A Report on Geopatterns Software: Describing and Analyzing Large-scale Geometry between Chacoan and Natural Sites in the American Southwest

Dennis Doxtater

School of Architecture
College of Architecture and Landscape Architecture
University of Arizona
Tucson, Arizona, USA
doxtater@u.arizona.edu

Abstract

Formal alignment of architectural features in prehistoric sites is recognized in the American Southwest. The present research seeks to extend the scale of analysis to formal geometric patterns of ceremonial sites in the larger natural landscape. "Geopatterns" software allows the user to both accurately describe such patterns and compare them with patterns created randomly. The user can enter latitude and longitude site points to determine ellipsoid-based distances, azimuths, and angular relationships. Tolerances can be set to find three patterns: three-point alignments, cardinal orientations, and four-point bisects. In testing against random phenomena, "z-scores" for simple patterns are created for 18 natural and 22 ceremonial sites at large scales. Because more complex patterns are rarer than numbers of simple patterns used in z-score comparisons, Geopatterns is used to also state unique existing pattern combinations and statistically test very large numbers of comparative random sets.

1 Alignments in the Historical and Ancestral Pueblo Record

Pueblo peoples of the American Southwest consciously aligned aspects of their buildings and site complexes. Prominent are architectural components of *kivas* (rooms, typically subterranean and round, used for religious and communal affairs) and "great houses" (large community or ceremonial structures, also sometimes called pueblos, and typically referred to by name) providing a number of carefully aligned features that in addition to associating different points within a particular structure, also might well have been extended to (or "intended" from) points in the larger landscape. The symbolic orientation of features like *sipapu* (ritual openings to the underworld) and ladder/roof hatch in Hopi kivas (Figure 1) is well documented. Chacoan and other prehistoric kivas (Figure 2) similarly line up opposite entrances, *sipapus*, and pillars, to produce a clear orientation to the structure.

One also finds straight wall features of many of the larger prehistoric Chacoan great houses (AD 900-1250). These, too, are intentional alignments of meticulously crafted stone walls to produce a frequently remarkable monumental feature. The examples in Figure 3 illustrate how often a particular wall or walls, or plan diagonals of a structure may have been singled out for this function. The fact that most of the smaller great houses are not interested in formal or apparently aligned wall features, in spite of their probable technological ability to do so, suggests a symbolic function associated with such elements in the larger or more important great houses. The west front wall and central perpendicular axis of Pueblo Bonito, one of the largest of the great houses, has of course been commented upon frequently as an example of a particular great house walls that were intentionally aligned with cardinal directions (Sofaer 1997; Stein et al. 2003). The range of the major back wall orientations

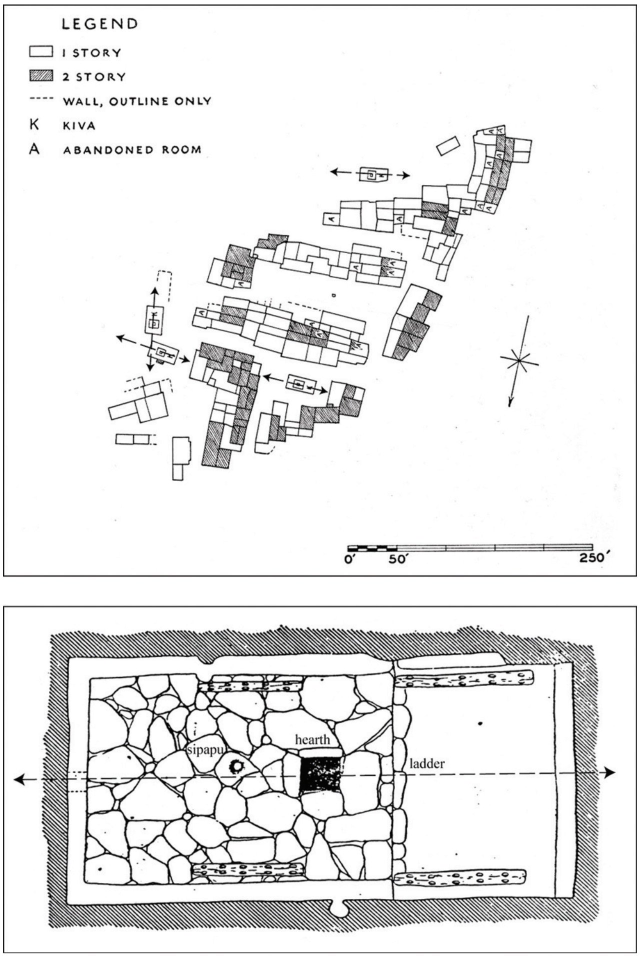


Figure 1. Orientations of ceremonial kivas in Historical Pueblos of the Southwest (aerial layout from Stubbs 1950, kiva from Stephen 1936).

of about 50 Chacoan great houses both within the canyon and in the larger region, as surveyed by the author, is a full 113°.

Moving beyond the alignment of features (orientations) within kivas or great houses, we can cite Fritz's (1978) description of two cardinal alignments creating a cross pattern among four great house structures at the apparent center of Chaco Canyon, as seen in Figure 4. The 88° 54' orientation of Pueblo Alto's back wall on the north rim of the canyon, together with the 88° 57' orientation of Tsin Kletzin's back wall on the south rim, combine with the nearly north-south alignment of these two great house positions (179° 46'), to produce at least one recognized example of intentional alignment of structures at a landscape scale of 3.8 km (all measurements and calculations by author). Fritz's described east-west alignment, that between Pueblo Bonito and Chetro Ketl, however, is much less accurate (only 87° 46' using the centers of each of their great kivas), and Chetro Ketl's orientation is far from being "east-west."

In a recent publication I describe a similar north-south, but much longer, alignment between two great house sites with a significant natural feature as an interim point (Doxtater 2003). In the case of the proposed Lowry-Village of the Great Kivas pair, the issue is not cardinality between the two, but simple alignment with the highly visible natural feature, Ship Rock along their interim line. The centers of the great kivas of the two sites form a line that passes about 122 m from the center point of Ship Rock. This is an average deviation of about 0.056° (as an average of the deviations from each end). The two "outlier" sites are 265 km from each other.

My argument that Lowry-Ship Rock-Village of the Great Kivas is a designed alignment rests primarily on the architectural sense that the form of the south village of the Great Kivas room block and its spatial relationship to its

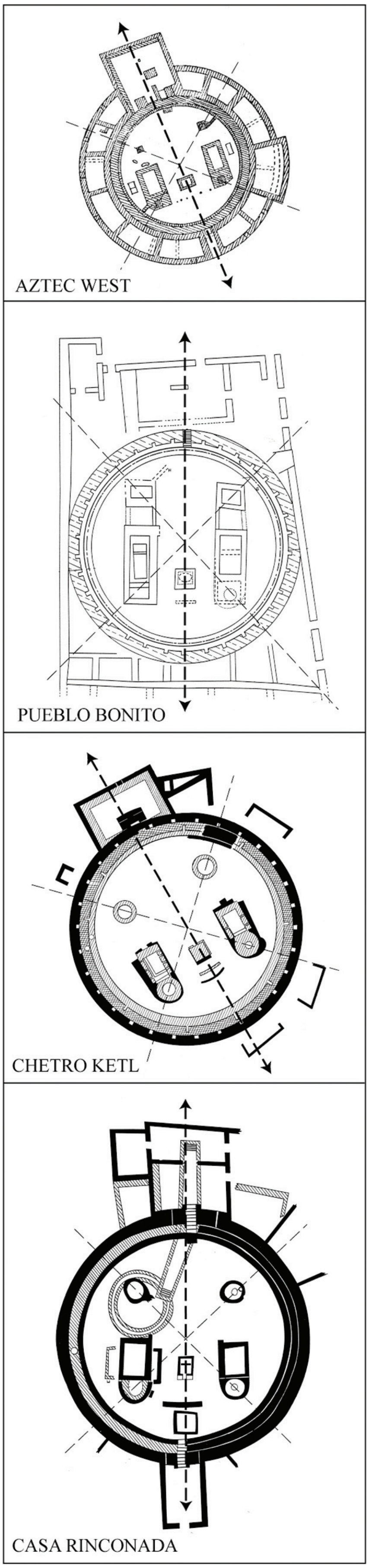


Figure 2. Orientations of great kivas in Chaco Canyon (from Vivian & Reiter 1960).

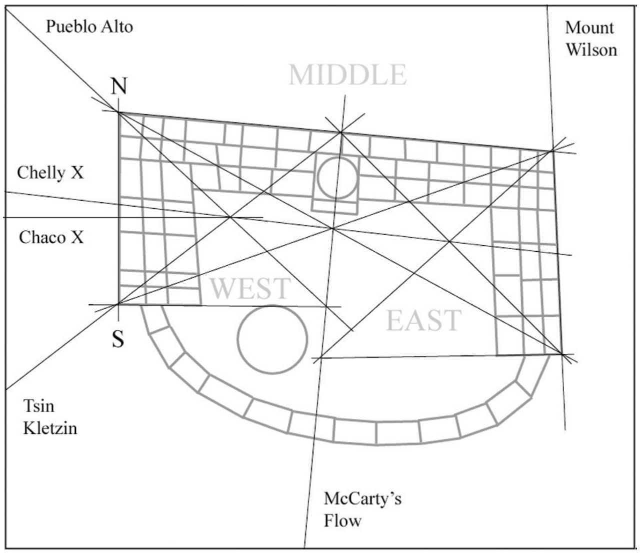


Figure 3. Possible multiple orientations of geometric features of Hungo Pavi great house in Chaco Canyon to distant features in the larger landscape. Sunshot measurements of building orientation can be combined with azimuth angles of distant sites as computed by new Geopatterns software to produce potential "alliance" relationships possibly embedded in the larger great houses.

great kiva emulates those two plan aspects of the Lowry site. Given the almost extreme architectural variability and lack of formality to outlier sites, it seems impossible that two unrelated sites could be so randomly similar. Plan examples for comparative purposes are shown in Doxtater (2003).

Far greater numbers of potential alignments, beyond the two patterns just mentioned, exist in the famed Chacoan Roads. Marshall provides a description of the cosmological implications of "constructed roadways as sacred pilgrimage avenues by historic and modern Pueblo peoples" (1997:63). These roads, often together with encircling mounds, "provide directional nexuses that channel the power of sacred landforms and mythic geography into the 'center' or Middle Place occupied by the great house" (Marshall 1997:67). Marshall speaks convincingly about *axis mundi* precedents in Pueblo culture and dedicates a text section to the Great North Road running from Chaco Canyon about 50 km north to Kutz Canyon. North is a "primary direction in many of the Puebloan cosmologies" (Marshall 1997:70).

It is recognized that short segments of Chacoan roads, of a few kilometers, accurately align particularly to great houses. But the largest segments of these seemingly straight roads vary considerably. Consider the detailed map of the Great North road from the Chaco Roads Project (Kincaid 1983). It begins about 870 m east of Pueblo Alto and Fritz's (1978) vertical axis, and runs in slight but apparent zigzags every couple of kilometers up to a point just below Pierre's Butte to the west. The northern point of this clearly cardinally oriented 20-km road lies 180 m east of the longitude point where it began. The overall deviation of the two ends of this segment is about 0.51° off true north. The azimuth from Pueblo Alto to the two small structures on Pierre's Butte is 177° 02' 23".

Lekson (1999, chapter four) discusses the apparent difficulty of native surveyors to lay out accurate meridians based either on sun or star observations. In my experience as well, cardinal alignments do seem to be consistently less accurate than lines laid out between two known distant points on the landscape. But a 0.51° figure seems uncharacteristically inaccurate. This, together with the clear zigzagging of road layout, seems unusual given the hypothesized abilities of prehistoric Pueblo people to understand and lay out very large, accurate georitual patterns. Given such abilities, they certainly would have been able to construct a much straighter road, if it were important to do so. Thus, the zigzagging notwithstanding, the great north road is a fairly accurate cardinal construction, but it does not align with Fritz's hypothetical Chaco center as widely assumed.

The final and largest scale example of possible alignments in the Puebloan record is Steve Lekson's *Chaco Meridian* (1999). Again, this is not a georitual notion where perimeter mountains create central ceremonial locations, but a theory about the founding of the original Chaco center by some elite kinship group, and then its cardinal extension, first north to Aztec and then south to Paquime (Casas Grandes). The relative inaccuracy of this line, almost a full degree for the entire 700 km line, is due again, according to Lekson, to technical inabilities to lay out cardinal alignments. If one uses Casa Rincoñada as a central point in the canyon, the Aztec Centroid lies at an azimuth of 2° 15' 9"

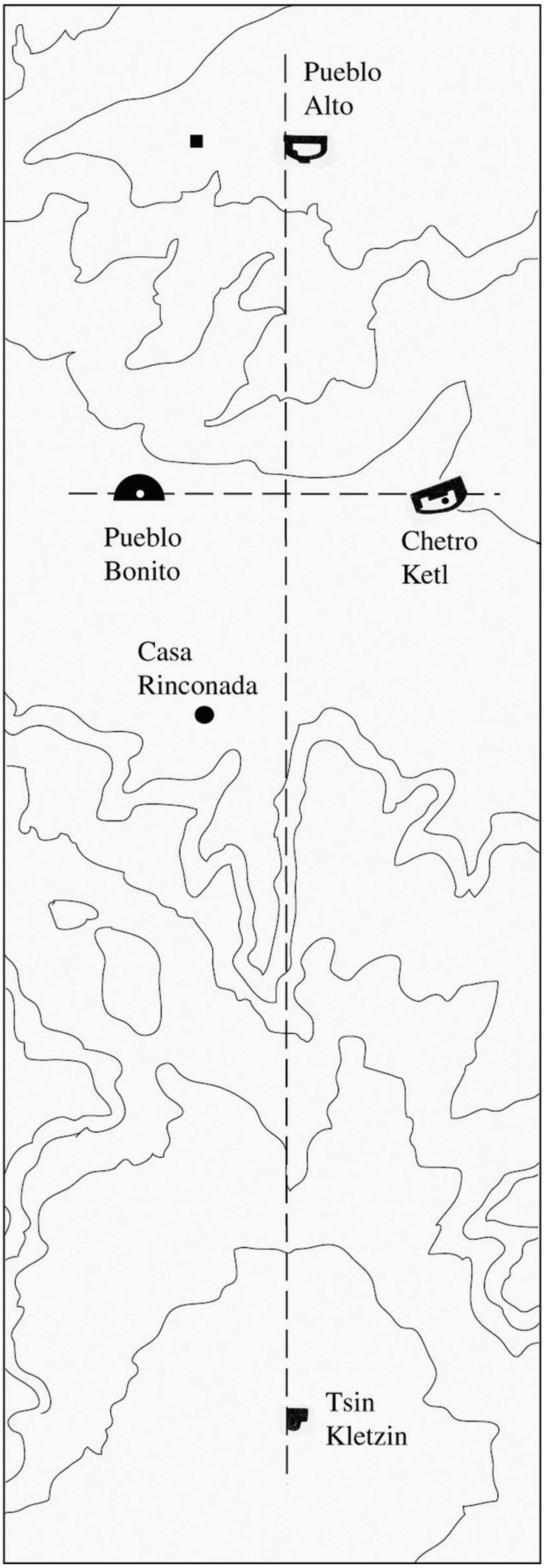


Figure 4. Fritz's diagram of symmetrical relationship between four great houses of Chaco Canyon (1978).

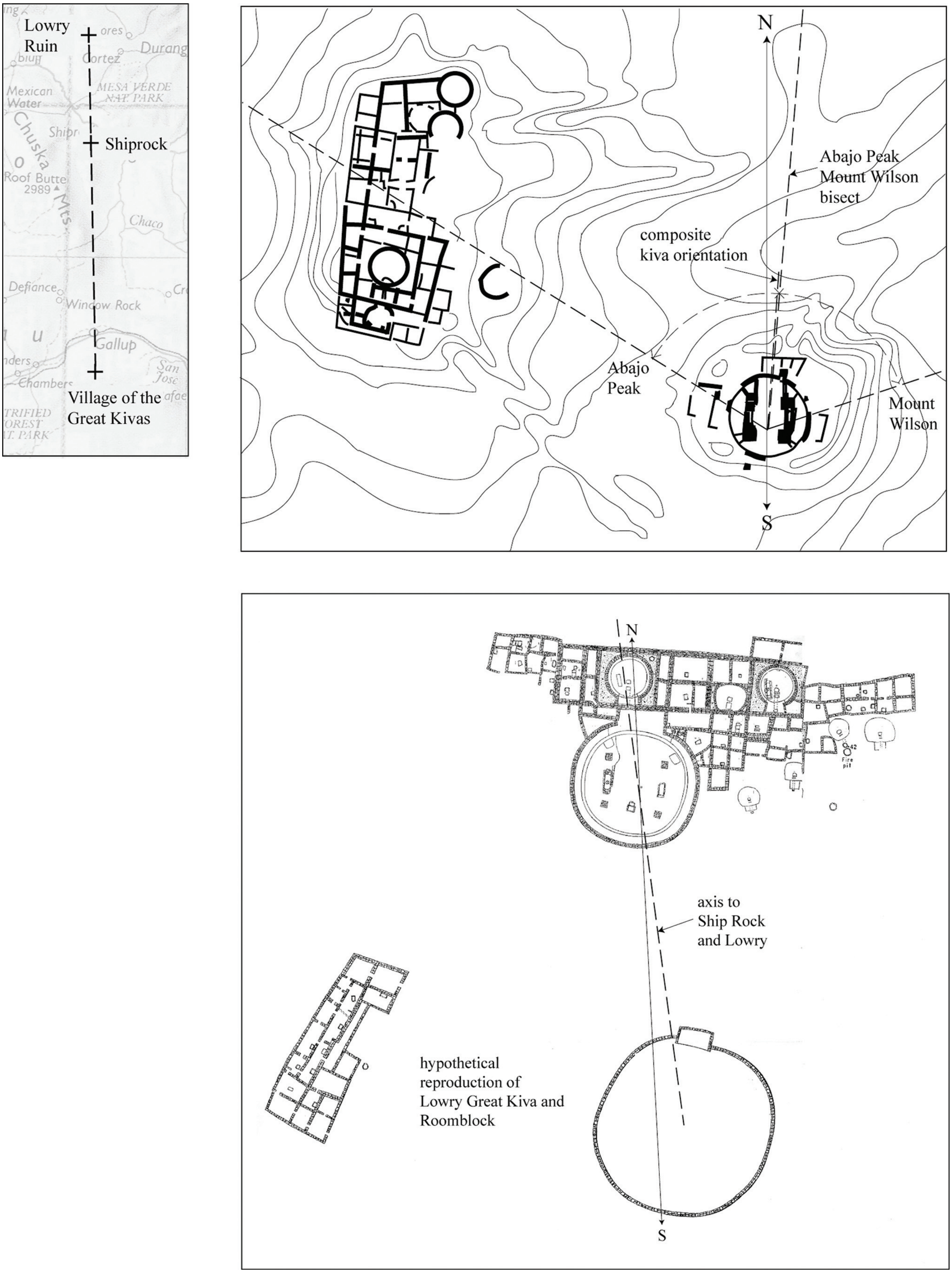


Figure 5. Alignment of Lowry Ruin, Ship Rock and Village of the Great Kivas (above left); Lowry Ruin site plan showing orientation of great kiva (above right); Village of the Great Kivas site plan illustrating two outliers in one site, the southern of which emulates the layout of Lowry Ruin (below).

west of true north. This is a huge inaccuracy across a relatively short space of 86.749 km. The author's work argues that the spatial locations of the Chaco center, Aztec, and Paquime were, as Lekson argues, influenced by a symbolic "Chaco Meridian," but that the much more accurate actual meridian only runs through one of these sites. Once again, perhaps mostly associated with the major *axis mundi*, some built spatial relationships like roads appear to only loosely reflect the geometry of an invisible georitual alignment without being superimposed upon it.

2 Describing and Testing Large-Scale Geometric Patterns Between Sites

In spite of the recent mainstreaming of archaeoastronomy (e.g., Malville and Putnam 1989), where alignments between features on the earth and very distant astronomical entities are the focus of most investigation, there has been relatively little inquiry (as in Doxtater 1991 and Lekson 1999) into possible large-scale alignments and other geometrical patterns between points entirely on the earth's surface, whether built, natural, or a combination of the two. One of the critical keys to such work is the availability of a computer application to accurately describe and test possible designed geometries between natural and built sites against random phenomena. The following describes such an application, Geopatterns, created for the author by Cross-River Software.

The calculations of Geopatterns are based on ellipsoid geometry of the earth and NOAA's interactive applications. Cross-River provided this source to explain its adaptation: "Direct and Inverse Solutions of Geodesics on the Ellipsoid with Application of Nested Equations" from the April 1975 issue of "Survey Review" (or see the website www.ngs.noaa.gov/PUBS_LIB/inverse.pdf.). Geopatterns functions in the following ways.

Illustrated in Figure 6 is the basic page layout with typical pull-down tabs at the top and a split screen below with lists of sites and test areas on the left, and the map of site locations on the right. The "Records" tab on the bottom of the page, Figure 7, pulls up a spread sheet to enter the names and latitude/longitude positions of sites. Opening the "Options" tab, Figure 8, under the main page's "View" tab allows the user to set the longitude format, distance units, and the earth's ellipsoid (major and minor axes).

Below the upper row of tabs back on the main page are two pull-down lists and windows to find the distance and the two azimuth angles between any two sites. At the left bottom of the screen is the latitude/longitude location of the cursor on the map. Prior to searching for patterns or testing against randomness, the user can also find additional basic geometric information. Pulling down the "Reports" tab at the top provides options of "Azimuths" (a list of all sites and the azimuths to all the other sites from each site point), "Axis Angles" (when one of the sites on the main page list is turned on, provides the angles to all pair combinations of the rest of the site list), and "Distances" (the distances between all sites in ascending magnitude).

Figure 7 also shows the pattern screen. Here, the user has the option of searching for each of the three patterns individually, or adding them together in any combination up to five additions. On the Options page, the user can set the accuracy or Pattern Angular Tolerance in degrees. The benchmark here is visual acuity or 0.017°. As a means of limiting some pattern combinations to more formal geometries, the user may limit alignments to their midpoints only (for cross patterns), constrain bisects to include the vertex or not, and include the side ray endpoints only.

Given these definitions the user can perform three kinds of operations. First is the basic Site Analysis to list all the patterns or composite patterns, as defined with the above options for a list of sites. Results are listed in the Report, with numerical accuracies for the four basic patterns. The user can display the patterns graphically on the Map. Next, to compare patterns associated with an existing set of points with those generated randomly, the user chooses the Create and Edit Test Areas page, as shown in Figure 8. One can either enter the coordinates of the desired test area, or draw it with the cursor. Any number of maps may be drawn, and the user can either generate sets of random points, one in each test area, or a set of some number of points within one area. On the Options page the user can require that all or any number of random points of a set participate in a defined pattern. The Options page also allows the determination of the number of sets of random points created in a run. In practice, one first uses Site Analysis to reveal existing patterns. Then random points are substituted for built sites, either as individual test areas or some total area where built sites occur, in a large number sets in Statistical Analysis. Depending on the complexity of the pattern or combination pattern, a run of 10,000 sets of random points may take only a few minutes.

3 "Z-scores" of Alignments, Bisects and Cardinals of major Chacoan Sites

While the analysis of three or more points in alignment (on the earth's surface) almost never occurs in archaeology, one publication tests the geometry between two points hypothetically used as signal networks. Swanson (2003:760), created his own GIS software to map intervisibility among features associated with the natural peak of Cerro Moctezuma, near Paquime (Lekson's southern terminus for his Meridian). Swanson compares possible intervisibility relationships (alignments) with some larger world of such relationships created randomly. He found that the number of lines of sight in ten random tests ranged from 43 to 72, while the existing sites formed 101 lines of sight with other points. Statistically, he concludes that at least some number of sites were built specifically in locations that enhanced signaling.

Geopatterns allows one to go beyond Swanson's analysis in several ways. Now one can search not only for alignments but bisected angles among four points and cardinal relationships. Furthermore one can seek combinations of these individual geometric patterns up to five levels of addition. Each of these combination patterns, then, can be compared with patterns created randomly.

Finally, one must discount the effect of ecological or

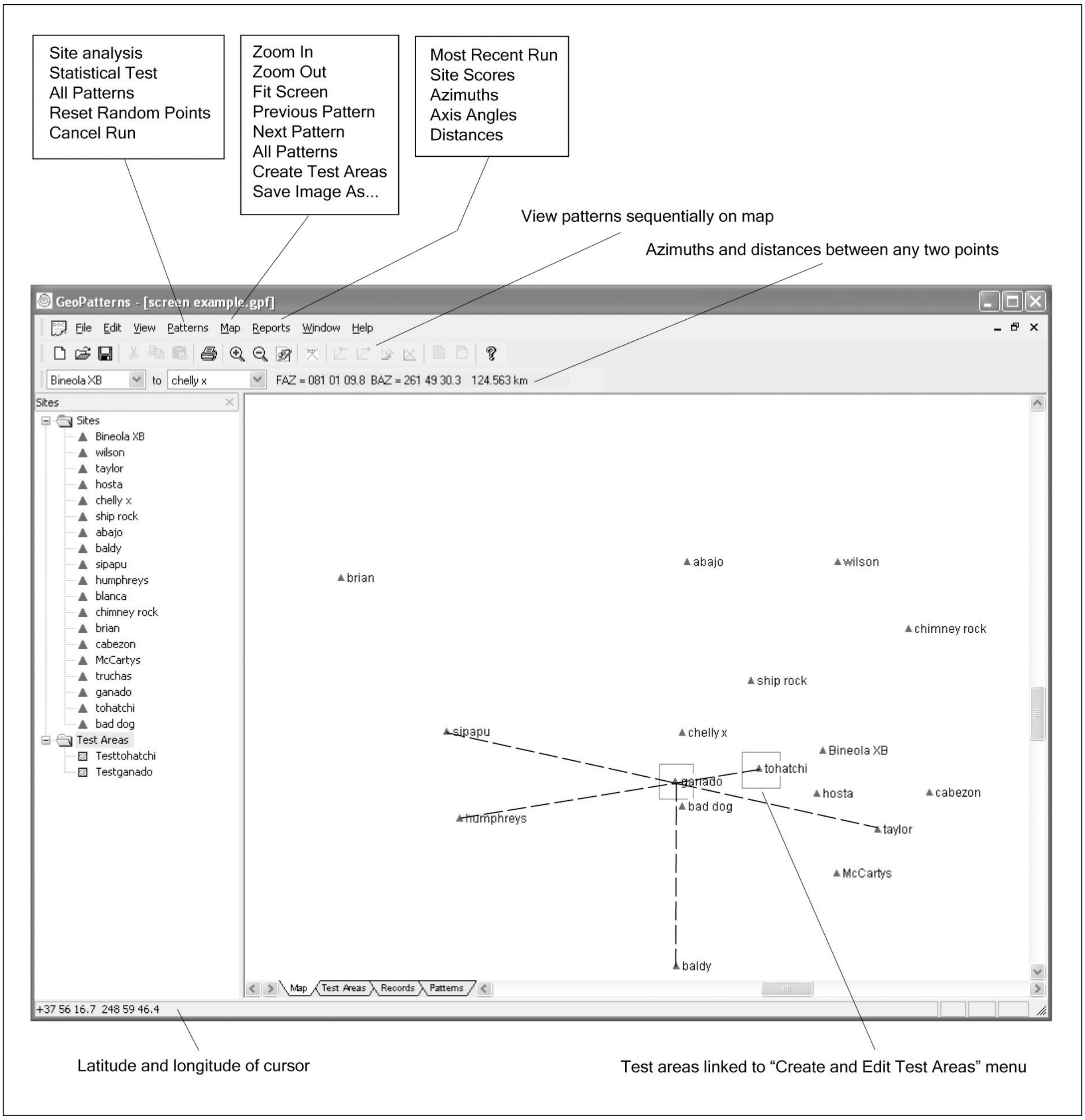
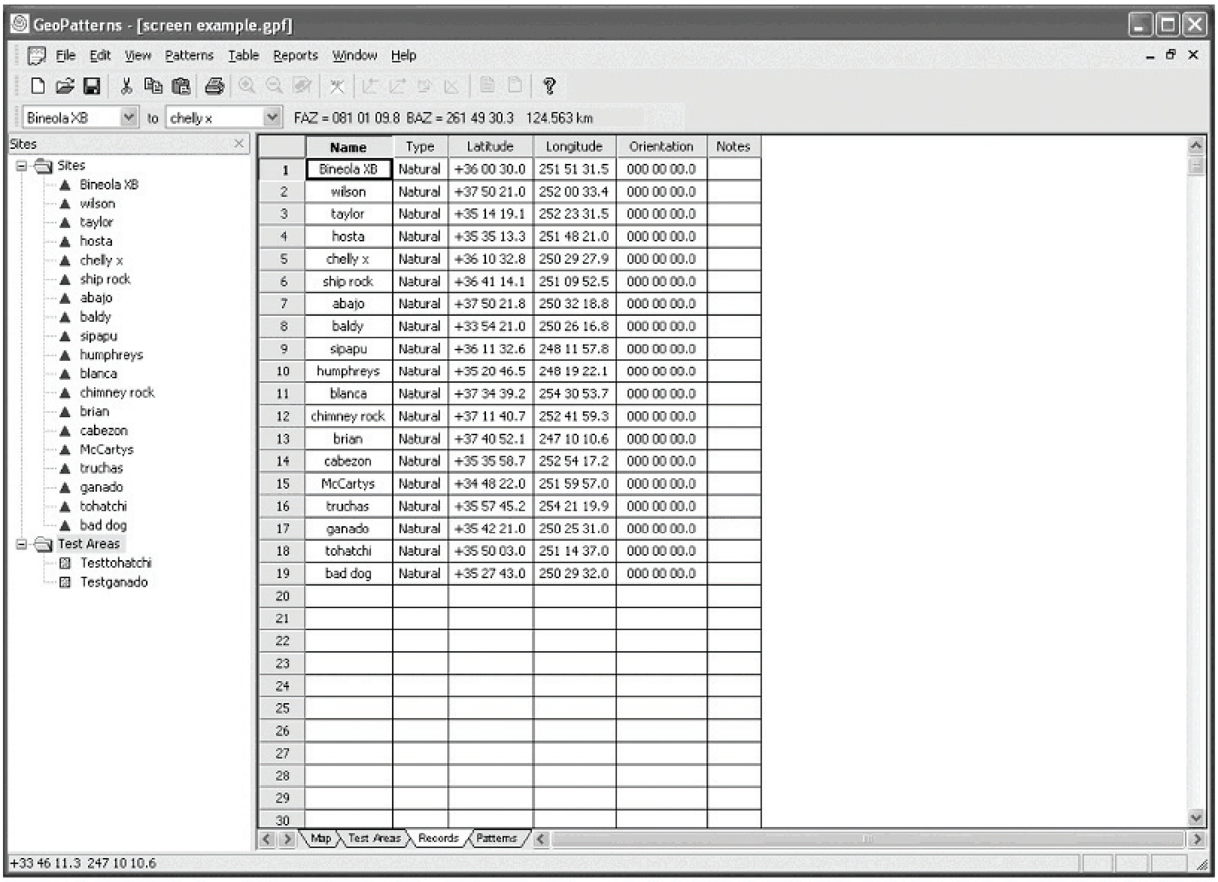


Figure 6. Main page of Geopatterns application.



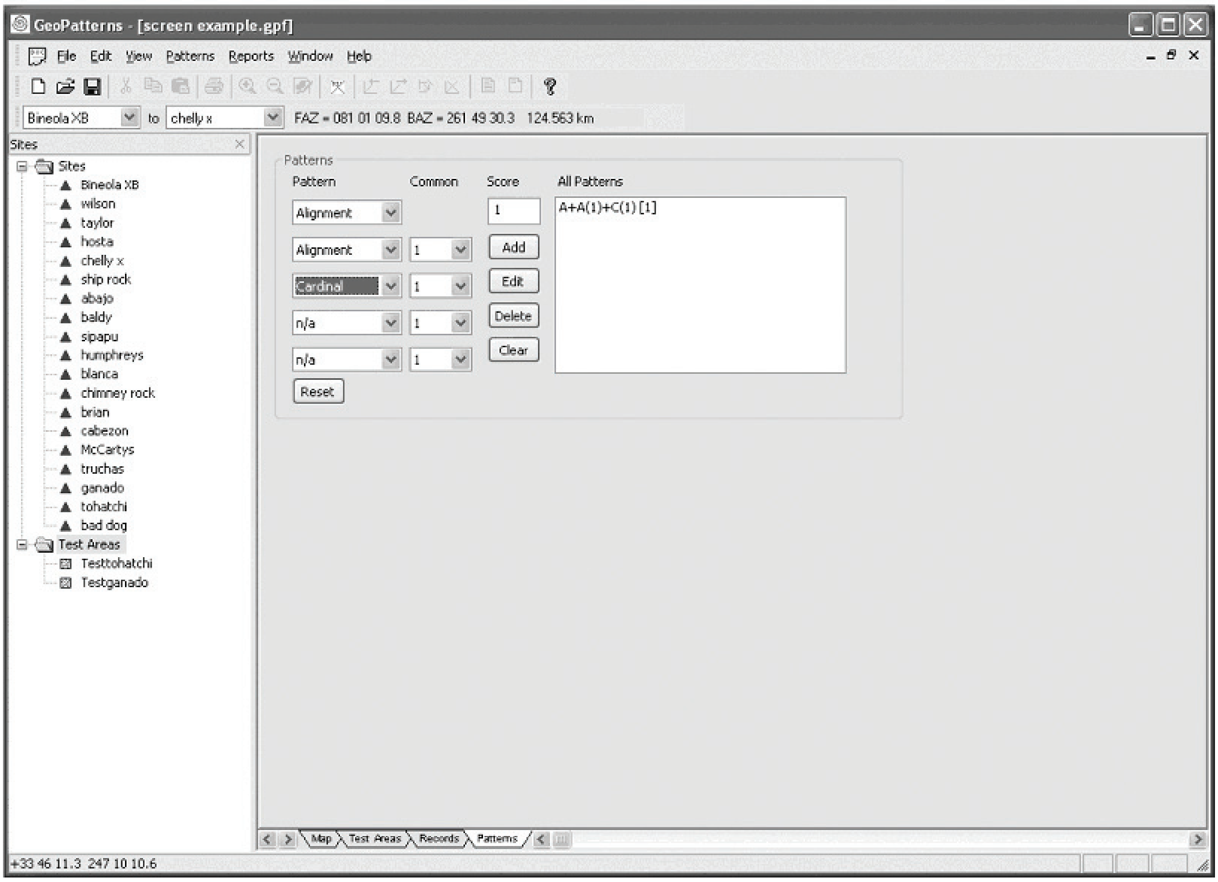


Figure 7. Records page (above), Patterns page (below).

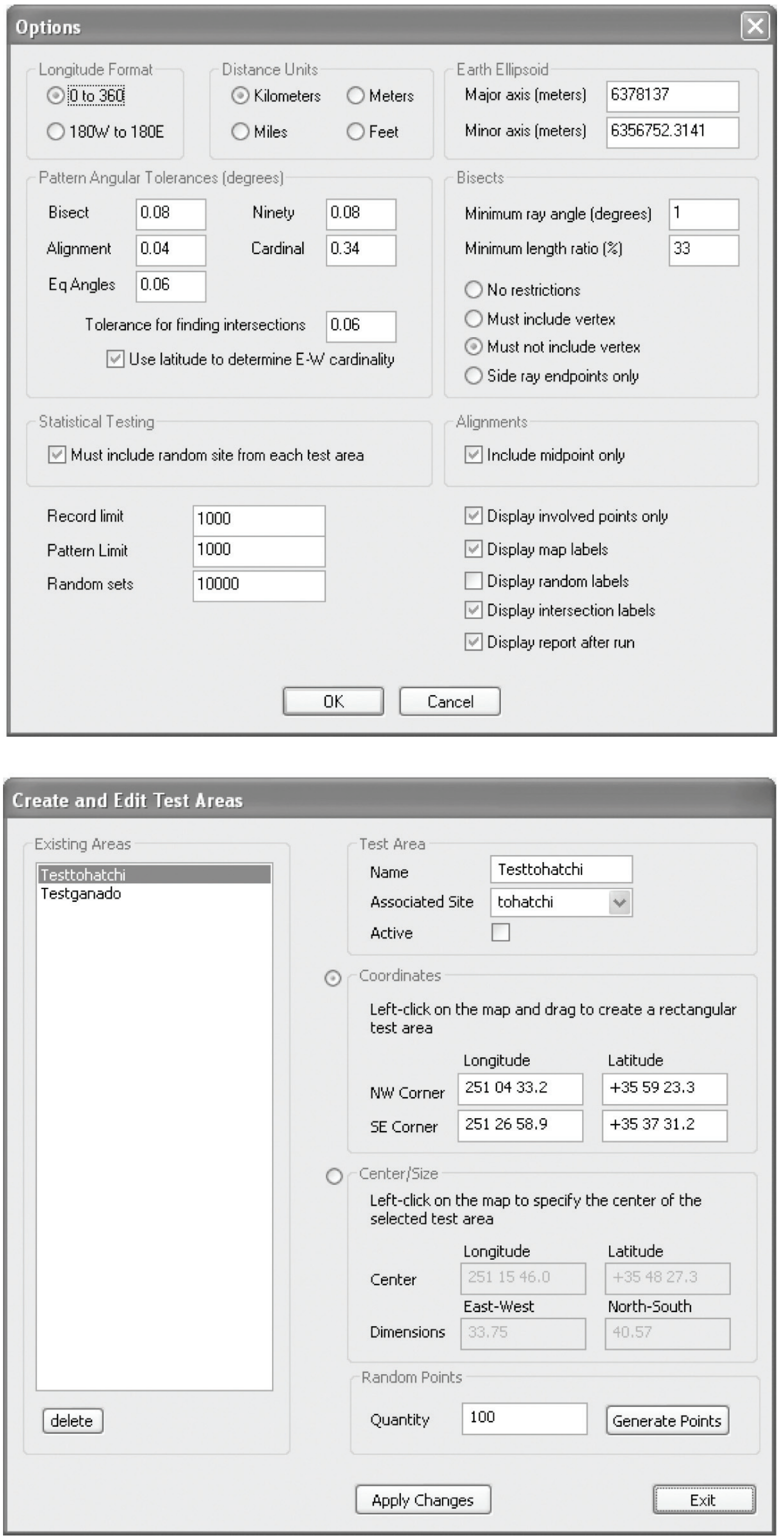


Figure 8. Options menu (above), and creation and editing of test areas (below).

topographic realities. The scale of this study on the Southern Colorado Plateau is so large that it seems highly unlikely that simple social propinquity, functional paths between places, locations by water sources, or topographic features like valleys could create in themselves any effect beyond that of random geometric patterns. Communicational site lines, such as those studied by Swanson (2003), however, would possibly be the exception here, but are as well determined by natural topography and hence would contribute few if any precise patterns beyond much less accurate viewsheds between points. Swanson finds no precise or seemingly symbolic pattern in his layout of site lines on Cerro Moctezuma. One strong example of the lack of topographically influenced geometric pattern in the present study is the fact that among the 17 natural features used in the present plateau study, no precise alignments and only one cardinal relationship occur.

The following analyses rely on quite precise latitude-

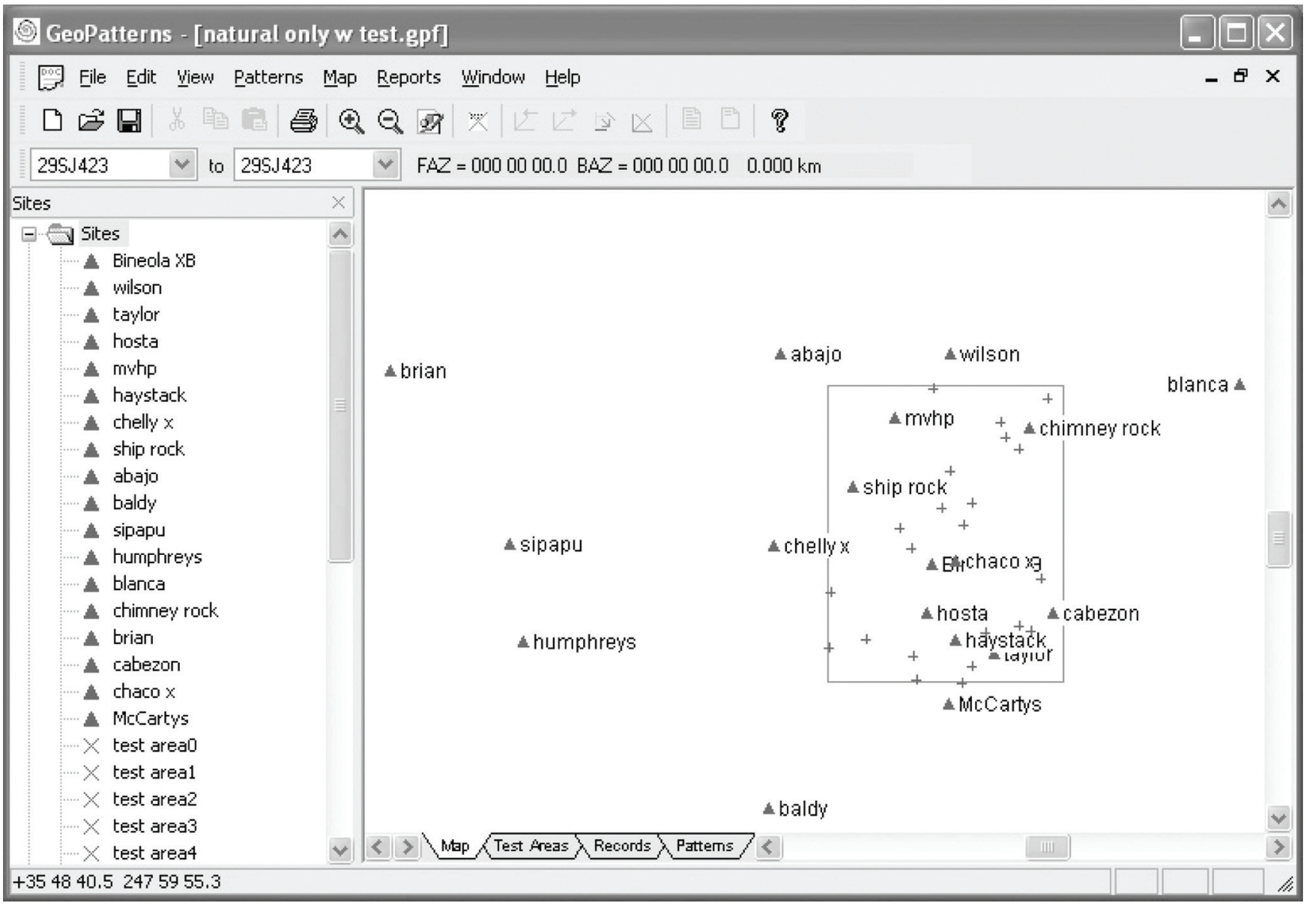


Figure 9. Geographic test area in which 100 sets of 22 random points each are created; fixed natural points are identified with the solid triangle markers.

longitude definitions of site locations and measures of angular deviation of patterns. Furthermore, the 18 natural features chosen for the analyses, with one possible exception (Mesa Verde), leave little doubt about their geographic uniqueness. The 22 built sites from the Chacoan period (900-1250), for their part, are determined primarily by an obvious size and apparent importance of site, and or the simple availability for GPS measurement. The Chacoan surveys were essential to this process (Marshall et al. 1979; Powers, et al. 1983). The fact that 22 Chacoan structures represent only about a fifth or so of some total known in the larger region does not alter the reliability of the work. As long as none of the sites was purposely chosen because it was part of some hypothesized geometric pattern, all can initially be thought of simply as a set of points to be studied in relation to themselves together with the 17 natural features. If 22 points randomly distributed in many tests produces considerably fewer geometric patterns, or combinations of patterns, then one can hypothesize that some of the geometry of the existing set must be designed.

Given the 39 sites, 17 natural and 22 built, the Site Analysis function can look for simple alignments of three sites, bisect relationships of four sites, and cardinal patterns between two sites. The angular deviation figures used—the average of the two deviations of interim point as seen from both ends for alignments and one half of the difference of the two angles of a bisect—is somewhat intuitive. As long as the same deviation figure is used in any comparison with patterns generated by random points, then the procedure is proper. Using the existing natural and built sites, and a deviation figure of 0.079°, the application discovers 26 alignments and 525 bisects; 35 cardinals are found at the tolerance of 0.34°.

One can now compare the number of patterns created by the existing 22 built sites with patterns created by sets of 22 random points. The 17 natural points are constant in the test. The strategy is to create a defined area in the Chacoan region within which all existing 22 built sites occur. Natural sites occur both inside and outside of the area (Figure 9). Because Cerro Moctezuma lies far to the south of the defined areas of the other built sites, it is included as a fixed natural site. Its kiva-like feature is right at the summit of the peak. One now creates sets of 22 randomly distributed points within the defined area.

The following is a summary of the z-score analysis done by Brandon M. Gabler, a PhD student in archaeology at the University of Arizona with a mathematics background. He prefaced the summary by noting that while only 100 trials were done, ideally one would want thousands or tens of thousands of trials to create a population. He concluded that visually these distributions were close to Gaussian (normal), though slightly skewed, and the standard deviations were quite reasonable for the range of data. Thus, a larger number of trials were not necessary:

Alignments. The histogram at right shows the frequency of alignments from random points placed by Geopatterns as an approximately normal distribution (Figure 10). With an observed number of alignments of 26, based on 22 known archaeological sites, I conducted a z-score to determine the probability of having 26 alignments randomly formed on a landscape of 22 known sites and 17 natural sites. Using the formula:

$$z = \frac{X - \mu}{s}, \quad (1)$$

where μ = 10.63 (the population mean number of alignments), s = 4.247 (the pop. std. dev.), and X = 26 (the observed number of archaeological alignments), we get the result:

$$z = \frac{26 - 10.63}{4.247} = 3.92,$$

producing p-value < 0.0001.

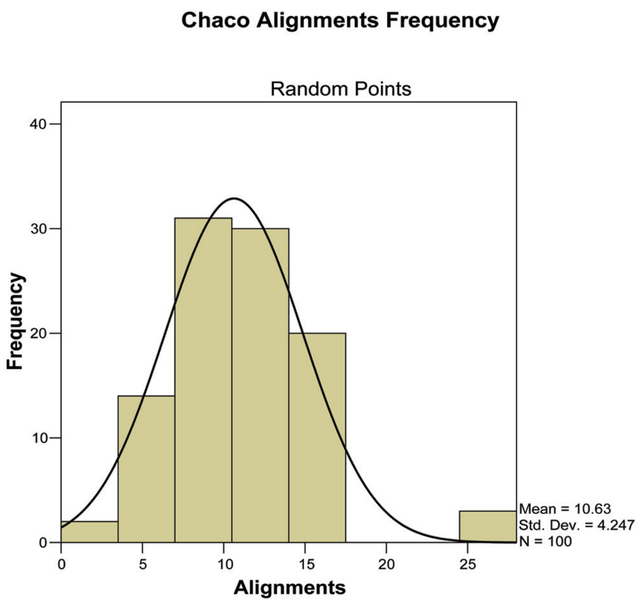


Figure 10. Chaco alignments frequency graph.

This result is significant at the 99% confidence level. Therefore, based on these data there is enough evidence to reject the hypothesis that the observed archaeological alignments are due to random chance. Therefore, the hypothesis that the observed alignments are due to some other unknown purposeful construction reason is supported.

Descriptive Statistics

	N	Mean	Std. Deviation	Variance
Alignments	100	10.63	4.246579134	18.03343

Bisects. The histogram at right shows the frequency of bisects from random points placed by GeoPatterns as an approximately normal distribution (Figure 11). With an observed number of bisects of 525, based on 22 known archaeological sites, I again conducted a z-score to determine the probability of having 525 bisects randomly occurring on a landscape of 22 known sites and 17 natural sites. Again using the formula:

$$z = \frac{X - \mu}{s}, \quad (1)$$

where μ = 455.64 (the population mean number of bisects), s = 28.356 (the pop. std. dev.), and X = 525 (the observed number of archaeological bisects), we get the result:

$$z = \frac{525 - 455.64}{28.356} = 2.45,$$

producing p-value = 0.0071.

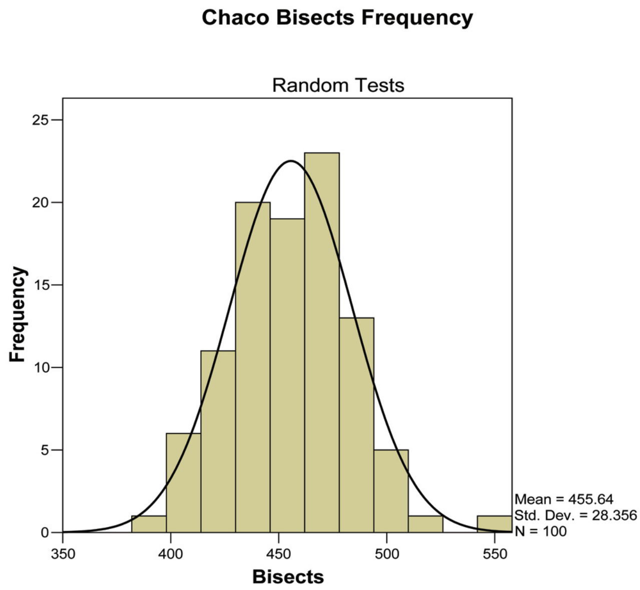


Figure 11. Chaco bisects frequency graph.

This result is significant at the 99% confidence level. Therefore, based on these data there is sufficient evidence to reject the hypothesis that the observed archaeological bisects are due to random chance. Instead, the hypothesis that the observed bisects are due to some other unknown purposeful construction reason is supported.

Descriptive Statistics

	N	Mean	Std. Deviation	Variance
Bisects	100	455.64	28.35614768	804.0711

Cardinals. The histogram at right shows the frequency of cardinals from random points placed by GeoPatterns as an approximately normal distribution, though slightly skewed (Figure 12). With an observed number of cardinals of 35, based on 22 known archaeological sites, I again conducted a z-score to determine the probability of having 35 cardinals randomly occurring on a landscape of 22 known sites and 17 natural sites. Again using the formula:

$$z = \frac{X - \mu}{s}, \quad (1)$$

where μ = 13.4 (the population mean number of cardinals), s = 3.525 (the pop. std. dev.), and X = 35 (the observed number of archaeological cardinals), we get the result:

$$z = \frac{35 - 13.4}{3.525} = 6.13,$$

producing p-value < 0.0001.

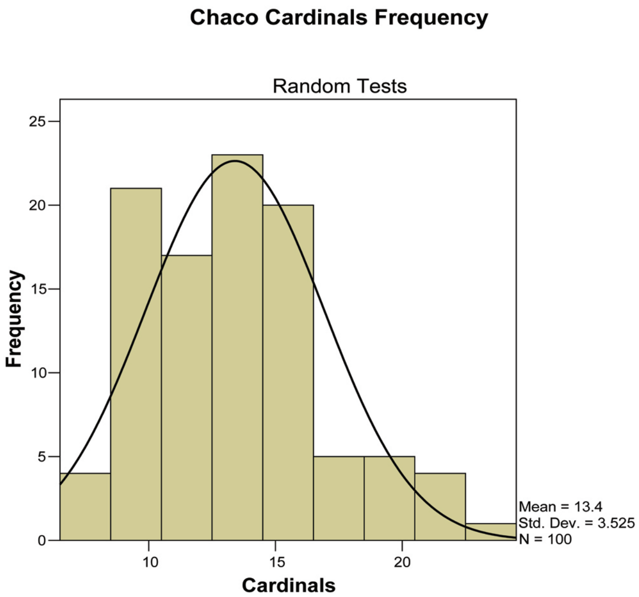


Figure 12. Chaco cardinals frequency graph.

This result is significant at the 99% confidence level. Therefore, based on these data there is enough evidence to reject the hypothesis that the observed archaeological cardinals are due to random chance, while the hypothesis that the observed cardinals are due to some other unknown purposeful construction reason.

Descriptive Statistics

	N	Mean	Std. Deviation	Variance
Cardinals	100	13.4	3.524803885	12.42424

Even though the z-tests show that the Chacoans very probably created alignments, bisects, and cardinals across larger landscapes, one cannot say that all such patterns would necessarily have been designed. Some certainly might be random, in spite of the good z-score numbers. Geopatterns can now identify not just these individual patterns, but much more unique and rare combinations of such.

Summarizing the involvement of each of the 39 sites, natural and built, in the 26 Site Analysis alignments is a first step in selecting combination patterns. Starting with this information, one can find several examples of complex patterns, three of which are included below as interesting examples. The first is a line with six aligned sites, the second a bisect with three-point alignments on all three "rays" including one as a cardinal, and the third illustrates multiple intersecting lines as a "cross."

4 Testing Complex Patterns against Sets of Random Points

4.1 An Accurate Chaco Meridian

As published previously (Doxtater 2002, 2003), Mount Wilson and some extended meridian to the south was held to be the primary initiator of the Chaco Canyon location and positioning of principal ceremonial sites therein, i.e., the most sacred northerly point in the Chacoan world (Lekson's less accurate meridian uses only Paquime, the Chaco center, and Aztec). Besides my more precise sites, the actual crater or source for the McCarty's Flow, of Acoma mythic memory, lies quite accurately to the south of the precise summit of Mount Wilson, see Figure 13. The azimuth from McCarty's Flow point to Mount Wilson is 179° 50' 32.7". My other four sites also have relatively accurate north-south relationships with Mount Wilson: Moctezuma is the most accurate at 179° 57' 35.6", the Aztec Centroid is 179° 40' 20.3", Peñasco Blanco's Great Kiva is 179° 41' 31.3", and Andrews down in the Red Mesa Valley is 179° 41' 10.1".

Each of the six points participates in one or more three-point alignments—what Geopatterns searches for—within the maximum figure of 0.079°. Furthermore, each of the sites has at least one cardinal relationship with one of the other sites within the maximum of 0.326°. Given the many alignment and cardinal relationships of the six points, the limiting factor in the test becomes the five pattern combination maximum of Geopatterns. Only a portion of its total geometry is therefore tested. The present test is set up for a combination pattern of two alignments and three cardinal alignments (pairs of points from each of the built sites to Mount Wilson), i.e., A+A(2)+C(2)+C(2)+C(2). The parenthesis figures indicate the number of points in common with the rest of the pattern. Angular tolerances are 0.079° for the alignments and 0.326° for the cardinal relationships.

The present version of Geopatterns was primarily designed to create some number of test areas, each with its random point, rather than many iterations of one test area with multiple random points, as was used in the z-score tests. Where the user wants to test against the entire number of

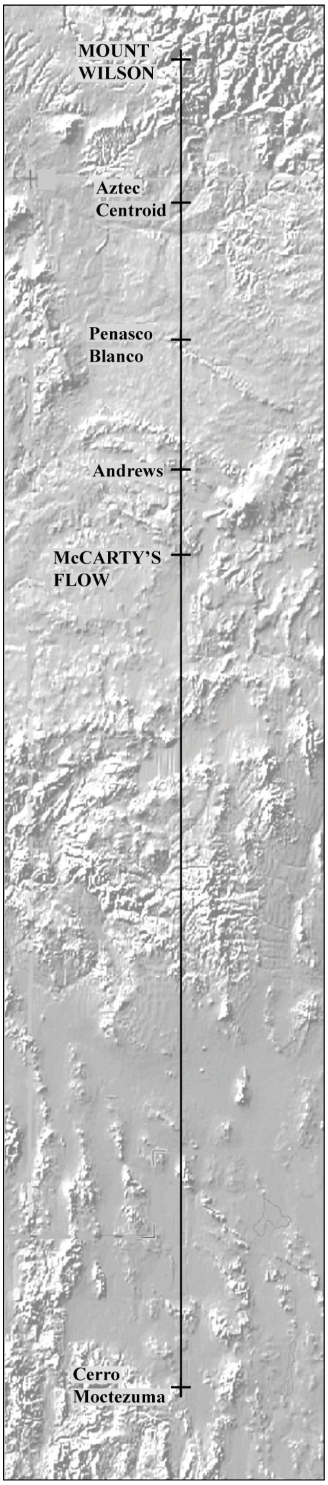


Figure 13. Six aligned sites of the Mount Wilson Meridian.

built sites with Statistical Analysis, it is logical to "tile" the entire area with a number of test areas equal to the number of actual built sites within the area. Figure 14 illustrates how the total area where the 22 existing built Chaco sites occur can be tiled to create 24 separate test areas. Because of the geometry of the rectangle, the number of tiles exceeds the existing sites by two, possibly skewing the results slightly toward greater probability of randomness.

In using the Statistical Analysis in the present meridian example, one seeks the single complex pattern at the desired accuracies. For each set, the application will create a random point in each of the 24 test areas and look for the desired pattern among each of these sets. In this first test a Mount Wilson meridian pattern occurs four times in 1000 sets of random points or 1:250 (0.004). Two other such cardinal alignment patterns occur in the 1000, one comprised entirely of random points, and the other involving McCarty's Flow. The likelihood of this pattern's random occurrence can also be measured in another way. One can think more specifically of the probability of each of the three built sites of the pattern being built in exactly the right location to be aligned with Mount Wilson and each other cardinally. If one creates a logically sized test area around each of the three sites, and asks Geopatterns to create sets with one random point in each, how many sets will it take to produce the pattern (again two alignments and three cardinal relationships at the same accuracies)? In this test the results are quite similar to the tiled method. Using test areas of 8 km square around each of the three sites, as determined by adjacency to other built sites primarily at Peñasco Blanco and Andrews, 1000 sets creates three of the patterns in question involving Mount Wilson. Eight additional ones are focused south to Cerro Moctezuma. The greater tendency for Cerro Moctezuma than Mount Wilson is probably due to the greater distance of the former. At greater distances, the angular deviations of interim points are smaller. Thus, the question is whether the similar 1:250 (0.004) or 1:333 (0.003) odds of this pattern happening randomly suggests design?

4.2 The Mount Wilson Bisect

The list of simple three-point alignments among the existing built sites, together with the natural, includes not only the three of the meridian pattern just tested, but two additional ones that align with Mount Wilson (Casa Rincoñda-Haystack Mountain, Kin Nahasbas-Haystack Outlier). The relationship between these latter two and the meridian form a bisect from Mount Wilson of 0.027°, as shown in Figure 15. The three alignments of the rays from west to east have average angular deviations of 0.023°, 0.001°, and 0.029°. The fifth component of this complex pattern, the cardinal alignment of any two of the three meridian points, is again 0.326. To test this pattern with the Statistical Analysis function—and a tiled map—one must turn on Geopatterns "vertex must be involved" control, setting the compound B+A(2)+A(2)+A(2)+C(2) at the existing accuracies given above. In a total number of 100,000 random sets, Bineola X and Chaco X excluded, the bisect pattern combination shows up five times, 0.00005. Two of the patterns are asymmetrically oriented with regard to any cardinal *axis mundi* and do not focus on natural sites but use random points. One site is asymmetrical as well but does use Chimney Rock for its vertex. Two random patterns of the 100,000 do use Mount Wilson and a cardinal (vertical) relationship with McCarty's Flow point. While the existing pattern does involve the meridian relationship with Aztec and Peñasco Blanco (and also Andrews, McCarty's Flow, and Cerro Moctezuma), the random examples are more symmetrical in the disposition of their two arms. The existing pattern uses the Mount Wilson-Casa Rincoñada-Haystack Mountain as

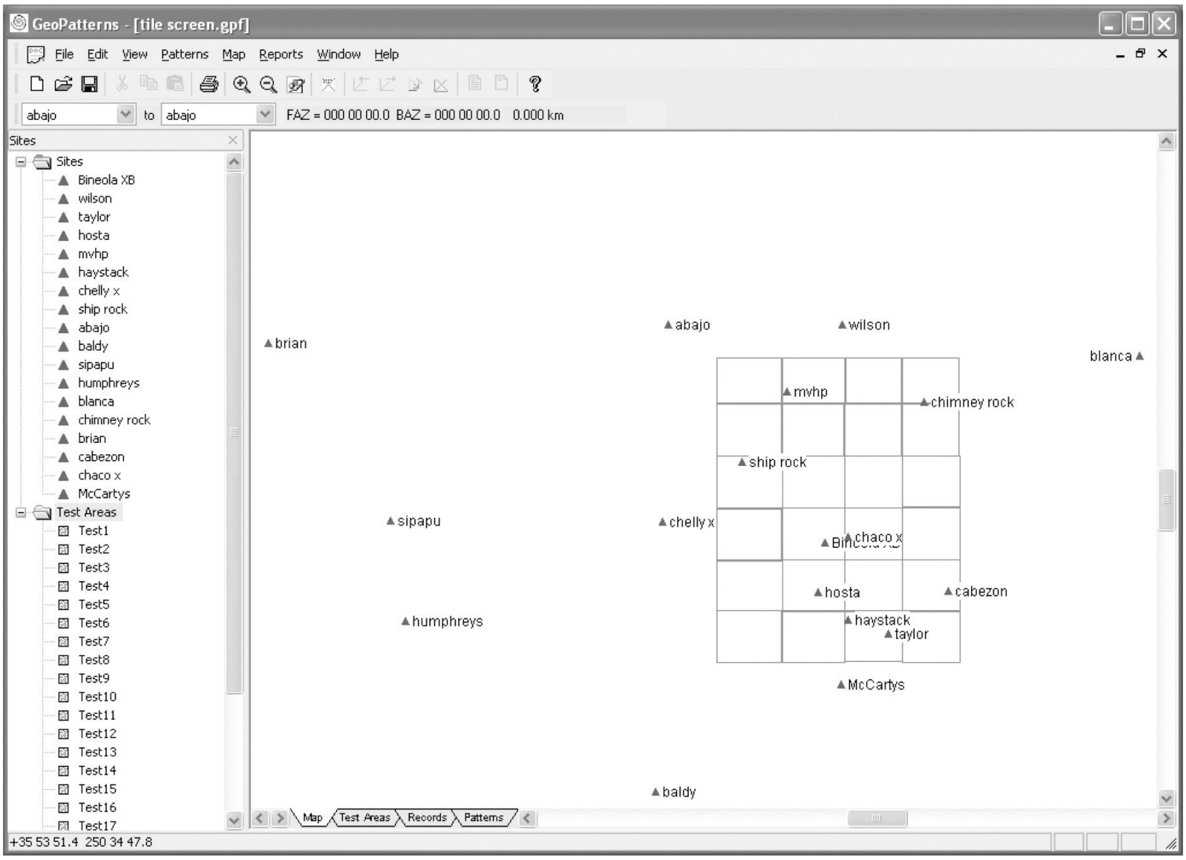


Figure 14. Geopatterns "tiled" setup to generate a very large number of random sets of points, each set locating a point within one of the 24 tiled areas.

its central axis, rather than the *axis mundi* arm to Aztec and Peñasco Blanco.

When one uses 4 km test areas around the five existing built sites of the combination bisect pattern, sized again due to adjacency of other built sites, Statistical Analysis finds only one such pattern in 100,000 sets (one random point for each of the five areas). It focuses on Mount Wilson. In this case Bineola X and Chaco X are included. Clearly, this composite pattern happens very rarely as a random event, either 0.00005 for the tiled test or 0.00001 for the test areas around each site.

4.3 Multiple Alignments as Cross Patterns

Other publications (Doxtater 2002, 2003) have illustrated ethnographic examples of large-scale cross patterns, most particularly the Warao (Wilbert 1993), Tewa (Ortiz 1969), Keres (Snead & Preucel 1999), and probably Hopi (Doxtater 1978). Most symbolic cosmologies, in both new and old worlds, are composed of intersecting lines that create symbolic Eliadian center points. If accurate points of intersection for two or more lines were understood, then each line constitutes an alignment of three points (or more). We do not ethnographically know whether the Warao had such an accurate point at the center of their two cardinal axes, although the accuracy of the vertical meridian would suggest that they did. When we examine the two Tewa axes, however, it is clear that the location of their "center" village of San Juan is not at the accurate point of axes intersection.

Certainly one of the primary difficulties of finding accurate center points is the possibility that such were no more than some seemingly ordinary natural feature such as the sacred tree of the Warao. In the Pueblo cultures we can think of major *sipapus* (ritual openings to the underworld) such as the very small mound and opening near the junction of the Little and Colorado rivers in the Grand Canyon, Figure 16, or the very simple hole in the major dance plaza at Hopi First Mesa or Walpi, and its *axis mundi* use as described by Waters (1977). Unlike more complex and more ranked societies where some pyramid stands at the symbolic and cosmic center, the farther back in the evolution of social space we go, the more likely that the most sacred of centers were neither permanently occupied by humans, nor architecturally defined. They may thus be very difficult to determine by typical archaeological methods. What, then, can our proto-investigation of large-scale geometry on the Southern Colorado Plateau contribute in this regard?

We set Geopatterns to first look for two alignments that intersect at their interim points respectively within 0.079° deviation. The existing set of 22 built Chacoan sites together with the 17 natural sites produces three such examples. These "bi-cross" patterns are created by the largest great kiva in Chaco Canyon, Casa Rincoñada (Mount Wilson-Rincoñada-Haystack 0.001° and Andrews (Red Valley)-Rincoñada-Pierre 0.072°); by the Aztec Centroid (Peñasco Blanco-Aztec-Mount Wilson 0.023°, and Andrews-Aztec-Wilson 0.054°); and by the site called Village of the Great

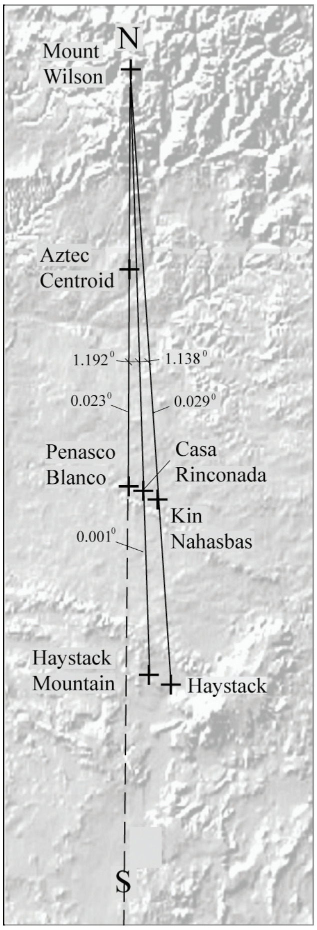


Figure 15. Mount Wilson bisect with three alignments and a cardinal relationship.

Figure 16. Ritual opening between worlds, "sipapu" at the junction of the Little Colorado and Colorado Rivers in the Grand Canyon (UA Press photo).

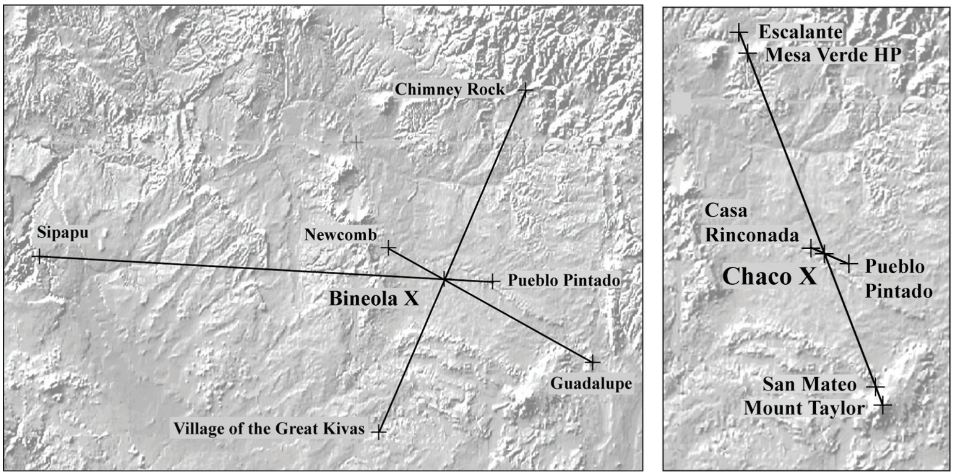


Figure 17. Two additional existing "tri-cross" intersection points: Bineola X & Chaco X.

Kivas (Mount Baldy-VGK-Kin Bineola 0.015°, and Mount Baldy-VGK-Chimney Rock 0.053°). When one substitutes 24 random points distributed in equal tiled areas for the existing built sites, we can readily see that such patterns are quite likely to happen randomly. In 100 different random point sets, 52 produced one bi-cross pattern (almost 1:2) and 24 created two bi-cross patterns (almost 1:4). No set of the 100, however, created three bi-crosses.

If we up the ante and look at triads of alignments (tri-crosses) with common interim points, we observe that three such patterns occur within the existing combination of built and natural points. The first is Pierre's Butte (Aztec-Pierre's Butte-Hungo Pavi, Twin Angels-Pierre's Butte-Moctezuma, and Mount Wilson-Pierre's Butte-Chaco X) and the other two are focused on the two natural intersection points of Bineola X (Newcomb-Bineola X-Guadalupe, Sipapu-Bineola X-Pueblo Pintado, and Village of the Great Kivas-Bineola X-Chimney Rock) and Chaco X (Escalante-Chaco X-Taylor, Mesa Verde High Point-Chaco X-San Mateo, and Casa Rincoñada-Chaco X-Pueblo Pintado). The reader should note that these two tri-cross patterns are in addition to the natural lines that create these intersection points (three for Bineola X and two for Chaco X).

In 500 sets of 24 random points, a single triple-cross pattern occurred 44 times (1: 11.36 or 0.088). Such a pattern occurred twice (1:250 or 0.004). No individual statistical test created three tri-cross patterns, though by using the frequencies for single and double occurrences, one might estimate that a triple could occur once in about 5,500 times or 0.00018. Because of present limitations in Geopatterns reporting, each statistical test in the above process must be done individually, thereby limiting the overall number of tests.

Because two of the sites are naturally occurring intersection points, one needs to distinguish these phenomena from possible additional alignments intentionally created. We can hypothesize that the intersection points of Bineola X and Chaco X—as shown in Figure 17—were known points and then add them to the list of existing natural sites. In adding two more site points to the existing 17, we can now ask why this simple addition creates three triple-cross patterns where none existed before. Again the new patterns are not dependent upon the natural intersection patterns that created the points originally. What happens in the addition is that pairs of built sites load up, as it were, on Bineola X and Chaco X, and Chaco X in turn creates an additional alignment to the Pierre tri-cross.

We can now repeat the Geopatterns exercise where we search for tri-cross patterns among 24 random (built site) sets asking how often one, two, or three such patterns will occur. The actual intersection points of Bineola X and Chaco X are added to the original 17 natural points. Geopatterns must in this case be set at its maximum cross pattern that seeks five alignments with a common interim point (at the deviation figure of 0.074°), this is because the application will pick up the natural intersecting lines of Bineola X and Chaco X, as well. Because the total number of intersecting lines at both Bineola X and Chaco X is six, compared with Geopatterns maximum of five, the test results will be skewed toward lower figures of probability. It also must be observed that using the five-cross pattern eliminates Pierre with its three-cross (and no additional natural intersecting lines). The application can ask for both five and three-cross patterns but limitations in report format make searching such results difficult.

Including the two natural intersection points, 500 tests of 24 random point sets produces 40 sets where a single five-cross pattern occurs at either Bineola X or Chaco X (1:12.5 or 0.08). The five-cross pattern does not double up in any of the 500 sets. Again, because the third existing three-cross pattern at Pierre has been eliminated, we are only looking to replicate the two that occur at Bineola X and Chaco X. Using the tile method of testing sets of 24 random points, we can only say that the odds of two three-cross patterns loading up on Bineola X and Chaco X at the time are greater than 1:500 or 0.002, and that the odds of three three-cross patterns happening in one random set, now including Pierre, must be far greater than this number.

While the report limitations of the present version of Geopatterns keeps us from testing great numbers using the above tile method, we are not so restricted when testing selected sites associated with particular patterns. As discussed earlier, we can focus on Bineola X, for example, and ask about the odds that the four built sites creating its fourth, fifth, and sixth intersecting alignments are in the right places within areas around each site to create the pattern. In Geopatterns we construct a 10-km square test area around Newcomb, Pueblo Pintado, Guadalupe and Village of the Great Kivas, assuming that it would not be unreasonable for these sites to vary to this extent in their location due to non-symbolic (sacred geometric) reasons. One asks the application to look for three alignments with a common interim point at a variance of 0.074° or less. The natural points of Bineola X and Chaco X are included in the list of natural sites. Because of the easier means of reading the reports in this process, one can test a much larger number of sets, each of which contains 4 random points, one in each 10-km test area. The actual four built sites are eliminated from each test, thereby substituting the random for the existing for each trial. For Bineola X, in 100,000 different 4-point sets, 16 create a three-cross pattern focused on this natural intersection point (1:6,250 or 0.00016). The occurrence of three-cross patterns at Chaco X is less frequent, 3 in 50,000, 1:16,666 or 0.00006. The 10-km test areas for the Chaco X analysis are drawn around the built sites of Escalante, San Mateo, and Pueblo Pintado. The box around Casa Rincoñada is only 3 km square because of the site's proximity to other built points.

What do these selected site tests tell us, then, in regard to the likelihood that any one array of total built and natural points (including Bineola X and Chaco X) will create three tri-cross patterns? Is it some sort of statistical combination of 0.00016 (Bineola X), 0.00006 (Chaco X) and 0.00085 (Pierre's Butte)? Also, we must recall that there is an additional, fourth alignment that also works with both Bineola X and Chaco X, and is not represented in the above odds. But again we are limited in understanding these selected site patterns against some total calculation of random points (in built site test areas) in relation to some total number of natural bi- and tri- intersection locations.

5 Summary of the Analyses

We have seen three different strategies of using Geopatterns to compare existing layouts with those created by random points. Keeping the natural points as constant, the first test used Statistical Analysis to place 22 random points (representing the existing Chacoan period built sites) within a single, large test area approximately covering the locations of existing sites. As a more manually determined process, the practical limit of random point sets was 100. Each of the four basic patterns of Geopatterns was searched for by using accuracies indicated by actual three-point alignments, cardinal relationships of two points, and bisect patterns of four points.

For each of the three patterns, even including the much more numerous bisects, z-scores indicate a clear statistical distinction between built and random patterns. The most probable designed relationship are the cardinals (6.13, 0.0001), followed by alignments (3.92, 0.0001), and bisects (2.45, 0.0071). The more ambitious intention of Geopatterns, however, is to search for combinations of patterns much more complex and rare than those captured by Site Analysis of 100 sets. Use of the Statistical Analysis function in this case involves two different Geopatterns strategies. First is the "tiled" layout of about the same area as the larger single test area of the mentioned Site Analysis process. Ideally, the number of tiles would be the same as the 22 actual built sites and would fill up these same overall areas where these sites exist. In present tests, 24 tiles were used because of the symmetry of the rectangular overall area. A second alternative was to create much smaller test areas, from 3-10 km, around each of the built sites of a particular composite pattern, and then generate one random point for each in each set tested.

Using these methods, 3 composite patterns among existing Chacoan sites and the 17 invariant natural features were compared to numbers of similar patterns generated by large numbers of sets with random points.

The statistical probabilities for complex patterns as well as the z-scores for simple alignments, bisects, and cardinals, appear to give considerable support to the idea that Pueblo ancestors were positioning their more important great house and great kiva sites in large-scale geometric relationships to natural features and each other. As suggested in the author's previous publications on the topic (Doxtater 1978, 1981, 1991, 2002, 2003), and a volume about to be completed, the cultural reasons for these "georitual" uses of space are to be found in not dissimilar layouts of sacred space usually associated with Eliadian-like phenomena throughout the primitive and/or traditional world. While georitual represents an unusual and larger-scale version of these forms of religious space, i.e., where the "center" is created by peripheral natural features associated with the most powerful spirits rather than being extended out from some more humanly (pre) established center (see Smith 1972), the essential components of *axes mundi*, orientations, thresholds, homologues (repetition of patterns at different scales), and generally of formalized symbolic oppositions are very similar.

Religiously, georitual patterns would undoubtedly have been affectively understood as the means by which spiritual power was channeled to ceremonial sites such as great kivas where contact was made at specific times determined probably by astronomical observation. Symbolic patterns in the landscape determined *where* contact could be made, while astronomy dictated the *when*. Most certainly, Mount Wilson was the most powerful location of Chacoan spiritual power, as its Meridian and Bisect patterns testify. Other important players were the cross intersection points of Bineola X and Chaco X, and Pierre's Butte.

The present paper, however, has not had space to discuss to any extent these social organizational or religious dimensions of the Pueblo ancestor experience on the Southern Colorado Plateau; nor has it spent time on how priest surveyors would have laid out these patterns (shown previously in Doxtater 2002, 2003), how site dating is related, or how a great deal of related smaller-scale pattern also is evident, particularly in the Chaco and Aztec centers, and in the construction of the greatest of great houses. The primary purpose of this exercise was to address the most critical problem of georitual research, i.e., being able to distinguish designed from random pattern. As an architect-anthropologist, I have long studied the formal, ritual patterns of religious space at dwelling, settlement, and even urban scales. There is no cultural or religious reason why traditional people would not use these same strategies, under the right social conditions, to organize themselves in this manner at larger scales. After it became evident that such people had the ready technology to do so, the remaining obstacle to archaeological acceptance was the present statistical question. It is hoped that this paper has at least seriously introduced the question and initial directions for possible solutions.

References Cited

Doxtater, Dennis. 1978. The Hopi Ritual Landscape. In, *Megaliths to Medicine Wheels: Selected Papers of the 11th Annual Chacmool Archaeology Conference*, M. Wilson ed, pp. 313-331. Calgary: University of Calgary Press.

Doxtater, Dennis. 1981. *Thursday at a Crossroads: The Symbolism, Structure and Politics of "Center" in the Old Scandinavian Farm Culture.* Ph.D. Dissertation, Architecture, University of Michigan, Ann Arbor.

Doxtater, Dennis. 1991. Reflections of the Anasazi Cosmos. In, *Social Space*. E. Engelstad, O. Gron and Y. Lindblom, eds., pp. 155-184. Odense: Odense University Press.

Doxtater, Dennis. 2002. A Hypothetical Layout of Chaco Canyon Structures via Large-Scale Alignments between Significant Natural Features. *Kiva* 68(1):1-25.

Doxtater, Dennis. 2003. Parallel universes on the Colorado Plateau: Indications of Chacoan integration of an earlier Anasazi Focus at Canyon De Chelly. *The Journal of the Southwest* 45(1 & 2):33-62.

Fritz, J. M. 1978. Paleopsychology today: Ideational systems and human adaptation in prehistory. In, *Social Archaeology: Beyond Subsistence and Dating*. C. Redman, ed., pp. 37-59. New York: Academic Press.

Kincaid, Chris, ed. 1983. *Chaco Roads Project Phase I*. Albuquerque: U.S. Department of Interior.

Lekson, Steven. 1999. *The Chaco Meridian*. Walnut Creek, CA: Altamira Press.

Malville, J. McKim and Putnam, Claudia. 1989. *Prehistoric Astronomy in the Southwest*. Boulder: Johnson Books.

Marshall, Michael P. 1997. The Chacoan roads: A cosmological interpretation. In, *Anasazi Architecture and American Design*, Baker H. Marrow and V. B. Price, eds., pp. 63-74. Albuquerque: University of New Mexico Press.

Marshall, Michael, Stein, John, Loose, Richard, and Novotny, Judith. 1979. *Anasazi Communities of the San Juan Basin*. Public Service Company of New Mexico, State of New Mexico, and Department of Interior.

Ortiz, Alfonso. 1969. *The Tewa world: Space, time being and becoming in a Pueblo society*. Chicago: University of Chicago Press.

Powers, Robert P.; Gillespie, William B., and Lekson, Stephen H. 1983. *The Outlier Survey: A Regional View of Settlement in the San Juan Basin*. Albuquerque: National Park Service.

Smith, Jonathan. 1972. The Wobbling Pivot. *Journal of Religion* 52:134-149.

Snead, James E. and Preucel, Robert W. 1999. The ideology of settlement: ancestral Keres landscapes in the Northern Rio Grande. In, *Archaeologies of Landscape,* Wendy Ashmore and Bernard A. Knapp, eds., pp. 169-197. Oxford: Blackwell Publishers.

Sofaer, Anna. 1997. The primary architecture of the Chacoan culture: A cosmological expression. In, *Anasazi Architecture and American Design*. Baker H. Morrow and V. B. Price, eds., pp. 88-132. Albuquerque: University of New Mexico Press.

Stein, John R., Suiter, Judith E., Ford, Dabney. 1997. High noon in Old Bonito. In, *Anasazi Architecture and American Design*. Baker H. Marrow and V. B. Price, eds., pp. 133-148. Albuquerque: University of New Mexico Press.

Stephen, Alexander M. 1936. *Hopi Journal*. New York: AMS Press.

Stubbs, Stanley. 1950. *Bird's-Eye View of the Pueblos*. Norman: University of Oklahoma Press.

Swanson, Steve. 2003. Documenting Prehistoric Communication Networks: A Case Study in the Paquime Polity. *American Antiquity* 68(4):753-767.

Vivian, Gordon and Reiter, Paul. 1960. *The Great Kivas of Chaco Canyon*, Number 22. Santa Fe: Monographs of the School of American Research and the Museum of New Mexico.

Waters, Frank. 1977. *Book of the Hopi*. New York: Penguin Books.

Wilbert, Johannes. 1993. *Mystic Endowment: Religious Ethnography of the Warao Indians.* Cambridge: Harvard University Center for the Study of World Religions.