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GEOMETRY AND ASTRONOMY IN PREHISTORIC OHIO

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Introduction

Prehistoric geometric earthworks more extensive than Avebury, and requiring an effort in design and construction comparable to Stonehenge, once covered an area of 10·4 square kilometres near the present city of Newark, Ohio. (Figure 1 is a 1934 aerial photograph showing a portion of the earthworks which still survives. Figure 2 shows the full extent of the works as they appeared in 1847.) The Newark earthworks have been the subject of amateur excavation and widespread curiosity for two centuries. Recent archaeological research has begun to build an understanding of the social and environmental context of Newark and other comparable Ohio sites. There has been much speculation, especially in the literature of archaeoastronomy, concerning the possible geometric and astronomical significance of these and related works.[1] Much of this speculation has been based upon nineteenth-century surveys which are known to be erroneous in quantitative details. Thus the aim of this paper is to provide a detailed analysis of the possible geometric and astronomical significance of the Newark earthworks, utilizing accurate survey data. Our analysis shows that the earthworks conform to a simple but precise geometric construction based on a single unit of length. Our work has also revealed substantial evidence that the earthworks may have been laid out at least in part as a lunar observatory.

Background

Since 1800, when settlers in the Licking Valley first noticed large geometric figures drawn in heavy earthen embankments at the confluence of Raccoon Creek and the South Fork of Licking River, the Newark earthworks have occupied an anomalous position in American archaeology. The still surviving walls of the large geometric figures extend for close to 4 kilometres. The original extent of the walls may have been five times as great. Yet there is a "paucity of information" about the works and their archaeological context.[2] If the Newark works had been the only Native American artifacts of their kind in the drainage system of the Ohio River, they would almost certainly have been more closely studied and perhaps better known today. They were, however, merely the largest and northernmost of many similar structures on rivers tributary to the Ohio. Other extensive geometrical works were to be found on the banks of the Scioto River north of Chillicothe, Ohio, on Paint Creek near its confluences with the Scioto, and at the confluence of the Scioto with the Ohio River near Portsmouth. Works on a similar scale were located at the confluence of the Little Miami River with the Ohio, near Cincinnati, and at the confluence of the Muskingum River (fed by the Licking River) with the Ohio, near Marietta. Altogether, more than one hundred Ohio sites involving large earthworks, many of them geometrically regular, were known by 1900.[3] Unfortunately, only the Newark site has been preserved in a manner which allows its main features

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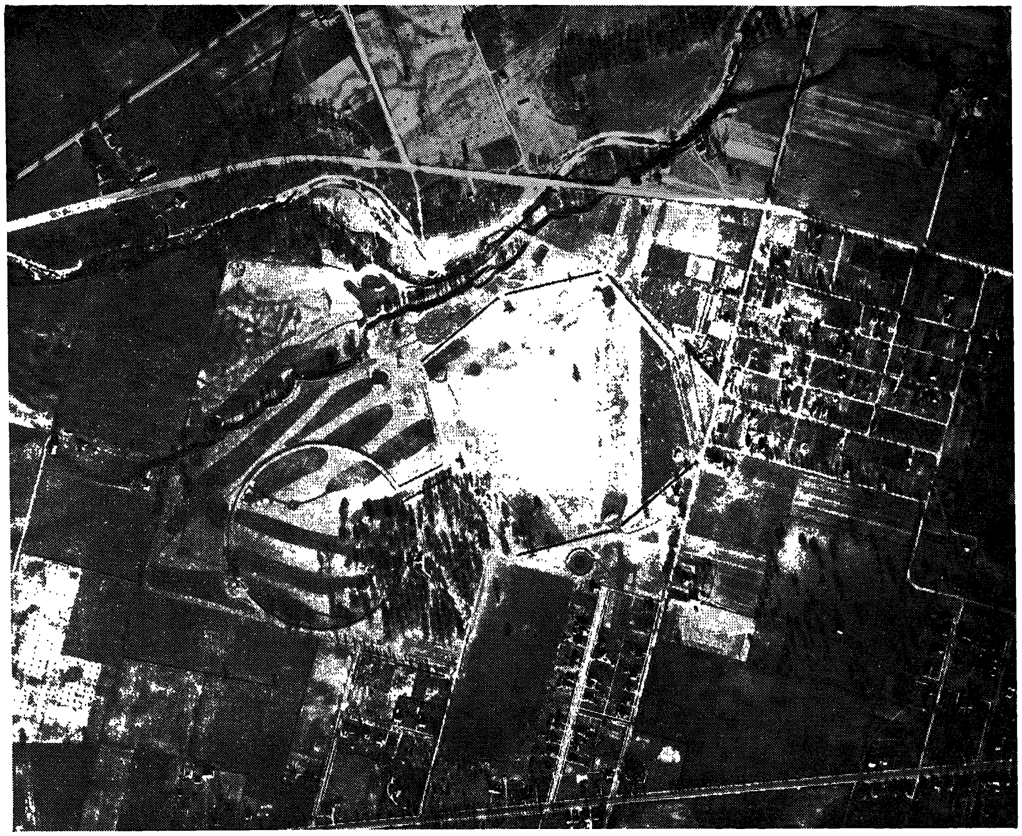

FIG. 1. This photograph taken in 1934 by Reeves[8] shows the most impressive part of the Newark earthworks which still survives, a circle (321 m in diameter and known as the Observatory Circle) connected by an avenue to an Octogon (with sides 190 m in length). This figure encloses 61 acres.

to be seen. The other geometric works have been damaged by erosion, the plough, and the bulldozer, until only a few features are still visible on the ground or on aerial photographs.

Geometric earthworks on the scale of Newark were the most spectacular evidence of complex social and economic organization found in Eastern North America in the period covering about 500 B.C.–A.D. 500. The archaeological evidence for the millenium shows hitherto isolated villages accustomed to a life of fishing, hunting and gathering, taking on traits of social stratification and cooperation perhaps related to the spread of maize as an important addition to village food resources. In many places, on the broad flood plains of glacial outwash streams, hierarchical social organization appeared in the village. Exchange of raw materials and manufactured goods gave otherwise independent villages the veneer of a common 'culture'. These common features are characteristic of an assembly of social, economic, and religious practices now called "Hopewell". They include, in addition to local hierarchy and inter-village exchange, the acquisition and redistribution of rare raw materials such as copper, marine shells, mica, galena, pipestone, obsidian, meteoritic iron, and jewel-quality flint used in the manufacture of ceremonial implements. In

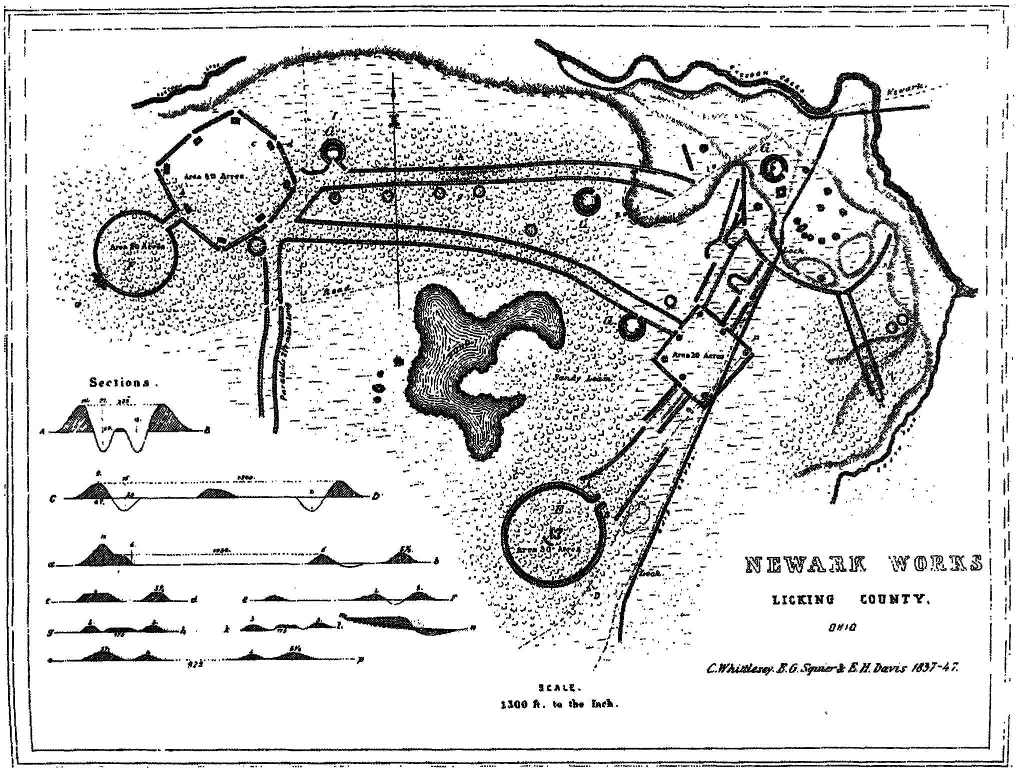

FIG. 2. A qualitative plan showing the original extent of the Newark earthworks taken from Squier and Davis.[11] Only the Observatory Circle, the Octagon, the small circle south of the Octagon, the Fairground Circle, and a small part of the Square survive today.

addition some "luxury" items such as mica mirrors, conch shell vessels, cold-hammered metal awls, and non-utilitarian celts were manufactured and traded. These exotic items both displayed the prestige of their owners and were essential features in a mortuary cult which consumed much of the labour and wealth of its adherents. What has been called the "Hopewell Interaction Sphere" covered much of the East, from the Great Lakes to the Gulf Coast. Raw materials were secured from areas as remote as the Grand Tetons. Some elaborate earthworks appear to have been ceremonial centres for the practice of the mortuary cult and, in some cases centres for the redistribution of exotic goods. The exchange-system may have made the redistribution of food in times of scarcity possible.[4] There is no evidence that the earthworks were themselves village locations or were even inhabited for long periods of time. The few traces of settlement in or near them appear to have been transient dwellings of construction crews or caretakers.[5] The Newark earthworks represent the acme of "Hopewell" in Ohio. They belong to a period, probably no earlier than A.D. 250, when other similarly intricate and extensive works were built on the Ohio River, near the present cities of Portsmouth, Marietta, and Cincinnati. Since no radiocarbon dates exist for Newark, the date suggested has been reached by comparing ceramics and, for example, the style of platform mounds in the Newark octagon with similar sites where radiocarbon dates have been secured.[6]

Description

The Newark works are so complicated that a detailed description cannot be given here. Perhaps the best impression of the works as a whole can be gained from a study of the map in Figure 2. We will give a cursory description of some of the major surviving figures in order to establish the terminology to be used in the detailed analysis which follows.

The figures shown on the map are formed by large embankments of earth typically measuring 12 m at the base and some 1·7 m high. Perhaps the most striking feature is the quite symmetrical octagon-circle combination (marked *F* in Figure 2) which encloses some 248,000 m² (61 acres). At the end of the circle directly opposite the avenue, the builders interrupted the wall, and extended it to 30·5 m outside its perimeter to form a large flat-topped mound which commands a view of the entire work. This structure, which has been called "Observatory Mound" for close to two centuries, stood 3·4 m high in 1847 and had a length of about 52 m; the associated circle will hereafter be referred to as the Observatory Circle. A large square enclosure encompassing over 81,000 m² (20 acres) is found southeast of the Octagon. The surviving part of this figure is now known as the Wright Square. We will refer to it as the Square. Another imposing figure (marked *E* in Figure 2), a somewhat imperfect circle enclosing about 103,000 m² (25 acres), is located about 2 km southeast of the Observatory Circle. As this enclosure once housed the Licking County Fairgrounds it has taken its name from them. We will refer to it as the Fairground Circle.

Originally, the Octagon, Square and Fairground Circle each contained one or more earthen mounds. In the Octagon there are eight oval flat-topped mounds situated opposite the vertices. Each is placed about 30 m inside its vertex. Near the centre of the Fairground Circle lies a group of low mounds joined to form a figure which has often been described as a bird-effigy. The wingspread of the bird is 61 m; behind the effigy, opposite the entrance to the circle, is another low mound, crescent-shaped, as long altogether as the wing-spread of the effigy.[7] The Octagon, the Observatory Circle, the Fairground Circle, a small portion of the Square, and a small circle southeast of the Octagon have been preserved. The remainder of the original earthworks shown on the 1847 map has been destroyed, although faint traces of additional features have been discerned on aerial photographs (see Figure 1).[8] A probable method for the construction of these, and other Hopewellian geometric earthworks, using stakes and fibre or hide ropes, has been described by Morgan.[9]

Survey of the Earthworks

The essential prerequisite for a reliable analysis of geometrical and astronomical content in an ancient work is an accurate plan of the original structure. An on-site survey of the Newark earthworks can no longer provide this information by itself, because the present structure is in part the product of at least two restorations. The Ohio Archaeological and Historical Society and the National Park Service undertook a major restoration project during 1933–36.[10] This project involved: (1) a major reconstruction of the walls of the Fairground Circle to restore it to a condition as described by the nineteenth-century survey of Squier and Davis;[11] (2) a reconstruction of part of the wall near the northern corner of the large Square; (3) cosmetic restoration of the Observatory Circle and Octagon involving such things as the elimination of footpaths and the removal of tree roots. A far more ambitious restoration of the Observatory Circle and Octagon was undertaken during 1893–96 by the Ohio National Guard. The State Adjutant General describes the restoration in his annual report of 1893:[12]

> Employing a surveyor, the original lines were ascertained. . . . The work at the start was very cautiously proceeded with, and all information which would assist in restoring the grounds to their early condition was eagerly sought for.

We have been unable to find, however, documentation, blueprints, or plans which give details of this restoration. Thus, no reliable conclusions can be formed from current surveys alone.

Three maps of the Newark earthworks, based on extensive surveys, were made prior to any recorded restoration: (1) a map published in 1820 by Atwater[13] giving the first detailed description of the site; (2) a map published in the voluminous and much celebrated work of Squier and Davis (Figure 2); (3) a map based on a careful and accurate survey by Middleton in 1887–88 and published by Cyrus Thomas of the Smithsonian Institution's Bureau of Ethnology.[14] The Smithsonian survey was undertaken to ascertain the degree of geometrical regularity in Hopewellian earthworks and to test the accuracy of the earlier surveys. This survey demonstrated that the earlier surveys contained numerous and large quantitative errors in the size, shape, and orientation of the earthworks. Thus, the maps of Atwater and of Squier and Davis are useless for precise quantitative work. However, the description of the Newark site by Squier and Davis does assure us that as late as 1847 much of the site (including the Fairground Circle, the Observatory Circle, and the Octagon) was still covered by forest and had apparently retained its original form. By the time of the Middleton survey (1887) the effects of cultivation and the expansion of the city of Newark had destroyed large portions of the earthworks. The only parts of the site which Middleton could survey accurately were the Fairground Circle, the Observatory Circle, the Octagon, and parts of the Square. However, with the exception of certain parts of the Square, the Middleton field notes show that all parts of the earthworks were distinctly traceable and that the walls were never less than 0·75 m in height.

The accuracy of the Middleton survey, which will form the basis of our analysis, may be judged in several ways. Fowke, an archaeologist who participated in the survey, described the care with which the measurements were carried out:[15]

> Greater care was taken in getting bearings and distances than is usually employed in railway 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.

An independent survey of the Observatory Circle was carried out by Holmes[16] in 1892. He obtained a mean diameter of 321·3 m for the Observatory Circle, precisely the same value obtained by Middleton. Finally, during the summer of

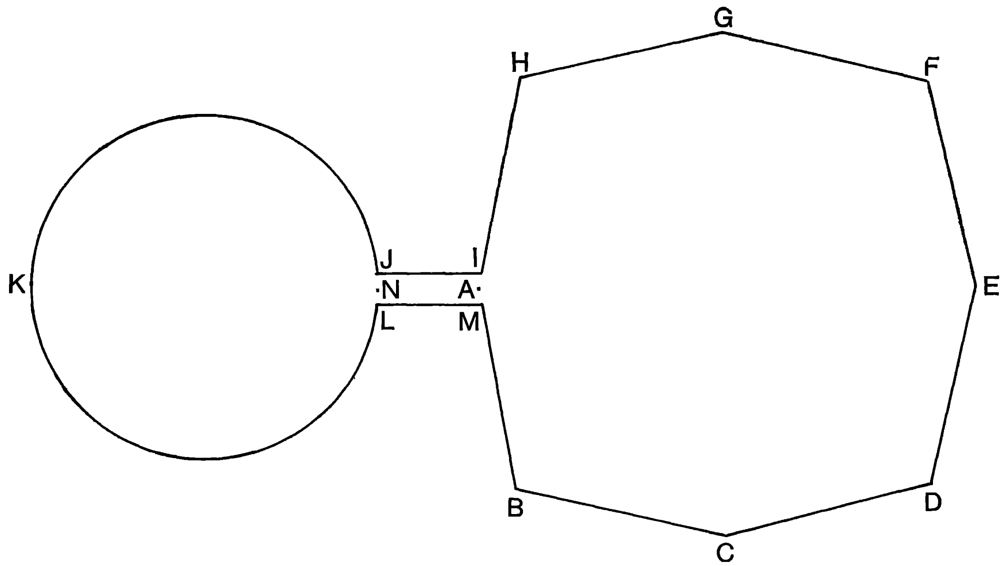

FIG. 3. A schematic plan of the geometry defined by the midline of the embankments of the Observatory Circle–Octagon combination shows the lettered points used to define the azimuths given in Table I. Point *A* is a vertex of the Octagon; Points *K* and *N* define the diameter of the circle passing through the centre of the avenue entrance.

1980 we undertook a survey of the site utilizing a transit and steel tape to judge the accuracy of the Middleton survey and to infer the nature of the State restoration. The results of our survey are compared with the measurements of Middleton in Table I using the notation defined in Figure 3. Distances and azimuths were all measured along the midline of the embankments. The comparison in Table I shows that the Middleton results agree with our results to within 30′ of arc for azimuth measurements and to within 1 m for distance measurements. The accuracy of the Middleton azimuths can best be judged from a comparison of the azimuths for the Octagon walls *AB* and *BC*, where the two surveys agree within 15′. According to the Middleton field notes these walls were uninjured in 1888 and were still covered by the original forest. Thus, it is unlikely that the State restoration in 1893 could have altered their configuration significantly. On reading the manuscript of this paper in December 1980, Professor John Eddy indicated that he had completed a transit survey at the Newark site in 1978, and that his measurements (unpublished) agree with ours (personal communication).

There are, however, two significent discrepancies between the current configuration of the Octagon and the 1888 survey. Both the Thomas reports and the unpublished Middleton field notes[17] show the wall *HA* as being 168·2 m in length, some 9·2 m shorter than the other walls which ranged from 177·4 to 182 m in length. The height of wall *HA* in 1888 was 1·1 m, and Middleton records no evidence that any part of it was obliterated or difficult to trace. Presently the length of wall *HA* is 177·4 m, the same as the length of wall *AB*. If we accept the Middleton data on this point, we must conclude that the State reconstruction "restored" wall *HA* to a length and symmetry it did not originally possess. An examination of the soil in wall *HA* might resolve this question.

TABLE I. Comparison of surveys of the Observatory Circle and Octagon

Alignment	Azimuth Middleton (1887–88)	Azimuth Hively-Horn (1980)	Distance (m) Middleton (1887–88)	Distance (m) Hively-Horn (1980)
KN	52° 0′	51° 50′	322·5 m	322·5 m
JK	52° 4′	52° 9′	89·9	89·0
LM	51° 53′	51° 38′	89·3	90·2
AB	130° 19′	130° 13′	189·6	189·7
BC	64° 18′	64° 31′	190·3	190·5
CD	39° 50′	39° 19′	190·5	191·0
DE	334° 32′	334° 20′	189·6	189·2
EF	308° 28′	308° 0′	189·3	188·4
GF	64° 40′	65° 38′	186·8	186·7
HG	39° 15′	39° 30′	189·4	189·3
AH	334° 20′	334° 29′	190·0	191·0

The present locations of the centres of the mounds interior to the Octagon (opposite the vertices) differ from the positions recorded by Middleton. The centres of the mounds as restored are separated by distances ranging from 162 m to 164 m whereas Middleton records the separations as ranging from 162 m to 168 m. Each of the Octagon walls originally contained about 2400 m^3 of earth, the great majority of which was in place for each wall in 1888. Thus, it is unlikely that the State would have significantly altered the alignment of the Octagon walls, and this is borne out by the close agreement of the surveys in Table I. This agreement suggests that the primary effect of the State reconstruction of the Octagon was to increase the height of the walls to about 1·7 m. It must be admitted that the accuracy of the present positions of the ends of the walls and the interior mounds is less secure. Their positions could easily have been altered by moving relatively modest amounts of earth. Fortunately, our subsequent analysis will not depend in any important way on the position of the mounds.

The Square northeast of the Fairground Circle can no longer be surveyed on the ground, as it has been obliterated by construction. Fortunately, we do have the Middleton survey data for the size and shape of the Square. The location of the Square relative to the remainder of the earthworks can be determined from the position of the eastern corner of the Square which is visible on aerial photographs of the site taken by Dache Reeves in 1934.[18] The location so determined is consistent with the location of the part of the Square near the north corner (which has been reconstructed) and with the size as given by Middleton. The estimated uncertainty in our knowledge of the position of the Square is about 5 m. All the available evidence suggests that the Middleton survey has sufficient accuracy (azimuths with a maximum error of $\pm 15'$) to provide a basis for a reliable analysis of the earthworks for geometrical regularity and astronomical orientation. Unless otherwise noted, the analysis of the following sections will be based on the Middleton data.

The Geometry of the Earthworks

The first point to be noted regarding the geometry of the earthworks is their remarkable regularity. Consider the Observatory Circle. The midline of the embankment walls deviates by no more than 1·2 m at any place from a

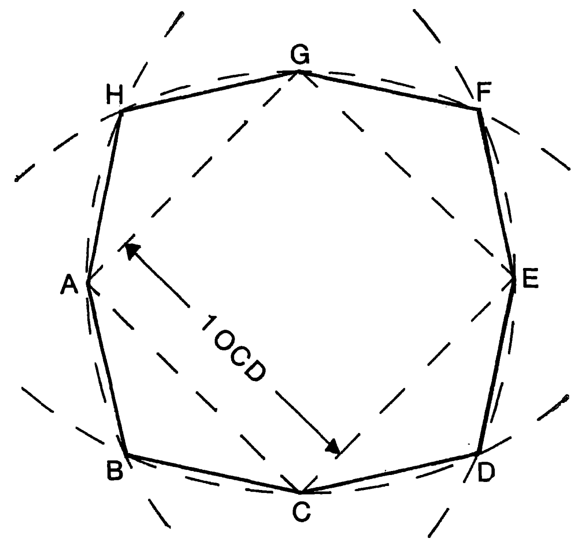

FIG. 4. The dotted lines show a method which may have been used to construct the Newark Octagon. First a square (*ACEG*) of side 1 OCD (321·3 m) is laid out; then circular arcs of radius $\sqrt{2}$ OCD are drawn with centres at the vertices *A*, *C*, *E* and *G*. The intersections of the circular arcs locate the remaining vertices *B*, *D*, *F* and *H*.

circle of diameter 321·3 m. A perfect circle of this diameter would have a circumference of 1009·4 m whereas the actual circle had a circumference of 1008·6 m. Thus, it is evident that the Observatory Circle very closely approximates a true circle. The configuration of the Octagon demonstrates a similar degree of regularity and precision. For example, the angle of intersection of the diagonals *BF* and *DH* (see Figure 3) differs by only 10′ from a right angle, and the angle of the intersection of the lines *AE* and *CG* differs by only 2′ from a right angle. The greatest departure from symmetry comes from the position of vertex *F*. It is located 6 m closer to the centre of the Octagon than its ideal position, and this results in side *FG* being about 2 per cent shorter than the other sides.

We will now show that the Octagon can be laid out quite precisely using a method of geometrical construction based on only one length, the diameter of the Observatory Circle (321·3 m and hereafter denoted by the abbreviation OCD). First, it should be noted that the vertices *A*, *C*, *E* and *G* form a square with sides $AC = 318{\cdot}6$ m, $CE = 320{\cdot}0$ m, $EG = 321{\cdot}0$ m and $GA = 320{\cdot}3$ m. The average deviation of these lengths from 1 OCD is 0·4 per cent. Thus, the Octagon can be constructed in the following manner (see Figure 4): first, lay out a square (*ACEG*) of side 1 OCD; secondly, draw circular arcs (of radius equal to the diagonal of the square) through each of the vertices *A*, *C*, *E* and *G* using the opposite vertex as the centre of the circular arc. The intersection of these circular arcs locates the positions of the vertices *B*, *D*, *F* and *H*. With the exception of the angles and lengths connected with the position of vertex *F*, this construction reproduces the azimuths of the Octagon walls within 0°·6 and the lengths of the walls within 0·6 per cent. The displacement of vertex *F* from its ideal position causes the azimuths of sides *FG* and *EF* to deviate by

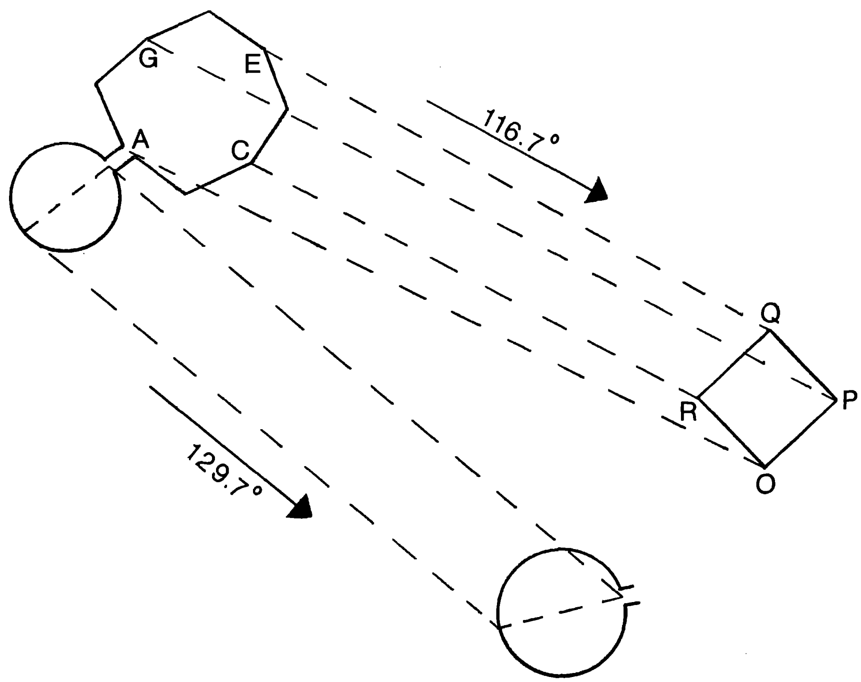

FIG. 5. A sketch shows the parallel-displaced relationships between the Fairground and Observatory Circles and between the Square and the Octagon. The azimuths of the displacements mark southern extreme lunar rising points.

about 1°·5 from the predicted azimuths. An explanation of this asymmetry will be offered in the next section.

The conclusion suggested by the geometry of the Observatory Circle–Octagon combination is that both figures have been carefully and skilfully constructed using the same fundamental length, the OCD. Further evidence for this comes from the positions of the interior mounds as given by Middleton. The square formed by the centres of the mounds *B*, *D*, *F* and *H* has sides of length 1·002 OCD, 1·004 OCD, 1·007 OCD and 1·002 OCD respectively. Further support for the special significance of the OCD is found in the relation between the Fairground and Observatory Circles and between the Octagon and the Square. The distance between the centres of the Fairground Circle and the Observatory Circle is 5·99 OCD, and the distance between the centres of the Octagon and the Square is 6·02 OCD. Thus, both distances are 6 OCDs within better than 0·4 per cent accuracy. These distances were determined from aerial photographs (taken in 1972) supplied by the Engineer's Office of Licking County, Ohio, and the distances are believed to be accurate to about 5 m. It should also be noted that the distance between the centre of the Octagon and the centre of the Observatory Mound differs by only 0·5 per cent, from 2 OCD. In addition, the diameter of the small circle south of wall *BC* is 1/7 OCD within 0·3 per cent. If the length of 1 OCD had a special significance for the builders of the earthworks, one would expect to find supporting evidence at other sites, and indeed this is the case. A Middleton survey as reported by Thomas[19] shows that the only other circle–octagon combination known to have been constructed by the Hopewell (the so-called High Bank Works near Chillicothe, Ohio) conforms to a geometric pattern based on a fundamental length of 0·998 OCD.[20]

Detailed survey data with respect to the Fairground Circle and Square are to be found in the Thomas reports, and we will only require a brief description here. It should be noted that the Fairground Circle is not a perfect circle, having maximum and minimum diameters differing by about 10 m. Thus, the position of the centre of the circle of best fit (with a diameter of 361·2 m) has an uncertainty of about 2 m. The Square has a geometrical precision comparable to that of the Octagon. The dimensions of the Fairground Circle and Square are not simply related to the OCD.[21]

The azimuthal orientations of the Fairground Circle and Square with respect to the Observatory Circle and Octagon display a curious relation which will prove to be important when considering the possible astronomical alignments of the site. Consider diameters of the Fairground and Observatory Circles oriented along the centres of the avenues leaving these circles as shown in Figure 5. A line between the northeast ends of these diameters has an azimuth of 129°·8. A line connecting the southwest ends has an azimuth of 129°·5. Thus, the Fairground Circle avenue axis is parallel displaced from the corresponding axis in the Observatory Circle along a mean azimuth of 129°·7. There are three reasons not to dismiss this as an unremarkable coincidence: (1) the distance between the centres of the two circles (6 OCD) suggests they may have been carefully placed with respect to one another; (2) the Square bears a similar kind of relation with respect to the Octagon; and (3) the azimuth of displacement, as shown in the next section, has a special astronomical significance. If lines are drawn from the Octagon vertices A, C, E and G to vertices of the Square as shown in Figure 5, one finds that the Square is displaced from the Octagon along the azimuths $AO = 116°{\cdot}2$, $CR = 116°{\cdot}2$, $EQ = 117°{\cdot}5$ and $GP = 117°{\cdot}0$. Thus, the vertices of the Square are parallel displaced from the vertices of the Square $ACEG$ along the mean azimuthal direction of 116°·7. As shown in the next section, this azimuth too has astronomical significance. These azimuths were determined from aerial photographs and have an uncertainty of $\pm 0°{\cdot}25$.

Astronomical Alignments

When examining the Newark site for conscious astronomical alignment it is essential to be conservative in method and interpretation. The site is very complex, and the number of alignments formed by connecting arbitrary points in the structure is so great that the likelihood of generating chance alignments with any astronomical phenomenon is disturbingly large. Consequently, we have only considered alignments between points for which independent geometric evidence exists to suggest that the points may have been consciously associated. For instance, we have considered alignments along linear embankments, axes of symmetry, and between special points (such as centres of geometric figures) separated by an integral number of OCDs. We have not considered alignments between mounds, between mounds and vertices, or between mounds and centres of geometrical figures. With only two exceptions we have rejected all potential alignments which did not have an azimuthal accuracy of better than 1°. The two exceptions occur because they are found in a context of similar alignments of much greater accuracy. It should also be remembered that a large portion of the original works shown in Figure 2 was destroyed before any accurate

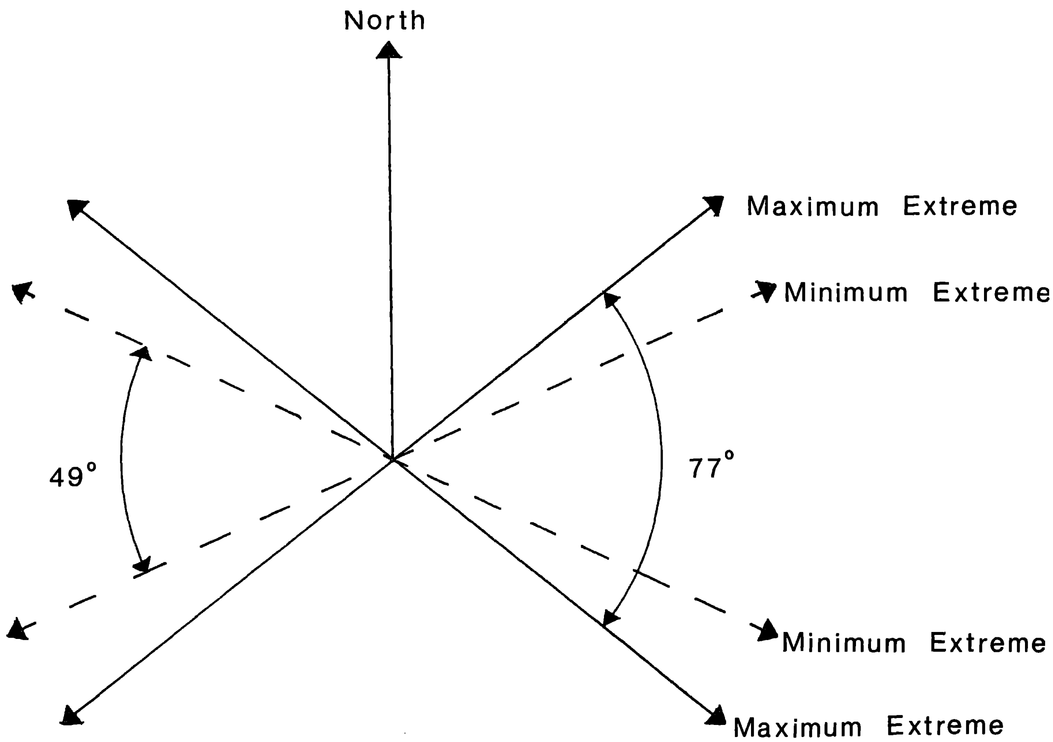

FIG. 6. The extreme azimuths of the lunar rise–set points at Newark are shown by the arrows. The azimuths shown are approximate in that the effects of horizon altitude and refraction have been ignored. When the Moon is at a position for maximum extremes, the extreme north and south moonrises in a given month are separated by 77°; at the position for minimum extremes, the extreme moonrises are separated by 49°.

survey data could be obtained; thus, any astronomical information associated with that part of the site has been lost.

We have not considered stellar alignments, because uncertainties in the date of the site (several hundred years) are so great as to make the effects of stellar precession unacceptably large. In contrast the rise and set points of the Sun, Moon and planets show a negligible variation over a time scale of a few hundred years. Therefore, we have tested for astronomical alignments involving only these objects. We have carried out this test by comparing measured azimuths associated with features in the earthworks with the azimuths for the rise and set points of astronomical objects as given by the tables computed by Aveni.[22] For definiteness we have used the astronomical azimuths computed for A.D. 250. We have found no convincing evidence for any alignments with the Sun or planets. We have, however, found a substantial amount of evidence for lunar alignment.

The rising point of the Moon as marked along the horizon oscillates between a northerly and southerly extreme during each sidereal month ($27\frac{1}{3}$ days). Due to a slow precession of the Moon's orbit, these extreme northerly and southerly rising points oscillate between two fixed azimuths with a period of 18·61 years. A similar variation occurs in the setting point of the Moon as shown in Figure 6. A careful observer of the 18·6 year lunar cycle would therefore notice eight significant directions along the horizon (four moonrise points and four moonset points) where the Moon periodically reaches a maximum or minimum extreme. We have defined the rising point as the azimuth of the first gleam where the Moon's leading edge just comes over the horizon; similarly the setting point is defined as the azimuth of last gleam. The precise azimuth of a moonrise or moonset depends on the altitude of the horizon. The distant horizons along the astronomically significant directions at Newark are obscured by buildings and vegetation. Thus, we computed the horizon altitudes from a topographic quadrangle map prepared by the US Geological Survey in 1961. This procedure was checked in the field for directions in which the natural horizons were visible and was found to yield an accuracy of better than 0°·1.

The physical structure of the walls of the Octagon is well suited to marking astronomical phenomena on the horizon. The great length (179 m) of the walls enables the midline of the walls to define a precise azimuth to within 0°·25. The uncertainty in azimuth arises from the slight asymmetry of the walls which makes it impossible to locate the midline with perfect accuracy. The original height of the walls was about 1·7 m;[23] an adult standing at the end of a wall could sight with ease along the entire midline. First it should be noted that the avenue axis of the Octagon (*KNAE* in Figure 3) points to the maximum northern extreme rising point of the Moon with an error of 0°·2. Our measurements on this point confirm an earlier conjecture by Eddy based on the Squier and Davis map.[24] The midline of the Octagon walls *AB*, *CB*, *EF* and *FG* are found to align closely with extreme rise and set points of the Moon. As shown in Table II, the avenue axis and four sides of the Octagon mark five of the eight extreme lunar rise-set points with a mean accuracy of 0°·5. Moreover, the observation points for these alignments occur at the vertices *A*, *C*, *E* and *G*, which (as shown in the last section) probably had a special rôle in the construction of the Octagon. It should also be noted that the four sides of the Octagon which are not astronomically aligned form closely parallel pairs as required by symmetry. Walls *CD* and *HG* differ by 0°·6 in azimuth, and walls *AH* and *DE* differ by only 0°·2. This stands in sharp contrast to the pairs of walls aligned to the Moon. Walls *AB* and *FE* differ in azimuth by 1°·9, and walls *BC* and *GF* differ by 1°·4. This suggests that the symmetry of the astronomically significant walls may have been deliberately distorted to achieve the lunar alignment.

In assessing the probability of these alignments being intentional there are a number of facts to be considered. First it should be noted that the requirements of (1) octagonal symmetry and of (2) alignment with lunar extrema uniquely define the Newark octagon. Of the infinity of possible octagons which could have been constructed at this site, the one we find is precisely the one which matches the lunar extrema most closely. In fact we have been unable to design an equilateral polygon with eight or fewer sides which incorporates the extreme lunar points more efficiently and accurately than does the Newark octagon. When this fact is combined with the apparently intentional distortion of the Octagon in the direction of more accurate lunar alignments, the hypothesis of deliberate alignment must be taken very seriously. If these alignments are not due to chance, one would expect to see three kinds of supporting evidence: (1) alignments of comparable accuracy for the three remaining lunar events; (2) a repetition of the lunar alignments in other parts of the earthworks; and

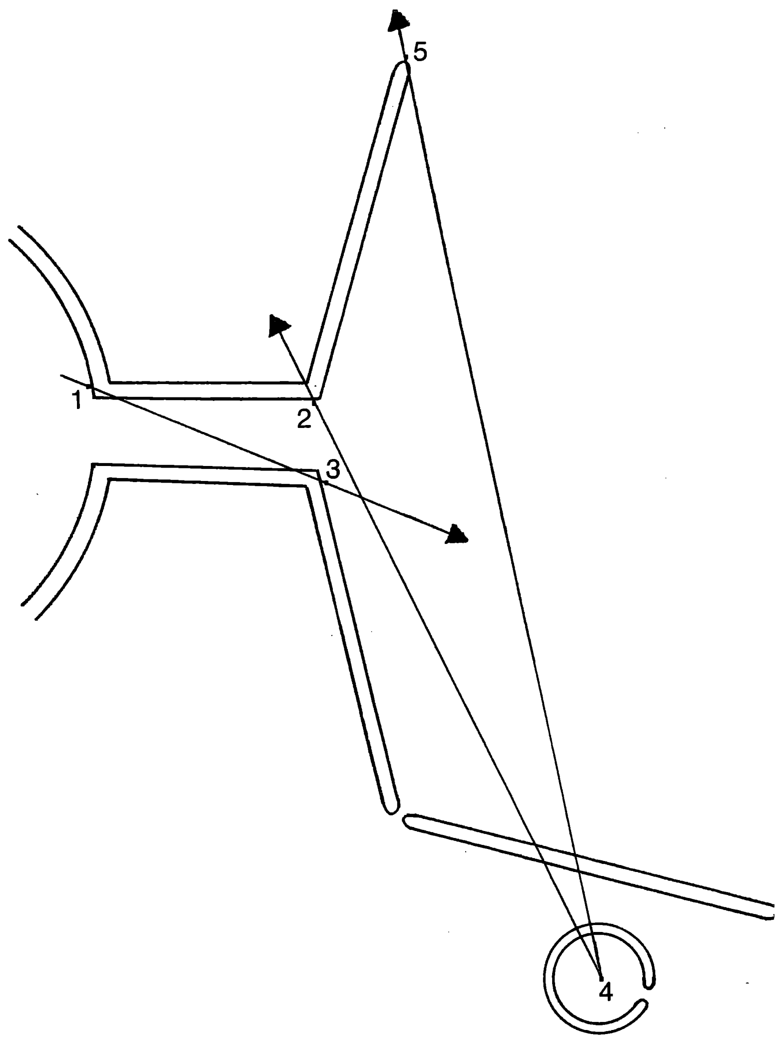

FIG. 7. The arrows in this plan show lunar alignments diagonally across the avenue (1–3) and across the ends of wall *HA* as seen from the centre of the small circle (4–2 and 4–5).

(3) a similar set of geometrical and astronomical patterns at other Hopewellian sites. Significantly, there is indeed supporting evidence of all three kinds.

Consider the avenue connecting the Octagon to the Observatory Circle. An observer sighting along the southern parallel of the avenue would be looking at the maximum northern extreme lunar rise point within 0°·1; an observer sighting along the northern parallel would be looking at the same lunar event within 0°·3. An observer sighting diagonally across the avenue (from Point 1 to Point 3 in Figure 7) would be looking at the minimum northern extreme rise point within about 0°·2. Thus, an observer standing at the entrance to the avenue where it leaves the Observatory Circle would see the Moon rise in the avenue only when it was between the maximum and minimum northern extremes. Moreover, the 18·6 year cycle could be easily and precisely monitored by noting the position of the monthly northern extreme rise point as viewed from the south end of the avenue. As seen by an observer at Point 1 in Figure 7, the

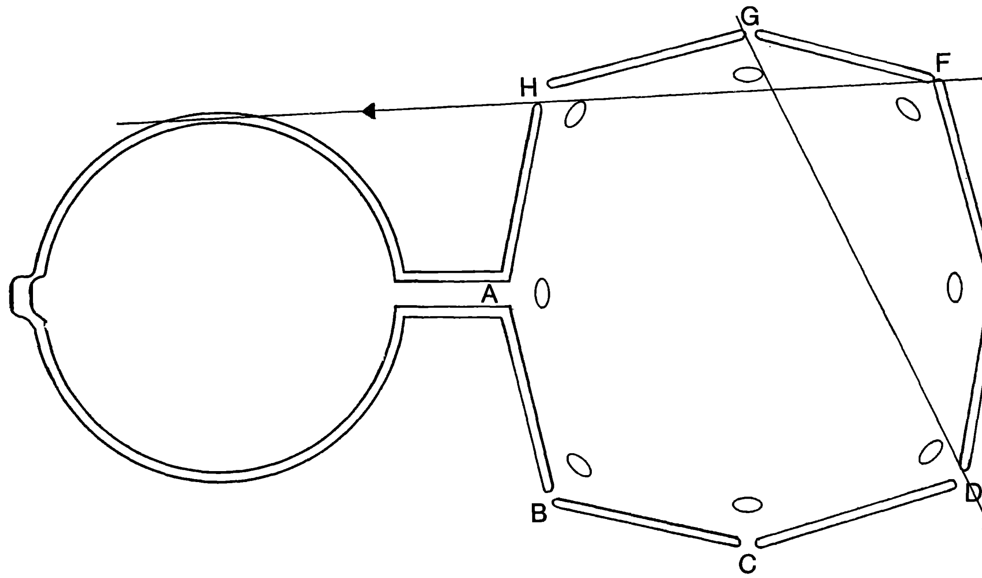

FIG. 8. A sketch shows two of the "missing" lunar alignments which are unmarked by the sides of the Octagon. If these alignments were deliberate, they would account for the narrowness of the gap at *F*, the relatively short length of wall *HA*, and the positions and sizes of mounds *H* and *G*.

rise point would appear to swing wide of the avenue when the Moon reached the maximum and minimum extremes. This feature, if intentional, would account for the length to width ratio of the avenue.

Next we will show that the three "missing" alignments can be incorporated into features associated with the Octagon, features which appear inexplicable purely in geometrical terms. If one examines the gaps which appear at the vertices of the Octagon, there are two which are significantly different from the others. The bases of the Octagon walls come together at vertex *F* to form a very narrow gap or "observation point". Wall *HA* is also 9 m shorter than the other walls (according to Middleton), producing an unusually large gap at vertex *H*. A line from vertex *F* through the north end of wall *HA* passes through the north edge of mound *H* and is tangent to the midline of the Observatory Circle (see Figure 8). This line also marks the maximum southern extreme set point within 0°·4. Thus, this alignment contains four significant features and if intentional would account for the narrow gap at *F*, the short wall *HA*, the position of mound *H*, and the length of the avenue connecting the circle and Octagon. The minimum southern extreme rise point is marked within 0°·7 by a line running from the north end of wall *HG* along the north edge of mound *G* and across the southern end of wall *DE* (see Figure 8). The best argument for this being an intentional alignment comes from the position of mound *G*; its position and size are such that the north edge of the mound helps define the alignment without obscuring it. Moreover, this alignment, if intended, would offer an explanation for the sizes of the gaps connected with vertices *G* and *E*.

Recall that from Position 1 in the avenue (see Figure 7) it was possible to monitor continuously the 18·6-year lunar cycle by observing the position of the extreme northern rise point. If this was an important function of the earthworks, one might expect to find a point from which the corresponding set points could be monitored in a similar fashion. Such a point is indeed marked by the centre of the small circle (of diameter 46 m) located south of wall *BC*. It should be noted that the position of this circle has no obvious geometrical relation to the rest of the structure. A line from the centre of the small circle through the south end of wall *HA* marks the minimum northern extreme set point within 0°·4. A line from the same centre to the northern end of wall *HA* marks the maximum northern extreme set point within 0°·8. These two alignments, if deliberate, would uniquely determine the position of the small circle. As viewed from the circle centre the northern extreme set point always appears behind wall *HA* and reaches the ends of the wall only when the Moon is at the maximum or minimum extreme. Thus, an observer located at the circle centre could monitor the lunar cycle by observing the monthly northern extreme set point in relation to wall *HA*. Evidence that the circle and Point 1 in the avenue could have been associated in the minds of the builders comes from the fact that the distance between Point 1 and the midline of the circle wall is 1 OCD within 1 per cent.

It must readily be acknowledged that the last group of four alignments we have proposed have an *ad hoc* character if considered alone. The argument for deliberate alignment is not as strong as for the alignments previously proposed. However, we believe there are two reasons not to dismiss these alignments as speculative or accidental without further consideration. First these alignments are precisely the ones predicted by the lunar context established by the more convincing alignments associated with the Octagon and its connecting avenue. Secondly, these alignments offer possible explanations for otherwise inexplicable features: the size of the gaps at the vertices; the position and size of the mounds; the location of the small circle.

Stronger evidence suggesting deliberate lunar alignments is found in the azimuthal directions of the parallel displacements of the Fairground Circle and the Square (Figure 5). The displacement of the Fairground Circle with respect to the Observatory Circle aligns with the maximum southern extreme rise point to within 0°·3. It may also be significant that a line from the centre of the Observatory Mound tangent to the Fairground Circle has an azimuth which points to the maximum southern rise to within 0°·1. Therefore, when the Moon was at the maximum extreme in the 18·6-year cycle, an observer on the Observatory Mound would see the northern extreme rise occurring along the Octagon axis, and would see the southern extreme rise occurring the same month tangent to the Fairground Circle. The axis of the avenue leading from the Fairground Circle (equidistant from the midline of the avenue walls) points within 0°·9 to the minimum northern extreme rise point. Curiously, however, the avenue axis does not pass through the centre of the Fairground Circle. A line from the centre of the circle to the centre of the avenue entrance misses the lunar rise point by more than 3°.

The displacement of the Square with respect to the Octagon aligns with the minimum southern extreme rise point to within 1°·2. The same alignment is repeated more accurately inside the Square. A line from the centre of the northwest entrance to the Square (in the avenue leading from the Octagon in Figure 2) to the north end of the southeastern wall of the Square points to the minimum south rise within 0°·3. This northwest entrance is not located at the centre

TABLE II. List of Lunar Alignments at Newark (A.D. 250).

Alignment	Azimuth (measured)	Horizon Elevation (computed)	Lunar Event	Lunar Azimuth (computed)	Error
Avenue axis of Octagon	52°·0	0°·51	max. north rise	51°·8	0°·2
Side *AB* of Octagon	130°·3	0°·61	max. south rise	130°·0	0°·3
Side *CB* of Octagon	244°·3	0°·59	min. south set	244°·6	0°·3
Side *EF* of Octagon	308°·5	1°·48	max. north set	307°·2	1°·3
Side *GF* of Octagon	65°·7	0°·46	min. north rise	66°·1	0°·4
Diagonal of avenue leading to Octagon (Figure 7)	65°·8	0°·35	min. north rise	66°·0	0°·2
Parallel displacement of Fairground Circle with respect to Observatory Circle (Figure 5)	129°·7	0°·60	max. south rise	130°·0	0°·3
Parallel displacement of Square with respect to Octagon (Figure 5)	116°·7	0°·75	min. south rise	115°·5	1°·2
Vertex *F*–north end of wall *HA*–tangent to Observatory Circle (Figure 8)	230°·5	0°·53	max. south set	230°·1	0°·4
North end of wall *HG* to south end of wall *DE* (Figure 8)	116°·3	0°·86	min. south rise	115°·6	0°·7
Centre of small circle to south end of wall *AH* (Figure 7)	293°·4	1°·43	min. north set	293°·0	0°·4
Centre of small circle to north end of wall *AH* (Figure 7)	308°·0	1°·45	max. north set	307°·2	0°·8
Observatory Mound centre–tangent to Fairground Circle	130°·1	0°·60	max. south rise	130°·0	0°·1
Northwest entrance to Square to north end of southeast wall of Square	116°·3	1°·18	min. south rise	116°·0	0°·3
Avenue axis of Fairground Circle	66°·6	0°·11	min. north rise	65°·7	0°·9
Centre of avenue entering northwest entrance of Square	306°·8	0°·97	max. north set	307°·7	0°·9
Diagonal of Square (*RP*, Figure 5)	92°·8	0°·98	rise–set points along straight line	92°·0	0°·8

of the side of the Square as is customary for squares constructed by the Hopewell.[25] Rather, the entrance is displaced about 30 m north of the centre of the northwestern side, probably for a conscious purpose and possibly to achieve the indicated lunar alignment. The other entrances to the Square were obliterated prior to the Middleton survey, and no reliable survey data are available for them. The avenue leading from the Octagon to the Square becomes straight for 160 m prior to joining the Square. The centre of this avenue points within 0°·9 to the maximum northern set point. No reliable survey data exist for the other avenues which entered the Square.

The diagonal of the Square (*RP* in Figure 5) also has a possible lunar significance. As the rising point of the Moon moves from south to north during the monthly cycle, there is a unique azimuth for which the Moon can be observed to rise and set on the same day in opposite directions along the same line. Due to the Moon's rapid apparent motion this azimuth is not 90° as it is for the Sun at the equinoxes; rather, for the Moon it is 92°·0.[26] The azimuth of *RP* is 92°·8. Thus, an observer could identify the midpoint of the monthly lunar cycle by noting the day when the rising and setting of the Moon most nearly occurred along the line *RP*. The fact that the rising and setting points of the Moon defined a straight line through the observer in this direction may well have had a special significance for the Hopewell, considering their obvious preoccupation with linear geometric figures.

The seventeen independent lunar alignments we have proposed for Newark are summarized in Table II. Not all of these alignments have an equal probability of being intentional, and some may well be due to chance. We believe the first eight listed in the table are most likely to have been deliberate. These eight alignments have a mean error magnitude of 0°·53. The mean error magnitude for all seventeen alignments is 0°·56. Some perspective on the possible significance of this mean error may be gained by comparing the Newark alignments to the thirteen best lunar alignments proposed by Hawkins for Stonehenge which have a mean azimuthal error magnitude of 1°·3.[27] It is well known that a precise marking of lunar extrema can be used in principle to predict lunar eclipses.[28] The average accuracy associated with the alignments we have proposed is sufficient to allow the prediction of the year when lunar eclipses occur near the equinoxes or solstices. This accuracy is not sufficient, however, to permit the prediction of all lunar eclipses. While eclipse prediction could have been a motivation for the Hopewell, our data do not justify any conclusions on this point.

Evidence from Other Sites

Ultimately the geometrical and astronomical hypotheses outlined here must be tested at other Hopewellian sites. The degree of geometrical and astronomical sophistication implied by these hypotheses is unlikely to have been unique to Newark, but almost certainly would have been developed over a great length of time during which it would be manifested at other sites. Those sites which would provide suitable tests for these hypotheses would satisfy two criteria: (1) accurate, reliable survey data must be available; and (2) the sites should exhibit evidence (such as geometrical regularity) of having been laid out with great care. The criterion of reliable survey data restricts us to those sites surveyed by Middleton. Of the sites which Middleton surveyed, he noted that four of the Ohio sites possessed significant geometrical regularity: the Newark earthworks; the circle-octagon combination known as the High Bank Works; the square at Liberty Township; and the square at the Baum Works.[29] Space does not permit a detailed analysis of these other sites here. It is significant to note, however, that the size and orientation of all of these sites can be explained using geometrical and astronomical hypotheses similar to those outlined for Newark.

The diameter of the circle at High Bank is virtually identical with that of the Observatory Circle at Newark. The octagon can also be constructed using a method similar to that at Newark. The octagon at High Bank is oriented so that one of its principle axes (the one perpendicular to the short avenue connecting the circle and octagon) is aligned with the northern extreme rise point of the Moon within 1°. One side of the octagon is aligned to the summer solstice sunrise within about 1°. These alignments, if intentional, would completely determine the orientation and structure of the High Bank octagon. The lengths of the diagonals of the Baum and Liberty squares are both equal to three times the radius of the Observatory Circle within better than 1 per cent. The Liberty square has exactly the same orientation as the Newark square to within 0°·3, which suggests some kind of astronomical orientation. Two sides of the Baum square are aligned with the summer solstice sunrise within 1°. This kind of analysis needs to be extended to other sites for which accurate survey data exist or for which such data can be obtained, perhaps by aerial photography.[30]

There is additional evidence suggesting celestial and perhaps lunar consciousness among the Hopewell. Specifically, six crescent-shaped mounds are present in the Newark earthworks. Five of these mounds are recorded on the Squier and Davis map, and one was discovered by Middleton.[31] The presence of numerous crescent-shaped mounds and the discovery of additional crescent-shaped artifacts associated with other Hopewell works have led to previous speculation that a lunar cult may have existed among the Hopewell,[32] although this speculation has found no champions among current archaeologists. A possible knowledge of the celestial origin of meteors has been attributed to the Hopewell by Prufer, based on evidence that they collected meteoritic iron.[33]

Conclusions

Our data and analysis show that the Newark earthworks were carefully conceived and constructed to exhibit a remarkable degree of symmetry, precision, and geometrical harmony, apparently based on a single length (the OCD). Further, we have shown that the structure of the Newark earthworks could be used for a relatively precise monitoring of the monthly and 18·6-year lunar cycles. The important and difficult question is whether the structure was consciously laid out by the Hopewell for this purpose. Surely it must be admitted that some of the lunar alignments may be due to chance. The difficulty in making objective, quantitative assessments of the probability of chance alignments is well known and has been widely discussed.[34] The large number of precise lunar alignments at Newark (especially those associated with the Octagon) weighs heavily against dismissing these alignments as mere coincidence and as unworthy of further investigation. Most of the main features related to the orientation, shape, relative size, and asymmetry of the surviving earthworks can be accounted for with the single hypothesis of deliberate lunar alignment. It should also be emphasized that all the alignments we have found correlate with a single object, the Moon. The intellectual power, tenacity of purpose, continuity, and desire for precision that would be implied by conscious lunar alignment is certainly no greater than that required in the construction of the earthworks themselves, a feat which is not in dispute. The geometric regularity of the works shows clearly that the Hopewell had a strong concern for geometrical harmony, and it is not surprising that they might record celestial harmonies (perhaps essential to their calendar) in the same structure.

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6. Prufer, *op. cit.*, 50. Most archaeologists place Newark in the late Hopewell period, for which radiocarbon dates suggest a range from A.D. 0 to 500.
7. None of the mounds within the works described has been systematically explored. The bird-effigy was opened under the direction of H. C. Shetrone in 1928, after earlier amateur digging may have destroyed some evidence. Shetrone's workers found two copper artefacts, a crescent and a small, three-dimensional figure of a beaver or manatee. (Unpublished field notes in the possession of the Archaeological Division of the Ohio Historical Society.)

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19. Thomas, "The circular, square and octagonal earthworks of Ohio", 22f.
20. Marshall, *op. cit.*, has sought to understand the geometry of the Hopewellian earthworks in terms of a design composed of right triangles with integral sides and using a unit of measurement of 57 m. The evidence from Newark alone does not provide a conclusive case for this suggestion. The published data and analysis for other sites are as yet too meagre to allow an evaluation of the suggestion.
21. But the following coincident *areas* should be noted. The area of the Square differs from that of the Observatory Circle by 0·36 per cent. The area of the Fairground Circle differs from that of square *ACEG* within the Octagon by 0·22 per cent. The total area of the Octagon doubles the area of the Observatory Circle and the Circle–Octagon avenue with an error of 0·19 per cent.
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23. *Cf.* Squier and Davis, *op. cit.*, 67ff.
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26. Due to variations in the Moon's apparent speed and in the orientation of the Moon's orbit, the precise value of this azimuth varies by $\pm 0^\circ\cdot 3$ about an average of $92^\circ\cdot 0$.
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