

SUPPLEMENTAL INFORMATION:

Great Houses, Shrines, and High Places: Intervisibility in the Chacoan World

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Our database includes 258 great houses, and 87 shrines or similar features. The database has progressed through several iterations. In 1999, as part of the Chaco Synthesis, John Kantner gathered information from many Chaco scholars into a GIS database of outlier locations (Kantner 2003; Kantner and Kintigh 2006). We substantially updated and revised this database. For temporal control, we placed great houses into groups. The Early Group includes 66 great houses where construction was initiated between A.D. 850 and A.D. 1000, and occupation may or may not have continued past that point (thus some Early Group sites also appear in the Late Group). The Late Group includes 180 great houses where occupation continued or construction was initiated between A.D. 1000 and A.D. 1150, and occupation may or may not have continued past that point. The Post-Chaco Group (not included in the viewnet analysis) contains 64 great houses where construction was initiated after A.D. 1150. This temporal organization reflects qualitative judgments grounded in existing literature as well as the authors' first-hand knowledge of most of the sites; we urge readers with additional or different information to communicate with the authors.

Our master database includes shrine and stone circle information collected by Windes, as well as additional shrine information from Winston Hurst, Mike Marshall, and Anna Sofaer. In spring 2007, Tucker Robinson compiled an early version of our GIS database, and we began running preliminary analyses (Robinson et al. 2007). From 2013 to 2015, Bocinsky and Van Dyke further refined the database and conducted the analyses reported in this article. This

supplementary document provides additional information on the shrines and related features, and technical details on our intervisibility analyses.

Shrines and Related Features

The word “shrine” pertains to a range of features in the ancient Southwest United States. As discussed in the main text, scholars have used various labels for enigmatic, small rock features, and these features likely represent a range of functions in the past. At some historic and contemporary Pueblos, features called shrines mark meaningful directions, ancestral routes, mythic events, or cosmographies. These shrines, which may include stacked stones, rock art, or oddly shaped boulders demarcate the cosmological organization of the landscape into nested layers and six directions revolving around the Pueblo as center place (Ellis 1969; Ortiz 1969, 1972). In Pueblo belief, shrines may indicate openings to the worlds below or other levels of reality (Parsons 1939). Using Tewa cosmology as a basis for investigating ancient Tiwa landscapes, Fowles (2009) identifies a complex of archaeologically visible directional shrines surrounding thirteenth century T’aitōna (Pot Creek Pueblo); Duwe (2011) conducted a similar study near coalescent Tewa villages in the Chama region of the northern Rio Grande.

In our analysis, we are particularly interested in enigmatic small rock features situated in places of high visibility on the Chacoan landscape, but some of these features probably had multiple functions; serving to mark boundaries, directions, or sacred places. These small rock features include J or box-shaped masonry-walled shrines (considered “communication shrines” by Hayes and Windes 1975), stone crescents, stone circles, *herraduras*, and cairns. Chaco scholars have used these labels inconsistently, sometimes conflating possible functions. For

example, on the Chaco Additions survey, Powers defined shrines as “ceremonial or other apparently esoteric sites including Anasazi (*sic*) C or fishhook shaped enclosures formed by a masonry wall, stone circles, and possible signaling sites at locations of high topographic prominence or visibility” (Powers and Van Dyke 2015: 31, Table 1.1). We are working on a systematic classification system, but in the meantime we offer the reader the following details.

Box or J-Shaped Shrines

Box or J-shaped Chacoan shrines are low, masonry-walled enclosures that sometimes contain turquoise beads, turquoise chips, or other offerings. The first shrine discovered in Chaco Canyon was a Classic Bonito phase J-shaped feature erected atop 29SJ 423, the Basketmaker III village above Peñasco Blanco (Hayes and Windes 1975; Windes 2015:95–100, 692). Similar J-shaped “Windes’ shrines” are often found along Chacoan roads (Kincaid 1983:20; Windes 1991:118). Hayes and Windes (1975) argued that these “Windes’ shrines” functioned primarily for communication, although they might also be marking places of cosmographic, mythic, or ritual importance. To date, Windes and others have documented over 40 shrines on high places across the greater Chacoan world (see for example Windes 1978, 2015:692; Windes et al. 2000:43).

Stone Crescents

In the course of the Solstice Project, Marshall and Sofaer (1988) recorded 42 features they labeled stone crescents. They considered these features to be a form of “ceremonial architecture.” The crescents are on elevated landforms near Chaco Canyon, adjacent to Chaco roads and associated with some outliers. There are no crescents documented along the Chuskan

slopes. Marshall and Sofaer occasionally observed turquoise fragments and ceramic artifacts in association with the crescents, and they ceramically dated the crescents to A.D. 950-1150. It is not immediately clear, however, how these features differ from those labeled “shrines” by Powers’ survey (Powers and Van Dyke 2015), or “J-shaped shrines” by Hayes and Windes (1975).

Stone Circles

Stone circles are almost always constructed on slickrock, on high points or benches above canyons, providing excellent vantage points. They consist of compound, core-and-veneer, or upright slab masonry. Stone circles range in size from 9 to 32 m (long axis) to 7 to 20 m (short axis). Most stone circles contain one or more circular or rectangular basins pecked or ground into the interior slickrock. Although associated ceramics are scarce, sandstone abraders are common. During the Chaco Project, Windes (1978) identified 16 stone circles on the north rim and four on the south mesas of Chaco Canyon. Windes and other researchers have located additional circles at outliers across the San Juan Basin, including Andrews, Kin Bineola, and Twin Angels (Marshall and Sofaer 1988; Van Dyke 2001; Windes 1978). Ancient builders seemed concerned with visibility when they positioned these enigmatic features. For example, from a stone circle on the north rim of Chaco Canyon (29SJ1572), a viewer sees Pueblo del Arroyo, South Gap, and Hosta Butte in perfect alignment along the trajectory of the South Road (Van Dyke 2007:Figure 6.6). Viewsheds from stone circles always include one or more great kivas, but the closest great houses are usually hidden beneath the canyon rim. If the circles were moved only a few meters, these dual attributes of visibility and invisibility would be lost. Windes (1978:68-69) suggests the

dual visible/invisible quality of circles might have made them ideal places for the manufacture of ritual items, or preparation for ceremonies.

Herraduras

Herraduras are horseshoe shaped structures defined by their association with Chacoan roads (Kincaid 1983:9–14; Lekson 1999:117–118; Marshall and Sofaer 1988; Nials et al. 1987). These features are found on major topographic breaks with good visibility. The horseshoe shaped, low walled masonry structures range from five to seven meters in diameter and usually open to the east.

Cairns

Cairns are found on high places across the San Juan Basin. For example, the Chacoans marked the southern and western tip of West Mesa with a dozen barrel-shaped cairns and a circular masonry enclosure (29SJ1088, hereafter Site 1088; first recorded in about 1901 by Wetherill and the Tozzer Expedition) (Windes 2015:692). From Site 1088, it is possible to see most of the western half of the San Juan Basin — a region that contained nearly 60 Classic Bonito phase outlier communities. If someone standing at Site 1088 can see most of the Chacoan world, it follows that many inhabitants living in outlier communities could also see West Mesa (and therefore Chaco). Navajo shepherds also built cairns; these are associated with Navajo homesteads. Many cairns lack associated artifacts or datable wood. Thus, archaeologists must

base temporal and cultural affiliation on masonry style, the presence of fill, or associations with nearby features. We do not include cairns that are clearly Navajo in this study.

Visibility Experiments and Anecdotal Observations

The Chaco Project conducted night-time line-of-sight verification with the use of highway flares between great houses, shrines, and some stone circles on August 13, 1975, August 17, 1977, and June 9, 1979 throughout Chaco Canyon and many outlying areas. These experiments established the connections throughout the canyon as described in Hayes and Windes (1975). They also established visual connections from Chaco Canyon to Kin Klizhin, the upper Kin Klizhin “tower” (LA 34205), Kin Ya’a, the Section 8 ruin at Dalton Pass (LA 17225), Standing Rock, Peach Springs, Coyote Canyon, the Yellow Point-Kin Bineola-Kin Klizhin shrine (LA 35417), Pierre’s, and the Chacra Mesa shrine (29Mc 186) connecting the East Community and Pueblo Pintado (see also Windes et al. 2000). The experimenters found that the two primary shrines linking many of the outlying areas are on West Mesa (29SJ 1088) and South Mesa (29SJ 2113). Field conditions prevented an experiment with Gray Hill Spring. In 2007, some 60 individuals conducted another test on the Chaco system using mirrors with Chimney Rock and Huerfano as main stations (Chimney Rock National Monument 2010).

Other researchers have also conducted signaling experiments in the Southwest. Florence and Andrea Ellis experimentally demonstrating intervisibility among towers in the Gallina area of northwest New Mexico (Ellis 1991). St. Ours (1985) documented a system of intervisible high places connecting sites in the northern San Juan Cajon Mesa area. The U.S. military has also been interested in signaling from high places in the Southwest. A communication system using

thirty heliograph stations on high peaks was employed by the U.S. Army across southern Arizona and New Mexico during the Apache Wars in the 1880s and 1890s (Basso 1971:314 fn 110; Rolak 2001).

Because high places are under active threat from developments across the San Juan Basin, some shrine locations are based on historic information. For example, the Aztec complex is visually linked to Huerfano Mesa (and thence to Pueblo Alto) by way of the Knickerbacker Peaks. Although any evidence of a shrine on the Knickerbacker summit has been destroyed by installation of communication towers, Hastings (1960:72) noted a shrine on Knickerbacker Peaks in the 1940s.

Technical Details of the GIS Analyses

All analyses were performed using open source tools—the GRASS GIS (version 7.0.1; GRASS 2015), GDAL (version 2.1.0, GDAL 2015), and R (version 3.2.0; R 2015) software suites. In R, we used the *FedData* (Bocinsky and Beaudette 2015), *sp* (Pebesma and Bivand 2005), *raster* (Hijmans 2015), *rgdal* (Bivand et al. 2015), *igraph* (Csardi and Nepusz 2006), and *rgrass7* (Bivand 2015) packages; in GRASS, we calculated viewsheds using the *r.viewshed* (Haverkort et al. 2009) function. We also relied heavily on the *GNU parallel* software package (Tange 2011) for accelerating analyses. All analyses detailed here were scripted to be reproducible, and scripts should have been included as a zipped archive with this document; if not, they are available from Kyle Bocinsky (bocinsky@wsu.edu), and are archived on tDAR.

Study Area

We chose a square study area that fully enclosed all the sites in our database, plus a small buffer. The study area is 400 km², and extends from 460000 m east to 860000 m east, and 3780000 m north to 4180000 m north in NAD 1983, UTM Zone 12 coordinates. The region contains a majority of the San Juan and Little Colorado river basins, and extends roughly from just east of the city of Flagstaff, Arizona to the Jemez Mountains in northern New Mexico, and from the Mogollon rim in the central Arizona to the Abajo Mountains in southern Utah. The study area includes prominent landforms such as the Chuska and Carrizo Mountains, Ute Mountain, Navajo Mountain, Shiprock, Monument Valley, Huerfano Mountain, Hosta Butte, Mount Taylor, Cedar Mesa, Black Mesa, and Mesa Verde.

We originally calculated viewsheds on a much larger area than reported here in order to include Wupatki (near modern-day Flagstaff, AZ). However, once we noted that Wupatki was a major spatial outlier among Chacoan great houses, and out of range any visual connections with other great houses, we reduced our study area substantially. Viewsheds for Wupatki are available from the corresponding authors.

Preparation of the Digital Elevation Model

This study uses a 50-meter digital elevation model (DEM) derived from the 1 arc-second (approximately 30 m) National Elevation Dataset, available from the USGS (Gesch et al. 2002, 2009). Fifty meter DEMs have become the *de facto* resolution for regional GIS visibility studies and represent a good balance between spatial definition and computational viability (cf. Lake et al. 1998; Lake and Ortega 2013; Llobera et al. 2010), although rapidly improving computational

power will undoubtedly drive regional visibility studies towards higher resolution DEMs in the future. In this study, we trade high-resolution for a very large study area; our study area encompasses 160,000 km², or 64 million 50 x 50 m pixels. Figures presented in this paper truncate the western part of the study area (including Wupatki), as visual connections did not extend that direction.

We prepared the DEM by re-projecting the NED from its native geographic (latitude/longitude) coordinate system to the UTM coordinate reference system (using the "projectRaster" function in the *raster* package for R), and resampling it at a 50-meter resolution using bilinear interpolation (via the "resample" function in *raster*). Finally, the resulting DEM was cropped to the study area using the "crop" function in *raster*.

Robust Viewshed Analysis

Viewshed analysis was performed using the *r.viewshed* tool in GRASS, using the parameters reported below. Viewsheds were calculated from the grid location (pixel) of each great house and shrine. Additionally, because many great houses are larger than the 50-meter resolution of our DEM, we calculated viewsheds from the eight pixels surrounding the primary coordinate of great houses (this is known as the "Moore neighborhood" of the primary pixel). The nine viewsheds—the primary pixel plus its eight neighbors—were then combined to generate a "robust" viewshed from each great house. In doing this, we hope to capture the *effective* viewshed from the great house, though we acknowledge the day-to-day range of great house occupants likely extended beyond the bounds of the building itself.

The *r.viewshed* function accepts many parameters, allowing the user to tune the analysis to their particular purpose. We calculated viewsheds from an observer height and target height of 5 m above the observer and target elevation on the DEM. Thus, we assume intentional signaling by individuals in elevated places such as a tower or roof of a great house, as opposed to a casual, ground-situated signaler or receiver. We calculated viewsheds for an infinite distance away from the observer, although by default the *r.viewshed* function corrects for the curvature of the Earth, which limited viewsheds at the horizon. We used the *r.viewshed* default refraction coefficient of 0.14286.

Cumulative Viewshed Analysis

Cumulative viewshed analysis (CVS; Wheatley 1995) is a way to assess covisibility shared between multiple places. We calculated cumulative viewsheds (1) for all great houses and (2) for all shrines in our database by summing each site's robust viewshed using the *gral_calc.py* python tool from GDAL, parallelized for rapid processing on multiple processing cores (Figure 5 in the main text). In the source code included in this supplemental information, the *calc.cvs.R* file details the function for calculating cumulative viewsheds.

Viewnet Analysis

A *viewnet* is a way of representing intervisibility—visibility between places—as a network. Nodes of the network represent sites or other important places (the locations in our site database), and an edge exists between two nodes if they are intervisible. Visibility in this case is

assumed to be reciprocal. Viewnets not only allow one to graphically represent intervisibility, but enable researchers to quantify characteristics of intervisibility in a system (through various network statistics) and estimate the significance or likelihood of a particular viewnet given a landscape (Swanson 2003).

To calculate the viewnet between all sites in our database, we wrote a function that builds an edge list between intervisible sites, and exports it as a network (graph) object using the *iGraph* library in R. In the source code included in this supplemental information, the *calc.viewnet.robust.R* file details the function for calculating viewnets from individual site viewsheds.

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