Paint Creek Valley, terminating on the various hills and ridges surrounding. The locations of these horizon foresights for each sightline are precisely determined using GIS and are provided in tabular and map form. Some of the sightlines terminate on Spruce Hill, a known Hopewell hilltop enclosure, specifically at or near fire-cracked rock mounds that were mapped by Squier and Davis. These horizon foresights may have functioned as confirmatory signaling stations for the sightlines and as places of ritual performance. These locations can be examined archaeologically or with geophysical survey, providing a hypothetico-deductive check on this calendrical sightline model. The paleoecology of the Hopewell landscape shaped and was shaped by these calendrical sightlines.

The Geometric Earthworks of the Ohio Hopewell

American archaeology has long marveled and wondered at the Hopewell phenomenon. Near its acme 2000 years ago in what is today southern Ohio, this colorful cultural florescence lasted five centuries, leaving a peculiar material record in its wake. Prehistoric Native Americans of the Middle Woodland Period, some two millennia ago, developed a complex long-distance exchange and acquisition network and an equally complex artistic aesthetic. Throughout most of the American Midwest and much of the South, regional variants of the Hopewell phenomenon

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existed, each with iconic art forms locally expressed through ceramics, copper, mica, or other media, including earthen architecture.

Monumental earthworks differ across the prehistoric landscape, and so it is that in Ohio we find the most unusual examples of Middle Woodland architecture: the Hopewell geometric enclosures. These earthen embankments trace outlines upon the landscape of great circles, squares, and octagons and were originally 1.5 meters (five feet) to 3.7 meters (twelve feet) tall and 15 m (fifty feet) wide or more at the base. Truly monumental in dimensions, a typical Hopewell square like Baum or Seip was 340 meters (1100 feet) or more in length on each side or more than 460 meters (1500 feet) across diagonally. When constructed in conjoined groupings, as most were, the cumulative linear and areal dimensions became even greater and were doubtlessly imposing to behold.

In total, the great Hopewell geometric earthwork sites once numbered perhaps twenty, and of these, twelve were within the Scioto River region. The junction of the Scioto River Valley with its principal tributary Paint Creek at Chillicothe marks the core of the Hopewell earthwork distribution. Here nine of the geometric earthworks sites are located. Ross County once had the greatest number of prehistoric earthworks in the United States. The seat of Ross County, Chillicothe, was the original capital of Ohio (1803). Interest in the mounds was immediate there and early in American history (Atwater 1820, Squier and Davis 1848). The geometric enclosures presented a unique question with regard to the exactitude and symmetry of their design.

In the 1880s, U.S. Bureau of Ethnology surveyors measured some of the then-extant earthworks. These surveyors (James Middleton and Gerard Fowke) described a total of seven polygonal enclosures (Thomas 1889, 1894:464-489). Tabular survey data were provided for each, and plats were drawn and published for all but one of the seven (the Seip square). The seven polygonal enclosures described by Middleton and Fowke are the Newark octagon (33LI10), the Newark square (33LI10), the High Bank octagon (33RO24), the Hopeton polygon (33RO26), the Liberty square (33RO22), the Baum square (33RO4), and the Seip square (33RO40). Hively and Horn published archaeoastronomical analyses of the Newark (1982) and High Bank (1984) octagons, while the current author presented analyses of the Hopeton earthworks (Turner 1983, 2011) and the Liberty square (Turner 2015).

Of the nine polygonal geometric sites proximate to Chillicothe, five were surveyed by Middleton and Fowke. The present paper investigates two of these: the Baum square (Figures 1 and 2) and the Seip square (Figure 3). The Middleton/Fowke survey data were cited when published to a precision of one minute of arc, or one sixtieth of a degree (Fowke 1902:186; Thomas 1889, 1894:464-489). Problematically, in using their data, I cannot state with certainty the accuracy of their figures. Therefore, and to be conservative, I assume an accuracy of one tenth degree, or one sixth of the value as published, and throughout the calculations I observe this one-tenth degree accuracy guideline. All equation results are cited to one tenth degree (Table 1).

Table 1. Sightline Data for Baum and Seip Squares†

Baum Square Sightline	Event	Azimuth	q	Horizon Altitude	Declination	Latitude	Longitude
H-D	SSr	60°.6	-0°.26	2°.50	+23°.7	39°.26470	-83°.13235
		60.8	0.00	2.50	+23.7	39.26463	-83.13230
		61.0	0.26	2.50	+23.7	39.26457	-83.13225
A-C	SSr	60.6	-0.26	2.50	+23.7	39.26601	-83.13327
		60.8	0.00	2.50	+23.7	39.26594	-83.13322
		61.1	0.26	2.50	+23.7	39.26588	-83.13317
G-E	SSr	60.5	-0.26	2.40	+23.7	39.26342	-83.13141
		60.7	0.00	2.30	+23.7	39.26336	-83.13136
		60.9	0.26	2.30	+23.7	39.26330	-83.13132
A-F	WSr	124.0	-0.26	3.20	-23.7	39.24713	-83.14061
		124.3	0.00	3.20	-23.7	39.24703	-83.14059
		124.5	0.26	3.20	-23.7	39.24700	-83.14067
B-E	WSr	124.6	-0.26	3.80	-23.7	39.25067	-83.14449
		124.9	0.00	3.80	-23.7	39.25065	-83.14454
		125.2	0.26	3.90	-23.7	39.25061	-83.14459
D-H	WSs	238.1	-0.26	1.30	-23.7	39.23676	-83.19226*
		237.8	0.00	1.30	-23.7	39.23657	-83.19210*
		237.5	0.26	1.40	-23.7	39.23642	-83.19200*
E-G	WSs	237.6	-0.26	1.70	-23.7	39.23461	-83.19224
		237.4	0.00	1.70	-23.7	39.23450	-83.19213
		237.1	0.26	1.70	-23.7	39.23434	-83.19202
C-A	WSs	238.3	-0.26	1.10	-23.7	39.22157	-83.22776
		238.0	0.00	1.10	-23.7	39.22118	-83.22771
		237.8	0.26	1.10	-23.7	39.22093	-83.22763

Seip Square Sightlines	Event	Azimuth	q	Horizon Altitude	Declination	Latitude	Longitude
F-C	NLXr	52°.7	0°.00	0°.60	+28°.8	39°.28133	-83°.13676
G-B	NLXr	52.4	0.00	0.40	+28.8	39.31438	-83.08536
C-A	NLXs	305.0	0.00	2.80	+28.8	39.25115	-83.24403
A-C	WSr	122.9	0.00	2.00	-23.7	39.22169	-83.18790
C-A	SSs	299.9	0.00	1.80	+23.7	39.24836	-83.24419**
H-A	CQr	69.7	0.00	0.56	+15.7	39.26130	-83.13048***
				0.59	+15.7	39.26931	-83.10270***

† All measurements in degrees.

*On slope of Copperas Mountain, see Figure 9.

** The summer solstice set sightline C-A horizon foresight appears to be located at a gap formed by two widely separated landforms (Figure 16).

*** There is only 3/100 degree horizon altitude difference between these two potential foresights (Figure 6).

Key to Table 1

Sightline: from gateway to gateway following Middleton/Fowke labels "A" through "H" for each respective earthwork.

Event: SSr = summer solstice rise, WSr = winter solstice rise, SSs = summer solstice set, WSs = winter solstice set, NLXr = north lunar maximum rise, NLXs = north lunar maximum set, CQr = May cross quarter sunrise

Azimuth: the horizon azimuth of a sightline, north = zero, east = 90°, etc.

q : the semi-diameter of the sun or moon, as it defines the phase of sunrise (or sunset or moonrise, etc).

Horizon Altitude: the angular height of the visible horizon along a sightline.

Methodology with GIS

Modern GIS mapping greatly improves the precision and accuracy of these analyses. Forty-odd years ago, Hively and Horn (1982:12) and I (Turner 1983) utilized USGS 7.5' topographic quadrangle maps to plot sightlines, and to calculate resultant data like horizon altitude. The following describes the method used with ESRI ArcMap software in the present analyses.

Upon creating a new ArcMap analysis, the properties of the data frame are those of the first data layer entered. This is a LIDAR-based DEM raster file from the online Ohio Geographically Referenced Information Program website (OGRIP 2008). The appropriate DEM tiles are joined together using the "Mosaic Tool" (in "Raster Dataset" in "ArcToolbox") to provide sufficient map extent to encompass the research area.

Importantly, the difference between map north and true north must be determined. Using the "Go to X-Y" tool, I created two test points flanking the map on the east and west boundaries of the research area, *each with the same specific latitude*. These two points should therefore lie exactly due east-west of one another in the data frame. Using the "Two Point Line" tool, a line is created bearing 90 degrees (due east) from the western of the two test points. This line will miss the eastern point by some measurable distance. This distance, divided by the distance between the two test points, is equal to the tangent of the ground to grid correction angle that needs to be applied to the data frame. After entering this figure in the "Ground to Grid Correction" box in editor mode, the test line should touch the eastern point, and the azimuth should read 90.0 degrees. I confirm this by using the "COGO Report Tool" with the "Description of an Existing Feature" option.

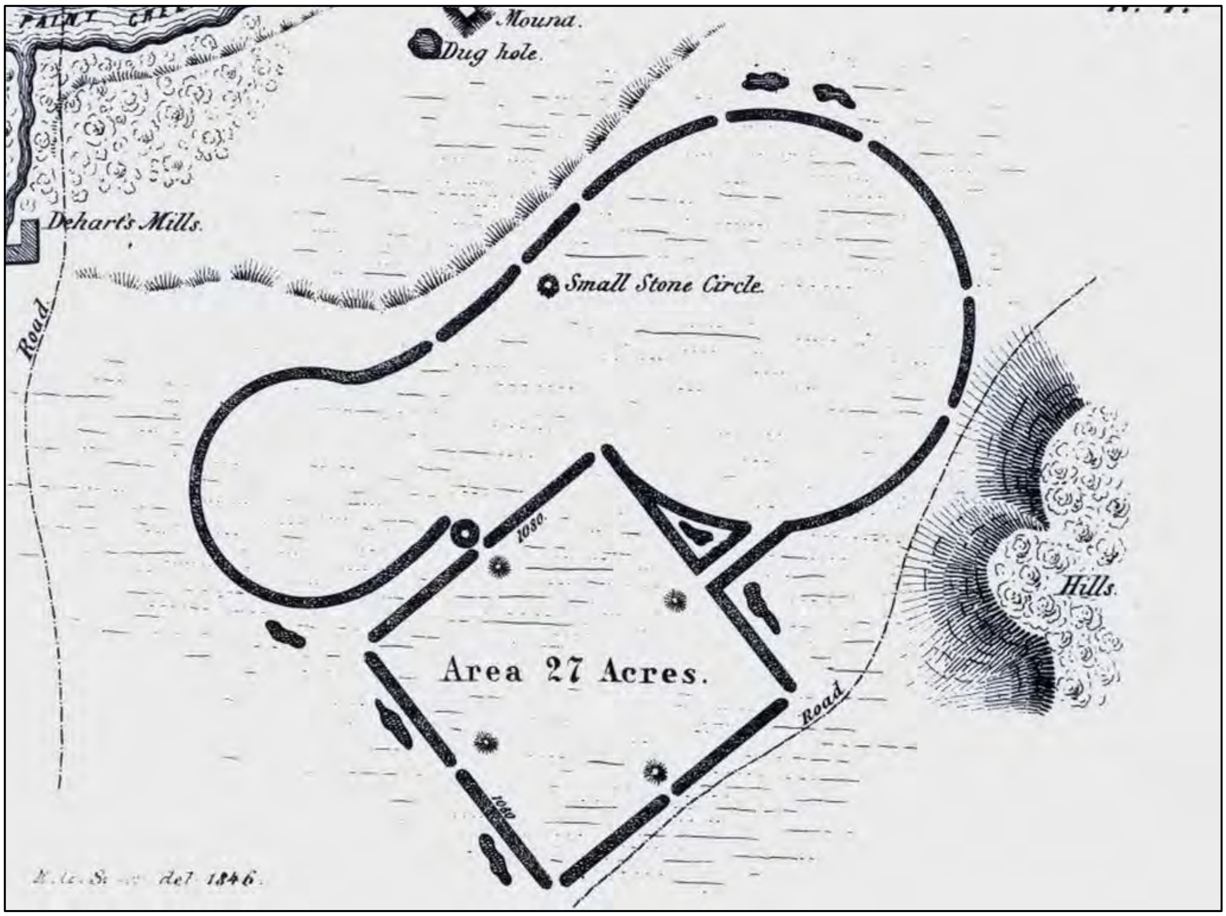

Figure 1. The Baum earthworks were illustrated by Squier and Davis (1848: 57, Pl. XXI, No. 1). The sides of the square are closer to 1110 feet than 1080 feet as shown. Note the immediate adjacency of uplands to the earthwork. North is up in all figures herein.

The DEM serves for all data analyses in the process. Political map layers showing roads and other civil features can be added for convenience, but they are not used in data calculations. To examine the locations of earthworks within the DEM data, the "Hillshade" option in "Surface Analyst" is utilized. To save processing time in making the hillshade, it is prudent to clip the

DEM to a smaller size commensurate with the earthwork or area in question. Trim from the master DEM using the "Clip" option in "Raster Processing" in ArcToolbox.

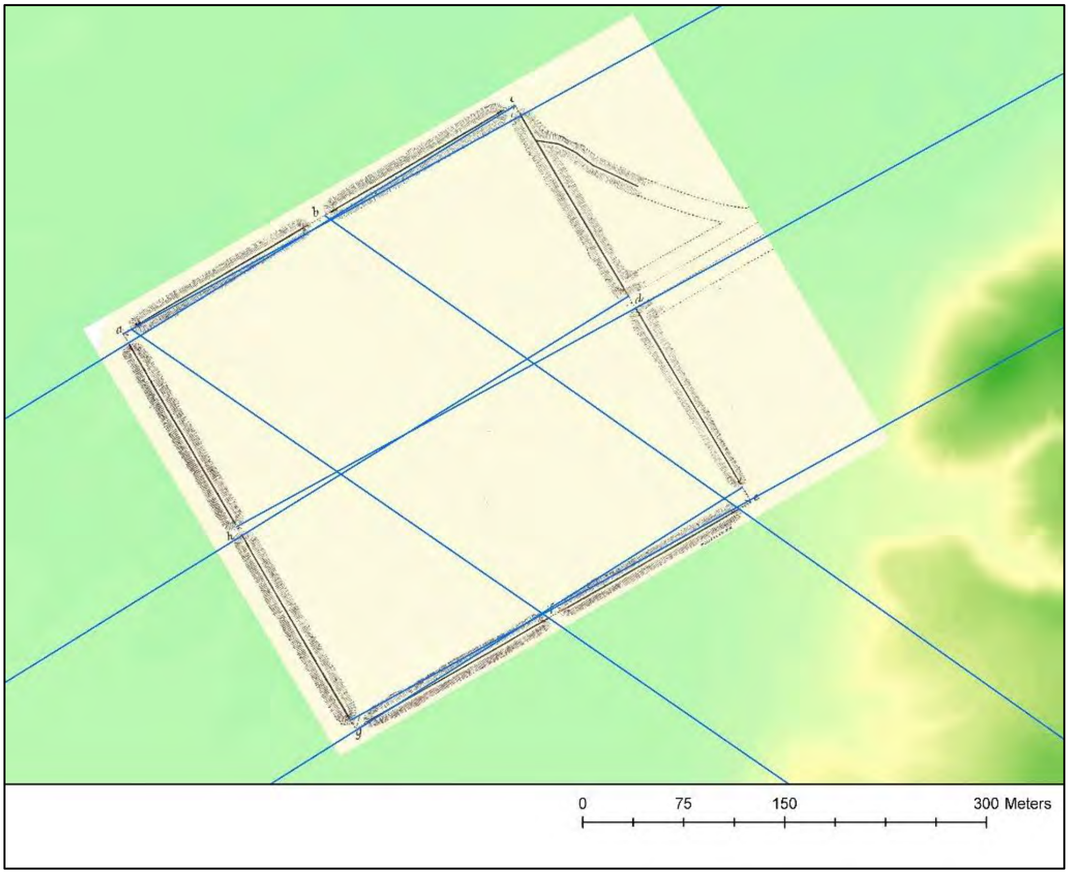

Figure 2. These are the calendrical sightlines revealed through analysis as plotted on the Middleton/Fowke plat of the Baum square (Thomas 1894: 494, Pl .XL). All of these are solstice events: summer solstice sunrise to the northeast, winter solstice sunrise to the southeast, and winter solstice sunset to the southwest. There are no summer solstice sunset sightlines (to the northwest) as defined between the gateways at the Baum square. The Middleton/Fowke nomenclature is visible, labeling the gateways "a" through "h". In this article, their system is used to label sightlines.

Once a hillshade image is created, the subtle landscape elevation features are more evident. It is quite easy to see for instance the Baum square earthwork using this method. Using the "Contour" tool in "Surface Analyst," elevation contours can be made of the same area, further revealing hard to see elevation variations in the degraded earthworks, particularly of features like gateways. At this point, a digitally scanned JPG image of the original Middleton/Fowke plat of the earthwork can be superimposed onto the square in the hillshade image. Using the "Measure" tool, the dimensions of this Middleton/Fowke plat can be compared to those dimensions as listed in the Middleton/Fowke survey data tables. This method can also be used to precisely define the widths of the various gateways, if such data are available. Then, this precisely measured plat can be best-fit (using the "Georeferencing Tool") to the hillshade image of the earthwork.

Based on visual inspection and measurement of embankment features in ArcMap, the ground error in this geo-referencing is estimated at +/- 2 meters. Note that any sightline azimuths are largely independent of this uncertainty, as these azimuths are internally consistent within the Middleton/Fowke survey data. What does result is a possible error with regard to the loci of the horizon foresights, though of low magnitude (two meters).

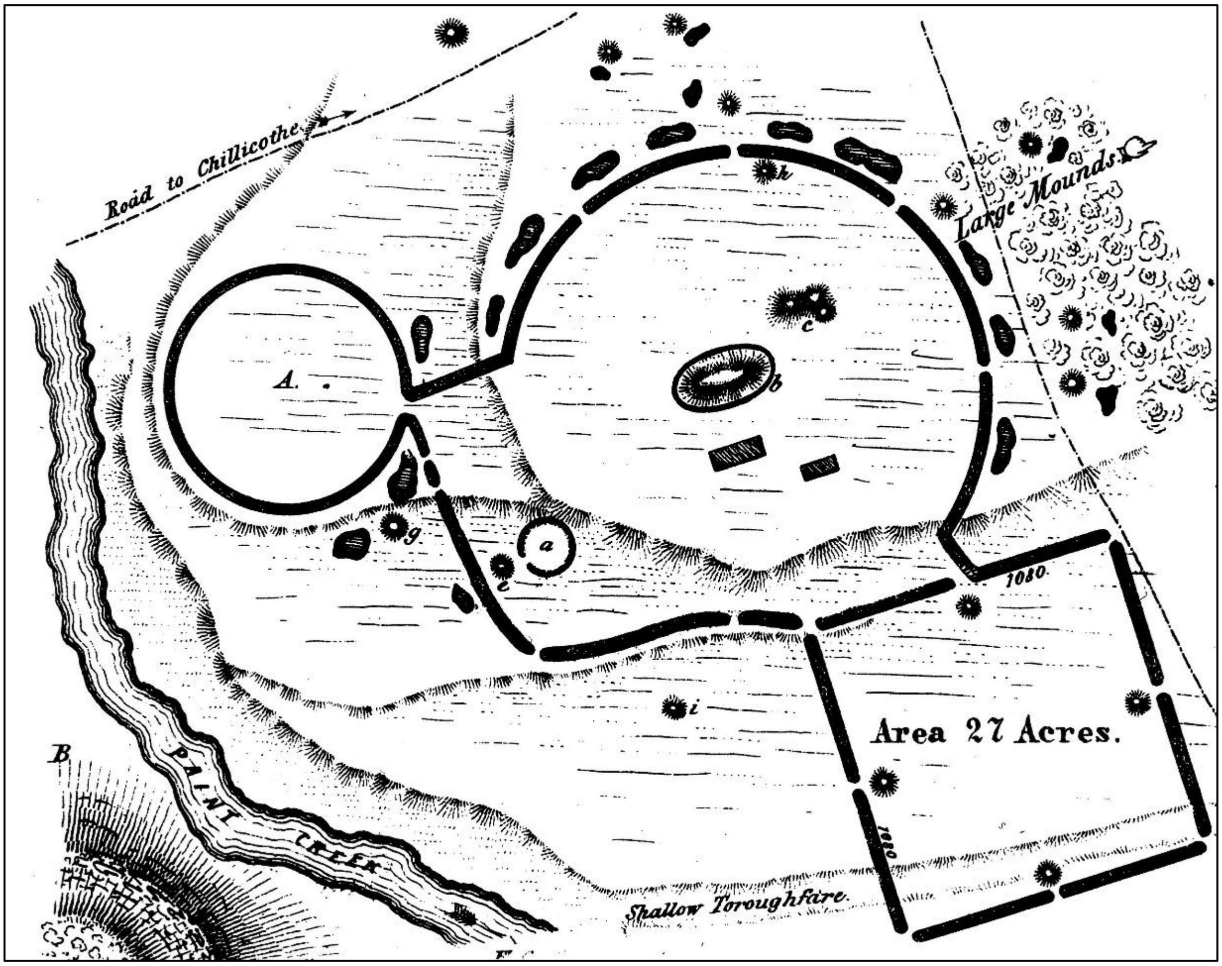

Figure 3. This is the Seip earthworks as mapped by Squier and Davis (1848: 57, Pl. XXI, No. 2). Numerous mounds, borrow pits, and enclosures surrounded the geometric earthworks. The large mortuary Seip Mound is at center marked "b". Today, the Seip earthworks are a component of Hopewell Culture National Historical Park.

With this accomplished, sightlines can now be generated that comport to the gateways of the earthwork. These polyline shape files are first created in ArcCatalog, and once added to the ArcMap can be manipulated in editor mode. Their properties (length and azimuth) are revealed by the "COGO Report Tool" in the "Description of an Existing Feature" option, also in editor mode.

Now, the numerical data needed for analyses are available. The other factors used are constants derived from tables; for example, refraction value for given horizon altitude. The length of the sightline and its azimuth are found using the COGO Tool. The elevation of the backsight (place where observer stands) and elevation of the horizon foresight are ascertainable using the "Identify Tool." This tool also provides exact latitude of the observer locus. These are the factors obtained from the map that are needed in calculations. Again, they are site latitude, azimuth of the sightline, length of the sightline, and backsight and horizon foresight elevations.

Note also that the "Viewshed Tool" in "Surface Analyst" must be used to determine the terminus of a given sightline. A point shape file must first be created in ArcCatalog to represent the observer locus. The viewshed tool will then define the limits of visibility as seen from the location of this point in the ArcMap. The observer point is set to five feet elevation above surface to approximate the height of a human viewer. The "Create Line of Sight" tool will also provide the same information but only for individual sightlines, not for entire viewsheds, as can be the case with the viewshed tool.

Analysis is a protracted process that must be repeated for each sightline. The azimuth of the sightline and the horizon foresight elevation must be entered for each iteration into an Excel spreadsheet, which is programmed with the appropriate algorithm. It is then a trial-and-error process. Sightlines of various azimuths are tested in ArcMap, and during each iteration, the data are again entered into the spreadsheet. When the resultant declination matches an astronomically salient declination of the Hopewell epoch, the sightline is considered "correct" (Table 1). The data describing the correct sightlines are then entered into the final data table.

The algorithm used in the spreadsheet follows the equation:

$$\sin \delta = \sin \varphi \sin h + \cos \varphi \cos h \cos A$$

which describes the relation between celestial declination (δ), the observer's geographic latitude (φ), the azimuth of a sightline (A), and the angular height of the horizon along that sightline (h). Factors that correct for atmospheric refraction are also used, and the results are calibrated for either solar or lunar events. Error can be introduced by the improper modeling of events. For example, which phase of sunrise did the Hopewell index: first gleam, half-risen, or fully risen disc? This variance changes the sightline azimuth by four-tenths degree, nearly the width of the sun or moon. In the accompanying data table for the Baum square I have modeled for all three phases, permitting the examination of the associated horizon foresight loci as potential archaeological sites.

Conservatively, I have modeled the rise and set events at Seip for half-risen phase only. The poorer state of preservation at Seip warrants this precaution. Nonetheless, the horizon foresights can be located in the field with sufficient precision using such data. In situ field survey can be augmented by the field testing of the sightlines. By stationing an assistant (equipped with a signal light) at the horizon foresight, sightlines can be field tested with an accuracy consistent with that of such Hopewellian observations.

Earthworks in the Landscape: Visibility, Ecology, Habitation

The Paint Creek Valley west of Chillicothe was replete with monuments, compelling Squier and Davis to render it in map form (Figure 4). Nearly adjacent to the Baum earthworks is the Hopewell enclosure atop Spruce Hill (Figure 5) (Ruby 2009). The Spruce Hill landform projects into the Paint Creek Valley, where it is a highly visible landscape feature from various points within the valley. The proximity of Baum and Spruce Hill suggests that these two enclosures may have served as components within a ritual precinct (Figure 6). The Seip square and Baum square are themselves only 5.5 km apart, and along with other nearby features presented a complex viewshed to the Hopewell inhabitants.

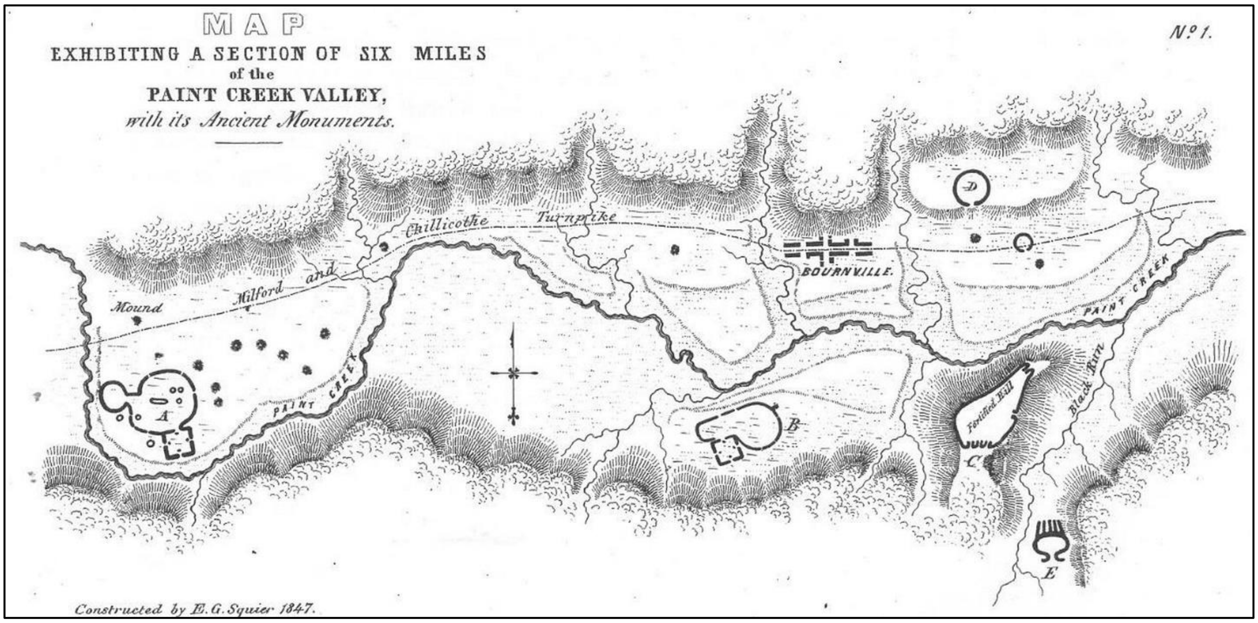

Figure 4. The prehistoric monuments in the Paint Creek Valley were illustrated by Squier and Davis (1848: 4, Pl. III, No. 2). The squares at Seip and Baum are seen left and center, respectively. Each square is part of a larger earthwork complex, with Seip attended by a retinue of mounds and smaller enclosures. The Hopewell hilltop enclosure Spruce Hill is shown at right, marked "C". The Black Run stone geoglyph is labeled "E", and is likely no longer extant.

In the Scioto valley, geometric sites generally lie north-south of one another, following the river. By contrast, in the Paint Creek Valley, Baum and Seip lie more east-west of each other. Because of this, the two arrays of calendrical sightlines overlap, and the associated horizon foresights are distributed in a complex network (Figure 7). This mutual use of the geographic space that lies between Baum and Seip compels the concurrent examination of them.

The Baum earthworks are immediately adjacent to uplands, and the nearby hilltop enclosure of Spruce Hill looms large on its horizon. Some of the sightlines defined by Baum mark the summer solstice sunrise, and the associated horizon foresights are located on Spruce Hill, proximate to the enclosure entrance (Figure 6) (Ruby 2009:55-59). Additionally, the axial sightline at the square is augmented by a pair of embankments that form an *avenue* (see Figures 1 and 2). This association of the horizon foresight with the Hopewell hilltop enclosure Spruce Hill, combined with the presence of the avenue, suggests that this was an important sightline. It is worth noting that another Hopewell hilltop enclosure, namely Ft. Ancient (33WA2), is constructed in association with an avenue feature that demonstrably also indexed the summer solstice sunrise (Turner 2004a).

As seen from Baum, the winter solstice sunrise occurs over terrain features that are extremely close to the earthwork (Figure 8). There are also three sightlines indexing the winter solstice sunset (Figure 7). Two of the associated horizon foresights occur on Copperas Mountain

(Figure 9), while the third is located on McMechan Hill. There is no summer solstice set sightline as defined from gateway to gateway at the Baum square.

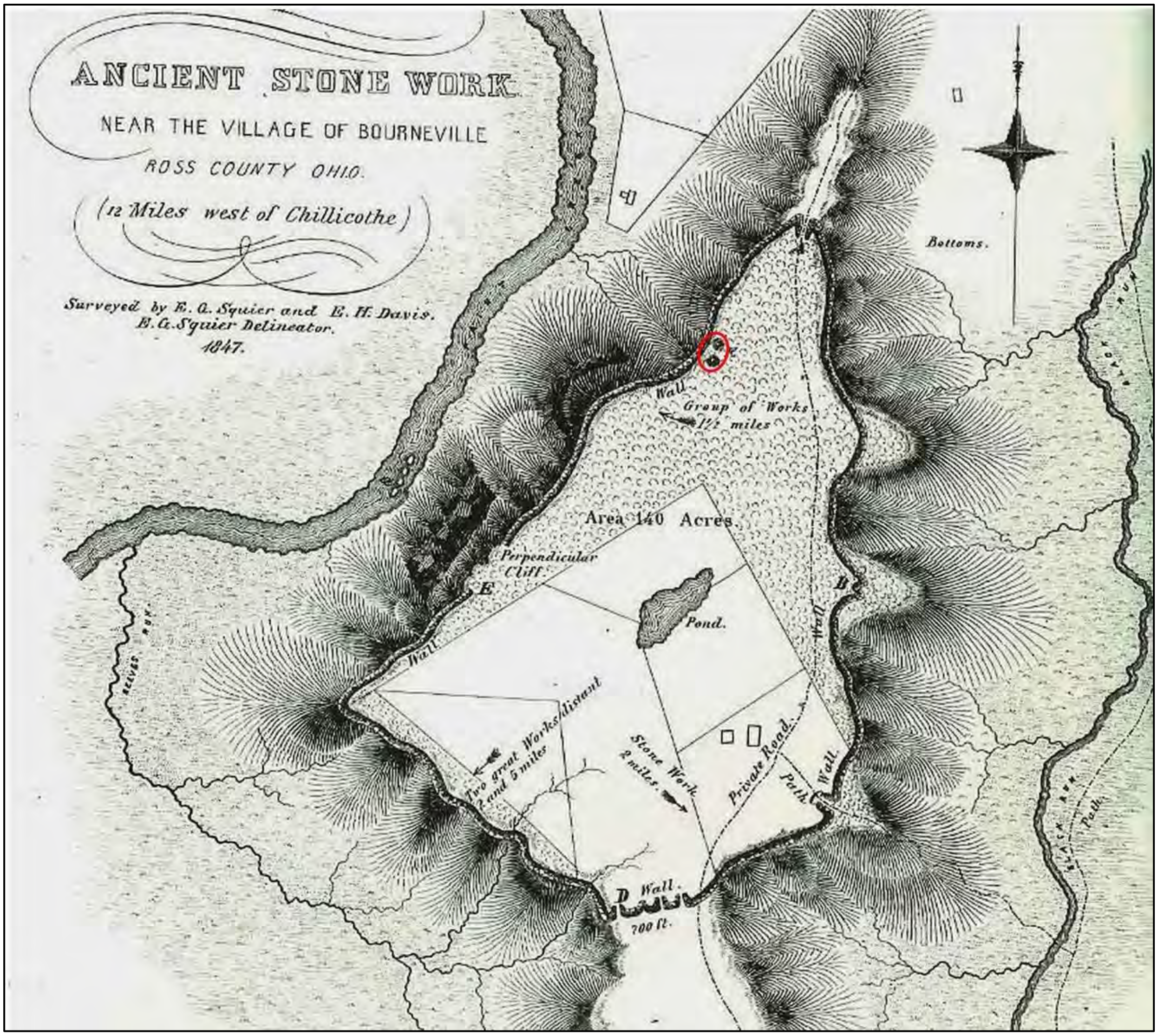

Figure 5. The Hopewell hilltop enclosure Spruce Hill was depicted by Squier and Davis (1848: 11, Pl. IV). A low berm composed of stone surrounds the enclosure, with a stone gateway across the isthmus entrance (marked D). Two fire cracked rock mounds are marked "F" (circled), and may have served as horizon foresights for a lunar maximum rise sightline as seen from Seip. Spruce Hill is a component of Hopewell Culture National Historical Park.

The square enclosure at the Seip earthworks has been subject to inundation by Paint Creek. Though Squier and Davis wrote that "the ground is here considerably broken, yet the work preserves its regularity throughout," they also reported that "the square enclosure…at periods of great freshets, is invaded by the water (1848:58, 59)." By 1885, the southern wall of the square was "obliterated," according to Middleton and Fowke (Thomas 1894:488). Hence their survey for this earthwork is incomplete, lacking the point data describing the corners and midpoint of the southern wall of the square (Figure 10). Fortunately, the remainder of the square was surveyed by Middleton and Fowke, who even listed the specific widths of the remaining five gateways (Thomas 1894:489).

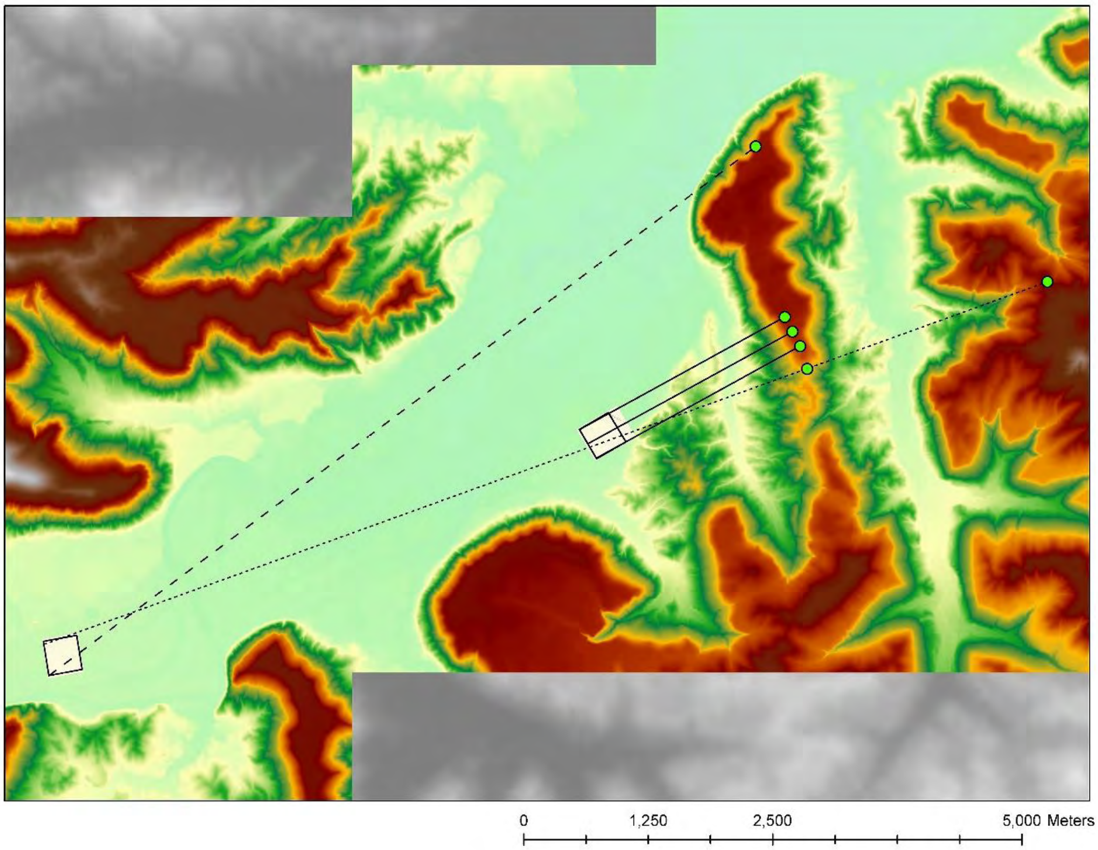

Figure 6. Sightlines from both Baum and Seip terminate on Spruce Hill. It is a unique situation to have so many foresights located on one landform. The three solid lines at Baum are summer solstice sunrise sightlines. The dashed Seip sightline at top is for the north lunar maximum rise event. The dotted line at bottom also begins at Seip, and is for the May cross quarter sunrise. Note that there are two potential horizon foresights for this latter sightline: one at southernmost Spruce Hill, the other about 2500 meters east. These two loci differ in horizon altitude by only three one-hundredths of a degree as seen from Seip (see Table 1). All of these foresight locations are potential archaeological sites.

While the Baum square is readily apparent in Lidar-based hillshade imagery, the Seip square is barely discernible. Contour maps generated from the Lidar data do show parts of the western and northern walls of the square. The entire Middleton/Fowke survey data can therefore be georeferenced in ArcMap using these features. During this process, the square and gateways are made to comport to the dimensions and azimuths as provided by Middleton and Fowke.

Thus plotted, the calendrical sightlines revealed by the Seip square differ from those at nearby Baum, where only solstices are indicated. At Seip, only two of the four solstices are indexed (winter solstice rise and summer solstice set), while the north lunar maximum moonrise is marked with two extremely long sightlines. The horizon foresight locations associated with these lunar sightlines are notable; one occurs within the Spruce Hill enclosure near or at known fire cracked rock concentrations (Ruby 2009:60-61) (Figure 11), while the other occurs on an eminence proximate to and visible from the distant Hopewell type-site (33RO27) (Figure 12).

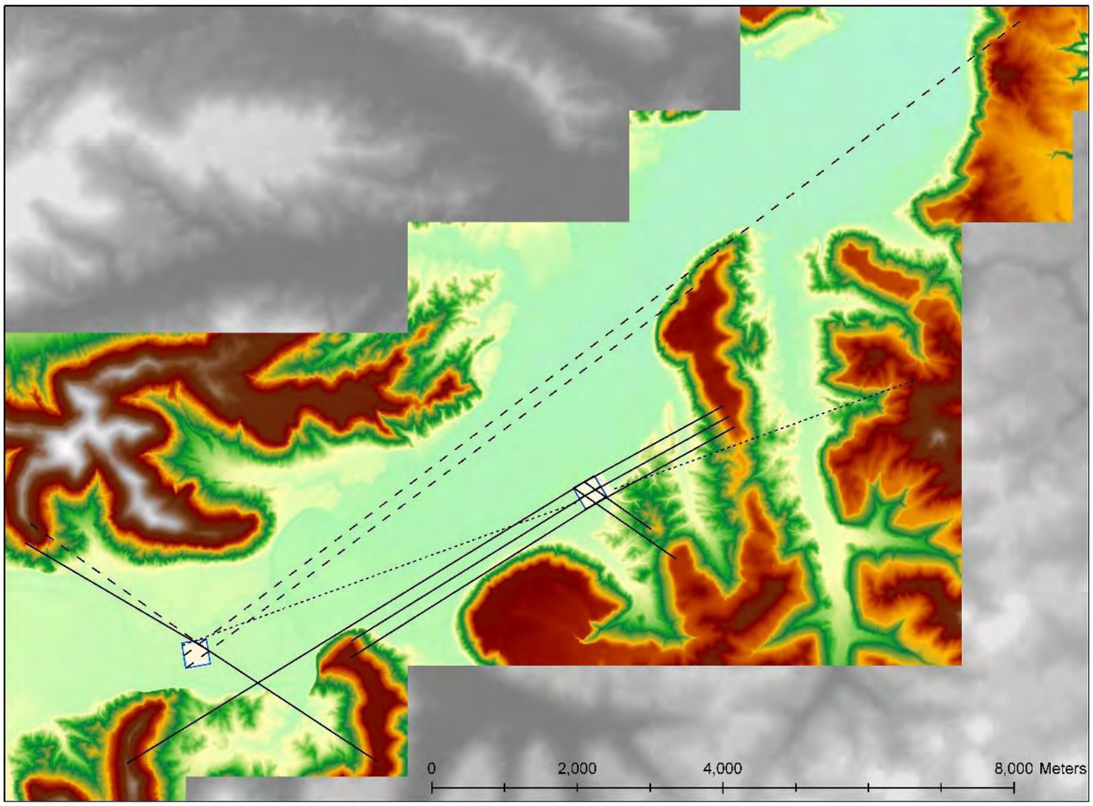

Figure 7. The combined sightlines from Baum and Seip span a broad section of the Paint Creek Valley. The long sightline at top is the north lunar maximum rise event. It is over fourteen kilometers in length. The coordinates for each horizon foresight are provided in the Table 1. The dashed lines are lunar maximum sightlines, the solid lines are solstices, while the single dotted line is a cross quarter rise event.

The latter sightline is over 14,000 meters in length, extending along the lowest swath in elevation of the Paint Creek Valley itself (Figures 7 and 13). This is the longest calendrical sightline that I have encountered in these studies.

Additionally, there is a May cross quarter date sunrise sightline indexed at Seip. The horizon foresight for this event also occurs on Spruce Hill, bringing to three the number of rise events that occur over that eminence (see Figure 6).

I have provided coordinates for the various horizon foresight loci, given in decimal degrees of longitude and latitude (Table 1). This degree of precision afforded by GIS allows researchers to find these sites and to test them archaeologically. In archaeoastronomy, we often do not have hypothesis testing opportunities, but here the archaeological examination of the horizon foresights provides a hypothetico-deductive check regarding the use of the geometrical earthworks as calendrical indices (Turner 2011:318).

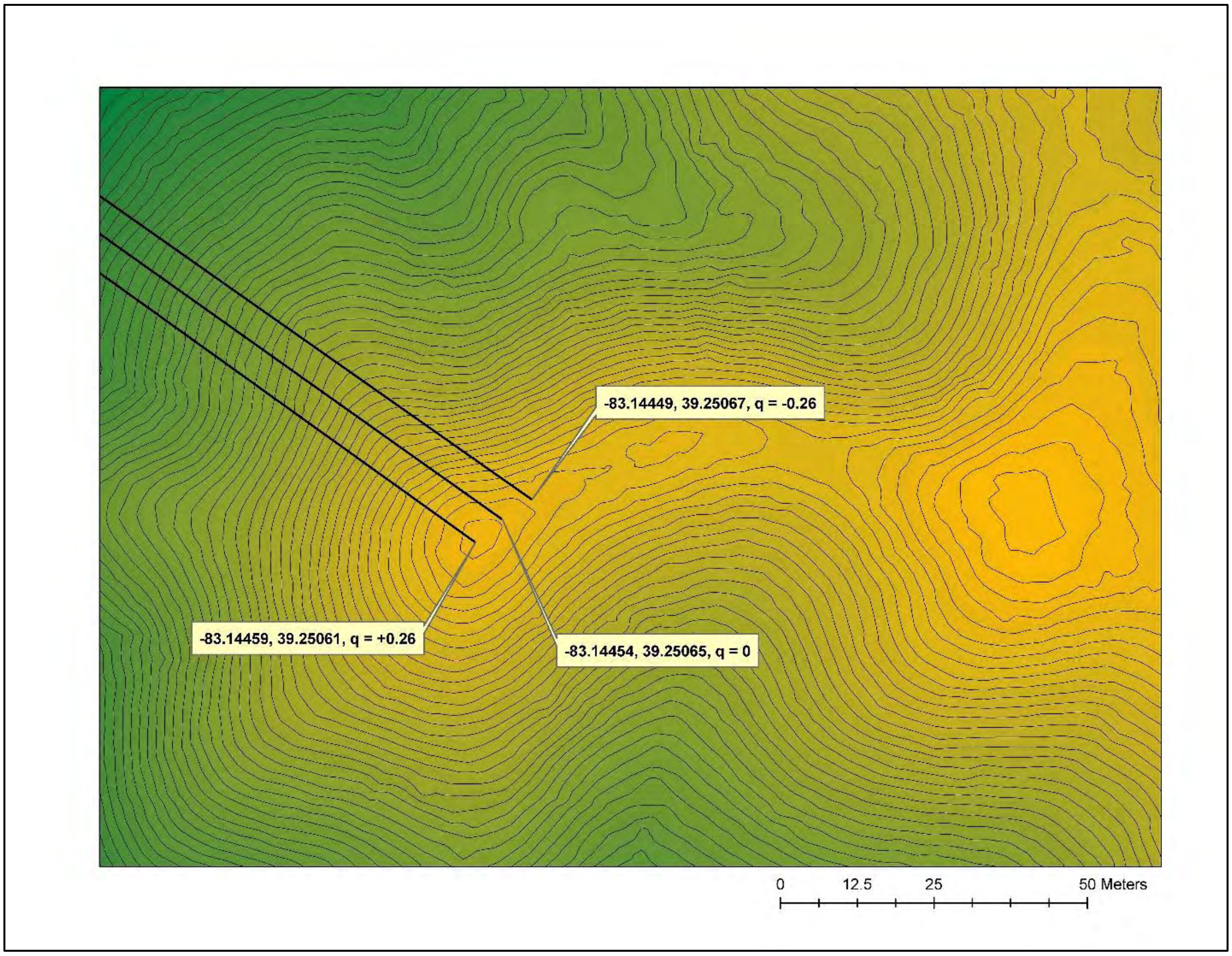

Figure 8. The Baum winter solstice sunrise sightline B-E terminates on an unnamed ridge only 1130 meters distant from the square. Individuals standing at this unusually close horizon foresight would be visible silhouetted against a rising sun. Archaeological evidence of ritual use would seem likely at this locale. The horizon foresights are plotted for the three phases of sunrise: first gleam (q=-0°.26), half disk (q=0°), and last tangent (q=+0°.26). The coordinates are in decimal degrees. Decimal degrees, quoted to five places, correspond to a precision of about one meter in the field.

It is difficult if not impossible to visualize the prehistoric landscapes known to the Hopewell. Squier and Davis described a wide array of mound types in the vicinity of Seip and Baum. The monumental mortuary mound at Seip was:

> …two hundred and forty feet long by one hundred and sixty broad, and thirty in height…. [It was] …composed… [in part] of stones and pebbles…surrounded by a low indistinct embankment…. To the right of this fine mound is a group of three others in

combination… [while] several very large and beautiful ones, composed entirely of clay, occur about one fourth of a mile distant (Squier and Davis 1848: 58).

Additionally, Mills's (1914) *Archaeological Atlas of Ohio* shows the clustering of mounds throughout Ross County including within the Paint Creek Valley (Figure 14). The scale and precision of the Mills's atlas permits limited insight, however (Dancey 1984). Even with such data, the lived-in visual landscape of the Hopewell is mostly unknowable. Were we able to

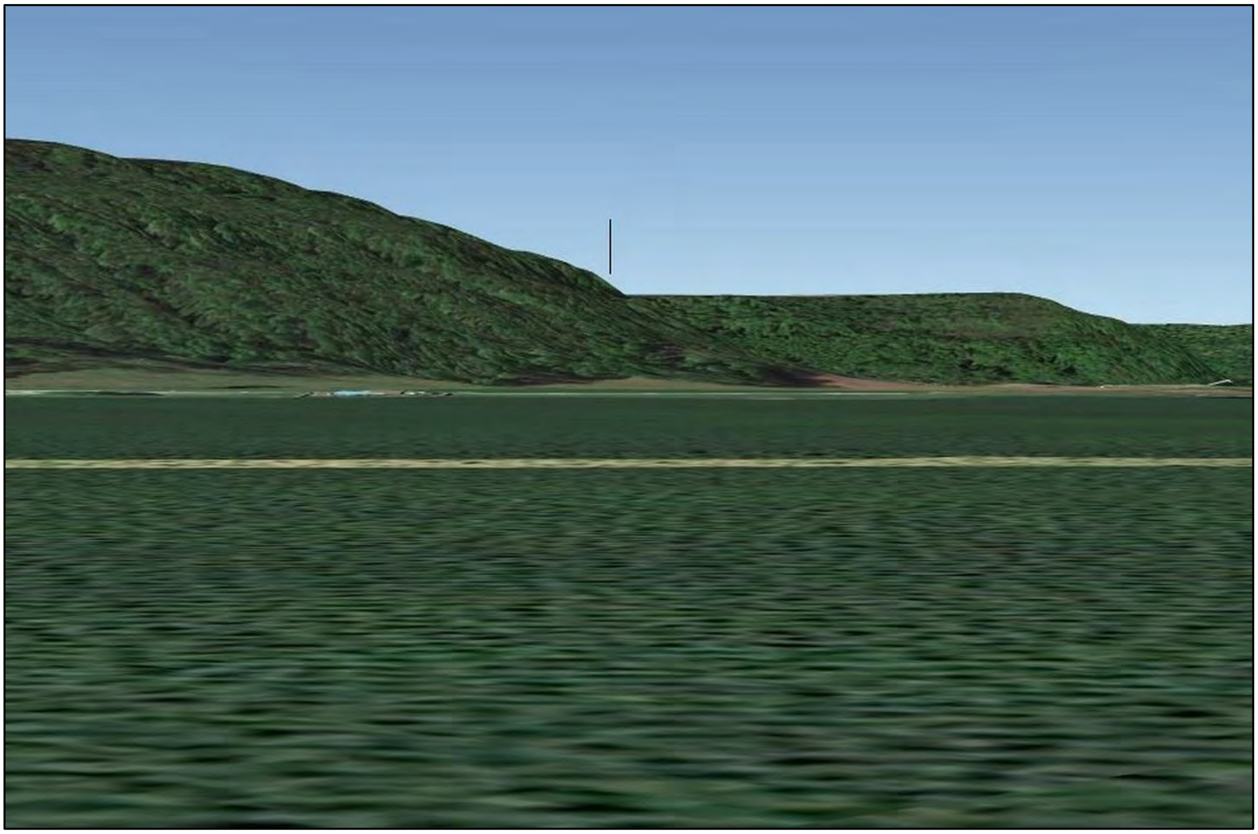

Figure 9. Google Earth image of horizon as seen from Baum square gateway D. The winter solstice set sightline D-H horizon foresight occurs on the slope of Copperas Mountain (locus indicated by tick mark). (See Table 1, Baum sightline D-H.) The use of natural landscpe features (e.g. gaps or peaks) corroborates the intentionality of the sightlines.

plot these earthen monuments in their entirety with precision, viewing them in three dimensions in a GIS application, viewers could gain insight into the social space induced by the monuments, ritual and domestic architecture, and landscape (Llobera 2007; Rennell 2012).

Because the Hopewell geometric enclosures embody viewsheds by utilizing sightlines, each earthwork group creates a visual catchment defined by the extent of the horizon foresights. The array of viewsheds defined by the geometric sites surrounding Chillicothe can be mapped using GIS. Some of these viewsheds appear to be distributed so as to overlap at their peripheries (Figure 15). Such arrays of calendrical sightlines and horizon foresights surrounding the various earthworks, possibly utilized as places of ritual enactment, may have served as elements within the cognitive mapping of the landscape (Meddens et al. 2008:351).

A similar situation has been described for the *ceque* system of ritual sightlines in sixteenth century Incan Peru, where it was "…reported that each local region and community had a similar system [of sightlines] in place to define the sacred landscape on a local level and scale, …which served to co-ordinate planting, irrigation and … ritual with calendrics and astronomy (Meddens et al. 2008:317)."

As a group, historic Puebloan societies of the American southwest exemplified the use of calendrical sightlines. The horizon foresight along a summer solstice rise line was utilized, in one

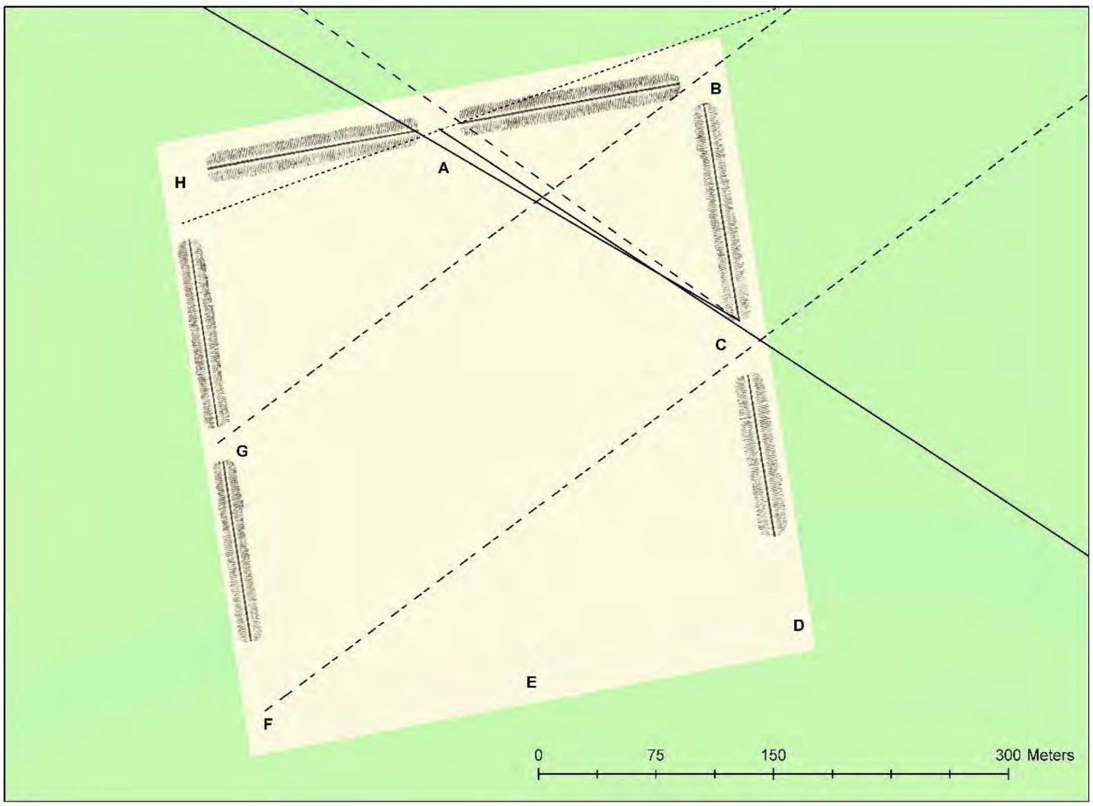

Figure 10. Middleton and Fowke did not produce a plat for the Seip square. Using GIS, I have created such a plat. By 1885, the southern embankment of the square was eroded ("obliterated") by the Paint Creek, as recorded by the surveyors, and as shown here following their data. The five extant gateways are also sized and labeled following their data and nomenclature. Sightlines are shown: dashed lines are lunar maxima, the dotted line cross quarter, and the solid lines solstices. Because we lack data for the south wall, the redundant sightlines D-H, E-G, C-F, H-D, and G-E are not shown, but were likely present. The north lunar maximum rise sightline F-C is shown, however. Importantly, the horizon foresight for this likely sightline is within the Spruce Hill enclosure. At this location, there are FCR concentrations still extant that were described and mapped by Squier and Davis (Ruby 2009:60-61).

Hopi example, as a place of ritual offering. A young Hopi man would run along the entire sightline to the horizon location to make the offering (Zeilik 1985:12). Given the apparent complexity of the Hopewellian calendrical sightlines and landscape, a more informed interpretation of them may lie in such ethnographic comparisons.

These Hopewellian viewsheds were a palimpsest of terrestrial and anthropogenic features, as Early Woodland Adena earthworks preceded and fomented the production of Middle Woodland landscapes (e.g., Carskadden and Morton 1997:372; Clay 1998:9-10). The Hopewell, known for their artistic expression, were apparently no less demonstrative with their earthen monuments. Terraforming proximate to the earthworks was often reported by Squier and Davis (e.g., 1848: 15, 48, 57, 66, 68, 88). Recent excavations at Hopeton indicated the careful removal of B-horizon soils during construction of the earthwork (Lynott 2014:106ff). Unique

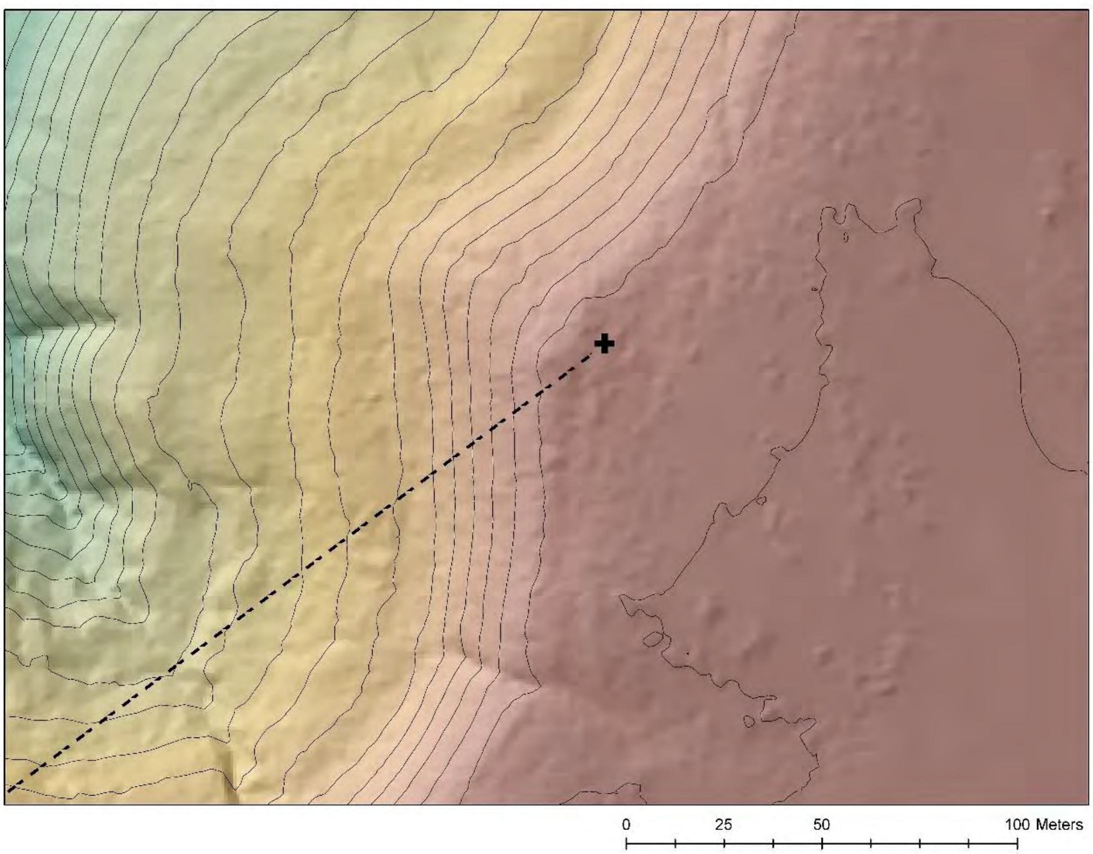

Figure 11. The lunar maximum rise sightline Seip F-C is shown by the dashed line. The location is the northwest section of the Hopewell hilltop enclosure Spruce Hill. The black cross marks the locus of the FCR concentrations noted by Squier and Davis (1848:12) and others (Ruby 2009:53, 60). This point datum was provided by Bret Ruby in the form of a geo-tagged photograph. Ruby is presently chief archaeologist at Hopewell Culture National Historical Park.

combinations of soils, clays, and gravels have frequently been noted in Hopewell earthwork stratigraphies (e.g., Lepper 1996:233; Mills 1907:26; Van Nest et al. 2001).

Archaeologists in the 1990s examined sub-embankment A-horizon paleosols beneath Hopeton (Ruby 1997: Figure 4) and the Newark Great (Fairground) Circle (Cummings 1992). Both studies suggested treeless environments prior to construction. Prolonged regional occupation surely led to some degree of deforestation and increased use of Eastern Agricultural Complex (EAC) cultivars and domesticates would also have impacted landscapes, as evidenced during the Early Woodland period in nearby Kentucky uplands (Delcourt et al. 1998). Within Ohio Hopewell, pollen and phytolith samples and charcoal assemblages demonstrate increasing deforestation and the presence of successional species and EAC cultivars and domesticates (Cummings 1992; Wymer 1996:45-47, 1997:159). As in the eastern Kentucky highlands example, this evidence is consistent with and likely due in part to swidden farming.

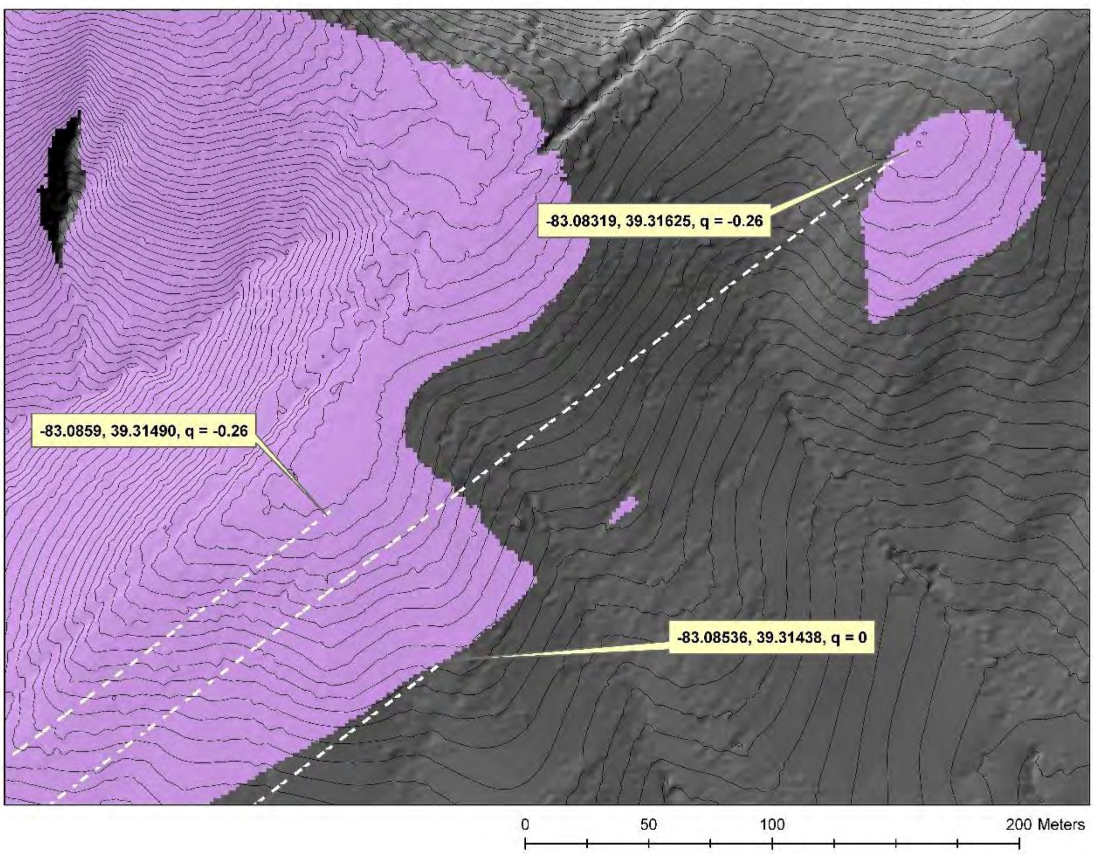

Figure 12. Shown is the horizon foresight locus for the Seip square north lunar maximum rise sightline G-B. Shaded in pink is the viewshed as seen from gateway G at Seip. The lowest of the three test lines is for the moon half risen (q = 0), whereas the upper two lines correspond to the first gleam event (modeled during analysis with q = -0.26 degrees). Note that the lower foresight occurs on a slope, whereas the upper two occupy apical landforms. These two loci should be tested with geophysical survey. The other lunar maximum line at Seip, F-C, terminates on known large FCR concentrations on Spruce Hill (see Figure 11). Should the same pattern hold with the G-B sightline, we might expect to find FCR at these foresight loci. Mills's *Archaeological Atlas of Ohio* shows three mounds in this location (Figure 14, upper right).

Paleobotanical data demonstrating Hopewellian use of EAC foods, though once rejected, have accrued and are now ubiquitous. Some regional evidence now even predates the Woodland Period (Patton and Curran 2016), with examples of EAC foods persisting in Ohio into the Late Woodland (Martin 2009).

Anthropogenic ponds that ring the interior of Ft. Ancient were created and terraformed by the Hopewell. In the pond sediments, Kendra McLauchlan found palynological evidence of deforestation and prolonged and extensive EAC use, writing "…the Hopewell cleared the area within and possibly surrounding Fort Ancient, and likely cultivated crops at this site for several hundred years (2003:564)."

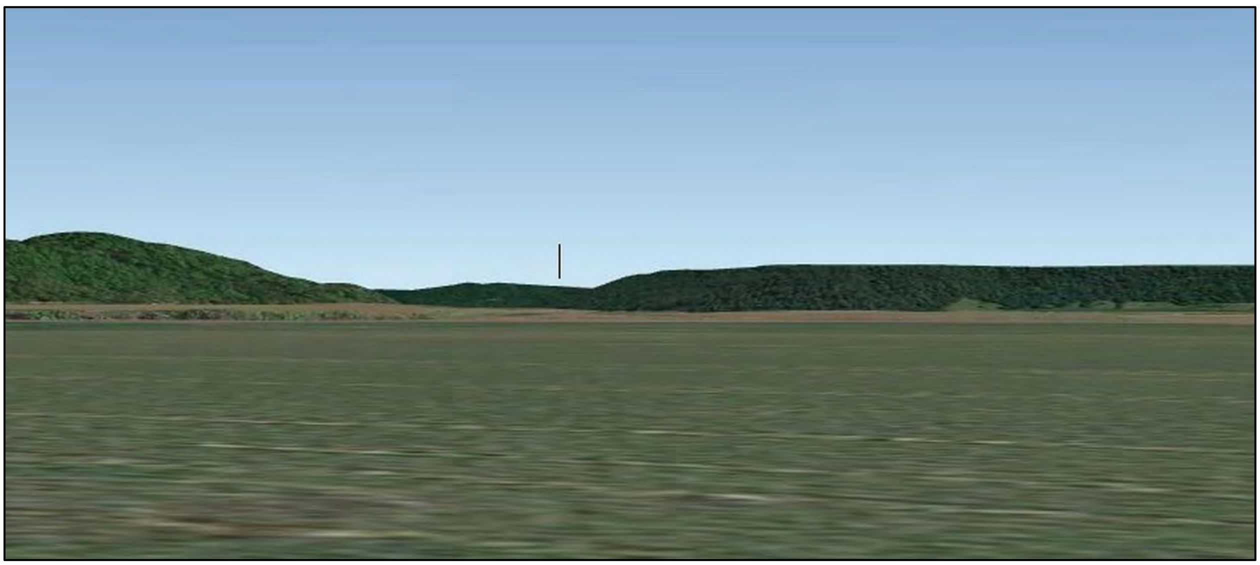

Figure 13. Again from Google Earth, this is the view from Seip gateway G, looking toward the northeast. Spruce Hill is the level landform seen on the right. The lower, centrally located landform hosts the foresight of Seip sightline G-B, as indicated by tick mark (see Figure 12). The landform is over 14 km distant from Seip.

Notwithstanding such definitive conclusions as those of McLauchlan, a robust understanding of Ohio Hopewell settlement patterns has eluded archaeologists. Research has often been focused on mortuary features, while data on habitation sites had been sparse (but see Griffin 1996). Dancey and Pacheco suggested that the Hopewell occupied small hamlets "…made up of single or multiple family households scattered across the landscape but concentrated around the centrally located burial and ceremonial precincts (1997:3)." Expanding on this idea, Ruby, Carr and Charles proposed that the "…earthworks may vary in their spatial relationships to communities. They may occur at the centers or edges of communities, or in less definable positions where community boundaries are fluid, overlapping, and/or continuously negotiated (2006:120)."

More recently, additional data have emerged. Some occupation sites featuring large structures have been found near geometrical earthworks (Kanter et al. 2015), while others have been located in upland environments. Prior lack of such evidence was perhaps due to resource destruction by farming and pot hunting, and to archaeological research design. The perceived "scarcity of Middle Woodland houses may simply be a matter of limited research and false expectations (Weaver et al. 2011:38)."

Discussion

The veracity of this report depends on the accuracy of the input data utilized in analysis. Herein those data are the 1880s Middleton/Fowke survey numbers. The GIS methods employed can make maximum use of such data, but it cannot improve them. Fortunately, we already know that the Middleton/Fowke data are valid. Sightlines that were predicted by Hively and Horn and I

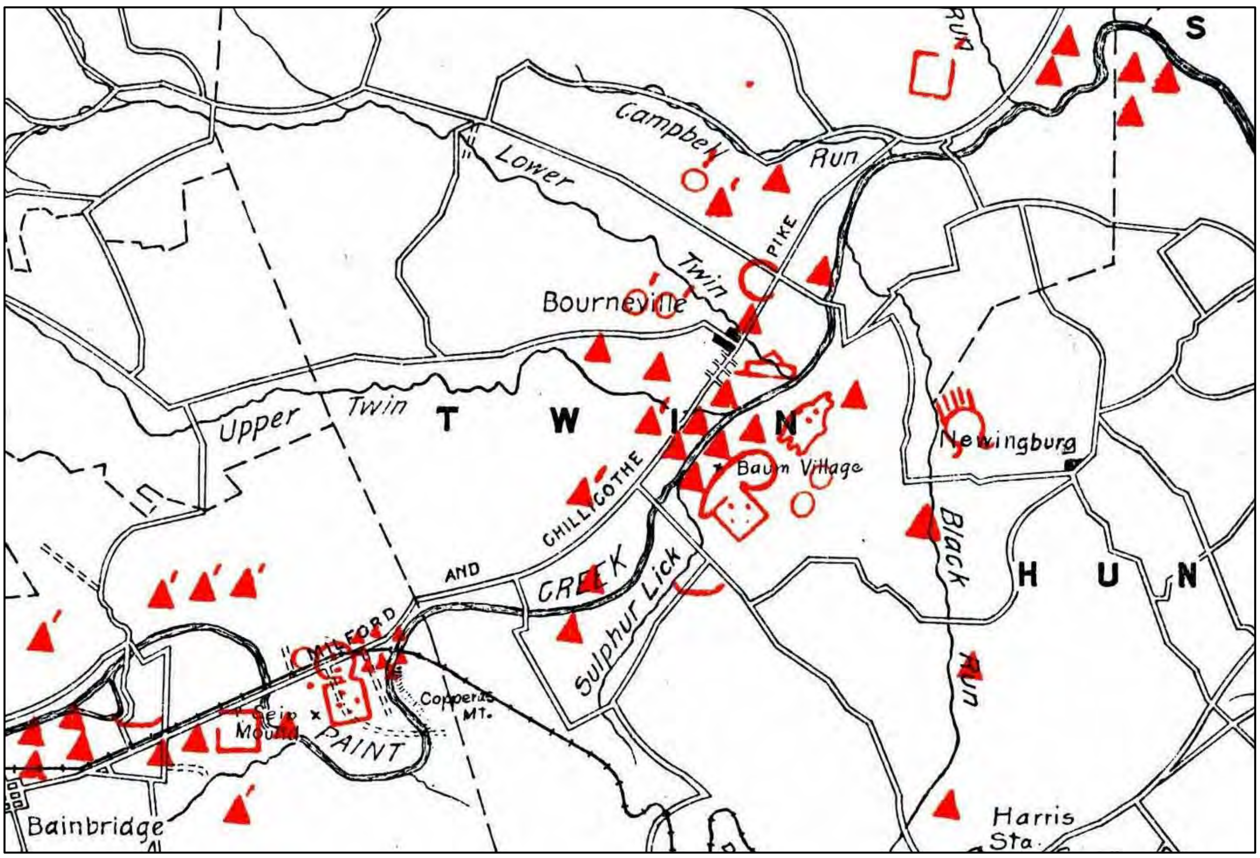

Figure 14. This is a section of the Ross County map from Mills' *Archaeological Atlas of Ohio*, showing the Paint Creek area. Seip earthworks is at left, Baum at center. Maps merely hint at the prehistoric visual landscape and associated viewsheds. Dancey (1984) examines the precision (or lack thereof) regarding the placement of earthwork and other symbols in the Mills atlas.

have been borne out through direct observation (e.g., compare Turner 1983, 2011). Our papers were generated circa 1980 with non-digital means but using the Middleton/Fowke data exclusively (Hively and Horn 1982:7, 1984:88-91). Future studies will also rely on geophysical survey (e.g. Komp et al. 2020), with specific attention to point data describing the enclosure gateways.

How accurate are the azimuths in the Middleton/Fowke survey data? Hively and Horn (1982:7, 1984:89) suggested a precision of +/- 1/4th degree, based on their own comparative survey in 1980 using "a transit and a steel tape (1982:6)." Fowke himself (1902:171) wrote of the 1885 survey that "Greater care was taken in getting bearings and distances than is usually employed in rail way or canal surveys. Middleton and I, who did the work, stand by our figures, and with all the more reason, too, that in some cases they completely upset our antecedent ideas and opinions." They published their azimuthal data to the nearest minute of arc, or 1/60th of a degree. The present paper suggests that the precision of the Middleton/Fowke data lies somewhere between these two poles. During calculations herein, the Middleton/Fowke data are presumed accurate to a precision of 1/10 degree.

Sightline azimuths generated from these data are cited to the same degree of precision. There are other criteria regarding these sightlines. A Hopewell sightline must indicate where the

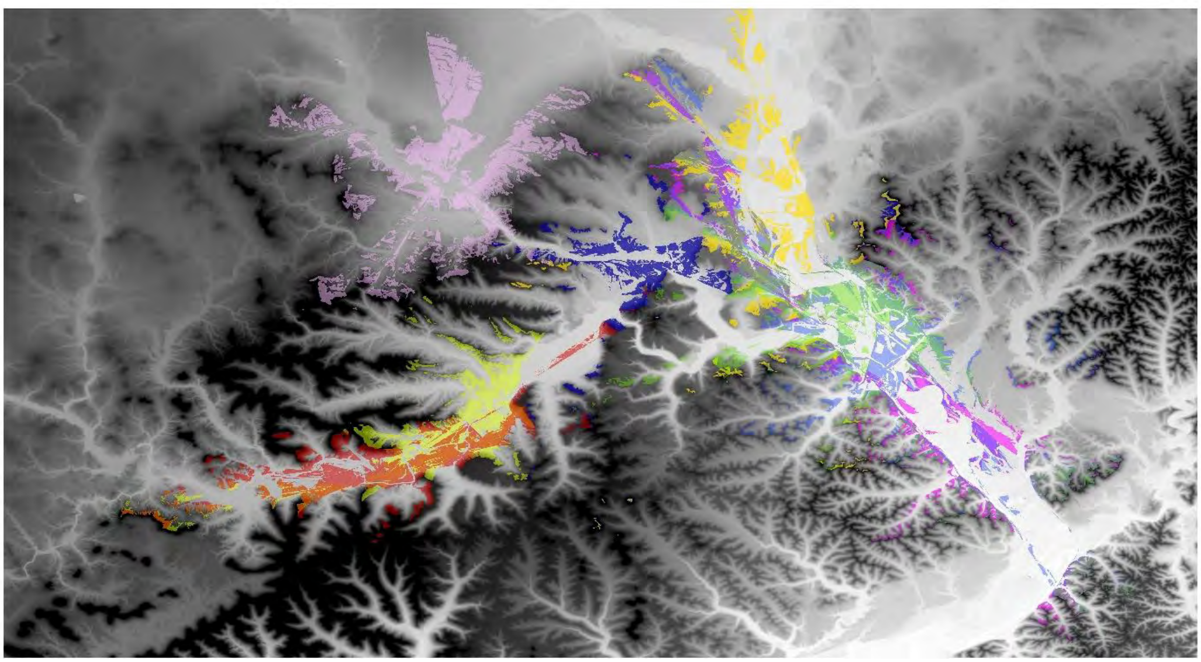

Figure 15. Shown are the viewsheds of eight geometric earthworks proximate to Chillicothe, the core area of Ohio Hopewell. Clockwise from lower left, the viewsheds are Seip (red), Baum (yellow), Frankfort (pink), Hopewell type-site (dark blue), Hopeton (dark yellow), Chillicothe East (green), High Bank (blue), Liberty (magenta). These colors are transparent so combine to form other hues that indicate overlap of viewsheds. (Note for instance the orange coloring between Seip and Baum at lower left) The red streak at center is the viewshed containing the Seip sightline G-B (Figures 7 and 12). Various peaks and ridges are intervisible from several of the geometric sites. Aside from issues of archaeoastronomy, signaling and communications systems can be examined by maps such as these.

sun or moon either rises or sets, as these are the only celestial events thus far demonstrated in a Hopewellian context. Sightlines must also of course comport to the earthwork itself. Generally speaking, for the geometric earthworks in question, the sightlines are from gateway to gateway. This concept began with John Eddy (1977), with regard to the primary axis at the Newark octagon. He suggested that this sightline was keyed to the azimuth of the north lunar maximum rise event. Then, in their 1982 paper on the Newark octagon, Hively and Horn confirmed the axial sightline suggested by Eddy. This is sightline A-E, following the gateway nomenclature in their article (1982:14, Figure 8). Two other sightlines, F-H and G-D, are also shown in the same figure.

The design of sightline F-H is very revealing and informative. According to Hively and Horn, the embankment labeled “HA” is nine meters shorter than the other seven walls of the octagon. They noted that the southern edge of the gateway at vertex H thereby functions as a foresight for sightline F-H. In other words, the octagon is distorted from geometric regularity in a direction accommodating sightline accuracy, and the sightline is specifically targeted at the *edge of the gateway*, not at the center of the gateway. In my own research, I have repeatedly found this to be the case: that sightlines are not simply from gateway-to-gateway, but from gateway edge to gateway edge. It is very impressive to repeatedly see this during analysis.

Hively and Horn (1982) actually suggested two means of observing a sightline. The other was to sight along the top of an embankment, thus defining an azimuth. They posited sightlines along the tops of octagon walls AB, CB, EF, and GF. It should be noted that each of these sightlines can be as easily realized by sighting between gateways, viz., sightline A-B, sightline C-B, sightline E-F, and sightline G-F, all gateway-to-gateway sightlines. In their paper on the High Bank octagon earthworks two years later in 1984, *none* of the sightlines suggested by Hively and Horn were embankment sightlines: nearly all were gateway-to-gateway. Using Occam’s razor, we can reject the embankment sightlines, and consider all such sightlines to be gateway-to-gateway (see Figures 2 and 10), because such sightlines function just as aptly as the posited embankment sightlines.

As such, Hively and Horn demonstrated that the gateway-to-gateway sightlines at the Newark octagon index seven of the eight lunar extrema or standstills. The orbital motion of the moon causes it to occupy these unique positions along the horizon for brief periods every 18.6 years (Ellegard 1981:105-107; Hardman and Hardman 1992; Hively and Horn 1982, 1984; Turner 2011:307).

A sightline can therefore be defined as (1) indexing a celestial phenomenon that has been demonstrated at other such Hopewell sites, (2) having a backsight located within a gateway, and (3) utilizing another gateway as a foresight. The data suggest that exact backsight and foresight loci may be at the edge of a gateway, immediately adjacent to the embankment slope, not in the center of the gateway. Hively and Horn noted that gateway F at the Newark octagon was intentionally made narrow so as to define a specific backsight locus, which they called a “very narrow gap or observation point (1982:14).” Middleton and Fowke reported a unique narrowing of gateway 5 at Hopeton, which is decidedly off center, not in the middle of the gateway (Thomas 1894:472; Turner 2015: Figure 5), and which appears to serve as a backsight for the Hopeton winter solstice rise sightline 5-11 (Turner 1983: Table 1, 2011:310-311).

Sightlines must not be blocked by natural vegetation. As noted earlier, it is evident that terraforming occurred in the vicinity of the earthworks. It is implicit that these places were deforested. Regarding the horizon foresights themselves, these are most frequently located on narrow ridges, hence the area that would need deforesting in order to clear a horizon foresight of vegetation is relatively small. We know from studies by Wymer, McClauchlan, and others that local forests were being disturbed for prolonged periods in the Middle Woodland.

The Hopewell Ft. Ancient site was apparently deforested (McLauchlan 2003). At Spruce Hill, the interior of the enclosure was “entirely devoid of stone,” according to those who had farmed the soil there (Ruby 2009:54). This indicates that both hilltop enclosures were likely treeless in Hopewell times. Certainly, the fires indicated by the extensive and heavily burned FCR concentrations on Spruce Hill would have destroyed any local foliage present. The amount of labor required to fell such trees may have been nominal compared to the total labor required in the construction of the earthworks themselves. Given these facts, we can assert that the lines of sight were not blocked by vegetation, and that land associated with the physical sightlines was terraformed or deforested as needed.

Sightlines can be examined from a probabalistic perspective. How likely is it for such sightlines to occur randomly? The Hively and Horn (2006:307) analysis of the eight-sided Newark enclosure modeled randomized octagons, which yielded a probability (of finding the same lunar sightlines among the randomized octagons) of $p = 0.0012$.

In testing the Newark octagon, I discovered that the sightlines there *do not index any solar phenomena*, even coincidentally. This includes all solstice, equinox, and cross-quarter events. The combined likelihood of the octagon *both* indexing the lunar sightlines found by Hively and Horn, *and* of not indexing any solar events is extremely small, about 1 in 1500 (Turner 2004b).

Also convincing is the repeated occurrence of these sightlines across the investigated earthworks. Note the similitude of design and the presence of lunar sightlines at both octagons, Newark and High Bank (Hively and Horn 1982, 1984). Consider that the north and south sides of Hopeton and the axial sightline at the Great (Fairground) Circle index the May cross-quarter sunrise (Turner 1982, 1983, 2011). Solstice sightlines are found at Hopeton (Turner 1983, 2011), High Bank (Hively and Horn 1984), Baum, and Seip.

Hively and Horn (2019:118) noted that the “repeated and likely deliberate regularity in design... [and the]… repetitive pattern of deliberate alignments” suggests intentionality on the part of the Hopewell. The present paper offers a means to test the model. By using GIS, the locations of the horizon foresights can be predicted with great specificity. If indeed the Hopewell utilized these locations, either for confirmatory signaling during observations, or for any possible associated ritual use, an archaeological signature may remain.

Most notable of these signatures may be FCR concentrations. For example, Figure 11 shows the termination of a Seip sightline at FCR mounds on Spruce Hill. Squier and Davis (1848:182-183) first noted the association of ridgetop FCR with the geometric earthworks. Horizon foresights may be terraformed. I observed evidence of this in the Great Seal Range east of Hopeton (Turner 1983). It would not seem unlikely given the terraforming present at the earthworks themselves. If the foresights were extensively used, there may be evidence of ritual deposits or prehistoric footpaths at or in the vicinity of the horizon foresights (McKee et al. 1994). Such are some of the archaeological correlates possible at the horizon foresights.

With this analysis of Seip and Baum, certain patterns continue to emerge. It appears that within the Hopewell corpus, each respective earthwork indexes a group of celestial events unique to that earthwork. The enclosures with the greatest geometrical regularity are unable to delineate more than a few sightlines. The highly regular Newark Octagon indicates lunar phenomena only, while the comparatively irregular High Bank octagon in Chillicothe marks the lunar extrema *along with* all of the solstice events (Hively and Horn 1982, 1984). Among squares, we find that Liberty marks only equinoxes and cross quarters (Turner 2015), but Baum only solstices. Seip, oriented yet differently, includes solstices, lunar extrema, and May cross quarter, albeit a limited subset of these. Only the Hopeton earthworks, the most distorted, least regular of these polygons, defines all of these sightlines, for both rise and set events (Turner 1983).

The Baum square is shown to define the summer and winter solstices *only*. We are left to speculate as to why the Hopewell appear to have partitioned the various celestial events across the various earthwork sites. The geometric design, celestial indexicality, and geographical placement across the local landscape are unique for each.

The Seip square earthwork sightlines are unique. All other Hopewell geometric enclosures each index groups of specific events. For instance, Baum highlights solstices, but the Newark Octagon marks only lunar extrema. High Bank indexes the entire suite of lunar events *and* the solstices, while the Liberty Square sightlines feature only equinoxes and cross quarters. These events are for both rise and set at all sites. Seip is unique because its sightlines are in partial groups only. It does, however, index what may be the three most important celestial events in the Hopewell corpus:

1) The north lunar maximum rise is delineated at Seip by two extremely long sightlines, each with notable horizon foresights. This is the same event that is marked by the axis of the Newark octagon, whose very architecture denotes the importance of this sightline to the Hopewell.

2) The Seip square gateways also mark the winter solstice sunrise. This winter solstice azimuth likely shaped the design and orientation of the nearby Hopeton earthworks (Turner 2011:310).

3) The May cross quarter sunrise is also indicated by the Seip gateway sightlines. This is the sole event marked by the Great (Fairground) Circle in Newark (Turner 1982), indicating its cultural salience.

Seip therefore incorporates these three important sightlines into its design: north lunar maximum rise, winter solstice rise, and May cross quarter rise. However, in the case of Seip, none of these events occur in complete groups (viz., including rises and sets and north and south events for each phenomena) as at all other such Hopewell sites.

The organization needed to manage this array of architectures accompanied the cognitive and observational successes evidenced by the calendrical sightlines themselves. There appear to have been well developed lineages of calendrical specialists present and influential in Ohio Hopewell. Use of EAC foodstuffs burgeoned regionally in Ohio at the turn of the Middle Woodland period (Case and Carr 2008:86-90). An adaptive and pragmatic scheduling regime responsive to this fulminating horticulture likely fomented the elite status of these calendrical specialists. Anthony Aveni (2016:247) has recently noted that:

> [The Hopewell] …grew the Eastern Agricultural Complex (including goosefoot, maygrass and sunflower), tended to the fish run, picked berries and other wild fruits and hunted wild animals, [hence] it would make sense that those who lived and worshipped there might, like

the Anasazi, have used the horizon position of the Sun to set out a specific range of dates that demarcated the hunting, fishing and planting seasons and the rites thereto appertaining.

The idea that a lineage of elites created these unusual earthworks is not new. Referring to Hopewell enclosures and associated social complexity, Griffin (1952:359) commented "...that this was probably dominated by male shamans who were promulgating the interpretation of the relationship of man to the universe as a whole. This suggests the development of a specialized priesthood." What we can now assert is that the Eastern Agricultural Complex, when managed at the latitude of Ohio, compelled at least in part the development of a subsistence scheduling regime that included the utilization of solar horizon calendars.

May cross quarter sightlines are found at four Hopewell sites including at the Great (Fairground) Circle in Newark, and in the Chillicothe area at Hopeton, Liberty, and now Seip. Familiarity with these solar horizon calendars likely eventuated in the specialized (and less observationally salient) lunar monitoring indicated at Hopeton, High Bank, Newark, and now the Seip earthworks (Ellegard 1981; Hardman and Hardman 1992). Because a *single* lunar cycle is completed only after 18.6 years, generations of subsistence scheduling specialists, likely spanning centuries, are evidenced by this corpus of earthworks (Lynott 2014:112-114).

GIS allows researchers to excel at analyzing data in archaeoastronomical applications. The use of Lidar-based DEM, viewshed, line of sight, hillshade, georeferencing, and other tools in ArcMap is especially important for these studies. The precision afforded by GIS allows for the full utilization of input data. These predicted sightlines can be field tested by witnessing each specific celestial event at the earthworks in question. Additionally, high resolution magnetic survey can locate destroyed embankment features, better establishing backsight and foresight gateway locations (e.g., Burks and Cook 2011; Komp et al. 2020). When actualized through in situ observation, the sightlines are definable to a precision evidenced by the rising or setting events themselves.

Regarding precision, and the calculating of sightlines, it is not germane to discuss theoretical limitations involving lunar motions when sightline calculations are in practice limited by human visual acuity during the phenomenon of observation. Fisher and Sims (2017:215) asserted that "the varying time of day when the extremes occur infers that precise alignment of the Moon to the horizon point is impractical, and that a tolerance of ±1° as determined by Ruggles is probably the only reasonable measure." Their statement seriously misconstrues the data. Though the moon may not rise at the exact moment of the lunar extreme, it must rise within twelve hours of that extreme, resulting in a maximum possible shift of only 14 minutes of arc in lunar declination, or less than half of the moon's diameter, at that moonrise. Similarly, during a twelve-month period centered on lunar maximum, the moon will reach a declination within 20 arc minutes of the extreme once each month. This is only 2/3 the diameter of the moon. These "misses" are minor compared to the ±1° figure cited by Fisher and Simms, which equals four moon widths. Moreover, if the Hopewell scheduling elites endured for centuries as the archaeology suggests (Lynott 2014:112-114), then during those centuries the cumulative lunar extreme observations would converge on the maximum azimuth, and would be duly recognized, likely eventuating in the indexing of the true extreme azimuth for that sightline.

It will be geophysical survey combined with standard archaeology that will best establish the locations of now destroyed geometric and other earthwork features (Burks and Cook 2011).

Pinpointing the enclosure gateway locations will then allow for definitive sightline testing. Results from the present study are intended to assist the search for these backsights, foresights, and sightlines. The actualized celestial observations made with respect to the reestablished gateway loci, honed by any apparent horizon foresight terrestrial features, will stand as the final arbiter on the functionality of the sightlines, and will yield, de facto, the working precision which renders the sightlines effectual.

Summary

The prehistoric Native American culture called Hopewell culminated circa 100 BC to AD 400, or during the Middle Woodland Period. The Ohio Hopewell created exceptionally large monumental earthworks that traced the outlines of great circles, squares, and octagons. Several of these enclosures have been shown to define calendrical sightlines. With this paper, I have examined the Baum square and Seip square for the presence of such sightlines.

Using ESRI ArcMap and Microsoft Excel software, archaeoastronomical analysis of the Baum and Seip squares was completed. The results indicate a corpus of solstice sightlines at Baum, and an array of various sightlines at Seip, all similar to such as have been previously noted at other Hopewell enclosures.

The horizon foresights indicated by these sightlines can be examined archaeologically to see whether they were utilized in conjunction with the sightlines, allowing for a hypothetical-deductive check on such use. Archaeological evidence at the horizon foresights might include FCR concentrations, terraforming, or ritual deposits, for example. Several of the sightlines at Baum and Seip terminate on the Hopewell hilltop enclosure Spruce Hill, including a lunar maximum rise line that appears to terminate at known FCR mounds. Squier and Davis themselves noted that many FCR concentrations occur on ridges surrounding the Hopewell geometric enclosures (Squier and Davis 1848:183).

I have argued that the impetus for this calendrical technology was the adoption of the Eastern Agricultural Complex cultivars and domesticates in southern Ohio. EAC use was fluorescing locally in the Middle Woodland, and the May cross quarter sightlines noted at Seip and other Hopewell sites were ideally suited to establishing a spring planting calendar (Zeilik 1985:20-21).

These calendrical sightlines must have originated with respect to natural terrain features and non-monumental architecture (e.g., Figures 9 and 16). The establishment and codification of the sightlines in earthwork form evidenced an enduring subsistence scheduling regime, and a calendrical and predictive technology.

The lunar maximum sightlines suggest a technology whose development spanned centuries. The associated lunar cycle is 18.6 years, and the repeated observation of these cycles, sufficient to establish the accurate lunar sightlines noted in this paper and elsewhere, surely required continuous generations of observers.

Field testing of these sightlines can be accomplished today in situ. Though many of the earthwork features have been destroyed or otherwise disturbed, the use of geophysical survey can reestablish these loci with great accuracy, rendering the sightlines testable. Field assistants located at the various horizon foresights, and equipped with bright spotlights, can reestablish the precise coordinates of these locations. The next lunar maximum within the 18.6-year cycle occurs in March 2025. Twice each month, over a period of several months centered on this date, the moon will be near its maximum declination. The lunar sightlines at Seip, Hopeton, High Bank, and the Newark Octagon will all be testable at these times. Viewing along these sightlines

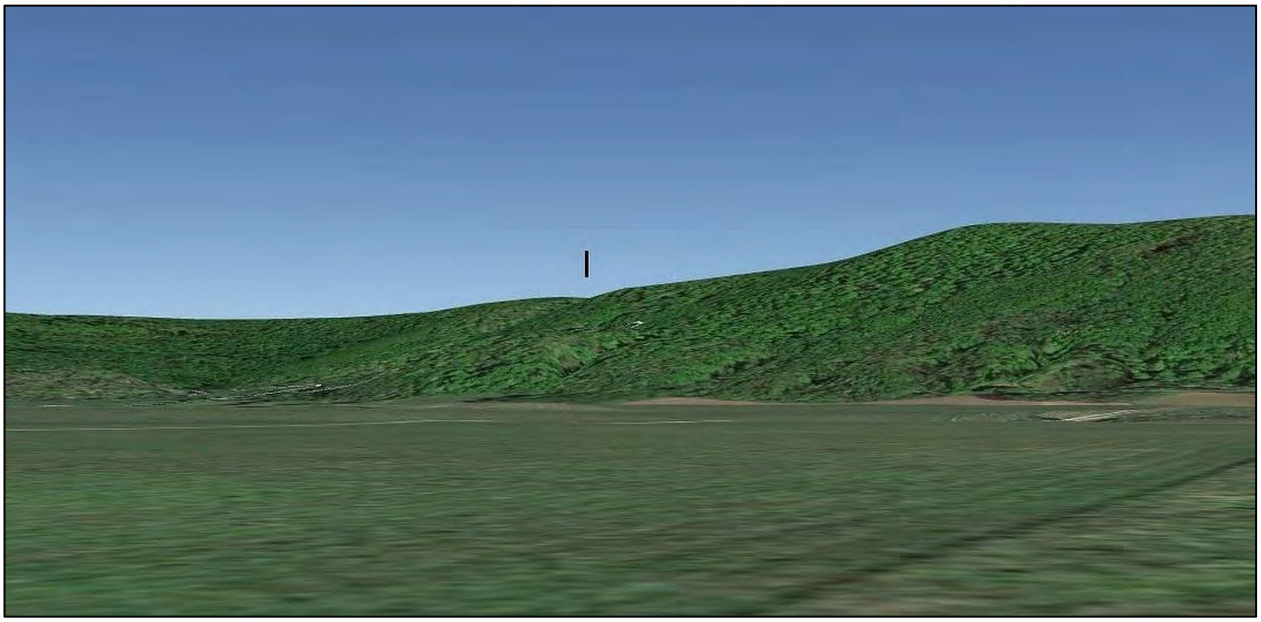

Figure 16. As seen from the Seip square, gateway C, the summer solstice sun sets in the gap indicated by tick mark. (See Table 1, Seip sightline C-A solar). This image is from Google Earth. Again, use of natural landscape features demonstrates intentionality on the part of the Hopewell.

can be actualized, both for research purposes, and with the intent of demonstrating to an interested public the use of these earthworks by the prehistoric Hopewell calendrical specialists.

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