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Investigation of Solstice Horizon Interactions at Chacoan Monumental Architecture

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Abstract: Multiple monumental structures built during the ninth through the twelfth centuries CE at Chaco Canyon, NM, are in locations where solstice sunrise or sunset visually interacts with horizon foresights. We report on the results of field survey and photo-confirmation of seven solstice foresight interactions at Chacoan Great Houses. These include two 'Early Bonito phase' (850–1040 CE) sites. A June solstice sunset (JSSS) horizon foresight is visible from Pueblo Bonito, including early (ninth century) portions of the structure. December solstice sunrise (DSSR) interacts with a foresight visible from Hungo Pavi kiva A. We also confirm solstice horizon foresights at five additional 'Late Bonito phase' (1100–1140 CE) Great Houses. These include DSSR at Kin Sabe, DSSR at the Peñasco Blanco McElmo unit, DSSR at the proposed Chetro Ketl McElmo unit (west room block), December solstice sunset (DSSS) at Hillside Ruin, and June solstice sunrise (JSSR) at Rabbit Ruin. Hillside Ruin, the Chetro Ketl McElmo unit, and Rabbit Ruin also participate in inter-site alignments to the cardinal directions.

Integration of this data with previous temporal analyses further highlights contrasting cultural intent between periods. A minority of Early and Classic Bonito phase Great Houses (850–1100 CE) are known to have been built at solstice foresight observing locations. During the Late Bonito phase, ten of thirteen (77%) newly built Great Houses are at such locations. Six of thirteen (46%) participate in inter-site alignments to the cardinal directions. Three of thirteen (23%) participate in both the inter-site cardinal alignment and solstitial foresight traditions. This provides direct evidence of common social intent and the growing importance of solar events for Late Bonito phase people at Chaco. These structures may indicate an interest in theophanies, i.e., conjoining the sacred sun at solstice with the cardinal directions and prominent features of the sacred landscape. They bolster the argument for either centralized leadership by an astronomically adept Late Bonito elite, or a religious revival among the Chacoan people after the severe drought of the 1090s CE.

Under the terms of a U.S. National Park Service field research permit, some location-specific site data has been deliberately withheld in this document, as required by the U.S. Archaeological Resources Protection Act of 1979.

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Introduction

John Fritz[1] developed the first model for Chaco's ideological landscape. He suggested that fundamental relationships between individuals and the cosmos are encoded in architecture and the landscape, utilizing 'symbolic resonance' wherein experiences of a particular pattern at one scale can invoke experiences and meaning at other scales. Thus, the alignment of interior features of a kiva (i.e., round room, frequently identified as ritual space) to the cardinal directions of north and south is repeated both within Great Houses and on an inter-site scale. Within and beyond the canyon, further examples of intra-site and inter-site alignments to the cardinal directions have been proposed.[2]

Fieldwork conducted under National Park Service and BLM permits between 2008 and 2010 provided additional evidence that Chacoan Great Houses are not randomly oriented or placed. The majority of Great Houses conform to one or more of four traditions that are derivative of or dependant on observational astronomy. They are either: 1) front facing to the south-southeast (most to 151°–161°, a subset to 170°–172°), 2) front facing to the east-southeast (most to 113°–116°), 3) individually aligned and/or inter-site aligned to the cardinal directions, and/or 4) built at a location where solstice sunrise and/or sunset is observed to interact with a horizon foresight. Temporal analysis of how Great House building starts are associated with these four traditions provides new insights into shifts of cultural focus with respect to cosmology over time at Chaco.[3]

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[1] John, M. Fritz, 'Paleopsychology Today: Ideational Systems and Human Adaptation in Prehistory', in Charles L. Redman, ed., *Social Archaeology: Beyond Subsistence and Dating* (New York: Academic Press, 1978), pp. 37–59; John M. Fritz, 'Chaco Canyon and Vijayanagara: Proposing Spatial Meaning in Two Societies', in Donald W. Ingersoll, and Gordon Bronitsky, eds., *Mirror and Metaphor* (Lanham: University Press of America, 1987), pp. 314–49.

[2] Stephen H. Lekson, *The Chaco Meridian: Centers of Political Power in the Ancient Southwest* (Walnut Creek, CA: Alta Mira Press, 1999); Anna Sofaer, *Chaco Astronomy, An Ancient American Cosmology* (Santa Fe: Ocean Tree Books, 2008); Ray A. Williamson, *Living in the Sky: The Cosmos of the American Indian* (Norman: University of Oklahoma Press, 1984), pp. 132–40.

[3] Andrew M. Munro and J. McKim Malville, 'Ancestors and the Sun: Astronomy, Architecture and Culture at Chaco Canyon', in Clive Ruggles, ed., *Archaeoastronomy and Ethnoastronomy: Building Bridges between Cultures,* (Cambridge: Cambridge University Press, 2011), pp. 255–65; Andrew M. Munro, 'The Astronomical Context of the Archaeology and Architecture of the Chacoan Culture' (PhD Thesis, James Cook University, 2012); J. McKim Malville and

To further test the identified pattern of astronomical associations with monumental architecture at Chaco, one previously published solstitial association required validation, and untested Late Bonito phase Great Houses documented at Chaco needed to be assessed.[4] This work was conducted under National Park Service permits during 2014 and 2015. During this study, we serendipitously identified an additional solstitial horizon foresight visible from Pueblo Bonito, validated William Calvin's published solstice horizon foresight at Hungo Pavi,[5] and assessed five additional Late Bonito or 'McElmo' phase sites. Each of the five was evaluated using published and archival material to assess their likely association to the Late Bonito period and tested for solstitial horizons. They include Kin Sabe, the Peñasco Blanco McElmo unit, a potential Chetro Ketl McElmo unit, Hillside Ruin, and Rabbit Ruin. We believe that the cumulative set of surveys conducted since 2008 now includes all Late Bonito Great Houses identified or proposed within the canyon.

The Late Bonito or 'McElmo' phase was defined by Vivian and Mathews and initially dated to approximately 1050 to 1124 CE. This determination was based on the presence of significant amounts of McElmo black-on-white pottery and architecture described as a compact, multi-story plan with kivas enclosed in house blocks. The masonry is cored, sometimes banded, but typically composed of large blocks of pecked and 'dimpled' sandstone with chinking between stones, which stands in contrast to the smaller tabular sandstone wall veneers in earlier Chacoan Great Houses. Kin Kletso was considered a typical example of a Late Bonito site with this type of construction and pottery.[6]

Later re-evaluation of this definition by Lekson refined the dating of these structures to the period 1100–1140 CE, and offered a suggested function of the buildings. His analysis of five sites from this period included

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Andrew M. Munro, 'Houses of the Sun and the Collapse of the Chacoan Culture', in Fabio Silva, Kim Malville, Tore Lomsdalen and Frank Ventura, eds., *The Materiality of the Sky, Proceedings of the 22nd Annual SEAC Conference* (Ceredigion: Sophia Centre Press, 2016), pp. 245–53.

[4] Munro, 'The Astronomical Context of the Archaeology and Architecture of the Chacoan Culture', pp. 227–29.

[5] William H. Calvin, *How the Shaman Stole the Moon* (New York: Bantam, 1991), pp. 125–38.

[6] Gordon Vivian and Tom W. Mathews, *Kin Kletso: A Pueblo III Community in Chaco Canyon, New Mexico* (Globe, AZ: Southwest Parks and Monuments Association, Technical Series 6(1), 1965), pp. 109–10.

Tsin Kletsin, Wijiji, Kin Kletso, Casa Chiquita, and New Alto. Lekson suggested that these sites are often associated with roads and probably functioned as storage facilities.[7] Van Dyke has contested this idea.[8]

It is notable that the majority of the Late Bonito phase Great Houses previously tested are located at workable observation points for horizon foresights that mark solstice sunrises or sunsets. These include Wijiji and Kin Kletso,[9] as well as Casa Chiquita, Headquarters Site A, and Bis sa'ani. In addition, while Robert's Small Pueblo does not mark an observation point for such a horizon marker, it is 125 m from the workable DSSR observation site at 29SJ 2538/2539.[10] The only two previously tested Late Bonito phase Great Houses that have no demonstrated solstitial associations (New Alto and Tsin Kletsin) are both involved in inter-site alignments to the cardinal directions.[11]

Field Survey Methods

The field survey methods used for this study were consistent with those applied in Munro and Malville's previously reported work at Chaco. A Suunto Tandem magnetic compass and clinometer were used for preliminary measurements to identify features as potentially worthy of accurate survey. Measurement of inter-site azimuths and horizon features was performed using a Wild T-2 theodolite and a GPS receiver. All surveys were conducted in relation to observable surface features, and (for the unexcavated Chetro Ketl and reduced Kin Sabe sites) unmarked but well-documented surface locations.

Survey of inter-site alignment azimuths and horizon features was a primary objective. When measuring inter-site alignments or points to determine azimuths to potential horizon foresights, both the horizon altitude

[7] Stephen H. Lekson, *Great Pueblo Architecture of Chaco Canyon, New Mexico* (Albuquerque: University of New Mexico Press, 1984), pp. 224–56, 267–69.

[8] Ruth M. Van Dyke, 'Memory, Meaning, and Masonry: The Late Bonito Chacoan Landscape', *American Antiquity* 69 (2004), pp. 413–31; Ruth M. Van Dyke, *The Chaco Experience, Landscape and Ideology at the Center Place* (Santa Fe: School for Advanced Research Press, 2008).

[9] J. McKim Malville, *A Guide to Prehistoric Astronomy in the Southwest,* revised ed., (Boulder: Johnson Books, 2008), pp. 70–74.

[10] Munro and Malville, 'Ancestors and the Sun', pp. 255–65.

[11] Fritz, 'Paleopsychology Today'; Sofaer, *Chaco Astronomy, An Ancient American Cosmology*, pp. 95–98.

and azimuth were recorded for each point. In addition, each point was measured and recorded four times to enable calculation of standard error.

To establish the orientation of the reference line relative to true north, we obtained sequences of at least four measurements of the azimuth and altitude of the sun ('sun sights'), timed by the GPS receiver and/or reference to NIST time standard station WWV. The altitude measurements provide an additional check on the field measurements. Standard surveying procedures are followed by setting up back sights to be used as reference points at the start and completion of the sun sights.

Confirmatory photography was conducted for any solar horizon foresights identified for solstices. Photographic confirmation was routinely performed using the method suggested by professional photographer Patrick René; a standard #11 Welder's Shade and exposure bracketing to obtain clear definition of the solar disk against the horizon.[12]

Pueblo Bonito (860–925 CE)

Pueblo Bonito is the largest and best studied monumental structure at Chaco Canyon. It was one of the earliest Great Houses at Chaco, and it expanded and gradually reoriented over centuries.[13] Pueblo Bonito has a well-documented JSSR horizon foresight identified by Zeilik in the 1980s.[14] Based on the survey results from Kin Sabe (see below), a prominent mesa top feature on the western horizon had been identified by our field team as a possible foresight for JSSS from some location in the vicinity. Just prior to sunset on 20 June 2015 three team members observed the sunset from a public trail and parking area adjacent to Pueblo del Arroyo. The team wished to determine whether the horizon feature might operate as a JSSS foresight as observed from one of the Great Houses in the 'downtown Chaco' area. Based on visual observations of shadow

[12] Andrew M. Munro and J. McKim Malville, 'Archaeoastronomy in the Field: Methodologies Applied in Chaco Canyon', *Journal of Cosmology* 9 (2010): pp. 2147–59, at http://journalofcosmology.com/AncientAstronomy115.html [accessed 1 Aug. 2010]; Munro, 'The Astronomical Context of the Archaeology and Architecture of the Chacoan Culture', pp. 96–114.

[13] John R. Stein, Dabney Ford, and Richard Friedman, 'Reconstructing Pueblo Bonito', in Jill E. Neitzel, ed., *Pueblo Bonito: Center of the Chacoan World* (Washington, DC: Smithsonian Institution, 2003), pp. 33–60.

[14] Michael Zeilik, 'Keeping a Seasonal Calendar at Pueblo Bonito', *Archaeo-astronomy; Supplement to the Journal for the History of Astronomy* 9 (1986) p. 79.

casting, the team determined that JSSS should be observable using this foresight from Pueblo Bonito.

On 21 June 2015 the team visually observed and photographically confirmed that a workable JSSS visual alignment exists to this foresight as viewed from the west wall of Pueblo Bonito. The foresight alignment is fully functional as viewed from the northwest section of that wall, which corresponds to the first phase of construction for the structure, dating to the late ninth or early tenth century CE.

Hungo Pavi (990–1010 CE)

William Calvin described a series of compass surveys he conducted from post-Chacoan Pueblo 'Anasazi' cliff structures inset into cliff alcoves or caves. Based on compass surveys, he proposed that kivas within ancestral Pueblo cliff dwellings at sites well to the north of Chaco, including Split-Level ruin, Perfect Kiva, and Betatakin, may have been sited to take advantage of alcove corners as sunrise or sunset foresights for December solstice. While he recognized that no convincing statistical case could be made for single foresight alignments in individual kivas, Calvin did suggest that a more convincing case could be made by identifying a pattern among a set of kivas. With these ideas in mind, his compass surveys among the structures at Chaco led him to propose a pair of solstitial horizon foresights visible from one of the kivas in the Great House of Hungo Pavi. He first describes the use of a foresight to the southeast; a, 'distant cliff rose up like a headland, forming a distinct step from the distant canyon floor'. Calvin noted that his proposed Hungo Pavi foresight works to 'corner' the sun. As it rose, it was 'cornered' in the frame established by the headland with the sun's disk intersecting both the horizontal horizon and the left side of the stepped foresight. Based upon a topographic analysis, Calvin went on to propose that the multi-story tower kiva of Tsin Kletsin Great House on South Mesa could have operated as a DSSS foresight as observed from Hungo Pavi.[15]

On 27 October 2014, our team conducted horizon theodolite surveys from the kiva depression in the west end of the plaza at Hungo Pavi, as well as from 'kiva A' of the structure. These locations were chosen to correspond to an unspecified observing location within a Hungo Pavi kiva provided by Calvin for his reported DSSR observation. Based on analysis of the survey

[15] Calvin, *How the Shaman Stole the Moon*.

results, we predicted that a prominent mesa edge would operate as a DSSR foresight from kiva A, in keeping with Calvin's reported alignment.

On 21 December 2014, team members observed and photographically confirmed the sunrise from Hungo Pavi kiva A. The DSSR alignment is not visible from the entire building due to parallax and the distance to the foresight; kiva A may have been specifically sited to be associated with this visual solstitial alignment.

Kin Sabe (est. 1100–1130 CE)

Because of its location on the south side of the Chaco Wash across from Pueblo del Arroyo, Kin Sabe has been subject to considerable erosion since it was first mentioned in 1877 by W. H. Jackson. Today, Kin Sabe is almost entirely reduced by a combination of erosion and materials salvage during the 1970s.

Because of its precarious position at the edge of the Chaco Wash, Kin Sabe did receive attention from archaeologists participating in major projects in the canyon for more than a century, including Pepper, Postlethwaite, and Hayes.[16] Nonetheless, the site is seldom mentioned in recently published literature. A hand drawn sketch map by Nels Nelson and photographs from the 1920 excavations under the direction of Edgar L. Hewett of the School of American Research/Museum of New Mexico provide our best evidence for this structure. Nelson's 1916 site plan shows three rows that are six rooms long and a kiva along the east side. The Chaco Research Archive has web-published some forty nine photographs associated with the site from multiple late nineteenth and early twentieth century expeditions. Judd visited the site in August 1920. During the evening of 12 August, two front walls collapsed. As documented by photographs on file at the Palace of the Governors Photo Archive, sometime after 12 August 1920 Hewett's excavation team uncovered at least six rooms. These figures and other photographs in this collection show before, during, and after views, as well as two masonry walls, each exhibiting late masonry types. These photographs from the 1920 excavation indicate that placement in the Late Bonito phase is reasonable based on both architectural form and masonry style. The photos depict a structure entirely consistent with Late Bonito 'McElmo unit' construction.

[16] Alden Hayes and Charles Harding III, *Excavation of Bc 51 [Kin Sabe or Bc 263]* (Chaco Culture NHP Museum Collection, Archive 86089/VA2103B, 1937).

The exact alignment of the site is difficult to assess, but its location is well documented in the archival material.[17]

On 31 October 2014, our team conducted a horizon theodolite survey at the now-reduced Kin Sabe Great House. The survey was conducted with the instrument placed at a documented Park Service site survey pin 3 m west of the wash's rim. It is notable that a small volume of residual large-block masonry is now exposed at the edge of the wash in this location, directly above a deposit of black-on-white potsherds that have apparently been deposited through ongoing erosion. Based on archived site data, including Judd's photographs and aerial imagery, we infer that this location was 3 m to 5 m directly west of the northwest corner of Kin Sabe prior to its reduction.

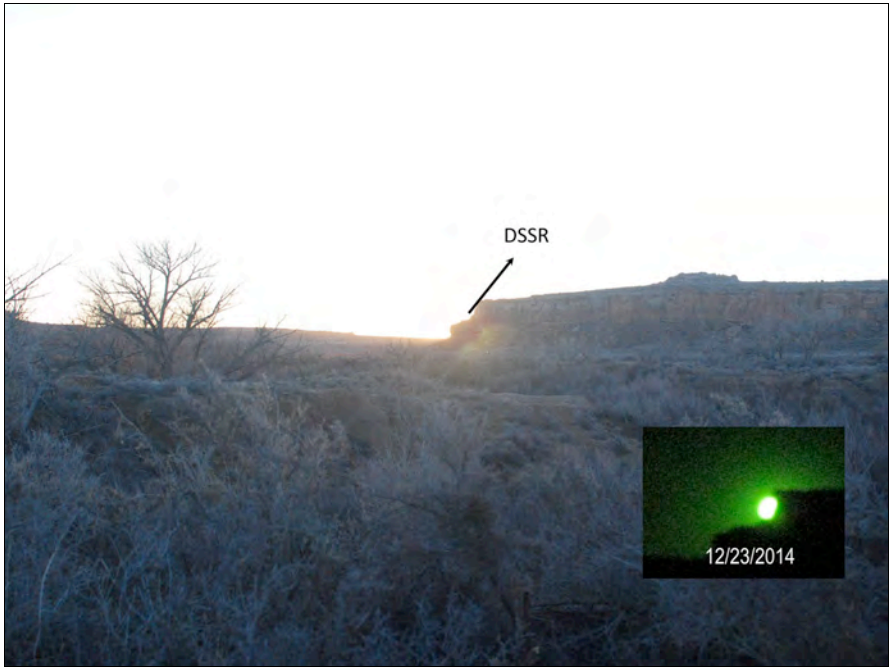

Fig. 1. Horizon foresight visible from the location of Kin Sabe, with confirmatory filtered DSSR photograph inset.

[17] Neil M. Judd, 'The Passing of a Small PIII Ruin', *Plateau* 39, no. 3 (1967): pp. 131–33; The Chaco Research Archive, 'Kin Sabe' at http://www.chacoarchive.org/cra/chaco-sites/kin-sabe/ [accessed 20 Oct. 2016].

Based on analysis of the survey results, we predicted that a prominent mesa edge would operate as a DSSR foresight. On 20, 21, and 22 December 2014 team members attempted to collect photographic data to confirm this prediction, but obscuring clouds were present. On 23 December 2014, team members returned and successfully captured the sunrise photographically. Fig. 1 presents a photograph of the horizon as seen from the theodolite's position. The inset, filtered image provides confirmation of the observable DSSR event.

Peñasco Blanco McElmo Unit (est. 1100–1140 CE)

The McElmo room block at Peñasco Blanco is dated to the Late Bonito phase based on its architectural form and masonry style by Lekson. He noted that this building is placed at the top of a manmade terrace, and that, 'If, as seems likely, the terrace was prepared for the McElmo Ruin, this constitutes a great deal of site preparation for a rather small building'.[18]

On 29 October 2014, we conducted a horizon theodolite survey from the west end of this McElmo Unit. The theodolite was positioned at the centre of the standing west wall section. Based on analysis of the survey results we determined that a pair of small but prominent points on an otherwise flat horizon section should interact with the rising December Solstice sun. On 22 December 2014, the team observed the sunrise at the Peñasco Blanco McElmo Unit. However, unfiltered photography yielded overexposed images, and the filtered images did not clearly demonstrate the sun's position with respect to the foresights. On 24 December 2014, we returned and successfully captured the sunrise photographically. Fig. 2 presents an unfiltered photograph of DSSR as the Sun first broke the horizon centred between the two foresights on the horizon.

Each of the two foresights is approximately one solar disk from the Sun as it first breaks the horizon; visually the Sun bisects the space between them. To our knowledge this dual-foresight bracketing approach is unique in the literature. Absent the previously identified pattern of solstice sunrise and sunset associations with Late Bonito McElmo Units, we might hesitate to propose this as an operating DSSR foresight. Notwithstanding, this bracketing marker is less subtle than some of the horizon markers documented by McCluskey among Hopi Sun watchers at Walpi and

[18] Lekson, *Great Pueblo Architecture of Chaco Canyon, New Mexico*, pp. 94–109.

Shungopavi.[19] It is certainly functional and visually repeatable. It will be useful to determine if this type of foresight is present at additional Great Houses as they are surveyed in the future. If such foresights are identified at additional ancestral Puebloan sites, that will increase the degree to which this proposed foresight is convincing.

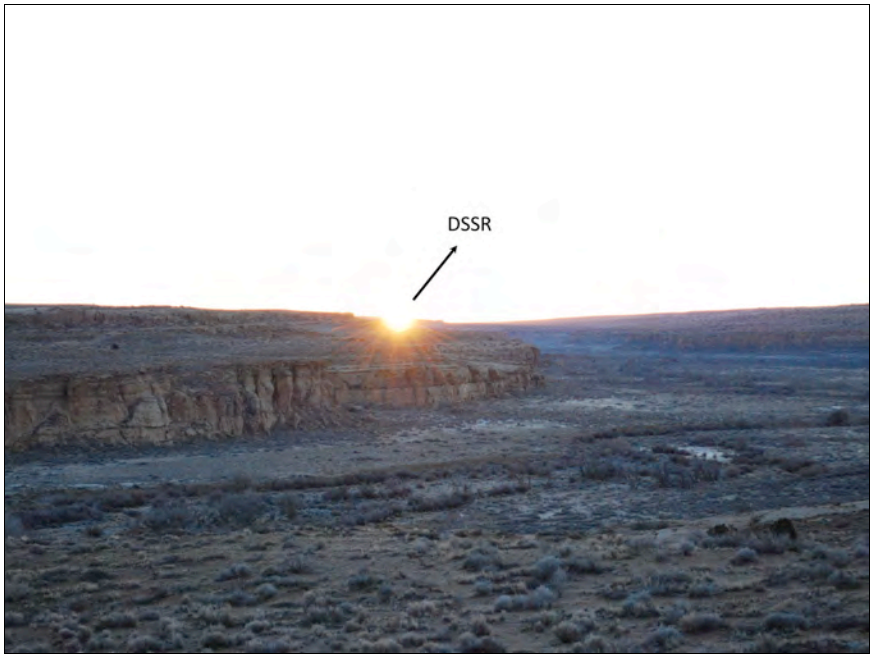

Fig. 2. Paired horizon foresights visible from the Peñasco Blanco McElmo unit bracket the unfiltered image of DSSR first light. Photo by Cherilynn Morrow, used with permission.

Proposed west room block at Chetro Ketl (est. 1100–1140 CE)

Excavations at Chetro Ketl were carried out under the direction of Edgar L. Hewett, initially in 1920–21 and again from 1929–37, the latter as part of the University of New Mexico field school. Paul Reiter, one of Hewett's field school students, prepared a plan view of this Great House that

[19] McCluskey, Stephen C., 'The Astronomy of the Hopi Indians', *The Journal for the History of Astronomy* 8 (1977): pp. 174–95.

includes the west building. Another student, Robert Coffin, created an interpretation of this site that Hewett would use in later publications.[20]

Because the west building/McElmo component at Chetro Ketl has not been excavated, dating for this component is by inference. Based on the original definition of ceramics found at Kin Kletso and comparison with those recovered from a 1920 sample from Chetro Ketl, Vivian and Mathews concluded a McElmo structural component was present. In his examination of the architecture of Great Houses in the canyon, Lekson states the ground plan for the construction phase dating to 1115–1140 CE includes the room block west of the site. A review of information that led to these conclusions follows.

The pottery assemblage for the McElmo period was defined as consisting of Escavada black-on-white, Gallup black-on-white, Chaco black-on-white (all mineral based painted ceramics), and McElmo black-on-white (a carbon based paint). Vivian and Mathews thought these types co-existed from 1025 to 1175 CE.[21] They proposed that:

> McElmo black-on-white as such, or as proto-Mesa Verde, has not previously been reported from this site [Chetro Ketl] (Hawley 1934). This appears to have been an oversight. Through the kindness of the late Stanley Stubbs we were able to examine 1,099 still unwashed sherds from Hewett's 1920 excavations in two locations in Chetro Ketl. This is an admittedly small sample from the tens of thousands of sherds that must have been taken from the work there.[22]

The sherds were from Kiva II (Layer 4 and to 3 feet from floor) and Room 2 of the main structure. Kiva II and Room 2 are part of later additions to Chetro Ketl. In all three samples, McElmo black-on-white was the dominant type, with Chaco black-on-white, Escavada black-on-white, and Gallup black-on-white present in slightly lesser proportions. Vivian and Mathews thought these data established the presence of McElmo black-on-white in at least some proveniences of Chetro Ketl in

[20] Edgar L. Hewett, *The Chaco Canyon and Its Monuments* (Albuquerque: University of New Mexico and School of American Research, 1936); Paul Reiter, 'The Ancient Pueblo of Chetro Ketl' (MA Thesis, University of New Mexico, 1933).
[21] Vivian and Mathews, *Kin Kletso*, p. 75; Lekson, *Great Pueblo Architecture of Chaco Canyon, New Mexico*, pp. 152–92.
[22] Vivian and Mathews, *Kin Kletso*, p. 77.

approximately the same proportions as in other contemporaneous Chaco Great Houses.[23]

Research by the National Park Service Chaco Project updates these statements. In his discussion of the architecture of the Great Houses, Lekson summarized the different forms of building construction through time. Between 1075 and 1115 CE the most massive construction phase included two sites, Pueblo del Arroyo and Wijiji, which predate the McElmo style ground plan that includes smaller rooms surrounding a circular structure/kiva. Lekson includes one of these structures outside the west wall of Chetro Ketl which he dates to the latter period, 1115–1140 CE.[24] Lekson indicates:

> The first major twelfth century building in the central canyon was the Kiva G complex at Chetro Ketl (Chetro Ketl XIIA, 1110–1115). This unit is constructed almost entirely of pecked massive sandstone, in a 'McElmo' style that would easily be lost at Kin Kletso, the 'McElmo' phase type site.[25]

In his presentation of the individual stages of construction at Chetro Ketl, Lekson does not elaborate on the subdivisions for Stage XII (dated 1090–1095 CE). However, he does discuss stage XIIIA (1095–1105 CE) and indicates Kivas G-1 and G-2 fell in this period. The Late Bonito or McElmo phase, thus, falls later than Vivian and Mathews suggested.

The question remains whether or not we can date the structure west of Chetro Ketl to the Late Bonito period. On his map of Chetro Ketl (his Figure 4.39) Lekson includes the unexcavated block located west of the main pueblo. It shows a circular structure within a rectangle, somewhat similar in form to the Kiva G complex (his Figure 4.41 a). In his discussion of the McElmo period, Lekson includes, 'the small room block appended to the west wing', as consistent in ground plan with, 'construction of a number of separate buildings, characterized by many small interior rooms and comparatively few round rooms', that are dated between 1115 and 1140 CE.[26]

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[23] Vivian and Mathews, *Kin Kletso*, p. 79.
[24] Lekson, *Great Pueblo Architecture of Chaco Canyon, New Mexico*, pp. 66–73.
[25] Lekson, *Great Pueblo Architecture of Chaco Canyon, New Mexico*, p. 72.
[26] Stephen H. Lekson, *The Architecture and Dendrochronology of Chetro Ketl, Chaco Canyon, New Mexico. Reports of the Chaco Center, No. 6* (Albuquerque: Division of Cultural Research, National Park Service, 1983); Lekson, *Great Pueblo Architecture of Chaco Canyon, New Mexico*, pp. 153, 156, 263, 268.

In summary, this unexcavated building is plausibly assigned to the Late Bonito phase based on its rectilinear form, single kiva depression, and pottery types. With regard to the orientation of the building, there is some room for discussion. Because the room block has not been excavated, archaeologists can easily interpret piles of rock coming from walls at slightly different orientations. Considering that maps by Paul Reiter, Reginald Fisher, and Stephen Lekson were made at different times and under different field circumstances, this is not surprising. A photogrammetric map of the Chetro Ketl community was published by Drager and Lyons. Although the McElmo rectangular feature just west of the west wall of Chetro Ketl near the current visitor trail is small, the illustration was enlarged for analysis. Because the map has been rectified, it shows the most accurate placement and alignment of this component, and thus, we used it and Lekson's derived map to locate the structure.[27]

On 28 October 2014, our team conducted horizon theodolite survey from the proposed McElmo room block adjacent to the southwest corner of Chetro Ketl. The theodolite survey was conducted with the instrument placed at the westernmost end of the crest of a berm (likely a reduced wall), just south of the public trail that traverses the unexcavated structure. The specific location was identified based on surface features to be the east end of the southern wall of the proposed structure.

Based on analysis of the survey results, we predicted that a prominence on a stepped horizon section would operate as a DSSR foresight.

On 20 December 2014, our team collected photographic data in an effort to confirm this prediction. Fig. 3 presents a photograph of the horizon as seen from the theodolite's position. The inset filtered image provides confirmation of the observable DSSR event. Of note, the foresight is the same topographic feature that operates as the right side foresight for the 'bracketing' DSSR alignment at the Peñasco Blanco McElmo unit. While the inset image is adequate to confirm the alignment, the image quality is poor due to cloudy conditions. The solstice event is visible from the entire footprint of the structure.

[27] Dwight L. Drager and Thomas R. Lyons, *Remote Sensing. Photogrammetry in Archeology: The Chaco Mapping Project. Supplement No. 10 to Remote Sensing: A Handbook for Archaeologists and Cultural Resources Managers* (Albuquerque: Branch of Remote Sensing, National Park Service, 1985).

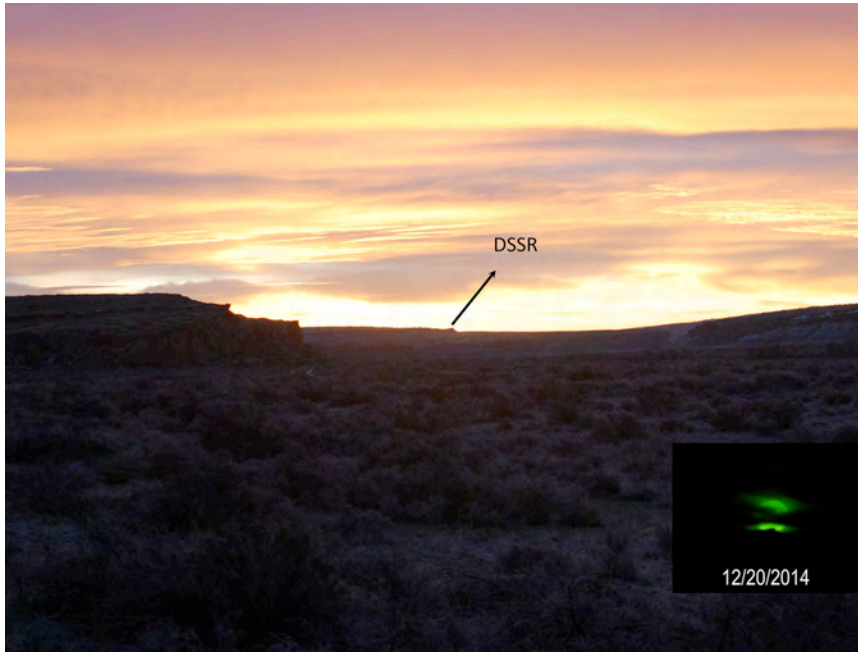

Fig. 3. Horizon foresight visible from the Chetro Ketl McElmo unit with confirmatory filtered DSSR photograph inset. Photos by Julia Munro, used with permission.

Hillside Ruin, 29SJ1175 (est. 1100–1140 CE)

What was known about Hillside Ruin prior to the NPS Chaco Project is reported by Judd, who provided a plan view that shows the southern and western walls and the kiva that was excavated. Masonry exposed in three trenches at the west end of the site was not the typical Bonito style; it rested on an adobe foundation that covered some units of the northeast foundation complex. Surface sherds, though few in number, were considered proto-Mesa Verde. Judd considered Hillside Ruin to be later than Pueblo Bonito and its unfinished northeast complex. Judd's photograph, Plate 47, clearly illustrates typical McElmo style masonry; Plate 45 indicates the location of three tests at the west side of the ruin.[28]

During his survey of this ruin for the NPS Chaco Project, Windes suggested Hillside was probably a two-story pueblo, mostly located at the

[28] Neil M. Judd, *The Architecture of Pueblo Bonito* (Washington, DC: Smithsonian Institution, 1964), pp. 146–53.

base of talus on bottom land, with the room block oriented east-west. It was probably two rooms deep. Windes suggests Hillside Ruin included twenty to thirty rooms, kivas, courtyards, and perhaps platforms and ramps.[29]

Windes' interpretation has not been unchallenged. A study by Stein and his colleagues consider this complex as part of a set of platforms that are part of a final component at Pueblo Bonito. They presented a plan view and perspective indicating how this late period (1115–1215 CE) may have been integrated with earlier construction at Pueblo Bonito. Roads and ramps are an important factor in their interpretative view.[30]

No matter which interpretation of Hillside Ruin is accepted, all investigators assign this site to the Late Bonito phase based on the masonry style pictured in Judd's photographs.

The potential for a DSSS foresight interaction from the vicinity of Hillside was identified by two of our team members while observing DSSS in 2014 on public trails in the area. On 20 December 2015 our team conducted horizon theodolite survey from Hillside. The theodolite survey was conducted with the instrument placed at the southeast extreme of the large kiva depression at the east end of the site.

Based on analysis of the survey results we subsequently confirmed that a prominent mesa edge on the horizon would operate as a DSSS foresight. Using GIS analysis, we also confirmed that Hillside Ruin lies directly on the north-south inter-site alignment to the cardinal directions between Casa Rinconada and New Alto identified by Sofaer.[31] Furthermore, it is possible to establish a cardinal east-west line from Pueblo Bonito, thorough Hillside and the Chetro Ketl McElmo Unit, to the front wall of Chetro Ketl itself. Thus, both Hillside and the Chetro Ketl McElmo unit lie on the cardinal east-west line between Pueblo Bonito and Chetro Ketl identified by Fritz.[32]

On 20 December 2015, our team also collected photographic data from both the east and west ends of Hillside Ruin. Fig. 4 presents a photograph of the horizon profile as seen from the theodolite's position. The inset,

[29] Thomas C. Windes, 'This Old House: Construction and Abandonment at Pueblo Bonito', in Jill E. Neitzel, ed., *Pueblo Bonito: Center of the Chacoan World* (Washington, DC: Smithsonian Institution, 2003), pp. 14–32.
[30] Stein, Ford, and Friedman, 'Reconstructing Pueblo Bonito', pp. 33–60; John R. Stein, Richard Friedman, Taft Blackhorse, and Richard Loose 'Revisiting Downtown Chaco', in Stephen H. Lekson, ed., *The Architecture of Chaco Canyon, New Mexico* (Salt Lake City: University of Utah Press, 2007), pp. 199–223.
[31] Sofaer, *Chaco Astronomy, An Ancient American Cosmology*, pp. 95–97.
[32] Fritz, 'Paleopsychology Today'.

filtered image provides confirmation of the DSSS event. The interaction is visible throughout the building's entire footprint.

Fig. 4. Horizon foresight visible from Hillside Ruin with confirmatory filtered DSSS photograph inset.

Rabbit Ruin, 29SJ390 (est. 1100–1140 CE)

Located north of Pueblo Alto, Rabbit Ruin is one of several larger houses in the Pueblo Alto Community. No excavations have been carried out at the site, but wall clearing was included as part of the NPS Chaco Project investigation at the Pueblo Alto Community. Dated to 1100–1140 CE, the site has approximately forty-one rooms and five kivas. It is located near road segment 43, which runs northwest from Pueblo Alto, passing Rabbit Ruin, and on to seeps on the east side of Clys Canyon. This road probably continues from the opposite side of the wash across North Mesa to Peñasco Blanco. Windes dated use of this road segment to 1050–1100 CE.

The configuration of the three sections of Rabbit Ruin, with two separate room blocks and part of a third, is typical of the McElmo pattern of rooms enclosing a kiva(s). Masonry was composed of rectangular blocks of dimpled sandstone in the typical McElmo style. In the

easternmost mound, one tree-ring date is available and it indicates that construction of Kiva 3 occurred sometime after 1088 CE. The few ceramics found suggest an early 1100s CE construction. The small rooms were suggestive of a habitation site rather than a storage facility.[33]

Lekson includes Rabbit Ruin in the Late Bonito phase that he dates to 1115–1140 CE. He bases his decision on the masonry style exposed during the wall clearing and stabilization project at this site.[34]

On 30 October 2014, our team conducted horizon theodolite survey from the west kiva of the east room block ('kiva 3') at Rabbit Ruin. The theodolite survey was conducted with the instrument placed at the north side of kiva 3. The survey included the eastern and southern horizon, which incorporate views of both Pueblo Alto and New Alto.

Based on analysis of the survey results, we predicted that a visible mesa edge on a mostly flat horizon section would operate as a JSSR foresight. By combining the survey results with GIS analysis, we also confirmed that the east wall of Rabbit Ruin lies due north of the west wall of Pueblo Alto and is therefore integrated into the emblematic north-south inter-site alignment to the cardinal directions between Tsin Kletsin and Pueblo Alto, first identified by Fritz.[35]

On 19 June 2015, our team collected photographic data in an effort to confirm the JSSR prediction. Smoky haze due to forest fires west of our location rendered filtered images useless. On 20 June 2015, we collected additional photographic data in an effort to confirm the prediction. On this date, the haze provided enough natural attenuation to enable collection of unfiltered images that clearly show a defined solar disk against the horizon feature. Confirmatory photographic images were obtained; the interaction is visible throughout the building's entire footprint.

Summary and Interpretation: Patterns in Time

The following positive fieldwork results were obtained at Chaco Canyon during this study. We determined that a JSSS horizon marker is observable from the west wall of Pueblo Bonito. The previously published DSSR alignment to a horizon foresight from Hungo Pavi is confirmed and

[33] Thomas C. Windes, *Investigations at the Pueblo Alto Complex, Chaco Canyon, New Mexico, 1975–1979. Volume I: Summary of Tests and Excavations at the Pueblo Alto Community* (Santa Fe: National Park Service, Publications in Archeology 18F, Chaco Canyon Studies, 1987), pp. 77–79, 94, 133.
[34] Lekson, *Great Pueblo Architecture of Chaco Canyon, New Mexico*, p. 72.
[35] Fritz, 'Paleopsychology Today'.

operates from kiva A. A DSSR horizon foresight interaction was observable from Kin Sabe. A pair of horizon foresights bracket DSSR as observed from the McElmo unit northeast of Peñasco Blanco. A DSSR horizon foresight interaction is observable from the proposed unexcavated McElmo unit immediately west of Chetro Ketl. A DSSR horizon foresight interaction is observable from Hillside Ruin, and a JSSR horizon foresight interaction is observable on the nearly-flat horizon from Rabbit Ruin. Three of the studied structures also participate in inter-site alignments to the cardinal directions including Rabbit Ruin, Hillside Ruin, and the Chetro Ketl McElmo room block.

Previous work has demonstrated that Chacoan Great Houses and Great Kivas are not randomly oriented or placed. The overwhelming majority of studied monumental structures at Chaco conform to one or more of four traditions that are derivative of observational astronomy. They are either: 1) front facing to the south-southeast ('SSE', most to 151°–161°, a subset to 170°–172°), 2) front facing to the east-southeast ('ESE', most to 113°–116°), 3) individually aligned and/or inter-site aligned to the cardinal directions, and/or 4) built at a location that enables visual observation of an interaction between the Sun's disk and a horizon foresight during a solstice sunrise or sunset.[36]

Fig. 5 presents a histogram of Chacoan architectural associations with these four traditions. If we are correct in inferring Late Bonito phase construction dates for Kin Sabe, Rabbit Ruin, the McElmo room block at Peñasco Blanco, and the potential McElmo Unit at Chetro Ketl, we now see that ten new monumental structures were built at Chaco during this period that have horizon foresights for solstice sunrises or sunsets. As shown, the previously discussed four-tradition pattern is significantly strengthened by the newly acquired data, including reinforcement of the remarkable association of Late Bonito monumental architecture with solstices and inter-site alignments to the cardinal directions.

[36] J. McKim Malville and Andrew M. Munro, 'Cultural Identity, Continuity, and Astronomy in Chaco Canyon', *Archaeoastronomy: The Journal of Astronomy in Culture* 23 (2010): pp. 62–81; Munro, 'The Astronomical Context of the Archaeology and Architecture of the Chacoan Culture'; Andrew M. Munro and J. McKim Malville, 'Change and Continuity in the Architecture and Cosmology of Chaco Canyon', paper presented at the 2014 Theoretical Archaeology Group (TAG) conference in Manchester, UK; Malville and Munro, 'Houses of the Sun and the Collapse of the Chacoan Culture'.

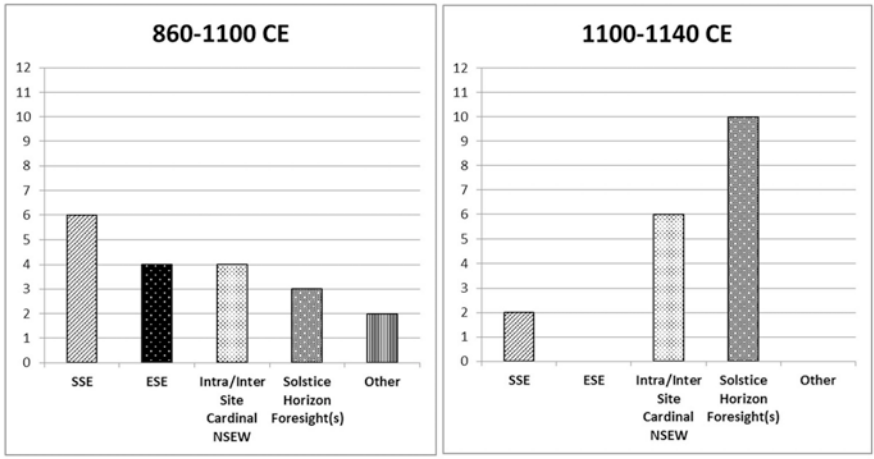

Fig. 5. Cumulative associations of Chacoan monumental building starts and major reorientations with four traditions.

The figure includes a cumulative count of associations with the traditions; for example, Pueblo Bonito is counted once for its SSE orientation, once for its solstice horizon foresights, and once for its reorientation to the cardinal directions. It should be noted that for the period 860–1100 CE, a total of four likely monumental Chacoan structures with solstice horizon foresights have been identified. They include Pueblo Bonito and Hungo Pavi (discussed in this study), as well Casa del Rio[37] and the Great Kiva at Marcia's Rincon.[38] Because it has not yet been possible to photographically confirm the proposed solstitial alignment at Casa del Rio, it is not included in the histogram.

The consistent associations of Late Bonito phase architecture with solstice observation locations and inter-site alignments to the cardinal directions are very provocative. These findings provide direct support for the idea that central planning occurred at Chaco during the Late Bonito phase, and Late Bonito Great Houses were constructed as monumental

[37] Andrew M. Munro and J. McKim Malville, 'Calendrical Stations in Chaco Canyon', *Archaeoastronomy: The Journal of Astronomy in Culture* 23 (2010): pp. 91–106.

[38] J. McKim Malville, 'The Enigmas of Fajada Butte', in Gregory E. Munson, Todd W. Bostwick, and Tony Hull, eds., *Astronomy and Ceremony in the Prehistoric Southwest: Revisited* (Albuquerque: Maxwell Museum of Anthropology, 2014), pp. 29–42.

architecture designed to incorporate cosmological references and ritual power. Lekson suggested these Late Bonito Great Houses served as storage facilities.[39] We believe that their purpose and function were much more complex, and their astronomical associations provide circumstantial support for Van Dyke's suggestion that Late Bonito Great House construction was undertaken to 'restore confidence in the rituals' that occurred in Chaco.[40]

Two of us (Munro and Malville) have previously identified this type of observable solstitial horizon alignment simply as 'calendrical'.[41] With the benefit of a much larger data set, we have increased confidence in a deeper inferential interpretation. Certainly, there was no functional benefit to generating a massive building program to create new Great Houses as solstice and cardinal direction markers. Chacoan people clearly had the capacity to find the cardinal directions and identify solar horizon calendrical markers. The overwhelming majority of the horizon profiles associated with the solstitial Great House sites are almost entirely flat – not terribly useful for finding dates other than the solstices. Two exceptions of note are Headquarters Site A, where foresights provide a granular solar calendar for almost the entire year including a mid-May date useful to help identify planting time, and Casa Chiquita, where June Solstice sunrise and sunset markers are also accompanied by a mid-May foresight.[42]

At least two Great Houses and one Great Kiva were constructed at such solstitial observation locations at Chaco in the late ninth or early tenth centuries. However, most monumental structures built at Chaco between 860 and 1100 CE do not manifest this characteristic. Rather, their front facing directional alignments appear to have had greatest importance. During the Late Bonito phase after 1100 CE, ten new, more compact monumental structures were erected in single construction phases that are now known to manifest this solstitial characteristic. Six are involved in inter-site cardinal alignments, and three of the six manifest both characteristics. This is evidence for a profound shift in cultural focus after 1100 CE. It provides unequivocal evidence for common social intent, and

[39] Lekson, *Great Pueblo Architecture of Chaco Canyon, New Mexico*, p. 269.
[40] Van Dyke, 'Memory, Meaning, and Masonry: The Late Bonito Chacoan Landscape', p. 423.
[41] Munro and Malville, 'Calendrical Stations in Chaco Canyon'.
[42] Munro, 'The Astronomical Context of the Archaeology and Architecture of the Chacoan Culture', pp. 125–30, 158–61.

may be indicative of astronomically-adept central leadership or of a spontaneous religious revival.

We consider the meaning and intent of the Late Bonito Great Houses to be of major importance in understanding the nature of Chacoan culture and how it changed in the early twelfth century. In particular, what did the Late Bonito Great Houses actually mean with their solstitial associations and cardinal direction alignments? What may they tell us about the religious and political processes that occurred during the decline in power and influence of the inhabitants of Chaco Canyon? It may be that these Great Houses represent an effort to construct theophanies to bring Chaco and its people into closer alignment with their own cosmovision as a 'centre place'. The construction of the sites may have been performative, and if they hosted ritual activities, those rituals would likely have been performative as well. These sites indicate a level of cultural continuity with modern Pueblo peoples for whom the solstices are calendrical anchors. December solstice is a date of special ritual importance. While the details of historic period December solstice ceremonials differ among Pueblo peoples, most relate this time to veneration of the Sun and performative rituals in support of its return for another agricultural season.[43]

Acknowledgements

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[43] McCluskey 'The Astronomy of the Hopi Indians', pp. 176–81; Alfonso Ortiz, *The Tewa World* (Chicago: University of Chicago Press, 1972), pp. 104–8, 555–56; Elsie C. Parsons, *Pueblo Indian Religion* (Lincoln: University of Nebraska Press, Bison Books edition, 1996), pp. 102, 122–23, 212, 496, 555–56.

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