The Astronomical Context of the Archaeology and Architecture of the Chacoan Culture

Thesis submitted by

Andrew M. MUNRO, M.Sc. Astron., Swinburne University of Technology

andrew.munro@my.jcu.edu.au

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Declaration

I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

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Statement on the Contribution of Others

Nature of Assistance	Contribution	Name & Affiliation
Methods and intellectual support	Guidance on literature review and sources Training on fieldwork, and data reduction techniques Fieldwork planning Recruiting assistance for fieldwork support team Collaborative review of data, and interpretation Coauthoring of peer reviewed articles Editorial support	J. McKim Malville, Ph.D., Principal Supervisor, Professor Emeritus, Department of Astrophysical and Planetary Sciences, University of Colorado & Adjunct Professor, Centre for Astronomy, James Cook University
	Guidance on literature review Leadership of confirmation seminar Program structure recommendations Guidance on thesis structure and content Editorial guidance	Wayne Orchiston, Ph.D., Co-Supervisor, Centre for Astronomy, James Cook University
	Overview of great circle distance and azimuth calculation methods utilized in navigation, and validation of initial calculated results	Tom Brand, Col., United States Air Force (retired)
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Data collection	Field research permit application and approval process	Wendy Bustard, Dabney Ford, Roger Moore, and Barbara West, U.S. National Park Service, Chaco Culture National Historic Park Jim Copeland, and Peggy Gaudy, U.S. Bureau of Land Management

	Site archival data access and site background information	Dabney Ford, Roger Moore, Russ Bodnar, Tracy Bodnar, and G.B. Cornucopia, U.S. National Park Service, Chaco Culture National Historic Park
	Recruiting assistance for fieldwork support team	Cherilynn Morrow, Ph.D., Professor of Physics, Department of Physics & Astronomy, Georgia State University
	Fieldwork support team: equipment transport, and surveys	Robert Beehler, Beverly Beehler, Nancy Malville, Ph.D., Assistant Professor Adjoint, Department of Anthropology, University of Colorado, Gene McCracken, Anne Marie Munro, Donald D. Munro IV, John Nickerson, Greggory Rothmeier
	Photographic methods	Patrick René
	Field photography	Patrick René, Jim Walton, Lauren Lamont, Elizabeth Munro-Jeffery, Clint Shoemaker
	Access for measurements and photography of curated artifacts	James Krakker, Archaeological Collections Specialist, Department of Anthropology, National Museum of Natural History, Smithsonian Institution Anibal Rodriguez, Sr. Museum Technician, American Museum of Natural History David Hurst Thomas, Ph.D., Curator of North American Archaeology, American Museum of Natural History
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Documentation	Editorial assistance, proofreading, and graphics production	Anne Marie Munro

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Abstract

Astronomical analysis of 10th to 12th century A.D. cultural evidence at Chaco Canyon New Mexico began in the 1970s. Published work includes a variety of proposals including horizon calendars, solar calendrical constructs in architecture, cardinal North-South and/or East-West (NS/EW) alignments of architecture and roads, building alignments to lunar standstills or June solstice sunrise, wall alignments to equinox sunrise or sunset, and the positioning of structures at observation points for horizon calendrical stations. Within the published archaeoastronomy work attention to Pueblo ethnography, archaeological evidence including temporal data, statistical significance, and the consideration of multiple hypotheses has varied widely. The sample of Chacoan Great Houses assessed for astronomical associations was unchanged from the mid 1990s to 2007.

There is active debate among archaeologists regarding the relative importance of political, ritual, and economic factors in the Chacoan regional system. Past archaeoastronomy work has had limited influence on such debate. Nonetheless, there is general acceptance among archaeologists of the idea that visual astronomy had a role in Chacoan culture, if for no other reason than to provide a calendrical system.

This research expands on previous samples of Chacoan Great Houses to include all those identified within “downtown Chaco,” as well as a small sample of “halo” and “outlier” Great Houses. The field work, conducted under National Park Service and Bureau of Land Management permits, included compass survey, theodolite survey, and photography at a total of 28 sites. Survey results were assessed in the context of positional astronomy, Pueblo ethnography, and the archaeological record including published construction dates for the sites.

I found no convincing evidence for previously proposed architectural alignments to lunar standstills, June solstice sunrises, or equinox events. I have found that a majority of the studied Chacoan structures to conform to one or more of four architectural traditions that have astronomical associations. These include front-

facing south-southeast (SSE) orientation, front facing east-southeast (ESE) orientation, alignments to the cardinal directions of North-South and/or East-West (NS/EW), and the construction of Great Houses at workable calendrical stations with horizon foresights for solstice dates. Multiple Great Houses exhibit two of these traditions in combination. A single case is identified that may incorporate three of the traditions. The "halo" Great House at Bis sa'ani includes a cardinal North-South and East-West ("NS/EW") structure, a possible SSE-facing room block, and a June solstice sunrise horizon foresight.

Building upon Hayes' and Lekson's assessments of orientations, temporal analysis of these four traditions may improve our understanding of shifting patterns of multi-cultural collaboration and dominance among ancestral Pueblo groups. A majority of the Great Houses built before A.D. 1000 are front-facing to the SSE. The SSE orientation tradition continued during the peak of Bonito Phase construction activity (A.D. 1020-1100). Most of the putative lunar standstill and June solstice sunrise alignments comprise a subset of this SSE facing group. During the same period, the first cardinal NS and EW architectural alignments were also completed. Four ESE facing Great Houses were constructed within and in proximity to Chaco between A.D. 860 and A.D. 1090. This third orientation tradition may represent some form of cultural affiliation with contemporary Rio Grande Valley people based upon comparison to previous orientation studies conducted by Lakatos, or it may perhaps represent an alternative cosmological intent.

The "new" Great Houses built during the Late Bonito phase at Chaco after A.D. 1100 are all either involved in inter-site cardinal NS alignments, or positioned at or in proximity to observing locations that can function as solstice calendrical stations. Workable solstice horizon calendars are now confirmed at Casa Chiquita, Kin Kletso, Headquarters Site A, Wijiji, Bis sa'ani, and 125 m from Roberts Small Pueblo at 29SJ 2538/2539. A potential calendrical station located in the vicinity of Peñasco Blanco's McElmo ruin is yet to be confirmed. The Late Bonito "calendrical" Great Houses may have been intended as pilgrimage destinations where people could witness a dramatic solstice sunrise or sunset. During the same time period, SSE orientation was dominant in the Totah region to the north at sites including Aztec and Chimney Rock.

The astronomical evidence presented supports the idea that people with at least three distinct cosmological intents collaborated at Chaco; it also supports Van Dyke's hypothesis that Late Bonito phase construction at Chaco represented an attempt by a weakened ritual elite to reinvigorate their legitimacy and power. The consistency of cosmological and solstitial references among Late Bonito Phase Great Houses at Chaco indicates that the Late Bonito Chacoan elite's power may have rested in part on esoteric astronomical knowledge, and an elevated cultural status for solar events.

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

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1 INTRODUCTION

Beginning in the 1970s, evidence has emerged that the 10th to 12th century A.D. builders of large-scale masonry buildings at Chaco Canyon New Mexico ***(Figure 1)***, or "Chacoans," were keen observers of the sky who expressed cosmological references in their architecture. The evidence includes well-documented intra- and inter-building alignments to the cardinal directions (North-South or "NS" and East-West or "EW"), as well as identification of calendrical stations that may have been used by sun watchers (see e.g. Hayes, 1981; Lipe, 2006; Malville, 2008; Reyman, 1976; Sofaer *et al.*, 1989; Williamson, 1977, 1984; Williamson *et al.*, 1975; Zeilik, 1986a). (Note: Historically, the ancestral Pueblo people who built these structures have been referred to as "Anasazi" by most archaeologists. Because that Navajo (or "Diné") term is viewed as pejorative by many modern Pueblo people, the term "Chacoans" will be applied in this work in reference to the 9th – early 12th Century A.D. people of Chaco.)

Visual astronomy provides a physical model that supports development of cultural cosmologies that may underpin symbolic associations in ritual and religious contexts (see e.g., VanPool *et al*., 2006: 4-7). The first well-defined model for cosmological linkage to design at varying scales at Chaco was proposed by Fritz (1978, 1987). He proposed that "symbolic resonance" is reflected in repetition of cosmologically linked features on multiple scales. These are based on the importance of the NS/EW cardinal directions and on reflective symmetry across NS lines on multiple scales in Chacoan architecture. For example, at the site level the accurate NS axes in the building designs of Pueblo Bonito and Casa Rinconada, and at the inter-site level in the NS inter-building alignment line between Tsin Kletsin and Pueblo Alto. Similarly, Fowler and Stein's (1992) discussion of Great Houses as a "sacred technology" in the context of the outlier at Manuelito Canyon is underpinned by their interpretation that Chacoan architecture operates on varied scales of design in a "nested pattern" to manifest symbolic cosmological meaning.

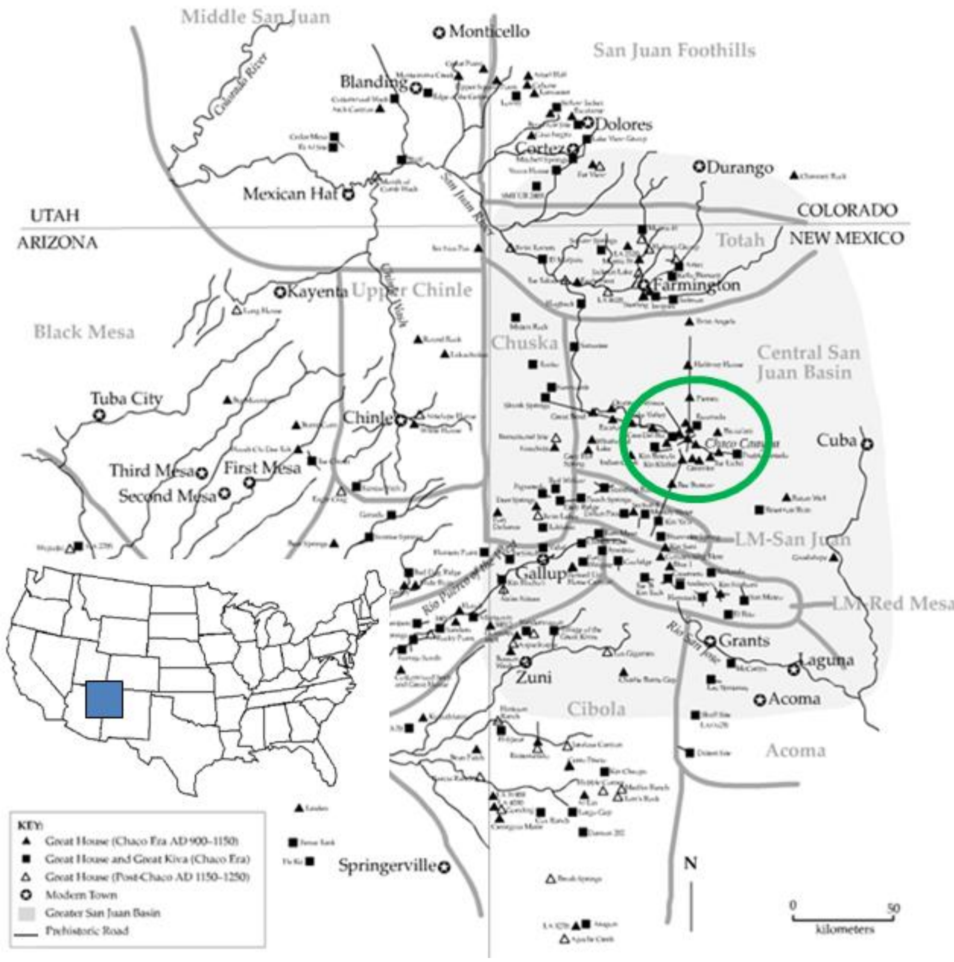


Figure 1. Geographic context

(Adapted from Kantner, 2006a) This map provides insight into the extent of the Chacoan regional system. All fieldwork surveys conducted during this study were in the immediate vicinity of Chaco Canyon, marked by the green ellipse in the figure.

Sofaer (1997) extended Fritz's concepts to propose that a systematic multi-generational inter-site cosmologic plan is evident at Chaco, principally based on solstitial and lunar standstill alignments within and between structures. Most of her proposals remain highly controversial among archaeoastronomers. Also controversial is the expansion of Fritz's model to encompass sites across the southwest and northern Mexico under the "Chaco Meridian" model proposed by Lekson (1999).

Hayes (1981) first identified a recurring bimodal pattern of cardinal NS and Southeast orientations among Chacoan architecture. Lipe (2006: 264-265) discusses north-south and northwest-southeast axes of symmetry operating on habitation, multi-room block, and village scales between A.D. 700 and 1300; another example of multi-scale design linkage with cosmology and directions. He suggested that these references likely represent common symbolic intent, and noted that they were distinctive in comparison to ancestral Pueblo patterns in other areas and later times.

It is especially notable that extraordinary archaeoastronomy claims such as Sofaer's (1997) lunar standstill hypothesis were created with limited reference to generally accepted timelines for construction at Chaco, without ethnographic support, and without reference to basic statistical testing. Similarly, published studies of calendrical stations vary in their standards of evidence, and in the quality of published interpretation.

1.1 Outline of the Thesis Topic

This thesis, entitled "The Astronomical Context of the Archaeology and Architecture of the Chacoan Culture" is intended to provide an interdisciplinary analysis of the astronomy of the people who built large scale masonry architecture at Chaco Canyon New Mexico from the 10th to 12th centuries A.D.

"Astronomical Context" refers to indicators in the material cultural evidence of visual astronomy tools and techniques relating to calendrical practices, the cosmological belief system of the builders, and astronomical techniques applicable to construction survey and navigation.

"Archaeology" refers specifically to the study of material culture at Chaco Canyon, as well as analysis and interpretation intended to provide cultural insight for the Chacoans.

"Architecture" refers generally to the remains of buildings at Chaco, and especially the massed masonry structures known as "Great Houses" that have been variously interpreted as uniquely large communal residences, "palaces" for political leaders, storage structures, or monumental architecture more generally.

"Chacoan Culture" refers to the system of knowledge, beliefs, and customs of the people who built at Chaco in the 9th to 12th centuries A.D., generally accepted to have been ancestors of some modern Pueblo people.

Fresh field surveys of Great House orientations and potential calendrical station horizons, as well as systematic analysis of astronomical features among structures may enhance our understanding of cultural variation during the Chacoan period. There is significant opportunity to improve the available base of archaeoastronomy data for Chaco, and enhance understanding of the role that astronomy played in Chacoan culture.

1.2 Justification and Relevance

While individual published archaeoastronomy findings are debatable, based on overwhelming physical evidence and ethnographic data it has been well demonstrated that the Chacoans did embed cosmological references in their architecture. Notwithstanding, the published work is inconsistent and incomplete. Standards of past archaeoastronomy fieldwork varied widely, and for a significant percentage of published work original source data is not available in archives. Further, the degree to which past archaeoastronomy work was reasonably integrated with Chacoan archaeology and Pueblo ethnography also varies. Since the "heyday" of archaeoastronomy at Chaco during the 1970s and 1980s, significant strides have been made in Chacoan archaeology, especially in dating structures and developing an integrated view of the vast archaeological record (see e.g., CRA, 2011; Kantner, 2006a; Kantner and Kintigh, 2006; Lekson, 2006, 2007, 2009; Mathien, 2005; Neitzel, 2003; Van Dyke, 2007a; Windes *et al.*, 1996). An integrated analysis of astronomical evidence conducted with reference to current archaeology offers the potential to improve our understanding of prehistoric cultural developments at Chaco.

1.3 Research Methodology

This is an interdisciplinary study, and as such it is depends upon multidisciplinary literature review. Literature review was conducted pertinent to the archaeology of Chaco Canyon, and the ethnographic record relating to the astronomical and cosmological beliefs and practices of the Pueblo people who are the most likely descendants of the Chacoans, as well as for the published archaeoastronomy.

Field surveys were conducted at the principal Great Houses at Chaco Canyon, as well as at selected small house, shrine, “halo,” and “outlier” Great House sites under the terms of National Park Service and Bureau of Land Management research permits. Preliminary field surveys were conducted using compass and clinometer. Theodolite surveys were applied to obtain data that could constrain building orientations, test possible astronomical alignments with architecture, and identify workable horizon calendar foresights. Survey results were analyzed in the context of positional visual astronomy using the United States Naval Observatory’s MICA ephemerides.

Upon confirmation of repetitive patterns of building orientation at Chaco, and in light of a limited number of ethnographic reports that link ceremonial “staffs” or “sticks” with Pueblo migration traditions, dimensional analysis was conducted of “ceremonial sticks” to test their potential application as survey instruments. These were recovered from Pueblo Bonito, and are curated at the Smithsonian Institution and the American Museum of Natural History.

1.4 Thesis Structure

The following chapters provide an overview of the rich archaeological record left by the people who constructed large scale architecture at Chaco, and explore the ways in which visual astronomy may have played a role in their culture.

Chapter 2: The People of Chaco presents an overview of the discovery and study of the archaeological evidence at Chaco, and defines some additional key terms.

Chapter 3: Archaeological Overview provides a review of the published archaeology, with a focus on temporal patterns in the material cultural evidence.

Chapter 4: The Ethnographic Record – Pueblo Astronomy discusses documented astronomically-related beliefs and practices among historic-period Pueblo People. In addition, the chapter includes a brief discussion of the limitations of the reporting, and introduces the approach used to apply astronomical ethnographic reports to the analysis of Chacoan cultural remains.

Chapter 5: Chaco Archaeoastronomy Prior to 2007 reviews the record of published studies conducted at Chaco in the past. This is intended as a near-complete review, and includes comparison and critique of the literature.

Chapter 6: Methods provides a detailed discussion of the field methods, data reduction techniques, and interpretive approach applied in this study. This chapter includes discussion of compass and clinometer surveys, field survey using the theodolite, data reduction techniques for surveys, the approach used to obtain confirmation photographs of solar events, and a discussion on how ethnographic data was applied to support interpretation.

Chapter 7: Presentation of Data includes site-by-site data collected. The central findings presented are previously unknown workable calendrical stations, and their consistent association with monumental architecture built during the Late Bonito phase from A.D. 1100-1140. In addition, the chapter discusses the methods applied to obtain dimensional data for “ceremonial sticks” recovered from Pueblo Bonito.

Chapter 8: Discussion includes an integrated review of the collected data, and interpretation of its meaning. Multiple sub-topics are covered in this chapter, including discussion of one potential alignment of architecture to “sacred” topography, three orientation traditions that may operate as identifiers for distinct culture groups or practices, and the construction of monumental architecture at calendrical stations. The chapter also includes preliminary findings regarding survey methods and tools that could have been used to achieve the architectural orientation traditions discussed.

Chapter 9: Conclusion discusses the potential to use three distinct orientation traditions as indicators of cultural affiliation or cultural beliefs for ancestral Pueblo builders. The approach discussed offers some potential to aid in identification of prehistoric cultural affiliations or migration patterns when applied to dated structures. In addition, the chapter discusses solar-calendrical astronomical associations with Late Bonito Phase architecture. These associations provide new circumstantial evidence in support of theories that Chaco operated, at least in part, as a ritual pilgrimage center, and that a Late Bonito elite may have implemented centrally planned construction of monumental architecture in an effort to bolster their legitimacy.

2 THE PEOPLE OF CHACO

This chapter presents a brief overview of the discovery and study of the archaeological evidence at Chaco, and defines some key terms.

For thousands of years, ancestral Native Americans lived in the hostile environment of the San Juan Basin in what is today the Four Corners region of the southwestern U.S. in a high-altitude desert environment. In the scorching heat of summer and the deathly cold of winter these people did not simply survive, they created a civilization. Between A.D. 1020 and A.D. 1140 people living in and around Chaco Canyon, New Mexico, succeeded in building one of the most complex collections of pre-Columbian architecture north of present day Mexico. Few modern structures in North America approached these buildings' scale before the 20th century, (Lekson, 2007: 13; Windes, 1996), and only the constructed earth "mounds" of Cahokia in the Mississippi river valley were apparently grander in scale (Lekson, 2008: 114-116; Pauketat and Emerson, 1997).

Spanish land grants and colonial records dating from the mid 1700s provide the earliest European documentation of landmarks in the area. The first reference specific to the impressive architectural remains located at Chaco Canyon, usually referred to as "Great Houses," dates to an 1823 trip by José Antonio Vizcarra and a party through the canyon. Lt. James Simpson of the U.S. Army created our first detailed report, documenting seven of the enormous Great Houses in 1849. Beginning in the 1870s, early archaeological study of the structures tended to focus on the potential for Mesoamerican (esp. Aztec) influence in their construction (Lister and Lister, 1981).

In the intervening 130 years, there has been ongoing archaeological work at Chaco of varying scale and quality. A particular difficulty for the modern researcher arises due to the sheer volume of archaeology conducted. It would be the work of a lifetime to review the enormous quantity of archaeological documentation available relating to the "Chacoans" who built the Great Houses.

Principal construction periods for the Great Houses occurred during the 10th through early 12th centuries A.D. Early construction took the form of “Prudden Unit" type pueblos composed of above ground room blocks fronted by semi-subterranean round rooms called “kivas.” During the 11th and early 12th centuries, the scale of architecture at Chaco became extraordinary and unique. While significant debate continues regarding the structure of Chacoan society and the cultural purposes of these large buildings, the surviving twelve Great Houses within the central 13 km stretch of the canyon are interpreted by many archaeologists as scaled-up and monumental versions of earlier unit-type pueblos (Lekson, 1984, 2006, 2009; Lipe, 2006; Noble, 2004; Powers *et al*., 1983; Sebastian, 1992, 2004; Van Dyke, 2007a). It has been proposed that Chaco may have operated in part as a ritual and pilgrimage center, and that Great Houses were significant both in ceremonial function and symbolic meaning (Judge, 1991, 2004; Judge and Malville, 2004; Malville and Malville, 2001a, 2001b; Renfrew, 2001, 2004; Toll, 1985, 2006).

The 13 km long portion of Chaco Canyon containing the twelve most famous ruins lies at the core of a regional system that spanned over 80,000 km^2 (Lekson, 2006: 15). Over 150 Chacoan Great Houses have been identified. “Chaco Outlier” Great Houses are characterized by the presence of one or more of: an imposing Great House that is architecturally dissimilar from surrounding habitations, large round rooms called “Great Kivas” exceeding 100 m^2 in area, formalized roads or road segments, and/or earthworks. Archaeologists debate which communities to include in the Chacoan regional system, and how to interpret the structure of that system. Much of the debate centers on the “Chacoan characteristics” found at each site, and the degree to which identified material evidence conforms to “Chacoan” norms (see. e.g., Kantner & Mahoney, 2000; Kantner & Kintigh, 2006; Kincaid, 1983; Lekson, 2006; Powers *et al*., 1983; Van Dyke, 2007a; Wilcox, 2004).

Variations in ceramic evidence, masonry styles, and the plans of the Great Houses are indicative of both cultural development and cultural variation during the “Chaco Florescence” from the late 10th through early 12th centuries A.D. Notably, the Great

Houses contain a mix of room styles, including suites of rectangular rooms and large numbers of the round rooms of varying sizes usually labeled as "kivas."

Most Chacoan kivas are built above ground into surrounding square masonry structures, with resulting "waste space" between circular interior walls and the outer square walls. Frequently these areas include buttresses. The architecture of all kivas, especially as regards their roof design, appears to show developmental continuity with earlier semi-subterranean ancestral Pueblo pit structures. Typical kiva features include benches, pilasters, and vented fire pits with deflectors. However, there are significant variations in the features based upon both size and temporal changes, as well as from example to example. Large numbers of kivas are present in both in-canyon Great Houses and outliers. They vary in size; many are small (less than 5 m in diameter), some range from 5 m to 10 m in diameter, and the largest have areas exceeding 100 m^2. Most of these largest kivas are semi-subterranean, incorporate more consistently formal design, and are referred to as "Great Kivas." Many kivas show evidence of multiple phases of partial deconstruction and reconstruction (Crown and Wills 2003: 518-520; Lekson, 2004, 2007: 18-28; Lekson et. al., 2005: 84-89; Windes, 1987).

The use of the term "kiva" is itself subject to debate. "Kiva" carries an implicit connotation of the room being "specially constructed for ceremonial purposes" (Lekson, 2009: 99), because during the historical period kivas have been used primarily for communal activities including rituals (Dozier, 1983: 213; Mindeleff, 1891; Ortiz, 1972). Notwithstanding, no firm archaeological consensus of the purpose for most kivas at Chaco exists. Some have ascribed sacred religious importance to kivas generally (see e.g., Fritz, 1978; Plog, 2008: 21, 63) while others define kivas more broadly as communal structures that had both ritual/ceremonial and non-ritual purposes (Crown and Wills, 2003: 518). Windes (1987) inferred that the size and design differentiation between small and mid-sized kivas made it likely that they had differentiated purposes. Lekson (1988; Lekson *et al*. 2006: 86) prefers to refer to them as "round rooms," and proposes that most are residential in nature. He suggests that design continuity from the earlier pit houses to the kivas of the modular Prudden Units that were the dominant architectural form in the region beginning in the

A.D. 700s is more than just coincidence, and that it was not until after A.D. 1300 that ancestral Pueblo people ceased using round rooms as housing.

Representations of consensus are a hazard in Chacoan archaeology. Notwithstanding, while the debate continues regarding the uses of small and mid-sized kivas, many archaeologists interpret the largest Great Kivas as communal spaces for gatherings and ceremonial, esoteric or ritual activity. Some view the number and locations of Great Kivas as indicative of particular concern among Chacoan leaders with creating social, ritual, and/or political integration, cohesion and legitimacy. Some Great Kivas are located within Great Houses, as at Pueblo Bonito. In other cases Great Kivas are stand-alone structures, as is the case with Casa Rinconada. The formal designs of the Great Kivas generally include a fire pit, deflector, and ventilator shaft in the floor. Many include benches, sockets with imported limestone foundation stones for vertical support pillars, and floor vaults. As with smaller kivas, the features provide clear architectural design linkage to earlier pithouses. In contrast to a majority of the smaller kivas, most of the 17 known Great Kivas at Chaco are semi-subterranean. All but two of the twelve Great Houses in "downtown Chaco" include Great Kivas, and stand-alone examples such as Casa Rinconada line the south side of the canyon among smaller habitation sites. Similar to many of the Great Houses and smaller kivas within them, some Great Kivas show evidence of multiple phases of reconstruction (Crown and Wills, 2003: 518-519; Fowler and Stein, 1992; Lekson 2009: 99-100; Lekson *et al.* 2006: 84-89; Vivian and Reiter, 1960; Van Dyke, 2007b).

The dramatic Great House ruins at Chaco have challenged the interpretive skills of generations of archaeologists. Though they are the largest monumental pre-Columbian masonry structures north of Mexico, current evidence indicates that they may have been nearly empty much of the time. The Great Houses in the canyon may have been built by a few permanent residents assisted by pilgrims, or possibly with corvée labor (Lekson, 1999: 21; Lekson *et al.,* 2006; Mills, 2004; Windes, 1984).

It is difficult to convey the scale of the architecture within Chaco Canyon and the surrounding area. ***Figure 2*** depicts the largest, best studied, and most famous

Chacoan Great House, Pueblo Bonito. This structure stood 4 or 5 stories tall, covers over 4762 m^2, and in its final form incorporated some 695 rooms (Van Dyke, 2007a: 119; Windes, 2003). While there is evidence for earlier structures on the site, the earliest reliable dendrochronology-based construction dates for Pueblo Bonito are A.D. 860-891. At least five major construction or reconstruction phases followed over the following two centuries (Lekson, 1984: 109-144; Stein *et al*., 2003, Windes and Ford, 1996).

The specifics of Pueblo Bonito's expansion remain an area of active research; nonetheless, some consensus has emerged. What began as a simple crescent shaped double room block oriented to the south-southeast (SSE) was expanded and reconstructed in stages. Of particular interest to archaeoastronomers, the building was ultimately reoriented circa A.D. 1070-1115 to incorporate accurate wall alignments to the cardinal directions (Stein *et al.*, 2003). In addition, there has been debate about the proposal that two windows in the Great House were constructed to incorporate December Solstice sunrise ("DSSR") alignments (Reyman, 1976; Williamson, 1977, 1984).

Figure 2. Pueblo Bonito as viewed from North Mesa

Chacoan people aligned this structure to the cardinal directions sometime after A.D. 1070. The central dividing wall lies within 12' of true North-South

Excavations and over a half century of subsequent analysis and interpretation have yielded some of Pueblo Bonito's secrets. While estimates vary, some archaeologists infer that during its entire history the building likely housed 100 or fewer people (Neitzel, 2003: 147). In addition, a number of apparently high status burials were found in two room clusters. Grave goods included ritual paraphernalia such as imported copper bells, macaws, sea shells, jet objects and turquoise. (Akins, 1986, 2003; Coltrain *et al*., 2007; Judd, 1954; Mathien, 2003; Neitzel, 2003: 143-149; Pepper, 1920; Plog and Heitman, 2010). Remarkably, over 20% of the over 200,000 timbers used in construction of Great Houses were imported from the Chuska Mountains over 70 km to the west, and the San Mateo mountains (Mount Taylor region) some 90 km to the southeast (English *et al*., 2001). The evidence indicates that this herculean logistics and transportation effort was accomplished by hand, without draft animals or the wheel. Many archaeologists today conclude that Pueblo Bonito was a form of monumental architecture at the center of a regional system. Nonetheless, there is active debate on the balance of cosmological, ritual, religious, economic, or political factors involved in the social developments that led to the construction of the structure and creation of the material evidence within it (see e.g., Williamson, 1984; Mathien, 2003; Neitzel, 2003; Stein *et al.*, 2003; Windes, 2003; Van Dyke, 2007a). Some archaeologists offer a focused political interpretation, for example Lekson (2006: 29-32, 2008: 124-130) views the Great Houses including Pueblo Bonito as oversized residences for a political elite, "trophy houses" that expanded into "palaces" where "kings" resided.

In and of itself Pueblo Bonito is remarkable; as the centerpiece of a complex regional system it is astounding. Within a few km of Pueblo Bonito are an additional 11 remaining massive and formalized Great House structures, built with similar core and veneer masonry. In addition, multiple Great Kivas exceeding 100 m^2 are known, one of which has been excavated. While most of the Great Houses are on or near the north side of the canyon, some were built high on the mesas to the north and south. Most of the buildings were placed within the canyon; perhaps to maximize their visual and emotional impact on arriving pilgrims and travelers. High placement of some of the structures may have provided long sightlines to establish markers of the Canyon's location for travelers approaching from the south, west, and north. The twelve Great

Houses of the “Chacoan Core” were linked to a regional system that included some 150 additional “outlier” Great Houses. Each outlier is associated with a village, and many are associated with formally constructed roads or road segments (Van Dyke, 2007a: 17-25).

One of the most distant outliers, Chimney Rock, is 150 km to the northeast. That site is also of interest to archaeoastronomers due to evidence that it may have been deliberately sited in response to an observed northern Major Lunar standstill (Fairchild *et al.*, 2006; Malville, 2004a). ***Figure 3*** provides a map including sites from multiple phases of occupation at Chaco.

The mountain of published Chaco archaeology is complemented by ethnographic sources relating to the Chacoans’ modern descendants, the Pueblo people of today’s American Southwest. Nonetheless, it is important to understand that available ethnographic data was collected in the face of tremendous social and governmental pressure from European and Mexican immigrants during the modern period, including both Spanish and American state-sponsored religious suppression. In addition, a majority of the ethnography that relates directly to astronomical activity was collected during the late 19th and early 20th centuries using standards that differ markedly from current anthropological approaches. The ethnographic record is also incomplete, in part because modern Pueblo people are suspicious of anthropologists; they maintain a keen focus on the preservation of their culture. Furthermore, Pueblo culture has been no more stagnant over the past ten centuries than any other culture (see e.g., Dozier, 1983; Sando, 1998: 84-85, 91-97, 198).

The archaeological data available to inform us of likely Chacoan astronomical practices is extensive. Additional details on this data, as well as how astronomy may have been recognized and used at Chaco are presented in Chapters 5, 8, and 9 below. A discussion of astronomy in Pueblo ethnography is presented in Chapter 4.

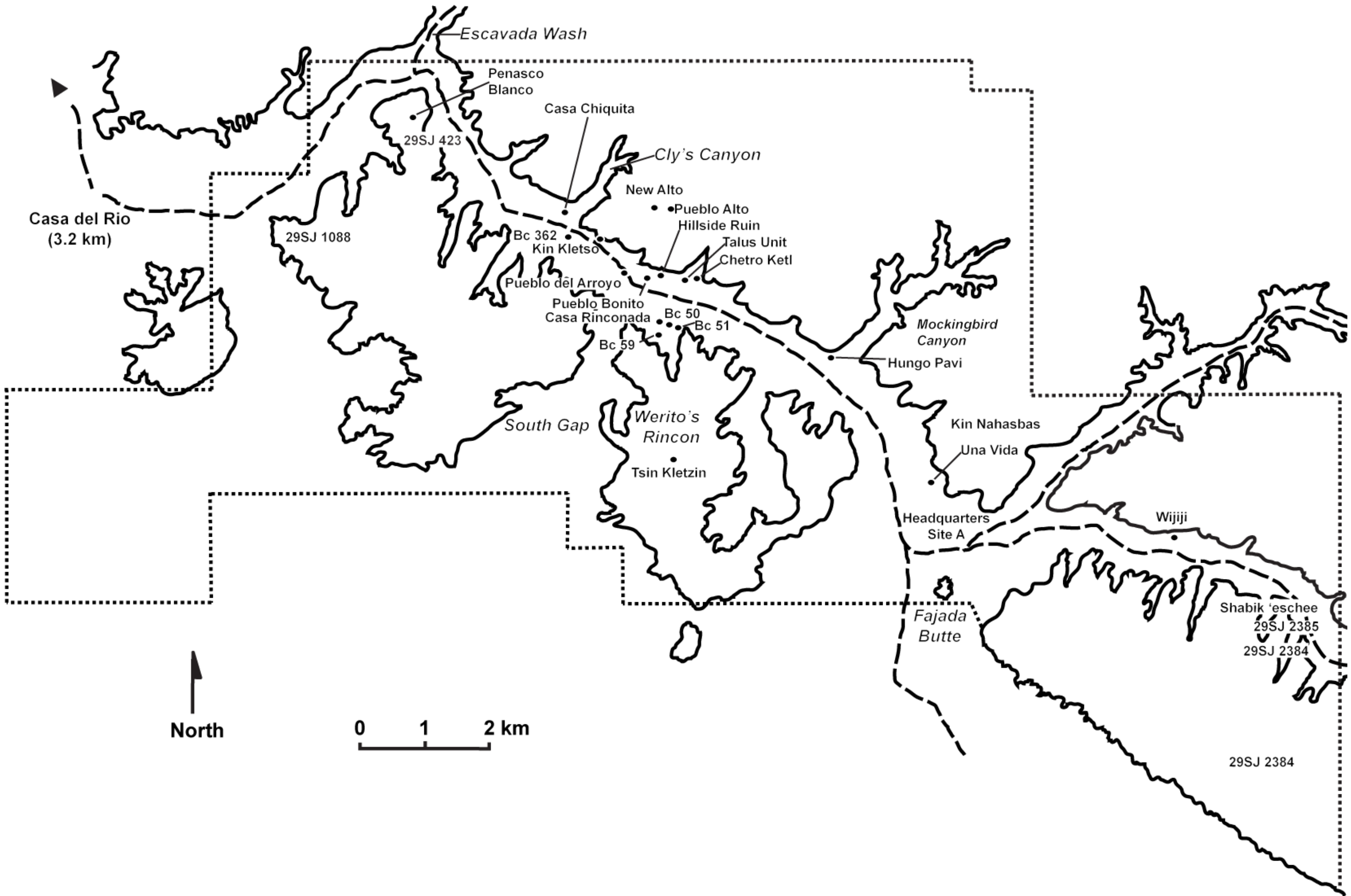


Figure 3. Chaco Canyon map with principal Great Houses

(Adapted from Lekson, 2007: 2, original by Windes). Principal Structures and Shrine sites of the Chacoan Core are shown.

3 ARCHAEOLOGICAL OVERVIEW

This chapter provides an overview of published Chaco archaeology, with a focus on temporal patterns in the material cultural evidence. It serves as an informational foundation that provides context for discussions of ethnology and archaeoastronomy that follow later in the thesis.

> I started out trying to figure out why no two Chaco researchers could ever agree on the nature and cause of the sociopolitical complexity of the Chaco system. Now I can't figure out how any of us ever even got up the nerve to ask the question (Sebastian, 1992: 29).

The degree of variation in archaeological interpretation regarding Chaco is a challenge for researchers who seek to apply interdisciplinary approaches such as archaeoastronomy. In that regard, it is a particularly useful time to engage in a fresh assessment of Chacoan archaeoastronomy given the recent publication of two volumes that present results of the Chaco Synthesis Project (Lekson, 2006; Mathien, 2005). Though they are not encyclopedic, these works do provide the foundation of an integrated assessment of archaeology at Chaco, highlighting areas of emerging consensus, as well as ongoing debates. In addition, recent web publication of integrated tree ring date information (dendrochronology) from multiple studies, as well as digitized versions of early papers and field notes by the Chaco Research Archive (and its predecessor effort, the Chaco Digital Initiative) provide an unprecedented chronological baseline to support interpretation (CRA, 2010). Notwithstanding, most Chacoan archaeological interpretation is impacted by the limitations of the published record. Much of the work done by early "leading lights" at Chaco including George Pepper, Frank Roberts, and the University of New Mexico Field School has never been fully published for various reasons (Reyman, 1989). It is also critical to note that for almost every opinion, interpretation, or "consensus" presented herein regarding the archaeological record at Chaco, alternative professional opinions can be found.

3.1 Introduction of Ceramics, and Expansion of Agriculture

Evidence for early Paleo-Indian and Archaic occupation at Chaco is thin. Stone points have been found at a total of five sites that date prior to B.C. 5500. Between B.C. 5500 and A.D. 400, ongoing cultural development is manifested in the archaeological evidence, culminating in a final pre-ceramic phase labeled "Basketmaker II" by archaeologists. Basketmaker II people lived in “pithouses”; semi-subterranean structures that incorporated fire pits and pillars supporting earth-covered timber roofs. They used spear-throwers or “atlatls” as their primary projectile weapon, stored surplus food in slab lined bins, and used “metates” (stone grinding troughs) to grind corn. These people were engaged in horticulture, but may have remained semi-nomadic. There is evidence that they made Chaco their home seasonally to grow corn, as well as take advantage of native piñon as a food source (Hayes, 1981: 21-23; Judge, 1972; Plog, 2008: 37-70; Sebastian and Atschul, 1986.).

Based upon extensive archaeological research over the past 140 years, a foundational developmental chronology for the period A.D. 400-1300 has emerged, as provided in ***Table 1.*** Changes in architecture, ceramics, and population density occurred throughout this period (CRA, 2010; Lekson, 1984, 2006; Lipe, 2006; Windes and Ford, 1996).

During the Basketmaker III phase between A.D. 400 and 700, evidence indicates that the bow and arrow, as well as ceramics were introduced. Pithouses became deeper, and benches were added within the structures. Most main rooms and antechambers within pithouses were “D” shaped. While a majority of sites were small and distributed, two large villages did develop at Chaco. 29SJ 423 at the west end of the Canyon, and Shabik’ eshchee village in the east were both located on the mesa tops. Each village included a single round Great Kiva some 20 m^2 larger than the surrounding pithouses, and many more pithouses than were commonly aggregated in villages in surrounding areas (Hayes, 1981; Mathien, 1997; Powers *et al*., 1983; Roberts, 1926-1927, 1929).

Pecos Classification Stage	Chaco Center Phase	Period (A.D.)	Architectural Characteristics	Great House or Great Kiva Estimated First Construction (A.D.)	Population Changes at Chaco
BM III	La Plata	400-700	Dispersed Shallow Pit Houses and Storage Cysts Large aggregated communities with Great Kivas at 29SJ 423 and Shabik' eshchee	-	-
Early PI	White Mound	700- 800	Dispersed deep pit houses	-	-
PI	White Mound	800-850	Small to moderate sized aboveground slab row houses, Major increase in storage	-	-
Late PI Early PII	Early Bonito	850-925	Small to moderate sized aboveground slab row houses	Pueblo Bonito, 860-925 Una Vida, 860-865	-
Early PII	Early Bonito	900-1040	Small house aggregation, expansion and increase in number of Great Houses	Peñasco Blanco, 900 Hungo Pavi, 990-1010 Chetro Ketl, 1010-1030 Pueblo Alto, 1020-1040 Casa Rinconada, 1060-1110	Major increase
Late PII	Classic Bonito	1040-1110	Major Great House construction at Chaco	Pueblo del Arroyo, 1065-1070	Decrease
Early Pueblo III	Late Bonito	1090-1140	Major Great House construction and reconstruction at Chaco Major Great House Construction in the Totah region north of the San Juan River	Casa Chiquita, 1100-1130 New Alto, 1100-1130 Wijiji, 1110-1115 Tsin Kletzin, 1110-1115 Kin Kletso, 1125-1130	First increasing, then major decrease
Pueblo III	McElmo	1140-1200	No additional Great House construction	-	Major decrease
Late Pueblo III	Mesa Verde	1200-1300	No additional Great House construction	-	Major increase

Table 1: Post-ceramic developmental chronology at Chaco Canyon

(Adapted from T. Windes' Chaco chronology in Lekson, 2006: 7)

3.2 Agricultural Surplus and Rapid Change

A shift in pattern clearly differentiates the next period at Chaco, the early and mid Pueblo I (A.D. 700-850). Pithouses became deeper and habitations were increasingly clustered in the canyon rather than on the mesa tops. This shift is interpreted by some as indicating that a gardening and horticulture economy was being replaced by larger scale farming. Locations lower in the canyon provided easier access to the moist ground necessary to support expanding agriculture. Ongoing developmental improvements in ceramics are evident. Above-ground construction of slab-walled room blocks began in the early to mid A.D. 800s (Hayes, 1981; Truell, 1986, 259-266; Vivian 1990).

Between A.D. 800 and 850, changes in cultural patterns begin to emerge including creation of much larger storage facilities, and the emergence of increasing trade, especially in ceramics. It is at this time that the first crescent shaped above-ground room blocks were built at Pueblo Bonito and Una Vida, unit pueblo type structures that would later develop into monumental Great Houses. Variations in pithouse and kiva design details, as well as variations in animal remains have been interpreted as indicating that at least two culture groups were present and living side by side. One group is believed to have come from the northern San Juan basin, and one from the South (Bullard, 1962; Vivian, 1990). The presence of differentiated cultural groups may have been similar to some modern Pueblos, where members of different clans and language groups live in proximity to one another while maintaining distinct cultural practices.

3.3 The Early Bonito Phase, A.D. 850-1040

During the latter portions of the Pueblo I phase (A.D. 850-925) change was rapid. Within the canyon, villages at Pueblo Bonito, Una Vida, and Peñasco Blanco were all founded. An additional lesser-known village adjacent to Una Vida named Kin Nahasbas was also constructed in the late 800s, possibly due to better sight-lines for signaling to the west than Una Vida enjoyed. Outlier sites also were expanded or begun, including Casa Del Rio and Pueblo Pintado, the later western and eastern "gateways" into the canyon. Archaeologists believe that additional as-yet unidentified early "proto-Great Houses" are likely to be in the region (Lekson *et al.*, 2006; Lister and Lister, 1981; McKenna and Truell, 1986; Plog, 2008; Vivian, 1990).

Casa del Rio is of particular interest because it has been identified as a possible precursor to later-period expansion at Chaco, and a possible periodic pilgrimage destination. The site has better horticultural potential than any other site in the vicinity of Chaco. Its large midden encompasses a volume of 1,702 m^3, and an estimated .609 to 1.520 million sherds. By comparison, the midden at Peñasco Blanco has a volume of 1,430-1,840 m^3 and an estimate of .585-1.460 million sherds. Of the early Great Houses within Chaco Canyon, only Peñasco Blanco can match the huge quantities of refuse generated at Casa del Rio; yet Casa del Rio was a very small community by comparison. Peñasco Blanco had some 124 rooms and was occupied for more than two centuries. Casa del Rio had some 21 to 27 rooms with perhaps 4 to 5 households. None of the other contemporary villages including Kin Bineola, Pueblo Bonito, Una Vida or the East Community produced similar quantities of refuse in the late A.D. 800s and 900s. Only the nearby house at Lake Valley has similar agricultural potential, and a similarly enormous midden. The amount of Chuskan ceramics found within the midden certainly indicates connections with settlements to the west, and is perhaps also indicative of periodic gatherings. Unlike the great mounds of the mid and late A.D. 1000s, these early mounds seem to be primarily domestic trash associated with food. The deposition of trash diminished or ceased in the 1000s when the Great Houses were being expanded in "downtown Chaco" (Lekson *et al*., 2006; Windes, 2007). Regarding Casa Del Rio, Windes (2007: 69) states that "It is difficult to believe that the few inhabitants of the Great House could have been responsible for the quantity of cultural materials contained in the mound." Consequently, "either the small number of inhabitants produced a prodigious amount of refuse or they had outside help to create such a volume."

A trough-like depression that partly encircles Casa del Rio's large midden suggests a formalized movement of people, perhaps participants in periodic festivals who may have reached the site on the Great West Road which runs south of the Chaco River from Peñasco Blanco westward. All these elements suggest that Casa del Rio may have been one of the early sites of periodic festivals in the Chaco area. The enormous scale of the Lake Valley midden suggests similar possibilities for periodic festival activity. Casa del Rio is within view of the shrine of 29SJ 1088 on West Point, the high westernmost extension of West Mesa. The shrine has been identified as a possible communication shrine that overlooks a vast area to the west including the distant Chuska Mountains (Windes, 2007: 67-71).

When founded during mid 9th century the first sites at Chaco that would later become Great Houses were small farming communities. They may have been founded by people migrating south from the Dolores river valley, and as they built, similar communities were being built to the west on the Chuskan slopes, visible from 29SJ 1088. These 9th century villages may have housed fewer than 100 residents each, and the material evidence suggests that they led relatively egalitarian lives. By the end of the Early Bonito phase some 200 years later, a group of these small villages at Chaco had been transformed into monumental and formalized Great Houses that may have operated as the “center place” for a regional ritual system (Van Dyke 2008).

The period from A.D. 900-1140 is often referred to as the “Chacoan Florescence.” Clear differentiation between monumental Great Houses and common habitations emerged. In addition to rapid expansion of monumental architecture at Chaco, the period saw expansion of trade including importation of goods such as Mesoamerican copper bells, seashells from the Gulf of Mexico and Pacific coast, scarlet macaws that were apparently kept for their plumage, and cacao. A regional “road” network was developed that included a variety of more or less formal engineered ways and trails, and over time increasing numbers of outlier Great Houses were constructed at villages across the region. Variations in ceramic styles through the period make it clear that ongoing changes in trade patterns and population migration occurred. Changes at Chaco during this period clearly included emergence of some form of sociopolitical, ritual, and/or economic expansion with hierarchical attributes, likely establishment of regional communications capacity, and the construction of cosmologically linked monumental architecture (Akins, 2003; Hayes, 1981; Kantner, 2004a: 87-142; Kantner and Kintigh, 2006; Lekson *et al.*, 2006; Lister and Lister, 1981; Malville, 1997; Renfrew, 2004).

Van Dyke (2008) has proposed a model to account for the rapid change that occurred at Chaco during this time. She suggests that understanding emergent social hierarchy depends upon a dialectical relationship; we need to understand not only the motivations of emerging leaders, but also those of the "led." Van Dyke contrasts the economic viability of villages at Chaco with those of their neighbors to the West on the Chuskan slopes as the basis for social specialization. She suggests that while Chuskan people relied upon exportation of economic resources (especially timber), at Chaco the more difficult environment led to a different developmental course. Given their relative lack of economic resources, Van Dyke suggests that Chacoans developed an increasingly complex system of ritual specialization linked to the hosting of pilgrims. This proposed model is based on the emergence of a regional interaction involving Chaco and their Chuskan slope neighbors based on the exchange of "spiritual resources" for economic resources. After a century of slow development along these lines, degradation of the local environment at Chaco and the need to obtain greater supplies of labor and ceremonial goods for ritual purposes drove things to a tipping point. To maintain the "spiritual resources" system at Chaco it had to grow, and as a result in the early 1000s Chacoans built the first formalized monumental Great Houses. By the mid 11th century, Chaco was the center of an ancestral Pueblo world; the only place where certain important ceremonies could be performed.

3.4 The Classic Bonito Phase, A.D. 1040-1110

The peak period of architectural development at Chaco occurred during the "Classic Bonito" phase from A.D. 1040-1100. During this period, Chaco apparently operated as the "center place" for a regional system. No doubt there were intersecting and competing socio-cultural groups at Chaco and in the surrounds, just as occur within the modern Pueblos. Scale, monumental architecture and evidence of hierarchy made the Chaco phenomenon unique in Pueblo cultural development. Distinctly Chacoan architecture incorporated elements consistent with modern Pueblo cosmology including the concepts of "center-place," and dualism (Van Dyke, 2007a).

While broad patterns are evident and it is certain that a rapid phase of cultural development occurred, archaeologists continue to disagree on the specifics of what happened at Chaco during this period. The Chacoan system apparently integrated degrees of political, economic, ceremonial/ritual or religious activity; active debate centers on the balance between these factors, the origin of the rapid cultural change, and the degree and form of social hierarchy present.

Toll (1991) interpreted the Chacoan system as egalitarian. In contrast Lekson (2006: 29-34) argues for a largely political interpretation. He suggests that the relatively egalitarian nature of modern Pueblo political and cultural structures may represent a direct "*reaction against* Chaco"; that the negative repercussions of emergent hierarchy and social coercion at Chaco resulted in deliberate shifts in culture and architecture to prevent reoccurrence of similar events. He interprets the Great Houses generally as "palaces" associated with varied political factions (Lekson, 2009: 126-127).

Other interpreters paint a more benign picture; that in the face of cultural and especially ecological and environmental stresses the Chacoan system expanded rapidly, but was simply too complex to be maintained (Kantner and Kintigh, 2006). Renfrew (2004) views Chaco as the ritual pilgrimage center of an egalitarian system which he terms a "Location of High Devotional Expression." Mills (2004) discusses the potential for hierarchy to develop without centralization of power. Wills (2001) proposes that more prosaic economic and agricultural explanations for the florescence are appropriate. He suggests that the evidence for ritual pilgrimage activity at Chaco is overblown, and that the common interpretation of outsize middens (especially at Pueblo Alto) as evidence for pilgrims' ritual breakage of pottery is inconsistent with midden contents. In contrast, Van Dyke; 2007a: 204-207) sees the Chaco phenomenon as hierarchical, and writes of potential Chacoan "colonization" in her interpretation of the evidence. As discussed above, she has also proposed a ritually-based "spiritual resources" model for the emergence of the Chacoan System (Van Dyke, 2008).

The question of hierarchy is important to understanding Chacoan culture. A small number of burials within Pueblo Bonito show the greatest level of differentiation in nutrition between apparent elites, and the midden burials elsewhere in the canyon associated with "common people." Two of the Pueblo Bonito burials are frequently cited as unique, and possibly indicative of late emergence of an elite at Chaco. Analysis of the question of hierarchy from a "canyonwide perspective" led one archaeologist to conclude that at least three levels of social status were present, including two distinct elites (Akins, 2003).

Recent isotopic evidence supports the idea that a stratified "high status" population may have been present at Pueblo Bonito as early as the 9th century A.D. Coltrain *et al.* (2007) have reported that PI burials from Pueblo Bonito have isotopic markers that "clearly indicate a diet considerably higher in animal protein than the Basketmaker II/III diets reported here, as well as Puebloan diets reported elsewhere."

Similarly, Plog and Heitman (2010) conducted a detailed reanalysis of unpublished archival records from Pepper's excavations of Pueblo Bonito rooms 28, 32, and 33, with a focus on positional analysis of esoteric grave goods, principally turquoise. Based on their positional analysis they suggest that the grave goods were positioned in directionally meaningful patterns with cosmological intent. The positional analysis of grave good was supplemented with radiocarbon dating of remains. They concluded that 14 high status burials were interred in room 33 over a long period from the 10th to 11th centuries A.D., and possibly into the early 12th century. They suggest that this was an element in legitimization of a sociopolitical hierarchy at Chaco. Plog and Heitman also concluded that social differentiation at Chaco was institutionalized over this long period by a ritually powerful elite who interred their deceased members “in association with ancestors and cosmologically powerful materials and symbols.”

Hayes (1981: 55-68) discussed a long-term pattern of differentiation in Chacoan Great House architecture. He identifies two architectural orientation traditions among structures built after A.D. 1030, one of buildings facing to the South (S), and one to the Southeast. Based on these orientations and associated architectural and material cultural evidence including room to kiva ratios, room size, kiva design and other factors, he identified two contemporaneous “phases” associated with apparently distinct culture groups, which he termed Hosta Butte (Southeast orientation) and Bonito (South orientation). Lipe (2006) discussed the same two traditions in the context of directional design consistency on different scales, and opined that these orientation traditions likely had symbolic meaning.

It was during the Classic Bonito phase that Pueblo Bonito itself completed its gradual reorientation from the earlier south-southeast (SSE) orientation to include cardinal NS and EW walls, as well as cardinal NS lines of symmetry within its Great Kivas. Additional preexisting Great Houses including Una Vida, Chetro Ketl, Hungo Pavi, Pueblo Alto and Peñasco Blanco experienced varying degrees of expansion and reconstruction. In many cases the architecture was made more formalized. Classic Bonito Great Houses and Great Kivas are formalized massive structures that incorporate symmetry and provide an architectural manifestation of “center place” and dualism. Some are framed by massive earthworks, such as the two enormous mounds located in front of Pueblo Bonito. Nonetheless, dualism and symmetry are not only reflected in building design; they are also manifested in the inter-site landscape architecture created at Chaco, and the dualistic contrast between long sight lines and the visible, versus hidden monumentalism within the canyon. It is evident that through their multiple phases of ongoing construction and reconstruction, the early Great Houses dominated the local landscape. However, most were situated such that they were not visible until one was within the canyon and close to them. During the 1090s, an apparent pause in monumental construction occurred; this pause corresponds with evidence for a severe drought that likely caused great stress in the Chacoan system. Agricultural surpluses would have been difficult to maintain and population within Chaco declined (Fritz, 1978; Lekson *et al.*, 2006: 67-115; Van Dyke, 2007a: 98-136).

Outside of the canyon, increasing numbers of Great Houses were built at “outlier” communities during the Classic Bonito phase. These offer direct physical evidence of expanding Chacoan regional influence. Many outlier Great Houses represent clear “foreign influence” architecturally; they are of a type, differentiated from earlier structures in most locations (Kantner and Kintigh, 2006). Chimney Rock is particularly of interest to astronomers, its Great House may have been sited based upon observation of an astronomical event that was magnified by the local topography, the Major Lunar Standstill of A.D. 1076 (Fairchild *et al.*, 2006; Malville, 1993b, 2004b, 2004d).

3.5 The Late Bonito Phase, A.D. 1090-1140

The Late Bonito Phase was a time of continued change. The area of Chacoan influence continued to expand, and new outliers were constructed. The three Great Houses at Aztec, north of Chaco on the Animas River were among the largest sites constructed outside of the canyon at this time. Additional outliers were built even farther away, including sites as distant as Lowry to the northwest of Mesa Verde (Van Dyke, 2007a: 202-213).

During the early 1100s a thirty-year wet period began that may have led to agricultural surplus and population growth, but the water surplus ended with a prolonged multi-decade drought (Vivien *et al*., 2006). At least seven new Great Houses were built or begun in the canyon during the wet period immediately after A.D. 1100. Five better known sites include Casa Chiquita, New Alto, Wijiji, Tsin Kletzin, and Kin Kletso (Lekson, 1984). In addition to these the lesser-known and now-backfilled sites at Headquarters Site A (Lister & Lister, 1981: 252) and Roberts Small Pueblo (Lister & Lister, 1981: 240) were constructed. These two may never have been completed, or their building materials may have been reused for later construction projects (Van Dyke, 2004a).

Six of these "Late Bonito" Great Houses or foundations, including Kin Kletso, Tsin Kletsin, Casa Chiquita, New Alto, Headquarters Site A, and Roberts Small Pueblo were constructed using "McElmo" style masonry, characterized by loaf-sized blocks of dressed tan sandstone (Lekson, 2007: 36-38; Lister and Lister, 1981: 231-232; Vivian and Mathews, 1965: 81). They contrast with earlier Chacoan masonry styles which used hard, dark brown tabular sandstone veneers (Lekson, 2007: 37-38). They are also more compact, and the combination of reduced scale and less labor intensive masonry may indicate a reduction in the availability of labor from the surrounding region (Kantner, 2004: 141). While dated by Lekson (1984: 224-231) as Late Bonito, Wijiji was built using Type III and IV masonry that required greater labor investment, and was characteristic of earlier Chacoan architecture.

During the Late Bonito building boom, multiple new "halo" and "outlier" Great Houses were also constructed outside of the canyon. This group includes Bis sa' ani, approximately 10 km northeast of Wijiji atop a pair of shale hills in Escavada Wash (Breternitz *et al*., 1982; Powers *et al*., 1983: 21-54).

Published early 12th century construction dates for the Late Bonito Great Houses are somewhat uncertain; many are unexcavated, and some structures have been dated (in part) by analogy from Kin Kletso based upon masonry style and design (Lekson, 1984: 224-238, 245-246, 251; Van Dyke, 2004a: 418-421). Negligible middens suggest that the Late Bonito Great Houses never fully functioned as residences. Lekson (1984: 269-272) argued that they may have had administrative and storage functions, an idea contested by Vivian (1990: 375-376).

The designs of four of the Late Bonito Great Houses include square or rectangular symmetrical room blocks enclosing a kiva, a floor plan known as a "McElmo Unit" (Lekson, 1984: 72-72; Van Dyke, 2007a: 217). Vivian and Mathews (1965: 107-115) proposed that McElmo architecture and masonry represented an intrusion into Chaco by people from the north. They originated the "McElmo" name in reference to southwestern Colorado's McElmo creek. Lekson (1984: 267-269; 2007: 36-38) argued that the shift to McElmo masonry may instead have related to diminished supplies of hard tabular sandstone within the canyon. Van Dyke (2007a, 219-219) makes a convincing case for the idea that diminished labor supplies may have driven the change to McElmo masonry, which is much more efficient to construct than earlier types. In addition to the multiple new Late Bonito phase Great Houses noted above, significant expansion and reconstruction projects were also completed on existing Great Houses within the canyon including Pueblo Bonito, Chetro Ketl, Penãsco Blanco, Pueblo Alto, and Pueblo del Arroyo (Lekson, 1984).

Van Dyke (2004a) proposed that the Late Bonito Great Houses were built at a time when Chaco was losing credibility as a ritual center. She suggests that visitors and pilgrims were switching their loyalties to the Totah region to the north, where Salmon Great House was constructed starting in A.D. 1088, and the Great Houses of the Aztec complex were built beginning in A.D. 1110. There was a significant decrease in agricultural production at Chaco due to drought in the decade of the A.D. 1090s, and the leaders of Chaco had every reason to fear loss of credibility and ritual power. The burst of construction activity following A.D. 1100 may have been intended, Van Dyke proposes, to demonstrate that there still was energy left in the ritual and political system centered in Chaco Canyon.

While much published Chaco archaeology has focused on the Great House sites, there are a number of studied small house habitation sites that show continuity of use for the entire period from PI through the end of the Late Bonito phase. One example is located on the bank of Chaco Wash, southeast of Wijiji. A nine or ten room structure first excavated by Roberts in 1926 is known as "Roberts Small House," or 29SJ 2385. First construction of the house has been dated to about A.D. 900. The site is also known as "Turkey House," a reference to the large number of turkey bones found within the structure by Roberts. Pot sherds at the site have been dated from Pueblo I through the Mesa Verde periods, indicative of long use (Bustard, 2008; Truell, 1986: Table 2.1; Turner, 1993; Turner and Turner, 1999: 172-178).

Human burials were found within rooms and in the adjacent trash midden. Roberts Small House is one of the sites within Chaco Canyon where evidence for anthropophagy was identified (Turner, 1993; Turner and Turner, 1999: 172-178). Turner and Turner (1999: 56-57) evaluated some 76 sites where archaeologists or physical anthropologists had documented evidence for the practice. They assessed 70% of these as convincing based upon either previously published evidence, or their own reexamination of the remains in question. Certainly evidence at some of the sites they assessed is quite strong, such as at Mancos (White, 1992). Nonetheless, the claims for multiple sites identified by Turner and Turner continue to be hotly debated, as does their characterization of Chacoan social hierarchy and architecture as being driven by Toltec "warrior-cultists" who exerted coercive social control (Turner and Turner, 1999: 463). Notwithstanding, the physical evidence at Robert's Small House is strong (McGuire and Van Dyke, 2008). However, Turner and Turner's temporal interpretation of the Robert's Small House remains as early Pueblo II (circa A.D. 900) has been questioned. Identification and analysis of stratigraphic evidence within the original site notes written by Amsden and Roberts at the time of excavation points to an earlier Pueblo I time period for the remains (Bustard, 2008).

3.6 Mesoamerican Influence

Mesoamerican influence has been proposed as having a direct impact on Chacoan cultural development. The presence of imported Mesoamerican goods at Chaco, including scarce material goods associated with ritual and ceremonial practices was noted as early as the 19^{th} century, and is indisputable. These include copper bells, macaws, shell bracelets (see e.g., Neitzel, 2003; Nelson, 2006) and the recent identification of cacao residue in Chacoan ceramic vessels (Crown and Hurst, 2008, Washburn *et al*., 2011).

As discussed immediately above, it has been posited by some that Chaco's development was a manifestation of direct Toltec cultural influence (see e.g., Turner and Turner, 1999: 462-484). In contrast, Mathien (1997) discussed various models that could account for Mesoamerican influence from diffused "hand-to-hand" trade routes, to direct contact by Toltec “pochtecas” seeking to trade, proselytize, or migrate. She suggested that these different types of contact should leave different evidence in the archaeological record. Mathien discussed past studies of evidence for trading patterns of goods including semi-precious stones and feathers, as well as the designs of architecture, cloisonné, ceramics and sandals, and that these have led to varied conclusions among Mesoamerican and Chaco archaeologists. While expressing support for the view that “local trade and economic networks” had a dominant role in development at Chaco, she also suggested that more thorough study of the turquoise trade could be useful in providing greater insight into the question of Mesoamerican influence.

Nelson (2006) analyzed the degree to which Chacoan material culture provided evidence for Mesoamerican influence. He investigated the nature, timing, and extent of Mesoamerican-Chacoan interaction using the lens of material cultural evidence. Nelson proposed that the growth of Chaco as a ritual center was stimulated in part by a “macroregional cycle originating in Mesoamerica.” He also discussed evidence for direct versus indirect influence, concluding that local ritual/religious specialists in a social hierarchy selectively adopted Mesoamerican symbolic references as they sought “sanctification” of their social power. Nelson viewed Chaco as the northernmost member of a group of “polities that were autonomous” that participated in a regional cycle originating in Teotihuacan circa A.D 900. His case was built on both the presence and absence of symbolic references in the material evidence. The evidence considered included the design of the well-known colonnade at Chetro Ketl, Chacoan roads, copper bells, shell bracelets, as well as the similarities between ceramic “cylinder jars” and “thong foot vessels” at Chaco and similar ceramic vessels from other “polities” to the south. He concluded that the Chacoans certainly had knowledge of and distant interaction with Mesoamericans, but were not dominated by them. He stated that “The elite probably were not kings, but people highly knowledgeable about the constructed supernatural and natural order….” Nelson suggested that they adopted Mesoamerican symbols to glorify and legitimize their social position.

Young (1989) assessed conceptual similarities and differences between Mesoamerican cosmology and the cosmology of the modern Western Pueblos. She identified a set of Western Pueblo (Hopi and Zuni) cosmological concepts that are similar to documented Aztec cosmology. However, the material cultural evidence associated with these ideas in the Western Pueblos apparently post-date Chaco's florescence by 300 years or more, so any suggested cosmological connections with Bonito phase Chaco are moot.

Overall it is clear that Mesoamerican trade and cultural influence did impact on Chaco's development, as well as on the varied subsequent development of ancestral Pueblo cultures after people departed from Chaco. Nonetheless, the case for such influence as a dominant feature of the Chaco Florescence is far from conclusive; diffused influence and regional interaction appears to be a more supportable model given current evidence.

3.7 Chacoan Roads

Reports beginning in the Late 19th and early 20th centuries by Loew, Morrison, and Holsinger described road segments originating at Chacoan Great Houses including Pueblo Bonito, Pueblo Alto and Chetro Ketl that included stairways cut into the Mesa sandstone at multiple locations. Early aerial photography in the 1930s provided an improved method for identification of prehistoric roads and trails, and during the 1970s the National Park Service's Chaco Center applied ground based and remote sensing techniques to improve understanding of the prehistoric road network associated with Chacoan Great Houses. While hundreds of linear km of additional roads were proposed based on remote sensing data, in many cases ground based follow-up either failed to confirm the presence of such roads, or such work was not conducted. In 1983, publication of the Bureau of Land Management's "Chaco Roads Project" Phase I report provided an integrated view of work done to that date in identification of Chacoan Roads, and assessment and interpretation of their construction and usage. The Chacoan roads studied include at least eight principal routes radiating from Chaco and linking some outliers directly, totaling over 300 linear km. They range from relatively small 3 m wide trails to formally engineered 9-10 m wide structures where vegetation and topsoil was removed and stone curbing was installed. In multiple cases parallel roads were constructed, and short sections of road originate at some outlier Great Houses but only travel short distances towards Chaco or distinctive landforms before ending. Two particularly famous roads in the network are the ”Great North Road” that travels north from Pueblo Alto to at least Kutz Canyon, and the “Great South Road” that exits South Gap and leads to the outlier of Kin Ya a, near modern Crown Point as shown in ***Figure 4*** (Kincaid, 1983; Powers *et al.,* 1983).

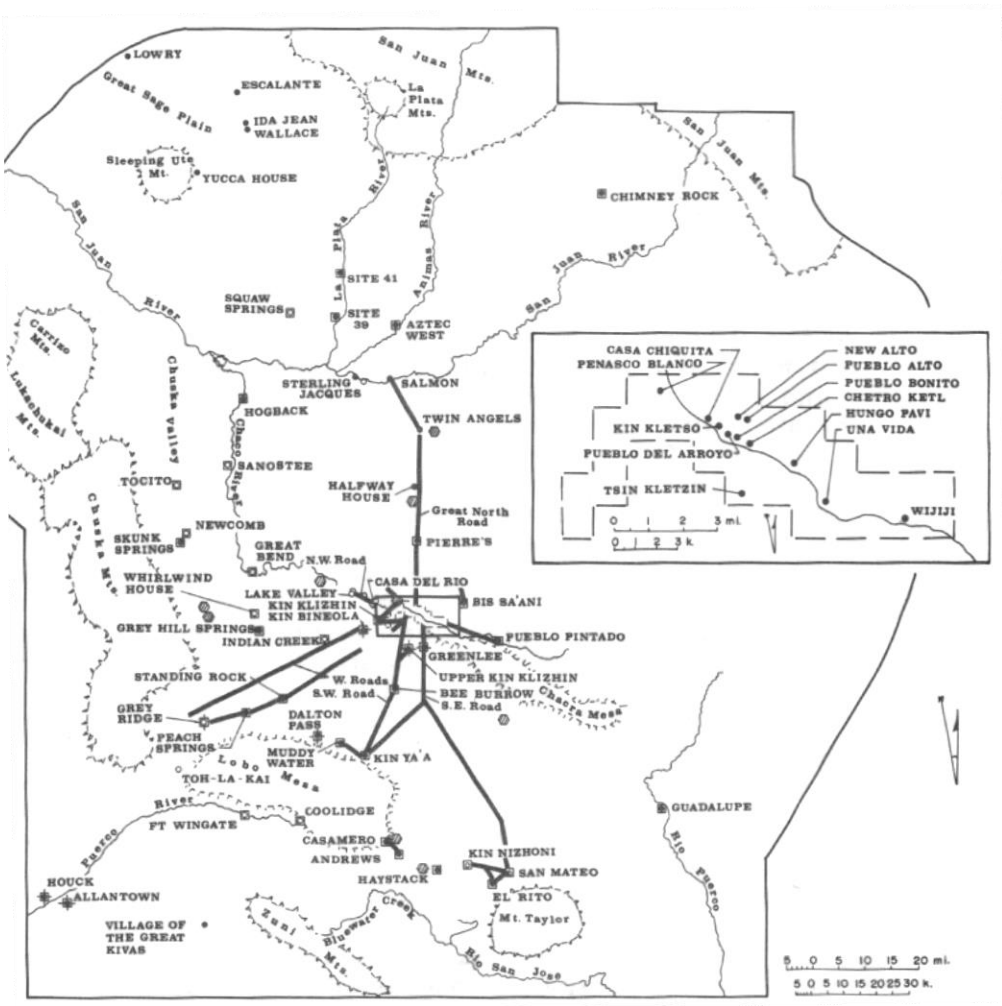


Figure 4. Principal Chacoan roads

(From Powers et al., 1983: 2). The scale of the Chacoan Road Network circa A.D. 1050-1175 is indicative of significant social investment of labor.

Chacoan roads have been variously assessed and interpreted over time. Initial models focused on the potential for transport of agricultural products in support of redistribution (see e.g., Ebert and Hitchcock, 1980). Interpretation of excavation results at Pueblo Alto led to adaptation of this model, instead indicating that a focus on transport into the canyon for ceremonial consumption associated with pilgrimage might be more accurate (see e.g., Judge, 1993: 35). Sofaer *et al.* (1989) interpreted the Great North Road as a primarily spiritual-cosmographic construct; however this conclusion was reached with limited reference to other elements of the Chacoan road network. A radically different explanation focuses on a militaristic-political interpretation of the road system. Wilcox (2004) proposes that the road system operated as an enabler for military transport in an emergent state that used force to extract resources as tribute from a dominated regional populace.

Roney (1992) proposed that the roads' primary importance was not utilitarian, but that they may have functioned as raceways or ritual ceremonial ways. He suggests that their construction was important to foster social integration. Kantner and Kintigh (2006) noted that a majority of Chacoan road sections connect outlier Great Houses to habitation sites, or appear to act as extensions of architecture to direct attention from Great Houses towards prominent landscape features. They also argue that the large number of disconnected roadway segments and road spurs are negative indicators for an economic or military transport model.

A particularly powerful example of linkage to landscape is the termination of the Great South Road near Hosta Butte, a distinctive landform visible over much of the San Juan Basin that remains sacred to Diné and some modern Pueblo people. While portions of the Chacoan roads were significantly over-built, this is predominantly true in proximity to Great Houses. Chacoan roads are frequently much less formal in remote areas between Great Houses, and sometimes peter out altogether. The roads may well have operated primarily as cosmographic representations or ritual roads, similar to Sofaer's proposal. They may be best interpreted as physical manifestations of roads through both time and space (Kantner and Kintigh, 2006; Van Dyke, 2007a: 144-164). Recent assessment of pottery breakage patterns along the Great North Road provides additional circumstantial evidence in support of this interpretation; the broken pottery does not appear to be randomly distributed along the road, rather it is spread along the edges of the road with sporadic distribution (Copeland, 2011).

3.8 Pilgrimage Models and Signaling

There is significant evidence that pilgrimage from outlying communities to attend large periodic gatherings may have been a feature of Chacoan ceremonialism. Primary indicators include the road network, the presence of outlandishly large middens at a few Great Houses, and the remarkable labor investment made in both Great House and road construction. Pilgrims may have converged on Chaco Canyon from more than 150 outlying communities, some distant enough to require 10 to 14 day journeys. Such events would have required a well organized calendar. Many festivals in the canyon would probably have occurred near December solstice, when agricultural tasks were light and the San Juan River could be crossed (Toll, 1985; Judge, 1991; Sebastian, 1992; Windes and Ford, 1996; Malville and Malville, 2001a, 2001b).

In a small community, announcement that an important festival was forthcoming can be by simple word of mouth. For a regional system, the announcement could be carried by runners or signaled with fire, smoke, or mirrors. Ellis (1991) provides a useful insight into signaling networks in the Pajarito Plateau, Galisteo Basin, Mesa Verde, Chaco Canyon, and Gallina. One of Ellis' guides identified a piece of selenite crystal as "Blue Sky Stone" because it reflected the blue of the sky so clearly. She was informed that sheets of selenite were shaved under water along the fracture line to obtain the most reflective surface. Gordon Page (1986) demonstrated that reflections from a wet unshaved selenite mirror 30.5 cm on a side can be seen from a distance of 7.6 km; using a wet shaved mirror the distance may be extended to 10 km. At the longer distances it was important to establish the direction from which a signal would come in advance. It was thus necessary to use “established signal locations” from which to transmit and receive signals; towers or high points, some of which were marked by circles of stones.

Most of the in-canyon Great Houses were inter-visible with multiple other Great Houses, and with Mesa-top shrines at locations such as 29SJ 423 (in the same location as the earlier Basketmaker III village) and 29SJ 1088. In combination with mesa-top buildings such as Pueblo Alto and multi-story “tower kivas” at outlier Great Houses like Kin Ya’a, this inter-visibility provided the potential for rapid regional signaling using line-of-sight communications (Hayes and Windes, 1975; Van Dyke, 2007a: 221-222). Testing has shown that a signal could be passed from Chimney Rock in the northeast, to Chaco itself, and subsequently to Kin Ya’a in the south near Hosta Butte, a distance of over 180 km, in a total of only four or five relays or “hops” depending upon the signaling path. Locating some of the shrines at the sites of villages from an earlier period may also indicate ancestor veneration, and a durable cultural focus on sites with long sightlines (Drager, 1976; Hayes and Windes, 1975: 154-155; Van Dyke, 2007a: 221-230; Windes, 1975).

If Chaco’s architecture was monumental and the canyon was a destination for pilgrims, it is worth considering what a pilgrim may have experienced during the peak of the florescence. The following brief narrative applies Van Dyke’s (2007a: 137-200) experiential descriptive approach for sites, viewscapes and inter-site foot travel between Outliers and Chaco. This narrative is informed by viewscape observations I made during visits to Bis sa’ ani, Pierre’s, Padilla Well, Kin Klizhin, 29SJ 423, 29SJ 1088, Pueblo Alto, Chetro Ketl, and Pueblo Bonito between 2008 and 2010. While conjectural, it may provide insight into the experiences of visiting pilgrims who may have supported the growth of the Chacoan system. The picture painted is general, and as discussed above it does not represent a consensus view shared by all archaeologists. Notwithstanding, it is plausibly supported by over a century of archaeological, ethnographic and astronomical research (see e.g., Lekson, 2006; Malville and Malville, 2001a, 2001b; Neitzel, 2003; Toll, 1985; Van Dyke, 2007a; Windes, 1975, 1987; Zeilik, 1987).

From any direction of approach most of Chaco is hidden from view, but one or two clear markers can be seen on the horizon to identify it as a destination. Approaching from the north, one may see Pueblo Alto high on North Mesa for the last two days of a walking journey. From the southwest and west, the shrine cairns at 29SJ 1088 provide an imposing marker for the western entrance into the canyon. Clearly visible for tens of kilometers, South Gap's break between mesas is a beckoning gateway if one approaches from the south. Coming from either the southeast or northeast, Fajada Butte provides a clear marker; visible for over a day's walk as seen in ***Figure 5***. No matter the approach, obvious topography or man-made markers point the way to the Chacoan Great Houses that are hidden from view at a distance.

Figure 5. Fajada Butte as seen from 13 km northeast of Chaco

From most approaches, there are clear markers of the canyon visible over long distances, yet the in-canyon Great Houses are hidden from view.

At an outlier community, the local sun watcher's horizon observations may have been confirmed by a signal from a highly visible shrine site nearer to the canyon. Sunlight flashing on a piece of polished selenite could confirm that the time for the winter solstice festival had arrived. With two weeks' warning, pilgrims prepare and then begin their journey on foot. It would be cold and windy for much of the multi-day journey to the center place at Chaco. They carry food, water, and perhaps offerings including grain and ceramics.

Pilgrims arriving from the north might spend the night at Pierre's outlier, and then walk for two days across the flat San Juan basin on the Great North Road. The road is almost perfectly straight for long sections, trending to the southwest as it follows a generally north to south path from Kutz Canyon near the San Juan River to Pueblo Alto.

Upon arrival at Pueblo Alto, the pilgrims deliver an offering of grain to be stored in the building. They pass through a break in the wall that extends from the east end of the Great House, and perhaps stop to break pots as a further sacrificial offering as they approach the "center place." After descending stairways cut into the sandstone of the Mesa, and upon their arrival on the canyon floor, the massive structure of Chetro Ketl comes into view. It faces to the SSE, as many Chacoan buildings have for generations. Hidden by the mesa just moments before, Chetro Ketl towers multiple stories above them as they approach. Looking across the wash to the south side of the canyon the pilgrims see clusters of much smaller buildings; homes like their own where farmers dwell. A few hundred meters further, and Pueblo Bonito comes into their field of view. Enormous in the morning light, it stands four or five stories tall and is covered with plaster. Pueblo Bonito's front entrance is flanked by huge earthen mounds surrounded by masonry walls. Perhaps one of the leaders of Pueblo Bonito stands on the mound outside; resplendent in a feather cape and beaded jewelry, he stands a full head above most of the people present.

It is the time when one cycle ends and another begins. The pilgrimage to the center place is important to all of the people, even if they speak different languages and tell different migration stories about their ancestors. They must observe proper ritual to ensure that the sun will come back from his winter house to warm the earth, so the corn and squash can grow again during the coming year.

3.9 Departure and Reuse

There is no clear consensus on how the Chacoan system ended, but physical evidence supports the idea that both agriculture and politics played a part. What is certain is that no Great House construction occurred at Chaco after about A.D. 1140. A severe and extended drought occurred between A.D. 1130 and 1180 (Vivien *et al*., 2006), making life at Chaco extremely challenging. Such a drought would likely reduce the legitimacy of any social elite claiming to have influence or control over rainfall and associated agricultural productivity.

By 1180, there may have been few people left in the canyon (Lister and Lister, 1981: 203-204; Vivian and Mathews, 1965). However, recent isotopic analysis of cobs dated to the late 1180s shows there was at least a small population at Chaco who were importing corn, potentially from the Totah region to the north; it is unclear whether this was a residual population or a reoccupation (Benson, 2010).

During the early portions of the period A.D. 1200-1300, the population grew again as climate conditions improved. Nonetheless, this final period of “Mesa Verdean” Pueblo reoccupation at Chaco is clearly different. No new monumental architecture was created, though many of the existing structures experienced periods of reuse. There is also clear evidence of increased warfare and strife in the Pueblo world at this time, though not within Chaco itself (Haas and Creamer, 2000, Kohler and Kramer, 2006; Kuckelman, 2000, 2006, 2010; Varian, 2006). Towards the end of the 1200s, yet another period of prolonged drought may have provided the final push that resulted in Pueblo people migrating back south and east to the Rio Grande valley, southwest to Acoma, or west to the Hopi lands (Judge and Cordell, 2006; Kantner and Kintigh, 2006; Lipe, 2006; Ortman, 2009; Van Dyke, 2007a; 206-209).

4 THE ETHNOGRAPHIC RECORD – PUEBLO ASTRONOMY

This chapter discusses documented astronomically-related beliefs and practices among historic-period Pueblo People who have been identified as likely descendants of Chacoan people. In addition, the chapter includes a brief discussion of the limitations of such reporting, and introduces the approach used to apply astronomical ethnographic reports to the analysis of Chacoan cultural remains.

Chacoan archaeoastronomy benefits from the availability of historic-period ethnographic data for Pueblo people. Oral histories maintained by Pueblo clans may provide some insight; it is clear that echoes of past socio-cultural stress are still recalled. Some Pueblo origin stories include a location known as the “White House,” where momentous events took place, ultimately leading to a downfall. While ethnographers and archaeologists debate which of the ancestral Pueblo locations may have been the “White House,” Chaco is almost always on the candidate list (Lekson, 1999: 145-147). Notwithstanding, “White House” is also frequently associated with the direction of East (Dozier, 1983: 207) which is at best curious given that the modern pueblos lie in an arc from southwest of Chaco in Arizona to southeast of Chaco along the Rio Grande.

The ethnographic record is rich enough to justify Zeilik’s observation (1985c: S95) that claims of astronomical use for any site require that “first, it must work astronomically…; second, it must make sense in the context of the culture.” Notwithstanding, application of the available ethnographic evidence has challenges that transcend simple issues of ethnocentrism. In particular, modern Pueblo people manifest significant diversity in their cultural traditions, as well as known divergence from apparent Chacoan traditions (see e.g. Kantner, 2006b; Parsons, 1939; VanPool *et al.* 2006). A period of some 800 years passed between the end of the Chacoan system and initial collection of anthropological data. In addition, archaeoastronomy research is particularly dependent upon 19th century ethnographic reports collected using methods that modern anthropologists justifiably find questionable.

The nineteen modern Rio Grande ("Eastern" or "New Mexico") Pueblos have experienced significant cultural adaptation as a result of Spanish contact and the acceptance of Roman Catholicism. Modern holidays and complex ceremonialism linked with the pre-contact religious traditions survive, but holidays have generally been relabeled as "Saints Days" and ceremonial practices have evolved. The specifics of religious society structure and retention of pre-contact observances vary significantly. In addition, the Rio Grande Pueblos apparently manifested significant pre-contact cultural differentiation (Dozier, 1983; McCluskey, 1977; Parsons, 1939; Zeilik, 1985c).

Within the Eastern Pueblos three distinct languages coexist; Tano (which includes three distinct dialects; Tiwa, Tewa, and Towa), as well as Keresan and Zuni (Sando, 1998: 1-45). The Katsina religion that probably developed in the A.D. 1300s also had significant influence on the Rio Grande Pueblos. It is evident that multiple prehistoric cultural traditions, including variations in political, social, religious, and ceremonial organization are integrated among modern Pueblo people (see e.g., Adams, 1991; Adams and Lamotta, 2006; Dozier, 1983: 31-37; Kantner, 2004a: 230-232; Lekson, 1999: 145; Parsons, 1939; VanPool *et al*., 2006).

The Pueblos clustered at First, Second and Third Mesa in Arizona ("Western Pueblos") are mostly populated by Hopi speakers, though there are also Tewa speakers whose ancestors migrated west during the 1696 Pueblo Revolt against Spanish rule. The Hopi clans have cultures less influenced by Europeans, and have rejected Roman Catholicism from the time of initial contact. Nonetheless, the development or importation from the south of the Katsina religion is certainly overlaid upon any remaining Chacoan traditions (Adams, 1991; Adams and Lamotta, 2006; Lekson, 1999: 145; Kantner, 2004a: 195, 230-232; Parsons, 1939; VanPool *et al*., 2006).

With this level of cultural differentiation and developmental complexity, reasonable identification of likely Chacoan cultural traits requires focus on those that are both widely incorporated across modern Pueblo cultures, and demonstrably linked to the physical evidence at Chaco.

4.1 Calendrical Stations and Sun Shrines

As a sedentary agricultural culture, Pueblo people traditionally relied heavily on the use of solar calendrical observations. These practices are in contrast to the stellar heliacal rise calendrical observations more familiar to westerners. Such stellar observations are more common in cosmopolitan or nomadic traditions, including those of the Greeks and Egyptians.

Though Pueblo calendrical systems have been more or less corrupted since European contact, recorded practices among the Hopi people of Walpi at First Mesa may be among the least disturbed. These people utilize both solar horizon and lunar observations to create a calendar that includes agricultural and ritual components (McCluskey, 1977). Similar practices utilizing solar horizon position, supplemented with daily timekeeping using solar shadows are maintained at Zuni and Isleta (Young, 1996: 53). These approaches are not unique adaptations. In the most general sense, all cultures are known to integrate astronomical calendrical observations into their ritual practices; people identify days of special significance based upon observation of certain astronomical events. Similar to the nature of the advent calendar and Christmas in the Christian world; the "apartness" of repeated calendrical festival days such as the Hopi winter solstice festival of Soyal differentiate them from "normal days." “Apartness” is a clear component in their very nature (Malville, 2006: 1-2).

While a wide range of ethnographic and anthropological publications contain fragments of related material, four sources in particular (McCluskey, 1977; Williamson, 1984; Zeilik, 1985b, 1986b) provide a summarized view of Pueblo calendrical practices. The practices differ in detail, but are surprisingly consistent across the Pueblo world. All but one modern Pueblo are known to have utilized related methods.

Sun Priests take daily observations utilizing horizon markers that make up a solar calendar. Individual sunrise (and less commonly sunset) horizon features are associated with days of both secular and spiritual significance. While some researchers have stated that there must always be a single calendrical station, this varies by Pueblo. Depending upon local topography a single calendrical station may be used for observations throughout the year, or multiple stations may be utilized to create an integrated calendar. Observing locations are not commonly marked; during the historic period a minority was associated with rock art.

In contrast to calendrical stations, sun shrines are usually marked with rock art. These are not observing locations; rather they function as places to make offerings to the sun. Sun shrines often occur at mesa tops or edges, and are frequently associated with the horizon foresights observed from calendrical sun watching stations. A variety of offerings may be made at such shrines, including grain meal, or prayer sticks. In addition to solar horizon calendars, sun priests also utilize constructed alignments. These are based on light and shadow play through windows or portals to create architectural alignments between the sun and wall features for calendrical purposes, as for example at Zuni.

Lunar phase observations are also integrated into many Pueblo calendars; lunar observation triggers are associated with many festival days, and there is evidence for a unique system of intercalary synchronization by at least one Pueblo.

The distinctions between agricultural and ritual use are sometimes subtle, frequently related, and sometimes integrated in unique ways within the calendrical system. For example, one Hopi calendar includes the spiritually significant lunar festival of Powamu, a time for ceremonial planting of bean seeds indoors. This festival takes place during the first moon after the winter solstice festival of Soyal, and foreshadows the commencement of the first agricultural planting day much later in the spring. The actual planting day is identified by a separate horizon sunrise foresight (McCluskey, 1977). This single Hopi example of linked festivals and planting dates based on the relationships between solar and lunar observations is relatively complex. When assessed in the context of known cultural variation and change in Pueblo practices over time, this complexity demonstrates the futility of attempting to recreate a Chacoan calendrical system in full detail. Nonetheless, general application of known observational and calendrical approaches is possible. Horizon foresight calendars linked to events of known significance such as the solstices are reasonably based on a foundation of supporting ethnography.

The accuracy of horizon calendars is worst when day-over-day solar motion along the horizon is smallest, at the solstices. As a result the solstices present the best possible time for a Sun Priest to impress the public with a display of skill; errors of a few days are undetectable. This situation is perfect for maintenance of ordered ritual activity. Calendrical ritual among historic-period Pueblo people operates as a foundational structure for social integration of both ritual and agricultural activity (Kuwanwisiwma, 2004: 43; Malville and Malville, 2001a; McCluskey, 1977; Ortiz, 1972: 98-111; Plog, 2008: 63-64, 100; Zeilik, 1985b, 1985c, 1986a, 1986b, 1987, 1989).

4.2 Cardinal Directions and Cosmology

As with calendrical systems, modern Pueblo cosmology includes significant variation, but is nonetheless characterized by a set of common principles. The most important of these principles involve cardinal directions, dualism, and “center place.”

All Pueblo cultures include the importance of cardinal directions or the inter-cardinals in their cosmological systems. The cardinal directions (North, South, East, and West) are cosmologically dominant among most of the Eastern Pueblos, while the inter-cardinals associated with the annual solar cycle are of cosmological importance at Zuni and Hopi. Most Pueblo people also include Zenith and Nadir in their system to yield a set of 6 cardinal directions. Multiple Pueblo creation myths (“cosmogony“) include descriptions of “emergence” into this world from an underworld (or multiple layers of underworlds) below. People are believed to have climbed up a plant or tree and through an opening or orifice of the lower world (“Sipapu” among the Hopi, “sipap” among Keresan people, “sipophene” among the Tewa) into this world. The orifice is also identified as the “navel of the world” or “earth navel” (Dozier, 1983:

204-212; Ortiz, 1972: 13-28; Parsons, 1939: 99-103, 210-266; White, 1935, 1962; Young, 1996).

Cardinal directions in the context of cosmology and emergence myths form one foundation for modern explanations of the design of the ceremonial kiva. In modern times kivas take varied physical forms at different pueblos, but they are consistently used as places of social interaction, refuge, cultural continuity, and ritual practice. As discussed above, during Chacoan times Great Kivas were built circular, with a set of formalized architectural features and, frequently, North-South alignment of the axis of symmetry. The Acoma explanation reported by Sterling (1942) discusses the kiva structure as a model cosmos based in part upon one creation myth.

> When they built the kiva, they first put up beams of four different trees. These were the trees that were planted in the underworld for the people to climb up on. In the north, under the foundation they placed yellow turquoise; in the west, blue turquoise; in the south red, and in the east white turquoise. Prayer sticks are placed at each place so the foundation will be strong and will never give way. The walls represent the sky, the beams of the roof (made of wood of the first four trees) represent the Milky Way. The sky looks like a circle, hence the round shape of the kiva.

Cardinal directions are symbolically associated with colors, mammals or birds. For example, eagles are associated with the cardinal Zenith direction among Zuni, Keresan, Jemez and Tewa people (Dozier, 1983: 205-206). Among the Zuni, the Eagle is also associated with the Sun. When impersonated, the Hopi sun god "Tawa" wears both eagle and parrot feathers arrayed in a circle about his face, like the rays of the sun (Young, 1989). The continued importance of eagles and their feathers as ritual objects is evidenced by inclusion of an eagle hunting clause in the Hopi tribal constitution (National Park Service, 2001). Hough (1915: 170-171) documented a method of eagle capture that is apparently no longer in use:

> Among the sacred hunts that of the eagle was one of the most ancient as well as important. Small circular stone towers about four feet [1.2 m] in

> height were built and across the top were laid beams to which were tied dead rabbits as a bait. … Within the tower the hunter hid after a ceremonial head washing symbolic of purification, and the deposit of a prayer-offering at a shrine. The eagle, attracted by the rabbits, circled around and at last launched himself upon his prey. When he had fastened his talons in a rabbit the concealed hunter reached through the beams and grasped the king of the air by the legs and made him captive, taking him to the village where a cage was provided for his reception.

Principles of dualism and binary opposition also run deep in Pueblo culture. Kivas are often built symmetrically across an axis of reflection. Mythological beings often appear in pairs (e.g., Twin War Gods, the Corn Girls, and the Cloud Boys), and dualism plays a strong role in social organization. The Rio Grande pueblos maintain moiety social structures (dual tribal subdivisions) where individuals are identified for example as “Winter People” and “Summer People,” or as “North” and “South” people. These moieties have particular religious and ceremonial importance (Dozier, 1983: 207-208; Ortiz, 1972; Sando, 1998: 34-35, 218).

For the Hopi, dualism explicitly underpins their cosmology, as well as concepts of time and life. The Hopi ceremonial year is divided into two distinct seasons, half the year includes masked Katsina ceremonies, and half does not. The “upper world” is associated with daytime, summer and life. The “lower world” is associated with nighttime, winter and death. Sunrise and sunset, as well as the winter and summer solstices are viewed as transition points in an ongoing dualistic cycle-of-cycles. The ceremonial cycle is reflective of this view. Recall how the Powamu ceremony is a foreshadowing event to actual planting. The act of planting is conducted in a dual way; ceremonial planting and agricultural planting. Similarly, the Hopi believe that within the “lower world” the ceremonial calendar is reversed. So, Powamu occurs in February in the upper world, and September in the lower. The dualism of the Pueblo world view is explicitly linked to visual astronomy; the sunrise and sunset cycles, as well as the seasonal path of the sun through the year (McCluskey, 1977; Young, 1996).

A third related element of the Pueblo world view is often described as “center place.” Pueblo people have a strong sense of ethnocentrism, and for most their Pueblo is traditionally viewed as the literal center of the universe. This is a particularly experiential approach to defining a society’s place in the world. The easiest way to explain the concept of “center place” is to identify it as the point of balance between identified dualities. It is the location around which the sun, moon and seasons move, the point around which the cosmos revolves, and thus the center of the cosmos. Identification as the “center place” has usually been reserved for a home pueblo during the historic period, but there is evidence that at Chaco the in-canyon Great Houses may have represented the center place for a regional system that supported emergence of socio-political, economic, and ritual hierarchy (Dozier, 1983: 209-210; Ortiz, 1972: 22-25; Van Dyke, 2007a: 105-135; Young, 1996: 54).

It is unreasonable to attempt detailed descriptions of intent, social organization or ceremonial life for the Chacoans based upon modern ethnographic information. Nonetheless, modern Pueblos share important space-and-time based culture elements. They share a world view that is tightly coupled to visual astronomy. Common observational practices, as well as the importance of cardinal directions, dualism and “center place” are core elements of pan-Pueblo cosmological and cosmographic beliefs. Chacoan archaeoastronomy should reasonably be grounded in these cultural principles.

4.3 Pueblo Star Lore

The star lore of Pueblo people is not as well documented as their sun watching traditions, but there are reports of asterisms and constellations with important symbolic content. Varied fragments of Pueblo constellation knowledge have been published, and observation of star groupings is mentioned in the anthropological literature as having importance. These include the constellations or asterisms now labeled as the Big Dipper, the Pleiades, and Orion, as well as Venus (both as morning and evening star) and a star referred to as the “Big Liar.” Observation of such stars or star groupings through rooftop kiva openings is documented as a timing marker for nighttime ceremonial activities. For example, it is reported that the "belt stars of Orion" were used as a timing marker for a ceremonial song that is a prominent component in the flute ceremony held among Hopi clans. In addition, star groupings that differ markedly from western constellations are reported, including the Zuni "Chief of the Night" which apparently covered much of the observable sky (Hough, 1959: 157; Young, 1996: 59-60).

Velarde (1989: 9-17) reported a star story she was told as a girl in Santa Clara Pueblo. It includes the migration and emergence story of the people, who were led by "Long Sash" (Orion). He guided the people on their migration, along the "Endless Trail" (Milky Way) that represented the path followed by the people. The "Stars of Decision" are associated with determining whether to travel on or turn back; they are identified as the brightest starts in Gemini (Castor and Pollux). A portion of Cancer is identified as Long Sash's "war bonnet," and stars in Leo represent the love, tolerance, and understanding shown by young men who dragged a load for the people on two poles. The Big Dipper is identified as the animal "Long Tail," a constellation made up of seven stars, each of which represents one of the animals that helped people on their journey. Of particular note, this story of migration also includes major mountains, demonstrating integration of sky objects and sacred topography into the cosmology described by an oral tradition.

A lady of Hopi birth who now lives in a Rio Grande Pueblo reported deliberate alignment of architecture with celestial objects to the author during a discussion regarding a recently identified solstice marker at a Great House at Chaco Canyon. She stated that "almost all of the buildings in the village where I grew up were built to align with the stars or the sun" (pers. comm., 2009).

An ancestral migration myth of the Hopi Snake clan as reported by A.M. Stephen to Mindeleff (1891: 18) explicitly links use of night sky object(s) and use of a staff technology for navigation during migration. It states in part:

> A brilliant star arose in the southeast, which would shine for a while and then disappear. The old men said, "Beneath that star there must be

> people," so they determined to travel toward it. They cut a staff and set it in the ground and watched till the star reached its top, then they started and traveled as long as the star shone; when it disappeared they halted. But the star did not shine every night, for sometimes many years elapsed before it appeared again. When this occurred, our people built houses during their halt; they built both round and square houses, and all the ruins between here and Navajo Mountain mark the places where our people lived. They waited till the star came to the top of the staff again, then they moved on, but many people were left in those houses and they followed afterward at various times. When our people reached Wipho (a spring a few miles north from Walpi) the star disappeared and has never been seen since.

Kuwanwisiwma (2004) similarly reported that a "new star" (specifically identified as SN 1054) was used as an ancestral migration signal, and discusses ceremonial staffs in the context of this tradition.

A systematic study of Pueblo stellar traditions has not been conducted as an element of this research program. Nonetheless, these fragmentary sources do demonstrate that night sky observation, and integration of night-time astronomical events into architecture may be an important feature of Chacoan culture. It is a worthy area of future research that may yield additional insights.

5 CHACO ARCHAEOASTRONOMY PRIOR TO 2007

This Chapter reviews the record of published studies conducted at Chaco in the past. This is intended as a near-complete review, and includes comparison and critique of the literature.

Early documentation regarding archaeoastronomy at Chaco is very limited. In his extensive analysis of Pueblo architecture, Mindeleff (1891: 148–149) explained how modern Pueblo people used standing stones at Zuni as “datum points” for solar calendrical observations. He further described a standing stone of similar appearance just east of the Peñasco Blanco Great House at Chaco Canyon, and speculated that it could have been used as a calendrical marker. Alas, field surveys during 2008 failed to identify the standing stone he described. According to a National Park Service archaeologist the area in proximity to Peñasco Blanco has been badly disturbed during the course of the last 110 years (R. Moore, pers. comm., 2008).

For decades after this scant reference, archaeology continued at Chaco Canyon without significant effort being dedicated to astronomical analysis. Only in the early 1970s did assessment of archaeoastronomy potential at Chaco begin in earnest. Evidence for calendrical stations was uncovered, and it was demonstrated that some Chacoan structures are designed to incorporate accurate orientation to the cardinal directions. From that time to the present, Chacoan archaeoastronomy claims have taken four main forms:

Calendrical Stations have usually been proposed based upon petroglyphs (rock carvings) or pictographs (pigment painted onto a rock surface) at suitable stations where observation of horizon features can be accomplished in proximity to Great Houses, or alternatively based upon observing locations at Great House structures.

Shrines are locations with ritual significance where offerings may have been associated with astronomical phenomena. These sites are often marked with cairns, low walls, and/or rock art. The positions of some also suggest potential use as signaling locations for communications related to pilgrimage for festivals.

Intra-site Alignments are constructed within an individual structure along a cosmological azimuth. Alignments of this type have been confirmed for the cardinal directions, and claimed for lunar standstill, equinox, and solstice events.

Inter-site Alignments have been well-documented between buildings on azimuths of cosmological significance, such as the North-South cardinal meridians. Most of these alignments are line-of-sight. There have also been controversial claims of long baseline alignments on cosmological azimuths that significantly exceed line-of-sight distances.

It is unfortunate that original field notes and data are unavailable for much of the published work. This is particularly disturbing given the fact that for many years National Park Service permits have been contingent on providing such data for archival purposes. In addition, descriptions of field methods, data reduction techniques, and justification of interpretation are quite variable in the literature.

5.1 Proposed Calendrical Stations

Three classes of potential calendrical stations have been identified at Chaco; Class 1 sites provide a suitable horizon calendar that includes both anticipatory markers and confirmatory markers for significant dates; Class 2 sites provide only confirmatory markers; and Class 3 sites are secondary calendrical stations that must have been constructed while using a Class 1 or Class 2 site as a primary reference.

In contrast to much of the surrounding southwest region, the local topography within Chaco Canyon prohibits broad vistas to well-marked horizons from most locations. Sites on the surrounding mesas and canyon rim such as the shrines at 29SJ 423 and 29SJ 1088, Pueblo Alto, and Tsin Kletsin have long sightlines across open views, but their horizons are generally very flat and are thus ill-suited for calendrical use. When suitable locations are identified, in much of the canyon horizon lines provide only close foresights, making calendrical station positioning much more critical than it would be in open terrain (Zeilik, 1989). ***Figure 6*** presents a typical view up or down the canyon from an in-canyon Great House, in this case from Talus Unit at the center of the canyon, adjacent to Chetro Ketl. ***Figure 7*** is typical of the horizon as viewed from a mesa-top location.

Figure 6. East Horizon as viewed from Talus Unit

A typical horizon as viewed from within Chaco Canyon. When looking up or down canyon the mesas generally present a small number of steps in an otherwise smooth horizon.

Figure 7. Northeast Horizon as viewed from 29SJ 423

Long sightlines to the northeast are shown from the location of a large Basketmaker III village that was later used as a shrine. Note the smooth horizons; typical when looking from a mesa top location at Chaco across the San Juan basin.

Pueblo horizon calendars are known to have been used for both ceremonial and agriculture purposes during the historic period. Solstitial celebrations such as Soyal among the Hopi exemplify ceremonial use (McCluskey, 1977; Williamson, 1984: 79-84). Most of the modern Pueblos, including members of all four language groups living at Hopi, Zuni, the Keres and Tanoan Pueblos maintain ritually important ceremonial festivals associated with a date on or near to the December Solstice (Zeilik, 1985b: S11). In the case of Chaco Canyon, there is circumstantial evidence that ceremonial calendrical practices may have been dominant. Accurate calendrical capabilities may have supported social integration of economic, political and spiritual authority by means of coordinated regional pilgrimage activity (Judge, 1991; Toll, 1991; Judge and Malville, 2004; Kantner, 2004: 93-95, 110, 138; Toll, 2006). For such purposes, anticipatory markers of significant ceremonial dates are very useful because they provide ritual and physical preparation time for participants and pilgrims. Calendrical precision is improved by making observations from two weeks prior to a particular date until two weeks following, especially at the solstices when day-over-day solar motion on the horizon is small. Anticipatory (Class 1) horizon calendar sites also provide the benefit of improved accuracy in the case of poor weather. For public gatherings a festival calendar with an accuracy of 1-2 days would enable visitors to reach the Canyon on time for a festival (Malville and Malville, 2001a; Zeilik, 1985b; Zeilik, 1987).

Class 1 calendrical sites are also important because, as a practical matter, accuracy of horizon calendars is worst at the time of either solstice when apparent solar motion is very small. For example, at the Winter Solstice of 2008 horizon movement of the Sun from Dec 19 through Dec 23 was less than 50 arcsec per day at Chaco. Human visual acuity is limited to a best resolution of ~ 45 arcsec for a person with 20/20 vision and a dilated pupil, not accounting for the difficulties of bright contrast when observing the Sun. A reasonable working estimate is that human observers are unlikely to be able to discriminate at levels better than ~ 1 arcmin (Malville, pers. comm., 2008).

As a result, apparent solar motion on the horizon for the days immediately around the time of solstice is essentially unobservable using naked eye astronomy. Even movement on the order of a few arc minutes would be discernible only with the aid of pronounced sharp horizon features. A byproduct of this fact is that the solstices present the best possible time for a Sun Priest to impress the public with a display of skill; errors of a few days are undetectable. This situation is perfect for maintenance of ordered ritual activity. Alternatively, integration of lunar phase observations can also provide a triggering event for festival activity, for example by holding a festival at the first full moon following the Solstice, similar to modern practices among some Hopi clans (Malville, 2008a).

Beyond a working horizon or secondary markers the identifying characteristics at calendrical sites are the subject of some debate. Early work tended to focus on the presence of pictographs or petroglyphs as markers (Benson, 1980; Williamson, 1984). Based upon historic ethnographic research Zeilik (1985c) recommended differentiation between sun shrines that were usually marked with rock art versus calendrical stations that were not; he also suggested that shrines were likely to be placed in locations that are working foresights for calendrical observations. Zeilik additionally noted complicating factors. Pueblo sun symbols have evolved noticeably during the historic period, and the usage and forms of rock art were apparently influenced heavily during the period in the 1300s when the Katsina religion arose (Adams, 1991; Adams and Lamotta, 2006; Schaafsma, 1980; Young, 1983). Clearly, additional qualification of calendrical site characteristics would be beneficial.

In the historic period, while most sun watching stations were not conspicuously marked, some were. At the Matsakya calendrical site a rock wall some 2-3 feet high enclosed a flat rock containing a sun symbol. At a Tanoan pueblo, perhaps Jemez, a sun watching station was identified by a solar monolith; some 2 feet high and 6 inches thick. In all cases, proximity of a calendrical site to the pueblo seemed to have a high priority because of the need for frequent observations at dawn (Zeilik, 1987, 1989).

5.1.1 The misnamed “Supernova Pictograph” (Unconfirmed Class 2)

In the northwest end of Chaco Canyon, approximately 500 m below Peñasco Blanco are pictographs consisting of a star, crescent moon, and handprint on an overhang (***Figure 8***). The set of concentric rings (lower vertical face) includes a difficult to photograph “tail” structure that extends to the right. It has been proposed to represent the sun’s disk, the 1066 appearance of comet Halley, or some other object.

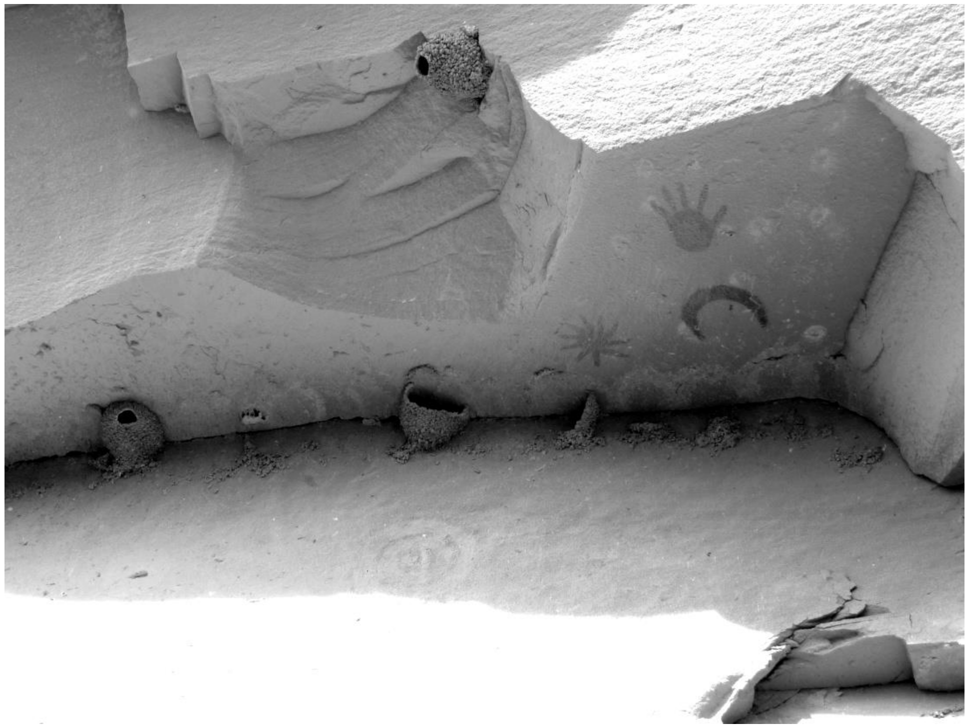


Figure 8. Pictographs below Peñasco Blanco

The hand, star, crescent, and concentric ring pictographs on this overhang have been variously interpreted as the morning star and crescent moon, a calendrical shrine, or (implausibly) the supernova of 1054.

Initial interpretation focused on the potential for the site to be a marker for a calendrical sun watching station, under the assumption that the three concentric rings represented a sun symbol. The upper three pictographs strongly resemble a group documented at a Zuni sun watching station (Cushing, 1883). The view in the immediate vicinity of the pictograph group does not present a useful horizon calendar. However, it was suggested by O'Flynn that a sheltered site approximately 20 yards above the pictographs on the mesa rim was suitable. He subsequently observed a sunrise "near the solstice" from this position that emerged along a "sharp mesa edge." Reportedly, the horizon line from this position also presents suitable markers for the equinoxes and summer solstice, but there is no documentation of anticipatory markers at the site (Williamson *et al.*, 1975; Williamson, 1984: 86-88). Subsequent efforts to confirm O'Flynn's observation have not yet been successful.

Later researchers suggested alternative interpretations for the pictographs, including the possibility that the starburst represented the Supernova of A.D. 1054 that created the Crab Nebula (Brandt *et al.*, 1975). This interpretation has so caught the public imagination that the site is usually now referred to as the "Supernova Pictograph." It has also been suggested that the lower panel containing the concentric circle pattern may represent the dramatic 1066 appearance of Comet Halley, recorded by both the Chinese and in the Bayeux Tapestry (Cornucopia, pers. comm., 2003; Nordgren, 2007; Malville, 2008a). A more prosaic explanation presents itself in ethnography; the morning star and crescent moon form a common motif among modern Pueblos (Ellis, 1975; Malville and Putman, 1993: 30, 36-38). The varied explanations are not mutually exclusive of course, multiple meanings may have been ascribed to the same symbols.

These widely varied interpretations point out some of the difficulties of archaeoastronomy, and Chacoan archaeoastronomy in particular. In the first instance, pictographs cannot be accurately dated by any current technology; nor for that matter can petroglyphs. As a result, the presumed Chacoan origin for this rock art is based upon circumstantial stylistic and ethnographic evidence. Paleo-Indian people inhabited this region before the Chacoans, and Mesa Verde Puebloans and Diné after them. A Chacoan origin is certainly plausible based upon the available evidence, but it is by no means certain.

In addition, the methods applied by early researchers leave us with knowledge gaps. Just as the location of Mindeleff's standing stone is unknown, so too O'Flynn's proposed calendrical station is not well documented; no documented horizon survey or confirmation photography from that point exists. At the very least, validation of O'Flynn's proposed calendrical station using a theodolite survey of the horizon would be of value in further analysis of the varied interpretations. Such analysis could determine if this is in fact a workable calendrical site, or that alternatively it may more likely be a shrine location. Since the site cannot be dated effectively at this time, its specific pertinence to the story of Chacoan Astronomy must remain speculative. Notwithstanding, the rock art at this site demonstrates clear Native American interest in the sky.

5.1.2 Kin Kletso (Class 1)

Kin Kletso Great House was constructed during the Late Bonito phase (A.D. 1125-1130); it is one of the late Great Houses built to single plans in the McElmo masonry style (Lekson, 1984:238-246). Kin Kletso provides a Class 1 calendrical capability by utilizing dual observing locations with a single horizon foresight. ***Figure 9*** presents the Kin Kletso sightlines to its December solstice sunrise horizon foresight. By standing at the southeast corner of the building, an anticipatory observation of the foresight may be made fifteen to sixteen days prior to solstice. On the solstice, a visually consistent sunrise is observable from the northeast corner (Malville 2008a, 70-71).

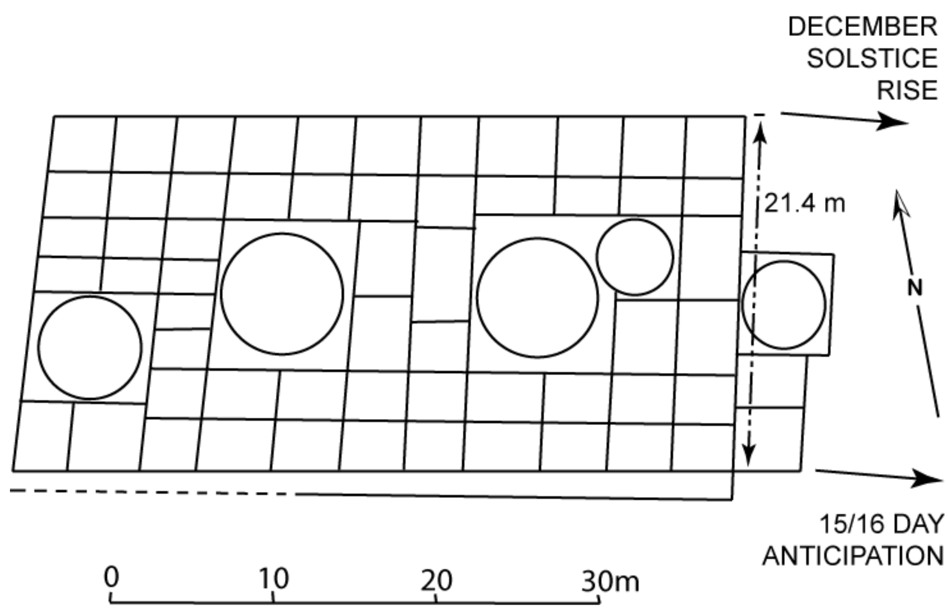


Figure 9. Kin Kletso site plan

(Adapted from Lekson, 1984: 239).

Kin Kletso's dual observing locations illustrate a primary concern of archaeoastronomers when assessing potential calendrical stations. Because of parallax, the observing location for a close foresight is more sensitive than for a distant foresight. We are skeptical of potential calendars with close foresights unless the observing locations are well marked, because small movements will "break" the alignment. In the case of Kin Kletso, it appears that the 21.4 m length of the east wall may have been designed to mark the anticipatory and confirmatory observation stations with building corners.

Kin Kletso may have been built at the site of a previously used calendrical station. The idea that a Great House was deliberately constructed at a known calendrical station has also been posited for Wijiji (see below). ***Figure 10*** depicts the sunrise as observed from the southeast corner of Kin Kletso on December 8, 2001. The view is visually consistent from the northeast corner on the solstice itself.

Figure 10. Kin Kletso December solstice anticipation sunrise
(Photograph by G.B. Cornucopia, used with permission).

Kin Kletso's December solstice sunrise foresight is the vertical mesa face directly behind Pueblo Bonito. The small horizon point visible to the right of the sun in ***Figure 10*** is a standing wall section within that Great House. The presence of a workable solstice calendrical horizon marker provides circumstantial evidence supporting interpretation of Kin Kletso as symbolic and monumental architecture (Malville *et al.*, 1996; Malville, 2008a: 70-71). During the late 10^{th} and early 11^{th} centuries, December solstice sunrise as viewed from the future site of Kin Kletso would have been framed by the mesa and a lone ponderosa pine standing in the plaza of Pueblo Bonito (Stein *et al.*, 1997; Ashmore, 2007: 187), presenting a particularly dramatic sight.

5.1.3 The East Horizon at Pueblo Bonito (Class 2)

In an effort to test the ability to apply ethnographically documented Pueblo sun watching practices in the context of a Chacoan Great House, Zeilik (1986a) visually observed and documented the calendrical potential of Pueblo Bonito's eastern horizon. He conducted visual observations from the southeast corner of the building, adjacent to room 176 (***Figure 11***). As shown, he found a workable set of horizon foresights for much of the year, including June Solstice Sunrise ("JSSR") and a range of markers that corresponded to the planting season documented for the Hopi. The flat horizon to the southeast does not provide any useful makers for late fall, or December solstice. However, when integrated with the proposed Class 3 calendrical station discussed in the next subsection, these dates are covered.

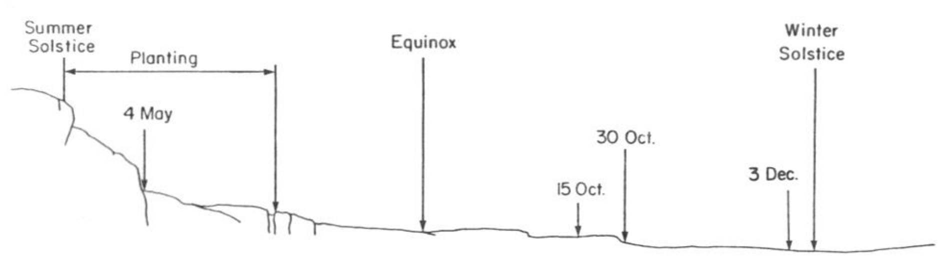


Figure 11. Pueblo Bonito East horizon

(After Zeilik, 1986a: figure 3) The indicated planting date range is based on modern records from the Hopi.

5.1.4 Corner "Solstice" Windows at Pueblo Bonito (Class 3)

Rooms 225C and 228C within the Southeast corner of Pueblo Bonito were identified as likely calendrical observation stations for the winter solstice by Reyman (1976). In both rooms, otherwise unique "corner windows" provide a view of the solstice sunrise horizon (***Figure 12***). The accepted construction dates for the portion of Pueblo Bonito containing these two windows correlates to the "Chacoan florescence," the period between A.D. 1070 and 1115 during which most rapid expansion of monumental architecture occurred (Stein *et al*., 2003). The basis for Reyman's hypothesis was an integrated analysis of ethnographic data for the modern Pueblos, and field analysis of the architectural remains at Pueblo Bonito. He noted correctly that a wide variety of ethnographic sources demonstrate modern Pueblo use of both architectural features and horizon foresights as calendrical markers. He also noted that all modern Pueblos save one are known to have engaged in solar calendrical observations, and that many utilize linked architectural and horizon calendar alignment systems.

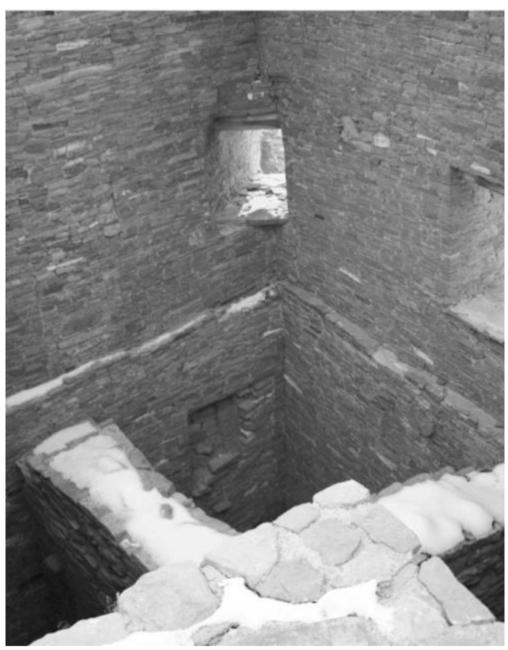


Figure 12. Pueblo Bonito; room 228 "corner window"

This photographs taken Dec 20, 2008 shows the "corner window" aperture though which light penetrates at sunrise to create a light play on the opposite wall.

Reyman's proposed tests for his alignment hypothesis were that a) the windows must have a clear view of the eastern horizon, b) they must provide an accurate parallel limb or cross-jamb sightline to the sun's solstice rise point on the horizon with an accuracy of plus or minus ½ degree, and c) that the sightline should be tangent to the sun's disk to maximize accuracy. Because the condition of the two rooms within Pueblo Bonito precluded accurate survey with a theodolite, Reyman undertook to test his hypothesis photographically. Based upon his photographic evidence he determined that his three tests were satisfied and that both windows provided plausible winter solstice calendrical stations.

Reyman did make note of the fact that the two windows are not in the outermost wall, and that the original height of the adjacent outer walls cannot be ascertained with certainty based upon available physical evidence. He also included an ex post facto explanation for the presence of two such windows, rather than one. He explains this seeming anomaly based upon a likely sequence of construction events associated with kiva C, which is adjacent. His construction sequence analysis was admittedly speculative, but is reasonably grounded in the archaeology, including the fact that room 228C likely became unusable during a construction phase for the kiva.

While Reyman's alignment finding was not disputed, within a year his interpretation had sparked debate. A number of salient facts and possibilities were identified, and primacy for the discovery was called into question. Reyman had identified the windows as third story features, and it was pointed out that they were in fact at a second story level, increasing the likelihood that outer walls were of the same height. It was also posited that because of their width and the sizes of the rooms in which they are located the windows do not adequately constrain an observational azimuth to be workable as a calendrical station without a foresight. Two alternative interpretations were identified; first that the windows were positioned to face the rising solstice sun more generally for ceremonial purposes (e.g., that special use rooms needed solstitial illumination without necessarily offering accurate calendrical markers), second that the presence of additional aligned ports in a now-missing outer wall would have enabled the light shafts to be applied for calendrical use (Williamson, 1977).

Most difficult is the uncertainty about the height of adjacent outer walls. Nonetheless, Reyman's central finding has stood the test of time. The two unique corner windows are aligned to the winter solstice sunrise azimuth. Room 228 in particular has become one of the most popular locations at Chaco to observe the December Solstice sunrise ***(Figure 13)***. In the weeks preceding the Solstice, the patch of light falling on the back wall of room 228 moves progressively closer to the northernmost room corner each day. The horizon line to the southeast of these windows does not provide any prominent features for calendrical foresights. As a result, they had to have been constructed on a secondary basis, with reference to some other primary calendrical station(s). Zeilik (1986a) confirmed that the corner window light play begins in late October, changing its geometry as December solstice nears. He noted that markings on the plaster wall of the illuminated room could have enabled anticipatory observation from this potential Class 3 calendrical station. In concert with the horizon calendar discussed immediately above, this station could provide a complete annual calendar at Pueblo Bonito.

Figure 13. Pueblo Bonito room 228 DSSR light play

As documented in this photograph taken Dec 20, 2008, as sunlight enters the corner window it aligns accurately to strike the corner of the room directly opposite.

5.1.5 June Solstice at the Great Kiva of Casa Rinconada (Class 3)

The Great Kiva of Casa Rinconada has become a place of "pilgrimage" in modern times for people interested in personally witnessing archaeoastronomical solar alignments. With a diameter in excess of 19 meters, Casa Rinconada stands on the south side of the Canyon among smaller habitations, in opposition to the northern placement of the Great House structures. The building contains twenty eight small regularly-spaced niches on an upper level of the wall that may have been intended to correlate with the monthly lunar phase cycle, possibly supplemented with a "missing" twenty ninth niche. Six larger irregularly-spaced niches are positioned on a lower level. In addition, the structure contains a pair of entry doors, an underground passage leading to a sipapu, and a window opening on the northeast side. Features of the Great Kiva are presented in ***Figure 14.*** Note that this simplified figure does not include depictions of now-reduced wall structures that made up antechambers outside of the north and south doorways, or the benches that are located around the circumference of the kiva.

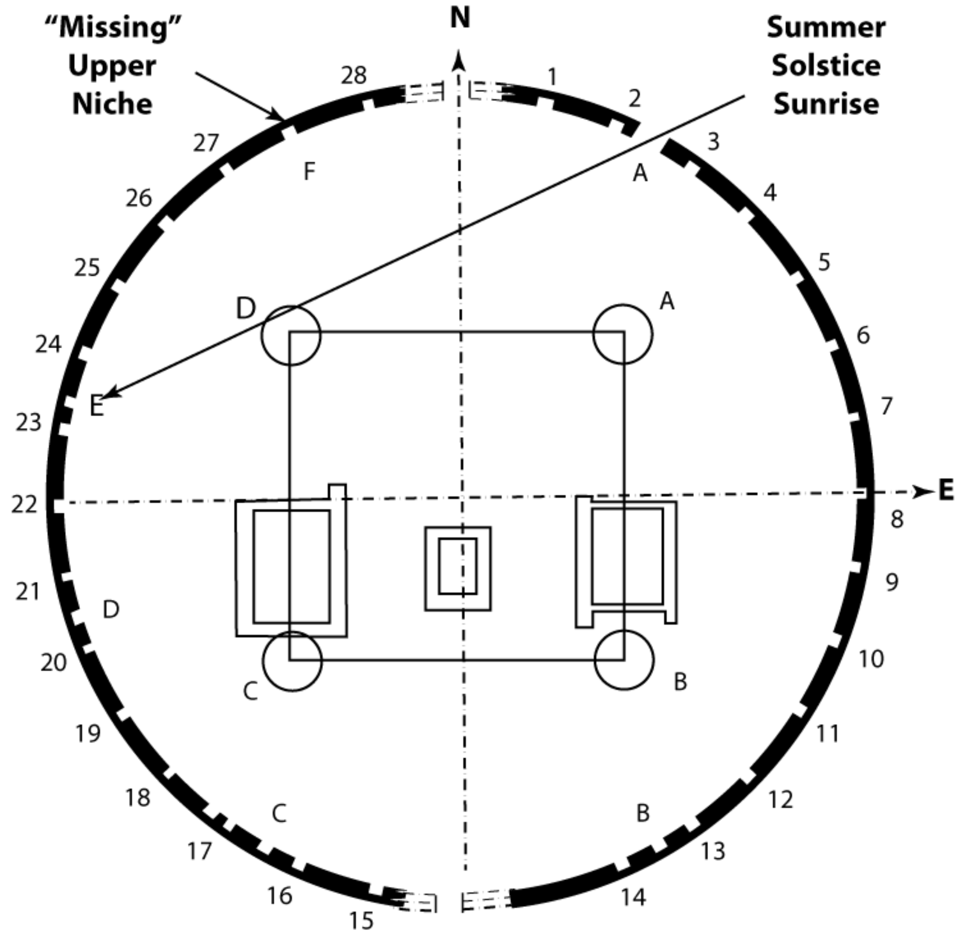


Figure 14. Casa Rinconada site plan

(Adapted from Malville & Putnam, 1993: 37; after Williamson, 1984: 137). Primary features of Casa Rinconada are illustrated by this floor plan, including 28 upper niches, six lower niches ("A-F"), and the possible blockage of the proposed Summer Solstice light path by the Pillar at "D."

Casa Rinconada's form is made clearer with reference to ***Figure 15***. The northern antechamber is visible outside of the north doorway in this photograph, as is the bench.

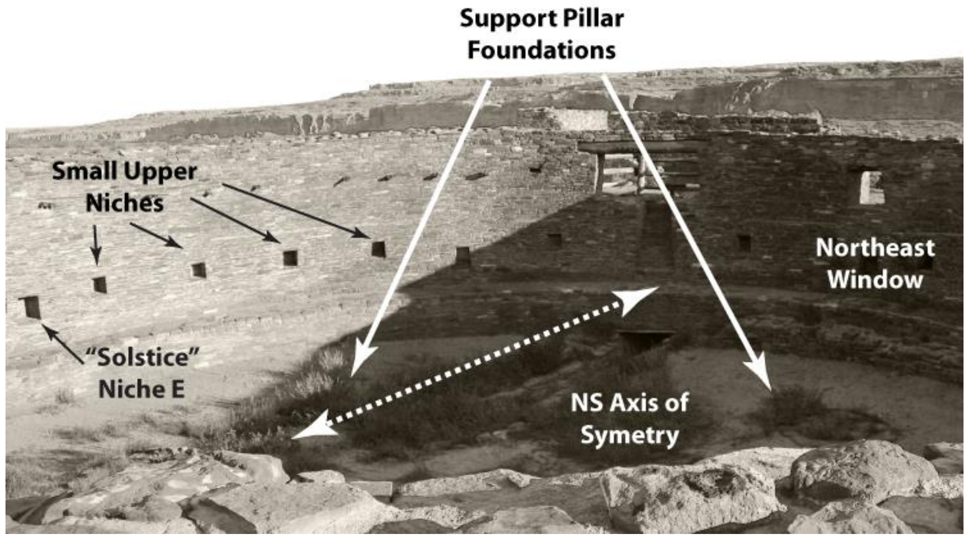


Figure 15. Casa Rinconada

Primary features of Casa Rinconada are illustrated by this photograph including upper niches, lower niche "E," and the Great Kiva's axis of symmetry.

On and near June solstice a dramatic light play occurs at Casa Rinconada. Shortly after sunrise, light entering the northeast window traverses across the kiva wall opposite and ultimately strikes lower niche "E" (Williamson, 1984: 136-137). This event is witnessed annually by hundreds of visitors who travel great distances to see it (***Figure 16***); for many it is their introduction to Chacoan archaeoastronomy.

Ironically, there is evidence to suggest that the alignment is a modern coincidence, and may not have been viewable in Chacoan times. Casa Rinconada was excavated by Gordon Vivian and the University of New Mexico/School of American Research field school in 1931, and reconstruction work began in 1933. Major elements of the structure, including the tops of the doorways, upper walls, antechamber elements, and multiple window lintels and window sides were reconstructed based on interpretation by Vivian and members of the reconstruction and stabilization team, and without certain data to drive decision making (CRA, 2010; Lister and Lister, 2004: 105-107). The particular window opening in question was reconstructed during the 1930s, and based on review of pre-reconstruction photography the relationship between its original and current opening size is very uncertain. In addition, the window occurs in a portion of the kiva that was surrounded by the outer wall of the north antechamber (***Figure 17***); it is impossible to determine if this outer chamber contained an aligned window or not, just like the case with the corner windows at Pueblo Bonito. In addition, the beam of light may have been partially or completely blocked by one of the four primary support pillars for the building (as shown at "D" above in ***Figure 14****)*. Lastly, there is some evidence that screens were installed in front of the niches, which also would have blocked sunlight (Cornucopia, pers. comm., 2007; Malville and Putnam, 1993: 35-36; Reyman, 1989).

Figure 16. JSSR light play in Casa Rinconada niche E

This annual visual alignment at Casa Rinconada draws crowds. While it may or may not have been intentional (see text) the fascination that modern visitors have with the event demonstrates some of the potential cultural impact of visual astronomical alignments with architecture.

Figure 17. North Antechamber at Casa Rinconada

The wall heights of the North antechamber, and presence or absence of windows to align with the reconstructed window (marked by the arrow) cannot be empirically determined. As a result, it is unknown if the modern JSSR light play operated during Chacoan times.

5.1.6 Hungo Pavi and Tsin Kletsin (unconfirmed Class 2/3)

William Calvin (1991: 75-120) 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 calendrical alignments in individual kivas, Calvin did suggest that a more convincing case could be made by identifying a pattern among a set of kivas. Alternatively, a more convincing case could be made by identifying both sunrise and sunset solstice foresights for the same kiva; the chances of that case arising serendipitously are lower than for a single sightline.

With these ideas in mind, Calvin's (1991: 125-138) compass survey work among the Ancestral Puebloan structures at Chaco led him to propose a pair of horizon calendrical 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. The sunrise he describes is geometrically similar to that shown above for the confirmed DSSR at Kin Kletso. 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 December Solstice sunset ("DSSS") foresight as observed from Hungo Pavi. Thus Calvin proposed both a Class 2 Sunrise, and a Class 3 (constructed) Sunset observable from Hungo Pavi's kiva. Because the author became aware of these proposals only after fieldwork for this study was completed, at this time Calvin's proposed calendrical alignments remain unconfirmed.

5.1.7 Piedra del Sol (Class 1)

Ft. Lewis College and the University of Colorado held a 1992 archaeoastronomy field school led by Jim Judge and Kim Malville. During that school participant Rick Watson, a professor of archaeology at San Juan College, pointed out a large spiral on the northeast face of a large boulder near the Visitors' Center. During their several days in Chaco Canyon the students of the field school investigated the multiple astronomies that seemed to be associated with this boulder. After consultation with park personnel the site, initially known as "Rick's Rock," was renamed "Piedra del Sol" due to its extensive solar symbolism. Theodolite measurements of the spiral and the pyramid shaped rock on the horizon by Malville made it appear likely that the spiral marked JSSR. The assistance of interpretive Ranger G.B. Cornucopia was enlisted to observe at the next June solstice, at which time this prediction was confirmed.

Approximately two weeks prior to the June solstice, a pyramid shaped rock above Piedra del Sol provides a sunrise foresight, casting a shadow onto a Spiral Petroglyph on the northeast side of the boulder. The shadow's penumbra prevents use as an accurate marker; however visual observations while an observer places the back of his or her head in front of the center of the spiral petroglyph allow precise determinations of the daily movement of the sun prior to solstice. From this location, anticipatory observation for the June solstice is possible; the sun rises directly over the pyramid shaped rock between June 4 and 6 (***Figure 18***). The days surrounding the solstice itself are confirmed by a notch on the foresight, to the left of the pyramid's sloping side.

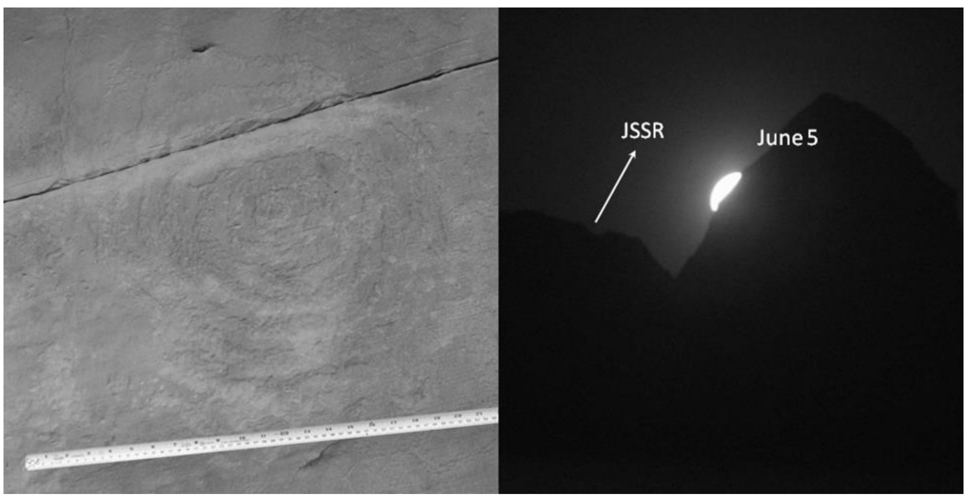


Figure 18. Anticipation of JSSR at Piedra del Sol.

(Right photograph by G.B. Cornucopia, used with permission.) An observer with their head positioned against the spiral petroglyph (left) can use the pyramid shaped rock (right) as an accurate anticipatory and confirmatory Summer Solstice foresight.

The south face of Piedra del Sol contains multiple additional petroglyphs, including one that may represent a coronal mass ejection observed during the July 1097 total eclipse that crossed the canyon (***Figure 19***). The western side of the rock includes a pecked basin similar to those found in Mesa Verde, which are often found in conjunction with bedrock grinding areas (Malville and Munson, 1998). These features may indicate post-Chacoan ceremonial activity at the rock. The basin, with a diameter of 8 cm and a depth of 5 cm, has a straight sided shape that distinguishes it from the more common round basins associated with Chacoan stone circles (Windes, 1978). The site is proximate to two Great Houses, Una Vida and Headquarters Site A.

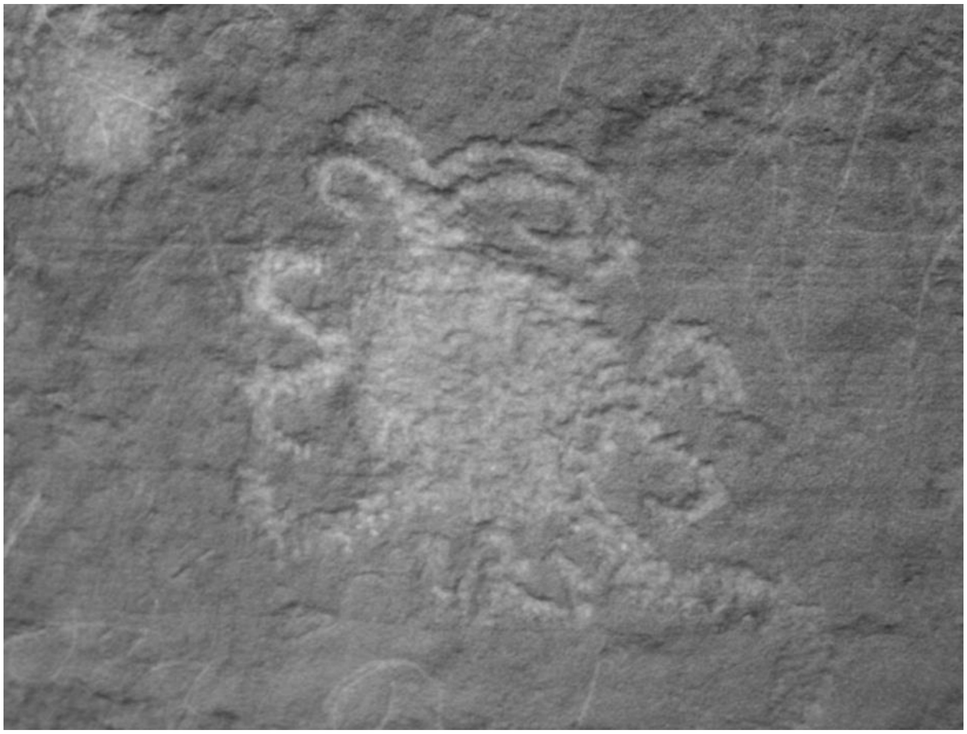


Figure 19. Piedra del Sol petroglyph

This unique form is visually reminiscent of a Coronal Mass Ejection, and may record the total solar eclipse of July 11 A.D. 1097. Venus, which was visible during totality, may be depicted by the circular petroglyph at upper left.

Subsequent observations by G.B. Cornucopia established that a west horizon feature also establishes sunset on December solstice as viewed from the pecked basin. The site has a direct line of sight to the three-slab “Sun Dagger” site on Fajada Butte (discussed immediately following), suggesting the possibility that it could have provided the primary reference for that Class 3 site (Malville, 2005; Malville, 2008: 67-70; Malville *et al.*, 1996). Piedra del Sol is unique among identified Chacoan calendrical sites not only due to its unusual rock art, but also because it includes both solstices and a direct line of sight to the Fajada Butte site.

5.1.8 Three Slab Site on Fajada Butte (Class 3)

High on Fajada Butte sits one of the most sensitive and famous archaeoastronomy sites at Chaco. First discovered serendipitously in 1977 during a National Park Service rock art survey by Anna Sofaer and Jay Crotty (Malville pers. comm. based on a report by Helen Crotty, 2011) the three-slab or “Sun Dagger” site provides a marker for summer solstice. The site consists of three large rock slabs oriented nearly vertical in front of two spiral petroglyphs. For a period of about 18 minutes just prior to mid-day on and near June solstice a bright “dagger” appears that traverses the center of the larger spiral. It is formed by light passing between the slabs. On the equinoxes a similar long “sun dagger” is positioned at the right side of the larger spiral, and a smaller “sun dagger” is marked against the smaller spiral. In spite of the sun’s much more rapid apparent motion at the time of equinox these effects are also visible for multiple days around the dates of significance. Near winter solstice a pair of similar “daggers” brackets the larger spiral. The initial report of the site also asserted that it was a deliberately engineered construct, stating that “Several pieces of evidence rule against the slabs’ having fallen into their present positions naturally.” The evidence for this conclusion included the distance the slabs had moved from their apparent point of origin in the rock face above, a lack of “impact marks” from a fall, a lack of rubble near the stones, and the presence of buttressing at their bases. In addition, multiple pieces of evidence were presented to suggest deliberate shaping of edges on the slabs. It was also noted that the slabs would provide the same collimating effect for lunar light during periods when the moon is within the Sun’s range of motion across the sky. Remarkably, the report included speculation on the potential to use the three slab site as a calendrical device for tracking the movement of the moon through its 18.6 year cycle from maximum, to minimum, and back to maximum declination; noting the close correlation between the number of solar years in that cycle and the count of turns (19) in the larger spiral. It was concluded that site “is unique in archaeoastronomy as the only device known to use the passage of the midday sun to create a solar calendar” (Sofaer *et al*., 1979; Sofaer *et al.*, 1982).

A subsequent paper by two geologists and one archaeologist (Newman *et al*., 1982) presented convincing evidence that the positions of the slabs at the site were most likely the result of a natural rock fall. They provided a geological assessment, including a sequenced description of the events that could plausibly have led to the final positions of the slabs. Photographic evidence was presented of six additional similar rock falls in the canyon, demonstrating that the nature of sandstone in the canyon combined with the annual freeze-thaw cycle created such slab rock falls on a repetitive basis at Chaco.

Ongoing analysis by Sofaer and her team focused on light and shadow plays at additional rock art panels on the butte that were proposed to act as supplementary solstice and equinox markers. In addition, they stated that Newman *et al*.'s analysis of the rock fall "does not, however, exclude the possibility of later deliberate movement of the rocks…" They reiterated the proposals that the three-slab site was deliberately designed and built to operate as a calendrical tool for the solar year, and expanded upon their previous speculation regarding correlation with the 18.6 year lunar standstill cycle to include shadow casting from the rock face above the site. Sofaer and her coauthors concluded that the three-slab site and additional petroglyphs on Fajada collectively "incorporate utilitarian calendric information, they do so with a redundancy and accuracy far beyond practical requirements of time-keeping devices" (Sofaer and Sinclair, 1987).

Zeilik (1985a) discussed the fact that the slow speed and small apparent day-over-day motion (~1 mm at the solstice) of the 2 cm wide light shaft on the rough rock spiral could not in practice be used to achieve the level of calendrical accuracy that is achievable using horizon foresight calendars. As discussed elsewhere in this thesis, such horizon calendars are well-documented in Pueblo ethnography. This accuracy issue is particularly important; the Sun's apparent daily motion is ~ ½ solar diameters (14 arcmin) four weeks before or after the solstice, which is readily observable on a horizon with prominent markers, but not at the three-slab site. Zeilik also demonstrated that the light plays associated with the proposed lunar standstill cycle were observable for very limited periods, only at moonrise, and only when the moon is at its northern declination. He noted a lack of evidence for Pueblo interest in or knowledge of the lunar standstill cycle, and presented evidence that the structure of the site was consistent with documented Pueblo sun shrines.

In a biting critique, Carlson (1987) reiterated Zeilik's findings, as well as the analysis of Newman *et al*. He discussed the plausibility of various scenarios for deliberate modification of a natural rock fall. Consistent with Zeilik, Carlson concluded that the overwhelming weight of physical and ethnographic evidence indicates that the site most likely operated as a shrine. He closed on a discussion of the unfortunate creation of modern mythology associated with the original claims for the site. Subsequently McCluskey (1988) found that the set of documented effects at the three-slab site were statistically indistinguishable from a set of chance (random) events.

While rare, similar forms in proximity to other ancestral Pueblo ruins have been identified, such as the “light serpent" at Hovenweep, a site that dates to the late PIII period well after the Chacoan florescence (Williamson, 1984).

Though the three-slab site's solar markers have been generally accepted as the result of deliberate creation of rock art associated with the light play, they provide poor calendrical utility. Additionally, there is a lack of evidence to support the proposed linkage to lunar standstill events. The most plausible explanation for the three-Slab site is that it operated as a Sun Shrine (Carlson, 1987; McCluskey, 1988; Newman *et al.*, 1982; Reyman, 1985; Zeilik, 1985a).

In addition to the debate about the site's purpose and utility, Sofaer and others (see e.g., Farmer, 2003) have assumed that the site is temporally associated with the peak of the Chacoan florescence, the period when monumental architecture was being created. Nonetheless, as with all petroglyphs the three-slab site itself cannot be accurately dated. Reyman (1980) provided a detailed assessment of the site in the context of both Pueblo ethnography, and temporal evidence. He concluded that the site is not consistent with the Pueblo ethnographic record, and may plausibly have been related to a range of times or cultures.

Circumstantial evidence including the presence of a ramp structure to ascend the butte, indicates that significant numbers of people were involved in construction in the vicinity for some brief period, but there is no basis to assume that the ramp's construction (also undated) is temporally associated with the three-slab site. Some of the masonry remaining on the Butte has been identified as being in a "Mesa Verdean" style that correlates with dates from A.D. 1220 to 1300, and the preponderance of potsherds atop Fajada are from that period (Ford, 1993; Malville, 2011). Ford (1993, and pers. comm., 2010) has also stated that some of the masonry on Fajada Butte is in a core and veneer style that likely dates to the earlier Bonito Phase, contemporaneous with masonry styles in the ramps.

Ironically, the most famous putative "solar and lunar observatory" site at Chaco remains one of the poorest in respect to calendrical utility, or the ability to draw useful cultural conclusions. It is unique in its use of mid-day sun, it provides low accuracy, and it is a Class 3 site that must have been established based upon observation at another location such as the Class 1 Piedra del Sol site, which is on a direct sightline from the three slabs. Nonetheless, there is no current consensus on a reasonable temporal assessment for the three-slab site. Given the inability to accurately date petroglyphs such a consensus is unlikely to emerge in the future.

5.1.9 29SJ 931 and Wijiji (Class 1)

Two Class 1 calendrical stations have been identified in proximity to Wijiji Great House. The first of these was initially identified by O'Flynn based upon his review of features in National Park Service survey maps. He assessed the area at 29SJ 931 near the pictograph shown in ***Figure 20,*** located on the mesa edge above Wijiji. He found that from a position north of the pictograph, a stone pillar to the Southeast was a workable foresight for December solstice sunrise calendrical observations. Subsequently, Williamson noted that the same pillar worked as an anticipatory calendrical marker some 16 days before the solstice by changing the observing location, but his suggested location is not well-identified on the ledge. Additional work by Michael Zeilik associated a group of nearby Pueblo petroglyphs with the site and identified an additional solstitial alignment option. After significant debate, a consensus emerged that this site likely represents multi-culture use by Pueblo and Diné people (Williamson, 1984: 88-92, Zeilik, 1989: 208-209).

Figure 20. Solar pictograph at 29SJ 931 above Wijiji

This pictograph is likely of Diné origin. It marks a proposed dual-culture use Ancestral Pueblo and Diné Calendrical Station.

The ledge also contains pecked basins and channels, which are similar to those found in Mesa Verde (Malville and Munson, 1998), suggesting the possibility of post-Chacoan Pueblo use. Additional circumstantial support for the dual-culture (Pueblo and Diné) interpretation of this site is provided by the fact that below the ledge are well-preserved petroglyphs depicting the Diné “holy twins,” Monster Slayer and Child Born for Water. This situation is not unique. There are multiple noteworthy instances of Diné reverence and reuse of apparent Chacoan sites (Ambruster and Hull, 1997; Malville, pers. comm., 2009).

As with the other rock art sites, the pictographs and petroglyphs at 29SJ 931 are not dateable. Nonetheless, the site is very convincing. Not only does it include likely Chacoan petroglyphs in proximity to a Great House, it also has strong ethnographic correlation to modern Pueblo solar observing practices, including the use of anticipatory horizon markers. The side of the foresight pillar forms a "ramp" along which the sun travels during its winter solstice display; this feature shows signs of possible human manipulation (Cornucopia, pers. comm., 2003).

The second calendrical station at Wijiji is marked by the Great House itself. Wijiji was built in a single construction effort around A.D. 1110 (Lekson, 1984). The Great House provides a Class 1 calendrical station for December solstice sunrise. Wijiji's solstice horizon foresight sightlines are presented in ***Figure 21***. As shown, from a common observing location at the northwest corner, dual sightlines to a notch on the southeast horizon provide anticipatory and confirmatory markers for December solstice sunrise. Between December 4th and 6th the sun rises from the north (left) side of this notch. At December solstice, the sun rises on the south (right) side of the same notch. The existence of a calendrical station at this site prior to the building's construction may have been a determining factor in site selection (Malville 2004; Malville *et al.*, 1996).

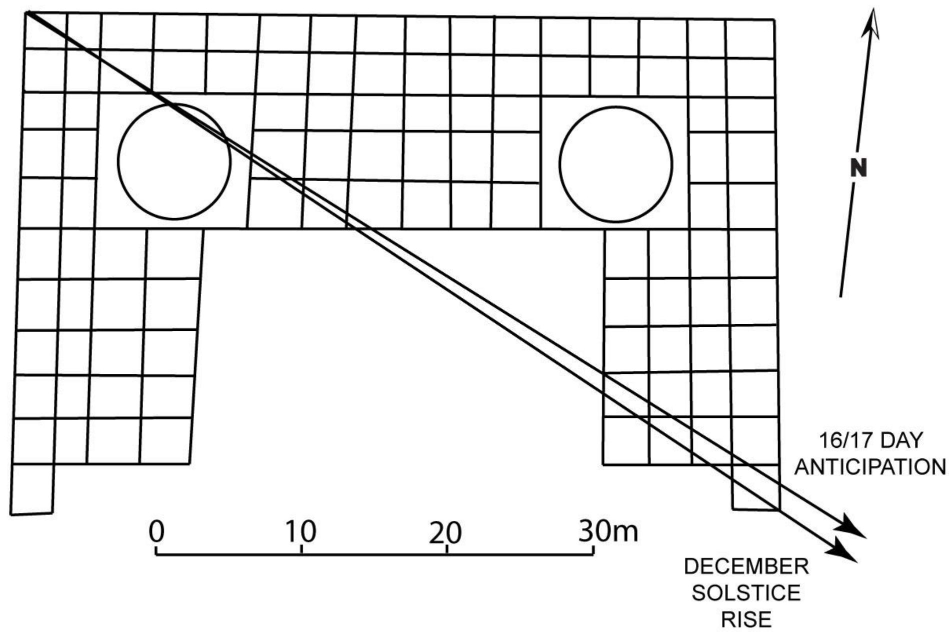


Figure 21. Wijiji site plan

(Adapted from Lekson, 1984: 225)

December solstice sunrise as observed from Wijiji is depicted in ***Figure 22***. Due to the sun's low apparent day-over-day motion on the horizon at solstice, the marker functions for a four day period. As noted in the figure, the left side of the notch provides an anticipatory marker as observed from the same location 16 or 17 days prior to solstice. Both the anticipatory and solstice alignments have been confirmed visually and photographically (Judge and Malville, 2004: 153-154; Malville, 2008a: 70-71; Malville *et al*., 1996).

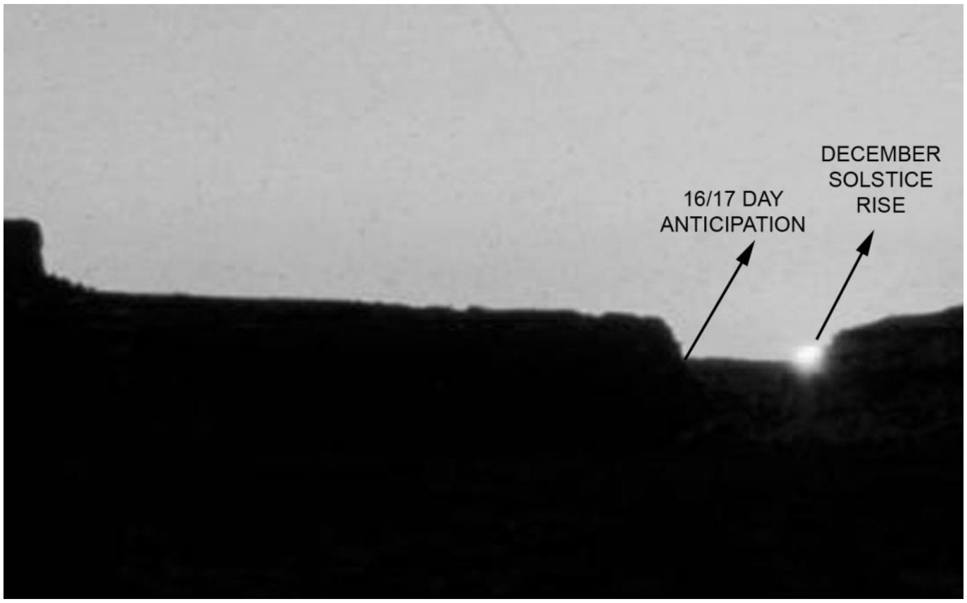


Figure 22. Wijiji DSSR
(Photograph by G.B. Cornucopia, used with permission)

The Wijiji Great House was constructed during the Late Bonito phase. It is uncertain whether Wijiji was ever occupied, and a common interpretation among archaeologists is that it represents a class of structures that had predominantly nondomestic purposes (Lekson *et al*., 2006). It is one of only two Great Houses within Chaco that do not have sight lines to other Great Houses (Van Dyke, 2007a: 223-224). These factors tend to support the idea that Wijiji was constructed at least in part for monumental purposes, and that the visual solstice horizon event may have been a factor in the selection of its location.

5.1.10 29SJ 1655 (Class 2)

East of Wijiji and below the Basketmaker village of Shabik' eshchee, boulders at three distinct locations are extensively marked with likely Diné petroglyphs. Each of the three locations operates as a Class 2 calendrical station for a date of importance using a horizon foresight; one each for June solstice, the equinoxes, and December solstice. The site has some indications of dual cultural use, including a possible Chacoan shine and nearby Chacoan rock art. The Diné rock art that dominates this site has been dated as eighteenth century due to its Gobernador-phase style (Ambruster and Hull, 1997).

5.2 Intra-Site South-Southeast Orientation

Hayes (1981: 55-61) first noted the multi-century pattern of front-facing SSE orientation (which he termed “Southeast” and associated with the “Hosta Butte Phase”) for ancestral Pueblo architecture in the San Juan and southern Colorado. This SSE orientation tradition predates Great House construction by hundreds of years. Ware (2002) has noted examples of pit structures situated under rock outcrops facing SSE during the BM II period, presumably for passive solar gain. The pattern is certainly identifiable among Basketmaker III phase pit structures (A.D. 400-700), as well as early to mid Pueblo (A.D. 700-850) and later “Prudden Units” (Lipe, 2006) across a wide area.

The orientation of the pithouses is based on their well-defined axes of bilateral symmetry through internal features including sipapus, hearths, deflector stones, and entrances. A majority of the structures in the (A.D. 450-700) villages of Shabik’ eshchee and 29SJ 423 at Chaco were front facing to between 151° and 161° (Malville and Munro, 2011). Later, people were migrating away from northern San Juan and southern Colorado villages containing Prudden Unit houses (A.D. 700-850) at about the same time as Great House construction began at Chaco (Lekson *et al.,* 2006; Lipe, 2006; Wilshusen and Van Dyke, 2006). Architectural and material culture evidence led Cameron (2009: 20) to suggest that immigrants from these villages established the Chacoan “identity.” The early Great Houses in Chaco appear to be “monumentally scaled-up versions of unit pueblos” (Lekson, 2009: 123). Reed (1956) discussed front-facing Prudden unit pueblos; each with a room block overlooking a kiva containing a well-defined axis of bilateral symmetry. Using the records of the Dolores Project, assessment of multiple villages from the period prior to the florescence at Chaco found consistent SSE orientations (Malville and Munro, 2011).

Two astronomical hypotheses have been advanced relating to this SSE tradition; one lunar and one solar.

5.2.1 The Lunar Standstill Hypothesis

Sofaer (1997) proposed that both the establishment of Chacoan Great House site locations and the designs of the Great Houses themselves are all cosmologically inspired ***(Figure 23)***. Sofaer claimed that three of the Great Houses in the Chacoan core and two principal outliers are aligned with minor lunar standstills, in addition to two claimed major lunar standstill alignments. A majority of these face SSE, however Sofaer's claims are based on a mix of back-wall alignments and axes of symmetry.

For the SSE-facing structures Sofaer's lunar standstill hypothesis requires two cognitive leaps. First, that back wall alignments of Great Houses are of importance notwithstanding a lack of ethnographic evidence to support the idea. Second, that the back wall alignments are unconnected with the preceding multi-century front-facing SSE orientation tradition, which she was apparently unaware of. In one case (Kin Kletso) Sofaer makes an alignment claim for a double McElmo room block for which any claim of a "primary axis" is entirely debatable. Among the individual building alignment claims, application of Student's t-test to assess Sofaer's (2007) five claimed back wall lunar standstill alignments, as well as her claimed June Solstice alignment at Aztec indicates that five of the six are rejected at the 95% confidence level (Malville and Munro, 2011). Critically, none of her proposed alignments have been photographically confirmed.

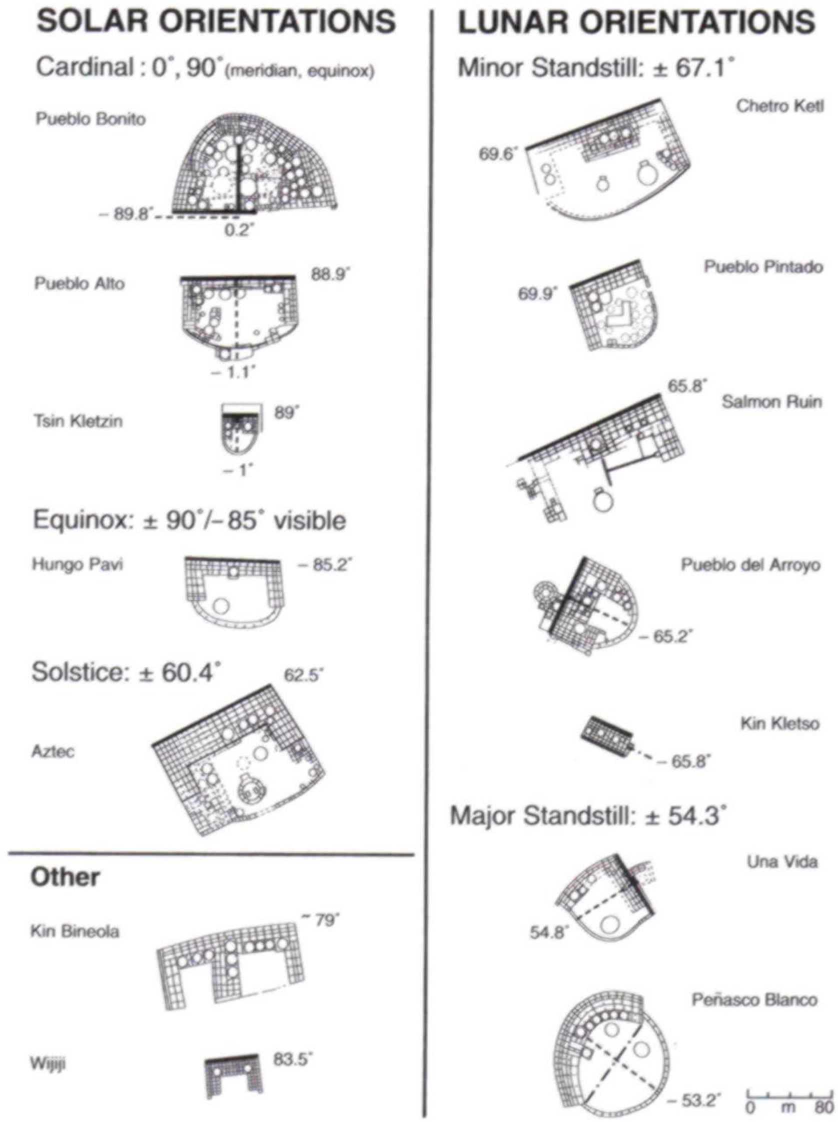


Figure 23. Sofaer's Great House alignment claims

Remarkably, Sofaer has proposed that five of the Great Houses at Chaco, as well as the Salmon and Pueblo Pintado outliers are aligned to Lunar Standstills. From Sofaer (1997); used with permission.

Skepticism is justified for alignment claims to minor lunar standstills because they are entirely unremarkable events. Minor standstills take place on horizon azimuths that the moon passes through every month. Better known lunar cycles include the Saros cycle that marks the crossing of the ecliptic by the full moon (associated with eclipse activity), and the Metonic cycle that marks a mathematical intersection point of day counts for tropical years and synodic months. Both of these cycles were discovered in antiquity by cultures that had reference to multiple years of recorded observational data. In contrast to such documented knowledge, there is no documented ethnographic evidence that the 18.6 year lunar standstill or “lunastice” cycle was known by modern Pueblo people; therefore some archaeoastronomers have discounted the idea that the cycle was known to their ancestors (Carlson, 1987; Zeilik, 1985a).

While there is abundant ethnographic evidence for calendrical use of lunar phase observations by Pueblo people, exhaustive review of the literature has identified no published evidence of lunar standstills being noted. Notwithstanding, modern Hopi informants (who as noted above traditionally keep ritual knowledge secret) have claimed to have knowledge of the major standstills as observed at Chimney Rock (Malville, pers. comm., 2009). The lunar standstill cycle is more plausibly noticeable by horizon-based calendrical observers at the time of the major standstill, when the Moon’s apparent position on the horizon falls “outside” of the sun’s annual positional extremes. This might be especially obvious in a location where pronounced horizon features amplify the visual impact of the event, such as at Chimney Rock (Fairchild *et al.,* 2006; Malville, 2004a, 2008). However, it is difficult to conceive of any mechanism whatsoever whereby observers could take note of a minor lunar standstill, let alone project any cultural utility for the observation.

In addition to the fundamental question of whether minor lunar standstills are noticeable events, Sofaer’s 1997 analysis suffers from multiple methodological errors. Sample size is a particular problem. While her model does incorporate a majority of structures in the Chacoan core, she has based her findings on a relatively small sample that includes fewer than 10% of the known Chacoan Great Houses when outlier Great Houses are considered. She also failed to consider the large number of earlier pithouses and Prudden units noted by Hayes in his identification of the SSE pattern (Hayes, 1981) and discussed by Lipe (2006).

Documented Pueblo calendrical astronomy is based on application of solar horizon calendars and moon phases. For solar rise and set observations, the angular altitude of the horizon is a critical factor in determining the observed azimuth. As the distance to horizon foresights is reduced, the effect becomes much more pronounced (Aveni, 2001: 100-113). For close foresights such as are common in the confines of Chaco Canyon, relatively small changes in observing location have major impacts on the observed azimuth of sun or moon rise and set. Sofaer ignores this effect, and calculates a majority of her proposed lunar alignments to what she terms the “sensible” (read “artificial”) horizon. No ethnographic, astronomical, or architectural data available supports this approach, and it has pronounced impact on her putative alignments.

Sofaer additionally claimed long-baseline inter-site alignments that exceed line-of-sight distances. For example, she claims a minor lunar standstill alignment between Chetro Ketl in “downtown Chaco” and Pueblo Pintado, an outlier nearly 27 km distant. In addition to the difficulties with minor lunar standstills noted above, documented construction dates present a real problem for this idea. Construction at Chetro Ketl began ~ A.D. 1010 (Lekson, 2006; Windes and Ford, 1996). Construction at Pueblo Pintado began in the early 900s (Windes and Ford, 1992). This is a mismatch of approximately a century. Thus, the claimed inter-site lunar alignment requires us to accept that a 27 km non-visual alignment was planned over 100 years before the Chacoans began to create inter-building NS/EW alignments in downtown Chaco along direct lines-of-sight. This is not plausible. A similar problem affects her claimed long baseline alignment to Kin Bineola. Both of these claimed inter-site alignments fail basic statistical testing; all of the great houses in “downtown Chaco” fall within Sofaer’s claimed error boxes for the putative individual alignments, indicative of a classic selection effect error (Malville and Munro, 2011).

Sofaer’s Solstice Project obtained funding to produce a feature-length documentary film entitled “The Mystery of Chaco Canyon,” which has been repeatedly broadcast by PBS in the United States and was previously shown at the Chaco Culture National Historic Park visitor’s center. Her conclusions of lunar standstill-based architecture are a central theme of this film, and unfortunately they form the basis of understanding for a many people interested in Chacoan archaeoastronomy.

In summary, evidence to support Sofaer's lunar standstill alignment claims is extremely weak. It is additionally problematic that the details of Sofaer's field notes and analysis approaches have never been made available for review. Her field notes and analysis have never been archived, and are therefore not available to other researchers (Ford, pers. comm., 2008).

5.2.2 The June Solstice Sunrise Hypotheses

Early construction at Pueblo Bonito (i.e. "Stage I" between A.D. 850-935) resulted in a "C" shaped double room structure facing so that it is oriented to the SSE (Stein *et al.*, 2003). Williamson's (1984: 149) discussion of the passive solar gain benefits of Chacoan architecture included a figure entitled ""Pueblo Bonito as solar collector" that incorporates azimuths for both summer and winter solstice sunrises. Based upon the text description, he apparently intended these to illustrate the seasonal relationships of sunrise positions for passive energy gain based on the building's orientation. At least one subsequent author has erroneously cited this as a claimed visual JSSR alignment (Farmer, 2003: 69).

Sofaer (1997, see ***Figure 23*** above) also claimed that the back wall of the Late Bonito phase Aztec West outlier was deliberately aligned to JSSR. More recently Lekson (2008: 127, 238) explicitly termed the SSE-facing orientation tradition as "solstitial." He states "Solstitial buildings faced southeast; with their long rear walls aligned more or less to the solstice…" Lekson did not provide cultural or ethnographic justification for the proposed use of back wall alignments.

In contrast to Sofaer's putative lunar standstill alignments, Lekson's proposed solstitial alignments across the fronts of C shaped room blocks or along the back walls of southeast-facing Great Houses are certainly plausible; the cultural importance of solstices among Pueblo people is well documented. Notwithstanding, the solstice proposal suffers from some of the same required cognitive leaps that plague the lunar standstill hypothesis. Of greatest importance, there is a lack of documented ethnographic support for the importance of back wall or perpendicular alignments. Consideration of such perpendicular azimuths as “solstitial” simply because of their low-accuracy association with June Solstice rise azimuths may be arbitrary given the multi-century front-facing SSE orientation tradition among pit houses and unit type pueblos discussed by Hayes (1981) and Lipe (2006).

5.3 Intra-Site East-Southeast Orientation

The remarkably durable front-facing SSE orientation tradition in the San Juan basin and Dolores river valleys (Hayes, 1981; Lipe, 2006; Malville and Munro, 2011) has an analogue in the Rio Grande valley to the southeast of Chaco; a multi-century tradition of orienting buildings such that their front-facing axes are in the general direction of the December solstice sunrise, facing east southeast (hereafter “ESE”). During the “Early Developmental” period from A.D. 600-900, pit structures in the northern Rio Grande valley were constructed with an average front-facing orientation (based on the axis of symmetry) of 118° (SD=32°, N=39). During the “Late Developmental” period from A.D. 900-1200, the tradition continued with an average front-facing orientation of 123° (SD=22°, N=85). These orientations correspond generally to the azimuth of December Solstice sunrise, and may have acted as architectural manifestations of ritually important symmetry associated with north/winter and south/summer, as well as with sodalities similar to those documented among modern Tewa people (Lakatos, 2007).

One site to the north of Chaco has been identified that also manifests ESE orientations; at the PI site of Sacred Ridge an average orientation of 119.8° (SD=18°, N=14) was found. Surrounding habitations in the Ridges Basin area do not manifest this orientation tradition. Two structures in Sacred Ridge village are found to have front-facing orientations to 245° and 248°, the direction of December solstice sunset (Malville and Munro, 2011).

The end of active habitation at Sacred Ridge ~ A.D. 810-840 is correlated with evidence for the violent executions of 33 people and their dogs (Stodder *et al*., 2010). If the SSE and ESE orientation traditions do represent distinct cultural markers, the violence at Sacred Ridge may be indicative of ethnic conflict. This provides circumstantial evidence that people with a different ethnic background, possibly affiliated with a Rio Grande culture group may not have been welcome in the north during the early A.D. 800s (Malville and Munro, 2011). There is abundant supporting evidence for ethnic diversity playing a role in the violence at Sacred Ridge. Potter and Chuipka (2007) suggested that the characteristics of four "oversize pit structures" at Sacred Ridge, including large usable floors and a lack of domestic trash middens, support the idea that the site operated in part as a habitation and in part as a "center where rituals occurred." McClelland (2010: 237) used dental evidence to conclude that the processed remains at Sacred Ridge are biologically distinct from the rest of the contemporaneous population in the surrounding Ridges Basin area. However, Ezzo (2010: 194) applied strontium analysis to determine that, of 28 individuals analyzed, 24 patterned as being local to Ridges Basin. None could "confidently be defined as immigrants," however three could have come from the San Juan basin or another "geologically younger" area. Potter and Chuipka (2010) assessed the "Extreme Processing" of remains that occurred, and concluded based on current evidence that the violently executed people of Sacred Ridge represented a distinct ethnic group in the area, and they may have been an extended family unit but most were not first generation immigrants. Potter and Chuipka suggest that the most plausible explanation for the violence is "sudden breakdown in leadership of political structures that had been keeping ethnic conflict at bay."

These findings are provocative, and provide at least one case where ESE architectural orientation evidence for the presence of distinct ethic affiliations is corroborated by other independent lines of evidence.

5.4 Alignments to the Cardinal Directions, NS/EW

As discussed above, the cardinal directions of NS/EW are important in the cosmology of the Eastern Pueblos, and it is therefore a mark of cultural continuity that alignments to these directions are a well-documented repetitive theme in Chacoan architecture. They also occur among pre-Chacoan pueblo structures in the San Juan and southern Colorado. It may have been highly important for one culture group that certain rituals, daily activities, or sleeping were carried out in parallel with the larger cosmos (Malville and Munro, 2011).

5.4.1 Pueblo Bonito

Williamson (1984: 145) found accurate cardinal alignments created in the final phases of construction at Pueblo Bonito. He reported that the NS wall bisecting Pueblo Bonito is “very nearly along the meridian,” and that the western portion of the building’s south wall is accurately aligned EW. These alignments were built during the “Stage IV” construction period between A.D. 1070 and 1115, at the height of the Chacoan florescence (Stein *et al.*, 2003). They also correlate well with modern ethnographic data regarding the importance of the cardinal directions in documented Eastern Pueblo cosmology, as well as the fact that many Chacoan kivas including Pueblo Bonito’s Great Kiva A are accurately aligned on a NS meridian axis (Williamson, 1984: 146).

Sofaer (2008: 50-54, 88-93) asserted that precise EW cardinal alignments are by definition associated with astronomical equinox alignments at multiple Great Houses and shrines including Pueblo Bonito. As discussed below, her assertion was made under the incorrect assumption that horizon altitude is not significant in determination of celestial rise and set azimuths. Farmer (2003) claimed a visual equinox alignment for the east section Pueblo Bonito’s south wall, which is aligned on an azimuth 4° north of cardinal east-west. Lekson (2009) contrasted orientation to the cardinal directions with “solstitial” orientations, proposing that they are hallmarks of competing political factions at Chaco.

5.4.2 Casa Rinconada

Casa Rinconada, built A.D. 1060-1109 (Vivian & Reiter, 1960) is one of the most remarkable structures at Chaco, and is certainly the most famous Great Kiva. Its overall design exhibits the characteristics of a “kiva as a model cosmos” documented in Pueblo ethnography and discussed above to a remarkable degree. The structure contains two axes of symmetry. The NS axis between the doors is accurate to within 20 arcmin. The East-West axis from niches 8 to 22 (see ***Figure 14*** above) is accurate to within 8 arcmin. As depicted, there is evidence to suggest that an additional upper niche may have been present before degradation of the structure and reconstruction. If this is correct the number of upper niches corresponded to the number of days in a lunar month. The four support pillars were accurately placed at the inter-cardinals, foreshadowing the focus on inter-cardinals within modern western Pueblo cosmologies. The accuracy of alignments within this structure encapsulates the Chacoan linkage of cosmology and monumental architecture (Malville and Putnam, 1993: 35-37; Williamson, 1984: 132-144).

In contrast to the metaphoric “model cosmos” interpretation of Casa Rinconada based on Pueblo ethnography, Williams *et al*. (2006) report that Diné elders and “medicine people” who live in the vicinity of Chaco today offer a different metaphorical symbolic explanation for elements of the structure’s design. Diné people view the design of floor features in the Great Kiva as symbolic representations of figures that also occur in sacred sand paintings and correspond to two constellations. These are “Revolving Male” which corresponds to Ursa Major, and “Revolving Female” ” which corresponds to Cassiopeia. The larger western floor vault in the Great Kiva is identified as associated with the Male/Ursa Major constellation; the smaller eastern floor vault is associated with the Female/Cassiopeia constellation. The floor features of the Great Kiva are also identified as schematically consistent with the design of the sacred sand painting of “Male and female in parallel unison.” This metaphorical model of linked schematic design is not consistent with the Pueblo “kiva as a model cosmos” metaphor discussed above. Nonetheless, it explicitly links visual astronomy references, architecture, and sacred sand paintings in a nested pattern on multiple scales to encode culturally important information.

It is important to recall that there are numerous additional Great Kiva structures similar to Casa Rinconada at Chaco. Every Chacoan Great House in the canyon save two incorporates one or more Great Kivas. There are additional isolated Great Kivas along the south side of the canyon at multiple locations, including one across from Wijiji (29SJ 1642) and one in Fajada Gap (29SJ 1253) that have not been excavated, or assessed by archaeoastronomers. While construction details of excavated Great Kivas vary, nonetheless the core components of a “kiva as cosmos” model, including accurate alignment to the cardinal directions are frequently present. Some archaeologists today view the Great Kivas as a manifestation of communal social space in the context of monumental architecture, in part as a mechanism for reinforcing and maintaining communal cosmological views. The Great Kivas are also demonstrably a developmental outgrowth of the housing structures of an earlier age, the pithouses of Basketmaker times. As such, in addition to incorporating cosmological references, Great Kivas may also provide implicit ancestor veneration in an architectural form (Van Dyke, 2007a: 122-128).

5.4.3 Inter Site Proposals: Symmetry, Asymmetry and Dualism at Chaco

Long before many of the site-specific archaeoastronomy proposals discussed in this thesis had been documented, Fritz (1978, 1987) provided a prescient analysis of the linkage between architecture, ideology, and cosmology at Chaco Canyon. He noted that alignments to cardinal directions and three forms of symmetry (“translation, reflection, and bi-fold rotation”) evidenced within Chacoan structures provide physical evidence for architectural expression of cosmological views. Fritz also noted that the same cosmological views were reflected by inter-building line-of-sight alignments within and across the canyon.

Great House inter-site relationships echo the Pueblo concern with cardinal directions and symmetry on a grander scale. An EW alignment was constructed between Pueblo Bonito and Chetro Ketl. An accurate inter-site NS cardinal alignment was established between Pueblo Alto on North Mesa, and Tsin Kletzin on South Mesa. Just as Casa Rinconada incorporates internal axes of symmetry aligned with the cardinal directions, so these inter-building lines provide axes of symmetry for the area of "downtown Chaco" as a whole. Fritz's interpretation included the idea that the southern side of the canyon (where small habitation sites were built) was socially asymmetrical to the power represented by monumental Great House structures along the canyon's northern side. He proposed that the sacred and profane are dualistically balanced across an architectural axis down the length of the canyon (Fritz, 1978, 1987).

This analysis of Chaco has strong correlation to the ethnographic record, including the above-discussed importance among the Pueblos of (cosmological) cardinal directions, dualism, and "center place" (Van Dyke, 2007a: 222). Available dendrochronology further supports Fritz's interpretation; the deliberate nature of the inter-site alignments he discussed is reinforced by the construction dates for the structures involved. The EW alignment between Pueblo Bonito and Chetro Ketl is an 11th century A.D construct. After ~ A.D. 1100, construction at Tsin Kletsin and New Alto expanded the focus on orientation to the cardinal directions (Lekson, 1984). Tsin Kletsin and New Alto are on South Mesa and North Mesa respectively, with commanding views of the surrounding countryside. Fritz identified the NS alignment between Tsin Kletsin and Pueblo Alto as the "line of symmetry" through the canyon that has become emblematic of Chacoan culture. Tsin Kletsin also includes an EW wall. Sofaer (2008: 98) expanded on Fritz's model by proposing a similar nearly-NS alignment between Casa Rinconada and New Alto, with an azimuth of 1.3°. Van Dyke (2004a: 425) suggested that the ~357° inter-building azimuth from Tsin Kletsin to New Alto may have had greater significance based on its alignment with a road segment atop South Mesa. New Alto is also due West of Pueblo Alto.

5.4.4 The Chaco Meridian Model

Lekson's (1999) Chaco Meridian model is both simple and audacious. He proposes that as Chaco's power diminished in the early 12th century, competition among political elites with differing cosmological traditions (one cardinal NS, one SSE which Lekson terms "solstitial") played a part. He suggests that a socio-political Chacoan elite first moved north and drove foundation of the Salmon great house, followed by establishment of the Aztec Great House complex, which became their "seat of power" from A.D. 1110-1275. Subsequently, from A.D. 1250-1450, their seat of power was moved south, to Paquime (Casa Grandes) in the modern Mexican state of Chihuahua. Lekson further proposes that the locations of both Aztec and Paquime were deliberately fixed on a common meridian; the same meridian identified by Fritz (1978, 1987) and Sofaer (1989) as an "axis mundi," but extended over a total distance of some 720 km (Lekson, 1999: 68-155).

The association of Chaco and early 12th century A.D. construction at Aztec is well documented, though the details of social dynamics underlying the move north are debatable. The early Aztec complex is clearly built in Chacoan Style, and there is a wealth of physical evidence to link the two. While Lekson focuses on a political story, other explanations of the depopulation of Chaco focus on the apparent move by some Chacoans to Aztec because of reductions in agricultural surplus due to climate change. Drought during the last decade of the 11th century may have made agricultural production particularly tenuous at Chaco. In contrast, Aztec's location on the Animas River was much better watered. In addition, the Great North Road does cover most of the distance from Chaco to Aztec, as well as to Aztec's late 11th century A.D. "neighbor" Great House of Salmon. Recently published evidence provides a strong basis to directly link construction at Aztec with people from Pueblo Bonito and Chetro Ketl (see e.g., Judge and Cordell, 2006: 205-206; Reed, 2008)

Debates surrounding the Great North Road's roughly cardinal orientation and its likely purposes are also pertinent. Portions of the Great North Road are overbuilt in the same way as other Chacoan Roads. In addition to its possible functional purposes the road's somewhat accurate cardinal NS path leads many to infer that this road in particular was a symbolic cardinal “axis mundi” for the Chacoans, an extension of the cardinal alignments at “downtown Chaco” intended to provide both spatial and temporal linkage (Sofaer *et al*., 1989; Van Dyke, 2007a: 234). So, the first phase of Lekson’s hypothesis seems plausible on its face. What of the second?

Paquime’s association with Chaco was suggested based upon identification of common traits in an exhaustive study of the Mexican site by Di Peso (1974). The core commonalities include: room-wide platforms, pillar foundations made of stone disks, colonnades, earthen “platform” mounds, tri-walled structures, and “T” Shaped doors. Lekson (1999) endeavors to eliminate selection effects from his analysis, noting that all but the first three of these common features are relatively ubiquitous across many southwestern sites. In contrast, he notes that the circular stone pillar foundations are only found at Chaco, Aztec, and Paquime. Similarly, colonnades are only found at two sites in the Southwest including Paquime and Chaco. The thirteen-column colonnade at Chaco’s Chetro Ketl is best known; a small four-column colonnade was also documented at the Chaco small house site of Bc-51 (29SJ 395) by Gordon Vivian (1950). Room-wide platforms only occur at Aztec, Chaco, and Paquime. Based initially upon these physical attributes, and also on the fact that Paquime is also on his “Chaco Meridian” Lekson builds his case. It includes common ceremonial use of macaws, and hypotheses linking esoteric ceramic objects (Chacoan “cylinder jars” and Paquime “hand drums”), as well as consideration of a host of additional traits including cardinal orientations for some rooms. Lekson also cites lack of common traits as supporting evidence for his idea; he is not proposing that large numbers of Chacoans made a two-stage migration, but rather that a small political elite that originated at Chaco made the moves and adapted to local material cultures (Lekson, 1999; 71-110).

Extension of the Chacoan “axis mundi” hundreds of kilometers to the south makes some archaeologists queasy enough to engage in pointed sarcasm in their critique. It has been pointed out that Aztec, Chaco and Paquime are not that precisely aligned. For example, Aztec is actually 2.5° west of Lekson’s proposed meridian through Pueblo Bonito; Aztec is actually due north of Peñasco Blanco at Chaco’s West end. It has also been noted that the Great North Road never reaches the Aztec or Salmon outliers, but in fact ends at the edge of Kutz Canyon (Marshall, 1997). It has further been suggested that the trip to Paquime was simply too long to be managed while surveying. These and other objections have been raised by multiple parties (see e.g., Mills, 2004: 129-130; Phillips, 2002).

5.5 An Integrated Critique

Chaco archaeoastronomy has suffered from a set of ironic flaws. While quality work has been done, the three most famous archaeoastronomy sites at Chaco Canyon are among the most difficult to interpret. The Fajada Butte three-slab ("sun dagger") site, "Supernova Pictograph" and Casa Rinconada all provide ample opportunity for uncertainty in their interpretation.

Dating of many Chacoan archaeoastronomy sites is not possible due to the dependence on rock art for site identification. For example, direct dating is impossible for the proposed calendrical station above Wijiji at 29SJ 931, the "Supernova Pictograph" site, and the three-slab site on Fajada Butte. Therefore, dates currently ascribed to such sites are based on circumstantial evidence in the form of proximity to other material, rock art styles, and reasoned assumptions. In contrast, archaeoastronomy evidence associated with dated structures includes multiple proposed horizon calendars, cosmological associations with the cardinal directions, and varied interpretations of the well-documented repetitive pattern of SSE-facing building orientation. For these dateable sites, expanding the set of considered structures, application of temporal analysis, and consideration of alternative hypotheses may yield insight into the development of Chacon culture over time.

Regarding the SSE-facing tradition, there is no identified justification in the archaeological or ethnographic record for any importance attached to the orientation of the back walls of unit pueblos or Great Houses, let alone the perpendicular azimuths for pit structures. This undermines both Sofaer's (1997) putative lunar standstill hypothesis, as well as the more plausible characterization of the SSE buildings as "solstitial" (Lekson, 2009: 127, 238). Notably, none of the proposed lunar or “solstitial” alignments among the SSE structures have been visually or photographically confirmed. Further, the claimed back wall alignments are associated with a subset of SSE-facing structures. The only apparent justification for focusing on such back wall or perpendicular azimuths is that a subset of the structures exhibits inaccurate association with celestial events. This supports the idea that the associations are coincidental (Malville and Munro, 2011).

Unfortunately, some past work has also ignored dependable chronological data when it is available. It is worthwhile to consider which of the astronomical evidence presented to date is date-constrained, and which is not. Due to the outstanding work done over the last twenty plus years by multiple teams of archaeologists, most notably Windes *et al.* (1996), a massive database of tree ring dates for many Chacoan sites now exists (CRA, 2010).

Standards for fieldwork are also worthy of review. Williamson (1977, 1984) used a transit for field survey work rather than a theodolite, in common with the work of Aveni (2001) in Mexico. The transit has inherently lower accuracy; on the order of +/- 1 arcmin versus +/- ~ 1 to 3 arcsec for a theodolite, as well as a low magnification telescope that is less useful for sighting on distant landmarks such as horizon foresights. Additionally, their practice was to use a solar filter and center the sun in the telescope instead of using the sun’s trailing limb for sun sights, also adversely affecting accuracy (Malville, pers. comm., 2009). In contrast Sofaer (1997) employed a team of professional geodesists to assist her in survey work. However, as discussed below the standard processes applied by surveyors for data reduction differ from those of archaeoastronomers (e.g., use of standard error versus standard deviation when measuring a wall), so interpretation of her published work is subject to uncertainty.

These problems highlight a particular difficulty regarding the fame of Chaco Canyon as an archaeoastronomy site. To date, reasoned synthesis and integration with archaeology and ethnography has been spotty at best. Large amounts of such evidence are available and many researchers have applied integrative analysis that takes good advantage of such material (see e.g., Fritz, 1978, 1987; Malville, 1993a, 2008; Malville and Putman, 1994; Reyman, 1976; Williamson, 1975, 1984; Zeilik, 1985a, 1986a). Unfortunately, some recent well-publicized analyses of archaeoastronomy at Chaco have synthesized astronomical evidence and inferred Chacoan intent absent consistent statistical methods, without reference to established archaeological timelines, and without reference to available ethnographic data (see e.g., Sofaer, 1997; Farmer, 2003). Deeper understanding of the development of Chacoan culture viewed through the lens of astronomy may be possible, but it depends on integrated analysis of the material physical evidence, accepted timelines, and ethnography with application of valid fieldwork and statistical analysis. Of critical importance, field notes and original data for much past work have either been lost, or were never archived. This has legitimately resulted in an attitude of suspicion among some southwestern archaeologists relating to archaeoastronomy as a useful interdisciplinary approach.

In summary, the archaeoastronomy literature for Chaco is varied, but has had limited influence on past archaeological interpretation. Multiple workable *Calendrical Stations* have been documented at Chaco that include foresights for dates of known ritual importance to modern Pueblo people. Two are located at the Late Bonito Phase Great Houses of Wijiji and Kin Kletso, both incorporate December solstice foresights. Multiple *Shrines* have been identified; some correlate to calendrical station foresights, others incorporate cairns, low walls, and/or rock art. Some of this rock art is explicitly astronomical. The positions of some shrines also suggest potential use as signaling locations for communications that may have been related to pilgrimage for festivals. *Intra-site Alignments* were constructed within an individual structure along a cosmological azimuth. The cardinal NS/EW walls in Pueblo Bonito and Pueblo Bonito’s Kiva A, as well as Casa Rinconada provide strong evidence for deliberate NS and EW alignment. There is also clear evidence for a Chacoan bias towards orienting buildings to the SSE. However, I find the explanations in the literature for this orientation, including proposed deliberate lunar standstill and June solstice orientation to be unconvincing. Finally, there is a clear pattern of line-of-sight *Inter-site Alignments* across the center of the canyon. These include the EW sight line between Chetro Ketl and Pueblo Bonito, as well as the NS sight line between Pueblo Alto and New Alto.

6 METHODS

This chapter provides a detailed discussion of the field methods, data reduction techniques, and interpretive approach applied in this study. It includes discussion of compass and clinometer surveys, field survey using the theodolite, data reduction techniques for surveys, the approach used to obtain confirmation photographs of solar events, and a discussion on how ethnographic data was applied to support interpretation. Field data collection was principally focused on a) constraining architectural orientation data for Great Houses and the Great Kiva of Casa Rinconada, b) testing previously published proposals for lunar standstill alignments, June solstice orientations, and equinox alignments, and c) testing of horizons to identify for workable calendrical stations with a focus on solstice dates.

As a relatively new interdisciplinary area of study, archaeoastronomy suffers from a set of particular risks. Evolving standards for archaeoastronomy fieldwork and data reduction have been developed; however they are contained in sources that have limited distribution (e.g., Aveni, 2001: 124-126; Aveni, 2003; Ruggles, 1996), and they have not been consistently applied in published work. Interpretive approaches and resulting conclusions have varied widely. At the most basic level, the standards of knowledge and training required of archaeoastronomers are not yet well agreed upon.

Through study of orientations, alignments, the placement of architecture, and calendrical practices the interdisciplinary study of archaeoastronomy may provide cultural insight that is not otherwise obtainable. Cognitive analysis of architectural evidence that can be linked to naked eye astronomy and calendrical functions is useful, but the presence of an astronomical alignment in and of itself does not prove that the alignment was intentional. Further, even if an alignment can be demonstrated as intentional this is far from sufficient to confirm social or symbolic intent on the part of the builders.

What originated as two schools of thought within the archaeoastronomy community have been merging over the past 20 years, but a fully defined methodological basis has not yet emerged. One group (predominantly "new world") focused on application of ethnographic or other cultural evidence to support inferences from art, architectural alignments, and other cultural material. Another group (predominantly "old world") leveraged rigorous statistical analysis of potential alignments to try and identify intentionality. Both groups sought to fulfill the same objective, to reveal the cultural conception of space and time held by the builders of ancient structures. In retrospect it is clear that proponents of these approaches tended to gravitate to their positions, in part, based upon the availability of ethnographic data for their specific study areas. Today, an emerging epistemological model for archaeoastronomy integrates both anthropological and statistical methods (see e.g., Iwaniszewski, 2001; Polcaro, 2009; Ruggles, 2011; Ruggles and Saunders, 1993; Sims, 2010).

In the specific context of Chaco, development of a consistent analytical interpretation approach would be beneficial. We are disadvantaged in comparison to studies of literate cultures such as the Mesoamericans or Chinese because the Chacoans did not have a written language. We are advantaged versus archaeoastronomers who study megalithic standing stones in Europe because we do have pertinent cultural evidence. A significant body of ethnographic and cultural evidence demonstrates linkage and a degree of continuity between Chacoan practices and some pan-Pueblo practices of modern times. This evidence is certainly influenced by cultural developments in the centuries since Chaco was an active building site; as well as by the understandable reticence of modern Pueblo people to discuss their cosmological and spiritual beliefs and practices with members of a dominant "foreign" culture. In this context it is critical to be explicit about what is well demonstrated versus what is plausible. Use of statistically valid quantitative analysis can help illuminate us as to the intent of builders, but it should be informed by the ethnographic data available. Creativity in identifying interpretive options must be tempered by reasonable integration with Pueblo ethnography, and informed opinion should be clearly labeled as such.

Fieldwork in support of this program applied multiple measurement methods. Preliminary surveys were conducted using a hand compass and clinometer. These surveys are not adequately accurate to validate alignments or calendrical sightlines; however they are useful in identifying candidate locations for theodolite survey. GPS and theodolite surveys were applied to obtain accurate positional, azimuth, and celestial (solar) measurements. Due to the accuracy limitations of naked eye astronomy, WAAS-enabled GPS units capable of 3-meter accuracy are sufficient for establishing location data for long baseline alignment testing.

The survey included assessment of calendrical, intra-site, and inter-site alignments. Criteria for selection of initial sites included re-survey of previously published sites to; a) validate measurement approaches and b) provide an explicit quantitative linkage between previous work and the new surveys. A beneficial by-product of this approach was to validate previous published work that had not yet been duplicated, as well as, to better define alignment accuracy for sites where original field notes and data are not available.

Theodolite surveys were conducted using standardized data recording and reduction methods (see Appendix 1). Confirmatory photographic evidence was obtained for proposed horizon calendar foresights. Field data, data reduction, and photographs will be archived with the National Park Service after finalization of this thesis.

6.1 Preliminary Assessment using Magnetic Compass

The magnetic compass is portable, low cost, and easy to use. Using a magnetic compass to measure azimuths is straightforward. A magnetic bearing is directly read from the instrument, and converted to an azimuth by correcting for the magnetic angle of declination. The best practice is to utilize a sighting compass and record magnetic bearings in field notes as they are taken. Conversion of bearings to polar coordinate azimuths should not be done in the field because it introduces multiple potential sources of error. The worst case is to record an erroneously converted azimuth without the original bearing. This results in the loss of useful data, and leads to interpretation errors. Similarly, adjustment of a compass for magnetic declination introduces an additional experimental error and should be avoided.

To convert a magnetic bearing a current angle of declination should be used; declination data is web published by the U.S. National Geophysical Data Center at http://www.ngdc.noaa.gov/geomagmodels/Declination.jsp. The angle of declination should never be taken from a map because movement of the earth's magnetic pole is significant. For example, based on NOAA data during a recent 10-year period the angle of declination has changed by over a degree in northwest New Mexico.

Accuracy of at least one solar/lunar disk width (~ ½°) is desirable when seeking solar or lunar alignments (Ruggles, 2005: 112-113). Multiple factors limit compass accuracy including annual and diurnal variations in the earth's magnetic field, as well as local magnetic anomalies. As a practical matter, errors of at least 1° to 2° commonly occur with magnetic compasses. It is theoretically possible to improve accuracy by means of averaging and use of corrective methods (see e.g., Rodgers, 1921), but results are inconsistent.

During this study, magnetic compasses were utilized for preliminary surveys only. Two sites at Chaco were identified where compass accuracy was problematic based on comparisons to theodolite data. Compass data from Talus Unit and the area near Penãsco Blanco were both inaccurate by over 2°, perhaps due to locally occurring magnetic mineral deposits. Similarly, Calvin (1991: 15) noted after observing a sunrise that did not operate as he had predicted that his first compass shots at Hungo Pavi were wrong; he attributed this to iron nodules embedded in the sandstone, creating errors of several degrees in some cases.

Compass survey data including the magnetic bearing, date, and location were recorded onto a sketch of the horizon or architectural feature being measured. Redundant measurement of a prominent topographic feature's bearing can be used to support error checking during data analysis. It is important to record clinometer measurements of horizon altitude on each bearing to enable comparison to ephemerides. For this study, a majority of assessed sites were subsequently surveyed using theodolite.

All predicted astronomical alignments should be subject to visual and photographic confirmation. For complex data sets such as multi-marker horizon lines or low frequency astronomical events (e.g. lunar cycles), follow up theodolite or transit survey is certainly desirable.

6.2 Field Theodolite Measurements

Surveys can be conducted using either transit or theodolite. Theodolites offer higher precision and image magnification, which is useful when sighting on distant horizon markers. Quality used theodolites may be purchased at very reasonable cost because they have largely been supplanted by total stations among professional surveyors.

Theodolite surveys require three tools to make accurate wall azimuth and horizon feature measurements including the theodolite itself, a time standard, and a data recording sheet. Field measurements for this study were performed using a Wild T-2 universal theodolite. This instrument reads to the 1 arc second level using a vernier scale, and has an accuracy of ~ +/- 2.5 seconds of arc depending upon atmospheric and lighting conditions (Cervarich, 1966).

Timekeeping to support recording of sun sights can be provided by a chronometer, a shortwave receiver tuned to a time-standard station (e.g., WWV or CHU in North America) or a GPS receiver. During this study a Garmin Model 72 GPS receiver was utilized. When using a chronometer or GPS receiver, displayed time may be validated for accuracy by comparison with a broadcast shortwave radio time-standard for a period of days in advance of the field work. In pre-survey testing it was found that the Garmin WAAS-enabled GPS receiver utilized was consistent with WWV broadcast data, initially providing high confidence that a time standard of +/- 1 second was achieved.

The procedure for measuring walls is intended to accurately establish the azimuth of the wall and the angular altitude of the horizons on that azimuth, as well as determine a quantifiable level of error. The theodolite setup is depicted in ***Figure 24***. The theodolite is positioned at a fixed distance from the base of the wall's surface (typically ~ 1 m) measured perpendicular from the end of the wall. This can be done using a tape measure and optical plumb, or a plumb bob suspended from the theodolite. The instrument is leveled in this position. The theodolite position (latitude and longitude) is recorded based upon the WAAS-Enabled GPS reading, and this position is recorded in the data sheet. Beginning two meters from the theodolite, a measurement point is identified each meter along the wall and marked with a flag.

A minimum of four measurement points are required to enable calculation of standard deviation during data reduction. In places where the wall is badly degraded above grade, gaps longer than 1 meter between measurement points will be present. The first point that needs to be fixed is a readily identified back-sight, preferably on an azimuth of 120 to 180 degrees with respect to the wall (i.e. "behind" the theodolite operator with reference to the line of measurement points). The cross hairs of the theodolite finder are positioned onto the backsight, and the instrument is zeroed. The backsight therefore becomes the arbitrary zero point for all azimuth measurements. The backsight is sketched and labeled on the data sheet as a memory aid.

Figure 24. Theodolite setup at Chetro Ketl

The theodolite is placed ~1 m from one end of the feature to be measured. Measurement points are established at 1 m intervals, and marked by the flags.

Beginning at the wall point closest to the theodolite and at each measurement point along the wall thereafter, a tape measure and bubble level are used to ensure consistent distance from the wall surface, irrespective of deformation of the wall. The cross-hairs of the theodolite finder scope are placed on the tape mark that corresponds to the theodolite’s distance from the wall (typically 1 m). To verify that the tape is level, when ready the team member operating the bubble level cries “mark,” and the theodolite operator validates alignment of the sights. For each measurement point, the angle (with reference to the backsight as zero point) is recorded in degrees, minutes, and seconds. This procedure continues until an angle is recorded for each point along the wall. During later work it was found that use of an adjustable length pole, set for length using the theodolite’s optical plumb and with a level attached (***Figure 25***) provided for improved survey speed and accuracy.

Figure 25. Improved angle measurement technique for walls

Survey speed and accuracy was improved by replacing a tape measure with the depicted adjustable-length pole.

Horizon altitudes are essential for use in validating visual astronomical alignments. Altitude measurements are taken for each horizon along the wall's azimuth if a celestial rise or set is of potential interest. The change in rise or set azimuth of a celestial object against an elevated horizon varies with latitude and distance to the horizon point, but is significant in all cases. After the horizon altitudes are recorded, the backsight is rechecked as a validation point, and its value is recorded. Significant changes in backsight azimuth (i.e. > 45 arcsec) indicate that the theodolite has been moved. In such cases the data is suspect and the entire procedure should be repeated.

Sun sights are taken so that the arbitrary backsight-based angle measurements can be converted to polar coordinates; four sun sights each are taken for azimuth and altitude. Two team members are needed to execute this procedure with precision, one to operate the theodolite, and one to keep time and record data.

The theodolite is positioned to project an image of the sun onto a piece of paper. The cross hairs are positioned near the trailing limb of the sun once the image is focused. The data recorder monitors time using the GPS receiver. When the trailing limb of the sun aligns with the cross hair precisely, the theodolite operator cries “mark.” The UTC time is recorded to the second. The data recorder confirms that they have successfully captured the time by responding “mark” in turn. The theodolite operator then reads off the measurement of solar azimuth or altitude. Four such azimuth measurements are taken, alternating with four altitude measurements. Alternating between azimuth and altitude sun sights enables independent validation of ephemeris data during data reduction. After the eight sun sights have been recorded, the backsight azimuth is read and recorded a third time (Aveni, 2001: 120-122; Williamson, 1984: 52-58; Malville, pers. comm., 2008).

Minor variations of this procedure may be needed to measure other features. For example, when measuring horizon points to determine azimuths to potential calendrical foresights, both the horizon altitude and azimuth should be recorded for each point. In addition, each horizon point should be measured and recorded four times in order to provide validation, and support calculation of standard error.

In cases where a wall azimuth is desired for a wall that is no longer standing (e.g., it has completely eroded or is buried under fill) azimuth measurements may be taken from points at the top of any resulting berm of material if one is present (***Figure 26)***. The case depicted is the outlier Great House called Pierre’s Acropolis, located on the Great North Road.

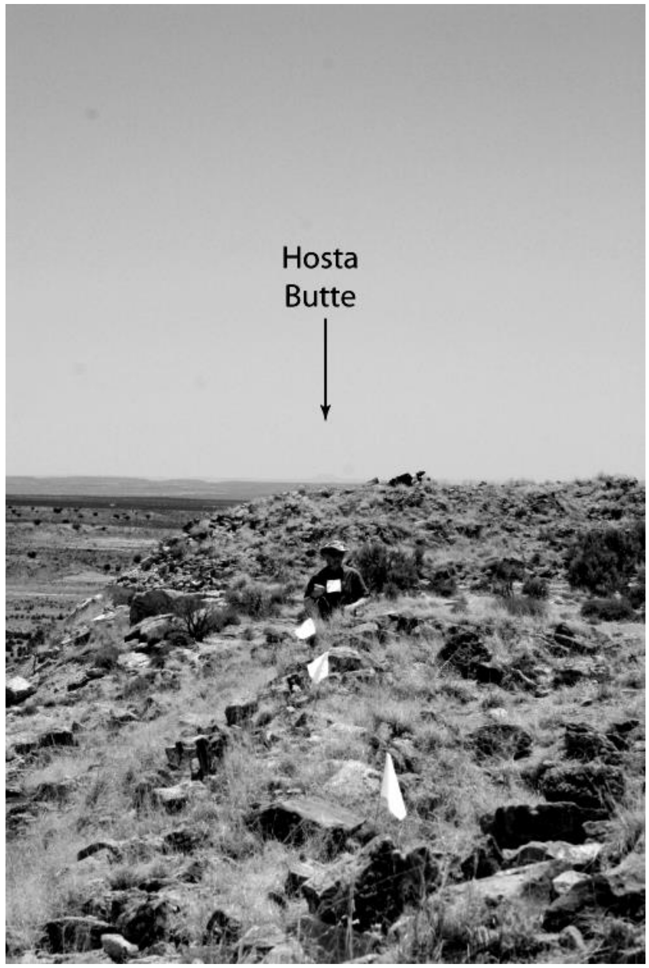


Figure 26. Measurement flags at Pierre's Acropolis unit B

The azimuth of a broken down or buried wall structure can be measured with reasonable accuracy by using the peak of any remaining berm of material as the line for measurement points.

6.3 Data Reduction

Reduction of field data from GPS readings and theodolite measurements is designed to find the mean measured angle, and mean polar coordinate azimuth(s) of surveyed features, the horizon altitudes on these azimuth(s), and the standard deviation of points measured. These can then be compared to ephemeris data for celestial objects to determine the date(s) of any astronomical alignments.

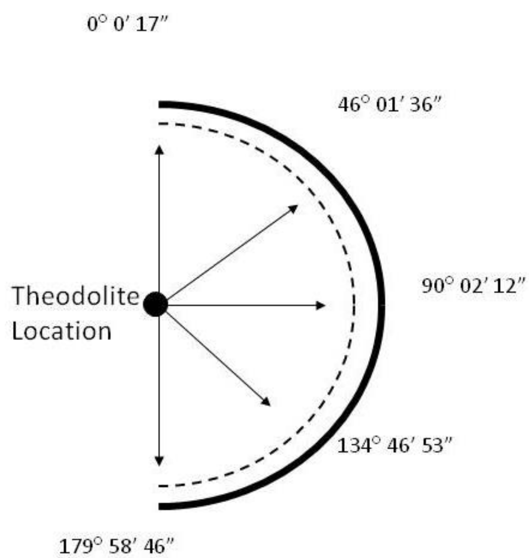
For this study, United States Naval Observatory (USNO) ephemeris data was applied. These ephemerides are calculated using the web-exposed Multiyear Interactive Computer Almanac (MICA) program, which provides data for the years 1800 to 2050. The accuracy of solar positions is .1 arcmin or better for all dates in the past (U.S. Naval Observatory, 2009). Because these studies were focused on lunar and solar alignment azimuths for dates less than 2,000 years ago, precession of the equinoxes does not introduce significant error and can reasonably be disregarded (Aveni, 2001: 100-103).

Data was reduced using the following procedure: First, all collected azimuth and altitude measurements were converted into decimal format. The mean and a standard deviation were calculated for each set of measurements (N must be 4 or more). Altitude measurements were then converted to account for the fact that the Wild T-2 theodolite is scaled with 0 degrees at Zenith. This is accomplished by simply subtracting the measured altitude from 90 degrees.

Use of standard deviation ("SD") in reduction of wall data differs from the convention applied by surveyors. A surveyor measuring a boundary is working with an assumed straight line and applies standard error to quantify variation in the measurement process. In contrast, we are seeking to infer astronomical intent based on inherently scattered data from measurements of physical structures with varied levels of deformation. As a result, use of standard error can create an unintentional illusion of precision, and therefore confuse interpretation.

To illustrate why use of SD is important, consider the extreme case presented in ***Figure 27***. If we measure thirty five points along a "C" shaped wall from the center point as shown in the figure at left, we might obtain the set of angles shown on the right. The calculated SD of 52.27° makes it abundantly clear that the wall is far from straight. The standard error of 8.96° is more open to misinterpretation.

To make matters worse, because the square root of the sample size (in this case 35) is the denominator of the standard error calculation, if we increase our number of data points the calculated error will diminish towards zero. For example, arbitrarily increasing N to 140 for this data set reduces the calculated standard error from 8.96° to 4.48°, further confusing interpretation.



Measured Azimuths	
0.00	
5.00	
10.17	
15.17	
20.34	
25.34	
30.51	
35.51	
40.51	
46.03	
51.02	
56.20	
61.19	
66.37	
71.36	
76.54	
81.53	
86.71	
90.04	
95.03	
100.21	
105.20	
110.38	
115.37	
120.55	
125.54	
134.78	
139.78	
144.95	
149.95	
155.12	
160.12	
165.29	
170.29	
179.98	
86.92	**MEAN**
52.27	**SD**
8.96	**SE**

Figure 27. Calculating error: a deliberately extreme illustration

The surveyor’s standard approach of using standard error for a wall measurement is inappropriate for archaeoastronomy survey, which should quantify error potential using standard deviation.

To summarize, because SD quantifies variance from the mean in a data set, it should be used to calculate the error level for a surveyed wall’s mean azimuth. This approach avoids arbitrarily reducing stated error for larger samples, and provides insight into how straight a wall actually is. In contrast, when making repetitive measurements of the same point (e.g., a potential horizon foresight) use of standard error is certainly correct, because the data should not be inherently scattered.

Sun sights are used to find the difference between measured angles and true azimuths. For each sun sight's recorded time in UTC, the sun's azimuth and altitude is obtained from the ephemeris. This azimuth or altitude is corrected using USNO's provided correction for atmospheric refraction and the angular radius of the solar or lunar disk. The radius is the difference between the ephemeris' positional target (the center of the solar disk) and the measured trailing limb. Correction must be done with attention to the local time as follows:

Local morning altitude, add limb correction

Local morning azimuth, add limb correction

Local afternoon altitude, subtract limb correction

Local afternoon azimuth, add limb correction

After limb correction is applied to the ephemeris data, the difference is taken between each resulting value and the recorded theodolite data. For azimuth, this difference provides the *correction factor* needed to convert theodolite readings (angles taken with respect to the arbitrary backsight) to polar coordinate azimuths. The altitude readings act as an error check.

All that remains to find the azimuth in polar coordinates is to take the difference between the measured azimuth(s) and the *correction factor* to calculate an azimuth(s) in polar coordinates. The resulting polar coordinate azimuths, and horizon altitudes can then be readily compared to the ephemeris values for celestial objects on given dates to ascertain the date (if any) when the rising or setting object would be aligned with the measured feature.

As an independent check of results, sun sights were compared to independently calculated values using the time and location data from the GPS receiver. Significant differences between the calculated and recorded sun sights indicate either an ephemeris error, or lower precision in the time standard as discussed above. The equations necessary to find the altitude and azimuth of the sun for any time at any location on the earth's surface follow (Aveni, 2001: 119-124).

$$HA = (UT-12^h) \times 15 - \lambda - Eq.T \times 15 \quad (1)$$

$$h = \arcsin(\sin \varphi \sin \delta + \cos \varphi \cos \delta \cos HA) \quad (2)$$

$$A = \arcsin(\sin HA \cos \delta / \cos h) \quad (3)$$

$$A = \arccos((\sin \delta - \sin \varphi \sin h) \cos \varphi \cos h \quad (4)$$

Where:

UT = Universal Time

Eq.T = Equation of time (in minutes)

φ = Latitude of Site

λ = Longitude of Site 1

HA = Hour Angle of the Sun in degrees

δ = Declination of the Sun in degrees

h = Altitude of the Sun in degrees

A = Azimuth of the Sun in degrees

Variations between the recorded and calculated solar positions for each set of theodolite data are presented in Appendix 1 below. Good quality results can be seen in the data for the west section of Pueblo Bonito's South Wall, (see Appendix 1, section 11.4.2). In this case the solar position azimuth delta was .0002°, and the altitude delta was .0081°. In contrast, the calculated check for the sun sights taken at Kin Bineola's west wall on May 29, 2008 (see Appendix 1, section 11.20.2) differed from the ephemerides by 0.0215°, or over 77 arcsec. This level of error is undesirable. Follow-on research of device specifications for the GPS receiver used identified the fact that the displays on most consumer grade hand held units such as the Garmin GPS 72 do not clearly state whether satellite-provided UTC correction signals have been applied. As a result, when used shortly after power up the receiver may show uncorrected GPS time, labeled as UTC. In future work this problem can be effectively managed by a) ensuring the GPS is powered up for some minutes prior to taking readings, b) performing more frequent periodic checks of GPS time against an RF time standard (such as WWV), or c) utilization of a chronometer and the GPS in combination. A more advanced GPS receiver with an averaging function would also be beneficial in future work.

In performing analysis of inter-site spatial relationships, it is convenient to use the geodesic spherical trigonometry calculations that are usually applied for maritime and aviation navigation. This enables rapid estimation of the distance (arc length) between any two sites, as well as determination of the inter-site azimuth from each location to the other using longitude and latitude as inputs. ***Equation 5*** enables calculation of the geodesic distance between two points on the earth's surface given the longitudes and latitudes of the two locations, and the earth's mean radius (3958.82 mi or 6371.10 km). Resulting units of distance (e.g., miles or km) are determined by the units of measure used for the value of the Earth's radius. ***Equation 6*** enables calculation of the azimuth from site 1 to site 2 utilizing MS Excel's "ATAN2" function, which provides the arctangent of a pair of (x,y) coordinates. Use of these formulae in MS Excel requires that calculations be completed using radians as the unit of angular measurement (Brand, pers. comm., 2008; Smart, 1977; Williams, 2001).

$$D^{1\text{-}2} = R_{\oplus} * \arcos(\cos\varphi^1 * \cos\varphi^2 + \sin\varphi^1 * \sin\varphi^2 * \cos(\lambda^1 - \lambda^2)) \quad (5)$$

$$Az^{1\text{-}2} = ATAN2(\cos\varphi^1 * \sin\varphi^2 - \sin\varphi^1 * \cos\varphi^2 * \cos(\lambda^1 - \lambda^2)), \sin(\lambda^1 - \lambda^2) * \cos\varphi^2 \quad (6)$$

Where:

$D^{1\text{-}2}$ = *Distance from Site 1 to Site 2*

$Az^{1\text{-}2}$ = *Azimuth from Site 1 to Site 2*

$R_{\oplus}$ = *Earth's Radius*

φ^1 = *Latitude of Site 1*

λ^1 = *Longitude of Site 1*

φ^2 = *Latitude of Site 2*

λ^2 = *Longitude of Site 2*

Figure 28 presents the MS Excel tool that was created for analysis of inter-site azimuths and distances, useful for assessment of potential inter-site alignments.

Great Circle Calculator

Input fields are in ***BOLD ITALIC.***

Calculated fields are in standard font.

Earth's Mean Radius

Mi	***3958.82***
Km	***6371.10***

Site Data

Enter Site Names & Coordinates	Latitude			Longitude		
	Deg	Min	Sec	Deg	Min	Sec
Chetro Ketl	***36***	***3***	***37.6***	***107***	***57***	***17.8***
Pueblo Pintado	***35***	***58***	***37.7***	***107***	***40***	***25.7***

Decimal Conversion		
Chetro Ketl	36.0604	-107.9549
Pueblo Pintado	35.9771	-107.6738

Radians Conversion			90deg
Chetro Ketl	0.629373485	-1.88417	1.57079633
Pueblo Pintado	0.627919529	-1.87926	

	Km	Miles
Geodesic Distance	26.93	16.73
(decimal based checksum)	26.93	16.73

Degrees

Azimuths

				Shift (Radians)	Shift (Degrees)	Azimuth
Azimuth From	Chetro Ketl	To	Pueblo Pintado	-1.920520578	-110.0377236	**249.9623**
Azimuth From	Pueblo Pintado	To	Chetro Ketl	1.218186625	69.79695227	**69.7970**

NOTE: For use in Western Hemisphere leave negative sign in E 13 and E 14 - for use in Eastern Hemisphere remove the negative sign.

Figure 28. MS Excel great circle calculation tool

This spreadsheet tool was used to model inter-site spatial relationships. Results for a subset of analyses conducted were validated using inter-site theodolite data, as well as Google Earth GIS data.

6.4 Confirmatory Photography

Photography is the best way to validate predicted visual alignments. Bracketed exposures with an unfiltered digital camera are adequate to demonstrate an operating solar or lunar alignment ***(Figure 29, left)***. Unfiltered photographs offer the benefit of more valid recreation of the visual experience. Notwithstanding, filtered images provide a defined disk that enables calibration of photographs to theodolite survey predictions as an independent check of the survey and data reduction process ***(Figure 29, right)***.

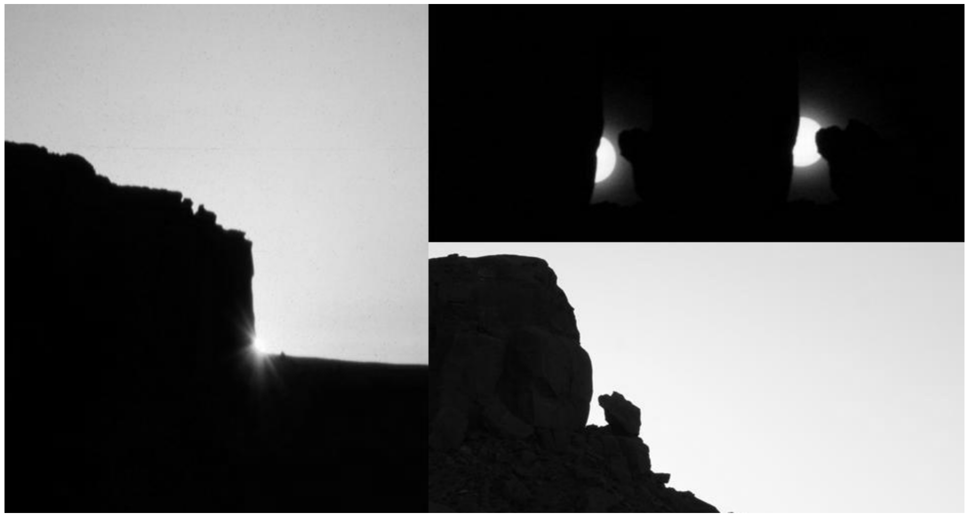


Figure 29. Comparative unfiltered and filtered sunrise photographs

The unfiltered Kin Kletso sunrise image (left photograph by G.B. Cornucopia and used with permission) provides confirmatory evidence. The Headquarters Site A background (bottom right) and filtered images (top right) support precise comparison of observed events to theodolite survey predictions.

As suggested by professional photographer Patrick René, a standard #11 Welder's Shade and exposure bracketing was used to obtain clear definition of the solar disk. To identify best exposure settings with a particular digital camera, experimentation was conducted using manual exposure settings in advance. ***Figure 30*** records the collection of June Solstice Sunset ("JSSS") data at Casa Chiquita as described. Using this method, sunrise and sunset confirmation images enable the solar disk to be precisely located on the horizon profile.

Figure 30. Taking a sunset confirmation photograph at Casa Chiquita
(Photograph by Lauren Lamont; used with permission).

6.5 Ethnography and Interpretation

The two early contrasting approaches to archaeoastronomy were labeled as "green" and "brown" by Aveni during the 1980s. Following the Oxford I conference two volumes were published, divided roughly into European and New World studies. The Green volume of old world archaeoastronomy contained studies that were heavily dependent on statistical analysis of sites for which little or no ethnographic data was available. The Brown volume described archaeoastronomy of the new world and benefitted from ethnography, anthropology, and cultural history (Aveni, 2008: 9; Iwaniszewski, 2001). Modern research in archaeoastronomy combines these two approaches whenever possible, utilizing available ethnographic, historical and archaeological information, as well as rigorous statistical methods when dealing with quantitative data (see e.g., Aveni, 2003, 2008; Bostwick and Bates, 2006; Chamberlain *et al.* 2005; Krupp, 1994, 1997; Malville, 2008a; Ruggles, 2011; Ruggles and Saunders, 1993; Young, 1986).

Pueblo culture is diverse; four distinct language families exist among the thirty one modern Pueblos in New Mexico and Arizona. Among these people, varied ancestral migration traditions and ritual practices operate within Pueblos, clans, religious societies, and moieties. Over nine centuries passed between the "Chaco Florescence" and initial 19th Century anthropological documentation of Pueblo culture. In addition, anthropological methods have changed significantly since much of the available Pueblo astronomical ethnography was recorded. As a result, ethnographic data must be applied cautiously. Nonetheless, there are widely-shared cosmological and astronomical concepts among Pueblo people that are consistent with Chacoan material evidence. The cardinal directions (NS/EW) or inter-cardinals are important in cosmogony and ritual systems. Also of importance are the concepts of "Center Place," dualism and symmetry. In addition, while traditional Pueblo ritual and agricultural calendars certainly vary, they commonly integrate solar horizon calendars and moon phase observations to identify dates of importance. Calendrical sky watching has remained socially and ritually important in the post-contact period (see e.g., McCluskey, 1977; Ortiz, 1972: 20-23, 102-119; Stirling, 1942: 5-6, 8-11, 19, 24; Snead and Preucel, 1999; Zeilik, 1985a, 1985b, 1986b, 1989).

In this study, I interpreted results that are consistent with broadly reported Pueblo cosmological and calendrical principles as likely points of cultural continuity for the Chacoans.

7 PRESENTATION OF DATA

I conducted field surveys at a total of 28 sites under the terms of National Park Service and Bureau of Land Management research permits. The objectives of the field survey work were to a) obtain data that could constrain building orientations, b) test published astronomical alignments with architecture, and c) identify workable solar and lunar horizon calendar foresights. The surveys included the principal Great Houses at Chaco Canyon, as well as selected small house, shrine, “halo,” and “outlier” Great House sites.

Preliminary field surveys were conducted using compass and clinometer. I analyzed theodolite survey results in the context of positional visual astronomy using the United States Naval Observatory’s MICA ephemerides. Upon confirmation of repetitive patterns of building orientation a Chaco, and in light of a limited number of ethnographic reports that link ceremonial “staffs” or “sticks” with Pueblo migration traditions, I also conducted follow-on dimensional analysis of “ceremonial sticks” recovered from Pueblo Bonito to test their potential for use as survey instruments. These staffs are curated at the Smithsonian Institution and the American Museum of Natural History.

The following subsections present the site by site field surveys conducted, including the data collection and analysis. The central findings presented include previously unknown workable calendrical stations that are consistently associated with monumental architecture built during the Late Bonito phase from A.D. 1100-1140. In addition, the chapter discusses the results of my dimensional analysis of Type 1 staffs with bows recovered from Pueblo Bonito. Detailed theodolite survey data for each site is presented in Appendix 1.

7.1 Padilla Well

I conducted a preliminary survey at Padilla Well on June 4, 2008. There is no standing architecture at this site, though multiple kiva depressions are evident. As shown in ***Figure 31***, five of the pillars at the west Mesa shrine site of 29SJ 1088 are clearly visible on the northeast horizon.

Figure 31. The 29SJ 1088 Shrine as viewed from Padilla Well

*Five pillars are clearly visible, feature numbers correspond to the entries in **Table 2.***

I took magnetic compass bearings and inclinometer measurements for the five visible pillars, as presented in ***Table 2***. Based upon these results, no astronomical events were predicted to occur using the pillars as foresights as observed from Padilla Well.

Pillar	Magnetic Bearing	NGDC Angle of Declination	Calculated Azimuth	Horizon Elevation
1 (at left in Fig. 29)	35.5°	10° 17’	45.8°	5°
2	37.5°	10° 17’	47.8°	5°
3	40.5°	10° 17’	50.8°	5°
4	42.5°	10° 17’	52.8°	5°
5 (at right in Fig. 29)	44.3°	10° 17’	54.6°	5°

Table 2: Magnetic bearings from Padilla Well to the shrine at 29SJ 1088

7.2 Casa del Rio and 29SJ 1088

During preliminary analysis of potential sites for field survey, Kim Malville identified one early Great House that was apparently built at a workable calendrical station with a December solstice horizon foresight. Malville's topographic analysis demonstrated that, as viewed from Casa del Rio, December solstice sunrise should occur directly over the 29SJ 1088 shrine on West Mesa, which is the highest feature of the southeastern horizon (***Figure 32***).

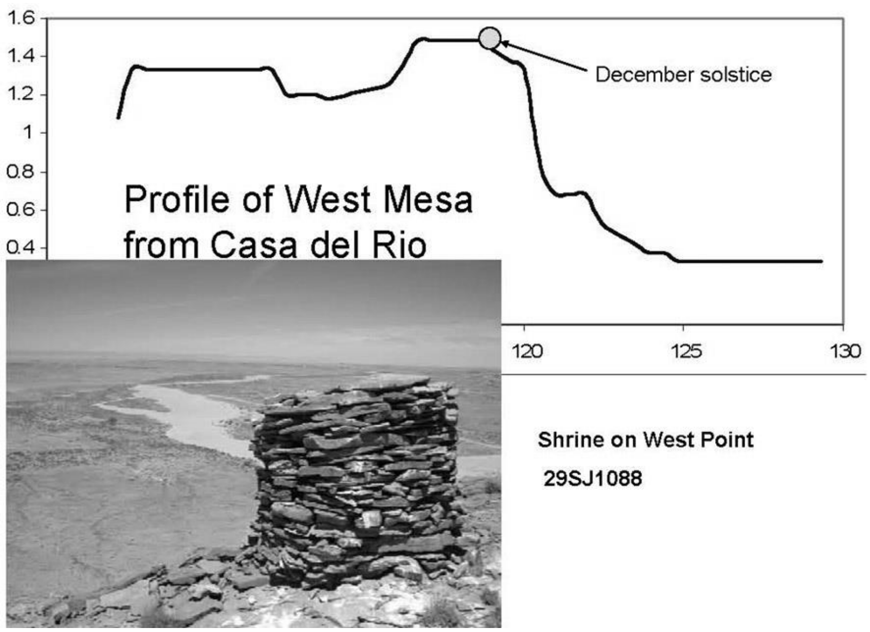


Figure 32. Proposed Casa del Rio DSSR horizon foresight at 29SJ 1088

The inset photo shows the view from the shrine towards Casa del Rio.

Casa del Rio is not managed by the National Park Service; it is on Diné land. Because permission for field work from the Navajo nation was not forthcoming (Stein, pers. comm., 2008), confirmatory field work at Casa del Rio was not possible.

7.3 29SJ 423

I conducted a preliminary compass survey at 29SJ 423 on June 11, 2008. Magnetic bearings for two prominent features on the east horizon shown in ***Figure 33*** were recorded. Magnetic compass bearings and inclinometer measurements for the two features are presented in ***Table 3***. Based upon these results, no astronomical events were predicted to occur using these horizon features as foresights from 29SJ 423. Additional survey was not conducted at this site.

Figure 33. Compass survey of east horizon at 29SJ 423

*Feature numbers correspond to the entries in **Table 3**.*

Horizon Feature	Magnetic Bearing	NGDC Angle of Declination	Calculated Azimuth	Horizon Elevation
1	61.5°	10° 16’	71.8°	0°
2	71.0°	10° 16’	81.3°	0°

Table 3: Magnetic bearings from 29SJ 423 to east horizon features.

7.4 29SJ 866

I conducted a preliminary compass survey at 29SJ 866 on June 11, 2008. Magnetic bearings were taken for the five prominent features on the west horizon marked in

Figure 34. Magnetic compass bearings and inclinometer measurements for the features are presented in ***Table 4***.

Figure 34. Compass survey of west horizon at 29SJ 866

The west horizon as viewed from 29SJ 866 has anticipatory DSSS calendrical potential based upon this preliminary compass survey.

Horizon Feature	Magnetic Bearing	NGDC Angle of Declination	Calculated Azimuth	Horizon Elevation
1	231.0°	10° 16’	241.3°	1
2	240.5°	10° 16’	250.8°	1°
3	241.8°	10° 16’	252.1°	-0.5°
4	246.5°	10° 16’	256.8°	-0.5°
5	252.0°	10° 16’	262.3°	-0.5°

Table 4: Magnetic bearings from 29SJ 866 to west horizon features.

Based upon comparison of these results to USNO ephemerides, a sunset date of December 5 is predicted to correspond to horizon feature 1. This is a good anticipatory date for December solstice calendrical observations. Interpretive caution is certainly in order as this preliminary prediction is based on compass survey only.

Additional survey was not conducted at this site due to time limitations. Follow-on theodolite survey to constrain the calendrical potential of the site would be beneficial.

7.5 Peñasco Blanco

I conducted a preliminary compass survey and theodolite surveys at Penãsco Blanco on June 4, 2009. A prominent point on the southeast horizon has been conjectured as a possible foresight for the period of December solstice sunrise as observed from the Great House; a second foresight should work for a date in November. However, varied magnetic compass results have been obtained in the past (Cornucopia, pers. comm., 2008). Magnetic compass bearings and inclinometer measurements were taken from a location 7.4 m in front of the standing front wall that surrounds Penãsco Blanco's plaza to the two horizon features (***Table 5***). The survey location was selected due to the presence of a degraded mound of material that could have been associated with the pillars reported by Mindeleff, as discussed in Chapter 5 above.

Horizon Feature	Magnetic Bearing	NGDC Angle of Declination	Calculated Azimuth	Horizon Elevation
1	108.0°	10° 1'	118.0°	0.3°
2	111.0°	10° 1'	121.0°	0.5°

Table 5: Magnetic bearings from Penãsco Blanco to east horizon features.

Subsequently, my theodolite survey of the horizon features was conducted from the same location; the theodolite setup is shown in ***Figure 35***. Four azimuth angles and four elevation angles taken for each feature were reduced using sun sights and USNO ephemerides. Comparison of the resulting polar coordinate azimuths to the magnetic data presented immediately above revealed a difference of 2.5° for the northernmost feature (theodolite survey of 116.5° versus 118.0° from the magnetic survey) and 2.6° for the more southerly feature (theodolite survey of 119.4° versus 121.0° from the magnetic survey). It is possible that locally occurring ferrous mineral deposits may impact on magnetic compass accuracy in the vicinity of Penãsco Blanco.

Figure 35. Theodolite survey of Penãsco Blanco's east horizon

Survey location was selected due to the presence of a low mound of material that we speculated may have been related to previously reported pillars.

The data for this theodolite survey is presented in Appendix 1 section 11.1.1. Resulting predicted sunrise dates are presented in ***Figure 36***. Notably, while the southerly horizon marker is too far south to act as a DSSR foresight from the observing location we selected, it is off by only 0.6°. I subsequently became aware that Dr. Tyler Nordgren of the University of Redlands had photographed DSSR from Penãsco Blanco's kiva G in 2007 (Cornucopia, pers. comm., 2010). Dr. Nordgren graciously provided his composite photograph (***Figure 37***).

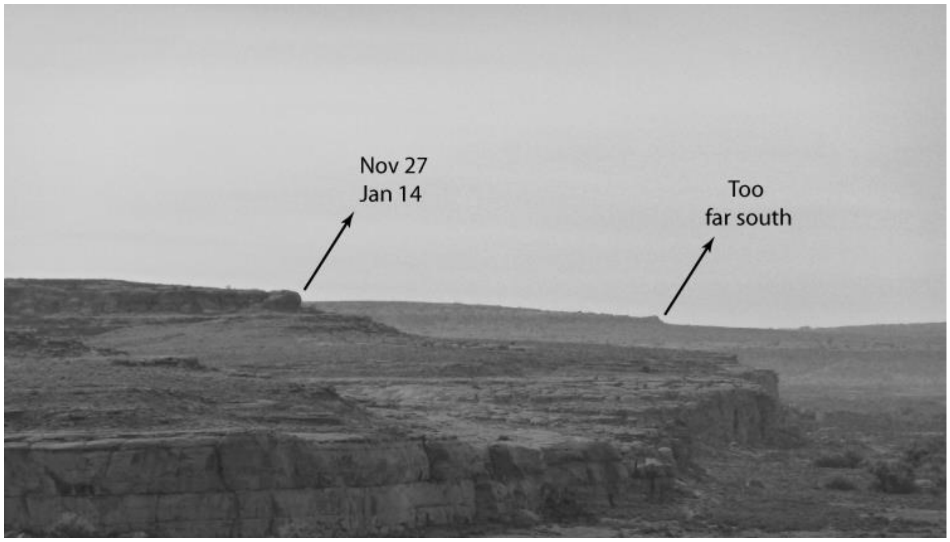


Figure 36. Penãsco Blanco east horizon

The sunrise dates shown are forecasted for the survey location, 7.4 m southeast of a standing wall section in front of Penãsco Blanco's plaza.

Figure 37. Penãsco Blanco DSSR

(Photography by Tyler Nordgren; used with permission). From kiva G the December solstice sun rises just to the north of a distinct horizon foresight.

The foresight in question is 10 km southeast of Penãsco Blanco. Topographic analysis demonstrates that at this distance, lateral movement of the observing location by some 105 m from kiva G to the northeast is predicted to result in a 0.5° shift in the sun's visual rise on the horizon with respect to the foresight. A possible

DSSR observation point for this foresight therefore corresponds with the small room block immediately northeast of Peñasco Blanco, and shown in the site plan in ***Figure 39*** below. Known as the "McElmo Ruin," this structure is situated atop a prepared terrace with a retaining wall, and based upon its McElmo style masonry (Lekson, 1984: 109) dates to the Late Bonito phase. Future efforts to perform follow up theodolite survey from the proposed observation point, and/or obtain photographic confirmation of DSSR would be beneficial.

Theodolite survey was also conducted to measure Peñasco Blanco's standing southeast wall to verify the building's orientation. The theodolite setup is shown in ***Figure 38***; resulting data is presented in Appendix 1 section 11.1.2.

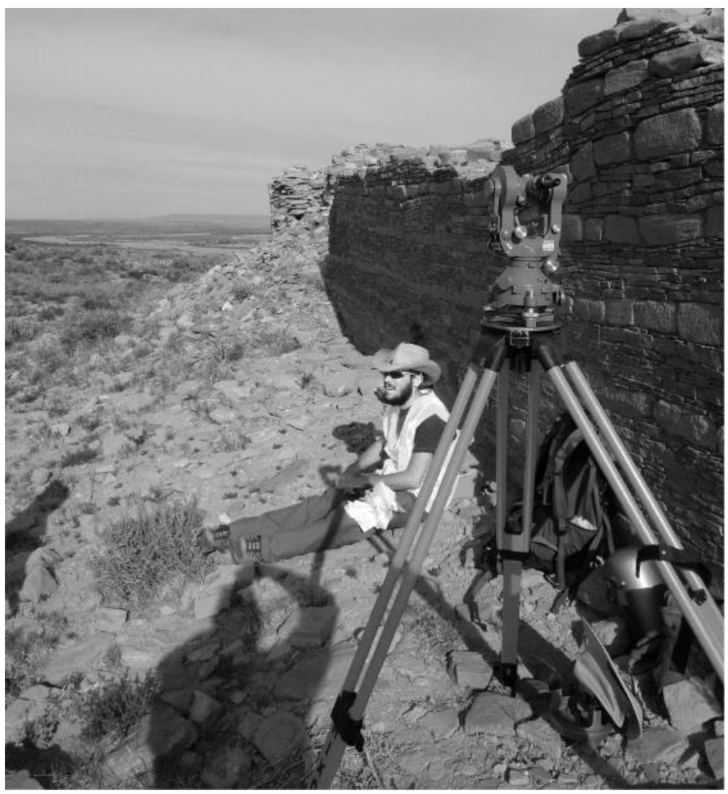


Figure 38. Theodolite position at Penãsco Blanco's southwest wall

This survey enabled confirmation of the building's orientation.

The mean measured wall angle was 177.2113° (N=10, SD=0.1971°). Using USNO ephemerides to convert this angle to polar coordinates yielded a wall azimuth of 257.0° / 77.0° as shown in ***Figure 39***. Also shown is the structure's approximate front facing azimuth along its axis of symmetry, determined for two different construction phases by taking measurements from corners of the c shaped room blocks in the site drawing. The first azimuth (~113°-116°) corresponds to the front facing azimuth for the C shaped room block after its initial phase of construction, or "Stage I" circa A.D. 900. The second azimuth (~127°-130°) corresponds to the final "Stage IV-V" form of the structure built after A.D. 1090 (Lekson, 1984: 99-105). The building is not precisely symmetrical, and therefore the selection of measurement points for the front facing azimuths are debatable, resulting in the range of values shown.

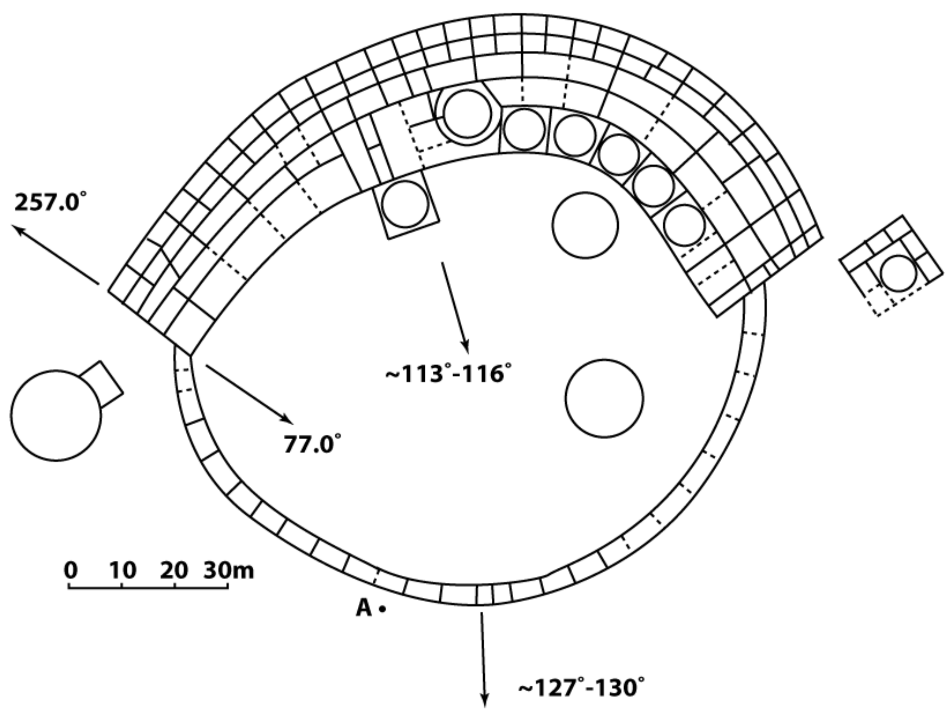


Figure 39. Peñasco Blanco site plan

(Adapted from Lekson, 1984: 95). The orientation of the southwest wall was confirmed using theodolite survey. The potential east horizon DSSR foresight was surveyed from the point marked as "A."

7.6 Casa Chiquita

I conducted a preliminary compass and inclinometer survey at Casa Chiquita May 24, 2009 that identified potentially useful calendrical foresights on the western horizon, as observed from the southwest corner of the Great House, directly west of room 4. These included a possible June solstice sunset marker. Magnetic compass bearings and inclinometer measurements for the west horizon features are presented in ***Table 6***. The horizon features are identified in ***Figure 42*** below with the associated theodolite survey results. The potential JSSS foresight appears visually similar to the December solstice sunrise foresight visible from the northwest corner at nearby Kin Kletso.

Horizon Feature	Magnetic Bearing	NGDC Angle of Declination	Calculated Azimuth	Horizon Elevation
1	271.0°	10° 8'	281.1°	1.3°
2	275.5°	10° 8'	285.6°	1.3°
3	284.0°	10° 8'	294.1°	1.5°
4	288.5°	10° 8'	298.6°	1.0°

Table 6: Magnetic bearings from Casa Chiquita to west horizon features.

Magnetic compass survey of the east horizon was conducted from atop the fill in room 4. Magnetic compass bearings and inclinometer measurements for the east horizon features are presented in ***Table 7***.

Horizon Feature	Magnetic Bearing	NGDC Angle of Declination	Calculated Azimuth	Horizon Elevation
5	59.0°	10°8’	69.1°	12.0°
6	63.0°	10°8’	73.1°	8.0°
7	64.0°	10°8’	74.1°	5.5°
8	65.0°	10°8’	75.1°	3.0°
9	99.0°	10°8’	109.1°	4.5°
10	106.0°	10°8’	116.1°	3.5°
11	108.5°	10°8’	118.6°	3.5°
12	109.5°	10°8’	119.6°	3.5°
13	115.3°	10°8’	125.4°	1.5°
14	115.0°	10°8’	126.1°	0.5°

Table 7: Magnetic bearings from Casa Chiquita to east horizon features.

The east horizon magnetic survey points are identified in ***Figure 40***. They provide adequate coverage of the horizon to enable preliminary assessment of calendrical potential. However some of the selected points may be too subtle for calendrical use.

Figure 40. East horizon compass survey key at Casa Chiquita

Some of these survey points are likely too subtle for calendrical use.

Based upon the preliminary compass survey results, theodolite surveys of both the western and eastern horizons were conducted. On May 25, 2009 Theodolite survey of the four distinct west horizon features was conducted from a position directly adjacent to the southwest corner of the building, just west of room 4. Four azimuth angles and four elevation angles were taken for each feature and subsequently reduced using sun sights and USNO ephemerides. The west wall of the structure was surveyed simultaneously to verify the building's orientation. The data for this theodolite survey is presented in Appendix 1 sections 11.2.2 and 11.2.3.

There is a blocked-in opening in the west wall of Casa Chiquita directly adjacent to the southwest corner of the building that may have worked as an observation point. However, review of pre-stabilization photography demonstrates that reconstruction masonry was added in this area (Plog, 2006); it is not certain if the sill of the blocked-in opening is original. Predicted sunset dates are presented in ***Figure 41***. The inset filtered JSSS confirmation image was taken June 21, 2010. Though there may have been an anticipatory maker for JSSS built into Casa Chiquita's architecture, no such feature has been identified in the building's remains. I therefore propose it as a Class 2 calendrical station.

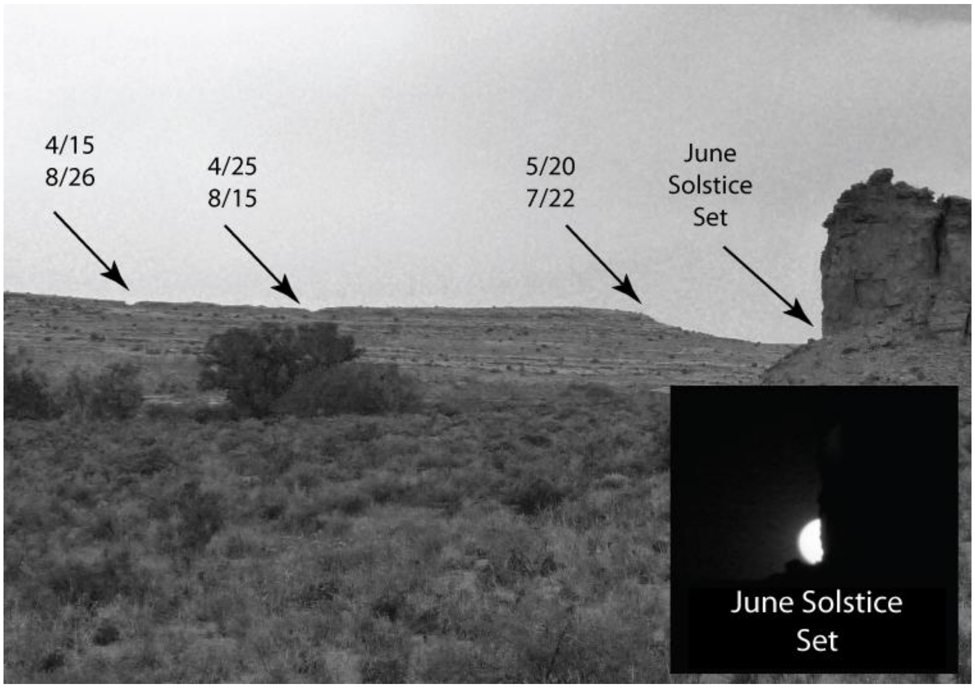


Figure 41. West horizon and JSSS at Casa Chiquita

Forecasted sunset dates from the theodolite survey and (inset) JSSS confirmation image

The eastern horizon survey was conducted from a position atop the fill in room 4 of the Great House (***Figure 42***). The data for this theodolite survey is presented in Appendix 1 section 11.2.1. Four azimuth angles and four elevation angles taken for each feature were reduced using sun sights and USNO ephemerides to predict sunrise dates associated with horizon features. In contrast to the west horizon survey, some theodolite survey points were different from the magnetic survey points presented above; more pronounced features were selected for enhanced calendrical potential.

Figure 42. Theodolite position at Casa Chiquita for survey of east horizon
East Horizon survey was conducted from atop the fill in room 4.

Forecasted sunrise dates are presented in ***Figure 43***. Please note that magnetic survey point 12 (see ***Figure 40*** above) corresponds to the 11/23 date shown. For this horizon feature the predicted azimuth based on the magnetic survey was 119.6°, but the theodolite survey yielded an azimuth of 118.6°, a difference of a full degree. This raises the possibility that steel material (“rebar”) may have been used in stabilization of the structure, or that there may be local magnetic ferrous mineral deposits. Irrespective, the mesa cliff face immediately to the south of the 11/23 foresight is not well placed for calendrical use as viewed from the Great House; it is south of the DSSR position. In contrast, the rounded horizon profile at upper left does provide a subtle but workable JSSR foresight that is visually similar to Zeilik’s (1986a) proposed JSSR foresight at Pueblo Bonito (see ***Figure 11*** above). The inset photo confirms the JSSR event as viewed from room 4.

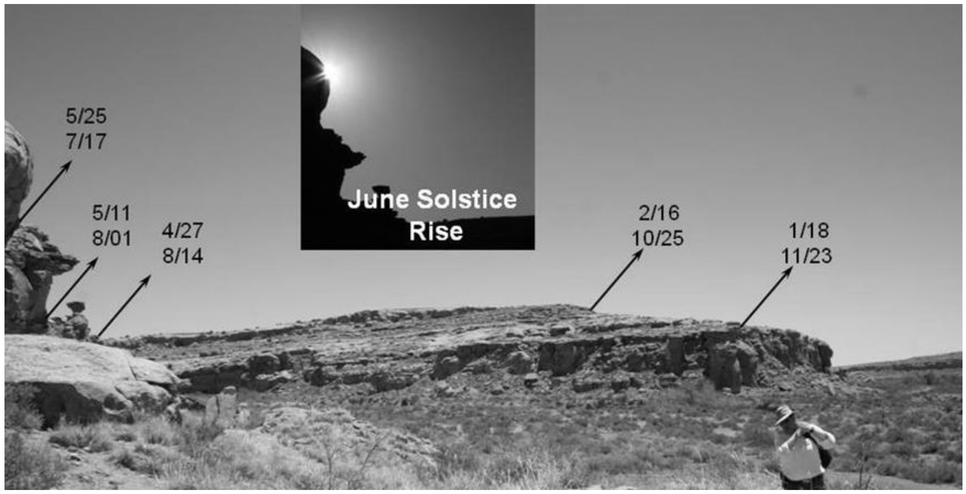


Figure 43. East Horizon and (inset) JSSR at Casa Chiquita

Inset JSSR confirmation photo by G.B. Cornucopia and used with permission.

The mean measured wall angle for the west wall of Casa Chiquita was 172.2252° (N=15, SD=0.5855°). Using sun sights and USNO ephemerides to convert this angle to polar coordinates yielded a wall azimuth of 200.5°/20.5° (***Figure 44)***.

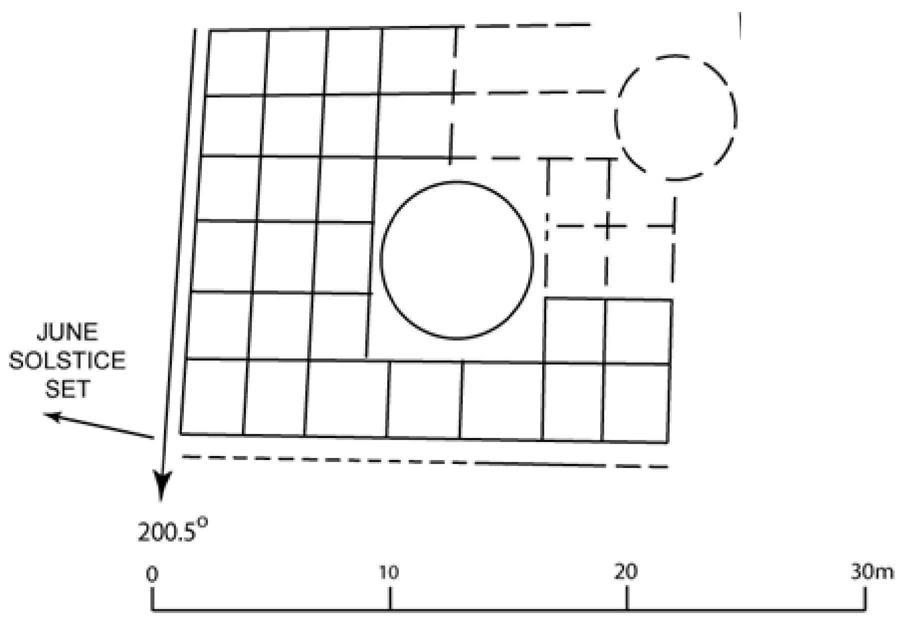


Figure 44. Casa Chiquita site plan

(Adapted from Lekson, 1984: 247). The JSSS Sightline and measured west wall orientation are shown.

7.7 Kin Kletso

As discussed in section 1.3.1.2 above, a previously confirmed workable Class 1 calendrical station is present at Kin Kletso. I conducted confirmatory photography on December 21, 2009 as presented in ***Figure 45***. No additional survey was conducted at Kin Kletso.

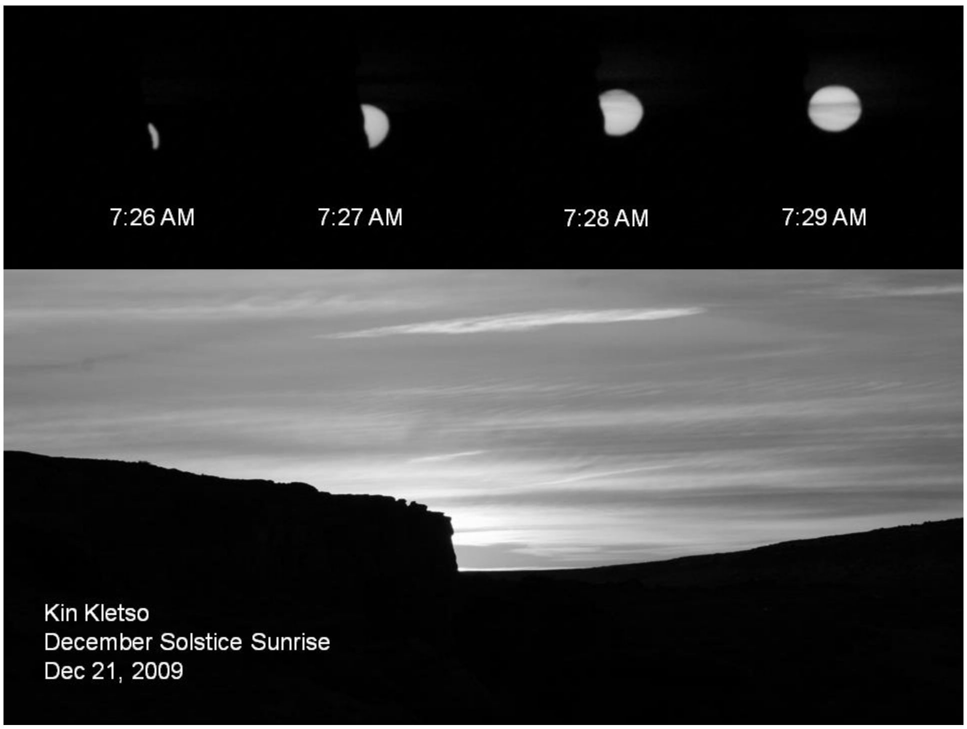


Figure 45. DSSR at Kin Kletso

The sun's disk is only briefly in contact with the flat horizon at the bottom of the mesa wall at sunrise; filtered sunrise disk images at top document the sunrise sequence observed.

7.8 Pueblo del Arroyo

On May 27, 2009 I conducted a theodolite survey of Pueblo del Arroyo's west wall from the high spot along that wall. The theodolite setup is shown in ***Figure 46*** and resulting data is presented in Appendix 1 section 11.3.

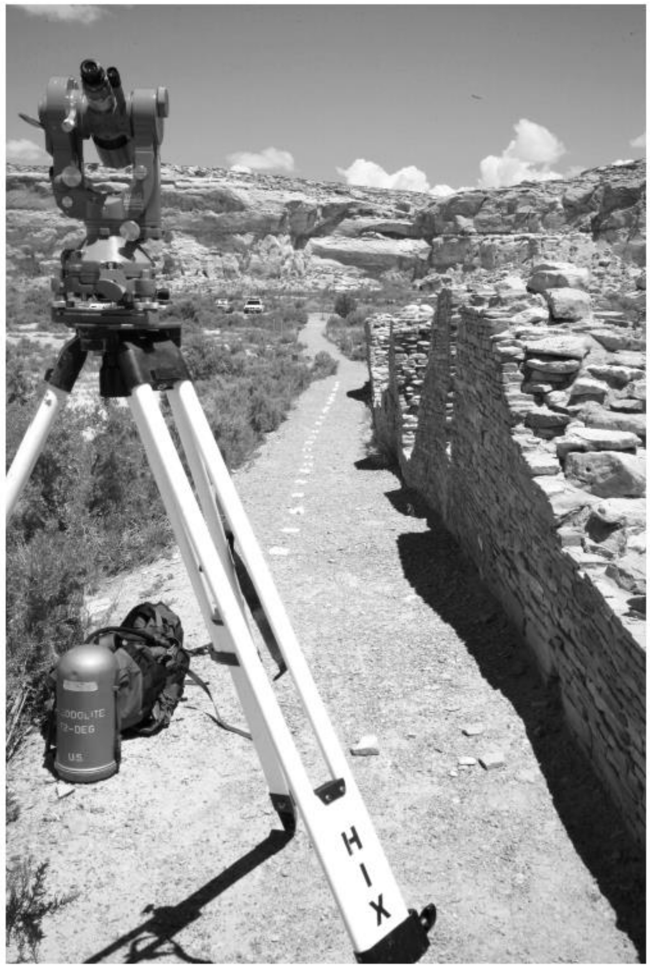


Figure 46. Theodolite position at Pueblo del Arroyo

Photograph by Clint Shoemaker and used with permission.

The mean measured wall angle was 190.0230° (N=64, SD=0.4988°). Using USNO ephemerides to convert this angle to polar coordinates yielded a wall azimuth of 204.9° / 24.9° as shown in ***Figure 47***. Also shown is the structure's approximate front facing azimuth along its axis of symmetry of 114.9°, determined by taking the perpendicular of the measured wall. The east horizon altitude on that azimuth was measured to be 1.1°.

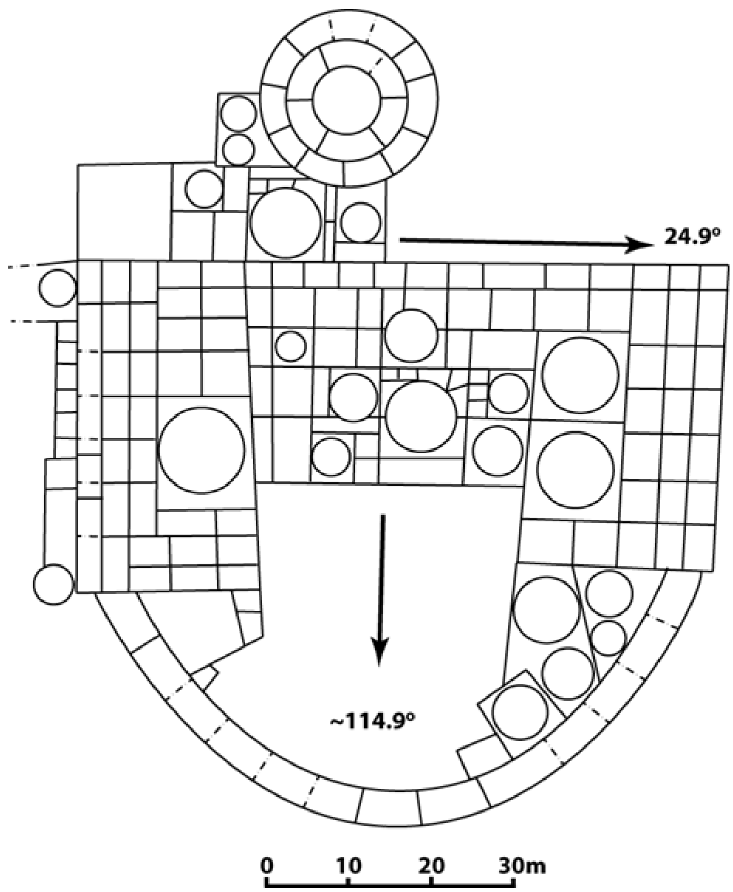


Figure 47. Pueblo del Arroyo site plan

(Adapted from Lekson, 1984: 211) The front facing azimuth was computed as the perpendicular of the survey results for the back wall of the Great House.

7.9 Pueblo Bonito

Four features at Pueblo Bonito were surveyed using the theodolite including the NS bisecting wall, the east section of the south wall, the west section of the south wall, and Great Kiva A.

On May 31, 2009 I conducted a theodolite survey of Pueblo Bonito's bisecting central NS wall from a position at the south end of the wall. The theodolite setup is shown in ***Figure 48***, and resulting data is presented in Appendix 1 section 11.4.1. The mean measured wall angle was 144.8850° (N=40, SD=0.3426°). Using USNO ephemerides and sun sights to convert this angle to polar coordinates yielded a wall azimuth of 180.7° / 0.7° as shown in the site plan in ***Figure 52*** below.

Figure 48. Survey of Pueblo Bonito's NS bisecting wall
(Photograph by Jim Walton, Used with permission).

On May 31, 2009 I conducted a theodolite survey of the west section of Pueblo Bonito's south wall from the east end of the wall section. The theodolite was positioned 1 m from the wall, adjacent to the west doorway into Pueblo Bonito's central plaza as shown in ***Figure 49***. The resulting data is presented in Appendix 1 section 11.4.2. The mean measured wall angle was 53.4818° (N=62, SD=0.0982°). Using USNO ephemerides to convert this angle to polar coordinates yielded a wall azimuth of 270.2° / 90.2° as shown in ***Figure 52***. In addition, horizon altitudes were measured for both the east and west horizons on the wall's azimuth to assess the potential for visual equinox alignments. I found a west horizon altitude of 2.1°; the east horizon's measured altitude is 2.6°.

Figure 49. Theodolite position at Pueblo Bonito's south wall, west section
Among all the features identified as aligned to the cardinal directions in surveyed Chacoan architecture, this wall section is the most accurate and precise.

On May 30, 2009 I conducted a theodolite survey of the east section of Pueblo Bonito's south wall from the west end of the wall section. The theodolite was positioned 1 m from the wall, adjacent to the east doorway into Pueblo Bonito's central plaza as shown in ***Figure 50***. The resulting data is presented in Appendix 1 section 11.4.3. The mean measured wall angle was 178.4318° (N=62, SD=0.4905°). Using USNO ephemerides to convert this angle to polar coordinates yielded a wall azimuth of 266.0° / 86.0° as shown in ***Figure 52***. In addition, horizon altitudes were measured for both the east and west horizons on the wall's azimuth to assess the potential for visual equinox alignments. The west horizon altitude is 2.9°; the east horizon's measured altitude is 2.8°.

Figure 50. Theodolite position at Pueblo Bonito's south wall, east section

This enigmatic wall section is deflected from cardinal EW by 4°.

In addition to the central and south wall surveys at Pueblo Bonito, I also conducted a theodolite survey at Great Kiva A. The theodolite was positioned at the center of the kiva's north stairway opening (***Figure 51***), and eight symmetrically placed features visible on the kiva floor were measured. Four independent azimuth angles were taken for each of the eight features and subsequently reduced using sun sights and USNO ephemerides. The data for this theodolite survey is presented in Appendix 1 section 11.4.4.

Figure 51. Theodolite position at Pueblo Bonito Great Kiva A

The theodolite was placed at the top of the north stairway to enable measurement of the axis of symmetry without the need to enter the kiva.

Each of the eight independently measured points on the kiva floor yielded low standard errors (from 0.0002° to 0.0021°); I found a mean azimuth for the set of features of 181.3°. To be sure, a more accurate and precise assessment of Great Kiva A's orientation may be obtained by entering the kiva to mark the center points of each of its support pillar foundations. In addition, some of the features measured are associated with floor boxes that have been stabilized since excavation. Notwithstanding, the non-intrusive survey we conducted does serve to generally confirm Great Kiva A's association with the set of Chacoan architecture aligned to the cardinal directions.

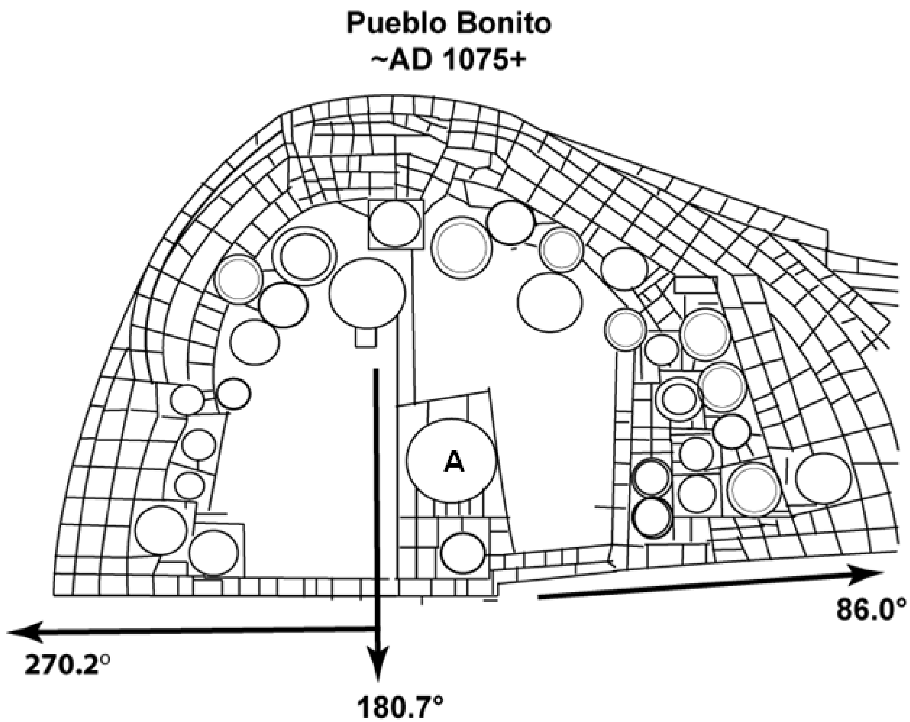


Figure 52. Pueblo Bonito site plan

Pueblo Bonito includes architectural features confirmed to be accurately aligned to the cardinal directions, including the identified walls, and kiva "A."

7.10 Talus Unit

Preliminary compass survey at Talus Unit on May 31, 2008 identified potentially useful DSSR and DSSS horizon features on the east and west horizons. The magnetic compass and clinometer data is presented in ***Table 8***. The horizon features are labeled for the east horizon in ***Figure 53***, and for the west horizon in ***Figure 54***.

Horizon Feature	Magnetic Bearing	NGDC Angle of Declination	Calculated Azimuth	Horizon elevation
1	105.5°	10° 15'	115.8°	1.5°
2	107.5°	10° 15'	117.8°	1.3°
3	110.5°	10° 15'	120.8°	0.5°
4	231.5°	10° 15'	241.8°	2.0°

Table 8: Magnetic bearings from Talus Unit to horizon features.

Figure 53. Talus Unit east horizon

Preliminary compass survey points of interest

Figure 54. Talus Unit west horizon

Preliminary compass survey point of interest

I conducted a theodolite survey of the western horizon feature (number 4 in Table 8) on June 6 2008. This feature survey was conducted from each of the front corners of Talus Unit. ***Figure 55*** shows the theodolite location selected at the southeast corner of the building. The data for the two theodolite surveys is presented in Appendix 1 sections 11.5.1 and 11.5.2. Four azimuth angles and four elevation angles were taken for the feature, and they were later reduced using sun sights and USNO ephemerides to identify potential sunrise dates associated with the feature. Irrespective of which corner of the building is chosen as an observing point, due to the horizon's elevation the horizon feature is too far south to operate as a DSSS foresight.

Figure 55. Talus Unit survey of the west horizon

In spite of provocative compass survey results, no workable solstice foresights were found to be observable from Talus Unit.

Subsequently, I visually confirmed on Dec 21 2008 that neither the east (possible sunrise) or west (possible sunset) horizon features operate as solstice foresights; both of these features are over a degree too far to the south as observed from Talus unit.

7.11 Chetro Ketl

On May 31, 2008 I conducted a theodolite survey of the Chetro Ketl's back (north) wall from the west end of the wall. The theodolite was positioned 1 m from the wall, as shown in ***Figure 24*** above. The resulting data is presented in Appendix 1 section 11.6.1. The mean measured wall angle was 166.0189° (N=101, SD=0.2442°). Using USNO ephemerides and sun sights to convert this angle to polar coordinates yielded a wall azimuth of 250.2° / 70.2° as shown in the site plan in ***Figure 57*** below. The east horizon altitude on the walls azimuth was found to be 5.1°. Also shown is the structure's approximate front facing azimuth along its axis of symmetry of 160.2°, determined by taking the perpendicular of the measured wall. Based on this front facing axis of symmetry Chetro Ketl exhibits the south southeast ("SSE") orientation discussed in section 1.3.2 above.

I conducted a second theodolite survey on June 3, 2009 to measure the axis of symmetry of the Great Kiva in Chetro Ketl's plaza. The theodolite was positioned above the center of the kiva's northwest stairway (***Figure 56***).

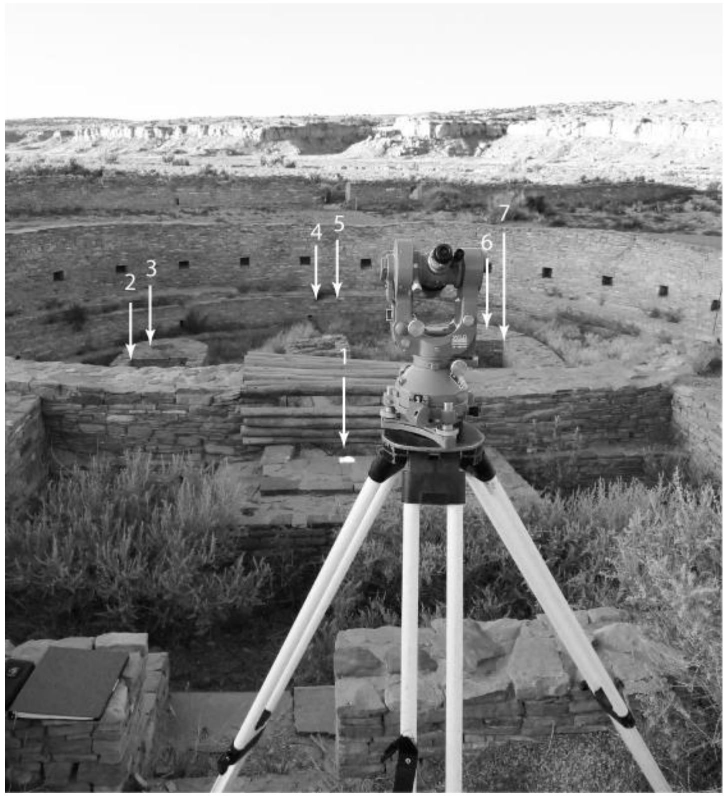


Figure 56. Chetro Ketl Great Kiva survey points

Similar to Pueblo Bonito, symmetrically placed visible features were measured without entering the kiva.

The center of the stairway opening and the six additional symmetrically placed features noted in the figure were measured. I took four independent azimuth angles for each of the seven features and subsequently reduced using sun sights and USNO ephemerides. The data for this theodolite survey is presented in Appendix 1 section 11.6.2.

The four repeated measurements of seven kiva features yielded moderate standard error's (from 0.0019° to 0.0085°); and the mean azimuth found for the set of features was 163.9° as shown at kiva "A" in ***Figure 57***. As with measurement at Pueblo Bonito's kiva A, a more accurate and precise assessment of this Great Kiva's orientation may be obtained by entering the kiva to mark the center points of each of its support pillar foundations. Also, some of the features measured are associated with floor boxes that have been stabilized since excavation. Notwithstanding, the non-intrusive survey we conducted does serve to generally confirm the Great Kiva A's association with the set of Chacoan architecture aligned to the SSE, consistent with the Great House itself.

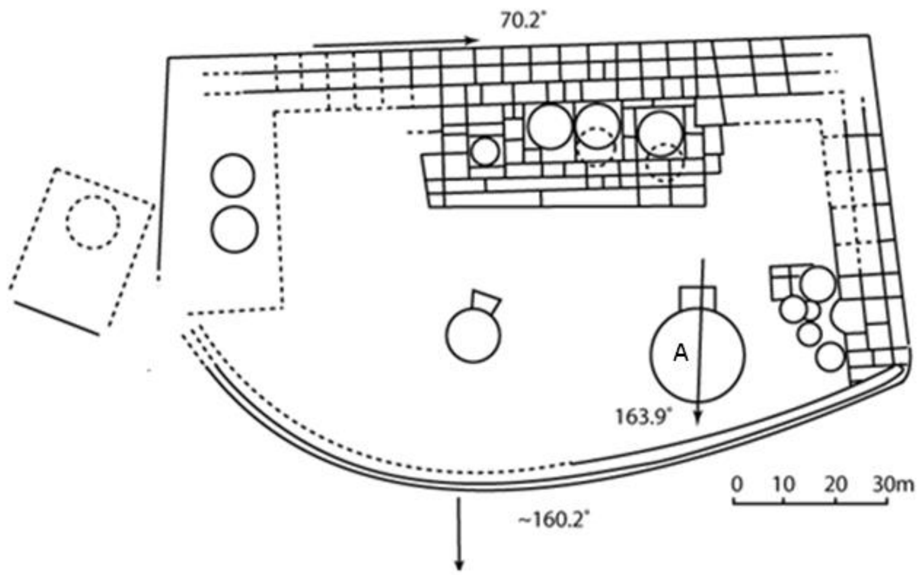


Figure 57. Chetro Ketl site plan

(Adapted from Lekson, 1984: 153) Chetro Ketl exhibits SSE front facing orientation.

7.12 Casa Rinconada

A theodolite survey was conducted on June 7, 2008 to measure the axis of symmetry of the Great Kiva of Casa Rinconada, as well as the line of sight azimuth from Casa Rinconada to New Alto. The theodolite was positioned just outside of the south room abutting the Great Kiva's southern stairway opening (***Figure 58***).

Figure 58. Theodolite survey at Casa Rinconada

A plumb bob was used to determine the angle to the west side of the south stairway, from a location outside the South antechamber where New Alto is visible on the Northern Horizon.

The theodolite location was chosen to avoid entry into the Great Kiva; it was the sole location available that permitted measurement of in-kiva features as well as the sightline to New Alto. Four in-kiva stairway features were measured, one in the south stairway and three in the north stairway. In addition to the sightlines to the visible east and west ends of New Alto were measured. The resulting data is presented in Appendix 1 section 11.7.

Theodolite survey found a sightline along the west side of both stairways to the west end of New Alto on a polar azimuth of 361.0 degrees with a Standard Deviation of .35 deg. Williamson (1984: 132-140) was able to enter the kiva and utilized bisected lines between wall niches, as well as bisected lines between support pillar footing sockets to identify the kiva's major axis of symmetry, aligned within 4'' of cardinal NS. This is clearly the most efficient way to constrain the structure's axis of symmetry. In contrast, our theodolite setup was established without direct reference to those features owing to the need to stay outside of the structure. Ultimately, Williamson's measured azimuth traversed from the east side of the kiva's south stairs and the center of the North Stair opening (1984: 137). Our survey therefore only serves to confirm the structure's cardinal NS alignment in a general way, but does verify the sight line azimuth the New Alto.

7.13 New Alto

On May 31, 2009 theodolite survey of New Alto's east wall was conducted from the southern end of the wall section. The theodolite was positioned 1 m from the end of the exposed wall base, as shown in ***Figure 59***.

Figure 59. Theodolite survey of New Alto's east wall

This location facilitated measurement of the Great House wall, as well as sightlines to the south.

The theodolite location was selected to enable measurement of the wall's azimuth, as well as the sight lines to Casa Rinconada and Tsin Kletsin from a single location. The resulting data is presented in Appendix 1 section 11.8. The mean measured wall angle was 159.5878° (N=13, SD=0.1065°). Using USNO ephemerides and sun sights to convert this angle to polar coordinates yielded a wall azimuth of 351.9° / 171.9° as shown in ***Figure 60***.

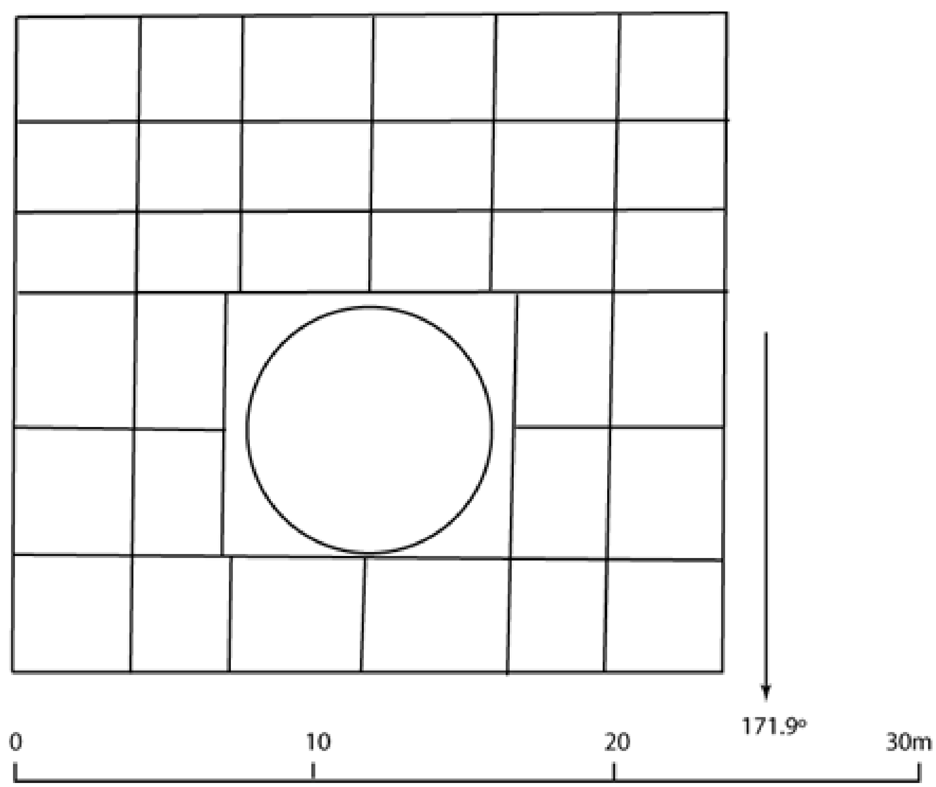


Figure 60. New Alto site plan

(Adapted from Lekson, 1984: 252) Based upon measurement of the east wall, New Alto is rotated by nearly 9° to the east from a cardinal NS orientation.

The sight lines to the visible east and west ends of Casa Rinconada and Tsin Kletsin were also measured. Four azimuth angles were taken for each feature and reduced using sun sights and USNO ephemerides. Resulting standard error for each measured feature ranged from 0.0002° to 0.0009°. The mean inter-site azimuth found for the sightline to Casa Rinconada is 181.5°, with an angular width of 0.2°. The mean inter-site azimuth found for the sightline to Tsin Kletsin is 177.2°, with an angular width of 0.5°. As shown in ***Figure 61***, the southern viewscape from New Alto encompasses Casa Rinconada and Tsin Kletsin, as well as Mount Taylor and Hosta Butte on the southern horizon.

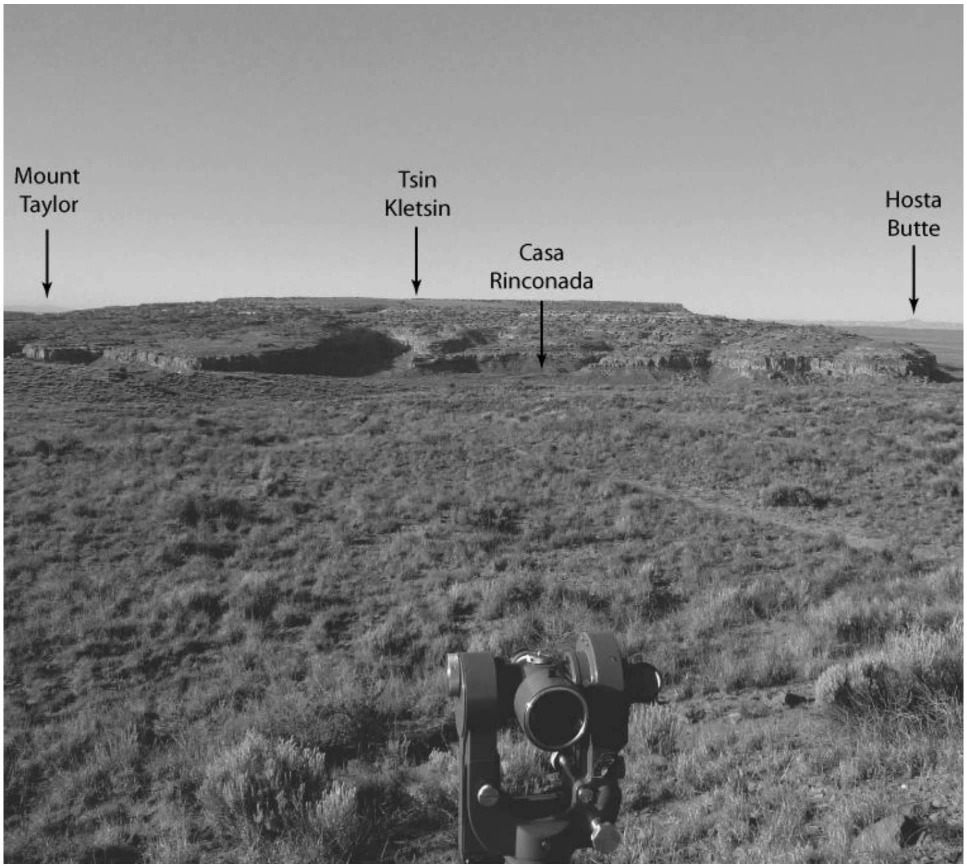


Figure 61. New Alto South horizon view

Mount Taylor and Hosta Butte are viewed as sacred landforms by some traditional Pueblo and Diné people. They may have had significance as sacred sites to the Chacoans as well.

7.14 Pueblo Alto

On June 1, 2008 I conducted a theodolite survey of the back (north) wall of Pueblo Alto from the west end of the wall. The theodolite was positioned 1 m from the wall, as shown in ***Figure 62***. With the benefit of experience and hindsight, a better theodolite location would have been approximately 50 m east of this point; due to the obscuring effects of local topography (a high spot along the wall at that point) we were unable to measure the entire wall from the chosen location. The resulting data is presented in Appendix 1 section 11.9. The mean measured wall angle for the west end of the wall was 161.5842° (N=33, SD=0.3741°). Using USNO ephemerides and sun sights to convert this angle to polar coordinates yielded an azimuth for the western end of the wall of 267.8° / 87.8° as shown in ***Figure 63***.

Figure 62. Theodolite survey of Pueblo Alto's north wall, west section

Survey would have been more effective if conducted from the center of the wall in the background of this image.

Sofaer (2008: 90) reported a mean azimuth of 268.9° / 88.9° for the entire north wall of Pueblo Alto; 1.1° closer to a cardinal EW line vice our measured value. Based upon Windes' (1987: 192-209) proposed construction sequence, Pueblo Alto's first stage of construction at ~ A.D. 1020-1040 included the west end of the north wall that we measured; this wall was extended to the east in later phases of construction. Assuming that Sofaer's reported azimuth for the entire structure is correct, our data indicates that the mean azimuth of this wall apparently became more accurately EW as phased additions were made to the east through ~ A.D. 1100. Future resurvey of the wall would be beneficial.

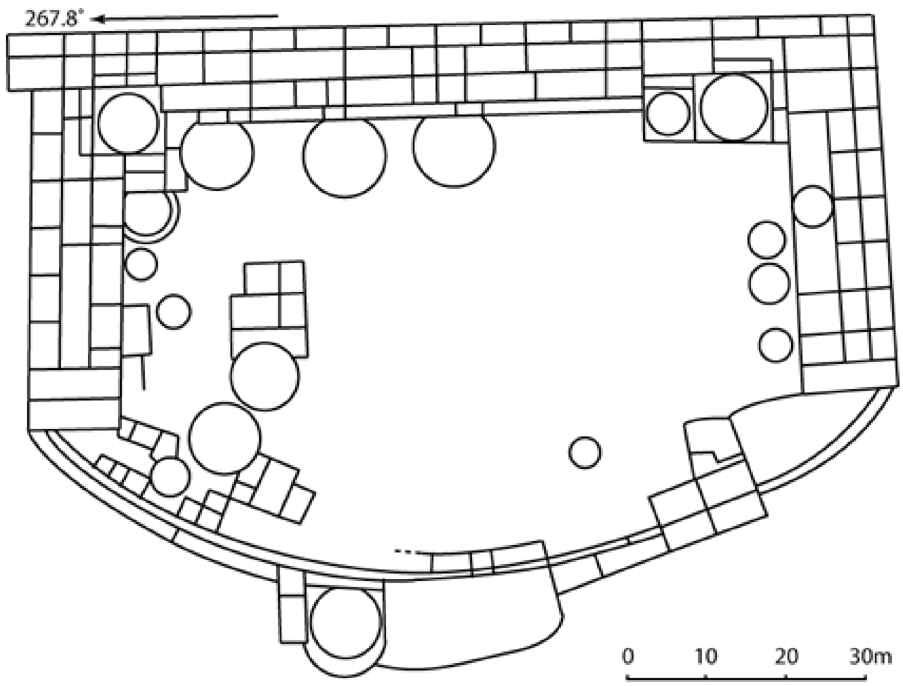


Figure 63. Pueblo Alto site plan

(Adapted from Lekson, 1984: 193) The indicated azimuth of orientation for the north wall is not applicable to the entire wall; 33 segments were measured at the west end of the structure.

7.15 Tsin Kletsin

On May 28, 2009 theodolite survey of Tsin Kletsin's northeast wall was conducted from the eastern end of the wall section. The theodolite was positioned 1 m from the end of the exposed wall base, at the northeast corner of the McElmo unit room block as shown in ***Figure 64***.

Figure 64. Theodolite position at Tsin Kletsin

The Theodolite was positioned at the northeast corner of the Tsin Kletsin's McElmo room block.

The theodolite location was selected to enable measurement of the wall's azimuth, as well as the sight lines to Pueblo Alto and New Alto from a single location. The resulting data is presented in Appendix 1 section 11.10. The mean measured wall angle was 204.9660° (N=12, SD=0.0545°). Using USNO ephemerides and sun sights to convert this angle to polar coordinates yielded a wall azimuth of 268.7° / 88.7° as shown in ***Figure 65***. Also shown is the structure's approximate back-facing azimuth along its axis of symmetry of 358.7°, determined by taking the perpendicular of the measured wall. In keeping with the interpretive approach used throughout this work, the front facing azimuth would be the reciprocal, 178.7°, as facing from the room block across the D shaped plaza.

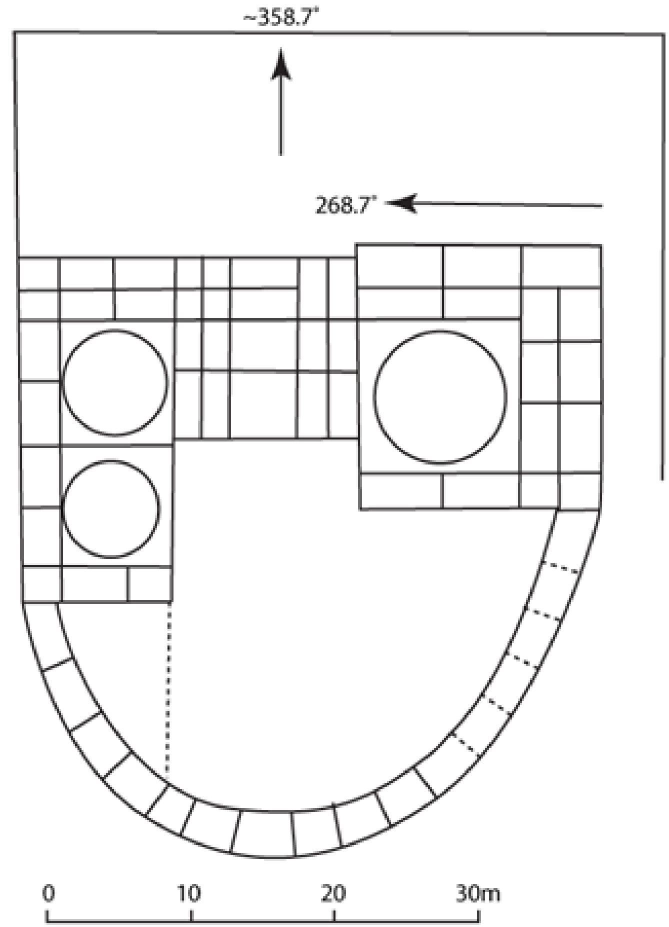


Figure 65. Tsin Kletsin site plan

(Adapted from Lekson, 1984: 232) Tsin Kletsin's NE wall is oriented within 1.3° of true EW.

The sight lines to the visible east and west ends of Pueblo Alto and New Alto were also measured. Four azimuth angles were taken for each feature and reduced using sun sights and USNO ephemerides. Resulting standard error for each measured feature ranged from 0.0003° to 0.0034°. The mean inter-site azimuth found for the sightline to Pueblo Alto is 360.2°, with an angular width of 1.7°. The mean inter-site azimuth found for the sightline to New Alto is 356.9°, with an angular width of 0.2°. As shown in ***Figure 66***, the northern viewscape from Tsin Kletsin encompasses New Alto and Pueblo Alto, as well as the broad expanse of the northern San Juan basin.

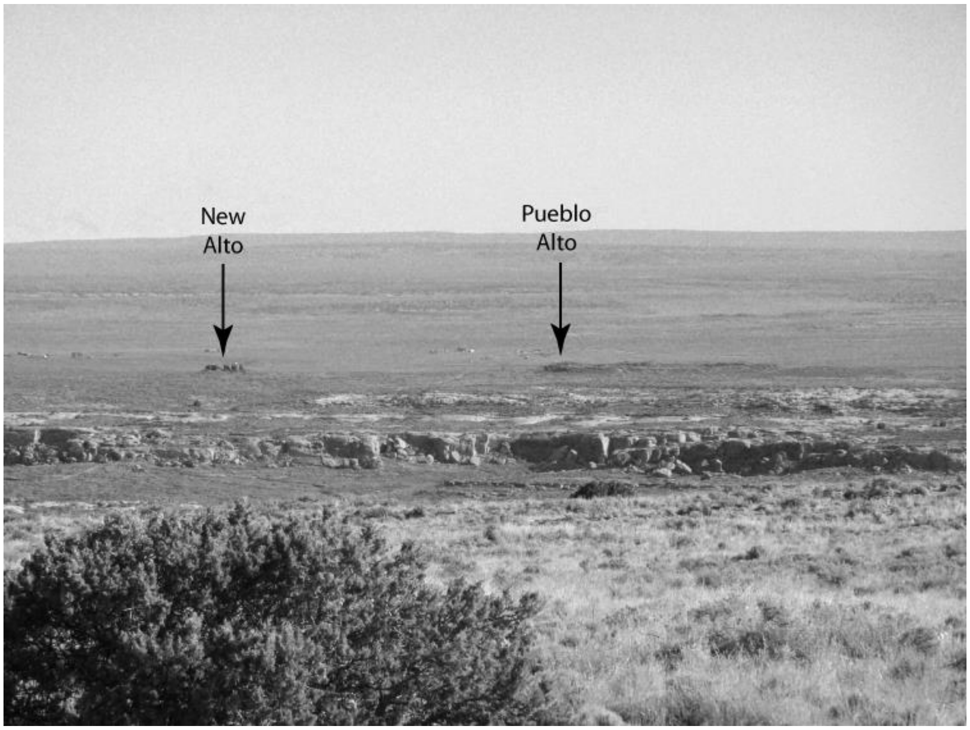


Figure 66. View to the north from Tsin Kletsin

This view from Tsin Kletsin on South Mesa looking north includes both the Pueblo Alto and New Alto Great Houses.

7.16 Hungo Pavi

On June 8, 2008 theodolite survey of Hungo Pavi's north (back) wall was conducted. The theodolite was positioned 1 m from the west end of the exposed wall base, at the northwest corner of the structure as shown in ***Figure 67***.

Figure 67. Theodolite survey of Hungo Pavi's back (north) wall
Survey included the wall azimuth, as well as the east horizon altitude on that azimuth.

The resulting data is presented in Appendix 1 section 11.11. The mean measured wall angle was 171.5407° (N=85, SD=0.5990°). Using USNO ephemerides and sun sights to convert this angle to polar coordinates yielded a wall azimuth of 275.4° / 95.4° as shown in ***Figure 68***. Also shown is the structure's approximate front-facing azimuth along its axis of symmetry of 185.4°, determined by taking the perpendicular of the measured wall. In addition, the east horizon altitude was measured on the wall's azimuth to assess the potential for a visual equinox sunrise alignment.

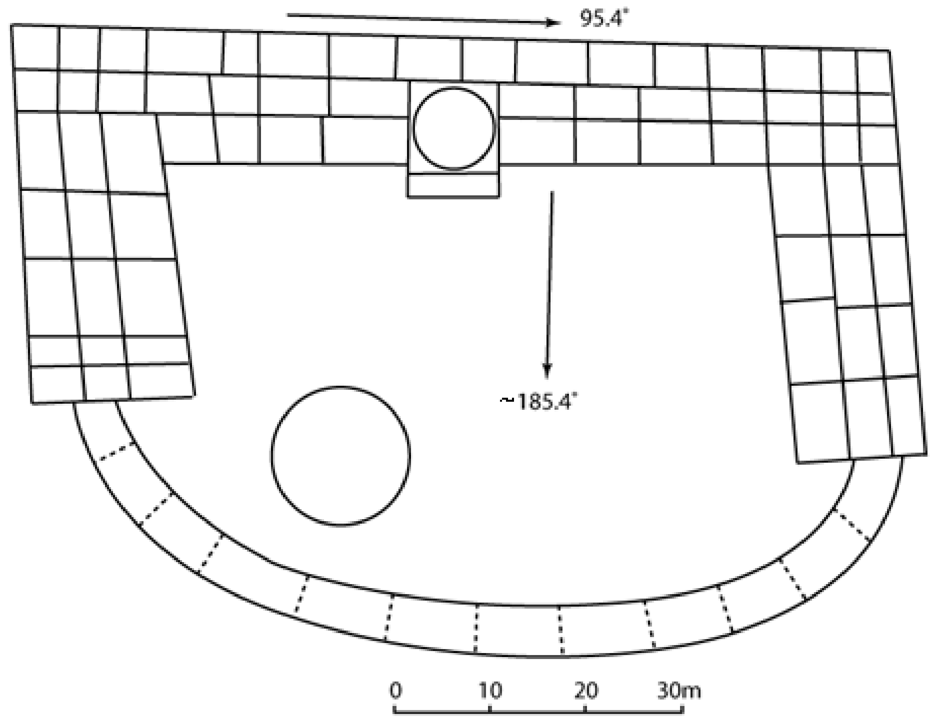


Figure 68. Hungo Pavi site plan

(Adapted from Lekson, 1984: 145) Survey indicates that a proposed visual equinox sunrise alignment is not workable due to the horizon altitude (see below).

7.17 Kin Nahasbas

I conducted a preliminary visual survey of Kin Nahasbas on May 31, 2008. While the Great Kiva depression is visible, this backfilled site presents inadequate feature definition or standing architecture to execute architectural survey, or constrain possible horizon viewing locations associated with the architecture (***Figure 69***). Inter-visibility to Una Vida and Pueblo Bonito was confirmed.

Figure 69. Kin Nahasbas

The backfilled Kin Nahasbas site offers limited options for archaeoastronomical survey.

Kim Malville's assessment of the front facing orientation of the structure was completed with reference to the Great Kiva features in the site plan reproduced in ***Figure 70***, and yielded an approximate value of 205° (Malville and Munro, 2011).

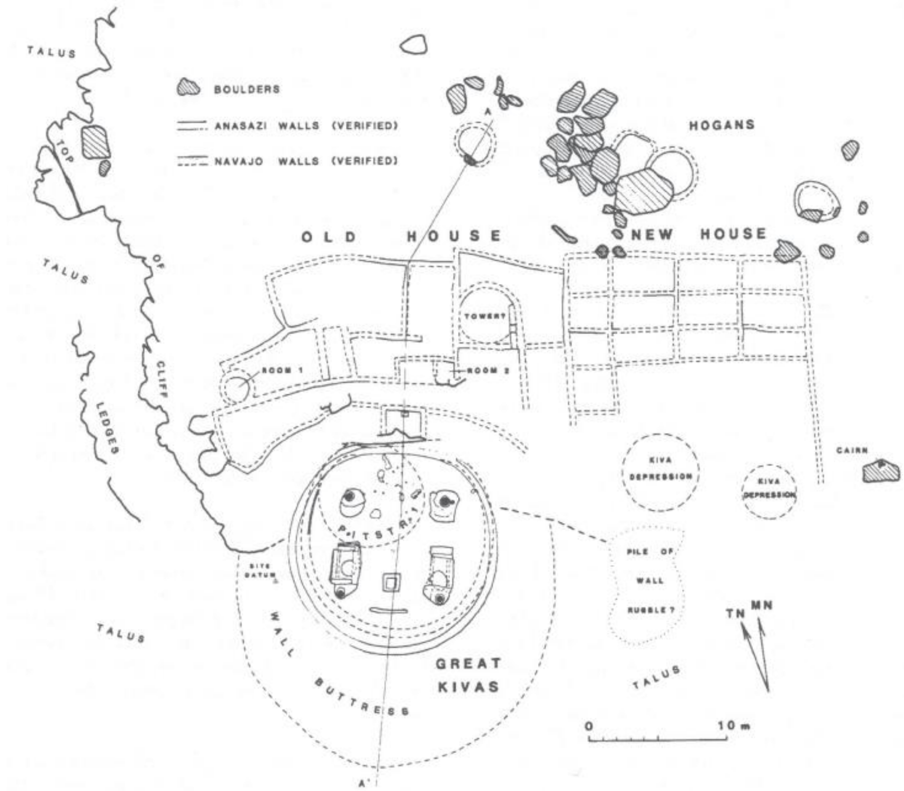


Figure 70. Kin Nahasbas site plan

(Site plan from Mathien and Windes, 1988: figure 4.)

7.18 Una Vida

On December 18, 2008 I conducted a theodolite survey of the southern end of Una Vida's northeast wall. The theodolite was positioned at the center of the wall, 1 m from the exposed wall base as shown in ***Figure 71***. The resulting data is presented in Appendix 1 section 11.12. The mean measured wall angle was 135.3850° (N=12, SD=0.3589°). Using USNO ephemerides and sun sights to convert this angle to polar coordinates yielded a wall azimuth of 325.2 / 145.2° as shown in ***Figure 72***. Also shown are the structure's approximate front facing azimuths along its axes of symmetry, determined for two different construction phases by taking measurements from corners of the room blocks in the site drawings. The first azimuth (~148°) corresponds to the front facing azimuth for the small room block built during the initial phase of construction, or "Stage I" circa A.D. 860. This azimuth differs by 3° from the previously reported azimuth of 151° for this construction phase (Malville and Munro, 2011; Munro and Malville, 2011a). The difference is due to the fact that previous reports were based the reference site plan compass rose (*Lekson, 1984: 80),* the revised azimuth is in reference to the surveyed wall. The second azimuth (~184.5°) corresponds to the final “Stage VI-VII” form of the structure built after A.D. 1070 (Lekson, 1984: 79-94). This azimuth was found by bisecting the structure’s plaza; the selection of measurement points for that analysis is to some degree arbitrary given the structure’s design so the resulting front facing azimuth should be considered approximate.

Figure 71. Theodolite survey at Una Vida

The south end of Una Vida’s northeast wall was surveyed, as well as the northeast horizon altitude perpendicular to the wall.

The perpendicular of the measured wall is 55.2°, which is comparable to Sofaer's (2007: 92) reported perpendicular azimuth of 54.8°. Sofaer associated this azimuth with major lunar standstill. The northeast horizon altitude on that azimuth is over 45.2° due to the high towering cliff face above Una Vida, making a visual moonrise observation on the azimuth impossible.

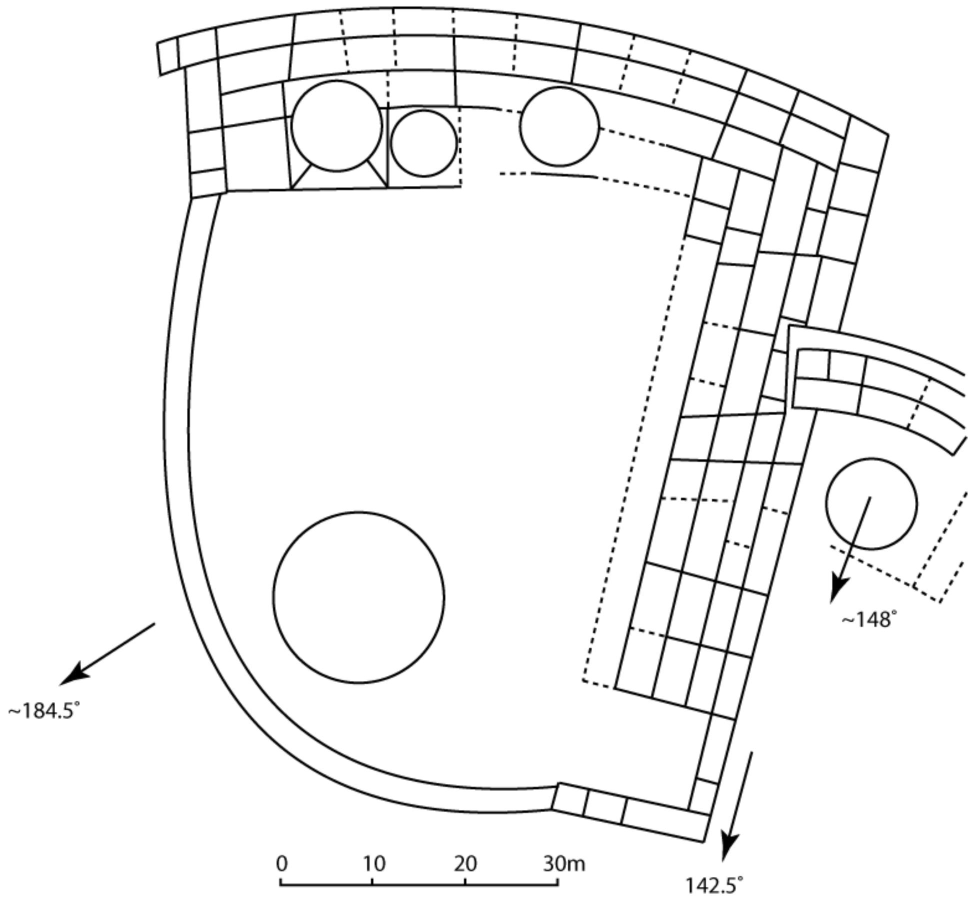


Figure 72. Una Vida site plan

(Adapted from Lekson, 1984: 80)

7.19 Headquarters Site A

Based on a June 7, 2008 preliminary compass survey at Headquarters Site A I believed that a workable horizon calendar with a solstice foresight might be present. However, selecting observation points for either a compass or theodolite survey was problematic because most of the horizon foresights are very close. As discussed above, close foresights cause a calendrical observing location to be very sensitive due to parallax. For this reason, visual December solstice observations were conducted at Headquarters Site A prior to theodolite survey. An east horizon foresight was identified that creates a dramatic December solstice sunrise light play or "casting of light" that includes much of the building's footprint. When sunrise is observed from a position adjacent to the building's kiva depression (marked as point "A" in ***Figure 73*** the sun rises from a horizon notch, and a shaft of light formed by the notch projects onto the ground. The horizon elevation of the notch as observed from point A is 8.3 degrees, resulting in the relatively late sunrise on an azimuth of 126.9 deg. As the sun rises higher, the light casting effect traverses the Great House's footprint from west to east. After it exits the east extent of the site the sun has risen high enough to exit the notch and the light play ends.

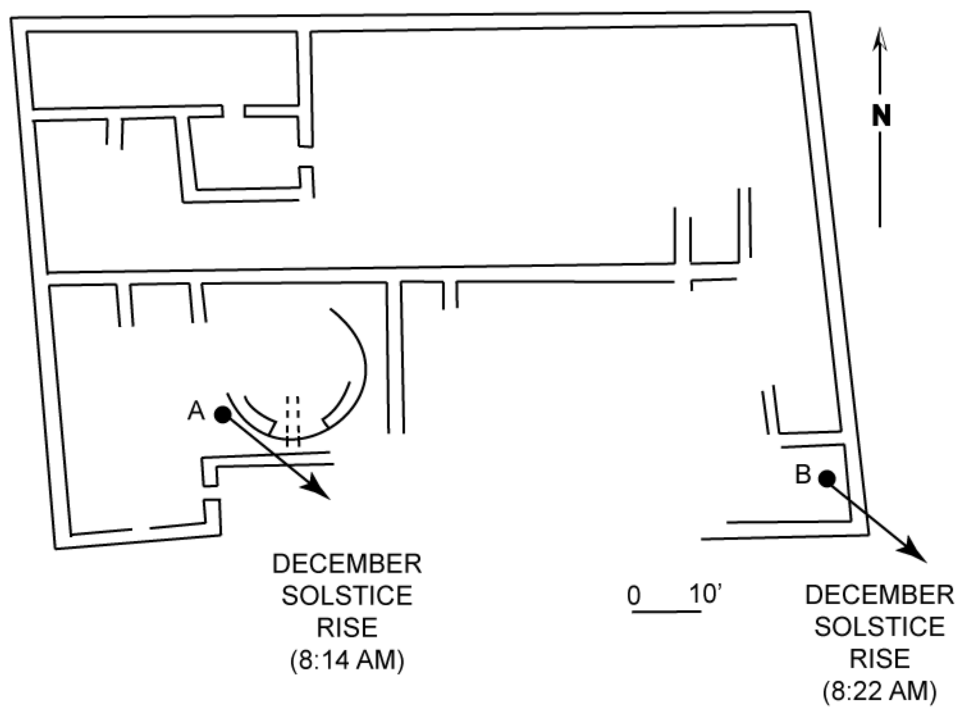


Figure 73. Headquarters Site A site plan

Observation points and sightlines (adapted from Mathien, 2005: 227; from original map C55320 in Chaco Culture NHP Archive).

Figure 74 includes confirmation photographs. The 8:14 AM filtered inset image shows the solar disk framed by the foresight notch as observed from position A in the site plan. The second filtered inset image was taken 8 minutes later, from the position marked as B. Because the foundation is filled with alluvial gravel and there are no standing walls; these locations were identified in reference to survey stakes and the remaining kiva depression. If the Great House had been completed to a height of one story, the December solstice sunrise light play would have been observable across the roof of the building.

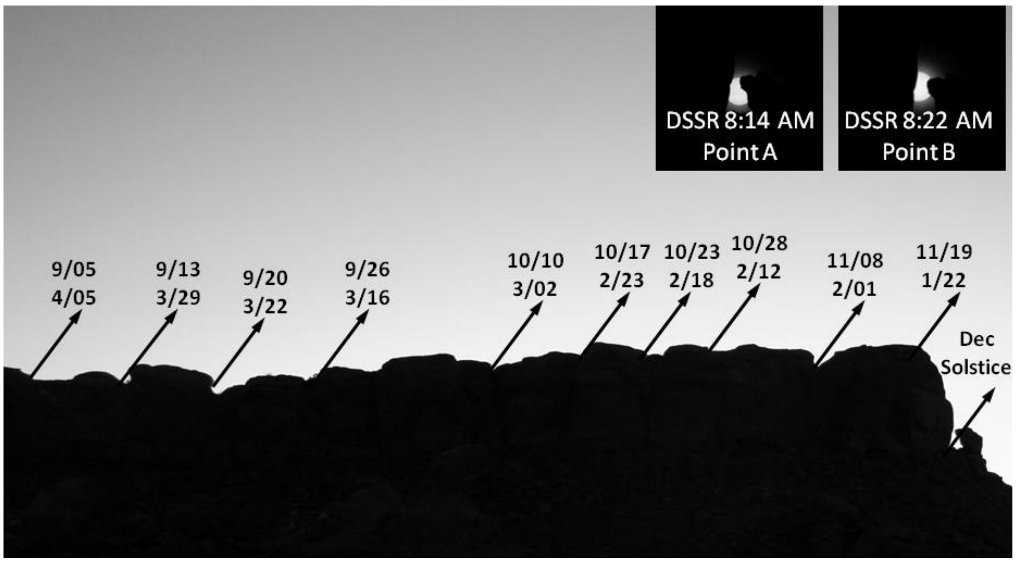


Figure 74. East horizon and DSSR at Headquarters Site A

Forecasted sunrise dates, and (insets) DSSR confirmation photos are shown.

The forecasted sunrise dates shown in ***Figure 74*** were derived from a theodolite survey conducted on December 20, 2009 from the point labeled as "A" in the building footprint. Sunset dates for the western horizon from the same location are also presented (***Figure 75***). Four azimuth angles were taken for each east horizon feature, however due to time limitations only a single angle was taken for each of the west horizon features. All were reduced using sun sights and USNO ephemerides. Resulting standard error for the east horizon features ranged from 0.0007° to 0.0025°. The theodolite survey data is included in Appendix 1, section 11.13.

The projected rise and set dates identified are to some extent arbitrary, a survey from point "B" would yield different dates for the close foresights. Nonetheless, the spacing between these foresights and the presence of a mid-May sunset marker that could provide one or two weeks advance notice of a planting date may have enabled agricultural use.

The proposed Headquarters Site A calendrical station is unique among those identified to date at Chaco because it provides a nearly complete annual calendar. It does not include an anticipatory marker for December Solstice, or a marker for June Solstice. However, the calendrical station at Piedra del Sol (Malville, 2008a: 64-70) includes both of these "missing" markers and is only 300 m distant. An integrated solar calendar kept using these two stations would provide coverage of the entire year. Both of the sites have a line-of-sight to the three-Slab "sun dagger" shrine on Fajada Butte.

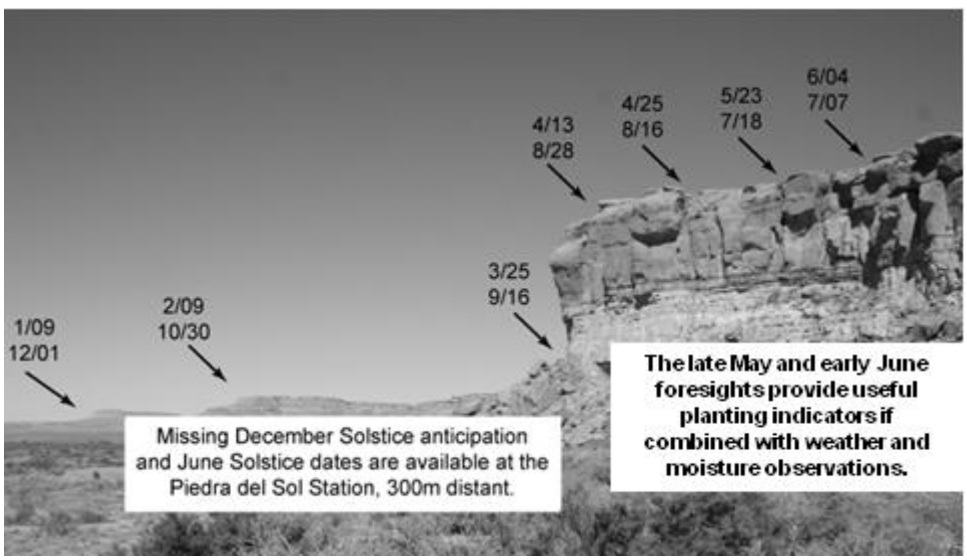


Figure 75. West horizon at Headquarters Site A with predicted sunset dates

In combination with Piedra del Sol, Headquarters Site A provides a complete annual solar calendar.

7.20 29SJ 913

At the request of National Park service staff my field team joined professional photographer Patrick René on December 19, 2009 for a site visit to 29SJ 913. NPS staff requested that we perform theodolite survey of the horizon to supplement

René’s photographic record. The site was identified as having archaeoastronomical potential by Dr. Jan Allen when she conducted a site survey for NPS in the area. Based upon her suggestion that the site appeared to have calendrical potential associated with rock art, interpretive ranger G.B. Cornucopia conducted a preliminary compass survey that led him to conclude that there was a likely DSSS calendrical foresight offered by Fajada Butte. The most prominent feature of the site itself is a large boulder with multiple petroglyphs, including dual spirals and multiple anthropomorphic forms (***Figure 76***).

Figure 76. 29SJ 913

Prominent spirals and anthropomorphs are the primary elements of this panel.

While the view of Fajada Butte from behind the art panel is of greatest interest, there is inadequate space behind the panel to set up a theodolite. Therefore, the theodolite was leveled in a position immediately in front of the site, 3.8 m from the panel as shown in ***Figure 77***. The theodolite shift of 3.8 m has no major impact on resulting survey predictions for sunset dates because the foresight is 2.5 km distant.

Figure 77. Theodolite survey from 29SJ 913

The theodolite was leveled as close to the rock art panel as was practical.

Four azimuth angles were taken for each feature on Fajada Butte and reduced using sun sights and USNO ephemerides. The detailed survey data and reduction are presented in Appendix 1, section 11.14. Resulting standard error for each measured feature ranged from 0.0003° to 0.0019°. The predicted sunset dates are shown in ***Figure 78***, with an inset confirmatory photograph of December solstice sunset by Patrick René. The vertical face on Fajada Butte directly left of the sunset foresight houses the “sun dagger” three-slab site. 29SJ 913 provides Class 1 December solstice sunset calendrical potential using Fajada Butte as a foresight.

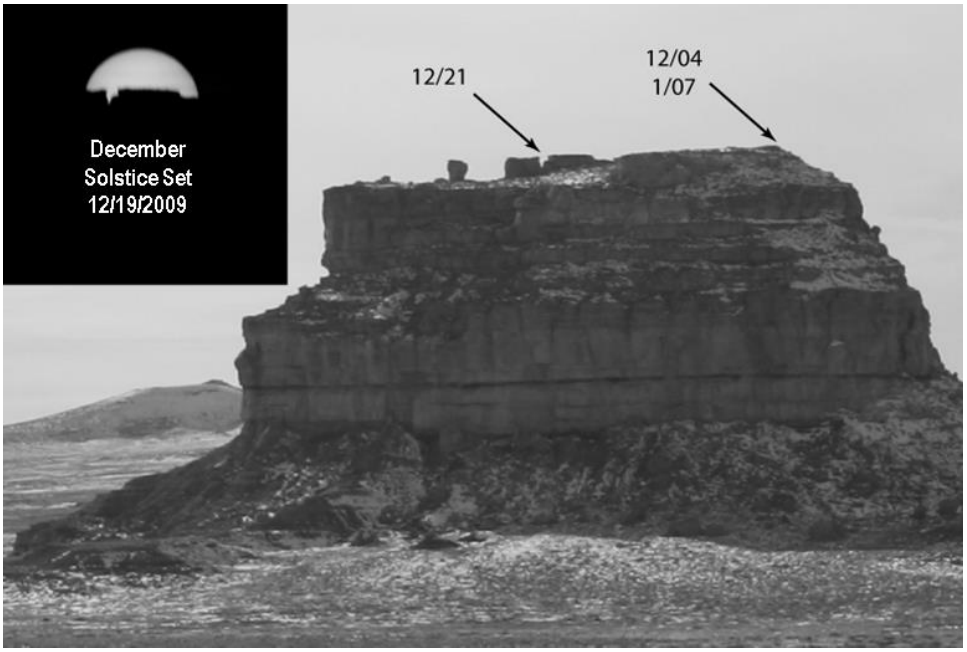


Figure 78. DSSS at 29SJ 913

(Inset Sunset Image by Patrick René; used with permission).

7.21 Shabik' eshchee

The overwhelming majority of pithouses at Shabik' eshchee village are filled with windblown material such that accurate determination of pithouse axes of symmetry from direct measurement is not possible without excavation. One pit house was found to be measurable based upon an exposed hearth deflector; this pithouse is labeled as "house B" in Roberts' (1929, plate 1) map of the village plan. On May 27, 2009 theodolite survey of this deflector was conducted. The theodolite was positioned 2 m east of the deflector's end, as shown in ***Figure 79***.

Figure 79. Theodolite survey of Shabik' eshchee's pithouse B deflector

Among the surrounding pithouses, only this site had adequate above ground exposure to enable survey.

The resulting survey data is presented in Appendix 1 section 11.15. The mean measured deflector angle was 160.4126° (N=5, SD=0.3484°). Using USNO ephemerides and sun sights to convert this angle to polar coordinates yielded a deflector azimuth of 249.8° / 69.8°. The perpendicular of this azimuth is 159.8°, which is the inferred front facing axis of symmetry for the pithouse.

This data point provided an independent confirmation point for Kim Malville's map-based (Roberts, 1926) assessment of SSE orientation among Shabik' eshchee pithouses. His analysis found an average axis of symmetry of 158.7° with a standard deviation of 7.7° for a sample of 15 SSE facing pithouses. It is interesting that the house we were able to survey was not well defined in the Roberts map, and was thus not included in Malville's analysis. The 159.8° azimuth we measured is consistent with the identified SSE pattern (Malville and Munro, 2011).

7.22 Roberts Small Pueblo, 29SJ 2384

Theodolite survey at Roberts Small Pueblo is not practical because the entire structure is backfilled. Notwithstanding, there are exposed wall sections visible from the wash below the site. On September 21, 2009 I conducted a compass survey of an exposed wall section, as shown in ***Figure 80***.

Figure 80. Compass measurement of exposed wall at Roberts Small Pueblo
Use of theodolite survey was not practical at Roberts Small Pueblo.

Ten compass measurements were conducted by directly reading bearings for individual sandstone blocks; the compass was held directly against the sandstone in the exposed McElmo masonry. Magnetic compass readings were adjusted for declination using NGDC's web tool. The results are presented in ***Table 9***.

Measurement Number	Magnetic Bearing	NGDC Angle of Declination	Calculated Azimuth
1	199.0°	10° 2'	189.0°
2	200.0°	10° 2'	190.0°
3	195.0°	10° 2'	185.0°
4	200.0°	10° 2'	190.0°
5	197.0°	10° 2'	187.0°
6	204.0°	10° 2'	194.0°
7	200.0°	10° 2'	190.0°
8	200.0°	10° 2'	190.0°
9	200.0°	10° 2'	190.0°
10	199.0°	10° 2'	189.0°
MEAN			189.4°
Standard Deviation			2.3°

Table 9: Magnetic bearings for exposed wall section at Roberts Small Pueblo.

The exposed wall section of Roberts Small Pueblo is oriented to ~ 189.4° / 9.4° as shown in ***Figure 81***.

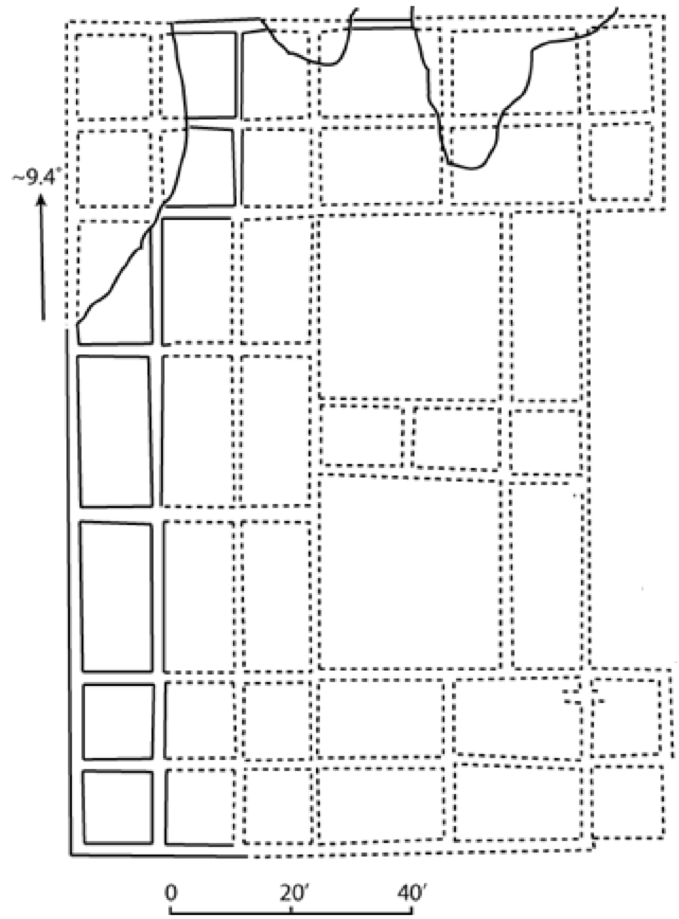


Figure 81. Roberts Small Pueblo site plan

(Adapted from NPS Site Notes by Miles, 1983, from the original in Roberts' field notebook "1926-27" on pg 15.) This backfilled McElmo masonry foundation is not currently exposed such that theodolite survey is practical.

7.23 Above Roberts Small House, 29SJ 2538 and 29SJ 2539

During our initial site visit to the habitation site of Roberts Small House, Kim Malville noted that the topography of the eastern horizon at this location had excellent calendrical potential. During his initial search across the adjacent slope on the compass back-azimuth for December solstice he identified a grinding stone inserted into a boulder cleft (***Figure 82***).

Figure 82. Grinding stone at 29SJ 2539

This metate was the initial piece of cultural evidence identified at 29SJ 2539.

Subsequent assessment of the area around this grinding stone identified a location with a large flat boulder and "backstop" that appeared to be well positioned to observe December solstice sunrise. This boulder is located 125 m from the Late Bonito foundation at Roberts Small Pueblo, and 90 m from Roberts Small House (or "Turkey House"). The proposed observing station is shown in ***Figure 83***.

Review of National Park Service files identified the site as 29SJ 2539; it is directly adjacent to 29SJ 2538, which includes a ledge overlooking the boulder. Much of 29SJ 2538/2539 is covered with cultural material including lithics, bone fragments, and potsherds. Apparent ancestral Pueblo and Diné rock art is present. The NPS site assessments note that pot sherds include both Chacoan and Diné types, and that while a ledge at 29SJ 2538 is suited for storage there is no evidence of such use. The assessments concluded that the two sites are linked, should possibly be considered as one, and may have been used as "as special activity area of some sort" (National Park Service 1983).

Figure 83. Proposed calendrical station at 29SJ 2538/2539
The observing site is 125 m from Roberts Small Pueblo, and 90 m from Roberts Small House.

A rich collection of rock art including both petroglyphs and pictographs is located at 29SJ 2538/2539. A modern inscription 15 m to the south of the observing location includes a sunburst symbol, the word “CHABAI” and the number “74” (***Figure 84***). This area was not transferred to National Park Service control until the late 1970s. The inscription may be indicative of recent reuse for ritual sun watching. A nearby panel includes a lightly inscribed petroglyph of a horse, and a circular form that are likely Diné in origin.

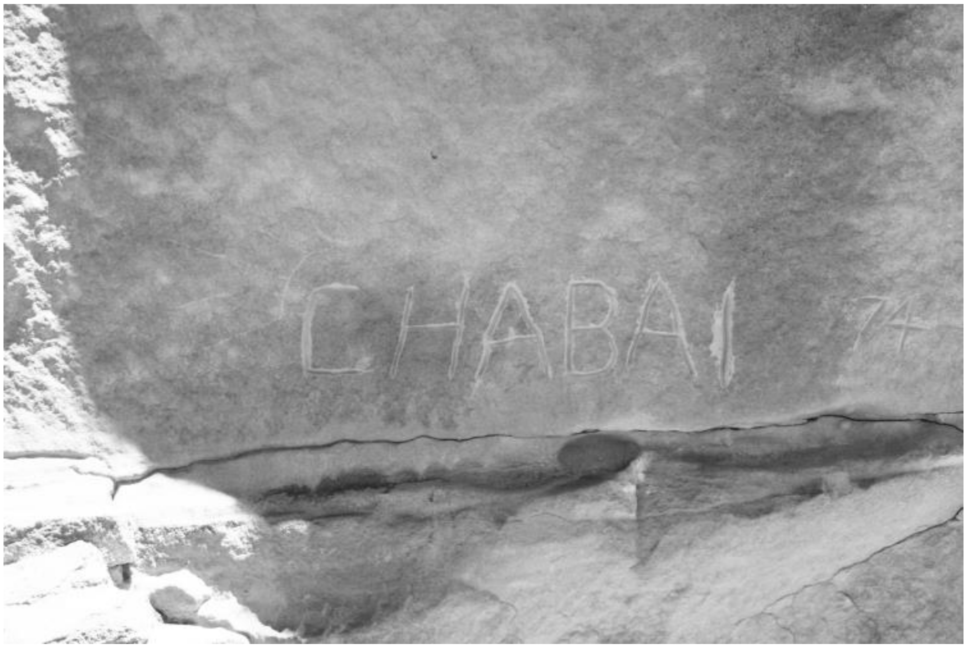


Figure 84. Modern petroglyph inscription at 29SJ 2539

The sunburst symbol is visible above and left from the letter "C."

Fifty meters to the north of the proposed observing location above the talus slope is a single round petroglyph containing a four-pointed pattern (***Figure 85***). This form is unique in comparison to other rock art I have seen at Chaco. It is similar to the "four pointed star" form identified with Venus in Pueblo iconography (Thompson, 2006, pp. 176-179). If this interpretation is correct, it should be noted that this form contrasts with the earlier cross images associated in the literature with Venus during the time of Chaco's heyday. This may be an indicator that the petroglyph post-dates the Late Bonito Phase by many years (Schaafsma, pers. comm.., 2011; Thompson, 2006).

Figure 85. Petroglyph marking ascent handholds to the ledge at 29SJ 2538
Many rock art designs are repeated; however this is the sole example of this design seen by me at Chaco.

Investigation of the surrounding area identified a set of hidden hand and foot holds carved into the rock (***Figure 86***). These are two meters south of the petroglyph, and they enable ascent to the ledge above. All had been previously documented (National Park Service, 1983).

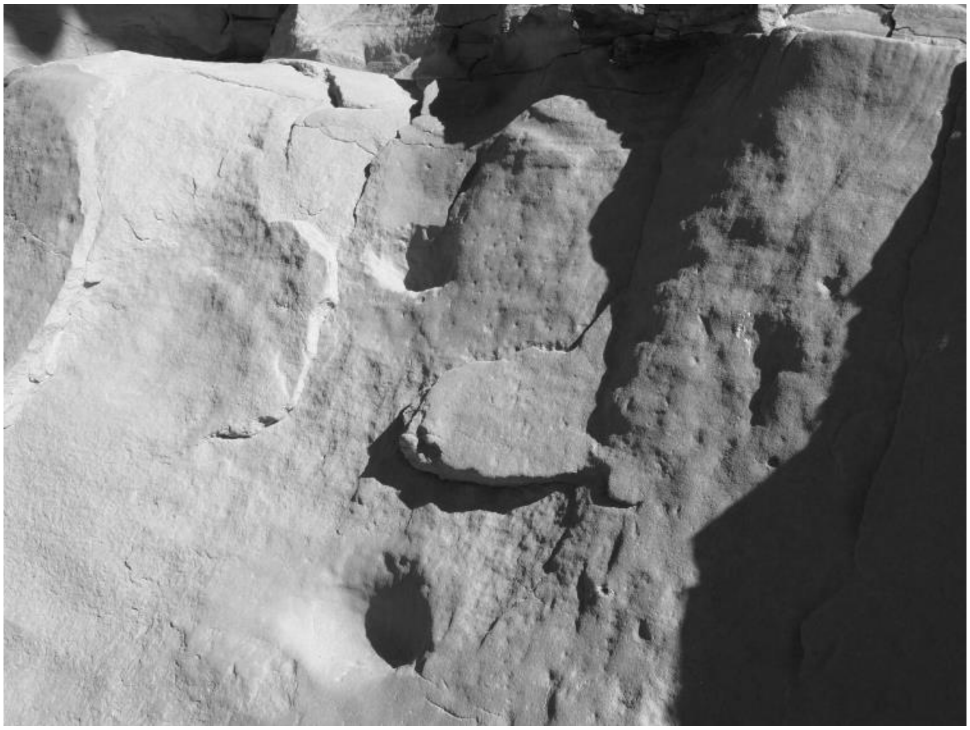


Figure 86. Footholds to aid ascent to the ledge at 29SJ 2538

A ledge above the proposed observing station includes additional rock art, and bedrock grinding features.

Once on the ledge, we identified a large number of bedrock grinding features in the ledge surface. Some of these resemble the grinding features seen at sites such as Piedra del Sol, however a number of enigmatic trough-like features with sharper edges are also present (***Figure 87***).

Figure 87. Bedrock grinding features on ledge at 29SJ 2538
These features are generally oriented to the southeast.

Traversing the ledge across these grinding features and troughs to the north leads to a cleft into the mesa edge; we confirmed that a ladder positioned in this cleft could make it possible to climb to the mesa top southeast of Shabik ‘eschee village. By traversing the ledge to the southwest, an observer can achieve a position 15 m above the proposed calendrical station, overlooking the boulder and backstop. A set of petroglyphs and pictographs in the shape of human hands is visible at that location (***Figure 88***) as documented in the site assessment (National Park Service, 1983).

Figure 88. Handprint pictographs and petroglyphs at 29SJ 2538

This rock art panel is at the southern end of the ledge at 29SJ 2538, overlooking the proposed observing location.

Cultural evidence at 29SJ 2538/2539 includes an apparent cache of selenite sheets. Five pieces of selenite were found on the surface of the ground under the protective overhang of a boulder (***Figure 89***) just east of the rock art panels at 29SJ 2539. These range from 4 cm to 9 cm in length; the largest piece is 7 cm x 9 cm. A source of selenite was identified in a coal layer some 60 m above (west of) this material; however, the local topography does not appear to support the possibility of the selenite having been deposited naturally. It appears that this collection may have been cached.

Additional material cultural evidence visible on the surface of the ground at 29SJ 2538/2539 includes varied pot sherds, lithics, bone fragments, and a corn cob.

Figure 89. Selenite cache at 29SJ 2539

Partial protection of this apparent surface cache is provided by the overhang of an adjacent boulder.

I conducted a theodolite survey from the potential calendrical station observation point marked by the boulder on May 26, 2009. Four azimuth angles were taken for each east horizon feature. All were reduced using sun sights and USNO ephemerides. Resulting standard error for the east horizon features ranged from 0.0002° to 0.0033°. The theodolite survey data is included in Appendix 1, section 11.16. The forecasted sunrise dates are shown in ***Figure 90***. Photography conducted on December 19, 2008 confirmed the solstice sunrise alignment (***Figure 90*** inset). Because the foresight is only 280 m distant the observing location is sensitive; only when sitting on (or directly in front of) the boulder does this alignment work.

The local slope in proximity to the observation point is pronounced enough to shift dates significantly with small movements, however we did not identify a well-marked observing position for anticipatory observations. Therefore I proposed 29SJ 2538/2539 as a Class 2 calendrical station with Class 1 potential.

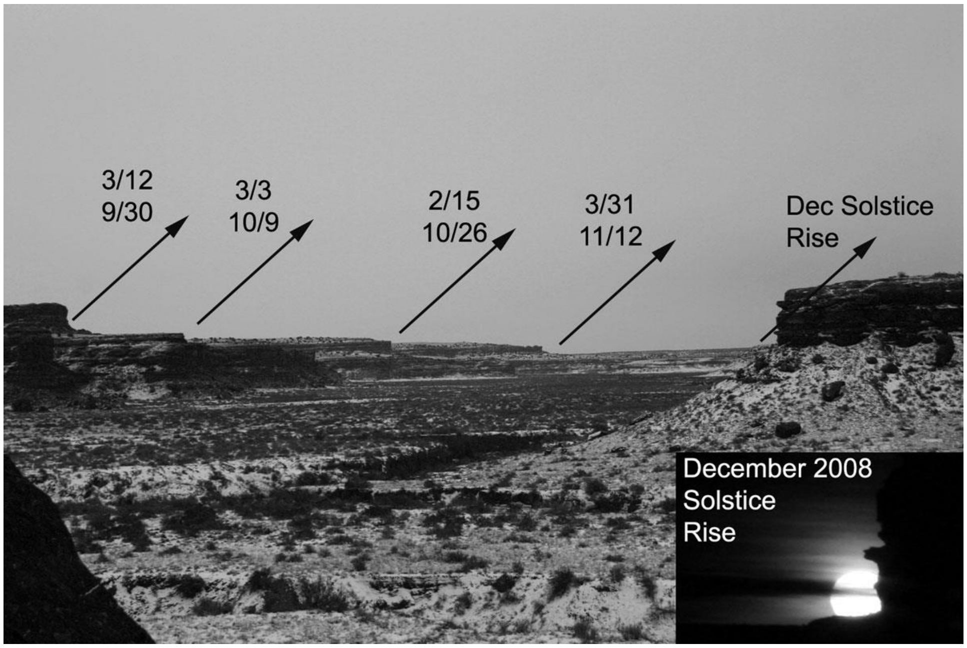


Figure 90. East horizon and DSSR at 29SJ 2538/2539

Forecasted sunrise dates, and (inset) DSSR confirmation photograph taken Dec 19, 2008.

On the mesa edge overlooking 29SJ 2538/2539, 120 m SSW of the proposed calendrical station are two circular stone structures (***Figure 91***). Each is just over one meter in height and just under one meter in diameter, with an open center. G.B. Cornucopia (pers. comm., 2008) reported that a Hopi informant associated these structures with eagle hunting. The structures are consistent with Hough's (1915) reported eagle hunting method discussed above.

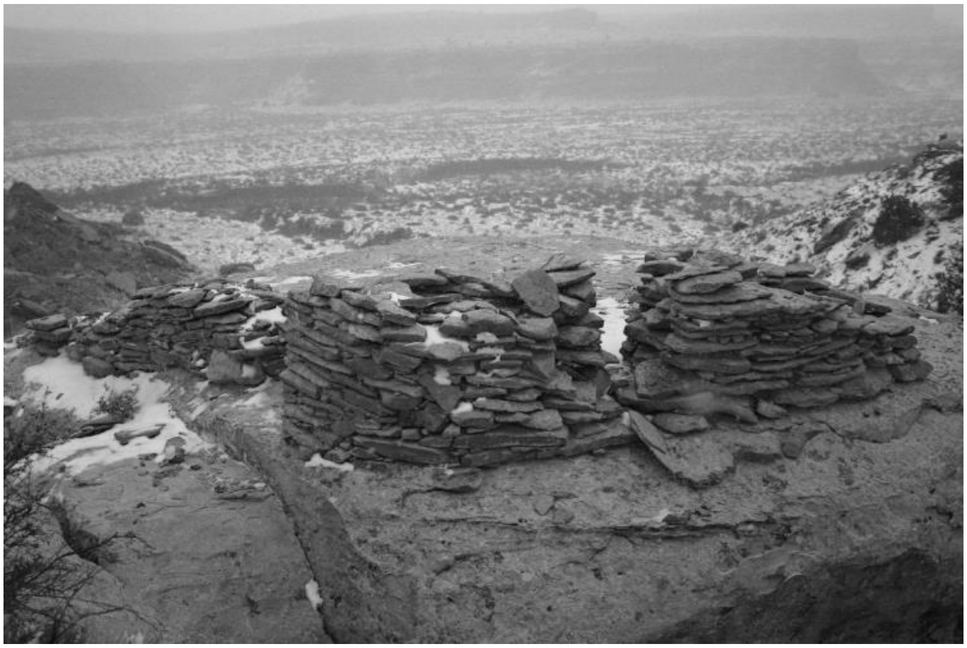


Figure 91. Proposed eagle traps above 29SJ 2538/2539

Eagles are documented as associated with the Sun and Zenith direction among some modern Pueblo people.

The presence of likely eagle traps less than 120 m from the proposed calendrical station is provocative due to the well documented association of eagle feathers with the sun, and solar ritual practices among some modern Pueblo people (Dozier, 1983: 205-206; Young, 1989).

7.24 Pierre's Acropolis

On June 3, 2008 I conducted a theodolite survey of the east and south walls at Pierre's Acropolis Unit B (Kin Bi Dagha Tao). Neither wall is standing; in both cases the survey was conducted by marking high spots on a remaining berm of material, as shown in ***Figure 26*** above. The theodolite was positioned at the intersection of the two wall segments that meet at the southeast corner of the structure. Survey was also conducted of the sightline from that point to Hosta Butte, distantly visible on the south-southwest horizon. This was done to test the accuracy of an apparent visual alignment between the east wall and that horizon feature. The resulting data is presented in Appendix 1 section 11.17. The mean measured south wall angle was

197.9153° (N=3, SD=N/A). The mean measured east wall angle including the sightline to Hosta Butte was 281.6763° (N=6, SD=0.5895). Using USNO ephemerides and sun sights to convert these angles to polar coordinates yielded a south wall azimuth of 293.0 / 113.0°, and an east wall and Hosta Butte sightline azimuth of 196.7 / 16.7° as shown in ***Figure 92***. The Great House of Peñasco Blanco is also visible from Pierre's just to the east of the sightline to Host Butte.

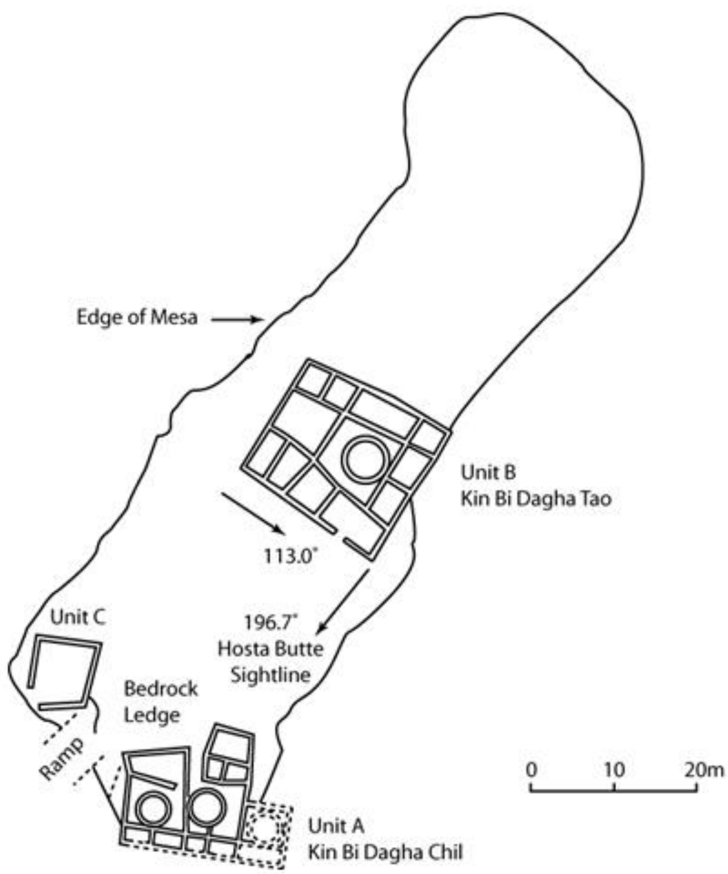


Figure 92. Pierre's Acropolis site plan

(Adapted from Kincaid, 1983: C-10, original by Stein et al.)

Independent checks of the sightline azimuths from Pierre's Acropolis to Hosta Butte, and from Pierre's Acropolis to Peñasco Blanco were also calculated. Longitude and latitude data for the three sites was used to calculate Great Circle azimuths and distances using equations 5 and 6. The results of that analysis are presented in ***Table 10***.

	Site	Latitude	Longitude	Calculated Azimuth	Calculated Distance
From:	Pierre's Acropolis	36° 14' 30.9"	107° 56' 48.5"		
To:	Peñasco Blanco (Western side)	36° 4' 54.1"	108° 0' 13.1"	196.0°	18.6 km
To:	Hosta Butte (Southeast mesa edge)	35° 35' 6.4"	108° 11' 27.6"	196.8°	76.3 km

Table 10: Pierre's Acropolis sightlines to Hosta Butte and Peñasco Blanco.

7.25 Bis sa'ani East Room block

The "halo" Great House at Bis sa'ani includes two room blocks perched in a seemingly precarious fashion atop a shale ridge in the center of Escavada wash, approximately 10 km northeast of Wijiji. Bis sa'ani's masonry is mostly core and veneer, but is constructed from large dark sandstone blocks that are crudely dressed and laid in comparison to Great House masonry at Chaco. The room blocks are proximate to multiple small house sites that made up a marginal agricultural community. The site is dated to the Late Bonito phase, and was apparently no longer in use by the mid 1100s (Breternitz *et al.*, 1982; Powers *et al.* 1983: 20-54). Irrespective of its crude masonry, Bis sa'ani's architectural design has been identified by at least one archaeologist as "McElmo looking" (Kantner, 2006b: 38).

Because of the extremely steep slope of the west hill, the west room block was not surveyed for safety reasons. On June 8, 2008 I conducted a theodolite survey of the east room block's west wall using the setup depicted in ***Figure 93***, which corresponds to the point marked as "A" in ***Figure 96***.

Figure 93. Theodolite setup at Bis sa'ani east room block

Survey from the location marked as "A" in figure 96 below enabled measurement of the west wall adjacent to the large kiva, as well as east and west horizon features.

The theodolite was positioned at the intersection of two walls, adjacent to the northwest kiva. The resulting data is presented in Appendix 1 section 11.18. The mean measured wall angle was 118.1237° (N=10, SD=1.2623°). The large Standard Deviation is indicative of both the wall's degraded and deformed state, as well as the relative crudeness of the masonry; it also reflects the difficulties inherent in survey on the badly eroded slope that undercuts the wall (***Figure 94***). Using USNO ephemerides to convert this angle to polar coordinates yielded a wall azimuth of 178.9° / 358.9° as shown in ***Figure 95***. Based upon this azimuth and extrapolation from the published site plan, we also find that the wall dividing the easternmost pair of kivas in Bis sa'ani's eastern room block is oriented to ~ 154°. Interpretation of a "front facing" direction for this attached room block is certainly debatable, however as discussed below the finding is provocative as it may represent deliberate SSE orientation.

Powers *et al.* (1983: 29) noted that "The orientation of both house blocks is almost due south." Notwithstanding, the west wall of Bis sa'ani's east block is shown in their site plan as over 5° off from true NS (Powers *et al.*, 1983: 31). The difference between that site plan and our theodolite results may be indicative of a magnetic declination error during site plan preparation.

Figure 94. Surveying Bis sa'ani's east room block, west wall

Survey of the room block and horizon was complicated by the eroded condition of the shale hill Bi sa'ani occupies.

In addition to the wall survey, horizon feature azimuths and altitudes were surveyed from the same location for both the east and west horizons. Based upon that theodolite survey, a distinctive mesa edge on the nearly flat east horizon was predicted to act as a June Solstice sunrise marker. This JSSR marker was subsequently confirmed photographically (***Figure 95***). This JSSR marker can be viewed from any location in the east room block due to the relatively long distance to the foresight; 6.2 km based on a topographic analysis.

Figure 95. East horizon and JSSR at Bis sa'ani east room block

Forecasted sunrise dates and (inset) sunrise on June 21, 2010 (JSSR)

Based on the theodolite survey, I determined that a hill on the western horizon also appears well-positioned to act as a December solstice sunset foresight; however this prediction has not yet been photographically confirmed. ***Figure 96*** provides site plan context for the survey results.

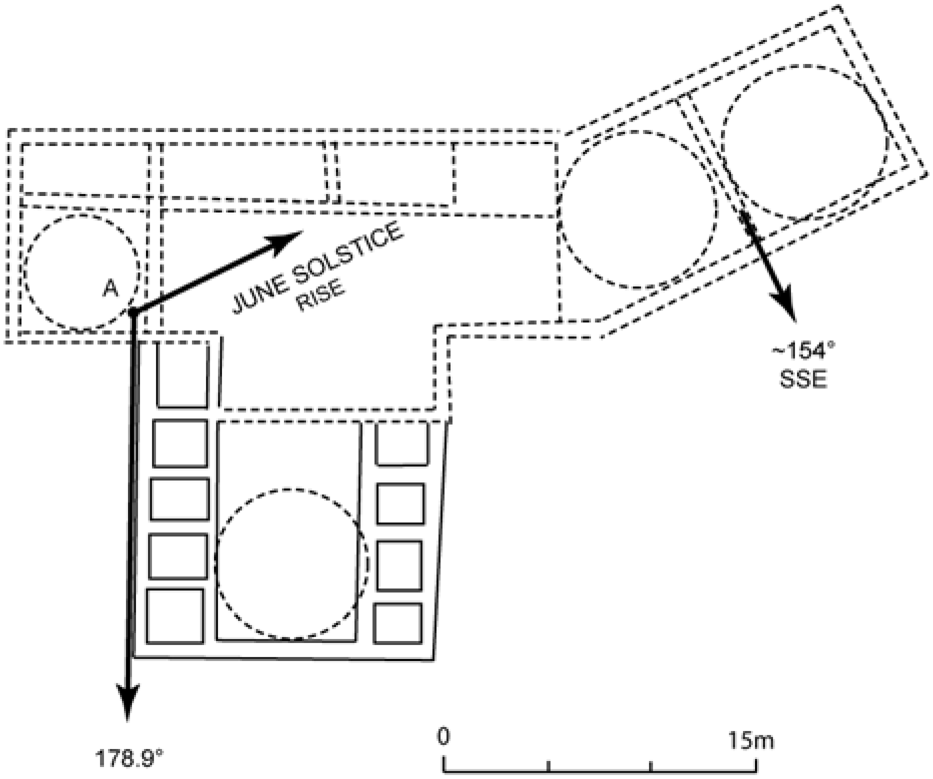


Figure 96. Bis sa'ani east room block site plan

(Adapted from Powers et al., 1983: 31)

7.26 Kin Klizhin

On June 1, 2009 I conducted a theodolite survey of Kin Klizhin's west wall from the theodolite setup location shown in ***Figure 97***. The resulting data is presented in Appendix 1 section 11.19. The mean measured wall angle was 182.1679° (N=16, SD=0.6300°). Using USNO ephemerides and sun sights to convert this angle to polar coordinates yielded a wall azimuth of 204.0° / 24.0° as shown in the site plan in ***Figure 98*** below.

Figure 97. Theodolite Survey of Kin Klizhin's back wall

The 204° back wall orientation yields a front-facing orientation of 114.0°.

As shown in the site plan, Kin Klizhin's approximate front-facing azimuth along its axis of symmetry is 114.0°, determined by taking the perpendicular of the measured back wall as facing across the elliptical plaza.

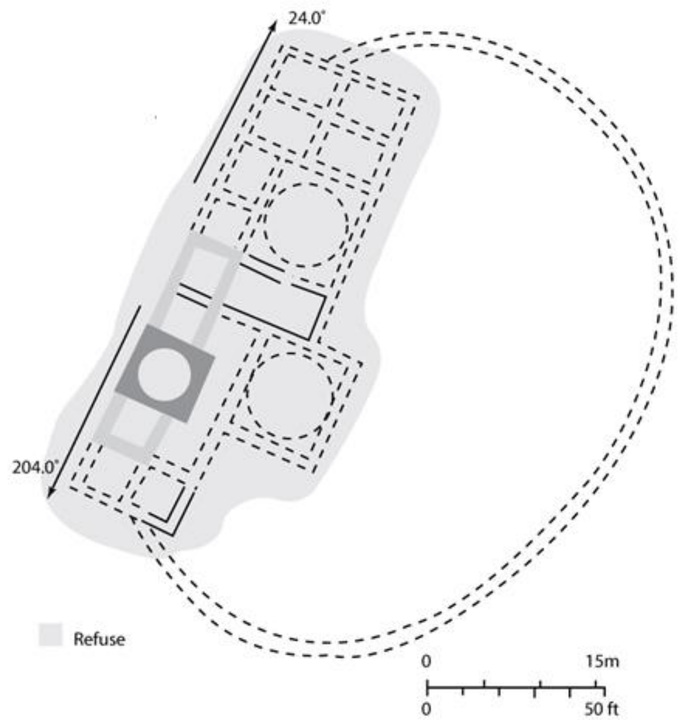


Figure 98. Kin Klizhin site plan

(Adapted from Powers et al., 1983: 208, original from 1973 NPS photogrammetric map.)

7.27 Kin Bineola

Kin Bineola's initial phase of construction occurred between A.D. 860 and 900 (Sebastian and Altschul, 1986), the expanded final structure that remains today was completed during the Late Bonito Phase, at approximately A.D. 1100 (Windes 2007). On May 29, 2009 I conducted theodolite surveys of Kin Bineola's standing east and west walls. For the east wall survey, the theodolite was positioned at a high spot along the wall to enable survey of its entire length, as shown in ***Figure 99***. The resulting data is presented in Appendix 1 section 11.20.1. The mean measured wall angle for the east wall was 166.1516° (N=27, SD=0.6651°). Using USNO ephemerides and sun sights to convert this angle to polar coordinates yielded an azimuth for the western end of the wall of 169.8° / 349.8° as shown in ***Figure 101***.

Figure 99. Theodolite survey of Kin Bineola's east wall

Survey at Kin Bineola was complicated by cloudy conditions that slowed collection of sun sights.

Survey of Kin Bineola's standing west wall was conducted from the exposed southwest corner, as shown in ***Figure 100***. The resulting data is presented in Appendix 1 section 11.20.2. The mean measured wall angle for the west wall was 162.3084° (N=17, SD=0.1826°). Using USNO ephemerides and sun sights to convert this angle to polar coordinates yielded an azimuth for the western end of the wall of 170.4° / 350.4° as shown in ***Figure 101***.

Figure 100. Theodolite survey of Kin Bineola's west wall

Results from this survey were integrated with east wall results to yield a mean front-facing orientation for the Great House.

The calculated mean azimuth of the standing east and west walls at Kin Bineola provides an approximate front facing azimuth of 170.1°. In contrast, using the site plan published by Windes (2007: 75) we find a front facing azimuth of between 158° and 164° with reference to the earliest remaining walls. Review of the site plan in ***Figure 101*** makes it clear that the back wall is not straight; the earlier front facing azimuth of approximately 158-164° corresponds more closely with the west end of the back wall, which is tilted to the south in comparison the that wall's eastern end. Kin Bineola was apparently reoriented by some 6° to 12° during its phased expansion and reconstruction.

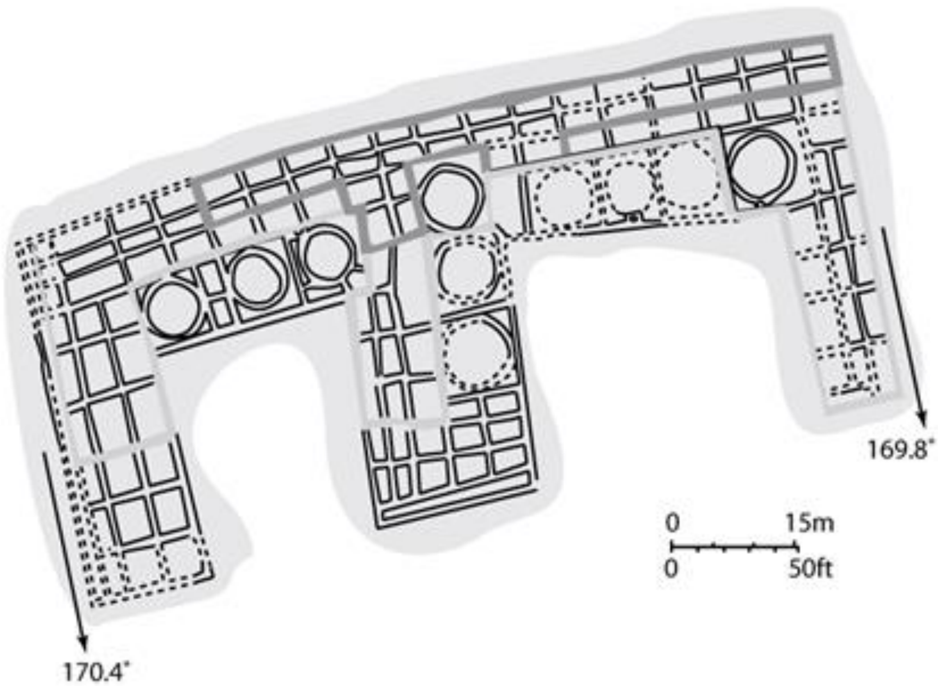


Figure 101. Kin Bineola site plan

(Adapted from Powers et al., 1983: 210, original from 1973 NPS photogrammetric map.)

7.28 Pueblo Pintado

On May 30, 2009 I conducted a theodolite survey of Pueblo Pintado's standing northwest wall. The theodolite was positioned at a high spot along the wall to enable survey of its entire length, ~ 30 m northeast of the apex where the measured wall meets the southwest wall, as shown in ***Figure 102***. The resulting data is presented in Appendix 1 section 11.21. The mean measured angle for the wall was 275.2371° (N=63, SD=0.3372°). Using USNO ephemerides and sun sights to convert this angle to polar coordinates yielded an azimuth for the wall of 250.3° / 70.3° as shown in ***Figure 103***.

Figure 102. Theodolite survey of Pueblo Pintado's west wall

Survey of the NW wall was intended to establish the original orientation of an assumed early unit pueblo, as well as determining the orientation of the final "L shaped" structure.

Pueblo Pintado was first constructed in the early 900s A.D. (Windes and Ford, 1992: 82). A proposed detailed construction sequence for the structure has not been published; however the published tree ring dates for Pueblo Pintado do show a pattern. Eleven pieces of wood with provenience that are dated to the 10^{th} century have been documented, of which eight were taken from rooms 7 and 8 (Windes and Fretwell, n.d.), the central rooms along the surveyed northwest wall. Based upon this data, I have assumed that these two rooms were elements in a 10^{th} century unit pueblo, and inferred that the measured northwest wall corresponds to the back wall of that unit pueblo. Application of this assumption results in a front facing azimuth of 160.3° for the earliest construction (Munro and Malville, 2011a: 257).

Based upon analysis of the final site plan (Powers *et al*. 1983: 187) the angle formed by the apex of the surveyed northwest wall, and the (not surveyed) southwest wall is ~ 89°. Therefore, the front-facing azimuth that bisects the plaza of the final expanded L-shaped great house circa A.D. 1060-1090 (Chaco Research Archive, 2010) can be calculated as ~ 114.8°.

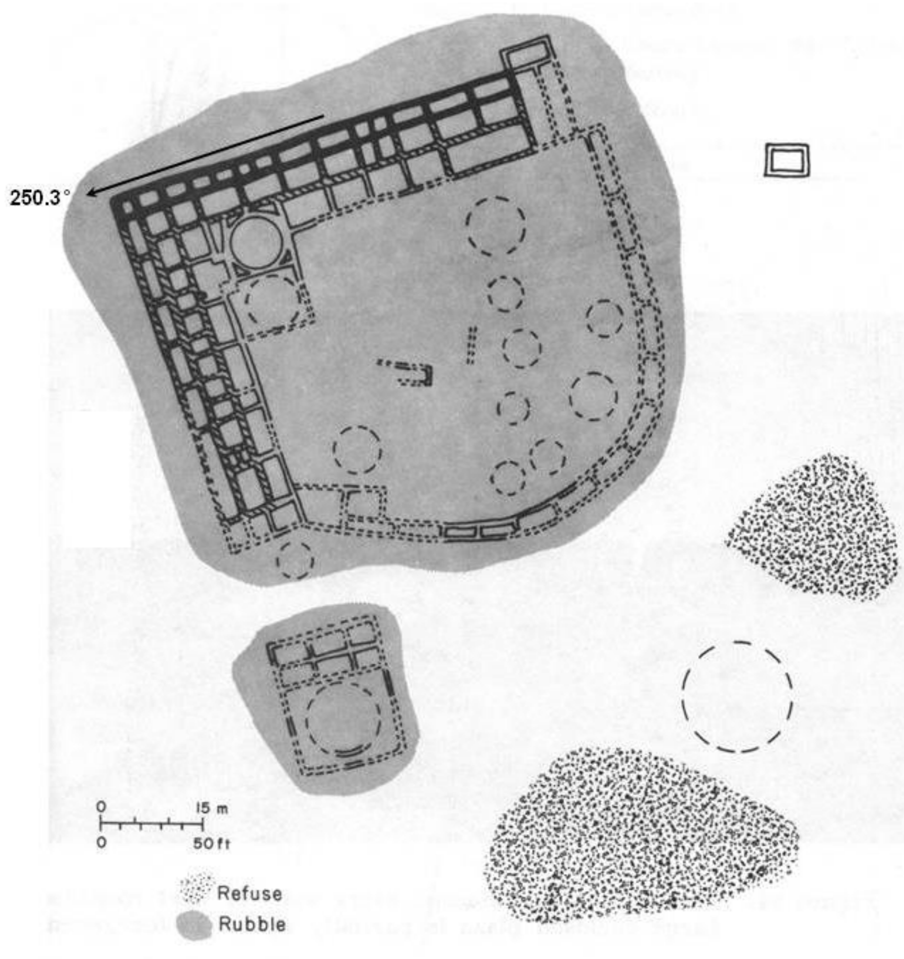


Figure 103. Pueblo Pintado site plan

(Adapted from Powers et al., 1983: 187) If the initial A.D. 900 unit pueblo was designed as discussed, Pueblo Pintado was reoriented from facing to 160.3° circa A.D. 900 (SSE) to ~114.8° circa A.D. 1060-1090 (ESE).

7.29 Ceremonial Sticks from Pueblo Bonito

Successful maintenance of the multi-century front-facing SSE architectural orientation tradition to between 151° to 161° as discussed in Chapter 5 above required some type of consistent measurement technique and/or tool. As discussed below, one option for consideration is the use of a staff technology to sight angles with reference to celestial objects(s). I conducted a dimensional analysis of ceremonial sticks recovered from Pueblo Bonito to determine if any could plausibly relate to such use.

Pepper identified a “mass” of long ceremonial sticks in Room 32. Most of these had decayed lower ends due to immersion in the sand that filled the room, making it impossible to be certain of their original lengths. The group included four varieties that Pepper categorized. Type 1 sticks end in a carved knob and have carved bands; a subgroup had “bow shaped pieces” attached with yucca as shown in Pepper’s figure 53. Type 2 sticks end in a carved shape that Pepper identified as a “bear claw.” Type 3 sticks have flattened ends shaped like a “broad spatula.” Type 4 sticks have “wedge” shaped ends (Pepper, 1920: 140-152). Among these four types, only the Type 1 staffs with attached bows appear to have potential for use as sighting devices to measure SSE angles. Though the straight sticks of various types could plausibly have been used as shadow-casting gnomons, only the subset with attached bows is dimensionally consistent with the ability to use them as a sighting tool to measure angular offsets.

The dimensions of 48 Type 1 sticks in the American Museum of Natural History collection were measured to determine if they could plausibly be used to achieve the SSE orientation tradition. The four “bow shaped pieces” shown in Pepper’s figure 53 photograph were not successfully located in the museum’s collection. Therefore, I measured each of the 48 sticks in length, from the edge of the carved band closest to the end knob to the tip of the end knob, as shown in ***Figure 104***. The shortest measured length between these features was 66 mm, the longest was 114 mm. The mean length measurement from stick bands to stick ends was 99 mm (N=48, SD=9). Pepper (1920: 144) reported a range of diameters for Type 1 sticks of 1.0 cm to 1.7 cm, but was nonspecific as to where on the sticks these diameters were measured. Diameters were measured for the 48 sticks just below their carved bands (furthest from the end knobs). The maximum diameter found was 15 mm, and the minimum diameter was 9 mm. The mean diameter was 11 mm (N=48, SD=2). The length and diameter measurements provide a scale to determine a range of dimensions for the bow shaped pieces using Pepper's photograph, as discussed below.

Figure 104. Type 1 "ceremonial sticks" in the AMNH collection

The black lines and arrow indicate the features measured for length to establish a scale for interpretation of Pepper's photograph.

Measurements were also taken from five bow shaped pieces in the Smithsonian collection (***Figure 105***). These were recovered from Pueblo Bonito, but their rooms of origin are not documented in the inventory. Their design and number are consistent with Judd's (1954: 271) description of the "staff attachments" recovered from rooms 202 and 203. Judd associated these with Pepper's bow shaped sticks described above. I measured each to determine what offset would result from their curvature if attached to a Type 1 stick as discussed below. The shortest measured offset was 62 mm, the longest was 92 mm, and the mean offset is 77 mm (N=5, SD=11).

Figure 105. Five bow shaped pieces of wood in the Smithsonian collection

The black lines and arrow indicate the "offset" dimension measured for each.

8 DISCUSSION

A cumulative overview of the front-facing SSE and ESE orientations, NS/EW Cardinal alignments, and workable Solstice Calendrical stations associated with Chacoan Great Houses and Great Kivas is presented in ***Table 11.*** The structures listed are organized sequentially by published construction dates. They are also regionally grouped; the first twenty seven (27) entries are all within Chaco Canyon or the surrounding region, the final five are located north of Chaco in the Totah region.

Five Great Houses are listed twice due to reorientation of the structures during phased expansion. Pueblo Bonito is listed once for an original “C” shaped room block circa A.D. 860-925, and a second time for its final expansion and reorientation to cardinal NS/EW after A.D. 1070. Peñasco Blanco is listed initially for its ESE-facing construction circa A.D. 900, and a second time for its final form circa A.D. 1090. Una Vida’s initial Unit Pueblo design from A.D. 860 and its final form circa A.D. 1070+ are both presented. Two rows of data are also presented for Kin Bineola; the first is based upon Windes’ (2007: 75) identification of wall sections linked to earliest construction, the second is based upon theodolite survey of the standing east and west walls. Similarly two rows of data are presented for Pueblo Pintado, one for the front facing orientation of the assumed unit pueblo discussed above from the early 900s A.D., and one for the reoriented L-shaped great house circa A.D. 1060-1090.

Orientations listed to .1° are based on field work conducted between 2007 and 2010 and presented in the preceding chapter. Orientations listed as approximate (“~”) are taken from published site plans; in the cases of Peñasco Blanco, Una Vida, Kin Bineola, Pueblo Pintado and Bis sa’ani these are validated by survey results for walls within the structures. The site plan sources include: Pueblo Bonito’s initial construction (Stein *et al*., 2003: 44), Penãsco Blanco (Lekson, 1984: 95-100), Una Vida (Lekson, 1984: 80-85), Kin Nahasbas (Mathien and Windes, 1988: fig. 4), Kin Bineola’s initial construction (Windes, 2007: 75), East Community (Windes *et al.*, 2000: 49), Pueblo Pintado (Powers *et al*., 1983: 187; Chaco Research Archive, 2010), Wijiji (Lekson, 1984: 225), Bis sa’ani (Powers *et al.*, 1983: 31), Salmon (Baker, 2008: 32), Chimney Rock (Eddy, 1977; Malville, 2004a), and the three Great Houses at Aztec (Lekson, 1999: 79).

"Front facing" orientation azimuths are inferred based upon axes of symmetry, and with reference to high walls to the rear and plazas at the front. No front facing orientation has been inferred for room blocks lacking plazas at Casa Chiquita, Kin Kletso, or New Alto, or for the backfilled foundations at Headquarters Site A and Roberts Small Pueblo; this is due to the fact that they are all either single/double McElmo units without plazas or below-grade foundations without a clear basis to infer what may be "front facing." Similarly, visible design queues at Pierre's Acropolis do not provide a clear front facing direction based upon an axis of symmetry. The possible "SSE facing" room block at Bis sa'ani is also open to varied interpretations. Because Aztec North has never been excavated, the NS (~180°) alignment of this structure is not well constrained (Lekson, 1999; Lister and Lister, 1987).

Remarkably, twenty eight of the thirty two listed structures (88%) explicitly conform to one or more of the four discussed astronomically-linked traditions. All of these are either: 1) front facing to the SSE (most to 151°-161°), 2) front facing to the ESE (most to 113°-116°), 3) individually aligned and/or inter-site aligned to the cardinal directions (NS/EW), and/or 4) built at or near to a workable horizon calendrical station incorporating solstice sunrise and/or sunset foresights.

Of the four structures that do not explicitly conform to any of these traditions; three are open to interpretation. Hungo Pavi's back wall and the reoriented Una Vida may have been intended as cardinal NS/EW structures. Similarly, one wall at Pierre's Acropolis Unit B is oriented to 113.0°; this may possibly be linked to the ESE tradition. Among the four, only Kin Nahasbas lacks any possible association with one of the four design traditions described. This is not entirely surprising as Kin Nahasbas is an early site that is architecturally dissimilar from other great houses at Chaco (Van Dyke, pers. comm., 2012).

Structure	Construction Start (A.D.)	Front Facing AZ (Deg)	Inter-Site Alignment Created	Astronomical / Orientation Associations			
				Solstice Horizon Calendar	SSE	ESE	Cardinal NS/EW
Pueblo Bonito I (“PB”)	860-925 (Stein *et al*., 2003)	~161°	-	JSSR Proximate (Zeilik, 1986)	X	-	-
Peñasco Blanco (Stage I)	900 (Lekson, 1984: 104)	~ 113°-116°	-	-	-	X	-
Una Vida (Stage I)	860-865 (Lekson, 1984: 83-92)	~ 148°	-	-	X	-	-
Kin Nahasbas	900s (Mathien & Windes, 1988)	~ 205°	-	-	-	-	-
Kin Bineola I	860-900 (Sebastian & Altschul, 1986)	~158°-164°	-	-	X	-	-
East Community	900 (Windes *et al*., 2000: 45)	~159°	-	-	X	-	-
Pueblo Pintado I	900 (Windes & Ford, 1992)	160.3°	-	-	X	-	-
Hungo Pavi	990-1010 (Lekson, 1984: 152)	185.4°	-	-	-	-	?
Chetro Ketl	1010-1030 (Lekson, 1984:173)	160.2°	EW to PB (Fritz, 1978: 49)	-	X	-	X

Structure	Construction Start (A.D.)	Front Facing AZ (Deg)	Inter-Site Alignment Created	Astronomical / Orientation Associations			
				Solstice Horizon Calendar	SSE	ESE	Cardinal NS/EW
Pueblo Alto ("PA")	1040 (Windes, 1984)	178.9°	-	-	-	-	X
Kin Klizhin	~ mid 1000s (Sebastian & Altschul, 1986) (Bannister *et al*., 1970)	114.0°	-	-	-	X	-
Pueblo del Arroyo	1065-1070 (Lekson, 1984: 210)	114.9°	-	-	-	X	-
Pueblo Pintado (Reoriented)	1060-1090 (Chaco Research Archive, 2010)	~ 115°	-	-	-	X	-
Casa Rinconada ("CR")	1060-1110 (Vivian and Reiter, 1960)	180.1°	-	-	-	-	X
Pueblo Bonito (Reoriented)	1070+ (Stein *et al*., 2003)	180.2°	-	JSSR (Zeilik, 1986)	-	-	X
Una Vida (Stage VI-VII)	1070+ (Lekson, 1984: 85-94)	~ 184.5°	-	-	-	-	?
Peñasco Blanco (Stage IV-V)	1090 (Lekson, 1984: 108-109)	~ 127°-130°	-	DSSR? (unconfirmed)	-	X	-
Kin Bineola	1100	170.1°	-	-	X	-	-

Structure	Construction Start (A.D.)	Front Facing AZ (Deg)	Inter-Site Alignment Created	Astronomical / Orientation Associations			
				Solstice Horizon Calendar	SSE	ESE	Cardinal NS/EW
(Reoriented)	(Windes, 2007: 73)						
New Alto	1100-1130 (Lekson, 1984: 251)	-	NS to CR EW to PA (Sofaer, 2008: 98)	-	-	-	X
Tsin Kletsin	1110-1115 (Lekson, 1984: 231)	178.7°	NS to PA (Fritz, 1978: 49)	-	-	-	X
Wijiji	1110-1115 (Lekson, 1984: 224)	~172°	-	DSSR (Malville, 2008: 71)	X	-	-
Kin Kletso	1125-1130 (Lekson, 1984: 238)	-	-	DSSR (Malville, 2008: 72)	-	-	-
Casa Chiquita	1100-1130 (Lekson, 1984:246)	-	-	JSSR & JSSS (Munro & Malville, 2010a)	-	-	-
Headquarters Site A	1100-1130 (Lister & Lister, 1981:252)	-	-	DSSR (Munro & Malville, 2010a)	-	-	-
Roberts Small Pueblo	1100s (Lister & Lister, 1981:240)	-	-	DSSR Proximate at 29SJ 2538/2539 (Munro & Malville, 2010a)	-	-	-

Structure	Construction Start (A.D.)	Front Facing AZ (Deg)	Inter-Site Alignment Created	Astronomical / Orientation Associations			
				Solstice Horizon Calendar	SSE	ESE	Cardinal NS/EW
Bis sa'ani	early 1100s (Powers *et al*., 1983: 21)	178.9°& ~154°	-	JSSR (Munro & Malville, 2010a)	?	-	X
Pierre's Acropolis	Not Dated	-	Hosta Butte?	-	-	?	-
Salmon	1066-1072 (Baker, 2008)	~ 155.8°	-	Untested	X	-	-
Chimney Rock	1076 (Eddy, 1977)	~ 156°	-	JSSR (Malville, 2004a: 140)	X	-	-
Aztec North	1110-1120 (Brown *et al*., 2008)	~180°	NS to Chaco? (Lekson, 1999)	Untested	-	-	X
Aztec E & W (2)		~ 153°-~160°		Untested	X	-	-

Table 11: Astronomically based orientations, alignments, and solstice calendars.

Where "JSSR"=June Solstice Sunrise, "JSSS" = June Solstice Sunset, and "DSSR"=December Solstice Sunrise.

As a point of validation for these results, ***Table 12*** presents the front-facing orientation data from ***Table 11*** above, compared to Hayes' (1981: 55) published orientation data for the subset of structures considered in both samples. Hayes did not specifically identify the data sources for his reported orientations, which complicates root cause determinations for differences. As shown, the results for ten of the structures are comparable; differences of fewer than three degrees may be accounted for based upon use of different site plan or survey sources, and a variety of minor associated errors.

Great House	Front Facing Orientation	Hayes' Reported Orientation	Delta
Kin Nahasbas	~205°	190°	15°
Hungo Pavi	185.4°	185°	0.6°
Chetro Ketl	160.2°	161°	0.8°
Pueblo Alto ("PA")	178.9°	177°	1.9°
Kin Klizhin	114.0°	112°	2°
Pueblo del Arroyo	114.9°	113°	1.9°
Pueblo Pintado (Reoriented)	~ 115°	160°	45°
Casa Rinconada ("CR")	180.1°	175°	5.1°
Pueblo Bonito (Reoriented)	180.2°	180°	0.2°
Una Vida (Stage VI-VII)	~ 184.5°	230°	45.5°
Peñasco Blanco (Stage IV-V)	~ 127°-130°	130°	0°-3°
Kin Bineola (Reoriented)	170.1°	170°	0.1°
Tsin Kletsin	178.7°	192°	13.3°
Wijiji	~172°	172°	0°
Bis sa'ani	178.9°& ~154°	177°	1.9°
Salmon	~ 155.8°	160°	4.2°
Chimney Rock	~ 156°	158°	2°
Aztec E & W (2)	~ 153°-~160°	150°	3°-10°

Table 12: Comparison to Hayes' published orientations.

Regarding the seven cases of significant differences (4° or greater) in reported front facing orientations, root causes may be inferred. For Kin Nahasbas, Hayes was certainly using site plan data that predates excavation and associated development of the plan used for this study (Mathien & Windes, 1988), and as a result a significant difference is reasonably to be expected. Further, as discussed above, the interpretation approach for a "front facing" azimuth for Kin Nahasbas is debatable; the reported ~205° azimuth is in reference to the Great Kiva (Malville and Munro, 2011), Hayes' 190° azimuth may have been identified with reference to the walls of the "New House" (see ***Figure 70*** above).

The approximately 45° differences identified for Pueblo Pintado (Reoriented) and Una Vida (Stage VI-VII) are certainly based upon use of a different interpretative approach rather than on propagation of an error. For both of these structures, the "front facing" azimuth reported in this study is based on taking a bisecting angle for the plaza of the Great House. In contrast, Hayes clearly used the perpendicular of each structure's straightest and longest "back wall" to define his orientation. It is notable that his approach for Pueblo Pintado yields the same general orientation result that is reported in ***Table 11*** above for the inferred design of Pueblo Pintado's initial unit pueblo. As to which of these approaches is more or less correct, that is reasonably debatable; both interpretive approaches are based on geometric assumptions without explicit ethnographic support.

The 5.1° difference reported for Casa Rinconada is an apparent error in the earlier data; this Great Kiva has been re-surveyed repeatedly (this study; Sutcliff, pers. comm.. 2010; Williamson, 1984: 132-144) and its axis of symmetry is reasonably well constrained. The reported difference for Tsin Kletsin may be the least explicable of the group. It is unlikely to be an interpretive difference given the structure's design. Tsin Kletsin's close-to-cardinal NS orientation is readily apparent when validated using GIS tools such as Google Earth. Therefore, the 13.2° difference may most plausibly be rooted in propagation of a magnetic angle of declination error impacting on Hayes' reported orientation.

The 4.2° difference reported for Salmon is likely to be the result of different site plans being utilized that may contain variable errors. Because this structure was not surveyed during the course of this study a more detailed root cause analysis is not possible at this time. For Aztec, it is possible that Hayes' reported orientation was an approximate finding for the complex as a whole, versus the individual Great House orientations reported herein. In any event, the SSE-facing nature of Aztec is explicit in both reported orientations.

In addition to the architectural assessments conducted and at the request of NPS staff as discussed above, a single potential calendrical site was assessed that was entirely unrelated to architecture. At 29SJ 913 a notch in the top of Fajada Butte operates as a workable DSSS calendrical foresight. This notch is directly adjacent to the location of the three-slab or "Sun Dagger" site (Sofaer *et al*., 1979) on Fajada. As discussed above, the three-slab site has been interpreted by many as a Sun Shrine rather than a calendrical tool (Carlson, 1987; McCluskey, 1988; Reyman, 1985; Zeilik, 1985a). Also as discussed above, the Pueblo ethnographic record indicates that calendrical foresights may operate as Sun Shrines that are ritually visited by sky watchers to make offerings (Zeilik, 1985b, 1985c, 1986a, 1986b, 1987, 1989). The close correlation between the three-slab site and the foresight for 29SJ 913 therefore provides additional circumstantial evidence that the interpretation of the three-slab site on Fajada Butte as a shrine is likely correct.

8.1 Pierre's Acropolis: Alignment to Sacred Topography?

As noted above, the southeast wall of Pierre's Acropolis Unit B is accurately aligned with Hosta Butte on the distant horizon on an azimuth of 196.7°. This result supports the idea that purely astronomical interpretations of Chacoan architecture may be an oversimplification. Sacred topography may certainly have importance in a traditional cosmology. This previously unreported alignment is consistent with the Hosta Butte alignment of the Great South Road discussed by Van Dyke (2007a: 150), and demonstrates the value of considering alternative hypotheses. Notwithstanding, no similar topographic alignments have been identified to date among other Great Houses. Furthermore, the wall alignment is less than 1° away from the sightline to

Peñasco Blanco. In addition, the adjacent wall is aligned to 113°, which could possibly indicate association with the ESE tradition. Pierre's Unit B is also constructed in alignment with the southeast edge of the mesa top, so local topography may have been a design consideration. Lastly, the design of the structure makes interpretation of a front-facing azimuth debatable. While there is nothing conclusive in the results from Pierre's, they do suggest that future consideration of topographic alignment hypotheses would be beneficial when Great House site surveys are conducted.

8.2 SSE Orientation of Architecture

> The directional orientation of San Juan sites, therefore, is expressed at the scale of the habitation unit, the roomblock, and the settlement. I believe that it has a strong symbolic referent, although I do not know the specific meanings associated with it (Lipe, 2006: 265).

Twelve of the Great Houses listed in ***Table 11*** (38%) manifest the SSE orientation tradition first discussed by Hayes (1981). That tradition predates construction of monumental architecture at Chaco by centuries. Both the SSE and cardinal NS orientation traditions were maintained for at least six hundred years across a range of latitudes across the San Juan basin and into southern Colorado. These two orientation traditions are prominent among the pithouses in the large Basketmaker III villages of Shabik' eschee and 29SJ 423 at Chaco. In the northern San Juan the traditions continued. Structures at McPhee Village were oriented to the SSE, while across the Dolores River, those of Grass Mesa Village were oriented NS (Malville and Munro, 2011).

Elsewhere in the northern San Juan, both orientation traditions are evident but they are not always coincident: for example SSE at other sites along the Dolores River and at Duckfoot; NS at Alkali Ridge and Yellow Jacket (5MT3). This bi-modality continued until the end of the Pueblo III period. Both Sand Canyon and Goodman Point have NS great kivas and D-shaped bi-walls with front facing orientations of 156-157° (Kuckelman, 2000, 2006, 2010; Kuckelman *et al.*, 2009; Malville and Munro, 2011; Malville, 2011).

The durability of the SSE orientation tradition, from at least A.D. 450 to at least 1140 is remarkable. The multi-century durability of the tradition suggests that it may have offered cultural utility that reinforced its importance. The utility of SSE facing pit houses in the vicinity of Chaco Canyon and into portions of southern Colorado may have been related to prevailing winter winds. Review of climate data for the period 1961 to 1990 (NCDC) demonstrates a consistent pattern of prevailing winds in the San Juan basin and to the north. Assuming similar climate patterns have been maintained during the past millennium, winter winds would have consistently blown east of south across this area from October to March. Positioning the door opening of a pit house to face away from the prevailing wind would provide shelter during the cold months. As suggested by Jonathan Reyman (pers. comm. 2011), for a pithouse this facing direction provides the additional benefit of using the wind to draw smoke out of the door opening during gusty conditions.

For later Pueblo period above-ground architecture, the SSE facing tradition retained utility. Any doorway opening that faces the front of the pueblo would be sheltered from winter winds. In addition, this benefit would be significantly reinforced by passive solar energy gain on cold winter mornings, as discussed by Williamson (1984:148-149). The combination of passive solar gain and massed masonry construction used at Chaco has been empirically demonstrated to be energy efficient (Knowles, 1974; Reyman, 1982).

How might the ancestral Pueblo people have achieved consistent front facing SSE orientation? Thought experiments help to constrain the options. There are no uniquely bright or notable celestial objects that rise on the dominant azimuths from 151° to 161°, nor are there prominent objects in the opposite direction in the sky. Similarly, there is not any visually notable landform that can be seen over the entire area where the SSE tradition is evident. Park Point on Mesa Verde has this approximate azimuth when viewed from the McPhee Pueblo, but this can hardly account for similar orientations at vastly different places and times.

Among contemporaneous structures the SSE orientation exhibits low accuracy. For example, the average orientation among 15 SSE facing pithouses measured from Roberts' map of Shabik' eschee is 153.7° with a standard deviation of 7.7° (Malville and Munro, 2011). If the SSE orientation tradition was based on direct sighting of a celestial object on its rise azimuth we might reasonably expect less variation. Therefore, direct orientation to very bright celestial object's rise, or to prominent landforms are not convincing explanations for survey to achieve SSE orientation.

As a result of these considerations I developed a preliminary hypothesis that the SSE orientation was measured using a common measurement tool that naturally resulted in angle variation, and yielded offsets between 19° and 29° east of due NS (mean of 24°). Some form of cross staff could have been used as an aid in measuring the angular offset east-of-south from a celestial object at its meridian height while facing south. Alternatively, the same tool could have been used while facing north to perform angular offset measurements west-of-north from the approximate area of the North Pole, by sighting on the central dark void in the northern sky. Due to precession of the earth's axis there was no North Star to refer to during the Basketmaker through Pueblo II periods. However, the north-facing measurement could have been done based upon a visual approximation while observing stellar motions around the pole through the night. Either the south or north facing method would naturally result in significant variation in identified SSE azimuths. This is due to variation in the stature of people making the measurements, variation in the distance between an observer's eye and their tool, and variations in the dimensions of the tool. Errors in estimating a referenced celestial object's meridian passage to the south, or the unmarked pole in the north would also have an influence. Significant variation in measured azimuths would therefore be a natural byproduct of these effects if such a measurement technique were applied.

Based upon these "thought experiment" results a search was conducted for Pueblo ethnographic references that include the use of staffs as sighting tools with reference to celestial objects. Two reports discussed above link ancestral migration stories, celestial objects, and references to "staffs," "ceremonial sticks," or "wands." The first was reported by A.M. Stephen to Mindeleff (1891: 18). This report explicitly discusses the southeast direction, use of a staff as a sighting tool with reference to a celestial object (enigmatically identified as a “new star”) and use of the celestial object as an ancestral migration signal.

The second report is provided in a paper by the Director of the Hopi Cultural Preservation Office (Kuwanwisiwma, 2004) that presents oral traditions of Chaco, and a discussion of the relationship between science and traditional Hopi world views. This report also discusses use of a celestial object as a migration signal; Kuwanwisiwma identifies the celestial object explicitly as SN 1054, which is an apparent example of cultural feedback. In contrast to the Stephen report the object’s appearance is discussed as a signal to end, rather than begin, a migration journey. Though not explicitly discussed as sighting tools, the report also includes discussion of “ceremonial wands” and the “ceremonial sticks” recovered from Pueblo Bonito by Pepper.

Based on their reported dimensions, the majority of “ceremonial sticks” recovered from Pueblo Bonito do not appear to have potential to be used as hand held tools for measuring 151° to 161° azimuths with reference to N or S celestial markers. They are not large enough to yield the required offset when used as a sighting tool. However, one reported sub-type is a candidate for such use. Pepper identified three Type 1 sticks from Room 32 that had “two slender ceremonial sticks fastened to their sides, directly below the carved end.” In each case, a pair of bowed slender sticks was bound to a Type 1 stick. Two were photographed and presented by Pepper as his Figure 53. He noted that such sticks had been found (usually in pairs) within other rooms and sites (Pepper, 1920: 142-145). A conjectural compound staff design that utilizes the attached pieces in a fashion consistent with the cross-staff hypothesis is presented in ***Figure 106***.

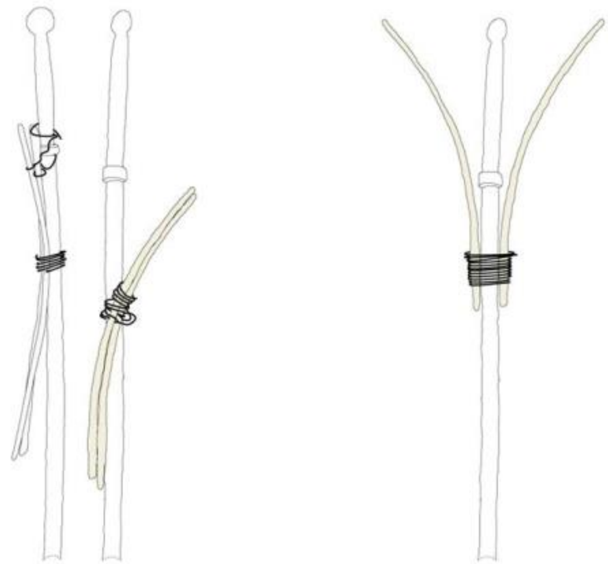


Figure 106. A conjectural staff configuration for use as a SSE sighting tool

At left: two type 1 "ceremonial sticks" with attached bows (line drawing taken from Pepper, 1920: Fig 53). At right: the conjectured compound staff.

A user could hold such a compound staff in his or her hands, and align the right tip of the "Y" shaped top with a celestial object at its meridian height while facing south, or with the visually estimated location of the celestial North Pole while facing north. By sighting along the left tip, the offset angle that yields SSE orientation could be measured. ***Figure 107*** depicts the conjectured measurement approach from a south-facing frame of reference. A similar procedure could have been followed to sight on the void in the area of the North Pole.

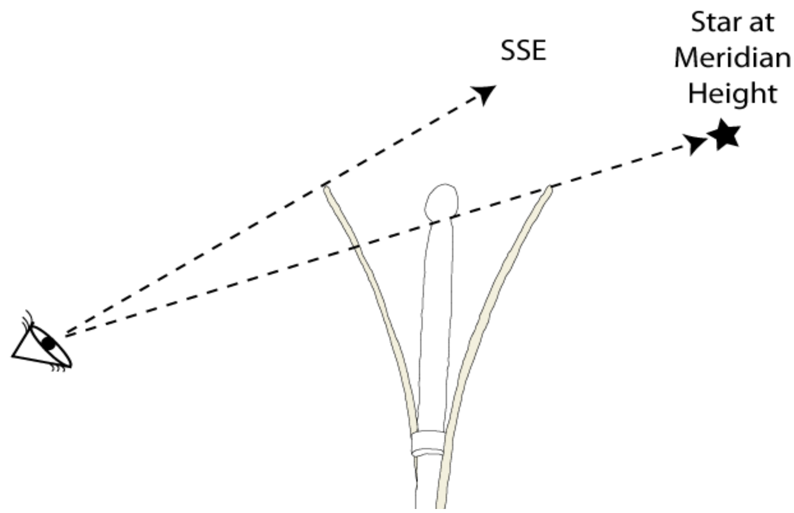


Figure 107. Conjectured use of a Type 1 Staff with bows

Use of the conjectured staff design could enable measurement of SSE angles during architectural survey.

I summed the offsets for bow shaped pieces measured in the Smithsonian collection with the staff diameters of 48 staffs at the American Museum to yield a range of tip-to-tip offsets, from 13.4 cm to 19.5 cm, under the assumption that the pieces were configured as shown in ***Figures 106 and 107***. As a separate check of these results, the mean length data for the 48 staffs at the American Museum was also used to establish a scale for measurement of Pepper's photograph; this resulted in an estimated tip to tip distance of 13.2 cm.

The conjectured staff design could be held in a range of positions. It might be clutched close to the chest, held with both arms extended forming close to an equilateral triangle, placed in some intermediary position, or held in one hand with an extended arm. Due to parallax, the farther away such a staff is held from the eye, the narrower the measured angle would be. The dimensional analysis for these options depends upon anthropometric factors that vary by population. Trigonometry enables us to identify the range of sighting distances that would be required to achieve azimuths of from 151° to 161°, given the known dimensions of ceremonial sticks recovered from Pueblo Bonito and using the conjectured staff configuration. ***Table 13*** presents the range of sighting distances required to successfully measure azimuths of 151° to 161°, using the smallest, mean, and largest staff dimensions from the presented measurements of Type I ceremonial sticks with bows recovered from Pueblo Bonito.

AZ	Angle of Deflection (east of south)	TAN of Deflection Angle	Staff Offset Dimension (CM)	Required Sighting Distance (CM)
			13.2	23.8
151°	29°	.5543	16.5	29.8
			19.5	35.2
			13.2	38.4
161°	19°	.3443	16.4	47.6
			19.5	56.5

Table 13: Staff sighting distances to achieve the range of SSE orientations.

A preliminary assessment of the viability of the staff hypothesis was conducted using measurements from volunteers; four mixed-race people (two men and two women) ranged in height from 163 cm to 180 cm. Two measurements were taken for each person including the distance from one eye to a staff in a two handed grip held clutched to the chest, and the distance from one eye to a staff in a two handed grip held with arms extended. The shortest distance found for a “close clutch” was 14 cm, the longest distance for an “arms extended” position was 53 cm. Only one of the calculated sighting distances shown in ***Table 12*** is outside of this range; measuring an offset of 19° with the largest size for the conjectured staff design (19.5 cm tip to tip) requires an additional 3.5 cm of eye-to-staff distance. All other test cases are within the expected range of possible sighting distances. Therefore, the proposed conjectural staff design could be used as a sighting tool to achieve the range of angular offsets from due south represented by the SSE orientation tradition. A more conclusive analysis would require assessment using anthropometric data for Pueblo people and Chacoan remains.

The presented evidence supports a preliminary conclusion; the documented multi-century tradition of front-facing SSE orientation among ancestral Pueblo pithouses, Prudden Units, and Great Houses may be linked to veneration and commemoration of ancestral migration traditions (Malville and Munro, 2011). Two ethnographic reports provide circumstantial support for this idea. One explicitly includes references to southeast, and use of a staff as a sighting tool. Both combine references to celestial objects, migration by ancestral people, and ceremonial sticks or staffs. A conjectural arrangement for assembly of Type 1 sticks with bows recovered from Pueblo Bonito rooms 32, 202, and 203 is dimensionally consistent with the proposed method to achieve SSE facing building orientations. The SSE facing building survey function would most likely have been performed by a specialist member of society with esoteric ritual knowledge. The variation in resulting SSE orientations is accounted for by variations in staff dimensions, user stature, and errors in finding an object's "meridian height" or in estimating the location of the celestial North Pole.

8.3 ESE Orientation and possible Multi-Cultural Ritual Integration

Five of the Great Houses listed in ***Table 11*** manifest ESE orientation, including both the initial and final stages of Peñasco Blanco's construction. All five are within one half of a standard deviation from the mean reported by Lakatos (2007) for Late Developmental structures in the Rio Grande. Four of these ESE facing structures are oriented to between 113° and 116°; all four are rotated by ~25° south of due east. Based on currently available evidence, this appears to be indicative of a third distinct cultural tradition in Chaco Canyon and the surrounding area that may have been associated with people from the Rio Grande valley. As discussed above, "Late Developmental" period structures in the northern Rio Grande maintained an ESE orientation in the approximate direction of December solstice sunrise. They had an average front-facing orientation of 123° (SD=22°, N=85) (Lakatos, 2007). The 113°-116° orientations of Peñasco Blanco, Kin Klizhin, Pueblo del Arroyo, and Pueblo Pintado may be linked with this Rio Grande cultural pattern (Malville, pers. comm., 2010; Mathien, pers. comm., 2011).

Given the large standard deviation among Rio Grande structures reported by Lakatos, the tightly constrained 113°-116° orientations among the four earliest ESE

Great Houses are somewhat surprising. This consistency may be linked to the fact that these ESE facing Great Houses share a common trait with those that face SSE. They are all rotated by ~25° with respect to one of the cardinal directions. Peñasco Blanco (Stage I), Kin Klizhin, Pueblo del Arroyo, and Pueblo Pintado all face ~25° south of due east (ESE). This 25° offset is remarkably similar to the mean offset from cardinal south for a majority of the SSE facing structures. The mean of SSE orientations between 151°-161° is ~154°, or 24° east of due south. A common survey tool such as the ceremonial staff discussed above could have been applied in different ways to achieve both orientations (ESE and SSE) based on reference to different cardinal directions.

The possibility that a common survey instrument may have been used by different culture groups to achieve varied front-facing orientations at Chaco is reinforced by an additional piece of circumstantial evidence; Kin Nahasbas is also rotated by ~25° from a cardinal direction. The Kin Nahasbas Great Kiva faces to ~ 205°, which is 25° west of due south. It is the sole structure presented in ***Table 11*** that has no evidence for association with SSE, ESE, Cardinal NS/EW, or Horizon Calendar design intent. Excluding the debatable "front facing" orientations of Bis sa'ani and Pierre's Acropolis, fourteen of the thirty two houses listed in ***Table 11*** (44%) are front facing to orientations that are rotated by ~ 25° (+/- 5°) with respect to a cardinal direction. This is unlikely to be coincidental. While inadequate evidence is available to make a conclusive case, related survey techniques and tools may have been applied to achieve such consistent results. Common use of a ritual measurement tool such as the staff design conjectured above may have provided a mechanism for social and ritual integration across disparate culture groups at Chaco.

8.4 NS/EW Cosmological Alignments

Alignments with the cardinal directions are emblematic of Chaco, and especially of the 11th century period of the "Chaco Florescence." With construction beginning A.D. 990-1010, Hungo Pavi is ~ 5° offset from true NS; this may represent an attempt by relatively unskilled specialists to achieve alignment to the cardinal directions. Pueblo Alto, built beginning A.D. 1020-1040 includes a more accurate EW wall. Sometime after A.D. 1070, Pueblo Bonito completed its staged reorientation from SSE to accurate NS/EW cardinal alignment (***Figure 108***). As shown in ***Table 14***, by the time large scale construction ended at Chaco Canyon (~A.D. 1140) seven of the structures considered at Chaco included more or less accurate NS and/or EW alignments. In addition, the well documented inter-site cardinal NS alignments across the center of "downtown Chaco" involving Pueblo Alto, Tsin Kletsin, New Alto, and Casa Rinconada were all completed in the period A.D. 1100-1140 (Ashmore, 2007; Fritz, 1978; Sofaer, 2008). Based upon the survey results from this study Pueblo Bonito is the most precisely and accurately aligned of these structures.

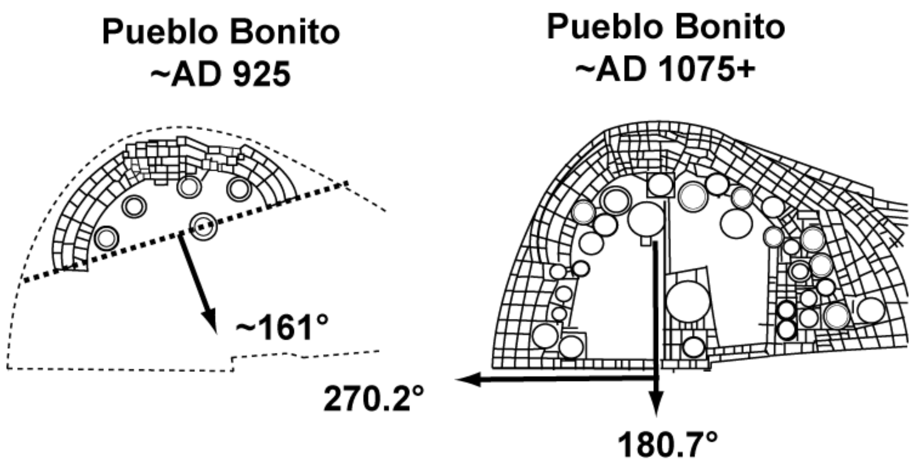


Figure 108. Pueblo Bonito's reorientation

(Left adapted from Stein et al., 2003: 44; right adapted from Stein et al., 2003: 50)

Site	Construction (A.D.)	Feature / Alignment	AZ	Δ from NS/EW	N	Error
Pueblo Bonito	~ 1070+[1]	Central Wall	0.7°	0.7°	40	SD=0.3°
		West end of South Wall	270.2°	0.2°	62	SD=0.1°
Tsin Kletsin	~ 1110-1115[2]	North Wall	268.7°	-1.3°	12	SD=0.1°
		Inter-site Azimuth, NE corner to West End of Pueblo Alto	359.4°	-0.6°	4	Std Err=0.0006°
		Inter-site Azimuth, NE corner to East End of Pueblo Alto	361.1°	1.1°	4	Std Err=0.0008°
		Mean Inter-site Azimuth to Pueblo Alto	360.3°	0.3°	8	NA
New Alto	~1100-1130[3]	Inter-site Azimuth, SE corner to East End of Casa Rinconada	181.4°	1.4°	4	Std Err=0.0009°
		Inter-site Azimuth, SE corner to North Door at Casa Rinconada	181.6°	1.6°	4	Std Err=0.0006°
		Mean Inter-site Azimuth to Casa Rinconada	181.5°	1.5°	NA	NA
Bis sa'ani	~early 1100s[4]	West Wall of East Room Block	178.9°	-1.1°	10	SD=1.3°

Table 14: NS/EW alignments at Pueblo Bonito and the Late Bonito Great Houses.

[1] Lekson, 1984: 137-140; Stein *et al*., 2003: 50-53

[2] Lekson, 1984: 231-238

[3] Lekson, 1984: 251-256

[4] Breternitz *et al*., 1982; Powers *et al*., 1983: 21-54

Measured sightlines from Casa Rinconada and Tsin Kletsin to New Alto are consistent with Sofaer's (2008: 98) and Van Dyke's (2004a: 425) results. However, the Tsin Kletsin to New Alto sight line does not "travel across" Casa Rinconada as proposed by Van Dyke; rather Casa Rinconada is ~ 100 m to the west of that line, a deviation of 2.6 degrees. In the context of available ethnographic and architectural evidence, the close-to-NS alignment between New Alto and Casa Rinconada appears to be more consistent with the overall pattern versus a Tsin-Kletsin to New Alto sightline.

These results do demonstrate sensitivity to the selection of inter-site measurement points. For example, the mean NS azimuth reported from Tsin Kletsin to Pueblo Alto is 360.3°. As viewed from Tsin Kletsin, Pueblo Alto has an angular size of 1.7°. No features within either building have been identified as "special" points to measure from. Nonetheless, the sites themselves can reasonably be identified as viewing points, given their inter-visibility, the length of the alignment sightlines, and the significant social investment represented by their construction.

Among the studied "cardinal" walls, only those within Pueblo Bonito manifest sub 1° accuracy for NS/EW alignments. The wall alignments at Tsin Kletsin (EW) and Bis sa'ani (NS) are both over 1° greater than expected based on the astronomical hypothesis. Notwithstanding, as suggested by Young (1987a), "When asked 'How accurate are these alignments?' one might well answer 'As accurate as they needed to be within the context of their use.' " The accuracy of Pueblo Bonito's cardinal alignments may be indicative of differentiated cultural intent for the structure. It may be that the unique importance of Pueblo Bonito as a preeminent monumental building at the center of the "Chacoan World" drove greater care in its survey. Repetition of gnomon measurements may have improved both accuracy and precision. What is certain is that a majority of the documented "NS" and "EW" Great House alignments are less accurate than the walls of Pueblo Bonito.

Regarding cultural intent, the inter-site NS alignments may have been intended in part to enable a demonstrable visual astronomical phenomenon. Looking due north from Tsin Kletsin at night one could observe Pueblo Alto directly beneath the north point of the heavens around which the stars circle. A similar opportunity for direct observation of the sky exists at Casa Rinconada, from which New Alto is seen to lie beneath the still northern point of the sky. While the most obvious explanation for NS/EW alignments is explicitly cosmological (i.e. aligning oneself with the cosmos) these alignments could also be related to migration traditions for people whose ancestors came from the north.

8.4.1 Cardinal EW and Equinox, a Probable Error of Ethnocentrism.

Sofaer (2008: 88-91) asserts that EW cardinal alignments and the astronomical equinox are equivalent, and identified Pueblo Bonito as being "associated with the cardinal directions (meridian and equinox)." Similarly, Farmer (2003) endeavored to explain the 4° deflection from EW of the east section of Pueblo Bonito's south wall based on a claimed visual equinox alignment. Farmer asserts that the wall's deflection was a design feature intended to create a visual alignment at equinox sunset as observed from the "platform" at the south wall's east end.

There is no compelling reason for traditional sky watchers to place importance on observation and measurement of the equinox. The modern definition of equinox is the time (or more broadly date) when the sun crosses the celestial equator with a declination of 0°. The celestial equator is itself a theoretical geometric construct. In addition, equinox sunrise and sunset are displaced from the cardinal azimuths when observed on an elevated horizon. Therefore, no precise visual association exists between orientation to cardinal EW and equinox in any place with a variable horizon such as within Chaco Canyon.

One alternative way to identify a date near to equinox would be to split the angle between solstice sunrise positions on the horizon. This approach also depends on a flat horizon to give consistent results, and is therefore unsuitable for use at any location with a variable horizon where the elevations of the horizons at summer and winter solstices differ. Dates of such an "equinox" will vary at different locations. Another alternative method is based on the idea of counting the days between the solstices, and using one half of that count to identify a near-equinox date. This method is rendered inaccurate by the difficulties in fixing solstice dates precisely using visual observations. Day counting will identify dates that vary by five or six days or more from year to year (Ruggles, 1997). At the latitude of Chaco Canyon a six day change near the equinox results in a shift of approximately 3° in the sun's rise or set azimuth.

Two other approaches to approximating the equinox have also been identified, including finding the day where sunrise and sunset occur exactly opposite one another (also dependent upon a flat horizon), or precise timing of the length of day and night (dependant on precise timekeeping). A detailed critique of equinox in the context of traditional visual astronomy, and the limitations of these techniques has been provided by Ruggles (1997), who reasonably concluded, that "easterly and westerly alignments have tended to be interpreted as 'equinoctial' because of a highly questionable implicit assumption that our western concept of the equinox is a universal one," and "In short, the equinox is a concept unlikely to have any meaning from an earth-based perspective within a non-western world view" (see also Ruggles, 1999).

The claims of equinox alignments at Chaco Canyon are particularly surprising given a nearly complete lack of Pueblo ethnographic support. No firm evidence of pre-Columbian Pueblo interest in, or knowledge of the equinox has been identified through review of astronomical ethnography (Ellis, 1975; McCluskey, 1977; Zeilik, 1985b, 1985c, 1986), or through review of multiple primary and secondary ethnographic sources that contain fragments of cosmological, calendrical or astronomical information (Cushing, 1883; Dozier, 1983; Fewkes, 1891, 1897; Hough, 1915; Lockett, 1933; Mindeleff, 1891; Ortiz, 1972; Parsons, 1926; Sando, 1998; Stirling, 1942). Among these sources, Ortiz (1972) alone includes discussion of important dates in the Tewa calendar that occur before or after the equinox, however he does not identify the equinoxes themselves as ritually important dates. Ortiz explicitly advances the hypothesis that post-contact Spanish-Catholic influence may have triggered calendrical adaptation among Tewa people (Ortiz, 1972: 116-119); such influence may account for modern calendrical use of equinox among the Tewa.

Complications certainly arise when applying ethnography to cultures such as ancestral Pueblo people. We have a significant body of ethnography relating to modern descendants of the people who built at Chaco Canyon. Nonetheless, no culture stagnates for centuries, so the ethnography must be applied cautiously (Young, 2006).

Theodolite surveys intended to test the equinox hypothesis were conducted from the center of Pueblo Bonito's south wall. The survey point was selected to minimize measured horizon altitudes, and thus minimize the impact that the horizon would have on the visual sunrise and sunset alignment dates. Comparison of survey results for Pueblo Bonito's two south wall sections to the ephemerides for equinox sunrises and sunsets found that Sofaer's assumed west section alignment is off by three days, and Farmer's claimed visual alignment for the east section is off by four. Even the three day difference is significant. The sun's horizon rise point shifts by over ½° per day at equinox at Chaco's latitude. A three day shift is over three solar diameters.

Photography on Sept 21, 2009 confirmed that Farmer's claimed visual equinox alignment does not occur (***Figure 109***). Neither section of Pueblo Bonito's south wall incorporates a working visual equinox alignment.

Figure 109. Pueblo Bonito sunset Sept 21, 2009, no visual equinox alignment

Simultaneous exposures: the filtered inset image shows the sun "setting" into the wall as observed from ground level at the end of the wall's "east platform."

In addition to her assertions that cardinal EW wall alignments are by definition equinoctial, Sofaer (2008: 93) asserts that Hungo Pavi is "oriented to within one degree of the visible equinox sunrise." Sofaer again neglects to account for horizon altitude, claiming that "differences between the orientations to the sensible and those to the visible horizon are so small as to not clearly indicate to which of these horizons the architects of Chaco oriented their buildings" (2008: 93). Sofaer's term "sensible horizon" is equivalent in meaning to the term "artificial horizon." Her assertion regarding the differences between local horizons and artificial horizons are incorrect; the 3.9° elevation of Hungo Pavi's east horizon shifts the sunrise azimuth by days. Comparison of our survey results for Hungo Pavi's back wall to the ephemerides for equinox sunrise predicts that Sofaer's claimed alignment is off by 2.9°. Because the sun's horizon rise point shifts by over ½° per day at equinox at Chaco's latitude, this equates to a six calendar day difference, amply demonstrating that failure to consider horizon altitudes in visual astronomical rise or set alignments will lead to incorrect conclusions. Photographic testing of Sofaer's claimed equinox alignment at Hungo Pavi has not yet been conducted, but may be beneficial.

In contrast to the lack of evidence for pre-contact Pueblo interest in equinox events, there is abundant ethnographic evidence that the cardinal directions are of central importance in eastern Pueblo cosmology (see e.g., Dozier, 1983: 203-207; Ortiz, 1972: 14-15, 20-23; Sterling, 1942: 5-6, 8-11, 19, 24). In the case of Pueblo Bonito, in addition to the EW cardinal alignment of the south wall's west section, the importance of the NS cardinal azimuth is demonstrated by the accuracy of the central dividing wall.

There is no conclusive ethnographic support for Pueblo interest in equinoxes, and none of the tested equinox alignment claims at Chaco function visually. Based on this evidence the EW alignment of the west section of Pueblo Bonito's south wall is most plausibly linked to intentional alignment with the cosmos, to the cardinal directions. The method used to achieve such accurate alignment remains open to future research and debate. Considering the local topography and the accuracy achieved, Chacoan people may have used a combination of night sky observations and daytime shadow casting with gnomons. In any event, neither the orientation of Pueblo Bonito nor the orientation of Hungo Pavi is plausibly linked to visual observation of equinox. Equinox is a western concept. Currently available evidence indicates that claims of Chacoan equinox alignments are errors of ethnocentrism.

8.5 Solstice Horizon Calendars at Great House Sites

Early work on horizon calendars at Chaco included identification of a workable calendrical station at 29SJ 931, above Wijiji Great House. The pillar foresight at this location operates for December solstice sunrise, as well as offering the potential to enable anticipatory observations (Williamson, 1984: 88-92, Zeilik, 1989: 208-209). Anticipatory foresights for approximately 2 weeks prior to a date of ritual significance have been discussed extensively in the literature as useful to enable advanced coordination and pilgrimage travel for upcoming festivals (see e.g., Malville & Malville, 2001a, 2001b; Zeilik, 1985a, 1987).

As discussed above, the earliest "proto Great House" that has evidence for a horizon calendar is Casa del Rio. Casa del Rio may have been a transitional locus for community integration in the tenth century, leading to the more formalized social cohesion implicit in the eleventh century Chacoan regional system. Based upon Malville's analysis (Munro and Malville, 2011c), the West Mesa Shrine at 29SJ 1088 is on the azimuth for observation of Winter Solstice Sunrise from Casa Del Rio. The solstice sightline to 29SJ 1088 from Casa Del Rio may have played a part in establishing the location for construction of that Great House. However, theodolite survey and photographic confirmation have not been possible to date.

The first horizon calendar confirmed at Chaco that is observable from a Great House includes a workable June solstice sunrise marker, visible at Pueblo Bonito (Zeilik, 1986a; 1989: 208-209). During the 1990s, December solstice sunrise markers were also found at Wijiji and Kin Kletso. These two calendrical horizons include anticipatory markers, and are photographically confirmed (Malville, 2008: 70-71; Malville *et al.,* 1996).

As shown in ***Table 11*** above, surveys and photography conducted during this study have confirmed that construction at or near workable horizon calendar stations is a consistent feature of Great Houses built in the vicinity of Chaco after A.D. 1100. Solstice sunrise or sunset horizon foresights are now photographically confirmed to be observable from points within Casa Chiquita (JSSR and JSSS), Headquarters Site A (DSSR), Wijiji (DSSR), Kin Kletso (DSSR), and Bis sa'ani (JSSR), as well as within 125 m of Roberts Small Pueblo at 29SJ 2538/2539 (DSSR). As with Casa del Rio, these confirmed solstice foresights visible from Late Bonito Great Houses are ***not*** architectural alignments of walls to significant azimuths; rather the buildings are located at observation sites for solstice horizon foresights (see e.g., Malville, 2008a: 70-73).

The eastern horizon from the now-backfilled site at Headquarters Site A (***Figure 74*** above) is perhaps the most dramatic of the Late Bonito solstice horizon calendars. December solstice sunrise emerges from a deep notch in the mesa wall. The sunrise is first observable from the westernmost extent of the building footprint, and visually exits the top of the notch as observed some ten minutes later from the easternmost extent of the structure. The inset photos show sunrise as seen from two different locations within the Great House footprint.

The cultural evidence in the area of the proposed calendrical station at 29SJ 2538/2539 near Roberts Small Pueblo is also remarkable; it includes rock art, cached selenite, probable eagle traps, and pot sherds. In addition there was a concentration of turkey bones found within Roberts Small House, 90 m away. This evidence suggests that the area may have been a center of ritual activity over an extended period. Based on this evidence the area around Roberts Small House and proximate to Roberts Small Pueblo appears unique among Chacoan small houses. The location may have acquired importance due to the proximity of an eagle trap location, naturally occurring selenite, and a December solstice calendrical station. No available evidence provides any basis for linkage of the proposed esoteric and astronomical activity at this site with the anthropophagy proposed by Turner (1993). The temporal data, preponderance of ethnographic data, the singular nature of the recovered remains, and the lack of similar evidence at any other identified calendrical station argues against such association.

Most of the Late Bonito Great Houses lack middens or other signs of occupation, and Lekson (Lekson *et al.*, 2006) suggested they were primarily intended for administration or storage. On the other hand, Van Dyke (2004a: 423) argued that the Late Bonito Great Houses were built at a time when the power of Chaco was declining, and these new building projects were undertaken to “restore confidence in the rituals” that occurred in Chaco. The identification of solstice horizon foresights at a majority of Great Houses from the period after A.D. 1100 supports the idea that these structures were deliberately designed as public statements of astronomical knowledge and ritual power. These buildings likely represent a centrally planned effort to reinvigorate a waning ritual/political system at Chaco, as suggested by Van Dyke (2004a, 2007a). Notwithstanding, construction at calendrical stations is not a consistent feature of earlier Great Houses, only Casa del Rio and Pueblo Bonito have been identified as earlier “calendrical” great houses. The calendrical associations among Late Bonito Great Houses may thus also reveal an enhanced interest in solar/astronomical ritual in the waning days of Chacoan power.

This astronomical evidence supports the idea that the “calendrical” Late Bonito Great Houses were centrally planned and constructed as monumental architecture placed within a “sacred geography” that expressed Chacoan world views (Van Dyke, 2004a, 2004b, 2007a), and possibly as sites for public rituals involving pilgrims.

8.6 Temporal Assessment of the Four Traditions

Initial assessment of the Cardinal NS/EW and SSE traditions included comparison of pit structures in Basketmaker villages at Chaco with later Bonito Phase Great Houses. Consistent with the findings of Hayes (1981) and Lipe (2006) a mix of cardinal (NS/EW) and SSE structures were found at Chaco during both periods. However, it was also found that between A.D. 500 and A.D. 900 the traditions had sometimes appeared separately in the Dolores river valley to the north. This lends additional support to the inference that the two orientation traditions may provide markers for two culture groups that sometimes collaborated and sometime separated (Malville and Munro, 2011), an idea that builds upon previous work by Bullard (1962), Hayes (1981), and Vivian (1990).

For Bonito Phase Great House construction at Chaco, Lekson (2009) interpreted the Cardinal NS/EW and SSE orientation traditions as architectural hallmarks of at least two competing political factions, each with its own conceptual framework. He suggested use of these orientations to mark faction-dominance at the time of construction, and contrasted the dominant NS/EW cardinal tradition at Chaco during the late 11^{th} and early 12^{th} centuries with the emergent dominance of the SSE tradition at Salmon and Aztec to the north in the Totah region.

I interpret the SSE orientation tradition using a migration and ancestor veneration hypothesis that stands in contrast to Lekson’s (2009) interpretation of SSE as “solstitial” based on approximate back wall alignments. Notwithstanding, the evidence presented supports Lekson’s core idea that temporal analysis of architectural orientations may provide some insight into shifts in cultural dominance among ancestral Pueblo groups. ***Figure 110*** presents a temporal analysis of new construction starts and reorientations for structures listed in ***Table 11*** above, based on their associations with the four astronomically-linked architectural traditions discussed. In this figure, each site is associated with traditions cumulatively; the total sample size is therefore exceeded by the sum of identified characteristics. Questionable associations (marked "?" in ***Table 11***) are not included in this analysis. As a result, Hungo Pavi (185.4°, possible NS/EW), and Una Vida Stage VI-VII (184.5°, possible NS/EW) are reported as "Other." Pierre's (113° wall, possible ESE but "front facing" is debatable) is not dated, and thus is not graphed.

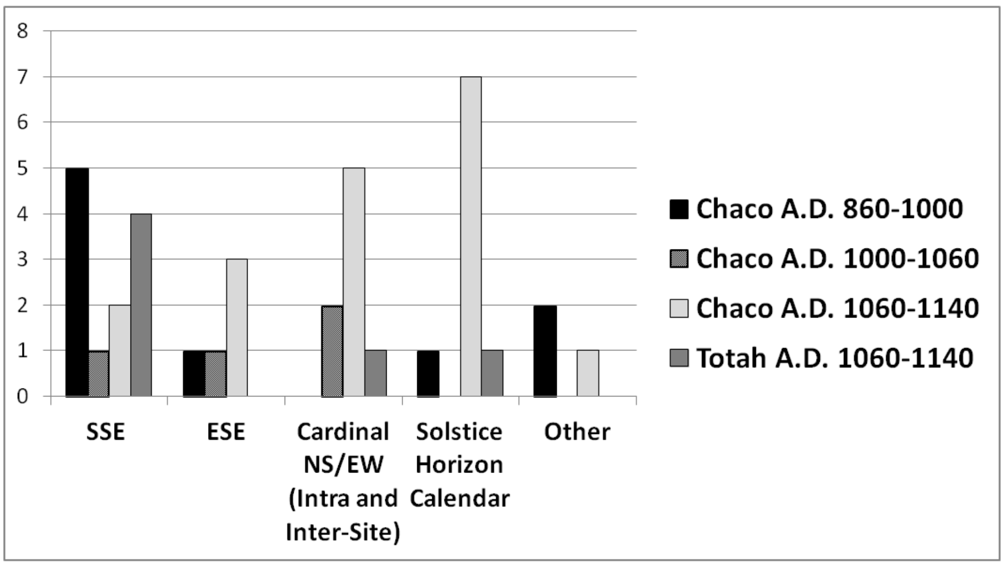


Figure 110. Construction starts by tradition, region, and timeframe

Shifts in the dominance of differing cosmologically-linked cultural practices or groups at Chaco and in the Totah may be identifiable based on the orientation and calendrical placement traditions associated with monumental architecture.

A majority of the Great Houses built before A.D. 1000 at and near to Chaco are oriented front facing to the SSE. One (Peñasco Blanco Stage I) faces ESE, and one (Pueblo Bonito) was near to a workable calendrical horizon for JSSR. During the first half of the 11th Century, SSE dominance was maintained, a second ESE Great House (Kin Klizhin) was constructed, and the Cardinal NS/EW tradition that was evident among Basketmaker pit structures at Chaco begins to reemerge. Hungo Pavi may have been intended as a Cardinal NS/EW structure; Pueblo Alto is almost certainly so intended. Sometime after A.D. 1070, Pueblo Bonito completed its gradual reorientation from SSE to accurate Cardinal NS/EW alignment.

After A.D. 1100 a major shift occurs at Chaco; while existing SSE structures in the canyon were expanded (e.g., Chetro Ketl), all subsequent new Great House construction starts created either cardinal NS/EW alignments (site-level and/or inter-site), or were built at workable solstice calendrical stations. The pattern of inter-building cosmological symmetry first noted by Fritz (1978) was formalized at this time. Tsin Kletzin was placed due south of Pueblo Alto, accurately aligned NS and dualistically symmetrical with Pueblo Alto across the East-West axis of the Canyon. Similarly, New Alto's position completes an approximate NS inter-site alignment with the Great Kiva of Casa Rinconada. If any portion of Chaco's history demonstrates working to a grand design plan it is the Late Bonito Phase.

In contrast, among the five Great Houses built in the Totah region after A.D. 1066, four are explicitly associated with the SSE orientation tradition. The "halo" Great House at Bis sa'ani, some 10km northeast of Wijiji on Escavada Wash, is the sole example found to date that may incorporate three traditions simultaneously. It includes a NS/EW cardinal alignment, a room block that may face SSE, and a working calendrical horizon that marks JSSR and may also mark DSSS.

The four astronomically-linked architectural traditions appear to offer some potential to trace cultural practices or migration paths in time and space. The presented astronomical evidence supports the idea that at least two distinct culture groups collaborated in Bonito Phase monumentalism at Chaco as suggested by Bullard (1962) and Vivian (1990).

ESE orientations are in the minority throughout the Bonito Phase. This tradition is more enigmatic based on current evidence. ESE buildings face generally in the direction of the rising December Solstice sun. Prior to its manifestation among Chacoan Great Houses, the front-facing ESE orientation tradition is evident in two different locations at different times. Lakatos (2007) has documented its dominance among populations present in the Rio Grande from A.D. 600 to 1200. The PI site at

Sacred Ridge provides uniquely convincing evidence as a case where ESE orientation is explicitly linked to a particular ethnic group. However, there is not yet strong evidence in the literature (other than the circumstantial evidence of the orientation tradition itself) to link the Sacred Ridge ethnic group to a Rio Grande origin. In addition, there is no significant body of evidence in the literature to indicate the presence of an ethic community originating in the Rio Grande valley at Chaco during the florescence. As a result, while it is tempting to speculate that ESE orientation may be a hallmark for a third ethic group at Chaco, available evidence does not provide a conclusive case. It may be that ESE orientation indicates an effort to attract pilgrims form the Rio Grande, or it could be indicative of a "borrowed" ritually important and cosmologically linked orientation tradition across culture groups.

The change in dominance from SSE orientation to a combination of cardinal NS/EW alignments and solstice calendrical station sites during the late 11th and early 12th centuries does suggest the likelihood of social schism or fragmentation (Lekson, 2009: 127, 238, 308n56). The SSE tradition emerges as dominant in the Totah at that time; which may be indicative of northward migration by a "SSE faction." Notwithstanding, multiple pieces of evidence suggest that changes in dominance among the groups did not equate to absolute social schism. Bis sa'ani Great House just north of Chaco Canyon may uniquely combine three traditions. In the Totah, the NS orientation of Aztec North Great House is associated with a group of SSE dominant structures, and Chimney Rock combines SSE and solstice-calendrical associations (Malville, 2004). The traditions continued to coexist in each region in spite of apparent changes in social dominance over time.

Relatively few Great Houses have been systematically surveyed for calendrical horizons. Salmon, Aztec, and over 100 outliers remain to be tested; they may or may not have horizon calendar associations. As a result, it is unclear whether the Late Bonito focus on building monumental architecture at calendrical stations was a brief cultural aberration associated with an exceptional effort to reestablish Chacoan primacy, or if construction at calendrical stations was also dominant in other places and times.

8.7 Suggested Future Work

The potential to enhance understanding of cultural development and collaboration among the ancestral Pueblo people of Chaco using archaeoastronomy techniques is dependent upon future expansion of sampling, and improved integration with broader ongoing archaeology. Based upon the results of this study, suggestions for future work to be conducted include the following:

1. Theodolite survey and/or photography to confirm the possible DSSR calendrical horizon foresight at the Late Bonito McElmo room block adjacent to Peñasco Blanco.
2. Archival research, theodolite survey, and photography to determine if the now-destroyed Late Bonito structure of Kin Sabe (CRA, 2010) had a workable DSSR foresight.
3. Visual and photographic confirmation of the possible DSSS foresight at Bis sa'ani.
4. Theodolite survey and/or photography to validate Calvin's (1991) proposed calendrical horizon foresight alignments at Hungo Pavi, including the proposed DSSS marked by use of the Tsin Kletsin tower kiva as a foresight.
5. Theodolite Survey and/or photography of the western horizon at 29SJ 866 to determine if the possible DSSS anticipatory marker functions.
6. Resurvey of Pueblo Pintado to verify the horizon altitude on the back wall's azimuth.
7. Sunrise photography at Hungo Pavi to test the putative equinox alignment.
8. Horizon survey at Salmon and Aztec to constrain the potential for solstice horizon calendars at those sites.
9. Expansion of the set of outlier Great Houses assessed for their fit with the four-tradition model discussed above, with a focus on those structures that can be reliably dated.
10. Further analysis and integration of documented Pueblo Star lore.

Items one and two in this list are of particular importance; preliminary GIS assessment of the Late Bonito room blocks at Peñasco Blanco and Kin Sabe suggests that both may have been built at workable DSSR calendrical stations. If this is confirmed, the dominant role of solstice calendrical stations providing the building sites for Late Bonito / McElmo architecture will be further strengthened. This may provide additional evidence to support theories of central planning and social control by an astronomically-adept elite between A.D. 1100-1140.

9 CONCLUSION

A majority of studied Chacoan Great Houses and Great Kivas are found to conform to one or more of four architectural traditions that astronomically derived. These include the construction of Great Houses at workable calendrical stations with solstice foresights, front-facing SSE orientation, alignments to the cardinal directions (NS/EW), and front facing ESE orientation. Multiple Great Houses exhibit two of these traditions in combination. A single case has been identified that may incorporate three of the traditions. The “halo” Great House at Bis sa’ani includes a cardinal North-South and East-West (“NS/EW”) structure, a possible SSE-facing room block, and a June solstice sunrise horizon foresight.

Fritz (1978: 40) discusses the explicitly mythic nature of symbolic architecture, and its usefulness as empirical evidence to help model attributes of prehistoric ideational systems. While relatively few Southwestern archaeologists have endeavored to link empirical monumental architecture and visual astronomy evidence, Kantner (2006b), and Williams *et al*. (2006) provide recent examples where such efforts have been applied to Chaco.

Based on the data presented in this study, two principal conclusions have been reached, and additional supplementary preliminary conclusions are offered for consideration and further research.

The principal finding of this study is that among the Late Bonito Great Houses assessed, all are associated with one or more of: a) NS/EW wall orientation(s), b) NS inter-building alignments, and c) placement at or near to a workable solstice calendrical station. The alignments to cardinal directions and calendrical station associations of the Late Bonito Great Houses collectively support the idea that they were centrally planned and built as monumental architecture designed to incorporate cosmological references and ritual power.

The inter-site NS alignments across the central canyon are especially interesting. Not only do they complete the patterns of symmetry discussed by Fritz

(1978) and Sofaer (2008: 90-91), in addition they are accurate enough to enable dramatic visual observations of the night sky rotating directly above Great House architecture. Recalling that Polaris was many degrees away from the north celestial pole in the 12th century, people at Tsin Kletsin could have watched the night sky rotate around the center of the cosmos directly above Pueblo Alto. Similarly, people observing the night sky from Casa Rinconada could have watched the cosmos rotate over New Alto. Torchlight at the northern mesa-top sites could have increased dramatic visual demonstrations that Chacoan Great Houses were explicitly located at the “Center Place” in the cosmos.

As discussed by multiple authors including Reyman (1975) and Šprajc (2010), in an agricultural society astronomical knowledge provides adaptive advantage and may support legitimization of power. For an agricultural society making use of horizon calendars, observation locations and foresights for significant dates may have particular importance. The placement of six Late Bonito Great Houses at or near to workable calendrical stations with solstice foresights is therefore quite provocative. While the solstices have ritual importance among modern Pueblo people, construction of monumental architecture at calendrical stations is at odds with Pueblo ethnography. Among modern Pueblo people calendrical stations are generally used privately by one or more socially-authorized sun-watchers or priests (Zeilik, 1985b). In contrast, among Late Bonito Great Houses the presence of a solstice calendrical station was apparently a site selection criterion for monumental architecture. Calendrical station Great Houses were most plausibly built at sites where earlier ancestral sacred sun watching had occurred. Therefore, in addition to their explicit solstice associations, these buildings may also represent ancestor veneration through construction of architecture to commemorate ancestral ritual activity.

Monumental construction at calendrical stations is especially intriguing in relation to theories that Chaco operated as a pilgrimage center (see e.g., Judge, 1989; Malville and Malville, 2001a, 2001b; Sebastian, 1992; Toll, 1985; Windes and Ford, 1996). The calendrical station Great Houses may have been destinations where pilgrims could share dramatic solstice sunrise or sunset visual experiences; demonstrations of astronomically-derived knowledge and power intended to bolster

Late Bonito Chacoan leaders' legitimacy. Acquisition of ritual power may have also supported accrual of political and economic power by Chacoan leaders, and is consistent with the idea of Chaco as an emergent segmentary state (Malville, 1997; Malville and Malville, 2001b) that grew out of pilgrimage traditions (Van Dyke 2008).

Chacoan cultural markers of dualism, symmetry, and asymmetry discussed by Fritz (1978), Ashmore (2007) and others are reinforced by these findings. In particular, the locations of the four confirmed calendrical station Great Houses of Casa Chiquita, Kin Kletso, Headquarters Site A, and Wijiji that are closest to "downtown Chaco" reinforce north/south asymmetry. All are on the north side of the canyon. Two are west of "downtown," and two are east. In addition to the visual association of north with the center of the cosmos based on nighttime observations; the sacredness of the canyon's north side may, in part, have been reinforced by the north-side locations of multiple calendrical stations with solstice foresights.

Van Dyke (2004a: 423) highlighted the monumental nature and efficient construction of the Late Bonito Great Houses, and suggested that irrespective of other uses they "… were meant to generate renewed interest in Chaco as a center place and to restore confidence in the rituals that took place there" after the drought years of the late 11th century. The finding that cosmological (NS/EW) and/or solstice calendrical associations are a consistent feature of studied Late Bonito Great Houses provides additional evidence to support her interpretation. These associations also provide circumstantial evidence in support of Nelson's (2006) interpretative conclusion regarding the Chacoan elite; their power likely rested to some degree on their knowledge of the "constructed supernatural and natural order."

A second conclusion of this study is that the majority of earlier (pre-1100) Chacoan Great Houses comport to one of three astronomically-derived orientation traditions. Among the studied pre-A.D. 1100 Great Houses at and near to Chaco, front-facing orientations to the SSE or ESE, or Cardinal NS/EW alignments are consistently manifested at every site save one. In this context, it is important to avoid oversimplification based on a single high-visibility marker in the material cultural evidence (see e.g., Ortman, 2009). While the intended meanings of these orientation traditions are open to debate pending accumulation of additional evidence, it is clear that the Great House orientations are not randomly distributed. Temporal assessment of the traditions may provide insight into shifting dominance of culture groups, or evolution of cultural practices at Chaco.

The front-facing SSE orientation tradition was dominant during the early phases of construction at what would become the first Great Houses at Chaco including Pueblo Bonito, Una Vida and East Community. This tradition may be linked to the direction of ancestral migrations. The path between Ute Mountain and Mesa Verde from the Great Sage Plain towards Chaco roughly parallels the range of SSE/NNW azimuths present in the architectural record (Malville and Munro, 2011). This idea has certain power in part due to the overarching cultural importance of ancestral migration traditions among diverse Pueblo clans (see e.g., Fewkes, 1900; Kuwanwisiwma, 2004; Lockett, 1933) and the remarkable temporal durability of the SSE tradition. Irrespective of how it was maintained, this tradition offered cultural utility because it aligned pit structures for protection from prevailing winter winds; in addition, above-ground architecture benefited from passive solar gain for winter warmth.

Alignment of architecture with the cardinal directions of NS/EW emerged as a hallmark of Chacoan monumental architecture during the 11th century, but was foreshadowed by similar alignments at Basketmaker villages, and in earlier Pueblo villages in the Dolores river valley to the north. These alignments are explicitly cosmological, and they are generally consistent with a pan-Pueblo concern for directions in cosmological systems, cosmogony, and ritual practice. They are specifically consistent with the modern Pueblo focus on the cardinal directions of NS/EW among the Eastern Pueblos. Pueblo Bonito’s wall alignments to the cardinal directions are uniquely accurate and precise; this is indicative of unusual skill and care being applied during survey and construction and may be evidence that this structure was of unique importance. Nonetheless, Pueblo Bonito’s EW walls do not align visually with Equinox sunrise or sunset.

In keeping with the proposals of Hayes (1981), Vivian (1990), and Lipe (2006: 264-265) temporal assessment of the SSE and Cardinal NS/EW orientation traditions may provide evidence of shifts in dominance between two cultural traditions or ethnic communities over time, one of which may have originated in the north, and one of which may have come from the south.

The ESE orientation tradition is certainly distinct from the SSE and cardinal NS/EW traditions, and it is consistent with Rio Grande traditions, as well as the PI Sacred Ridge site. Therefore, ESE orientation may be indicative of a third ethnic group's presence, or alternatively it may indicate of some form of cross ethnic-group transfer of a cosmological practice. Such borrowing of a cosmologically-linked practice might plausibly have resulted from trade contact, or it might represent an effort (successful or otherwise) to attract pilgrims from the Rio Grande valley region to Chaco. Certainly many documented cases exist of the "borrowing" of ritual and religious practices among modern Pueblos, irrespective of language boundaries (Parsons, 1939: 968-986).

Preliminary conclusions are offered regarding how some of these traditions could have been maintained. During Basketmaker times, specialists who were familiar with the sky may have advised individuals on how to establish SSE, Cardinal NS/EW, and ESE building alignments or orientations; the methods they used were likely preserved, improved upon, and applied during the Bonito Phase to Great House architecture. The NS orientation would have been simplest to achieve, for example using the area of the northern skies around which all stars revolve as a visual key, or by use of a shadow casting gnomon. Both the ESE tradition and the dominance of December solstices among identified calendrical stations support that date's overarching ritual importance at Chaco, which is indicative of cultural continuity into modern times. Similarly, the continued importance of the cardinal directions in Eastern Pueblo cosmology attests to cultural continuity.

The astronomical evidence presented is potentially linked to varied forms of ancestor veneration. As discussed, the SSE tradition may be commemorative of migration mythology, an implicit form of ancestor veneration. While additional research is needed to fully justify this idea, it is more consistent with the body of evidence than previous hypotheses. It is well-documented ethnographically that the cardinal NS/EW tradition is explicitly linked to Eastern Pueblo cosmology; it may also be linked to traditions of migration from the north.

The proposed staff model to measure angles as offsets with reference to the heavens and achieve orientation of architecture has circumstantial support from multiple independent lines of evidence. The Pueblo Bonito Type 1 ceremonial sticks with bows may be stylized versions of cross staffs that were in use throughout the Basketmaker III to Pueblo III periods. It has recently been communicated to the author that at least one photograph survives of a Hopi Sun Priest holding a similarly designed "Y-shaped" staff; the picture was reportedly taken during a Powamu celebration during the first decade of the 20th century (Krupp, pers. comm., 2011). However, this model is not conclusive based on the available evidence. It depends in part on conjectural inferences to connect lines of evidence, and the identified ethnographic support is quite limited. Additional review of recorded ethnography, further ethnographic research, and more extensive anthropometric assessment will be beneficial. In addition, hypothesis testing may be conducted through live tests to determine if the range of building orientations in the archaeological record can be achieved as proposed.

It is also remarkable that the entire set of Chacoan SSE and ESE facing Great Houses, as well as the 205°-facing site at Kin Nahasbas all face in directions that are rotated ~ 25° from a Cardinal direction. As proposed, a common ritual staff technology may have emerged as a hallmark of multi-cultural integration at Chaco; applied in different ways by different culture groups to manifest different cosmologically-linked traditions. It could have been used to establish the ~25° angular off-set from NS to achieve the SSE orientation, from east-west to achieve the ESE orientation, and west-of-south to achieve the 205° orientation at Kin Nahasbas. Lipe (2006: 268) comments: "…for at least five or six centuries, San Juan households and communities employed in their architecture and manner of spatial arrangement a set of powerful symbols, at least some of which referred to widespread emergence/creation beliefs." Migration stories may have been interwoven into emergence and creation mythologies. Depending upon ones heritage, mytho-historic ancestors deserving of veneration may have come from the North or north northwest and travelled South, or SSE. A tool used for SSE commemorative architectural survey could also be applied to achieve a rough orientation with DSSR (ESE), in commemoration of entirely different traditions.

The "halo" Great House at Bis sa'ani is unique among the Great Houses assessed because it may incorporate three traditions including a cardinal NS wall alignment adjacent to a kiva, a possible SSE oriented room block, and a working June Solstice Sunrise (JSSR) horizon foresight. This may be indicative of an outlying agricultural community endeavoring to maintain balanced relationships with competing elites at Chaco and Aztec by communicating respect for multiple traditions, or it may simply signal that multiple culture groups were present in that community.

Astronomical associations with architecture emerge as a clear cultural marker among ancestral Pueblo people. Construction survey for the SSE, ESE and NS/EW traditions may have been conducted with technology such as gnomons and cross staffs. All of the identified astronomically-associated traditions are plausibly visual in origin, no recourse to exotic "lost knowledge" is necessary to explain them. Public ceremonies for pilgrims involving predicted solstice sunrises and sunsets would make for powerful social bonding experiences. Similarly, the NS inter-building alignments provided opportunities for nighttime events where spectators could observe that a Great House was aligned directly under the visible void in the north about which the night sky rotates. These sites would have offered public demonstrations of the astronomical knowledge, predictive power, and legitimacy of the Chacoan elite in the "center place."

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11 APPENDIX 1: THEODOLITE SURVEYS & DATA REDUCTION

11.1 Peñasco Blanco

11.1.1 East Horizon

Field Data Collection Form: Munro - Chaco Survey May/June 2009					
Site Name	Peñasco Blanco			Date	4-Jun-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	East Horizon: Measured from mound 7.4 m in front (SE) of standing outer "front" wall, SE of the plaza.				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***4***	***52.1***	4.8683	36.0811
Long	***108***	***0***	***9.1***	0.1517	108.0025

Theodolite Observations

	Measurement 1			Measurement 2			Measurement 3			Measurement 4			Mean	Std Err
	D	M	S	D	M	S	D	M	S	D	M	S		
Horiz 1 Az	***101***	***5***	***52***	***101***	***5***	***42***	***101***	***5***	***50***	***101***	***5***	***49***	101.0967	0.0006
Horiz 1 Alt	***89***	***36***	***40***	***89***	***36***	***30***	***89***	***36***	***19***	***89***	***36***	***18***	89.6074	0.0014
Horiz 2 Az	***104***	***20***	***54***	***104***	***20***	***55***	***104***	***20***	***59***	***104***	***20***	***54***	104.3488	0.0003
Horiz 2 Alt	***89***	***44***	***53***	***89***	***44***	***4***	***89***	***44***	***0***	***89***	***43***	***56***	89.7370	0.0037
Backsight (a)	***0***	***0***	***14***											

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***14:54:28***	***69***	***28***	***36***			***85.1***	***14.4***	84.8600	-15.3833	-15.4075	0.0289
Sun Az 2	***14:56:53***	***69***	***48***	***14***			***85.5***	***14.4***	85.2600	-15.4561		
Sun Az 3	***14:58:05***	***69***	***58***	***17***			***85.6***	***14.4***	85.3600	-15.3886		
Sun Az 4	***15:00:56***	***70***	***21***	***29***			***86.0***	***14.4***	85.7600	-15.4019		
Sun Alt 1	***14:54:53***	***56***	***37***	***54***	***33***	***29.1***		***14.4***	33.2450	-0.1233	0.0033	0.0654
Sun Alt 2	***14:57:21***	***56***	***8***	***14***	***34***	***8.9***		***14.4***	33.9083	0.0456		
Sun Alt 3	***14:58:41***	***55***	***52***	***15***	***34***	***25.0***		***14.4***	34.1767	0.0475		
Sun Alt 4	***15:01:24***	***55***	***19***	***19***	***34***	***57.8***		***14.5***	34.7217	0.0436		
Back Sight (b)		***0***	***0***	***11***								
Operator		Andy Munro										

Sunrise Dates

	Horizon Az (deg)	Horizon Alt (deg)	Nearest Sunrise Dates	Sunrise Az (deg)	Sunrise Alt (deg)
EastHoriz 1	116.5	0.4	***01.14.2009***	***116.5***	***0.4***
			11.27.2009	***116.5***	***0.4***
EastHoriz 2	119.8	0.3	***Too Far South for 12.21.2009***	***119.4***	***0.3***

Spherical Trig Check of Sun Sights

D to R		R to D									
0.017453293		57.2957795									
UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated AZ	Observed AZ	Δ
14:54:28	***44***	***1.5***	-63.9775	***22***	***29.7***	33.5674			85.1468	85.1242	0.0226
14:54:53	***44***	***7.8***	-63.8725	***22***	***29.7***	33.6520	33.6050	0.0470	85.2039		
14:56:53	***44***	***37.8***	-63.3725	***22***	***29.7***	34.0547			85.4763	85.4514	0.0249
14:57:21	***44***	***44.8***	-63.2559	***22***	***29.7***	34.1487	34.0994	0.0493	85.5400		
14:58:05	***44***	***55.8***	-63.0725	***22***	***29.7***	34.2964			85.6402	85.6189	0.0213
14:58:41	***45***	***4.8***	-62.9225	***22***	***29.7***	34.4173	34.3658	0.0515	85.7223		
15:00:56	***45***	***38.5***	-62.3609	***22***	***29.7***	34.8701			86.0306	86.0056	0.0250
15:01:24	***45***	***45.5***	-62.2442	***22***	***29.7***	34.9641	34.9164	0.0478	86.0947		
							AVG Δ	0.0489		AVG Δ	0.0235

11.1.2 Southeast Standing Wall

Field Data Collection & Analysis: Munro - Chaco Survey May 2009					
Site Name			Peñasco Blanco	Local Date	4-Jun-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	Southeast Wall Section (end of C Shaped Room Block) Theodolite adjacent to room 90, 1 meter from wall				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***4***	***52***	4.87	36.08
Long	***108***	***0***	***12.3***	0.21	108.00

Theodolite Observations

	D	M	S	Decimal Conversion
Angle 1	***177***	***10***	***16***	177.1711
Angle 2	***177***	***27***	***18***	177.4550
Angle 3	***177***	***0***	***0***	177.0000
Angle 4	***177***	***12***	***0***	177.2000
Angle 5	***177***	***19***	***13***	177.3203
Angle 6	***177***	***25***	***50***	177.4306
Angle 7	***177***	***18***	***20***	177.3056
Angle 8	***176***	***48***	***1***	176.8003
Angle 9	***177***	***3***	***55***	177.0653
Angle 10	***177***	***21***	***55***	177.3653
MEAN Angle				177.2113

STD DEV				0.1971
Back Sight (a)	***359***	***59***	***56***	359.9989

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***13:50:00***	***356***	***42***	***34***			76.7	13.3	76.4783	280.2311	280.2472	0.0323
Sun Az 2	***13:53:41***	***357***	***10***	***50***			77.2	13.4	76.9767	280.2039		
Sun Az 3	***13:54:56***	***357***	***20***	***30***			77.3	13.4	77.0767	280.2650		
Sun Az 4	***13:55:54***	***357***	***27***	***55***			77.4	13.4	77.1767	280.2886		
Sun Alt 1	***13:51:02***	***69***	***21***	***24***	20	55.2		13.3	20.6983	-0.0550	-0.0556	0.0007
Sun Alt 2	***13:54:09***	***68***	***44***	***41***	21	32.0		13.4	21.3100	-0.0547		
Sun Alt 3	***13:55:23***	***68***	***30***	***11***	21	46.6		13.4	21.5533	-0.0564		
Sun Alt 4	***13:56:19***	***68***	***19***	***4***	21	57.7		13.4	21.7383	-0.0561		
Back Sight (b)		***359***	***59***	***58***								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Wall Azimuth	Reciprocal Azimuth
257.0	77.0

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated AZ	Observed AZ	Δ
13:50:00	***27***	***54.7***	-80.0918	***22***	***29.4***	20.7179			76.6783	76.6840	-0.0056
13:51:02	***28***	***10.1***	-79.8351	***22***	***29.4***	20.9198	20.9206	-0.0007	76.8114		
13:53:41	***28***	***49.9***	-79.1718	***22***	***29.4***	21.4421			77.1553	77.1567	-0.0015
13:54:09	***28***	***56.9***	-79.0551	***22***	***29.4***	21.5341	21.5342	-0.0001	77.2157		
13:54:56	***29***	***8.6***	-78.8601	***22***	***29.4***	21.6878			77.3168	77.3178	-0.0010
13:55:23	***29***	***15.4***	-78.7468	***22***	***29.4***	21.7772	21.7758	0.0013	77.3756		
13:55:54	***29***	***23.1***	-78.6184	***22***	***29.4***	21.8784			77.4421	77.4415	0.0006
13:56:19	***29***	***29.4***	-78.5134	***22***	***29.4***	21.9612	21.9611	0.0001	77.4965		
							AVG Δ	0.0002		AVG Δ	-0.0019

11.2 Casa Chiquita

11.2.1 East Horizon

Field Data Collection Form: Munro - Chaco Survey May/June 2009					
Site Name	Casa Chiquita			Date	28-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	East Horizon from Room 8 at the Southwest Corner of Building				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***4***	***9.1***	4.1517	36.0692
Long	***107***	***58***	***36.3***	58.6050	107.9768

Theodolite Observations

	Measurement 1			Measurement 2			Measurement 3			Measurement 4			Mean	Std Err
	D	M	S	D	M	S	D	M	S	D	M	S		
Horiz 1 Az	***132***	***13***	***55***	***132***	***14***	***20***	***132***	***13***	***40***	***132***	***13***	***40***	132.2316	0.0026
Horiz 1 Alt	***75***	***36***	***51***	***75***	***36***	***59***	***75***	***36***	***34***	***75***	***36***	***50***	75.6135	0.0015
Horiz 2 Az	***135***	***29***	***17***	***135***	***28***	***34***	***135***	***28***	***38***	***135***	***28***	***25***	135.4788	0.0032
Horiz 2 Alt	***81***	***20***	***1***	***81***	***19***	***23***	***81***	***19***	***45***	***81***	***20***	***3***	81.3300	0.0026
Horiz 3 Az	***136***	***37***	***23***	***136***	***37***	***41***	***136***	***37***	***49***	***136***	***37***	***19***	136.6258	0.0020
Horiz 3 Alt	***85***	***18***	***55***	***85***	***19***	***10***	***85***	***20***	***0***	***85***	***18***	***51***	85.3206	0.0044

Horiz 4 Az	***140***	***19***	***27***	***140***	***19***	***44***	***140***	***20***	***0***	***140***	***19***	***50***	140.3292	0.0019
Horiz 4 Alt	***86***	***32***	***33***	***86***	***33***	***29***	***86***	***33***	***30***	***86***	***33***	***4***	86.5525	0.0037
Horiz 5 Az	***158***	***53***	***59***	***158***	***54***	***6***	***158***	***54***	***7***	***158***	***54***	***8***	158.9014	0.0006
Horiz 5 Alt	***84***	***48***	***20***	***84***	***48***	***6***	***84***	***48***	***11***	***84***	***48***	***31***	84.8047	0.0015
Horiz 6 Az	***169***	***14***	***10***	***169***	***14***	***12***	***169***	***14***	***17***	***169***	***14***	***0***	169.2360	0.0010
Horiz 6 Alt	***84***	***40***	***53***	***84***	***40***	***49***	***84***	***40***	***45***	***84***	***41***	***5***	84.6814	0.0012
Horiz 7 Az	***174***	***15***	***11***	***174***	***15***	***22***	***174***	***15***	***28***	***174***	***15***	***14***	174.2552	0.0011
Horiz 7 Alt	***85***	***3***	***36***	***85***	***4***	***1***	***85***	***3***	***34***	***85***	***3***	***53***	85.0628	0.0018
Horiz 8 Az	***181***	***24***	***25***	***181***	***24***	***3***	***181***	***24***	***10***	***181***	***24***	***2***	181.4028	0.0015
Horiz 8 Alt	***85***	***55***	***23***	***85***	***55***	***46***	***85***	***55***	***45***	***85***	***55***	***57***	85.9285	0.0020
Horiz 9 Az	***184***	***8***	***5***	***184***	***8***	***14***	***184***	***8***	***9***	***184***	***7***	***58***	184.1351	0.0009
Horiz 9 Alt	***86***	***18***	***25***	***86***	***18***	***40***	***86***	***18***	***36***	***86***	***18***	***33***	86.3093	0.0009
Backsight (a)	***359***	***59***	***37***											

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***17:10:56***	***176***	***35***	***55***			***111.3***	***15.3***	111.0450	65.5536	65.4858	0.0401
Sun Az 2	***17:17:41***	***178***	***29***	***58***			***113.3***	***15.3***	113.0450	65.4544		
Sun Az 3	***17:19:42***	***179***	***6***	***11***			***113.9***	***15.3***	113.6450	65.4581		
Sun Az 4	***17:23:03***	***180***	***7***	***20***			***114.9***	***15.3***	114.6450	65.4772		
Sun Alt 1	***17:16:18***	***28***	***48***	***57***	***61***	***29.1***		***15.3***	61.2300	0.0458	0.0348	0.0218
Sun Alt 2	***17:18:44***	***28***	***19***	***8***	***61***	***56.3***		***15.3***	61.6833	0.0022		
Sun Alt 3	***17:21:50***	***27***	***47***	***30***	***62***	***30.6***		***15.3***	62.2550	0.0467		
Sun Alt 4	***17:23:34***	***27***	***28***	***16***	***62***	***49.7***		***15.3***	62.5733	0.0444		
Back Sight (b)		***359***	***59***	***55***								
Operator		Andy Munro										

Sunrise Dates

	Horizon Az (deg)	Horizon Alt (deg)	Nearest Sunrise Dates	Sunrise Az (deg)	Sunrise Alt (deg)
Horiz 1	66.7	14.4	N/A		
			N/A		
Horiz 2	70.0	8.7	***5.25.2009***	***70.2***	***8.7***
			7.17.2009	***70.1***	***8.7***
Horiz 3	71.1	4.7	***5.11.2009***	***71.1***	***4.8***
			8.01.2009	***71.7***	***4.7***
Horiz 4	74.8	3.4	***4.27.2009***	***75.0***	***3.4***
			8.14.2009	***74.8***	***3.5***
Horiz 5	93.4	5.2	***3.20.2009***	***93.6***	***5.2***
			9.22.2009	***93.5***	***5.2***
Horiz 6	103.8	5.3	***2.27.2009***	***103.9***	***5.2***
			10.13.2009	***103.8***	***5.4***
Horiz 7	108.8	4.9	***2.16.2009***	***108.8***	***5.0***
			10.25.2009	***108.9***	***4.9***
Horiz 8	115.9	4.1	***1.28.2009***	***115.7***	***4.1***
			11.14.2009	***116.0***	***4.0***
Horiz 9	118.6	3.7	***1.18.2009***	***118.5***	***3.7***
			11.23.2009	***118.5***	***3.7***

Spherical Trig Check of Sun Sights

D to R		R to D	
0.017453293		57.2957795	

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated AZ	Observed AZ	Δ
17:10:56	***78***	***24.3***	-29.5718	***21***	***33.7***	60.4809			111.3252	111.3678	-0.0426
17:16:18	***79***	***44.8***	-28.2301	***21***	***33.7***	61.4858	61.4740	0.0118	112.8504		
17:17:41	***80***	***5.5***	-27.8851	***21***	***33.7***	61.7424			113.2556	113.2686	-0.0131
17:18:44	***80***	***21.3***	-27.6218	***21***	***33.8***	61.9387	61.9709	-0.0322	113.5658		
17:19:42	***80***	***35.8***	-27.3801	***21***	***33.8***	62.1176			113.8560	113.8722	-0.0163
17:21:50	***81***	***7.8***	-26.8468	***21***	***33.8***	62.5109	62.4981	0.0127	114.5065		
17:23:03	***81***	***26***	-26.5434	***21***	***33.8***	62.7336			114.8829	114.8914	-0.0085
17:23:34	***81***	***33.8***	-26.4134	***21***	***33.8***	62.8289	62.8187	0.0102	115.0457		
							AVG Δ	0.0006		AVG Δ	-0.0201

11.2.2 West Horizon

Field Data Collection Form: Munro - Chaco Survey May/June 2009					
Site Name			Casa Chiquita	Date	25-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	West Horizon from Southwest Corner of Building				
Text Key: ***Input*****,** Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***4***	***8.5***	4.1417	36.0690
Long	***107***	***58***	***36.3***	58.6050	107.9768

Theodolite Observations

	Measurement 1			Measurement 2			Measurement 3			Measurement 4			Mean	Std Err
	D	M	S	D	M	S	D	M	S	D	M	S		
Horiz 1 Az	***73***	***10***	***44***	***73***	***10***	***45***	***73***	***10***	***59***	***73***	***10***	***51***	73.1805	0.0010
Horiz 1 Alt	***88***	***17***	***50***	***88***	***17***	***42***	***88***	***17***	***29***	***88***	***17***	***36***	88.2942	0.0012
Horiz 2 Az	***77***	***40***	***34***	***77***	***39***	***36***	***77***	***40***	***25***	***77***	***40***	***29***	77.6711	0.0037
Horiz 2 Alt	***88***	***22***	***50***	***88***	***22***	***39***	***88***	***22***	***9***	***88***	***22***	***9***	88.3741	0.0029
Horiz 3 Az	***85***	***58***	***10***	***85***	***58***	***4***	***85***	***58***	***2***	***85***	***58***	***13***	85.9687	0.0007
Horiz 3 Alt	***88***	***25***	***51***	***88***	***26***	***10***	***88***	***26***	***3***	***88***	***26***	***12***	88.4344	0.0013
Horiz 4 Az	***90***	***22***	***28***	***90***	***22***	***32***	***90***	***22***	***15***	***90***	***22***	***29***	90.3739	0.0010
Horiz 4 Alt	***88***	***52***	***28***	***88***	***52***	***34***	***88***	***52***	***27***	***88***	***52***	***30***	88.8749	0.0004

Backsight (a)	***0***	***1***	***37***

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***15:55:57***	***247***	***41***	***58***			96.2	14.9	95.9517	151.7478	151.7369	0.0133
Sun Az 2	***16:01:47***	***248***	***41***	***43***			97.2	14.9	96.9517	151.7436		
Sun Az 3	***16:03:20***	***248***	***57***	***51***			97.5	15.0	97.2500	151.7142		
Sun Az 4	***16:05:47***	***249***	***23***	***31***			97.9	15.0	97.6500	151.7419		
Sun Alt 1	***15:58:50***	***44***	***9***	***23***	46	8.6		14.9	45.8950	0.0514	0.0573	0.0231
Sun Alt 2	***16:02:43***	***43***	***23***	***11***	46	55.3		14.9	46.6733	0.0597		
Sun Alt 3	***16:05:05***	***42***	***54***	***40***	47	23.8		15.0	47.1467	0.0578		
Sun Alt 4	***16:06:42***	***42***	***35***	***25***	47	43.2		15.0	47.4700	0.0603		
Back Sight (b)		***0***	***1***	***34***								
Operator		Andy Munro										

Sunset Dates

	Horizon Az (deg)	Horizon Alt (deg)	Nearest Sunrise Dates	Sunrise Az (deg)	Sunrise Alt (deg)
Horiz 1	281.4436	1.7058	***04.15.2009***	***281.6***	***1.7***
			08.26.2009	***281.4***	***1.8***
Horiz 2	285.9342	1.6259	***04.25.2009***	***285.9***	***1.5***
			08.15.2009	***286.0***	***1.7***
Horiz 3	294.2318	1.5656	***05.20.2009***	***294.3***	***1.6***
			07.22.2009	***294.1***	***1.6***
Horiz 4	298.6370	1.1251	***6.21.2009***	***298.8***	***1.2***

Spherical Trig Check of Sun Sights

D to R		R to D									
0.017453293		57.2957795									
UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
15:55:57	***59***	***44.9***	-48.2284	***21***	***3.2***	45.5633			96.2034	96.2109	-0.0075
15:58:50	***60***	***28.2***	-47.5068	***21***	***3.2***	46.1429	46.1492	-0.0063	96.6958		
16:01:47	***61***	***12.4***	-46.7701	***21***	***3.3***	46.7349			97.2032	97.2067	-0.0035
16:02:43	***61***	***26.4***	-46.5368	***21***	***3.3***	46.9220	46.9192	0.0027	97.3661		
16:03:20	***61***	***35.7***	-46.3818	***21***	***3.3***	47.0462			97.4747	97.4773	-0.0026
16:05:05	***62***	***1.9***	-45.9451	***21***	***3.3***	47.3960	47.3962	-0.0002	97.7824		
16:05:47	***62***	***12.4***	-45.7701	***21***	***3.3***	47.5362			97.9065	97.9051	0.0014
16:06:42	***62***	***12.4***	-45.7701	***21***	***3.3***	47.5362	47.7170	-0.1809	97.9065		
							AVG Δ	-0.0461		AVG Δ	-0.0030

11.2.3 West Wall

Field Data Collection & Analysis: Munro - Chaco Survey May 2009					
Site Name			Casa Chiquita	Local Date	25-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	West Wall surveyed from SW Corner				
Text Key: ***Input,*** Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***8***	***8.5***	8.14	36.1357
Long	***107***	***58***	***36.3***	58.61	107.9768

Theodolite Observations

Feature Description	West Wall surveyed from SW Corner			
	D	M	S	Decimal Conversion
Angle 1	***174***	***6***	***40***	174.1111
Angle 2	***173***	***0***	***44***	173.0122
Angle 3	***171***	***47***	***58***	171.7994
Angle 4	***172***	***12***	***47***	172.2131
Angle 5	***171***	***42***	***3***	171.7008
Angle 6	***171***	***50***	***53***	171.8481
Angle 7	***171***	***47***	***17***	171.7881
Angle 8	***171***	***59***	***57***	171.9992
Angle 9	***172***	***2***	***16***	172.0378

Angle 10	***172***	***11***	***8***	172.1856
Angle 11	***172***	***15***	***37***	172.2603
Angle 12	***172***	***9***	***23***	172.1564
Angle 13	***172***	***7***	***39***	172.1275
Angle 14	***172***	***10***	***53***	172.1814
Angle 15	***171***	***57***	***26***	171.9572
MEAN Azimuth				172.2252
STD DEV				0.5855
Back Sight (a)	***0***	***1***	***37***	0.0269

Observed Sun Sights: See West Horizon Data Immediately Above

Wall Azimuth

Mean Measured Wall Azimuth	Reciprocal Azimuth	Calculated Perpendicular Azimuth	Reciprocal Perpendicular Azimuth
20.5	200.5	110.5	290.5

Spherical Trig Check of Sun Sights: See West Horizon Data Immediately Above

11.3 Pueblo del Arroyo

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2009					
Site Name			Pueblo del Arroyo	Local Date	27-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	NW (Back) Wall surveyed from high spot along wall				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***3***	***40.5***	3.7	36.0613
Long	***107***	***57***	***56.7***	57.9	107.9658

Theodolite Observations

Feature Description	Horizon Altitudes				
	D	M	S	Decimal Conversion	Az/Alt
East Horizon Perpendicular to Wall Az	***100***	***2***	***45***	100.0458	114.8788
East Horizon Perpendicular to Wall Alt	***88***	***53***	***15***	88.8875	1.1125
Horizon Alt on Wall Az: NORTH	***89***	***31***	***54***	89.5317	0.4683
Horizon Alt on Wall Az: SOUTH	***83***	***33***	***48***	83.5633	6.4367
Feature Description					
Angle 1	***190***	***14***	***8***	190.2356	
Angle 2	***190***	***18***	***8***	190.3022	
Angle 3	***190***	***21***	***13***	190.3536	
Angle 4	***190***	***23***	***47***	190.3964	

Angle 5	***190***	***25***	***55***	190.4319
Angle 6	***190***	***30***	***28***	190.5078
Angle 7	***190***	***32***	***32***	190.5422
Angle 8	***190***	***32***	***16***	190.5378
Angle 9	***190***	***33***	***2***	190.5506
Angle 10	***190***	***33***	***32***	190.5589
Angle 11	***190***	***33***	***37***	190.5603
Angle 12	***190***	***31***	***20***	190.5222
Angle 13	***190***	***29***	***19***	190.4886
Angle 14	***190***	***28***	***42***	190.4783
Angle 15	***190***	***24***	***36***	190.4100
Angle 16	***190***	***23***	***46***	190.3961
Angle 17	***190***	***21***	***38***	190.3606
Angle 18	***190***	***30***	***3***	190.5008
Angle 19	***190***	***20***	***54***	190.3483
Angle 20	***190***	***22***	***44***	190.3789
Angle 21	***190***	***23***	***14***	190.3872
Angle 22	***190***	***19***	***26***	190.3239
Angle 23	***190***	***20***	***51***	190.3475
Angle 24	***190***	***22***	***5***	190.3681
Angle 25	***190***	***13***	***19***	190.2219
Angle 26	***190***	***12***	***18***	190.2050
Angle 27	***190***	***19***	***41***	190.3281
Angle 28	***190***	***18***	***11***	190.3031
Angle 29	***190***	***27***	***28***	190.4578
Angle 30	***190***	***15***	***42***	190.2617

Angle 31	***190***	***13***	***29***	190.2247
Angle 32	***190***	***2***	***2***	190.0339
Angle 33	***190***	***6***	***46***	190.1128
Angle 34	***190***	***20***	***33***	190.3425
Angle 35	***190***	***9***	***31***	190.1586
Angle 36	***190***	***40***	***25***	190.6736
Angle 37	***190***	***29***	***27***	190.4908
Angle 38	***9***	***17***	***34***	189.2928
Angle 39	***9***	***28***	***21***	189.4725
Angle 40	***9***	***40***	***51***	189.6808
Angle 41	***9***	***38***	***9***	189.6358
Angle 42	***9***	***13***	***19***	189.2219
Angle 43	***9***	***2***	***14***	189.0372
Angle 44	***9***	***8***	***27***	189.1408
Angle 45	***9***	***9***	***9***	189.1525
Angle 46	***9***	***7***	***6***	189.1183
Angle 47	***8***	***55***	***48***	188.9300
Angle 48	***8***	***59***	***53***	188.9981
Angle 49	***9***	***2***	***59***	189.0497
Angle 50	***9***	***10***	***44***	189.1789
Angle 51	***9***	***21***	***46***	189.3628
Angle 52	***9***	***29***	***25***	189.4903
Angle 53	***9***	***30***	***6***	189.5017
Angle 54	***9***	***34***	***43***	189.5786
Angle 55	***9***	***41***	***59***	189.6997
Angle 56	***9***	***42***	***48***	189.7133
Angle 57	***9***	***49***	***15***	189.8208
Angle 58	***9***	***49***	***53***	189.8314
Angle 59	***10***	***2***	***5***	190.0347

Angle 60	***10***	***7***	***28***	190.1244
Angle 61	***10***	***9***	***35***	190.1597
Angle 62	***10***	***2***	***19***	190.0386
Angle 63	***10***	***2***	***50***	190.0472
Angle 64	***10***	***3***	***20***	190.0556
MEAN Angle				190.0230
STD DEV				0.4988
Back Sight (a)	***0***	***0***	***10***	0.0028

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***17:28:04***	***101***	***43***	***17***			***116.8***	***15.3***	116.5450	-14.8236	**-14.8330**	0.0269
Sun Az 2	***17:29:56***	***102***	***20***	***34***			***117.4***	***15.4***	117.1433	-14.8006		
Sun Az 3	***17:32:14***	***103***	***6***	***38***			***118.2***	***15.4***	117.9433	-14.8328		
Sun Az 4	***17:34:09***	***103***	***46***	***6***			***118.9***	***15.4***	118.6433	-14.8750		
Sun Alt 1	***17:28:59***	***26***	***33***	***10***	***63***	***44.8***		***15.4***	63.4900	-0.0428	0.1207	0.2896
Sun Alt 2	***17:28:59***	***26***	***7***	***48***	***64***	***10.6***		***15.4***	63.9200	-0.0500		
Sun Alt 3	***17:33:30***	***25***	***4***	***52***	***64***	***33.2***		***15.4***	64.2967	0.6222		
Sun Alt 4	***17:35:05***	***25***	***28***	***12***	***64***	***50.0***		***15.4***	64.5767	-0.0467		
Back Sight (b)		***0***	***0***	***6***								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Wall Azimuth	Reciprocal Azimuth	Perpendicular Azimuth	Reciprocal Perpendicular Azimuth
204.9	24.9	114.9	294.9

Test of Proposed Lunar Standstill Alignment

Front Facing Horizon Alt	Front Facing Azimuth	USNO Refraction (Refr) and Parrallax (PA) Correction Jul 1 2015 @ 19:18 Local (Arcmin)	Corrected Horizon Alt	USNO Minor Standstill AZ @ 0.6 deg Alt: Jul 1, 2015	Difference: Measured Facing Az and Forecasted Lunar Azimuth (Deg)	Diff / SD of Wall
1.1	114.9	32.8	0.6	113.5	1.4	3

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
17:28:04	***82***	***43.1***	-25.2474	***21***	***24.2***	63.5802			116.8113	116.8094	0.0019
17:28:59	***82***	***56.9***	-25.0174	***21***	***24.2***	63.7459	63.5832	0.1627	117.1170		
17:29:56	***83***	***11.1***	-24.7808	***21***	***24.2***	63.9159			117.4348	117.4324	0.0023
17:28:59	***83***	***32.9***	-24.4174	***21***	***24.2***	64.1760	64.0060	0.1700	117.9290		
17:32:14	***83***	***45.6***	-24.2058	***21***	***24.2***	64.3270			118.2205	118.2002	0.0203
17:33:30	***84***	***4.6***	-23.8891	***21***	***24.2***	64.5521	65.0549	-0.5028	118.6618		
17:34:09	***84***	***14.4***	-23.7258	***21***	***24.3***	64.6689			118.8889	118.8580	0.0310
17:35:05	***84***	***28.4***	-23.4924	***21***	***24.3***	64.8338	64.6660	0.1678	119.2205		
							AVG Δ	-0.0006		AVG Δ	0.0139

11.4 Pueblo Bonito

11.4.1 Central NS Wall

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2009					
Site Name			Pueblo Bonito	Local Date	31-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	Central (North/South) surveyed S to N: Theodolite adjacent to room 143, 1 meter from wall				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***3***	***37***	3.62	36.0603
Long	***107***	***57***	***42.4***	57.71	107.9618

Theodolite Observations

Feature Description	Central Wall			
	D	M	S	Decimal Conversion
Angle 1	***142***	***57***	***24***	142.9567
Angle 2	***144***	***23***	***36***	144.3933
Angle 3	***144***	***55***	***6***	144.9183
Angle 4	***144***	***56***	***13***	144.9369
Angle 5	***144***	***57***	***49***	144.9636
Angle 6	***145***	***5***	***56***	145.0989
Angle 7	***145***	***0***	***1***	145.0003
Angle 8	***145***	***1***	***55***	145.0319

Angle 9	***145***	***12***	***32***	145.2089
Angle 10	***145***	***9***	***24***	145.1567
Angle 11	***145***	***13***	***7***	145.2186
Angle 12	***145***	***5***	***1***	145.0836
Angle 13	***145***	***7***	***35***	145.1264
Angle 14	***145***	***7***	***56***	145.1322
Angle 15	***145***	***11***	***4***	145.1844
Angle 16	***145***	***4***	***33***	145.0758
Angle 17	***145***	***1***	***3***	145.0175
Angle 18	***144***	***52***	***51***	144.8808
Angle 19	***144***	***53***	***59***	144.8997
Angle 20	***144***	***55***	***0***	144.9167
Angle 21	***144***	***56***	***40***	144.9444
Angle 22	***144***	***55***	***40***	144.9278
Angle 23	***144***	***55***	***31***	144.9253
Angle 24	***144***	***55***	***48***	144.9300
Angle 25	***144***	***53***	***50***	144.8972
Angle 26	***144***	***51***	***55***	144.8653
Angle 27	***144***	***49***	***19***	144.8219
Angle 28	***144***	***50***	***0***	144.8333
Angle 29	***144***	***48***	***58***	144.8161
Angle 30	***144***	***51***	***39***	144.8608
Angle 31	***144***	***51***	***40***	144.8611
Angle 32	***144***	***52***	***12***	144.8700
Angle 33	***144***	***50***	***29***	144.8414
Angle 34	***144***	***52***	***22***	144.8728

Angle 35	144	51	27	144.8575
Angle 36	144	50	56	144.8489
Angle 37	144	48	0	144.8000
Angle 38	144	48	22	144.8061
Angle 39	144	48	15	144.8042
Angle 40	144	48	46	144.8128
MEAN Azimuth				144.8850
STD DEV				0.3426
Back Sight (a)	359	59	42	359.9950

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	17:05:36	252	59	2			109.1	15.3	108.8450	144.1389	144.1830	0.0293
Sun Az 2	17:08:06	253	37	33			109.7	15.3	109.4450	144.1808		
Sun Az 3	17:10:04	254	9	56			110.2	15.3	109.9450	144.2206		
Sun Az 4	17:11:52	254	38	12			110.7	15.3	110.4450	144.1917		
Sun Alt 1	17:06:41	30	26	25	59	52		15.3	59.6117	-0.0519	-0.0510	0.0017
Sun Alt 2	17:09:15	29	57	12	60	21.3		15.3	60.1000	-0.0533		
Sun Alt 3	17:10:52	29	38	36	60	39.7		15.3	60.4067	-0.0500		
Sun Alt 4	17:12:43	29	17	32	61	0.7		15.3	60.7567	-0.0489		
Back Sight (b)		359	59	44								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Wall Azimuth	Reciprocal Azimuth	Perpendicular Azimuth	Reciprocal Perpendicular Azimuth
0.7	180.7	90.7	270.7

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
17:05:36	***76***	***58***	-30.9951	***22***	***0.2***	59.6588			109.0597	109.0559	0.0038
17:06:41	***77***	***14.2***	-30.7251	***22***	***0.3***	59.8659	59.8658	0.0001	109.3390		
17:08:06	***77***	***35.5***	-30.3701	***22***	***0.3***	60.1363			109.7141	109.6978	0.0163
17:09:15	***77***	***52.7***	-30.0834	***22***	***0.3***	60.3543	60.3527	0.0016	110.0206		
17:10:04	***78***	***5***	-29.8784	***22***	***0.3***	60.5099			110.2418	110.2376	0.0043
17:10:52	***78***	***17***	-29.6784	***22***	***0.3***	60.6615	60.6627	-0.0012	110.4593		
17:11:52	***78***	***32***	-29.4284	***22***	***0.3***	60.8506			110.7334	110.7087	0.0248
17:12:43	***78***	***44.7***	-29.2168	***22***	***0.3***	61.0105	61.0138	-0.0033	110.9676		
							AVG Δ	-0.0007		AVG Δ	0.0123

11.4.2 South Wall, West Section

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2009					
Site Name			Pueblo Bonito	Local Date	31-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	West End of the South Wall surveyed E to W: Theodolite adjacent to room 142, 1 meter from wall				
Text Key: ***Input,*** Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***3***	***36.8***	3.61	36.0602
Long	***107***	***57***	***41.7***	57.70	107.9616

Theodolite Observations

Feature Description	Horizon Altitudes				
	D	M	S	Decimal Conversion	Alt
Horizon Alt: EAST	***272***	***36***	***35***	272.6097	2.6097
Horizon Alt: WEST	***87***	***55***	***28***	87.9244	2.0756
Feature Description	South Wall: West Section				
Angle 1	***53***	***20***	***1***	53.3336	
Angle 2	***53***	***13***	***27***	53.2242	
Angle 3	***53***	***12***	***23***	53.2064	
Angle 4	***53***	***19***	***46***	53.3294	
Angle 5	***53***	***17***	***54***	53.2983	
Angle 6	***53***	***19***	***39***	53.3275	
Angle 7	***53***	***26***	***43***	53.4453	
Angle 8	***53***	***21***	***1***	53.3503	
Angle 9	***53***	***22***	***8***	53.3689	

Angle 10	***53***	***27***	***22***	53.4561
Angle 11	***53***	***42***	***39***	53.7108
Angle 12	***53***	***42***	***2***	53.7006
Angle 13	***53***	***38***	***58***	53.6494
Angle 14	***53***	***37***	***35***	53.6264
Angle 15	***53***	***33***	***30***	53.5583
Angle 16	***53***	***29***	***18***	53.4883
Angle 17	***53***	***28***	***8***	53.4689
Angle 18	***53***	***26***	***1***	53.4336
Angle 19	***53***	***24***	***33***	53.4092
Angle 20	***53***	***27***	***40***	53.4611
Angle 21	***53***	***25***	***58***	53.4328
Angle 22	***53***	***24***	***44***	53.4122
Angle 23	***53***	***24***	***0***	53.4000
Angle 24	***53***	***23***	***6***	53.3850
Angle 25	***53***	***25***	***50***	53.4306
Angle 26	***53***	***25***	***29***	53.4247
Angle 27	***53***	***24***	***30***	53.4083
Angle 28	***53***	***24***	***50***	53.4139
Angle 29	***53***	***26***	***7***	53.4353
Angle 30	***53***	***28***	***8***	53.4689
Angle 31	***53***	***28***	***37***	53.4769
Angle 32	***53***	***28***	***49***	53.4803
Angle 33	***53***	***30***	***22***	53.5061
Angle 34	***53***	***30***	***51***	53.5142
Angle 35	***53***	***31***	***15***	53.5208

Angle 36	***53***	***32***	***50***	53.5472
Angle 37	***53***	***31***	***7***	53.5186
Angle 38	***53***	***29***	***33***	53.4925
Angle 39	***53***	***30***	***11***	53.5031
Angle 40	***53***	***28***	***5***	53.4681
Angle 41	***53***	***28***	***38***	53.4772
Angle 42	***53***	***28***	***15***	53.4708
Angle 43	***53***	***28***	***9***	53.4692
Angle 44	***53***	***28***	***25***	53.4736
Angle 45	***53***	***28***	***53***	53.4814
Angle 46	***53***	***28***	***45***	53.4792
Angle 47	***53***	***29***	***46***	53.4961
Angle 48	***53***	***32***	***43***	53.5453
Angle 49	***53***	***33***	***4***	53.5511
Angle 50	***53***	***32***	***53***	53.5481
Angle 51	***53***	***31***	***58***	53.5328
Angle 52	***53***	***32***	***27***	53.5408
Angle 53	***53***	***34***	***21***	53.5725
Angle 54	***53***	***33***	***8***	53.5522
Angle 55	***53***	***31***	***51***	53.5308
Angle 56	***53***	***32***	***35***	53.5431
Angle 57	***53***	***33***	***51***	53.5642
Angle 58	***53***	***34***	***17***	53.5714
Angle 59	***53***	***34***	***22***	53.5728
Angle 60	***53***	***35***	***39***	53.5942
Angle 61	***53***	***36***	***6***	53.6017
Angle 62	***53***	***36***	***51***	53.6142
MEAN Azimuth				53.4818
STD DEV				0.0982

Back Sight (a)	***0***	***0***	***11***	0.0031

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***15:56:55***	***238***	***5***	***0***			***95.1***	***14.9***	94.8517	143.2317	143.2683	0.0329
Sun Az 2	***15:58:46***	***238***	***24***	***8***			***95.4***	***14.9***	95.1517	143.2506		
Sun Az 3	***16:00:57***	***238***	***46***	***18***			***95.7***	***14.9***	95.4517	143.3200		
Sun Az 4	***16:03:01***	***239***	***7***	***22***			***96.1***	***14.9***	95.8517	143.2711		
Sun Alt 1	***15:57:57***	***43***	***59***	***50***	***46***	***17.9***		***14.9***	46.0500	-0.0472	-0.0443	0.0023
Sun Alt 2	***16:00:17***	***43***	***31***	***27***	***46***	***46***		***14.9***	46.5183	-0.0425		
Sun Alt 3	***16:01:33***	***43***	***16***	***6***	***47***	***1.3***		***14.9***	46.7733	-0.0417		
Sun Alt 4	***16:03:46***	***42***	***49***	***39***	***47***	***28.1***		***15.0***	47.2183	-0.0458		
Back Sight (b)		***0***	***0***	***13***								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Wall Azimuth	Reciprocal Azimuth	Perpendicular Azimuth	Reciprocal Perpendicular Azimuth	Delta from True Cardinal (ArcMin)
270.2	90.2	180.2	360.2	12.81

Equinox Sunset Alignment Assessment

Measured Horizon Azimuth (Deg)	Measured Horizon Altitude (Deg)	Nearest Sunset Date	Sunset AZ (deg)	Sunset Alt (deg)	Calendar Days from equinox
270.2	2.1	***03.23.2009***	***270.4***	***2.2***	2
		09.18.2009	***270.5***	***2.1***	3

Equinox Sunrise Alignment Assessment

Measured Horizon Azimuth (Deg)	Measured Horizon Altitude (Deg)	Nearest Sunrise Date	Sunrise AZ (deg)	Sunrise Alt (deg)	Calendar Days from equinox
90.2	2.6	03.23.2009	***90.2***	***2.6***	2
		09.18.2009	***90.2***	***2.7***	3

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
15:56:55	***59***	***47.9***	-48.1633	***21***	***59.8***	46.0903			95.0674	95.0633	0.0041
15:57:57	***60***	***3.3***	-47.9066	***21***	***59.8***	46.2970	46.2954	0.0015	95.2379		
15:58:46	***60***	***15.6***	-47.7016	***21***	***59.9***	46.4628			95.3725	95.3822	-0.0097
16:00:17	***60***	***38.3***	-47.3233	***21***	***59.9***	46.7672	46.7685	-0.0012	95.6263		
16:00:57	***60***	***48.3***	-47.1566	***21***	***59.9***	46.9013			95.7386	95.7517	-0.0131
16:01:33	***60***	***57.3***	-47.0066	***21***	***59.9***	47.0219	47.0243	-0.0024	95.8400		
16:03:01	***61***	***19.3***	-46.6399	***21***	***59.9***	47.3168			96.0890	96.1028	-0.0137
16:03:46	***61***	***30.6***	-46.4516	***21***	***59.9***	47.4681	47.4668	0.0013	96.2176		
							AVG Δ	-0.0002		AVG Δ	-0.0081

11.4.3 South Wall, East Section

Field Data Collection & Analysis: Munro - Chaco Survey May-June 2009					
Site Name			Pueblo Bonito	Local Date	30-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	East End of the South Wall surveyed W to E: Theodolite adjacent to room 159, 1 meter from wall				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***3***	***36.9***	3.62	36.0603
Long	***107***	***57***	***40.9***	57.68	107.9614

Theodolite Observations

Feature Description	Horizon Altitudes				
	D	M	S	Decimal Conversion	Alt
Horizon Alt: EAST	***87***	***9***	***40***	87.1611	2.8389
Horizon Alt: WEST	***272***	***54***	***31***	272.9086	2.9086
Feature Description	South Wall: West Section				
Angle 1	***179***	***26***	***1***	179.4336	
Angle 2	***179***	***38***	***30***	179.6417	
Angle 3	***179***	***35***	***38***	179.5939	
Angle 4	***180***	***1***	***20***	180.0222	
Angle 5	***180***	***15***	***27***	180.2575	
Angle 6	***180***	***5***	***16***	180.0878	
Angle 7	***178***	***57***	***6***	178.9517	
Angle 8	***178***	***36***	***18***	178.6050	
Angle 9	***178***	***31***	***47***	178.5297	

Angle 10	***178***	***30***	***18***	178.5050
Angle 11	***178***	***37***	***4***	178.6178
Angle 12	***178***	***34***	***37***	178.5769
Angle 13	***178***	***29***	***26***	178.4906
Angle 14	***178***	***28***	***5***	178.4681
Angle 15	***178***	***15***	***43***	178.2619
Angle 16	***178***	***10***	***49***	178.1803
Angle 17	***178***	***12***	***10***	178.2028
Angle 18	***178***	***10***	***45***	178.1792
Angle 19	***178***	***10***	***40***	178.1778
Angle 20	***178***	***13***	***9***	178.2192
Angle 21	***178***	***17***	***35***	178.2931
Angle 22	***178***	***17***	***26***	178.2906
Angle 23	***178***	***15***	***21***	178.2558
Angle 24	***178***	***10***	***42***	178.1783
Angle 25	***178***	***7***	***27***	178.1242
Angle 26	***178***	***7***	***8***	178.1189
Angle 27	***178***	***9***	***23***	178.1564
Angle 28	***178***	***7***	***12***	178.1200
Angle 29	***178***	***7***	***32***	178.1256
Angle 30	***178***	***8***	***2***	178.1339
Angle 31	***178***	***11***	***9***	178.1858
Angle 32	***178***	***13***	***27***	178.2242
Angle 33	***178***	***12***	***47***	178.2131
Angle 34	***178***	***10***	***48***	178.1800
Angle 35	***178***	***10***	***53***	178.1814

Angle 36	***178***	***11***	***0***	178.1833
Angle 37	***178***	***11***	***27***	178.1908
Angle 38	***178***	***13***	***14***	178.2206
Angle 39	***178***	***15***	***58***	178.2661
Angle 40	***178***	***15***	***38***	178.2606
Angle 41	***178***	***15***	***54***	178.2650
Angle 42	***178***	***16***	***27***	178.2742
Angle 43	***178***	***15***	***24***	178.2567
Angle 44	***178***	***13***	***33***	178.2258
Angle 45	***178***	***15***	***12***	178.2533
Angle 46	***178***	***15***	***23***	178.2564
Angle 47	***178***	***16***	***43***	178.2786
Angle 48	***178***	***16***	***46***	178.2794
Angle 49	***178***	***20***	***20***	178.3389
Angle 50	***178***	***17***	***58***	178.2994
Angle 51	***178***	***15***	***19***	178.2553
Angle 52	***178***	***17***	***1***	178.2836
Angle 53	***178***	***18***	***16***	178.3044
Angle 54	***178***	***17***	***25***	178.2903
Angle 55	***178***	***17***	***5***	178.2847
Angle 56	***178***	***16***	***24***	178.2733
Angle 57	***178***	***16***	***37***	178.2769
Angle 58	***178***	***15***	***33***	178.2592
Angle 59	***178***	***14***	***45***	178.2458
Angle 60	***178***	***13***	***35***	178.2264
Angle 61	***178***	***13***	***4***	178.2178
Angle 62	***178***	***13***	***19***	178.2219
MEAN Azimuth				178.4318
STD DEV				0.4905

Back Sight (a)	359	59	27	359.9908

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***17:11:49***	***203***	***12***	***18***			***111.0***	***15.3***	110.7450	92.4600	92.4641	0.0161
Sun Az 2	***17:15:21***	***204***	***11***	***17***			***112.0***	***15.3***	111.7450	92.4431		
Sun Az 3	***17:17:51***	***204***	***54***	***37***			***112.7***	***15.3***	112.4450	92.4653		
Sun Az 4	***17:19:56***	***205***	***31***	***59***			***113.3***	***15.3***	113.0450	92.4881		
Sun Alt 1	***17:14:24***	***29***	***1***	***40***	***61***	***16.4***		***15.3***	61.0183	-0.0461	-0.0478	0.0014
Sun Alt 2	***17:16:59***	***28***	***32***	***36***	***61***	***45.5***		***15.3***	61.5033	-0.0467		
Sun Alt 3	***17:19:06***	***28***	***9***	***9***	***62***	***9.1***		***15.3***	61.8967	-0.0492		
Sun Alt 4	***17:22:31***	***27***	***31***	***9***	***62***	***47.1***		***15.3***	62.5300	-0.0492		
Back Sight (b)		***359***	***59***	***11***								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Wall Azimuth	Reciprocal Azimuth	Perpendicular Azimuth	Reciprocal Perpendicular Azimuth	Degrees Off of Cardinal
86.0	266.0	176.0	356.0	4.0

Equinox Sunset Alignment Assessment

Measured Horizon Azimuth (Deg)	Measure d Horizon Altitude (Deg)	Nearest Sunset Date	Sunset AZ (deg)	Sunset Alt (deg)	Deg Off (AZ)	Calendar Days Off
266.0	2.9	***03.15.2009***	***266.0***	***2.8***	2.8	7
		09.26.2009	***266.0***	***2.9***	2.4	5
		03.21.2009	***268.8***	***3.0***		
		9.21.2009	***268.4***	***3.0***		

Equinox Sunrise Alignment Assessment

Measured Horizon Azimuth (Deg)	Measured Horizon Altitude (Deg)	Nearest Sunrise Date	Sunrise AZ (deg)	Sunrise Alt (deg)	Deg Off (AZ)	Calendar Days Off
86.0	2.8	***04.01.2009***	***86.1***	***2.9***	5.3	11
		09.10.2009	***86.0***	***2.9***	5.2	10
		03.21.2009	***91.3***	***2.7***		
		9.21.2009	***91.2***	***2.8***		

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
17:11:49	***78***	***33.4***	-29.4047	***21***	***51.8***	60.7864			110.9962	110.9959	0.0003
17:14:24	***79***	***12.2***	-28.7580	***21***	***51.8***	61.2732	61.2750	-0.0018	111.7208		
17:15:21	***79***	***26.4***	-28.5214	***21***	***51.8***	61.4508			111.9905	111.9790	0.0116
17:16:59	***79***	***50.9***	-28.1130	***21***	***51.8***	61.7564	61.7594	-0.0031	112.4618		
17:17:51	***80***	***3.9***	-27.8964	***21***	***51.8***	61.9181			112.7150	112.7012	0.0139
17:19:06	***80***	***22.7***	-27.5830	***21***	***51.8***	62.1514	62.1503	0.0011	113.0851		
17:19:56	***80***	***35.2***	-27.3747	***21***	***51.8***	62.3062			113.3338	113.3240	0.0098
17:22:31	***81***	***13.9***	-26.7297	***21***	***51.9***	62.7846	62.7836	0.0010	114.1144		
							AVG Δ	-0.0007		AVG Δ	0.0089

11.4.4 Great Kiva A

Field Data Collection & Analysis: Munro - Chaco Survey May 2009					
Site Name	Pueblo Bonito Kiva A			Local Date	3-Jun-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	Great Kiva A: Measurement of "line of symmetry" using on-floor and bench features as guide (see photo key)				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***3***	***37.9***	3.63	36.0605
Long	***107***	***57***	***41.8***	57.70	107.9616

Theodolite Observations

Feature Description	Angles to Kiva Features as marked in photo key: 4 readings per point							
	D	M	S	Decimal Conversion				
Angle 1A	***145***	***59***	***33***	145.9925				
Angle 1B	***145***	***59***	***56***	145.9989				
Angle 1C	***146***	***0***	***9***	146.0025				
Angle 1D	***145***	***59***	***54***	145.9983	Mean Angle	145.9981	Std Err	0.0021
Angle 2A	***159***	***28***	***58***	159.4828				
Angle 2B	***159***	***29***	***15***	159.4875				
Angle 2C	***159***	***29***	***14***	159.4872				
Angle 2D	***159***	***29***	***8***	159.4856	Mean Angle	159.4858	Std Err	0.0011
Angle 3A	***161***	***30***	***58***	161.5161				
Angle 3B	***161***	***31***	***6***	161.5183				

Angle 3C	***161***	***31***	***6***	161.5183				
Angle 3D	***161***	***31***	***6***	161.5183	Mean Angle	161.5178	Std Err	0.0006
Angle 4A	***172***	***33***	***12***	172.5533				
Angle 4B	***172***	***33***	***23***	172.5564				
Angle 4C	***172***	***33***	***25***	172.5569				
Angle 4D	***172***	***33***	***17***	172.5547	Mean Angle	172.5553	Std Err	0.0008
Angle 5A	***181***	***6***	***5***	181.1014				
Angle 5B	***181***	***5***	***52***	181.0978				
Angle 5C	***181***	***5***	***48***	181.0967				
Angle 5D	***181***	***5***	***53***	181.0981	Mean Angle	181.0985	Std Err	0.0010
Angle 6A	***193***	***53***	***6***	193.8850				
Angle 6B	***193***	***53***	***4***	193.8844				
Angle 6C	***193***	***53***	***3***	193.8842				
Angle 6D	***193***	***53***	***6***	193.8850	Mean Angle	193.8847	Std Err	0.0002
Angle 7A	***195***	***45***	***22***	195.7561				
Angle 7B	***195***	***45***	***15***	195.7542				
Angle 7C	***195***	***45***	***25***	195.7569				
Angle 7D	***195***	***45***	***32***	195.7589	Mean Angle	195.7565	Std Err	0.0010
Angle 8A	***211***	***24***	***39***	211.4108				
Angle 8B	***211***	***24***	***49***	211.4136				
Angle 8C	***211***	***24***	***42***	211.4117				
Angle 8D	***211***	***24***	***45***	211.4125	Mean Angle	211.4122	Std Err	0.0006
MEAN Angle				177.7136				
STD DEV				20.4974				
Back Sight (a)	***359***	***59***	***42***	359.9950				

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***14:18:59***	***76***	***49***	***58***			***80.6***	***13.9***	80.3683	-3.5356	-3.5531	0.0144
Sun Az 2	***14:20:28***	***77***	***1***	***29***			***80.8***	***13.9***	80.5683	-3.5436		
Sun Az 3	***14:21:52***	***77***	***12***	***26***			***81***	***13.9***	80.7683	-3.5611		
Sun Az 4	***14:23:16***	***77***	***23***	***40***			***81.2***	***14***	80.9667	-3.5722		
Sun Alt 1	***14:19:43***	***63***	***40***	***40***	***26***	***36.1***			26.3700	-0.0478	-0.0469	0.0021
Sun Alt 2	***14:21:14***	***63***	***22***	***36***	***26***	***54.3***			26.6733	-0.0500		
Sun Alt 3	***14:22:27***	***63***	***7***	***49***	***27***	***8.8***			26.9150	-0.0453		
Sun Alt 4	***14:23:32***	***62***	***54***	***53***	***27***	***21.8***			27.1300	-0.0447		
Back Sight (b)		***359***	***59***	***58***								
Operator		Andy Munro										

Line of Symmetry Azimuth

Mean Azimuth All Angles	Reciprocal Azimuth	Mean Azimuth Angles 4 & 5 Only
181.3	1.3	181.0

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
14:18:59	***35***	***12.6***	-72.7516	***22***	***20.7***	26.4549			80.6207	80.6176	0.0032
14:19:43	***35***	***23.6***	-72.5683	***22***	***20.7***	26.6011	26.6008	0.0003	80.7167		
14:20:28	***35***	***34.9***	-72.3799	***22***	***20.7***	26.7514			80.8152	80.8095	0.0057
14:21:14	***35***	***46.4***	-72.1883	***22***	***20.7***	26.9044	26.9019	0.0024	80.9156		
14:21:52	***35***	***55.9***	-72.0299	***22***	***20.7***	27.0308			80.9986	80.9920	0.0066
14:22:27	***36***	***4.6***	-71.8849	***22***	***20.8***	27.1474	27.1483	-0.0009	81.0730		
14:23:16	***36***	***16.9***	-71.6799	***22***	***20.8***	27.3111			81.1805	81.1809	-0.0004
14:23:32	***36***	***20.9***	-71.6133	***22***	***20.8***	27.3644	27.3656	-0.0011	81.2155		
							AVG Δ	0.0002		AVG Δ	0.0038

11.5 Talus Unit

11.5.1 West Horizon from SE Corner

Field Data Collection Form: Munro - Chaco Survey May/June 2008					
Site Name			Talus Unit	Date	6-Jun-08
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	West Horizon from SE corner of front E/W wall. 15 cm North of outer wall corner, 3 cm east.				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***3***	***37.8***	3.6300	36.0605
Long	***107***	***57***	***19.5***	57.3250	107.9554

Theodolite Observations

	Measurement 1		
	D	M	S
Horiz 1 Az	***158***	***8***	***56***
Horiz 1 Alt	***87***	***1***	***1***
Horiz 2 Az	***158***	***2***	***29***
Horiz 2 Alt	***87***	***5***	***36***
Horiz 3 Az	***157***	***56***	***7***
Horiz 3 Alt	***87***	***6***	***20***
Horiz 4 Az	***157***	***55***	***48***
Horiz 4 Alt	***87***	***14***	***3***
Backsight (a)	***0***	***0***	***5***

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	21:41:29	173	51	44			258.3	15.1	258.0483	-84.1861	-84.2190	0.0987
Sun Az 2	21:44:14	174	15	42			258.9	15.1	258.6483	-84.3867		
Sun Az 3	21:47:27	175	4	43			259.5	15.1	259.2483	-84.1697		
Sun Az 4	21:49:40	175	30	54			259.9	15.1	259.6483	-84.1333		
Sun Alt 1	21:52:15	37	5	37	52	41.6		15.1	52.9450	0.0386	0.0724	0.0711
Sun Alt 2	21:54:57	37	47	28	52	9.3		15.1	52.4067	0.1978		
Sun Alt 3	21:56:43	37	58	19	51	48.1		15.1	52.0533	0.0253		
Sun Alt 4	21:58:26	38	19	5	51	27.5		15.1	51.7100	0.0281		
Back Sight (b)		359	59	33								
Operator		Andy Munro										

Sunset Dates

	Horizon Az (deg)	Horizon Alt (deg)	Nearest Sunrise Dates
Horiz 1	242.4	3.0	N/A too far south
			N/A too far south
Horiz 2	242.3	2.9	N/A too far south
			N/A too far south
Horiz 3	242.2	2.9	N/A too far south
			N/A too far south
Horiz 4	242.1	2.8	N/A too far south

Spherical Trig Check of Sun Sights

D to R		R to D									
0.017453293		57.2957795									
UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
21:41:29	***145***	***39.9***	37.7096	***22***	***45.5***				258.3099	258.3328	-0.0229
21:52:15	***148***	***21.4***	40.4013	***22***	***45.6***		52.5823	0.1113	260.4443		
21:44:14	***146***	***21.2***	38.3979	***22***	***45.6***				258.8722	258.7323	0.1399
21:54:57	***149***	***1.9***	41.0763	***22***	***45.6***		51.8848	0.2703	260.9563		
21:47:27	***147***	***9.4***	39.2013	***22***	***45.6***				259.5125	259.5492	-0.0367
21:56:43	***149***	***28.4***	41.5179	***22***	***45.6***		51.7040	0.0983	261.2867		
21:49:40	***147***	***42.7***	39.7563	***22***	***45.6***				259.9470	259.9856	-0.0386
21:58:26	***149***	***54.2***	41.9479	***22***	***45.6***		51.3578	0.1007	261.6051		
							AVG Δ	0.1451		AVG Δ	0.0104

11.5.2 West Horizon from SW Corner

Field Data Collection Form: Munro - Chaco Survey May/June 2008					
Site Name			Talus Unit	Date	6-Jun-08
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	West Horizon from SW corner of front E/W wall.				
Text Key: *Input*, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***3***	***37.8***	3.6300	36.0605
Long	***107***	***57***	***21.2***	57.3533	107.9559

Theodolite Observations

	Measurement 1		
	D	M	S
Horiz 1 Az	***157***	***33***	***37***
Horiz 1 Alt	***86***	***57***	***5***
Horiz 2 Az	***157***	***27***	***39***
Horiz 2 Alt	***87***	***1***	***47***
Horiz 3 Az	***157***	***21***	***15***
Horiz 3 Alt	***87***	***2***	***47***
Horiz 4 Az	***157***	***21***	***7***
Horiz 4 Alt	***87***	***12***	***5***
Backsight (a)	***359***	***59***	***43***

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***22:45:49***	***184***	***37***	***27***			***268.9***	***14.7***	268.6550	-84.0308	-83.9226	0.0668
Sun Az 2	***22:48:35***	***185***	***12***	***21***			***269.3***	***14.7***	269.0550	-83.8492		
Sun Az 3	***22:50:13***	***185***	***26***	***32***			***269.6***	***14.7***	269.3550	-83.9128		
Sun Az 4	***22:51:39***	***185***	***39***	***27***			***269.8***	***14.7***	269.5550	-83.8975		
Sun Alt 1	***22:54:09***	***49***	***32***	***26***	***40***	***14.5***		***14.7***	40.4867	0.0272	0.0381	0.0179
Sun Alt 2	***22:56:01***	***49***	***56***	***27***	***39***	***52.1***		***14.7***	40.1133	0.0542		
Sun Alt 3	***22:57:31***	***50***	***13***	***8***	***39***	***34.0***		***14.7***	39.8117	0.0306		
Sun Alt 4	***22:58:37***	***50***	***27***	***2***	***39***	***20.8***		***14.6***	39.5900	0.0406		
Back Sight (b)		***359***	***59***	***43***								
Operator		Andy Munro										

Sunset Dates

	Horizon Az (deg)	Horizon Alt (deg)	Nearest Sunrise Dates
Horiz 1	241.5	3.0	N/A too far south
			N/A too far south
Horiz 2	241.4	3.0	N/A too far south
			N/A too far south
Horiz 3	241.3	3.0	N/A too far south
			N/A too far south
Horiz 4	241.3	2.8	N/A too far south

Spherical Trig Check of Sun Sights

D to R		R to D	
0.017453293		57.2957795	

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
22:45:49	***161***	***44.8***	53.7908	***22***	***45.8***	41.9215			269.3950	268.7917	0.6033
22:54:09	***163***	***49.8***	55.8741	***22***	***45.8***	40.2374	40.1763	0.0611	270.6212		
22:48:35	***162***	***26.3***	54.4824	***22***	***45.8***	41.3624			269.8056	269.3734	0.4322
22:56:01	***164***	***17.8***	56.3408	***22***	***45.8***	39.8602	39.7760	0.0841	270.8917		
22:50:13	***162***	***50.8***	54.8908	***22***	***45.8***	41.0323			270.0463	269.6098	0.4365
22:57:31	***164***	***40.3***	56.7158	***22***	***45.8***	39.5571	39.4980	0.0591	271.1081		
22:51:39	***163***	***12.3***	55.2491	***22***	***45.8***	40.7426			270.2566	269.8251	0.4315
22:58:37	***164***	***56.8***	56.9908	***22***	***45.9***	39.3356	39.2680	0.0676	271.2680		
							AVG Δ	0.0680		AVG Δ	0.4759

11.6 Chetro Ketl

11.6.1 North (Back) Wall

Field Data Collection & Analysis: Munro & Malville - Chaco Survey May/June 2008					
Site Name		Chetro Ketl	Date	31-May-08	
GPS Observations					
Text Key: ***Input***, Calculated Value					
GPS Device	Garmin GPS 72				
Feature Description	North Wall: westernmost exposed point				
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***3***	***37.6***	3.63	36.06
Long	***107***	***57***	***17.8***	57.30	107.95
Feature Description	North Wall: easternmost exposed point				
Lat	***36***	***3***	***38.9***	3.65	36.06
Long	***107***	***57***	***14***	57.23	107.95

Theodolite Observations

Feature Description	Horizon Altitudes			
	D	M	S	Decimal Conversion
Horizon Alt: EAST	***84***	***53***	***49***	84.8969
Horizon Alt: WEST	***273***	***7***	***2***	273.1172
Feature Description	South Wall: West Section			
Angle 1	***167***	***4***	***49***	167.0803
Angle 2	***166***	***38***	***9***	166.6358
Angle 3	***166***	***36***	***56***	166.6156
Angle 4	***166***	***27***	***54***	166.4650
Angle 5	***166***	***26***	***6***	166.4350

Angle 6	***166***	***28***	***35***	166.4764
Angle 7	***166***	***26***	***18***	166.4383
Angle 8	***166***	***21***	***10***	166.3528
Angle 9	***166***	***23***	***6***	166.3850
Angle 10	***166***	***15***	***16***	166.2544
Angle 11	***166***	***11***	***47***	166.1964
Angle 12	***166***	***10***	***14***	166.1706
Angle 13	***166***	***9***	***5***	166.1514
Angle 14	***166***	***4***	***41***	166.0781
Angle 15	***166***	***0***	***12***	166.0033
Angle 16	***166***	***11***	***40***	166.1944
Angle 17	***166***	***13***	***50***	166.2306
Angle 18	***166***	***15***	***49***	166.2636
Angle 19	***166***	***15***	***41***	166.2614
Angle 20	***166***	***13***	***51***	166.2308
Angle 21	***166***	***13***	***41***	166.2281
Angle 22	***166***	***13***	***4***	166.2178
Angle 23	***166***	***10***	***10***	166.1694
Angle 24	***166***	***7***	***54***	166.1317
Angle 25	***166***	***5***	***24***	166.0900
Angle 26	***166***	***2***	***19***	166.0386
Angle 27	***166***	***0***	***20***	166.0056
Angle 28	***166***	***1***	***53***	166.0314
Angle 29	***166***	***2***	***44***	166.0456
Angle 30	***166***	***1***	***56***	166.0322
Angle 31	***166***	***2***	***14***	166.0372

Angle 32	***166***	***1***	***58***	166.0328
Angle 33	***166***	***2***	***10***	166.0361
Angle 34	***166***	***3***	***9***	166.0525
Angle 35	***166***	***3***	***34***	166.0594
Angle 36	***166***	***2***	***46***	166.0461
Angle 37	***166***	***1***	***4***	166.0178
Angle 38	***165***	***56***	***29***	165.9414
Angle 39	***165***	***57***	***54***	165.9650
Angle 40	***166***	***58***	***27***	166.9742
Angle 41	***165***	***58***	***47***	165.9797
Angle 42	***165***	***57***	***56***	165.9656
Angle 43	***165***	***57***	***31***	165.9586
Angle 44	***165***	***56***	***53***	165.9481
Angle 45	***165***	***56***	***56***	165.9489
Angle 46	***166***	***1***	***37***	166.0269
Angle 47	***166***	***2***	***4***	166.0344
Angle 48	***166***	***2***	***17***	166.0381
Angle 49	***166***	***2***	***1***	166.0336
Angle 50	***166***	***1***	***24***	166.0233
Angle 51	***166***	***1***	***1***	166.0169
Angle 52	***166***	***0***	***27***	166.0075
Angle 53	***166***	***0***	***42***	166.0117
Angle 54	***166***	***0***	***33***	166.0092
Angle 55	***165***	***59***	***12***	165.9867
Angle 56	***165***	***58***	***55***	165.9819
Angle 57	***165***	***58***	***23***	165.9731
Angle 58	***165***	***59***	***24***	165.9900
Angle 59	***165***	***59***	***38***	165.9939
Angle 60	***165***	***49***	***50***	165.8306

Angle 61	***165***	***59***	***20***	165.9889
Angle 62	***165***	***57***	***55***	165.9653
Angle 63	***165***	***57***	***26***	165.9572
Angle 64	***165***	***56***	***56***	165.9489
Angle 65	***165***	***56***	***33***	165.9425
Angle 66	***165***	***55***	***1***	165.9169
Angle 67	***165***	***53***	***41***	165.8947
Angle 68	***165***	***53***	***37***	165.8936
Angle 69	***165***	***52***	***35***	165.8764
Angle 70	***165***	***52***	***35***	165.8764
Angle 71	***165***	***52***	***7***	165.8686
Angle 72	***165***	***52***	***45***	165.8792
Angle 73	***165***	***52***	***17***	165.8714
Angle 74	***165***	***51***	***12***	165.8533
Angle 75	***165***	***51***	***12***	165.8533
Angle 76	***165***	***50***	***53***	165.8481
Angle 77	***165***	***50***	***33***	165.8425
Angle 78	***165***	***50***	***33***	165.8425
Angle 79	***165***	***50***	***3***	165.8342
Angle 80	***165***	***49***	***16***	165.8211
Angle 81	***165***	***49***	***21***	165.8225
Angle 82	***165***	***49***	***7***	165.8186
Angle 83	***165***	***49***	***34***	165.8261
Angle 84	***165***	***50***	***34***	165.8428
Angle 85	***165***	***51***	***24***	165.8567
Angle 86	***165***	***50***	***47***	165.8464
Angle 87	***165***	***47***	***49***	165.7969
Angle 88	***165***	***47***	***26***	165.7906
Angle 89	***165***	***47***	***43***	165.7953

Angle 90	***165***	***46***	***53***	165.7814
Angle 91	***165***	***46***	***9***	165.7692
Angle 92	***165***	***45***	***53***	165.7647
Angle 93	***165***	***45***	***53***	165.7647
Angle 94	***165***	***50***	***24***	165.8400
Angle 95	***165***	***43***	***5***	165.7181
Angle 96	***165***	***43***	***37***	165.7269
Angle 97	***165***	***43***	***19***	165.7219
Angle 98	***165***	***43***	***3***	165.7175
Angle 99	***165***	***41***	***58***	165.6994
Angle 100	***165***	***41***	***57***	165.6992
Angle 101	***165***	***42***	***12***	165.7033
MEAN Azimuth				166.0189
STD DEV				0.2442
Back Sight (a)	***0***	***0***	***32***	0.0089

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***15:05:54***	***183***	***1***	***37***			***87.3***	***14.5***	87.0583	95.9686	95.8331	0.0821
Sun Az 2	***15:10:21***	***183***	***28***	***46***			***87.9***	***14.5***	87.6583	95.8211		
Sun Az 3	***15:12:17***	***183***	***44***	***53***			***88.2***	***14.6***	87.9567	95.7914		
Sun Az 4	***15:14:07***	***184***	***0***	***28***			***88.5***	***14.6***	88.2567	95.7511		
Sun Alt 1	***15:15:51***	***52***	***19***	***33***	***37***	***48.9***		***15.8***	37.5517	0.1225	0.0761	0.0730
Sun Alt 2	***15:17:34***	***52***	***9***	***7***	***38***	***9.7***		***15.8***	37.8983	-0.0503		
Sun Alt 3	***15:19:15***	***51***	***38***	***53***	***38***	***30.1***		***15.8***	38.2383	0.1136		
Sun Alt 4	***15:21:36***	***51***	***10***	***5***	***38***	***58.6***		***15.8***	38.7133	0.1186		
Back Sight (b)		***0***	***1***	***30***								
Operator		John Nickerson, Andy Munro, Kim Malville										

Wall Azimuth & Lunar Minor Standstill Analysis

Horizon Alt	Mean Measured Wall Azimuth	USNO Refraction and Parallax Correction Arcmin Jan 3 2015 @ 23:24 UTC	Corrected Horizon Alt	USNO Minor Standstill AZ @ 4.7 deg Alt	Difference - Corrected Calculated Az Minus Wall Az (Deg)	Diff / SD of Wall
5.1	70.2	26.0	4.7	70.9	0.7	2.9

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
15:05:54	***47***	***2.3***	-60.9166	***22***	***1.6***	35.8049			87.3188	87.3000	0.0188
15:10:21	***48***	***9.1***	-59.8033	***22***	***1.6***	36.7042			87.9470	87.9000	0.0470
15:12:17	***48***	***38.1***	-59.3199	***22***	***1.6***	37.0947			88.2217	88.2403	-0.0186
15:14:07	***49***	***5.5***	-58.8633	***22***	***1.6***	37.4637			88.4824	88.5000	-0.0176
15:15:51	***49***	***31.5***	-58.4299	***22***	***1.6***	37.8139	37.8614	-0.0475	88.7309		
15:17:34	***49***	***57.3***	-57.9999	***22***	***1.6***	38.1614	38.0353	0.1262	88.9786		
15:19:15	***50***	***22.5***	-57.5799	***22***	***1.7***	38.5017	38.5392	-0.0374	89.2197		
15:21:36	***50***	***57.8***	-56.9916	***22***	***1.7***	38.9773	39.0192	-0.0419	89.5620		
							AVG Δ	-0.0002		AVG Δ	0.0074

11.6.2 Great Kiva

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2009					
Site Name	Chetro Ketl Great Kiva			Date	3-Jun-09
GPS Observation	Garmin GPS 72				
Feature Description	Great Kiva: Measurement of "line of symmetry" using on-floor and bench features as guide (see photo key) Theodolite located at center of NW Stair opening outside of antechamber.				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***3***	***37.3***	3.62	36.0604
Long	***107***	***57***	***13.6***	57.23	107.9538

Theodolite Observations

Feature Description	Angles to Kiva Features as marked in photo key: 4 readings per point							
	D	M	S	Decimal Conversion				
Angle 1A	177	16	52	177.2811				
Angle 1B	177	17	46	177.2961				
Angle 1C	177	19	3	177.3175				
Angle 1D	177	18	53	177.3147	Mean Angle	177.3024	Std Err	0.0085
Angle 2A	162	11	7	162.1853				
Angle 2B	162	11	56	162.1989				
Angle 2C	162	11	34	162.1928				
Angle 2D	162	11	43	162.1953	Mean Angle	162.1931	Std Err	0.0029
Angle 3A	163	45	28	163.7578				
Angle 3B	163	46	50	163.7806				

Angle 3C	163	46	28	163.7744				
Angle 3D	163	46	45	163.7792	Mean Angle	163.7730	Std Err	0.0052
Angle 4A	176	29	53	176.4981				
Angle 4B	176	30	22	176.5061				
Angle 4C	176	29	40	176.4944				
Angle 4D	176	30	22	176.5061	Mean Angle	176.5012	Std Err	0.0029
Angle 5A	178	13	0	178.2167				
Angle 5B	178	13	15	178.2208				
Angle 5C	178	12	45	178.2125				
Angle 5D	178	13	19	178.2219	Mean Angle	178.2180	Std Err	0.0022
Angle 6A	189	48	25	189.8069				
Angle 6B	189	48	35	189.8097				
Angle 6C	189	47	47	189.7964				
Angle 6D	189	48	37	189.8103	Mean Angle	189.8058	Std Err	0.0032
Angle 7A	191	12	20	191.2056				
Angle 7B	191	12	18	191.2050				
Angle 7C	191	11	55	191.1986				
Angle 7D	191	12	27	191.2075	Mean Angle	191.2042	Std Err	0.0019
MEAN Angle				176.9997				
STD DEV				10.4319				
Back Sight (a)	0	0	37	0.0103				

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***13:00:26***	***83***	***16***	***13***			***70.3***	***11.0***	70.1167	13.1536	13.1224	0.0440
Sun Az 2	***13:01:42***	***83***	***26***	***20***			***70.5***	***11.1***	70.3150	13.1239		
Sun Az 3	***13:03:22***	***83***	***33***	***49***			***70.7***	***11.2***	70.5133	13.0503		
Sun Az 4	***13:04:12***	***83***	***46***	***31***			***70.8***	***11.2***	70.6133	13.1619		
Sun Alt 1	***13:01:01***	***79***	***0***	***50***	***11***	***13.8***		***11***	11.0467	-0.0606	-0.0622	0.0028
Sun Alt 2	***13:02:44***	***78***	***41***	***18***	***11***	***33.4***		***11.1***	11.3717	-0.0600		
Sun Alt 3	***13:03:47***	***78***	***29***	***28***	***11***	***45.4***		***11.2***	11.5700	-0.0611		
Sun Alt 4	***13:04:47***	***78***	***18***	***25***	***11***	***56.9***		***11.3***	11.7600	-0.0669		
Back Sight (b)		***0***	***0***	***14***								
Operator		Andy Munro										

Kiva Line of Symmetry Azimuth

Mean Azimuth	Reciprocal Azimuth
163.9	343.9

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
13:00:26	***15***	***33.8***	-92.3904	***22***	***22.1***	11.1180			70.3261	70.3312	-0.0051
13:01:01	***15***	***42.5***	-92.2454	***22***	***22.1***	11.2284	11.2316	-0.0032	70.4037		
13:01:42	***15***	***52.8***	-92.0738	***22***	***22.1***	11.3592			70.4955	70.5015	-0.0060
13:02:44	***16***	***8.3***	-91.8154	***22***	***22.1***	11.5562	11.5588	-0.0027	70.6335		
13:03:22	***16***	***17.8***	-91.6571	***22***	***22.2***	11.6779			70.7165	70.6278	0.0887
13:03:47	***16***	***24***	-91.5538	***22***	***22.2***	11.7567	11.7577	-0.0010	70.7717		
13:04:12	***16***	***30.3***	-91.4488	***22***	***22.2***	11.8369			70.8276	70.8395	-0.0119
13:04:47	***16***	***39***	-91.3038	***22***	***22.2***	11.9476	11.9435	0.0041	70.9049		
							AVG Δ	-0.0007		AVG Δ	0.0164

11.7 Casa Rinconada

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2008					
Site Name	Casa Rinconada			Local Date	7-Jun-08
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	Sightline to NA Azimuth: Theodolite Location is adjacent to west side of south alcove - 83 cm west of door opening, 245 cm south of alcove wall - location necessary to enable simultaneous views of : a) plumb bob suspended over west wall of south stair, b) west wall of north stair, and c) New Alto				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***3***	***16.7***	3.3	36.0546
Long	***107***	***57***	***36.9***	57.6	107.9603

Theodolite Observations

Feature Description	Sight line across CR stairs to NA			
	D	M	S	Decimal Conversion
Angle 1: plumb bob line aligned with west side of south stairway.	***190***	***35***	***27***	190.5908
Angle 2: bottom corner of the North stairs - west side of north stair	***191***	***24***	***1***	191.4003
Angle 3: bottom of top step, west side of north stair	***191***	***29***	***31***	191.4919
Angle 4: top of top step; west side of north stair	***191***	***29***	***52***	191.4978
Angle 5: New Alto westmost point visible	***191***	***28***	***43***	191.4786
Angle 6: New Alto eastmost point visible	***192***	***6***	***0***	192.1000
MEAN Angle (angles 1-5)				191.2919
STD DEV (angles 1-5)				0.3523
Back Sight (a)				0.0028

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***23:06:48***	***102***	***34***	***11***			***272.5***	14.6	272.2567	-169.6869	-169.7003	0.0157
Sun Az 2	***23:08:41***	***102***	***50***	***5***			***272.8***	14.6	272.5567	-169.7219		
Sun Az 3	***23:09:29***	***102***	***56***	***53***			***272.9***	14.6	272.6567	-169.7086		
Sun Az 4	***23:10:23***	***103***	***4***	***28***			***273.0***	14.5	272.7583	-169.6839		
Sun Alt 1	***23:11:56***	***53***	***2***	***34***	***36***	***44.0***		14.5	36.4917	0.4656	0.4660	0.0018
Sun Alt 2	***23:13:03***	***53***	***16***	***12***	***36***	***30.5***		14.5	36.2667	0.4633		
Sun Alt 3	***23:13:57***	***53***	***26***	***48***	***36***	***19.6***		14.5	36.0850	0.4683		
Sun Alt 4	***23:16:06***	***53***	***52***	***54***	***35***	***53.6***		14.5	35.6517	0.4667		
Back Sight (b)		***0***	***0***	***24***								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Azimuth	Angular Width of NA as Observed from PB
361.0	0.6214

Spherical Trig Check of Sun Sights

D to R		R to D									
0.017453293		57.2957795									
UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
23:06:48	***166***	***56.7***	58.9848	***22***	***51.4***	37.7685			272.5069	272.5134	-0.0065
23:11:56	***168***	***13.7***	60.2681	***22***	***51.4***	36.7323	36.7329	-0.0007	273.2228		
23:08:41	***167***	***24.9***	59.4548	***22***	***51.4***	37.3889			272.7700	272.7784	-0.0084
23:13:03	***168***	***30.4***	60.5464	***22***	***51.5***	36.5084	36.5057	0.0027	273.3788		
23:09:29	***167***	***36.9***	59.6548	***22***	***51.4***	37.2274			272.8817	272.8917	-0.0101
23:13:57	***168***	***43.9***	60.7714	***22***	***51.5***	36.3268	36.3290	-0.0022	273.5031		
23:10:23	***167***	***50.4***	59.8798	***22***	***51.4***	37.0457			273.0070	273.0165	-0.0094
23:16:06	***169***	***16.2***	61.3098	***22***	***51.5***	35.8925	35.8940	-0.0015	273.7998		
							AVG Δ	**-0.0004**		AVG Δ	**-0.0086**

11.8 New Alto

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2009					
Site Name	New Alto			***Date***	31-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	Southeast Corner of New Alto - Measured Azimuth of East Wall, as well as Azimuth to Casa Rinconada and Azimuth to Tsin Kletsin				
Text Key: ***Input,*** Calculated Value					
	DEG	MIN	SEC	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***4***	***11***	4.18	36.0697
Long	***107***	***57***	***34.7***	57.58	107.9596

Theodolite Observations

Feature Description	East Wall			
	D	M	S	Decimal Conversion
Angle 1	***159***	***47***	***16***	159.7878
Angle 2	***159***	***49***	***44***	159.8289
Angle 3	***159***	***37***	***27***	159.6242
Angle 4	***159***	***36***	***18***	159.6050
Angle 5	***159***	***27***	***37***	159.4603
Angle 6	***159***	***32***	***30***	159.5417
Angle 7	***159***	***37***	***12***	159.6200
Angle 8	***159***	***34***	***1***	159.5669
Angle 9	***159***	***33***	***11***	159.5531

Angle 10	***159***	***31***	***43***	159.5286
Angle 11	***159***	***33***	***33***	159.5592
Angle 12	***159***	***27***	***59***	159.4664
Angle 13	***159***	***30***	***0***	159.5000
MEAN Azimuth				159.5878
STD DEV				0.1065
Back Sight (a)				0.0033

Feature Description	Inter-Site Azimuths to Casa Rinconada													
	Measurement 1			Measurement 2			Measurement 3			Measurement 4			Mean	Std Err
	D	M	S	D	M	S	D	M	S	D	M	S		
East Side Rinconada Angle 14	***349***	***5***	***37***	***349***	***5***	***33***	***349***	***5***	***48***	***349***	***5***	***42***	349.0944	0.0009
West Side of North Door Angle 15	***349***	***18***	***30***	***349***	***18***	***33***	***349***	***18***	***37***	***349***	***18***	***40***	349.3097	0.0006

Feature Description	Inter-Site Azimuths to Tsin Kletsin													
	Measurement 1			Measurement 2			Measurement 3			Measurement 4			Mean	Std Err
	D	M	S	D	M	S	D	M	S	D	M	S		
West End Tsin Kletsin Angle 16	***344***	***40***	***27***	***344***	***40***	***20***	***344***	***40***	***27***	***344***	***40***	***29***	344.6738	0.0005
East End Tsin Kletsin Angle 17	***345***	***14***	***51***	***345***	***14***	***50***	***345***	***14***	***48***	***345***	***14***	***49***	345.2471	0.0002

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***13:24:29***	***241***	***9***	***45***			***73.0***	***12.4***	72.7933	168.3692	167.7186	0.3759
Sun Az 2	***13:26:11***	***241***	***23***	***27***			***74.1***	***12.5***	73.8917	167.4992		
Sun Az 3	***13:28:18***	***241***	***40***	***19***			***74.4***	***12.5***	74.1917	167.4803		
Sun Az 4	***13:30:10***	***241***	***54***	***57***			***74.6***	***12.6***	74.3900	167.5258		
Sun Alt 1	***13:25:28***	***74***	***27***	***33***	***15***	***48.4***		***12.4***	15.6000	-0.0592	-0.0569	0.0031
Sun Alt 2	***13:26:41***	***74***	***13***	***24***	***16***	***2.6***		***12.5***	15.8350	-0.0583		
Sun Alt 3	***13:29:11***	***73***	***44***	***19***	***16***	***31.8***		***12.6***	16.3200	-0.0586		
Sun Alt 4	***13:31:27***	***73***	***17***	***30***	***16***	***58.3***		***12.7***	16.7600	-0.0517		
Back Sight (b)		***0***	***0***	***16***								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Wall Azimuth	Reciprocal Azimuth	Perpendicular Azimuth	Reciprocal Perpendicular Azimuth
351.9	171.9	261.9	81.9

Inter-Site Azimuths to Casa Rinconada

AZ 14	181.4
AZ 15	181.6
Mean	181.5

Inter-Site Azimuths to Tsin Kletsin

AZ 16	177.0
AZ 17	177.5
Mean	177.2

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
13:24:29	***21***	***41.6***	-86.2663	***21***	***59***	15.6171			73.9032	73.6506	0.2527
13:25:28	***21***	***56.3***	-86.0213	***21***	***59***	15.8074	15.8044	0.0030	74.0321		
13:26:11	***22***	***7.1***	-85.8413	***21***	***59***	15.9473			74.1267	73.8806	0.2462
13:26:41	***22***	***14.6***	-85.7163	***21***	***59***	16.0445	16.0419	0.0026	74.1924		
13:28:18	***22***	***38.8***	-85.3130	***21***	***59***	16.3584			74.4043	74.1617	0.2426
13:29:11	***22***	***52.1***	-85.0913	***21***	***59***	16.5310	16.5283	0.0027	74.5206		
13:30:10	***23***	***6.8***	-84.8463	***21***	***59***	16.7219			74.6491	74.4072	0.2419
13:31:27	***23***	***26.1***	-84.5246	***21***	***59***	16.9727	16.9769	-0.0042	74.8178		
							AVG Δ	0.0010		AVG Δ	0.2458

11.9 Pueblo Alto

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2009					
Site Name	Pueblo Alto			Local Date	1-Jun-08
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	North Exterior Wall - west most exposed point along wall (west to east)				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***4***	***12.5***	4.2	36.0701
Long	***107***	***57***	***28.3***	57.5	107.9579

Theodolite Observations

Feature Description	NE Horizon Altitude: Perpendicular to Wall			
	D	M	S	Decimal Conversion
Angle 1	***161***	***27***	***54***	161.4650
Angle 2	***162***	***12***	***17***	162.2047
Angle 3	***162***	***15***	***6***	162.2517
Angle 4	***161***	***45***	***24***	161.7567
Angle 5	***162***	***12***	***36***	162.2100
Angle 6	***162***	***1***	***50***	162.0306
Angle 7	***161***	***49***	***29***	161.8247

Angle 8	***161***	***25***	***58***	161.4328
Angle 9	***161***	***13***	***31***	161.2253
Angle 10	***161***	***7***	***41***	161.1281
Angle 11	***161***	***6***	***12***	161.1033
Angle 12	***161***	***14***	***44***	161.2456
Angle 13	***161***	***14***	***59***	161.2497
Angle 14	***161***	***16***	***7***	161.2686
Angle 15	***161***	***15***	***38***	161.2606
Angle 16	***161***	***17***	***24***	161.2900
Angle 17	***161***	***17***	***53***	161.2981
Angle 18	***161***	***12***	***48***	161.2133
Angle 19	***161***	***18***	***50***	161.3139
Angle 20	***161***	***25***	***51***	161.4308
Angle 21	***161***	***19***	***50***	161.3306
Angle 22	***161***	***16***	***45***	161.2792
Angle 23	***161***	***15***	***26***	161.2572
Angle 24	***161***	***9***	***24***	161.1567
Angle 25	***161***	***42***	***20***	161.7056
Angle 26	***161***	***38***	***26***	161.6406
Angle 27	***161***	***35***	***55***	161.5986
Angle 28	***161***	***46***	***2***	161.7672
Angle 29	***162***	***4***	***4***	162.0678
Angle 30	***162***	***4***	***59***	162.0831
Angle 31	***162***	***4***	***33***	162.0758
Angle 32	***162***	***3***	***19***	162.0553
Angle 33	***162***	***3***	***31***	162.0586

MEAN Angle				161.5842
STD DEV				0.3741
Back Sight (a)	***0***	***0***	***11***	0.0031

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***20:56:13***	***320***	***29***	***31***			***246.5***	***15.3***	246.7550	73.7369	**73.7978**	0.0703
Sun Az 2	***20:58:12***	***321***	***5***	***42***			***247.1***	***15.3***	247.3550	73.7400		
Sun Az 3	***21:00:53***	***322***	***3***	***56***			***247.9***	***15.3***	248.1550	73.9106		
Sun Az 4	***21:03:07***	***322***	***33***	***32***			***248.5***	***15.3***	248.7550	73.8039		
Sun Alt 1	***21:05:19***	***28***	***20***	***43***	***61***	***28.2***		***15.3***	61.7250	-0.0703	-0.0753	0.0038
Sun Alt 2	***21:07:17***	***28***	***43***	***16***	***61***	***5.9***		***15.3***	61.3533	-0.0744		
Sun Alt 3	***21:09:55***	***29***	***13***	***21***	***60***	***35.9***		***15.3***	60.8533	-0.0758		
Sun Alt 4	***21:11:00***	***29***	***26***	***3***	***60***	***23.5***		***15.3***	60.6467	-0.0808		
Back Sight (b)		***359***	***59***	***56***								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Wall Azimuth	Reciprocal Azimuth	Perpendicular Azimuth	Reciprocal Perpendicular Azimuth
87.8	267.8	-2.2	177.8

Spherical Trig Check of Sun Sights

D to R		R to D									
0.017453293		57.2957795									
UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated AZ	Observed AZ	Δ
20:56:13	***134***	***31.7***	26.5705	***22***	***19.1***	63.1715			246.4686	246.4391	0.0295
20:58:12	***135***	***1.4***	27.0655	***22***	***19.1***	62.8038			247.0696	247.0422	0.0274
21:00:53	***135***	***41.7***	27.7371	***22***	***19.1***	62.3023			247.8656	248.0127	-0.1471
21:03:07	***136***	***15.2***	28.2955	***22***	***19.1***	61.8834			248.5109	248.5060	0.0049
21:05:19	***136***	***48.2***	28.8455	***22***	***19.1***	61.4688	61.4751	-0.0063	249.1327		
21:07:17	***137***	***17.7***	29.3371	***22***	***19.1***	61.0968	61.0992	-0.0024	249.6774		
21:09:55	***137***	***57.2***	29.9955	***22***	***19.1***	60.5967	60.5978	-0.0012	250.3907		
21:11:00	***138***	***13.4***	30.2655	***22***	***19.1***	60.3909	60.3862	0.0047	250.6782		
							AVG Δ	-0.0013		AVG Δ	-0.0213

11.10 Tsin Kletsin

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2009					
Site Name	Tsin Kletsin			Date	28-May-09
GPS *Observation*	Garmin GPS 72				
Feature Description	East end of North Wall; as well as alignments to New Alto and Pueblo Alto				
Text Key: *Input*, Calculated Value					
	DEG	MIN	SEC	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***2***	***11.3***	2.19	36.0365
Long	***107***	***57***	***27.3***	57.46	107.9576

Theodolite Observations

Feature Description	North Wall: East Section			
	D	M	S	Decimal Conversion
Angle 1	***204***	***54***	***57***	204.9158
Angle 2	***205***	***1***	***47***	205.0297
Angle 3	***204***	***58***	***20***	204.9722
Angle 4	***205***	***1***	***11***	205.0197
Angle 5	***204***	***55***	***44***	204.9289
Angle 6	***205***	***0***	***47***	205.0131
Angle 7	***205***	***3***	***20***	205.0556
Angle 8	***204***	***56***	***7***	204.9353
Angle 9	***204***	***52***	***46***	204.8794
Angle 10	***204***	***53***	***46***	204.8961
Angle 11	***204***	***59***	***47***	204.9964
Angle 12	***204***	***56***	***58***	204.9494

MEAN Azimuth				204.9660
STD DEV				0.0545
Back Sight (a)	***0***	***0***	***9***	0.0025

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***14:02:08***	***15***	***23***	***16***			***79.3***	***13.5***	79.1	-63.7	-63.8	0.1
Sun Az 2	***14:03:55***	***15***	***27***	***34***			***79.5***	***13.6***	79.3	-63.8		
Sun Az 3	***14:06:29***	***15***	***47***	***50***			***79.8***	***13.6***	79.6	-63.8		
Sun Az 4	***14:09:54***	***16***	***14***	***38***			***80.3***	***13.7***	80.1	-63.8		
Sun Alt 1	***14:03:14***	***67***	***11***	***57***	***23***	***4.4***		***13.6***	22.8	0.0	0.0	0.0
Sun Alt 2	***14:04:55***	***66***	***51***	***47***	***23***	***24.5***		***13.6***	23.2	0.0		
Sun Alt 3	***14:07:58***	***66***	***16***	***16***	***24***	***0.9***		***13.7***	23.8	-0.1		
Sun Alt 4	***14:10:20***	***65***	***47***	***12***	***24***	***29.2***		***13.7***	24.3	0.0		
Back Sight (b)		***0***	***0***	***12***								
Operator	Andy Munro											

Wall Azimuth

Mean AZ	Recip AZ	Perp AZ	Recip Perp AZ
268.7	88.7	358.7	178.7

Theodolite Observations: Inter-Site Azimuths to New Alto

	Measurement 1			Measurement 2			Measurement 3			Measurement 4			Mean	Std Err
	D	M	S	D	M	S	D	M	S	D	M	S		
West End 1 AZ	***292***	***59***	***19***	***292***	***59***	***10***	***292***	***59***	***15***	***292***	***59***	***6***	292.9868	0.0008
West End 1 Alt	***91***	***9***	***4***	***91***	***8***	***29***	***91***	***9***	***10***	***91***	***9***	***27***	91.1507	0.0034
East End 2 AZ	***293***	***15***	***55***	***293***	***15***	***50***	***293***	***15***	***50***	***293***	***15***	***51***	293.2643	0.0003
East End 2 Alt	***91***	***8***	***39***	***91***	***8***	***29***	***91***	***8***	***44***	***91***	***8***	***50***	91.1446	0.0012
West Az 1													356.8	
East Az 2													357.0	
Mean													356.9	

Theodolite Observations: Inter-Site Azimuths to Pueblo Alto

	Measurement 1			Measurement 2			Measurement 3			Measurement 4			Mean	Std Err
	D	M	S	D	M	S		D	M	S	D	M	S	
West End 3 AZ	***295***	***34***	***44***	***295***	***34***	***52***	***295***	***34***	***54***	***295***	***34***	***48***	295.5804	0.0006
West End 3 Alt	***91***	***8***	***31***	***91***	***8***	***1***	***91***	***8***	***46***	***91***	***8***	***50***	91.1422	0.0031
East End 4 AZ	***297***	***21***	***14***	***297***	***21***	***24***	***297***	***21***	***22***	***297***	***21***	***27***	297.3560	0.0008
East End 4 Alt	***91***	***7***	***34***	***91***	***7***	***7***	***91***	***7***	***10***	***91***	***7***	***42***	91.1231	0.0024
West Az 1													359.4	
East Az 2													361.1	
Mean													360.2	

Spherical Trig Check of Sun Sights

D to R		R to D										
0.017453293		57.2957795										
UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
14:02:08	***31***	***12.5***	-76.7493	***21***	***32.5***	22.8559			79.2747	79.3890	-0.1143
14:03:14	***31***	***29***	-76.4743	***21***	***32.5***	23.0745	23.0758	-0.0013	79.4191		
14:03:55	***31***	***39.3***	-76.3026	***21***	***32.5***	23.2110			79.5092	79.4624	0.0469
14:04:55	***31***	***54.3***	-76.0526	***21***	***32.5***	23.4098	23.4119	-0.0022	79.6405		
14:06:29	***32***	***17.8***	-75.6609	***21***	***32.5***	23.7214			79.8464	79.8001	0.0462
14:07:58	***32***	***40***	-75.2909	***21***	***32.5***	24.0160	24.0056	0.0105	80.0409		
14:09:54	***33***	***9***	-74.8076	***21***	***32.5***	24.4012			80.2953	80.2485	0.0468
14:10:20	***33***	***15.5***	-74.6993	***21***	***32.5***	24.4875	24.4900	-0.0025	80.3523		
							AVG Δ	0.0011		AVG Δ	0.0064

11.11 Hungo Pavi

Field Data Collection & Analysis: Munro & Malville - Chaco Survey May/June 2008					
Site Name			Hungo Pavi	Date	8-Jun-08
GPS Observations					
Text Key: ***Input***, Calculated Value					
GPS Device	Garmin GPS 72				
Feature Description	North Wall measured from the west end - theodolite 1 meter north of wall end				
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***3***	***1.5***	3.0	36.050
Long	***107***	***55***	***49.1***	55.8	107.930

Theodolite Observations

Feature Description	Horizon Altitudes			
	D	M	S	Decimal Conversion
Horizon Alt: EAST	***86***	***4***	***41***	86.0781
Horizon Alt: WEST	***271***	***26***	***42***	271.4450
Feature Description	South Wall: West Section			
Angle 1	***173***	***52***	***50***	173.8806
Angle 2	***173***	***7***	***59***	173.1331
Angle 3	***172***	***11***	***18***	172.1883
Angle 4	***171***	***54***	***14***	171.9039
Angle 5	***171***	***31***	***29***	171.5247
Angle 6	***171***	***40***	***21***	171.6725
Angle 7	***171***	***38***	***55***	171.6486
Angle 8	***171***	***45***	***39***	171.7608
Angle 9	***171***	***50***	***31***	171.8419

Angle 10	***171***	***57***	***51***	171.9642
Angle 11	***171***	***57***	***5***	171.9514
Angle 12	***171***	***57***	***45***	171.9625
Angle 13	***171***	***59***	***46***	171.9961
Angle 14	***172***	***2***	***27***	172.0408
Angle 15	***172***	***8***	***55***	172.1486
Angle 16	***172***	***14***	***12***	172.2367
Angle 17	***172***	***14***	***9***	172.2358
Angle 18	***172***	***20***	***24***	172.3400
Angle 19	***172***	***35***	***19***	172.5886
Angle 20	***172***	***48***	***4***	172.8011
Angle 21	***172***	***58***	***53***	172.9814
Angle 22	***172***	***53***	***46***	172.8961
Angle 23	***172***	***41***	***36***	172.6933
Angle 24	***172***	***26***	***58***	172.4494
Angle 25	***172***	***15***	***37***	172.2603
Angle 26	***172***	***10***	***11***	172.1697
Angle 27	***172***	***5***	***34***	172.0928
Angle 28	***171***	***58***	***28***	171.9744
Angle 29	***171***	***49***	***33***	171.8258
Angle 30	***171***	***38***	***47***	171.6464
Angle 31	***171***	***25***	***53***	171.4314
Angle 32	***171***	***15***	***56***	171.2656
Angle 33	***171***	***12***	***21***	171.2058
Angle 34	***171***	***11***	***46***	171.1961
Angle 35	***171***	***7***	***40***	171.1278

Angle 36	***171***	***9***	***1***	171.1503
Angle 37	***171***	***11***	***0***	171.1833
Angle 38	***171***	***6***	***26***	171.1072
Angle 39	***171***	***21***	***10***	171.3528
Angle 40	***171***	***17***	***14***	171.2872
Angle 41	***171***	***18***	***9***	171.3025
Angle 42	***171***	***15***	***5***	171.2514
Angle 43	***171***	***14***	***23***	171.2397
Angle 44	***171***	***12***	***41***	171.2114
Angle 45	***171***	***9***	***33***	171.1592
Angle 46	***171***	***10***	***5***	171.1681
Angle 47	***171***	***11***	***6***	171.1850
Angle 48	***171***	***12***	***54***	171.2150
Angle 49	***171***	***13***	***3***	171.2175
Angle 50	***171***	***13***	***42***	171.2283
Angle 51	***171***	***14***	***5***	171.2347
Angle 52	***171***	***16***	***14***	171.2706
Angle 53	***171***	***18***	***33***	171.3092
Angle 54	***171***	***20***	***23***	171.3397
Angle 55	***171***	***22***	***50***	171.3806
Angle 56	***171***	***22***	***50***	171.3806
Angle 57	***171***	***21***	***5***	171.3514
Angle 58	***171***	***21***	***10***	171.3528
Angle 59	***171***	***19***	***4***	171.3178
Angle 60	***171***	***17***	***2***	171.2839
Angle 61	***171***	***14***	***7***	171.2353
Angle 62	***171***	***9***	***18***	171.1550
Angle 63	***171***	***5***	***48***	171.0967
Angle 64	***171***	***2***	***4***	171.0344

Angle 65	***171***	***0***	***21***	171.0058
Angle 66	***170***	***57***	***51***	170.9642
Angle 67	***170***	***57***	***50***	170.9639
Angle 68	***170***	***59***	***46***	170.9961
Angle 69	***171***	***1***	***11***	171.0197
Angle 70	***171***	***4***	***0***	171.0667
Angle 71	***171***	***4***	***45***	171.0792
Angle 72	***171***	***5***	***49***	171.0969
Angle 73	***171***	***6***	***38***	171.1106
Angle 74	***171***	***6***	***48***	171.1133
Angle 75	***171***	***7***	***25***	171.1236
Angle 76	***171***	***6***	***2***	171.1006
Angle 77	***171***	***6***	***3***	171.1008
Angle 78	***171***	***5***	***47***	171.0964
Angle 79	***171***	***4***	***45***	171.0792
Angle 80	***171***	***3***	***7***	171.0519
Angle 81	***171***	***1***	***6***	171.0183
Angle 82	***171***	***0***	***53***	171.0147
Angle 83	***171***	***0***	***25***	171.0069
Angle 84	***170***	***58***	***59***	170.9831
Angle 85	***170***	***55***	***48***	170.9300
MEAN Azimuth				171.5407
STD DEV				0.5990
Back Sight (a)	***359***	***59***	***37***	359.9936

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***23:40:29***	***352***	***58***	***59***			***277.0***	***14.2***	276.7633	76.2197	76.1302	0.0727
Sun Az 2	***23:42:22***	***353***	***12***	***57***			***277.3***	***14.2***	277.0633	76.1525		
Sun Az 3	***23:42:56***	***353***	***17***	***39***			***277.4***	***14.2***	277.1633	76.1308		
Sun Az 4	***23:43:37***	***353***	***22***	***52***			***277.4***	***14.2***	277.3633	76.0178		
Sun Alt 1	***23:45:22***	***59***	***42***	***27***	***29***	***54.1***		***14.1***	30.1367	0.1558	0.1603	0.0035
Sun Alt 2	***23:45:55***	***59***	***48***	***54***	***29***	***47.5***		***14.1***	30.0267	0.1583		
Sun Alt 3	***23:46:51***	***59***	***59***	***52***	***29***	***36.3***		***14.1***	29.8400	0.1622		
Sun Alt 4	***23:47:24***	***60***	***6***	***18***	***29***	***29.7***		***14.1***	29.7300	0.1650		
Back Sight (b)		***359***	***59***	***24***								
Operator		Andy Munro										

Wall Azimuth & Equinox Sunrise Analysis

Mean Measured Wall Azimuth	East Horizon Alt on Wall Az	Equinox Sunrise Az 9.22.2009	Equinox Sunrise Alt 9.22.2009	Next Aligned Sunrise Date	Δ Days from Equinox
95.4	3.9	92.5	3.8	9.28.2009	6

Spherical Trig Check of Sun Sights

D to R		R to D									
0.017453293		57.2957795									
UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
23:40:29	***175***	***24.7***	67.4814	***22***	***46***	30.8808			277.0306	277.0895	-0.0589
23:45:22	***176***	***38.0***	68.7030	***22***	***46***	29.9012	29.8972	0.0041	277.6754		
23:42:22	***175***	***53.0***	67.9530	***22***	***46***	30.5024			277.2800	277.3223	-0.0423
23:45:55	***176***	***46.2***	68.8397	***22***	***46***	29.7917	29.7897	0.0021	277.7473		
23:42:56	***176***	***1.5***	68.0947	***22***	***46***	30.3888			277.3548	277.4006	-0.0458
23:46:51	***177***	***0.2***	69.0730	***22***	***46***	29.6048	29.6069	-0.0021	277.8700		
23:43:37	***176***	***11.7***	68.2647	***22***	***46***	30.2525			277.4445	277.4876	-0.0431
23:47:24	***177***	***8.5***	69.2114	***22***	***46***	29.4940	29.4997	-0.0056	277.9427		
							AVG Δ	-0.0004		AVG Δ	-0.0475

11.12 Una Vida

Field Data Collection & Analysis: Munro - Chaco Survey Dec 2008					
Site Name			Una Vida	Local Date	18-Dec-08
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	North Wall at East End - surveyed from high spot (west to east) along wall				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***2***	***1***	2.0	36.0336
Long	***107***	***54***	***42.7***	54.7	107.9119

Theodolite Observations

Feature Description	NE Horizon Altitude: Perpendicular to Wall			
	D	M	S	Decimal Conversion
Horizon Alt:	***45***	***10***	***0***	45.1667
Feature Description	South Wall: West Section			
	D	M	S	Decimal Conversion
Angle 1	***136***	***1***	***56***	136.0322
Angle 2	***136***	***17***	***59***	136.2997
Angle 3	***135***	***8***	***36***	135.1433
Angle 4	***135***	***15***	***9***	135.2525
Angle 5	***135***	***18***	***4***	135.3011
Angle 6	***135***	***16***	***1***	135.2669
Angle 7	***135***	***20***	***31***	135.3419

Angle 8	***135***	***17***	***1***	135.2836
Angle 9	***135***	***13***	***11***	135.2197
Angle 10	***135***	***10***	***35***	135.1764
Angle 11	***135***	***9***	***57***	135.1658
Angle 12	***135***	***8***	***11***	135.1364
MEAN Angle				135.3850
STD DEV				0.3589
Back Sight (a)	***359***	***59***	***46***	359.9961

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***22:11:06***	***213***	***12***	***14***			***223.2***	***13.1***	222.9817	-9.7778	-9.7669	0.0268
Sun Az 2	***22:13:30***	***213***	***39***	***45***			***223.6***	***13.0***	223.3833	-9.7208		
Sun Az 3	***22:15:16***	***214***	***0***	***14***			***224.0***	***12.9***	223.7850	-9.7811		
Sun Az 4	***22:16:51***	***214***	***17***	***50***			***224.3***	***12.9***	224.0850	-9.7878		
Sun Alt 1	***22:18:41***	***74***	***33***	***27***	***15***	***30.9***		***12.8***	15.7283	-0.2858	-0.2681	0.0108
Sun Alt 2	***22:21:15***	***74***	***54***	***5***	***15***	***8.9***		***12.8***	15.3617	-0.2631		
Sun Alt 3	***22:21:55***	***75***	***0***	***5***	***15***	***3.2***		***12.7***	15.2650	-0.2664		
Sun Alt 4	***22:22:32***	***75***	***4***	***49***	***14***	***57.9***		***12.7***	15.1767	-0.2569		
Back Sight (b)		***359***	***59***	***53***								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Wall Azimuth	Perpendicular Azimuth
145.2	55.2

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated AZ	Observed AZ	Δ
22:11:06	***153***	***31.7***	45.6165	***-23***	***-24.8***	16.5772			223.1782	223.1891	-0.0109
22:13:30	***154***	***7.7***	46.2165	***-23***	***-24.8***	16.2438			223.6350	223.6460	-0.0110
22:15:16	***154***	***34.1***	46.6565	***-23***	***-24.8***	15.9975			223.9681	223.9858	-0.0177
22:16:51	***154***	***57.9***	47.0531	***-23***	***-24.8***	15.7742			224.2669	224.2791	-0.0122
22:18:41	***155***	***25.4***	47.5115	***-23***	***-24.8***	15.5147	15.4989	0.0158	223.1782	223.1891	-0.0109
22:21:15	***156***	***3.9***	48.1531	***-23***	***-24.8***	15.1488	15.1550	-0.0062	223.6350	223.6460	-0.0110
22:21:55	***156***	***13.9***	48.3198	***-23***	***-24.8***	15.0532	15.0533	-0.0001	223.9681	223.9858	-0.0177
22:22:32	***156***	***23.1***	48.4731	***-23***	***-24.8***	14.9651	14.9744	-0.0093	224.2669	224.2791	-0.0122
							AVG Δ	0.0000		AVG Δ	-0.0129

11.13 Headquarters Site A

Field Data Collection Form: Munro - Chaco Survey Dec 2009					
Site Name	Headquarters Site A			Date	20-Dec-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	East & West Horizons from stake adjacent to and SW of Kiva Depression				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***Redacted under the terms of the NPS/BLM Permits. Data to be archived with NPS.***				
Long					

Theodolite Observations

	Measurement 1			Measurement 2			Measurement 3			Measurement 4			Mean	Std Err
	D	M	S	D	M	S	D	M	S	D	M	S		
EHoriz 1 Az	***218***	***9***	***21***	***218***	***9***	***6***	***218***	***9***	***12***	***218***	***9***	***26***	218.1545	0.0012
EHoriz 1 Alt	***81***	***43***	***31***	***81***	***44***	***12***	***81***	***43***	***54***	***81***	***43***	***41***	81.7304	0.0025
EHoriz 2 Az	***217***	***20***	***22***	***217***	***20***	***29***	***217***	***20***	***24***	***217***	***20***	***42***	217.3415	0.0012
EHoriz 2 Alt	***77***	***48***	***36***	***77***	***48***	***37***	***77***	***48***	***53***	***77***	***48***	***46***	77.8119	0.0011
EHoriz 3 Az	***213***	***2***	***58***	***213***	***2***	***44***	***213***	***3***	***7***	***213***	***3***	***14***	213.0502	0.0018
EHoriz 3 Alt	***78***	***12***	***51***	***78***	***12***	***45***	***78***	***12***	***57***	***78***	***12***	***53***	78.2143	0.0007
EHoriz 4 Az	***208***	***46***	***35***	***208***	***46***	***26***	***208***	***46***	***58***	***208***	***47***	***1***	208.7792	0.0024
EHoriz 4 Alt	***77***	***34***	***41***	***77***	***34***	***34***	***77***	***35***	***0***	***77***	***34***	***56***	77.5799	0.0017
EHoriz 5 Az	***206***	***12***	***40***	***206***	***12***	***50***	***206***	***12***	***45***	***206***	***13***	***11***	206.2143	0.0019
EHoriz 5 Alt	***77***	***43***	***22***	***77***	***43***	***5***	***77***	***43***	***24***	***77***	***43***	***28***	77.7222	0.0014
EHoriz 6 Az	***203***	***24***	***57***	***203***	***24***	***58***	***203***	***25***	***2***	***203***	***25***	***29***	203.4185	0.0021
EHoriz 6 Alt	***77***	***46***	***32***	***77***	***46***	***27***	***77***	***46***	***31***	***77***	***46***	***34***	77.7753	0.0004
EHoriz 7 Az	***199***	***39***	***6***	***199***	***39***	***27***	***199***	***39***	***16***	***199***	***39***	***29***	199.6554	0.0015

EHoriz 7 Alt	***78***	***19***	***50***	***78***	***20***	***8***	***78***	***20***	***6***	***78***	***20***	***16***	78.3347	0.0015
EHoriz 8 Az	***191***	***54***	***0***	***191***	***54***	***1***	***191***	***53***	***50***	***191***	***54***	***16***	191.9005	0.0015
EHoriz 8 Alt	***78***	***59***	***18***	***78***	***59***	***29***	***78***	***59***	***31***	***78***	***59***	***27***	78.9906	0.0008
EHoriz 9 Az	***188***	***18***	***15***	***188***	***18***	***19***	***188***	***18***	***6***	***188***	***18***	***27***	188.3047	0.0012
EHoriz 9 Alt	***79***	***36***	***14***	***79***	***36***	***12***	***79***	***36***	***3***	***79***	***35***	***56***	79.6017	0.0012
EHoriz 10 Az	***184***	***53***	***32***	***184***	***53***	***49***	***184***	***53***	***20***	***184***	***53***	***34***	184.8927	0.0017
EHoriz 10 Alt	***79***	***30***	***4***	***79***	***30***	***11***	***79***	***30***	***27***	***79***	***29***	***57***	79.5027	0.0018
EHoriz 11 Az	***181***	***22***	***35***	***181***	***23***	***12***	***181***	***22***	***58***	***181***	***22***	***57***	181.3821	0.0021
EHoriz 11 Alt	***79***	***34***	***15***	***79***	***34***	***6***	***79***	***34***	***9***	***79***	***34***	***36***	79.5713	0.0019
EHoriz 12 Az	***153***	***21***	***35***	***153***	***21***	***26***	***153***	***21***	***51***	***153***	***21***	***40***	153.3606	0.0014
EHoriz 12 Alt	***81***	***6***	***14***	***81***	***6***	***13***	***81***	***6***	***9***	***81***	***6***	***3***	81.1027	0.0007
WHoriz 13 Az	***19***	***10***	***18***										19.1717	n/a
WHoriz 13 Alt	***75***	***1***	***47***										75.0297	n/a
WHoriz 14 Az	***17***	***7***	***15***										17.1208	n/a
WHoriz 14 Alt	***75***	***24***	***56***										75.4156	n/a
WHoriz 15 Az	***8***	***47***	***6***										8.7850	n/a
WHoriz 15 Alt	***76***	***8***	***20***										76.1389	n/a
WHoriz 16 Az	***3***	***59***	***58***										3.9994	n/a
WHoriz 16 Alt	***76***	***47***	***16***										76.7878	n/a
WHoriz 17 Az	***1***	***29***	***53***										1.4981	n/a
WHoriz 17 Alt	***85***	***25***	***9***										85.4192	n/a
WHoriz 18 Az	***355***	***15***	***12***										355.2533	n/a
WHoriz 18 Alt	***87***	***41***	***15***										87.6875	n/a
WHoriz 19 Az	***353***	***18***	***34***										353.3094	n/a
WHoriz 19 Alt	***87***	***59***	***37***										87.9936	n/a
WHoriz 20 Az	***349***	***4***	***42***										349.0783	n/a
WHoriz 20 Alt	***87***	***55***	***56***										87.9322	n/a
WHoriz 21 Az	***342***	***53***	***12***										342.8867	n/a
WHoriz 21 Alt	***87***	***57***	***53***										87.9647	n/a
WHoriz 22 Az	***334***	***1***	***31***										334.0253	n/a

West Horizon Data Points (# 13 - # 22) were only taken once due to time constraints. Therefore no standard error can be calculated for these ten (10) points and forecasted dates are preliminary.

	D	M	S		
WHoriz 22 Alt	89	13	27	89.2242	n/a
Backsight (a)	359	59	57		

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	17:45:38	249	47	38			158.3	14.5	158.0583	91.7356	91.7231	0.0095
Sun Az 2	17:48:27	250	28	45			159.0	14.5	158.7583	91.7208		
Sun Az 3	17:50:59	251	11	6			159.7	14.5	159.4583	91.7267		
Sun Az 4	17:52:29	251	28	4			160.0	14.5	159.7583	91.7094		
Sun Alt 1	17:47:51	61	48	12	27	29.3		14.5	27.2467	-0.9500	-0.9231	0.3719
Sun Alt 2	17:50:10	61	38	1	27	39.3		14.5	27.4133	-0.9531		
Sun Alt 3	17:51:50	61	38	1	27	46.3		14.5	27.5300	-0.8364		
Sun Alt 4	17:53:43	61	23	14	27	54.1		14.5	27.6600	-0.9528		
Back Sight (b)		359	59	33								
Operator		Andy Munro										

Sunrise Dates

	Horizon Az (deg)	Horizon Alt (deg)	Nearest Sunrise Dates	Sunrise/set Az (deg)	Sunrise/set Alt (deg)
EHoriz 1	126.4	8.3	***12.20.2009***	***126.9***	***8.3***
			Notch photo confirmed prior to survey		
EHoriz 2	125.6	12.2	***11.19.2009***	***125.4***	***12.2***
			1.22.2009	***125.4***	***12.1***
EHoriz 3	121.3	11.8	***11.08.2009***	***121.1***	***11.9***
			2.01.2009	***121.2***	***11.8***
EHoriz 4	117.1	12.4	***10.28.2009***	***116.8***	***12.5***
			2.12.2009	***117.1***	***12.4***
EHoriz 5	114.5	12.3	***10.23.2009***	***114.3***	***12.2***
			2.18.2009	***114.2***	***12.4***
EHoriz 6	111.7	12.2	***10.17.2009***	***111.4***	***12.3***
			2.23.2009	***111.6***	***12.2***
EHoriz 7	107.9	11.7	***10.10.2009***	***107.5***	***11.8***
			3.02.2009	***107.6***	***11.6***
EHoriz 8	100.2	11.0	***09.26.2009***	***100.0***	***11.1***
			3.16.2009	***100.0***	***11.0***
EHoriz 9	96.6	10.4	***9.20.2009***	***96.4***	***10.4***
			3.22.2009	***96.5***	***10.4***
EHoriz 10	93.2	10.5	***9.13.2009***	***93.1***	***10.4***
			3.29.2009	***93.1***	***10.4***
EHoriz 11	89.7	10.4	***9.05.2009***	***89.3***	***10.4***
			4.05.2009	***89.7***	***10.4***
EHoriz 12	61.6	8.9	*n/a*	*Too Far North*	
			n/a	*Too Far North*	
WHoriz 13	287.4	15.0	***7.07.2009***	***287.1***	***15.1***
			6.04.2009	***287.2***	***15.0***
WHoriz 14	285.4	14.6	***7.18.2009***	***285.4***	***14.6***

			5.23.2009	***285.3***	***14.7***
WHoriz 15	277.1	13.9	***8.16.2009***	***276.7***	***13.9***
			4.25.2008	***276.8***	***13.8***
WHoriz 16	272.3	13.2	***8.28.2009***	***272.2***	***13.1***
			4.13.2009	***272.1***	***13.2***
WHoriz 17	269.8	4.6	***9.16.2009***	***269.6***	***4.6***
			3.25.2009	***269.5***	***4.6***
WHoriz 18	263.5	2.3	***10.03.2009***	***263.2***	***2.3***
			3.09.2009	***263.4***	***2.3***
WHoriz 19	261.6	2.0	***10.07.2009***	***261.4***	***2.1***
			3.04.2009	***261.2***	***2.0***
WHoriz 20	257.4	2.1	***10.16.2009***	***257.3***	***2.1***
			2.24.2009	***257.4***	***2.1***
WHoriz 21	251.2	2.0	***10.30.2009***	***251.1***	***2.1***
			2.09.2009	***250.8***	***2.0***
WHoriz 22	242.3	0.8	***12.01.2009***	***242.2***	***0.8***
			1.09.2009	***242.2***	***0.8***

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated AZ	Observed AZ	Δ
17:45:38	***86***	***57.8***	-20.9424	***-23***	***-26.1***	27.3249			158.3378	158.3124	0.0253
17:47:51	***87***	***31***	-20.3891	***-23***	***-26.1***	27.4881	27.4858	0.0022	158.8793		
17:48:27	***87***	***40***	-20.2391	***-23***	***-26.1***	27.5316			159.0265	158.9977	0.0288
17:50:10	***88***	***5.7***	-19.8107	***-23***	***-26.1***	27.6544	27.6556	-0.0011	159.4477		
17:50:59	***88***	***18***	-19.6057	***-23***	***-26.1***	27.7124			159.6498	159.7035	-0.0537
17:51:50	***88***	***30.7***	-19.3941	***-23***	***-26.1***	27.7716	27.7733	-0.0017	159.8588		
17:52:29	***88***	***40.5***	-19.2307	***-23***	***-26.1***	27.8169			160.0203	159.9863	0.0339
17:53:43	***88***	***59***	-18.9224	***-23***	***-26.1***	27.9015	27.9019	-0.0005	160.3256		
							AVG Δ	-0.0003		AVG Δ	0.0086

11.14 29SJ 913

Field Data Collection Form: Munro - Chaco Survey Dec 2009					
Site Name	29SJ 913			Date	19-Dec-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	Horizon Survey of potential calendrical station. added to survey at request of NPS Staff, who guided us to the site. Theodolite positioned 3.8 m in front of the rock containing dual spirals. Survey of two points (1, 2) on east horizon, and 6 (3 through 8) west horizon points on Fajada Butte.				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***Redacted under the terms of the NPS/BLM Permits. Data to be archived with NPS.***				
Long					

Theodolite Observations

	Measurement 1			Measurement 2			Measurement 3			Measurement 4			Mean	Std Err
	D	M	S	D	M	S	D	M	S	D	M	S		
Horiz 1 Az	***15***	***3***	***0***	***15***	***2***	***55***	***15***	***2***	***53***	***15***	***2***	***50***	15.0485	0.0006
Horiz 1 Alt	***89***	***25***	***40***	***89***	***25***	***29***	***89***	***25***	***39***	***89***	***25***	***20***	89.4256	0.0013
Horiz 2 Az	***18***	***8***	***27***	***18***	***7***	***57***	***18***	***8***	***7***	***18***	***8***	***3***	18.1357	0.0018
Horiz 2 Alt	***89***	***28***	***13***	***89***	***28***	***13***	***89***	***28***	***5***	***89***	***28***	***37***	89.4714	0.0019
Horiz 3 Az	***139***	***45***	***41***	***139***	***45***	***38***	***139***	***45***	***28***	***139***	***45***	***29***	139.7594	0.0009
Horiz 3 Alt	***89***	***28***	***37***	***89***	***28***	***43***	***89***	***28***	***27***	***89***	***28***	***40***	89.4769	0.0010
Horiz 4 Az	***140***	***30***	***40***	***140***	***30***	***39***	***140***	***30***	***33***	***140***	***30***	***41***	140.5106	0.0005
Horiz 4 Alt	***88***	***52***	***25***	***88***	***52***	***31***	***88***	***52***	***44***	***88***	***52***	***46***	88.8768	0.0014

Horiz 5 Az	***140***	***18***	***50***	***140***	***18***	***46***	***140***	***18***	***51***	***140***	***18***	***55***	140.3140	0.0005
Horiz 5 Alt	***88***	***20***	***30***	***88***	***20***	***29***	***88***	***20***	***35***	***88***	***20***	***37***	88.3424	0.0005
Horiz 6 Az	***141***	***7***	***54***	***141***	***7***	***43***	***141***	***7***	***51***	***141***	***7***	***51***	141.1305	0.0007
Horiz 6 Alt	***88***	***7***	***35***	***88***	***7***	***39***	***88***	***7***	***33***	***88***	***7***	***39***	88.1268	0.0004
Horiz 7 Az	***141***	***28***	***31***	***141***	***28***	***26***	***141***	***28***	***32***	***141***	***28***	***29***	141.4749	0.0004
Horiz 7 Alt	***88***	***17***	***49***	***88***	***17***	***51***	***88***	***17***	***51***	***88***	***17***	***43***	88.2968	0.0005
Horiz 8 Az	***143***	***14***	***32***	***143***	***14***	***49***	***143***	***14***	***56***	***143***	***14***	***47***	143.2461	0.0014
Horiz 8 Alt	***88***	***8***	***16***	***88***	***8***	***21***	***88***	***8***	***19***	***88***	***8***	***20***	88.1386	0.0003
Backsight (a)	***0***	***0***	***27***											

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***21:26:42***	***116***	***22***	***17***			***214.1***	***14***	213.8667	-97.4953	-97.4642	0.0965
Sun Az 2	***21:27:57***	***116***	***37***	***58***			***214.4***	***13.9***	214.1683	-97.5356		
Sun Az 3	***21:28:26***	***116***	***44***	***29***			***214.5***	***13.9***	214.2683	-97.5269		
Sun Az 4	***21:29:11***	***117***	***4***	***9***			***214.6***	***13.9***	214.3683	-97.2992		
Sun Alt 1	***21:30:20***	***67***	***56***	***32***	***21***	***47.9***		***13.9***	22.0300	-0.0278	-0.0294	0.0119
Sun Alt 2	***21:31:29***	***68***	***4***	***24***	***21***	***39.9***		***13.9***	21.8967	-0.0300		
Sun Alt 3	***21:32:48***	***68***	***13***	***46***	***21***	***30.7***		***13.9***	21.7433	-0.0272		
Sun Alt 4	***21:33:47***	***68***	***20***	***21***	***21***	***23.8***		***13.9***	21.6283	-0.0325		
Back Sight (b)		***359***	***59***	***47***								
Operator		Andy Munro										

Sunrise Dates

	Horizon Az (deg)	Horizon Alt (deg)	Nearest Sunrise Dates	Sunrise Az (deg)	Sunrise Alt (deg)
Horiz 1	112.5	0.6	***1.28.2009***	***112.6***	***0.6***
			11.13.2009	***112.6***	***0.5***
Horiz 2	115.6	0.5	***1.18.2009***	***115.6***	***0.5***
			11.23.2009	***115.6***	***0.5***
			Nearest Sunset Dates	Sunrise Az (deg)	Sunrise Alt (deg)
Horiz 3	237.2	0.5	N/A: point is too far south		
Horiz 4	238.0	1.1			
Horiz 5	237.8	1.7			
Horiz 6	238.6	1.9			
Horiz 7	238.9	1.7			
Horiz 8	240.7	1.9	***1.07.2009***	***240.8***	***1.9***
			12.4.2009	***240.7***	***1.8***

Spherical Trig Check of Sun Sights

D to R		R to D									
0.017453293		57.2957795									
UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated AZ	Observed AZ	Δ
21:26:42	***142***	***20.1***	34.4495	***-23***	***-25.5***	22.2143			214.1023	214.0690	0.0333
21:30:20	***143***	***14.5***	35.3561	***-23***	***-25.5***	21.7991	21.7967	0.0023	214.8798		
21:27:57	***142***	***38.8***	34.7611	***-23***	***-25.5***	22.0725			214.3704	214.3287	0.0417
21:31:29	***143***	***31.8***	35.6445	***-23***	***-25.5***	21.6653	21.6656	-0.0003	215.1256		
21:28:26	***142***	***46.1***	34.8828	***-23***	***-25.5***	22.0169			214.4748	214.4373	0.0375
21:32:48	***143***	***51.5***	35.9728	***-23***	***-25.5***	21.5120	21.5095	0.0025	215.4045		
21:29:11	***142***	***57.3***	35.0695	***-23***	***-25.5***	21.9312			214.6348	214.7651	-0.1303
21:33:47	***144***	***6.3***	36.2195	***-23***	***-25.5***	21.3961	21.3998	-0.0036	215.6134		
							AVG Δ	0.0002		AVG Δ	-0.0044

11.15 Shabik' eshchee

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2009					
Site Name			Sha bik ischee Pithouse B Deflector	Local Date	27-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	Deflector surveyed E to N: Theodolite at east end of deflector, 2 m from deflector				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***Redacted under the terms of the NPS/BLM Permits. Data to be archived with NPS***				
Long					

Theodolite Observations

Feature Description	Deflector			
	D	M	S	Decimal Conversion
Angle 1	***160***	***31***	***4***	160.5178
Angle 2	***159***	***53***	***43***	159.8953
Angle 3	***160***	***17***	***26***	160.2906
Angle 4	***160***	***23***	***16***	160.3878
Angle 5	***160***	***58***	***18***	160.9717
MEAN Azimuth				160.4126
STD DEV				0.3484
Back Sight (a)	***359***	***59***	***42***	359.9950

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***14:31:03***	***353***	***42***	***12***			***83.3***	***14.1***	83.0650	270.6383	270.5989	0.0231
Sun Az 2	***14:32:49***	***353***	***56***	***51***			***83.6***	***14.1***	83.3650	270.5825		
Sun Az 3	***14:34:17***	***354***	***8***	***53***			***83.8***	***14.1***	83.5650	270.5831		
Sun Az 4	***14:36:35***	***354***	***27***	***18***			***84.1***	***14.2***	83.8633	270.5917		
Sun Alt 1	***14:32:02***	***61***	***25***	***25***	***28***	***51.5***		***14.1***	28.6233	-0.0469	-0.0424	0.0032
Sun Alt 2	***14:33:32***	***61***	***7***	***7***	***29***	***9.6***		***14.1***	28.9250	-0.0436		
Sun Alt 3	***14:35:04***	***60***	***48***	***20***	***29***	***28.1***		***14.1***	29.2333	-0.0389		
Sun Alt 4	***14:38:27***	***60***	***7***	***42***	***30***	***8.9***		***14.2***	29.9117	-0.0400		
Back Sight (b)		***0***	***0***	***14***								
Operator		Andy Munro										

Deflector Azimuth

Mean Measured Deflector Azimuth	Reciprocal Azimuth	Perpendicular Azimuth	Front facing Axis of Symmetry
249.8	69.8	339.8	159.8

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
14:31:03	***38***	***28.1***	-69.3821	***21***	***23***	28.6600			83.3178	83.3394	-0.0217
14:32:02	***38***	***42.9***	-69.1354	***21***	***23***	28.8581	28.8538	0.0044	83.4502		
14:32:49	***38***	***54.6***	-68.9404	***21***	***23***	29.0149			83.5550	83.5836	-0.0286
14:33:32	***39***	***5.4***	-68.7604	***21***	***23***	29.1595	29.1588	0.0008	83.6518		
14:34:17	***39***	***16.6***	-68.5738	***21***	***23***	29.3096			83.7523	83.7842	-0.0319
14:35:04	***39***	***28.3***	-68.3788	***21***	***23***	29.4664	29.4718	-0.0054	83.8574		
14:36:35	***39***	***51.1***	-67.9988	***21***	***23***	29.7721			84.0624	84.0928	-0.0303
14:38:27	***40***	***19.1***	-67.5321	***21***	***23***	30.1476	30.1507	-0.0031	84.3148		
							AVG Δ	-0.0008		AVG Δ	-0.0281

11.16 29SJ 2538/2539

Field Data Collection Form: Munro - Chaco Survey May/June 2009					
Site Name	29SJ 2539			Date	26-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	Proposed sunwatching boulder, 19 m upslope from Shelter, 19 m downslope from hand prints at 29SJ 2538				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***Redacted under the terms of the NPS/BLM Permits. Data to be archived with NPS***				
Long					

Theodolite Observations

	Measurement 1			Measurement 2			Measurement 3			Measurement 4			Mean	Std Err
	D	M	S	D	M	S	D	M	S	D	M	S		
Horiz 1 Az	***214***	***34***	***17***	***214***	***34***	***23***	***214***	***34***	***20***	***214***	***34***	***15***	214.5719	0.0005
Horiz 1 Alt	***87***	***13***	***37***	***87***	***14***	***9***	***87***	***14***	***11***	***87***	***14***	***10***	87.2338	0.0023
Horiz 2 Az	***230***	***43***	***38***	***230***	***43***	***53***	***230***	***43***	***44***	***230***	***43***	***45***	230.7292	0.0009
Horiz 2 Alt	***88***	***10***	***59***	***88***	***10***	***59***	***88***	***10***	***43***	***88***	***10***	***8***	88.1784	0.0033
Horiz 3 Az	***234***	***35***	***22***	***234***	***35***	***24***	***234***	***35***	***21***	***234***	***35***	***22***	234.5895	0.0002
Horiz 3 Alt	***88***	***33***	***33***	***88***	***33***	***40***	***88***	***33***	***45***	***88***	***33***	***52***	88.5618	0.0011
Horiz 4 Az	***242***	***7***	***27***	***242***	***7***	***30***	***242***	***7***	***27***	***242***	***7***	***25***	242.1242	0.0003
Horiz 4 Alt	***88***	***51***	***3***	***88***	***50***	***44***	***88***	***51***	***2***	***88***	***51***	***8***	88.8498	0.0015
Horiz 5 Az	***247***	***46***	***16***	***247***	***46***	***29***	***247***	***46***	***23***	***247***	***46***	***29***	247.7734	0.0009
Horiz 5 Alt	***89***	***15***	***37***	***89***	***15***	***50***	***89***	***15***	***54***	***89***	***15***	***43***	89.2628	0.0010
Horiz 6 Az	***256***	***38***	***25***	***256***	***38***	***24***	***256***	***38***	***43***	***256***	***38***	***31***	256.6419	0.0012
Horiz 6 Alt	***89***	***6***	***31***	***89***	***6***	***9***	***89***	***6***	***14***	***89***	***6***	***11***	89.1045	0.0014
Backsight (a)	***359***	***59***	***50***											

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***15:08:14***	***224***	***19***	***22***			***88.6***	***14.5***	88.3583	135.9644	135.7948	0.0984
Sun Az 2	***15:10:39***	***224***	***28***	***44***			***89***	***14.6***	88.7567	135.7222		
Sun Az 3	***15:12:13***	***224***	***42***	***12***			***89.2***	***14.6***	88.9567	135.7467		
Sun Az 4	***15:13:33***	***224***	***54***	***9***			***89.4***	***14.6***	89.1567	135.7458		
Sun Alt 1	***15:09:52***	***53***	***52***	***9***	***36***	***25.8***		***14.5***	36.1883	0.0575	0.0515	0.0208
Sun Alt 2	***15:11:18***	***53***	***34***	***26***	***36***	***43.2***		***14.6***	36.4767	0.0506		
Sun Alt 3	***15:12:57***	***53***	***14***	***19***	***37***	***3.2***		***14.6***	36.8100	0.0486		
Sun Alt 4	***15:15:01***	***52***	***49***	***16***	***37***	***28.3***		***14.6***	37.2283	0.0494		
Back Sight (b)		***0***	***0***	***11***								
Operator		Andy Munro										

Sunrise Dates

	Horizon Az (deg)	Horizon Alt (deg)	Nearest Sunrise Dates	Sunrise Az (deg)	Sunrise Alt (deg)
Horiz 1	78.8	2.8	***4.17.2008***	***78.6***	***2.8***
			8.25.2009	***78.7***	***2.6***
Horiz 2	94.9	1.8	***3.12.2008***	***94.8***	***1.8***
			9.30.2008	***94.8***	***1.7***
Horiz 3	98.8	1.4	***3.3.2008***	***98.8***	***1.3***
			10.09.2008	***98.9***	***1.4***
Horiz 4	106.3	1.2	***2.15.2008***	***106.4***	***1.1***
			10.26.2008	***106.3***	***1.2***
Horiz 5	112.0	0.7	***3.31.2008***	***112.0***	***0.7***
			11.10.2008	***111.8***	***0.7***
Horiz 6	120.8	0.9	***12.21.2008***	***119.9***	***0.9***

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated AZ	Observed AZ	Δ
15:08:14	***47***	***47.1***	-60.0652	***21***	***13.2***	36.0926			88.6347	88.7697	-0.1349
15:09:52	***48***	***12.1***	-59.6485	***21***	***13.3***	36.4304	36.4240	0.0064	88.8726		
15:10:39	***48***	***23.8***	-59.4535	***21***	***13.3***	36.5881			88.9850	88.9274	0.0576
15:11:18	***48***	***33.6***	-59.2902	***21***	***13.3***	36.7202	36.7210	-0.0008	89.0794		
15:12:13	***48***	***47.3***	-59.0619	***21***	***13.3***	36.9049			89.2116	89.1519	0.0597
15:12:57	***48***	***58.3***	-58.8785	***21***	***13.3***	37.0531	37.0563	-0.0031	89.3180		
15:13:33	***49***	***7.3***	-58.7285	***21***	***13.3***	37.1745			89.4051	89.3510	0.0541
15:15:01	***49***	***29.3***	-58.3619	***21***	***13.3***	37.4710	37.4738	-0.0027	89.6188		
							AVG Δ	-0.0001		AVG Δ	0.0091

11.17 Pierre's Acropolis Unit B

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2008					
Site Name			Pierre's Acropolis	Local Date	3-Jun-08
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	Theodolite set at SE corner of Pierre's Unit B.				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***Redacted under the terms of the NPS/BLM Permits. Data to be archived with NPS***				
Long					

Theodolite Observations

Feature Description	Pierre's Unit B, South Wall (rooms 8 - 11)			
	D	M	S	Decimal Conversion
Angle 1	***197***	***1***	***59***	197.0331
Angle 2	***198***	***0***	***20***	198.0056
Angle 3	***198***	***42***	***26***	198.7072
MEAN Azimuth				197.9153
STD DEV				0.6865

Feature Description	Pierre's Unit B, East Wall (rooms 5-8) and Host Butte Visual Alignment			
	D	M	S	Decimal Conversion
Angle 1	***282***	***33***	***59***	282.5664
Angle 2	***283***	***1***	***20***	283.0222

Angle 3	***282***	***3***	***9***	282.0525
Angle 3	***281***	***7***	***10***	281.1194
Angle 5 (Hosta Butte East Top)	***101***	***52***	***37***	281.8769
Angle 6 (Hosta Butte West Top)	***102***	***1***	***57***	282.0325
MEAN Azimuth				281.6763
STD DEV				0.5895
Back Sight (a)	***0***	***0***	***4***	0.0011

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***21:31:01***	***160***	***9***	***0***			***255.4***	***15.2***	255.1467	-94.9967	-95.0545	0.1732
Sun Az 2	***21:32:37***	***160***	***43***	***52***			***255.8***	***15.2***	255.5467	-94.8156		
Sun Az 3	***21:33:52***	***160***	***43***	***55***			***256.1***	***15.2***	255.8467	-95.1147		
Sun Az 4	***21:34:59***	***160***	***45***	***20***			***256.3***	***15.2***	256.0467	-95.2911		
Sun Alt 1	***21:35:44***	***34***	***18***	***44***	***55***	***38.7***		***15.2***	55.8983	-0.2106	-0.3692	0.0976
Sun Alt 2	***21:37:12***	***34***	***51***	***53***	***55***	***21.4***		***15.2***	55.6100	-0.4747		
Sun Alt 3	***21:38:12***	***34***	***59***	***51***	***55***	***9.6***		***15.1***	55.4117	-0.4092		
Sun Alt 4	***21:40:25***	***35***	***24***	***21***	***54***	***43.5***		***15.1***	54.9767	-0.3825		
Back Sight (b)		***359***	***59***	***44***								
Operator		Andy Munro and John Nickerson										

Wall & Visual Alignment Azimuths

Mean Measured South Wall Azimuth	Reciprocal Azimuth	Perpendicular Azimuth	Reciprocal Perpendicular Azimuth
293.0	113.0	203.0	23.0

Mean Measured East Wall & Hosta Butte Azimuth	Reciprocal Azimuth	Perpendicular Azimuth	Reciprocal Perpendicular Azimuth
196.7	16.7	286.7	106.7

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
21:31:01	***143***	***11.1***	35.2382	***22***	***26.4***	56.5668			255.4476	255.4578	-0.0103
21:35:44	***144***	***21.8***	36.4165	***22***	***26.4***	55.6448	55.8037	-0.1589	256.4872		
21:32:37	***143***	***35.1***	35.6382	***22***	***26.4***	56.2543			255.8047	256.0390	-0.2343
21:37:12	***144***	***43.8***	36.7832	***22***	***26.4***	55.3571	55.2512	0.1059	256.8034		
21:33:52	***143***	***53.8***	35.9499	***22***	***26.4***	56.0105			256.0799	256.0398	0.0401
21:38:12	***144***	***58.8***	37.0332	***22***	***26.4***	55.1607	55.1201	0.0406	257.0170		
21:34:59	***144***	***10.6***	36.2299	***22***	***26.4***	55.7912			256.3250	256.0634	0.2616
21:40:25	***145***	***32.1***	37.5882	***22***	***26.4***	54.7241	54.7117	0.0124	257.4859		
							AVG Δ	0.0000		AVG Δ	0.0143

11.18 Bis sa'ani

Field Data Collection Form: Munro - Chaco Survey May/June 2008					
Site Name	Bis sa'ani east			Date	8-Jun-08
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	Theodolite location - 1 mtr west of the west wall adjoining the Southern kiva in east houseblock				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***Redacted under the terms of the NPS/BLM Permits. Data to be archived with NPS***				
Long					

Theodolite Observations

Feature Description	West wall adjoining the Southern kiva in east block			
	D	M	S	Decimal Conversion
Angle 1	***120***	***55***	***15***	120.9208
Angle 2	***119***	***45***	***14***	119.7539
Angle 3	***115***	***10***	***36***	***
Angle 4	***116***	***25***	***52***	***
Angle 5	***118***	***34***	***56***	118.5822
Angle 6	***118***	***6***	***49***	118.1136
Angle 7	***118***	***3***	***12***	118.0533
Angle 8	***117***	***44***	***6***	117.7350
Angle 9	***117***	***1***	***13***	117.0203

Angle 10	***117***	***23***	***27***	117.3908
Angle 11	***116***	***52***	***41***	116.8781
Angle 12	***116***	***47***	***21***	116.7892
MEAN Azimuth				118.1237
STD DEV				1.2623
Back Sight (a)				359.9944
*** Note two measurement points for wall were at locations where the veneer layer of stone wall was missing. These were eliminated from the calculated mean.				

Horizons			
	Measurement 1		
	D	M	S
WHoriz 1 Az	***171***	***20***	***27***
WHoriz 1 Alt	***89***	***58***	***58***
WHoriz 2 Az	***173***	***18***	***23***
WHoriz 2 Alt	***90***	***0***	***1***
WHoriz 3 Az	***174***	***5***	***51***
WHoriz 3 Alt	***90***	***1***	***54***
WHoriz 4 Az	***174***	***49***	***26***
WHoriz 4 Alt	***90***	***3***	***48***
WHoriz 5 Az	***179***	***11***	***28***
WHoriz 5 Alt	***90***	***6***	***18***
WHoriz 6 Az	***179***	***45***	***1***
WHoriz 6 Alt	***90***	***2***	***32***
EHoriz 1 Az	***357***	***13***	***32***
EHoriz 1 Alt	***89***	***23***	***41***
EHoriz 2 Az	***358***	***8***	***18***

EHoriz 2 Alt	***89***	***23***	***8***
EHoriz 3 Az	***359***	***4***	***22***
EHoriz 3 Alt	***89***	***25***	***21***
EHoriz 4 Az	***359***	***59***	***57***
EHoriz 4 Alt	***89***	***29***	***12***
EHoriz 5 Az	***5***	***49***	***50***
EHoriz 5 Alt	***89***	***34***	***53***
EHoriz 6 Az	***13***	***25***	***38***
EHoriz 6 Alt	***89***	***22***	***56***
EHoriz 7 Az	***15***	***51***	***28***
EHoriz 7 Alt	***89***	***25***	***35***
EHoriz 8 Az	***36***	***6***	***52***
EHoriz 8 Alt	***89***	***24***	***58***
Backsight (a)	***359***	***59***	***54***

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***16:18:03***	***36***	***23***	***46***			***97.4***	***15.0***	97.1500	-60.7539	-60.7547	0.0290
Sun Az 2	***16:18:56***	***36***	***33***	***27***			***97.6***	***15.0***	97.3500	-60.7925		
Sun Az 3	***16:19:58***	***36***	***44***	***20***			***97.7***	***15.0***	97.4500	-60.7111		
Sun Az 4	***16:21:22***	***36***	***59***	***19***			***98.0***	***15.0***	97.7500	-60.7614		
Sun Alt 1	***16:22:48***	***38***	***42***	***44***	***51***	***35.4***		***15.0***	51.3400	-0.0522	-0.0488	0.0033
Sun Alt 2	***16:23:42***	***38***	***31***	***39***	***51***	***46.1***		***15.1***	51.5167	-0.0442		
Sun Alt 3	***16:24:13***	***38***	***25***	***38***	***51***	***52.3***		***15.1***	51.6200	-0.0472		
Sun Alt 4	***16:24:50***	***38***	***18***	***30***	***51***	***59.7***		***15.1***	51.7433	-0.0517		
Back Sight (b)		***359***	***59***	***50***								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Wall Azimuth	Reciprocal Azimuth
178.9	358.9

Sunrise & Sunset Dates

	Horizon Az (deg)	Horizon Alt (deg)	Nearest Sunrise Dates	Sunrise Az (deg)	Sunrise Alt (deg)	Nearest Sunset Dates	Sunset Az (deg)	Sunset Alt (deg)
WHoriz 1	232.1	0.0	N/A	N/A	N/A	N/A	N/A	N/A
			N/A	N/A	N/A	N/A	N/A	N/A
WHoriz 2	234.1	0.0	N/A	N/A	N/A	N/A	N/A	N/A
			N/A	N/A	N/A	N/A	N/A	N/A
WHoriz 3	234.9	0.0	N/A	N/A	N/A	N/A	N/A	N/A
			N/A	N/A	N/A	N/A	N/A	N/A
WHoriz 4	235.6	-0.1	N/A	N/A	N/A	N/A	N/A	N/A
			N/A	N/A	N/A	N/A	N/A	N/A
WHoriz 5	239.9	-0.1	N/A	N/A	N/A	N/A	N/A	N/A
			N/A	N/A	N/A	N/A	N/A	N/A
WHoriz 6	240.5	0.0	N/A	N/A	N/A	***12.21.2009***	***241.0***	***0.0***
			N/A	N/A	N/A			
EHoriz 1	58.0	0.6	N/A	N/A	N/A	N/A	N/A	N/A
			N/A	N/A	N/A	N/A	N/A	N/A
EHoriz 2	58.9	0.6	N/A	N/A	N/A	N/A	N/A	N/A
			N/A	N/A	N/A	N/A	N/A	N/A
EHoriz 3	59.8	0.6	N/A	N/A	N/A	N/A	N/A	N/A
			N/A	N/A	N/A	N/A	N/A	N/A
EHoriz 4	60.8	0.5	***6.19.2009***	***60.6***	***0.5***	N/A	N/A	N/A

			6.23.2009	***60.6***	***0.5***	N/A	N/A	N/A
EHoriz 5	66.6	0.4	***5.14.2009***	***66.6***	***0.5***	N/A	N/A	N/A
			7.29.2009	***66.6***	***0.4***	N/A	N/A	N/A
EHoriz 6	74.2	0.6	***4.23.2009***	***74.3***	***0.5***	N/A	N/A	N/A
			8.19.2009	***74.4***	***0.6***	N/A	N/A	N/A
EHoriz 7	76.6	0.6	***4.18.2008***	***76.5***	***0.7***	N/A	N/A	N/A
			8.24.2009	***76.6***	***0.7***	N/A	N/A	N/A
EHoriz 8	96.9	0.6	***3.6.2009***	***96.9***	***0.6***	N/A	N/A	N/A
			10.07.2009	***97.1***	***0.6***	N/A	N/A	N/A

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated AZ	Observed AZ	Δ
16:18:03	***64***	***43.3***	-43.0671	***22***	***55.2***	50.6381			97.3944	97.4008	-0.0065
16:22:48	***65***	***54.6***	-41.8787	***22***	***55.2***	51.5895	51.5866	0.0029	98.2565		
16:18:56	***64***	***56.6***	-42.8454	***22***	***55.2***	50.8157			97.5534	97.5622	-0.0088
16:23:42	***66***	***8.1***	-41.6537	***22***	***55.2***	51.7694	51.7730	-0.0036	98.4224		
16:19:58	***65***	***12.1***	-42.5871	***22***	***55.2***	51.0226			97.7398	97.7436	-0.0038
16:24:13	***66***	***15.8***	-41.5254	***22***	***55.2***	51.8720	51.8733	-0.0013	98.5174		
16:21:22	***65***	***33.1***	-42.2371	***22***	***55.2***	51.3028			97.9940	97.9933	0.0007
16:24:50	***66***	***25.1***	-41.3704	***22***	***55.2***	51.9958	51.9922	0.0037	98.6325		
							AVG Δ	0.0004		AVG Δ	-0.0046

11.19 Kin Klizhin

Field Data Collection & Analysis: Munro - Chaco Survey May 2009					
Site Name	Kin Klizhin			Local Date	1-Jun-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	West Exterior wall.				
Text Key: ***Input***, Calculated Value					
	DEG	MIN	SEC	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***1***	***44.1***	1.74	36.03
Long	***108***	***4***	***22.8***	4.38	108.07

Theodolite Observations

Feature Description	West Exterior Wall			
	D	M	S	Decimal Conversion
Angle 1	***180***	***34***	***28***	180.5744
Angle 2	***181***	***1***	***36***	181.0267
Angle 3	***181***	***22***	***19***	181.3719
Angle 4	***181***	***46***	***27***	181.7742
Angle 5	***181***	***58***	***46***	181.9794
Angle 6	***182***	***17***	***52***	182.2978
Angle 7	***182***	***23***	***50***	182.3972
Angle 8	***182***	***33***	***32***	182.5589
Angle 9	***182***	***31***	***8***	182.5189

Angle 10	***182***	***31***	***35***	182.5264
Angle 11	***182***	***36***	***10***	182.6028
Angle 12	***182***	***35***	***22***	182.5894
Angle 13	***182***	***42***	***30***	182.7083
Angle 14	***182***	***39***	***56***	182.6656
Angle 15	***182***	***38***	***20***	182.6389
Angle 16	***182***	***27***	***20***	182.4556
MEAN Azimuth				182.1679
STD DEV				0.6300
Back Sight (a)	***0***	***0***	***47***	0.0131

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***14:19:26***	***58***	***47***	***55***			***80.9***	***13.9***	80.6683	-21.8697	-21.8255	0.0323
Sun Az 2	***14:21:32***	***59***	***4***	***38***			***81.1***	***13.9***	80.8683	-21.7911		
Sun Az 3	***14:22:59***	***59***	***16***	***12***			***81.3***	***13.9***	81.0683	-21.7983		
Sun Az 4	***14:24:10***	***59***	***25***	***26***			***81.5***	***14.0***	81.2667	-21.8428		
Sun Alt 1	***14:20:21***	***63***	***42***	***23***	***26***	***34.6***		***13.9***	26.3450	-0.0514	-0.0506	0.0016
Sun Alt 2	***14:22:18***	***63***	***19***	***8***	***26***	***57.9***		***13.9***	26.7333	-0.0522		
Sun Alt 3	***14:23:29***	***63***	***4***	***56***	***27***	***12.1***		***14.0***	26.9683	-0.0506		
Sun Alt 4	***14:25:05***	***62***	***45***	***35***	***27***	***31.3***		***14.0***	27.2883	-0.0481		
Back Sight (b)		***0***	***0***	***9***								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Wall Azimuth	Reciprocal Azimuth	Perpendicular Azimuth	Reciprocal Perpendicular Azimuth
204.0	24.0	294.0	114.0

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
14:19:26	***35***	***23.5***	-72.6813	***22***	***7.4***	26.3936			80.8554	80.8558	-0.0003
14:20:21	***35***	***37.2***	-72.4530	***22***	***7.4***	26.5759	26.5758	0.0001	80.9752		
14:21:32	***35***	***55***	-72.1563	***22***	***7.4***	26.8129			81.1309	81.1344	-0.0034
14:22:18	***36***	***6.5***	-71.9647	***22***	***7.4***	26.9661	26.9633	0.0027	81.2316		
14:22:59	***36***	***16.7***	-71.7947	***22***	***7.4***	27.1020			81.3210	81.3272	-0.0062
14:23:29	***36***	***24.3***	-71.6680	***22***	***7.4***	27.2032	27.2017	0.0016	81.3876		
14:24:10	***36***	***34.5***	-71.4980	***22***	***7.4***	27.3392			81.4770	81.4827	-0.0057
14:25:05	***36***	***48.2***	-71.2697	***22***	***7.4***	27.5218	27.5242	-0.0023	81.5972		
							AVG Δ	0.0005		AVG Δ	-0.0039

11.20 Kin Bineola

11.20.1 East Wall

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2009					
Site Name		Kin Bineola	Local Date		29-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	East wall, survey taken from high spot along wall				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***0***	***12.6***	0.21	36.0035
Long	***108***	***8***	***25***	8.42	108.1403

Theodolite Observations

Feature Description	Central Wall			
	D	M	S	Decimal Conversion
Angle 1	***345***	***31***	***34***	165.5261
Angle 2	***345***	***30***	***57***	165.5158
Angle 3	***345***	***28***	***18***	165.4717
Angle 4	***345***	***29***	***45***	165.4958
Angle 5	***345***	***23***	***7***	165.3853
Angle 6	***345***	***28***	***36***	165.4767
Angle 7	***345***	***34***	***50***	165.5806
Angle 8	***345***	***33***	***30***	165.5583
Angle 9	***345***	***38***	***44***	165.6456
Angle 10	***345***	***23***	***19***	165.3886

Angle 11	***167***	***30***	***1***	167.5003
Angle 12	***167***	***24***	***51***	167.4142
Angle 13	***167***	***8***	***16***	167.1378
Angle 14	***167***	***23***	***44***	167.3956
Angle 15	***167***	***19***	***56***	167.3322
Angle 16	***166***	***43***	***11***	166.7197
Angle 17	***166***	***11***	***32***	166.1922
Angle 18	***166***	***11***	***56***	166.1989
Angle 19	***166***	***11***	***10***	166.1861
Angle 20	***166***	***6***	***49***	166.1136
Angle 21	***166***	***5***	***44***	166.0956
Angle 22	***166***	***3***	***36***	166.0600
Angle 23	***166***	***6***	***20***	166.1056
Angle 24	***166***	***4***	***57***	166.0825
Angle 25	***166***	***2***	***55***	166.0486
Angle 26	***166***	***13***	***37***	166.2269
Angle 27	***166***	***14***	***18***	166.2383
MEAN Angle				166.1516
STD DEV				0.6651
Back Sight (a)	***0***	***0***	***16***	0.0044

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***15:55:55***	***91***	***14***	***37***			***95.1***	***14.9***	94.8517	-3.6081	-3.6790	0.0795
Sun Az 2	***16:06:52***	***93***	***6***	***58***			***97.0***	***15.0***	96.7500	-3.6339		
Sun Az 3	***16:08:05***	***93***	***8***	***14***			***97.2***	***15.0***	96.9500	-3.8128		
Sun Az 4	***16:09:08***	***93***	***29***	***20***			***97.4***	***15.0***	97.1500	-3.6611		
Sun Alt 1	***15:56:23***	***44***	***33***	***42***	***45***	***45.5***		***15.0***	45.5083	-0.0700	-0.0492	0.0121
Sun Alt 2	***16:07:28***	***42***	***18***	***22***	***47***	***59.2***		***15.0***	47.7367	-0.0428		
Sun Alt 3	***16:08:33***	***42***	***5***	***10***	***48***	***12.2***		***15.0***	47.9533	-0.0394		
Sun Alt 4	***16:09:31***	***41***	***53***	***47***	***48***	***23.9***		***15.0***	48.1483	-0.0447		
Back Sight (b)		***0***	***0***	***5***								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Wall Azimuth	Reciprocal Azimuth
169.8	349.8

Spherical Trig Check of Sun Sights

D to R		R to D									
0.017453293		57.2957795									
UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
15:55:55	***59***	***37.1***	-48.5219	***21***	***42.5***	45.6632			-0.0894	95.1310	95.1709
15:56:23	***59***	***44.1***	-48.4053	***21***	***42.5***	45.7572	45.7376	0.0196	-0.0908	95.2083	
16:06:52	***62***	***21.4***	-45.7836	***21***	***42.5***	47.8660			-0.1217	96.9896	97.0451
16:07:28	***62***	***30.4***	-45.6336	***21***	***42.5***	47.9864	47.9931	-0.0067	-0.1235	97.0943	
16:08:05	***62***	***39.6***	-45.4803	***21***	***42.5***	48.1095			-0.1254	97.2016	97.0662
16:08:33	***62***	***46.6***	-45.3636	***21***	***42.5***	48.2031	48.2131	-0.0100	-0.1268	97.2835	
16:09:08	***62***	***55.4***	-45.2169	***21***	***42.6***	48.3217			-0.1285	97.3845	97.4178
16:09:31	***63***	***1.1***	-45.1219	***21***	***42.6***	48.3979	48.4028	-0.0050	-0.1297	97.4515	
							AVG Δ	-0.0005		AVG Δ	0.0017

11.20.2 West Wall

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2009					
Site Name			Kin Bineola	Local Date	29-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	West wall, survey taken from NW corner of front section				
Text Key: ***Input***, Calculated Value					
	D	M	S	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***36***	***0***	***11.3***	0.19	36.0031
Long	***108***	***8***	***29.2***	8.49	108.1414

Theodolite Observations

Feature Description	Central Wall			
	D	M	S	Decimal Conversion
Angle 1	***162***	***31***	***18***	162.5217
Angle 2	***162***	***41***	***24***	162.6900
Angle 3	***162***	***36***	***29***	162.6081
Angle 4	***162***	***29***	***0***	162.4833
Angle 5	***162***	***19***	***17***	162.3214
Angle 6	***162***	***12***	***26***	162.2072
Angle 7	***162***	***4***	***48***	162.0800
Angle 8	***162***	***8***	***17***	162.1381
Angle 9	***162***	***2***	***40***	162.0444
Angle 10	***162***	***8***	***53***	162.1481
Angle 11	***162***	***9***	***37***	162.1603

Angle 12	***162***	***9***	***5***	162.1514
Angle 13	***162***	***22***	***16***	162.3711
Angle 14	***162***	***25***	***42***	162.4283
Angle 15	***162***	***17***	***39***	162.2942
Angle 16	***162***	***20***	***15***	162.3375
Angle 17	***162***	***15***	***28***	162.2578
MEAN Azimuth				162.3084
STD DEV				0.1826
Back Sight (a)	***359***	***59***	***58***	359.9994

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***17:07:33***	***281***	***30***	***38***			***109.8***	***15.3***	109.5450	171.9656	171.9494	0.0348
Sun Az 2	***17:08:43***	***281***	***49***	***25***			***110.1***	***15.3***	109.8450	171.9786		
Sun Az 3	***17:09:54***	***282***	***8***	***6***			***110.5***	***15.3***	110.2450	171.8900		
Sun Az 4	***17:11:17***	***282***	***30***	***31***			***110.8***	***15.3***	110.5450	171.9636		
Sun Alt 1	***17:08:05***	***30***	***23***	***46***	***59***	***54.2***		***15.3***	59.6483	-0.0444	-0.0458	0.0034
Sun Alt 2	***17:09:23***	***30***	***9***	***5***	***60***	***9.1***		***15.3***	59.8967	-0.0481		
Sun Alt 3	***17:10:21***	***29***	***57***	***45***	***60***	***20.0***		***15.3***	60.0783	-0.0408		
Sun Alt 4	***17:12:11***	***29***	***37***	***29***	***60***	***40.8***		***15.3***	60.4250	-0.0497		
Back Sight (b)		***0***	***0***	***3***								
Operator		Andy Munro										

Wall Azimuth and Mean of West and East Walls

Mean Measured Wall Azimuth	Reciprocal Azimuth	Mean Azimuth of East and West Walls
170.4	350.4	170.1

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
17:07:33	***77***	***31.5***	-30.6164	***21***	***42.9***	59.8022			-0.3393	109.8348	109.8161
17:08:05	***77***	***39.5***	-30.4831	***21***	***42.9***	59.9036	59.9047	-0.0010	-0.3416	109.9764	
17:08:43	***77***	***49.0***	-30.3248	***21***	***42.9***	60.0239			-0.3444	110.1454	110.1292
17:09:23	***77***	***59.0***	-30.1581	***21***	***42.9***	60.1504	60.1494	0.0011	-0.3473	110.3245	
17:09:54	***78***	***6.8***	-30.0281	***21***	***42.9***	60.2490			-0.3496	110.4649	110.4406
17:10:21	***78***	***13.5***	-29.9164	***21***	***42.9***	60.3336	60.3383	-0.0046	-0.3516	110.5860	
17:11:17	***78***	***27.5***	-29.6831	***21***	***42.9***	60.5102			-0.3558	110.8408	110.8142
17:12:11	***78***	***41.0***	-29.4581	***21***	***42.9***	60.6802	60.6760	0.0041	-0.3598	111.0886	
							AVG Δ	-0.0001		AVG Δ	0.0215

11.21 Pueblo Pintado

Field Data Collection & Analysis: Munro - Chaco Survey May/June 2009					
Site Name	Pueblo Pintado			Local Date	30-May-09
GPS Observations					
GPS Device	Garmin GPS 72				
Feature Description	NW (Back) Wall surveyed from high spot along wall				
Text Key: ***Input***, Calculated Value					
	DEG	MIN	SEC	Converted Min for USNO Format (00.0 min)	Decimal Conversion
Lat	***35***	***58***	***37.7***	58.63	35.9771
Long	***107***	***40***	***25.7***	40.43	107.6738

Theodolite Observations

Feature Description	Central Wall			
	D	M	S	Decimal Conversion
Angle 1	***94***	***54***	***43***	274.9119
Angle 2	***94***	***56***	***12***	274.9367
Angle 3	***94***	***56***	***53***	274.9481
Angle 4	***95***	***0***	***5***	275.0014
Angle 5	***95***	***2***	***16***	275.0378
Angle 6	***95***	***1***	***53***	275.0314
Angle 7	***95***	***1***	***55***	275.0319
Angle 8	***94***	***59***	***25***	274.9903

Angle 9	***94***	***58***	***48***	274.9800
Angle 10	***94***	***52***	***49***	274.8803
Angle 11	***94***	***55***	***11***	274.9197
Angle 12	***94***	***52***	***9***	274.8692
Angle 13	***94***	***50***	***24***	274.8400
Angle 14	***94***	***46***	***11***	274.7697
Angle 15	***94***	***48***	***36***	274.8100
Angle 16	***94***	***46***	***19***	274.7719
Angle 17	***94***	***46***	***47***	274.7797
Angle 18	***94***	***48***	***18***	274.8050
Angle 19	***94***	***44***	***37***	274.7436
Angle 20	***94***	***46***	***38***	274.7772
Angle 21	***94***	***54***	***40***	274.9111
Angle 22	***94***	***51***	***10***	274.8528
Angle 23	***95***	***1***	***10***	275.0194
Angle 24	***95***	***8***	***48***	275.1467
Angle 25	***95***	***14***	***49***	275.2469
Angle 26	***95***	***1***	***12***	275.0200
Angle 27	***94***	***49***	***11***	274.8197
Angle 28	***95***	***1***	***33***	275.0258
Angle 29	***94***	***51***	***12***	274.8533
Angle 30	***95***	***15***	***30***	275.2583
Angle 31	***275***	***29***	***53***	275.4981
Angle 32	***275***	***59***	***53***	275.9981
Angle 33	***275***	***53***	***46***	275.8961
Angle 34	***275***	***54***	***44***	275.9122

Angle 35	***275***	***53***	***50***	275.8972
Angle 36	***275***	***40***	***28***	275.6744
Angle 37	***275***	***14***	***34***	275.2428
Angle 38	***275***	***26***	***47***	275.4464
Angle 39	***275***	***28***	***25***	275.4736
Angle 40	***275***	***15***	***17***	275.2547
Angle 41	***275***	***16***	***59***	275.2831
Angle 42	***275***	***3***	***14***	275.0539
Angle 43	***275***	***12***	***35***	275.2097
Angle 44	***275***	***16***	***11***	275.2697
Angle 45	***275***	***21***	***48***	275.3633
Angle 46	***275***	***25***	***52***	275.4311
Angle 47	***275***	***25***	***4***	275.4178
Angle 48	***275***	***33***	***13***	275.5536
Angle 49	***275***	***35***	***30***	275.5917
Angle 50	***275***	***33***	***32***	275.5589
Angle 51	***275***	***33***	***37***	275.5603
Angle 52	***275***	***33***	***17***	275.5547
Angle 53	***275***	***31***	***31***	275.5253
Angle 54	***275***	***34***	***10***	275.5694
Angle 55	***275***	***35***	***14***	275.5872
Angle 56	***275***	***33***	***50***	275.5639
Angle 57	***275***	***32***	***28***	275.5411
Angle 58	***275***	***31***	***12***	275.5200
Angle 59	***275***	***30***	***19***	275.5053
Angle 60	***275***	***29***	***58***	275.4994
Angle 61	***275***	***29***	***15***	275.4875
Angle 62	***275***	***31***	***25***	275.5236
Angle 63	***275***	***28***	***48***	275.4800

MEAN Azimuth				275.2371
STD DEV				0.3372
Back Sight (a)	***0***	***0***	***10***	0.0028

Observed Sun Sights

	UTC	D	M	S	USNO Alt (Hc)		USNO Az (Zn)	USNO Limb Correction	Corrected USNO Az/Alt	Az/Alt Δ	MEAN Δ	SD
					D	M	D	M				
Sun Az 1	***14:05:04***	***284***	***11***	***32***			***79.5***	***13.6***	79.2733	204.9189	204.9365	0.0236
Sun Az 2	***14:06:40***	***284***	***24***	***6***			***79.7***	***13.7***	79.4717	204.9300		
Sun Az 3	***14:07:46***	***284***	***32***	***54***			***79.8***	***13.7***	79.5717	204.9767		
Sun Az 4	***14:08:48***	***284***	***41***	***31***			***80.0***	***13.7***	79.7717	204.9203		
Sun Alt 1	***14:05:58***	***66***	***20***	***55***	***23***	***56.2***		***13.7***	23.7083	-0.0569	-0.0550	0.0020
Sun Alt 2	***14:07:05***	***66***	***7***	***22***	***24***	***9.5***		***13.7***	23.9300	-0.0528		
Sun Alt 3	***14:08:15***	***65***	***53***	***24***	***24***	***23.5***		***13.7***	24.1633	-0.0533		
Sun Alt 4	***14:09:22***	***65***	***40***	***19***	***24***	***36.8***		***13.7***	24.3850	-0.0569		
Back Sight (b)		***0***	***0***	***7***								
Operator		Andy Munro										

Wall Azimuth

Mean Measured Wall Azimuth	Reciprocal Azimuth	Perpendicular Azimuth	Reciprocal Perpendicular Azimuth	Plaza Bisecting front-facing Azimuth
70.3	250.3	160.3	340.3	115.3

Spherical Trig Check of Sun Sights

D to R	R to D
0.017453293	57.2957795

UTC	GHA D	GHA M	LHA	Sun Dec D	Sun Dec M	Calculated Alt	Observed Alt	Δ	Calculated Az	Observed Az	Δ
14:05:04	***31***	***52.5***	-75.7988	***21***	***50.7***	23.7576			79.4646	79.4824	-0.0178
14:05:58	***32***	***6***	-75.5738	***21***	***50.7***	23.9367	23.9347	0.0020	79.5822		
14:06:40	***32***	***16.5***	-75.3988	***21***	***50.7***	24.0760			79.6736	79.6935	-0.0199
14:07:05	***32***	***22.7***	-75.2955	***21***	***50.7***	24.1583	24.1606	-0.0023	79.7276		
14:07:46	***32***	***33***	-75.1238	***21***	***50.7***	24.2950			79.8174	79.8402	-0.0228
14:08:15	***32***	***40.2***	-75.0038	***21***	***50.7***	24.3906	24.3933	-0.0028	79.8801		
14:08:48	***32***	***48.5***	-74.8655	***21***	***50.7***	24.5008			79.9525	79.9838	-0.0313
14:09:22	***32***	***56.9***	-74.7255	***21***	***50.7***	24.6124	24.6114	0.0010	80.0257		
							AVG Δ	-0.0005		AVG Δ	-0.0230

12 APPENDIX 2: COPYRIGHT PERMISSIONS CORRESPONDENCE

The following email correspondence documents permission for use of a copywrited and previously published drawing (Figure 23 above).

12.1 Anna Sofaer, The Solstice Project

From: Anna Sofaer <[*email address redacted*]>

Sent: Wednesday, November 21, 2007 12:44 PM

To: Andy Munro

Subject: Re: Request for Use of Graphics

Hello Andy,

yes that is fine. I hope that you can get them off the web site? Anna

----- Original Message ----

From: Andy Munro <andrewmmunro@comcast.net>

To: Anna Sofaer <[*email address redacted*]>

Sent: Thursday, November 15, 2007 2:17:10 PM

Subject: RE: Request for Use of Graphics

Thank you Anna,

From the 1979 paper: Fig 4a, Fig 5 a and b, Fig 7 a - e. Fig 9c.

From the 1982 paper: Fig and Fig 6

From the 1997 Paper: Fig 8.6, Fig 8.10a and b

Thanks so much for your consideration.

Best Regards, Andy

-----Original Message-----

From: Anna Sofaer <[*email address redacted*]>

Sent: Wednesday, November 14, 2007 7:10 PM

To: Andy Munro

Subject: RE: Request for Use of Graphics yes let me know which figures you would be wanting to use. Sounds interesting. A S

Andy Munro <andrewmmunro@comcast.net> wrote:

Anna,

Thanks very much for your help. As it happens, I ordered a copy of your new book this morning.

It is early in the process for me - I am still actively engaged in literature review reading your work, Williamson, Farmer, Malville, Aveni, Ruggles and others, as well as the conventional archaeology of Windes, Ford, Mathien and Lekson etc. As you say it is a complex subject. My opening perspectives are pretty simple:

a) improved linkage between archaeology and archaeoastronomy (e.g., use of expanded tree ring data) is beneficial in interpretation of alignment data

b) valid alignment results should be analytically repeatable (e.g., how well accepted are Farmer's claims regarding the east section of Bonito's south wall? Has anyone repeated his measurements?)

c) Assessing broader samples of unsurveyed outlier great houses may be illuminating.

Regarding graphics, at this point I'm particularly interested in using your figures from the 1979, 1982, and 1997 papers to illustrate the solar and lunar workings of the "sun dagger" slab and spiral structure, and the intra and inter-building alignments you have documented. Would it be helpful if I provide a specific list of figures? The intent is to use them only in my thesis, not a published paper.

Thanks very much and Best Regards,

Andy

-----Original Message-----
From: Anna Sofaer <[*email address redacted*]>

Sent: Wednesday, November 14, 2007 12:11 PM

To: Andy Munro

Subject: Re: Request for Use of Graphics

Hi Andy,

I appreciate your request. Please let me know which graphics you request. I think there is not a problem. I would appreciate also learning your thoughts and queries as you approach this complex subject. We have a new book out "Chaco Astronomy" with all the Solstice Project research papers and many references to the work of ohers. You can find how to obtain a copy, if of ineterest, through our web site, solsticeproject.org. perhaps it would be helpful. Best regards, Anna

Andy Munro <andrewmmunro@comcast.net> wrote:

Dear Anna,

I hope that you are well. We met in September of 2006 at Chaco while I was volunteering for G.B., during the week while you and Kim Malville spoke to the teachers group.

Recently I have begun a Doctoral research program on Ancestral Puebloan and Chacoan Archaeoastronomy (my MSc is in Astronomy). I am writing to request permission to use (with full attribution) graphics from some of the Solstice Project's papers in my Doctoral Thesis as it develops. Please let me know if this would be acceptable.

Thanks very much,

Andy Munro