9

The Primary Architecture of the Chacoan Culture

A Cosmological Expression

Anna Sofaer

Studies by the solstice project indicate that the major buildings of the ancient Chacoan culture of New Mexico contain solar and lunar cosmology in three separate articulations: their orientations, internal geometry, and geographic interrelationships were developed in relationship to the cycles of the sun and moon.

From approximately 900 to 1130, the Chacoan society, a prehistoric Pueblo culture, constructed numerous multistoried buildings and extensive roads throughout the eighty thousand square kilometers of the arid San Juan Basin of northwestern New Mexico (Cordell 1984; Lekson et al. 1988; Marshall et al. 1979; Vivian 1990) (Figure 9.1). Evidence suggests that expressions of the Chacoan culture extended over a region two to four times the size of the San Juan Basin (Fowler and Stein 1992; Lekson et al. 1988). Chaco Canyon, where most of the largest buildings were constructed, was the center of the culture (Figures 9.2 and 9.3). The canyon is located close to the center of the high desert of the San Juan Basin.

Twelve of the fourteen major Chacoan buildings are oriented to the midpoints and extremes of the solar and lunar cycles (Sofaer, Sinclair, and Donahue 1991). The eleven rectangular major Chacoan buildings have internal geometry that corresponds to the relationship of the solar and lunar cycles (Sofaer, Sinclair, and Donahue 1991). Most of the major buildings also appear to be organized in a solar-and-lunar regional pattern that is symmetrically ordered about Chaco Canyon's central complex of large ceremonial buildings (Sofaer, Sinclair, and Williams 1987). These findings suggest a cosmological purpose motivating and directing the construction and the orientation, internal geometry, and interrelationships of the primary Chacoan architecture.

This essay presents a synthesis of the results of several studies by the Solstice Project between 1984 and 1997 and hypotheses about the conceptual and symbolic meaning of the Chacoan astronomical achievements. For certain details of Solstice Project studies, the reader is referred to several earlier published papers.[1]

Background

The Chacoan buildings were of a huge scale and "spectacular appearance" (Neitzel 1989). The buildings typically had large public plazas and elaborate "architectural earthworks" that formed road entries (Stein and McKenna 1988). The major Chacoan buildings, the subject of the Solstice Project's studies (Figures 9.3 and 9.4), are noted in particular for their massive core veneer masonry. They were up to four stories high and contained as many as seven hundred rooms, as well as numerous kivas, including great kivas, the large ceremonial chambers of prehistoric Pueblo culture (Lekson

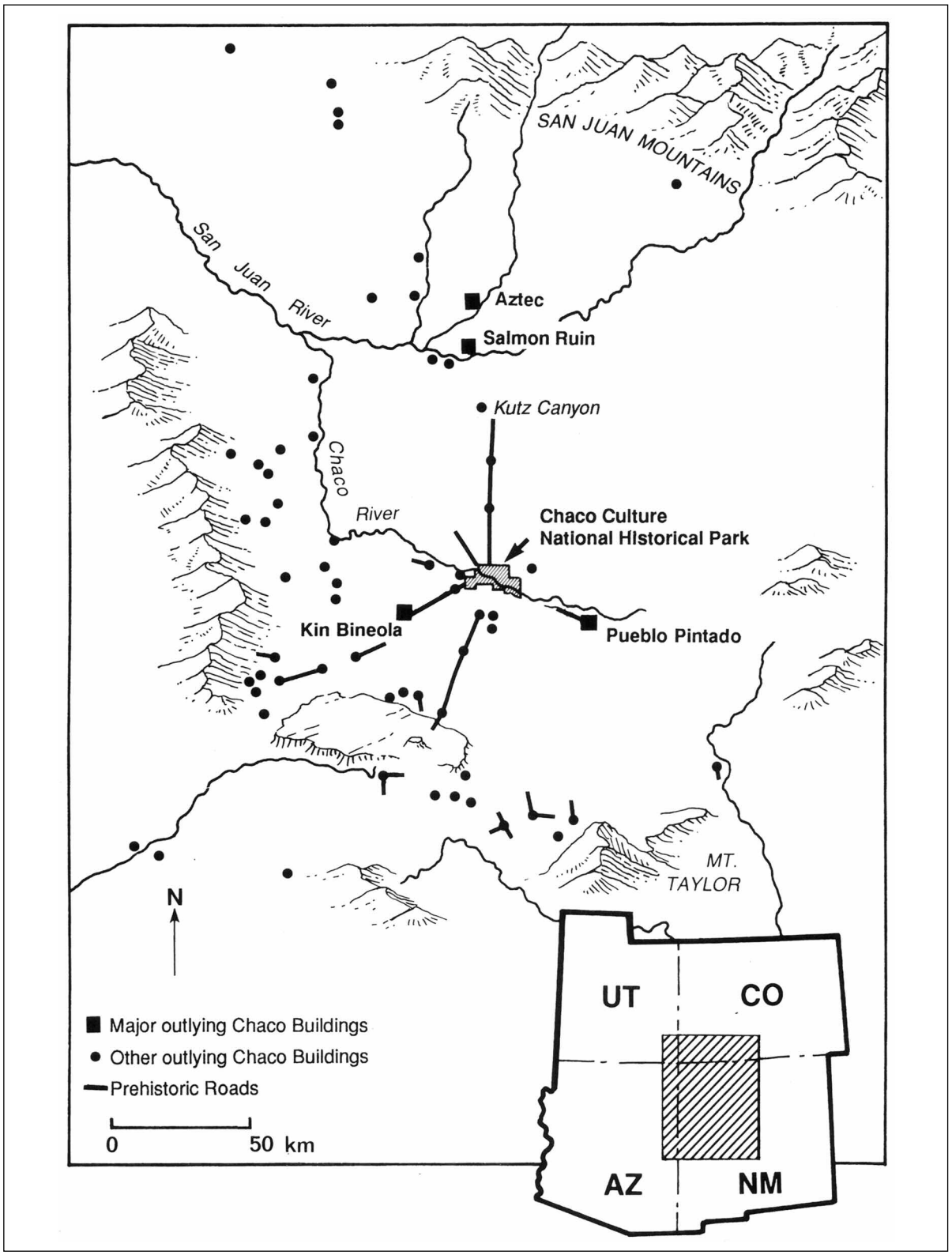

FIGURE 9.1. The San Juan Basin and adjoining region, showing the buildings and roads of the Chacoan culture. The inset shows the relation of this region to the present-day states. (Suzanne Samuels, By Design Graphics; © 1995 by The Solstice Project)

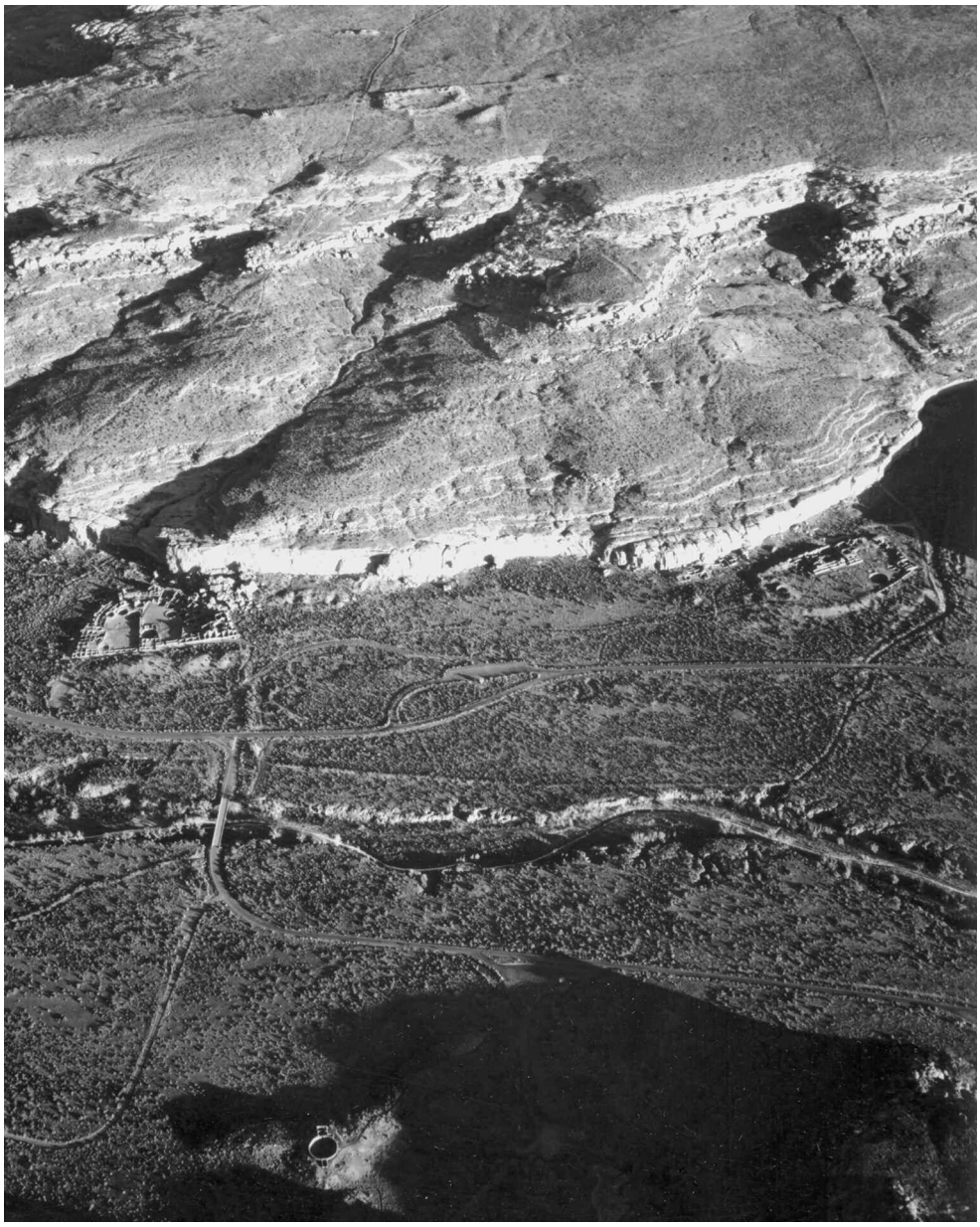

FIGURE 9.2. Aerial view of central area of Chaco Canyon, looking north. The photograph shows three major buildings: Pueblo Bonito (left), Pueblo Alto (above center), and Chetro Ketl (right). Casa Rinconada (bottom center) and New Alto are also shown. (Photograph by Adriel Heisey, © 1995 by Adriel Heisey)

1984; Marshall et al. 1979; Powers, Gillespie, and Lekson 1983).

The construction of the major Chacoan buildings employed enormous quantities of stone and wood. For example, 215,000 timbers—transported from distances of more than 80 km—were used in the canyon in the major buildings alone (Lekson et al. 1988). The orderly, gridlike layout of the buildings suggests that extensive planning and engineering were involved in their construction (Lekson 1984; Lekson et al. 1988).

No clear topographic or utilitarian explanations have been developed for the orientations of the Chacoan buildings. The buildings stand free of the cliffs, and their specific orientations are not significantly constrained by local topography.[2]

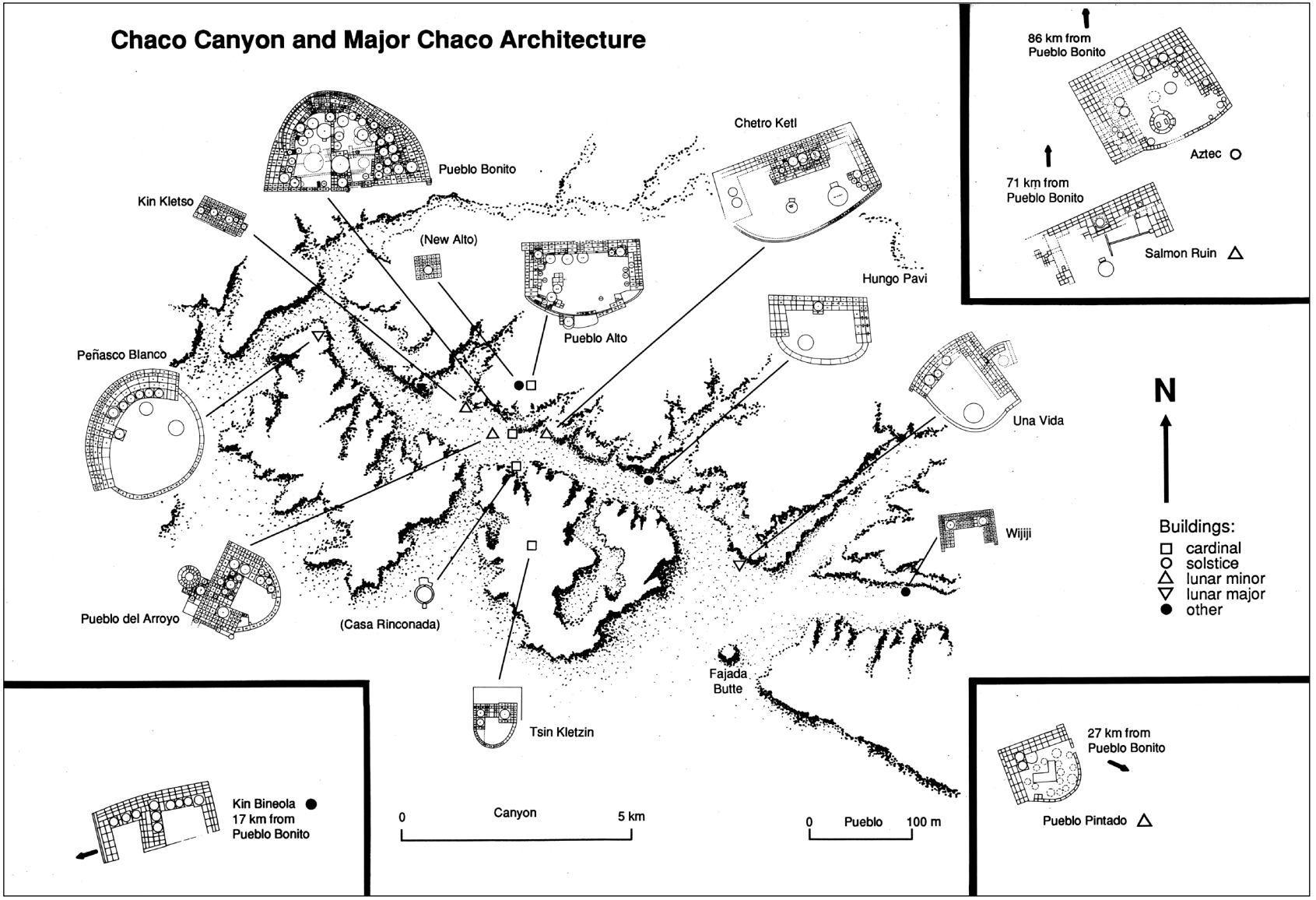

FIGURE 9.3. Chaco Canyon, showing the locations and ground plans of ten major buildings (and two minor buildings). Four outlying major buildings are also shown. The astronomical orientations of the buildings are indicated. (Fabian Schmid, Davis, Inc.; and Suzanne Samuels, By Design Graphics; © 1995 by The Solstice Project)

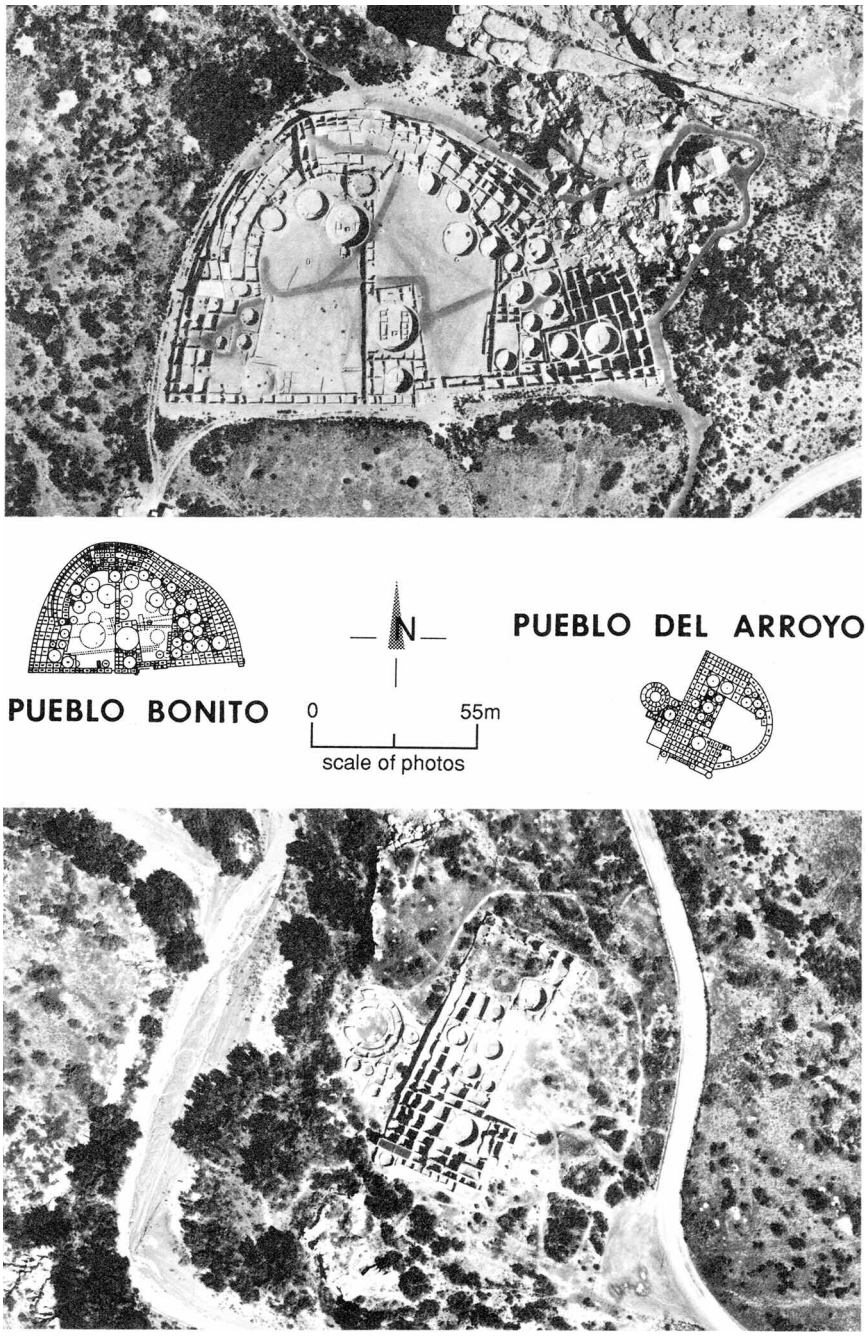

FIGURE 9.4. Aerial photographs of two major buildings in Chaco Canyon, Pueblo Bonito (upper) and Pueblo del Arroyo (lower) with ground plans of these buildings. (Photographs by Koogle and Pouls for the National Park Service; graphics by Suzanne Samuels, By Design Graphics; © 1993 by The Solstice Project)

Although the need to optimize solar heating may have influenced the general orientations of the buildings, it probably did not restrict their orientations to specific azimuths. Similarly, environmental factors, such as access to water, appear not to have dominated or constrained the Chacoans' choice of specific locations for their buildings.[3]

The Chacoans also constructed more than two hundred kilometers of roads. The roads were of great width (averaging 9 m wide), and they were

developed, with unusual linearity, over distances of up to fifty kilometers. Their construction required extensive surveying and engineering (Kincaid 1983). Investigations show that certain of the roads were clearly overbuilt if they were intended to serve purely utilitarian purposes (Lekson 1991; Roney 1992; Sofaer, Marshall, and Sinclair 1989; Stein 1989),[4] and that they may have been constructed as cosmographic expressions (Marshall 1997; Sofaer, Marshall, and Sinclair 1989).

Scholars have puzzled for decades over why the Chacoan culture flourished in the center of the desolate environment of the San Juan Basin. Earlier models proposed that Chaco Canyon was a political and economic center where the Chacoans administered a widespread trade and redistribution system (Judge 1989; Sebastian 1992). Recent archaeological investigations show that major buildings in Chaco Canyon were not built or used primarily for household occupation (Lekson et al. 1988). This evidence, along with the dearth of burials found in the canyon, suggests that, even at the peak of the Chacoan development, there was a low resident population. (Estimates of this population range from 1,500 to 2,700 [Lekson 1991; Windes 1987].) Evidence of periodic, large-scale breakage of vessels at key central buildings indicates, however, that Chaco Canyon may have served as a center for seasonal ceremonial visitations by great numbers of residents of the outlying communities (Judge 1984; Toll 1991).

Many aspects of the Chacoan culture—such as the transport of thousands of beams and pots—have struck archaeologists as having a "decided aura of inefficiency" (Toll 1991). Other findings—such as "intentionally destroyed items in the trash mounds," "plastered-over exquisite masonry," and strings of beads "sealed into niches" in a central great kiva—indicate esoteric uses of Chacoan constructions. It has been suggested that, in the "absence of any evidence that there is either a natural or societal resource to which Chaco could control access by virtue of its location" (Toll 1991), Chaco Canyon was the center of exchange of information and knowledge (Sebastian 1991). Two other archaeologists suggest that Chaco Canyon was a "central archive for esoteric knowledge, such as maintenance of the region's ceremonial calendar" (Crown and Judge 1991).

Scholars have commented extensively on the impractical and enigmatic aspects of Chacoan buildings, describing them as "overbuilt and overembellished" and proposing that they were built primarily for public image and ritual expression (Lekson et al. 1988; Stein and Lekson 1992). Some observers have thought that the Chacoan buildings were developed as expressions of the Chacoans' "concepts of the cosmos" (Stein and Lekson 1992) and that their placement and design may have been determined in part by "Chacoan cosmography" (Marshall and Doyel 1981). One report proposes that "Chaco and its hinterland are related by a canon of shared design concepts" and that the Chacoan architecture is a "common ideational bond" across a "broad geographic space" (Stein and Lekson 1992). That report suggests that the architectural characteristics of Pueblo Bonito, one of the two largest and most central buildings of the Chacoan system, are rigorously repeated throughout the Chaco region. Thus, important clues to the symbology and ideology of the Chacoan culture may be embedded in its central and primary architecture and expressed in the relationship of this architecture to primary buildings in the outlying region.

Numerous parallels to the Chacoan expressions of cosmology appear in the astronomically and geometrically ordered constructions of Mesoamerica—a region with which the Chacoans are known to have had cultural associations (Aveni 1980; Broda 1993). Moreover, traditions of the descendants of the prehistoric Pueblo people, who live today in New Mexico and Arizona, also suggest parallels to the Chacoan cosmology and give us insight into the general cosmological concepts of the Chacoan culture.

Previous Work

Solstice Project studies, begun in 1978, documented astronomical markings at three petroglyph sites on Fajada Butte, a natural promontory at the south entrance of Chaco Canyon (Figure 9.3). Near the top of the butte, three rock slabs collimate light so that markings of shadow and light on two spiral petroglyphs indicate the summer and winter solstices, the equinoxes, and the extreme positions of the moon, that is, the lunar major and

minor standstills (Sofaer, Zinser, and Sinclair 1979; Sofaer, Sinclair, and Doggett 1982; Sinclair et al. 1987). At two other sites on the butte, shadow and light patterns on five petroglyphs indicate solar noon and the solstices and equinoxes (Sofaer and Sinclair 1987).

A 1989 Solstice Project study showed astronomical significance in the Chacoans' construction of the Great North Road (Sofaer, Marshall, and Sinclair 1989). This 9-m-wide, engineered road extends from Chaco Canyon north 50 km to a badlands site, Kutz Canyon (Figure 9.1). The purpose of the road appears to have been to articulate the north-south axis and to connect the canyon's central ceremonial complex with distinctive topographic features in the north.

Prior to the Solstice Project studies of the Chacoan constructions, others had reported cardinal orientations in the primary walls and the great kiva of Pueblo Bonito, a major building located in the central complex of Chaco Canyon, and in Casa Rinconada, an isolated great kiva (Williamson et al. 1975, 1977). Researchers have also shown that certain features in Pueblo Bonito and Casa Rinconada may be oriented to the solstices (Reyman 1976; Williamson et al. 1977; Zeilik 1984).[5]

Certain early research also highlighted astronomically related geometry and symmetry in the Chacoan architecture. One scholar describes "geometrical/astronomical patterns" in the extensive cardinal organization of Casa Rinconada (Williamson 1984). His report notes that these patterns were derived from the symmetry of the solar cycle, rather than from the observation of astronomical events from this building. Similarly, other research describes a symmetric, cardinal patterning in the geographic relationships of several central buildings, and it further suggests that other major buildings—outside of the center and out of sight of the center—were organized in symmetric relationships to the cardinal axes of the center (Fritz 1978).

These previous findings led the Solstice Project to examine and analyze the orientations, internal geometry, and interrelationships of the major Chacoan buildings for possible astronomical significance. The Solstice Project's study regarded as important both orientations to visible astronomical events and expressions of astronomically related geometry. In the following analysis, the Solstice Project considers the orientations of the major Chacoan buildings, and of their interbuilding relationships, to astronomical events on both the sensible and the visible horizons.[6]

Solar and Lunar Orientations of the Major Chacoan Buildings

The Solstice Project asked if the fourteen major buildings were oriented to the sun and moon at the extremes and mid-positions of their cycles—in other words, the meridian passage, the solstices and the equinoxes, and the lunar major and minor standstills. The rising and setting azimuths for these astronomical events at the latitude of Chaco Canyon are given in Figure 9.5. (The angles of the solstices, equinoxes, and lunar standstills are expressed as single values taken east and west of north as positive to the east of north and negative to the west of north.)

In the clear skies of the high desert environment of the San Juan Basin, the Chacoans had nearly continuous opportunity to view the sun and the moon, to observe the progression of their cycles, and to see the changes in their relationships to the surrounding landscape and in patterns of shadow and light.

The sun: The yearly cycle of the sun is evident by its excursions to the extreme positions: rising in the northeast at the summer solstice and in the southeast at the winter solstice; setting in the northwest at the summer solstice and in the southwest at the winter solstice. At equinox, in the middle of these excursions, it rises and sets east and west. At solar noon, in the middle of its daily excursion, the sun is on the meridian—in other words, aligned with the north-south axis.

The cardinal directions (0°, 90°) are regarded in this paper as having the solar associations of equinox and meridian passage.[7] In a location surrounded by significantly elevated topography, however, the equinox sun can also be observed on the visible horizon in sunrise and sunset azimuths that are not the cardinal east-west axis of the sensible horizon.

The moon: The moon's standstill cycle is longer (18.6 years) and more complex than the sun's cycle, but its rhythms and patterns also can be observed in its shifting positions on the horizon, as

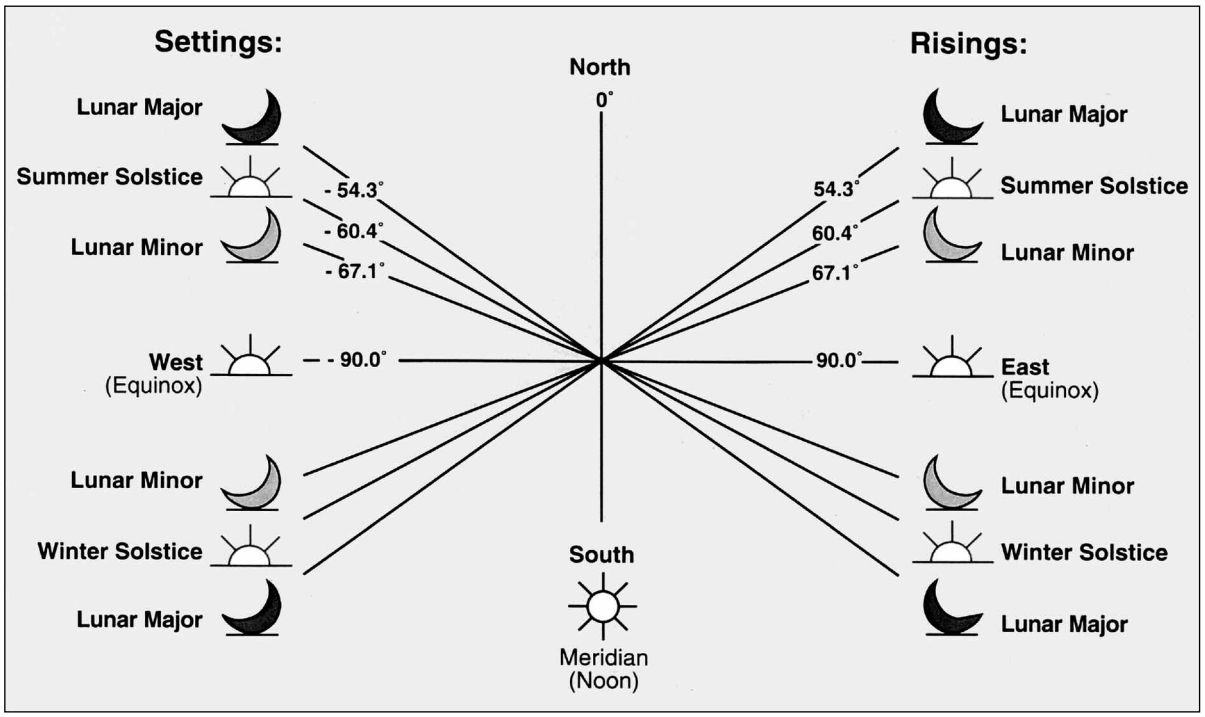

FIGURE 9.5. Azimuths of the rising and setting of the sun and moon at the extremes and mid-positions of their cycles, at the latitude (36° north) of Chaco Canyon. The meridian passage of the sun is also indicated. The lunar extremes are the northern and southern limits of rising or setting at the major and minor standstills. (Fabian Schmid, Davis, Inc.; and Suzanne Samuels, By Design Graphics; © 1995 by The Solstice Project)

well as in its relationship to the sun (see also Aveni 1980: Chapter 3). In its excursions each month it shifts from rising roughly in the northeast to rising roughly in the southeast and from setting roughly in the northwest to setting roughly in the southwest, but a closer look reveals that the envelope of these excursions expands and contracts through the 18.6-year standstill cycle. In the year of the major standstill, this envelope is at its maximum width, and at the latitude of Chaco, the moon rises and sets approximately 6.1° north and south of the positions of the rising and setting solstice suns. These positions are the farthest to the northeast and northwest and southeast and southwest that the moon ever reaches. In the year of the minor standstill, nine to ten years later, the envelope is at its minimum width, and the moon rises and sets approximately 6.7° within the envelope of the rising and setting solstice suns.

The progression of the sun and the moon in their cycles can also be quite accurately observed in their changing heights at meridian passage and in the accompanying shifts in shadow patterns.

A number of factors, such as parallax and atmospheric refraction, can shift and broaden the range of azimuth where the risings and settings of the solstice suns and the standstill moons appear on the horizon. In addition, judgments in determining a solar or lunar event introduce uncertainties. These judgments involve determining which portion of the object to sight on and what time to sight it in its rising or setting, as well as identifying the exact time of a solstice or a standstill. Calculations for the latitude and environment of the Chaco region show the standard deviation developed from these sighting conditions and uncertainties: 0.5° in locating a solstice event; 0.5° in locating the minor standstill; and 0.7° in locating the major standstill (Sinclair and Sofaer 1993; see also Hawkins 1973:287–288).

The Solstice Project surveyed the orientations of the fourteen largest buildings of the Chaco cultural region as ranked by room count (Powers, Gillespie, and Lekson 1983) (Figures 9.1 and 9.3, Table 9.1). The group comprises twelve rectangular and two crescent-shaped buildings that contained 115 to 695

TABLE 9.1. Sizes and Orientations of Major Chacoan Buildings (Positive azimuths are east of north; negative azimuths are west of north.)

Building	Number of Rooms	Area (m^2)	Length of Principal Wall or Axis (m)	Orientations of: Princ. Wall or Axis	Perp.	Diagonals
Pueblo Bonito	695	18,530	65	0.21° 0.14°	-89.79° ± 0.14°	
Chetro Ketl	580	23,395	140	69.60° ± 0.50°	-20.40° ± 0.50°	-86.4°
Aztec	405	15,030	120	62.47° ± 0.33°	-27.53° ± 0.33°	86.6° 37.2° -81.4° 24.8°
Pueblo del Arroyo	290	8,990	80	24.79° ± 0.25°	-65.21° ± 0.25°	-1.6° 49.9°
Kin Bineola	230	8,225	110	78.7° ± 3.2°	-11.3° ± 3.2°	-77.6° 54.2°
Peñasco Blanco	215	15,010	100	36.8° ± 1.3°	-53.2° ± 1.3°	
Wijiji	190	2,535	53	83.48° ± 0.15°	-6.52° ± 0.15°	-62.0° 49.2°
Salmon Ruin	175	8,320	130	65.75° ± 0.15°	-24.75° ± 0.15°	88.4° 43.3°
Una Vida	160	8,750	80	-35.18° ± 0.15°	54.82° ± 0.15°	
Hungo Pavi	150	8,025	90	-85.24° ±0.15°	4.76° ±0.15°	-61.4° 70.7°
Pueblo Pintado	135	5,935	70	69.90° ±0.15°	-20.10° ± 0.15°	31.4°
Kin Kletso	135	2,640	42	-65.82° ± 0.64°	24.18° ± 0.64°	87.38° -38.09°
Pueblo Alto	130	8,260	110	88.9° ±1.3°	-1.1° ± 1.3°	-68.6° 64.8°
Tsin Kletzin	115	3,552	40	89° ± 2°	-1° ± 2°	-66° 51°

Note: Number of rooms and area from Powers et al. 1983: Table 41.

rooms and were one to four stories high (Powers, Gillespie, and Lekson 1983). Ten buildings are located in the canyon, and four are located outside the canyon.

The buildings in the survey represent the Chacoans' most elaborate architecture. They include all of the large buildings in the canyon and the only outlying buildings that share the massive scale and impressive formality of the large buildings in the canyon (Lekson 1991; Roney 1992).[8]

All of the buildings in the Solstice Project's studies were developed between the late 800s and 1120s (Lekson 1984; Marshall et al. 1979; Powers, Gillespie, and Lekson 1983). Although the earlier buildings were modified and whole new buildings were constructed within this period, all the buildings that the Solstice Project surveyed were in use and most were being extensively worked on in the last and most intensive phase of Chacoan construction, from 1075 to about 1115 (Lekson 1984).

Six teams, working with the Solstice Project between 1984 and 1989, surveyed the orientations of most of the exterior walls of the twelve rectangular buildings. (The teams did not survey three short exterior walls of the rectangular buildings because the walls were too deteriorated.) The Solstice Project also surveyed the long back wall and the exterior corners of Peñasco Blanco, as well as the two halves of the exterior south wall and the primary interior wall of Pueblo Bonito, which approximately divides the plaza. In addition, the Solstice Project surveyed the dimensions of most of the exterior walls of the fourteen buildings. The teams established references at the sites by orienting to the sun, Venus, Sirius, or Polaris, or by tying to first- and second-order survey control stations.

Most of the walls are quite straight and in good condition at ground level and can be located within a few centimeters. Ten to thirty points were established along the walls and were measured in relation to the established references. These values were averaged to calculate the orientations of the walls. The Solstice Project was able to estimate based on multiple surveys of several walls that most of its measurements are accurate to within 0.25° of the orientation of the original walls. (Table 9.1 indicates where the survey was less accurate.)

The survey defined the orientations of the twelve rectangular buildings as either the direction of the longest wall (termed here the "principal" wall) or the perpendicular to this wall.[9] In all but one of the rectangular buildings, this perpendicular represents the "facing" direction of the building, the direction that crosses the large plaza. With respect to the crescent-shaped buildings, the orientation of Pueblo Bonito is defined as the primary interior wall that approximately divides the plaza and the perpendicular to that wall, which corresponds closely in its orientation to that of a major exterior wall.[10] The orientation of Peñasco Blanco is defined by its symmetry as the line between the ends of the crescent and the perpendicular to this line (Figure 9.6).

The results of the survey show that the orientations of eleven of the fourteen major buildings are associated with one of the four solar or lunar azimuths on the sensible horizon (Tables 9.1 and 9.2, and Figure 9.6).[11] Three buildings (Pueblo Bonito, Pueblo Alto, and Tsin Kletzin) are associated with the cardinal directions (meridian and equinox). One building (Aztec) is associated with the solstice azimuth. Five buildings (Chetro Ketl, Kin Kletso, Pueblo del Arroyo, Pueblo Pintado, and Salmon Ruin) are associated with the lunar minor standstill azimuth (Figure 9.7), and two buildings (Peñasco Blanco and Una Vida) are associated with the lunar major standstill.[12]

The orientations of the eleven major buildings that are associated with solar and lunar azimuths fall within 0.2° and 2.8° of the astronomical azimuths on the sensible horizon. Of these eleven, nine fall within 0.2° and 2.1° of the astronomical azimuths. The remaining two buildings, Chetro Ketl and Pueblo Pintado, are oriented respectively within 2.5° and 2.8° of the azimuth of the lunar minor standstill. (The wider differences in the orientations of these latter buildings from the lunar minor standstill are in the direction away from the solstice azimuth, which reinforces the conclusion that these buildings are associated with the moon rather than the sun.)

A number of factors (together or separately) could account for the divergence of the actual orientations of the major Chacoan buildings from the astronomical azimuths. These may include small errors in observation, surveying, and construction and a desire by the Chacoans to integrate into their astronomically oriented architecture symbolic relationships to significant topographic features and/or other major Chacoan buildings. (See for example the discussion in this essay of the solar-lunar regional pattern among the major Chacoan buildings.)[13]

The Solstice Project found that the eleven buildings that are oriented to astronomical events on the sensible horizon are also oriented to the same events on the visible horizon. The reason for this is that the topography introduces no significant variable in the observation of the rising or the setting astronomical events from these buildings. The divergence of the orientations of these buildings from the azimuths of astronomical events in one direction on the visible horizon (0.5° to 2.5°) is approximately the same as the divergence described above of their orientations from the azimuths of the same astronomical events on the sensible horizon.[14] The 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

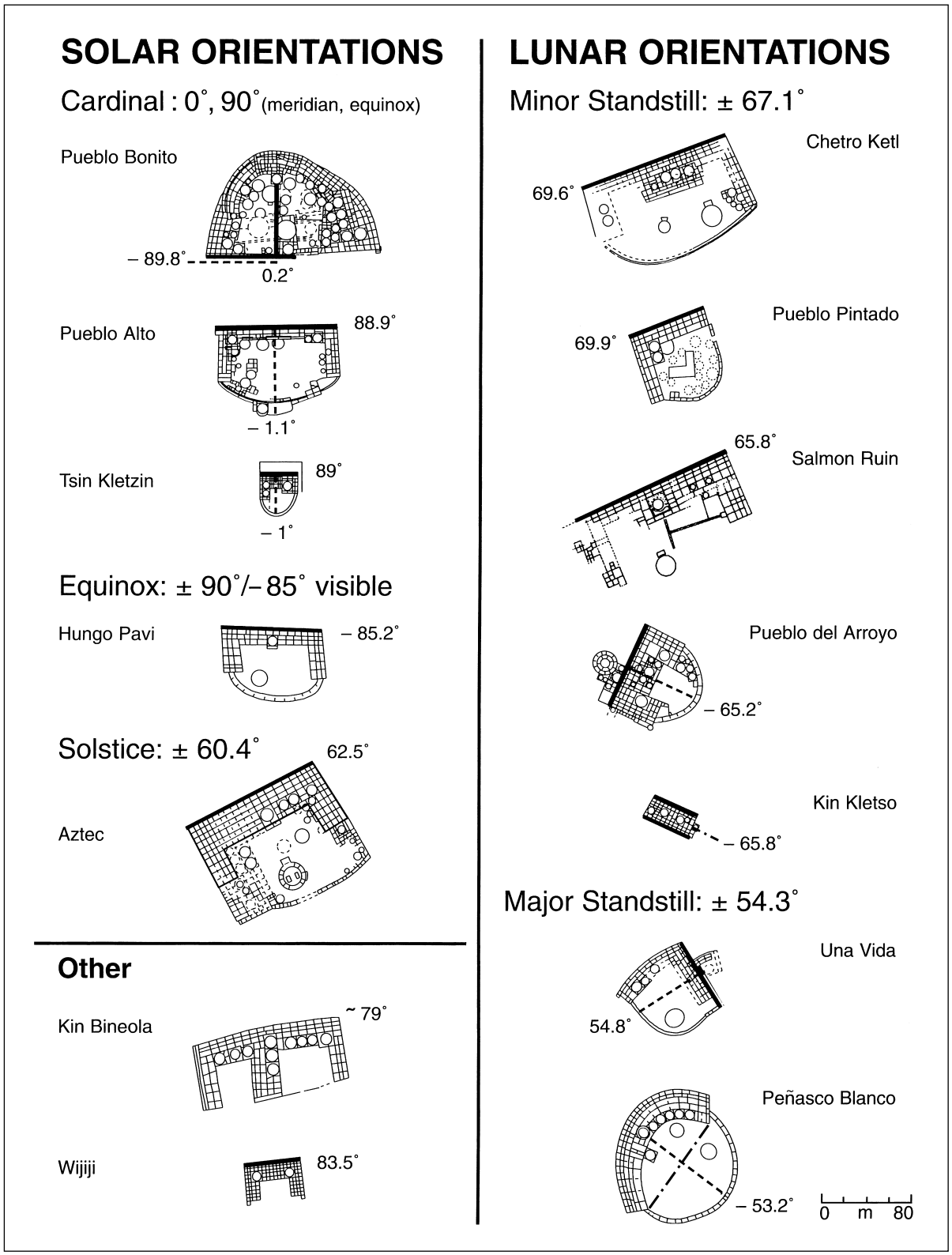

FIGURE 9.6. Orientations of the fourteen major Chacoan buildings shown in relation to the astronomical azimuths on the sensible horizon. For one building, Hungo Pavi, the orientation to the equinox sunrise on the visible horizon also is indicated. (Suzanne Samuels, By Design Graphics; © 1995 by The Solstice Project)

Table 9.2. Orientations of Major Chacoan Buildings (Positive azimuths are east of north; negative azimuths are west of north.

	Principal Wall or Axis	Perpendicular	
Pueblo Bonito	0.2°	-89.8°	0°, 90° Cardinal (meridian, equinox)
Pueblo Alto	88.9°	-1.1°	
Tsin Kletzin	89.0°	-1.0°	
Hungo Pavi	-85.2°		-85° Equinox/visible
Aztec	62.5°		60.4° Solstice
Peñasco Blanco		-53.2°	54.3° Lunar Major Standstill
Una Vida		54.8°	
Pueblo del Arroyo		-65.2°	67.1° Lunar Minor Standstill
Kin Kletso	-65.8°		
Salmon Ruin	65.8°		
Chetro Ketl	69.6°		
Pueblo Pintado	69.9°		
Wijiji	83.5°		
Kin Bineola	~ 79.0°		

buildings. The Solstice Project finds no evidence that the Chacoans were interested in making such a distinction in the case of eleven buildings.

Hungo Pavi, the twelfth building, appears to be oriented too far (4.8°) from the equinox rising or setting sun on the sensible horizon to qualify as an orientation associated with the solar azimuths on that horizon. It is, however, oriented to within one degree of the visible equinox sunrise.[15] Because of the topography, there is no corresponding visibility from Hungo Pavi to the equinox setting sun.

With respect to Wijiji and Kin Bineola, there appear to be no solar or lunar events associated with either the sensible or the visible horizon.[16] To conclude, orientation to the extremes and midpositions of the solar and lunar cycles apparently played a significant role in the construction of the primary Chacoan architecture. No utilitarian reasons appear to explain the astronomic orientations of twelve of the fourteen major buildings.

Other researchers of prehistoric puebloan buildings report solar and lunar orientations and associations. At Hovenweep, in southern Utah, the orientations and locations of portholes of certain tower-like structures appear to be related to the solar cycle (Williamson 1984). Chimney Rock, an outlying Chacoan building in southern Colorado, appears to have been situated for its view of the major northern standstill moon rising between natural stone pillars, "chimney rocks" (Malville and Putnam 1989; Malville et al. 1991). The relationship of this building to the lunar major standstill moon is underscored by the close correspondence of the tree-ring dates of its timbers with the occurrences of the lunar major standstill (1075 and 1094) at the peak of the Chacoan civilization. These findings in the outlying region of the Chacoan culture, as well as earlier findings of solar and lunar light markings in Chaco Canyon, support the phenomenon of solar and lunar orientations in the primary Chacoan buildings.

Solar-Lunar Geometry Internal to the Major Chacoan Buildings

The Solstice Project's survey of the eleven rectangular major Chacoan buildings found strictly repeated internal diagonal angles and a correspondence between these angles and astronomy. The internal angles formed by the two diagonals and

the long back walls of the rectangular buildings cluster in two groups (Figure 9.8A): sixteen angles in nine buildings are between 23° and 28°;[17] and six angles in four buildings are between 34° and 39°. (One of the buildings, Aztec, was constructed first as a rectangular building with shorter side walls [Aztec I] that were extended in a later building stage [Aztec II] [Ahlstrom 1985]. It is of interest that when the side walls of Aztec I were extended to form Aztec II, the builders shifted from one preferred angle to the other.)

At the latitude of Chaco, the angles between the lunar standstill azimuths on the sensible horizon and the east-west cardinal axis are 22.9° and 35.7°, respectively (Figure 9.8B). The correspondence between these angles of the solar-lunar relationships and the internal diagonal angles is intriguing. It suggests that the Chacoans may have favored these particular angles in order to incorporate a geometry of the sun and moon in the internal organization of the buildings.[18]

In addition, three rectangular buildings (Pueblo Alto, Salmon Ruin, and Pueblo del Arroyo) are oriented on the sensible and visible horizons along one or both of their diagonals, as well as on their principal walls or perpendiculars, to the lunar minor standstill azimuth and to one of the cardinals (Table 9.1). The Chacoans may have intended the two phenomena—internal geometry and external orientation—to be so integrated that these three rectangular buildings would have both solar and lunar orientation.

A similar solar-lunar geometry appears to have guided the design of all of the major Chacoan buildings (Sofaer 1994).[19] Furthermore, as with the three rectangular buildings discussed above, it appears that certain other of the major buildings also contain both solar and lunar orientations.

Solar-Lunar Regional Pattern between the Major Chacoan Buildings

Having seen that the Chacoans oriented and internally proportioned their major buildings in relationship to astronomy, the Solstice Project asked if the geographical relationships between the major buildings likewise expressed astronomical significance.

One scholar observed that four key central buildings are organized in a cardinal pattern (Fritz 1978).

Figure 9.7. The moonrise seen through two doorways of Pueblo del Arroyo on April 10, 1990, when the moon rose at –67.5° on the visible horizon, close to the 67.1° azimuth of the lunar minor standstill. Although we do not know whether an exterior wall, which is now deteriorated, blocked this view, the photograph illustrates the framing of the minor standstill moon by other exterior doorways and it conveys the perpendicular direction of the building toward the minor standstill moon (see Figure 9.6). (Photograph by Crawford MacCallum, © 1990 by The Solstice Project)

The line between Pueblo Alto and Tsin Kletzin is north-south; the line between Pueblo Bonito and Chetro Ketl is east-west. This work also showed that these cardinal interrelationships of four central buildings involved a symmetric patterning. The north-south line between Pueblo Alto and Tsin Kletzin evenly divides the east-west line between Pueblo Bonito and Chetro Ketl.

The Solstice Project found, in addition, that three of the four buildings involved in these cardinal interbuilding relationships are cardinal in their individual building orientations (Table 9.3; Figures 9.2, 9.9, and 9.10).[20] These findings suggest that the Chacoans coordinated the orientations and locations of several central buildings to form astronomical interbuilding relationships. The Project

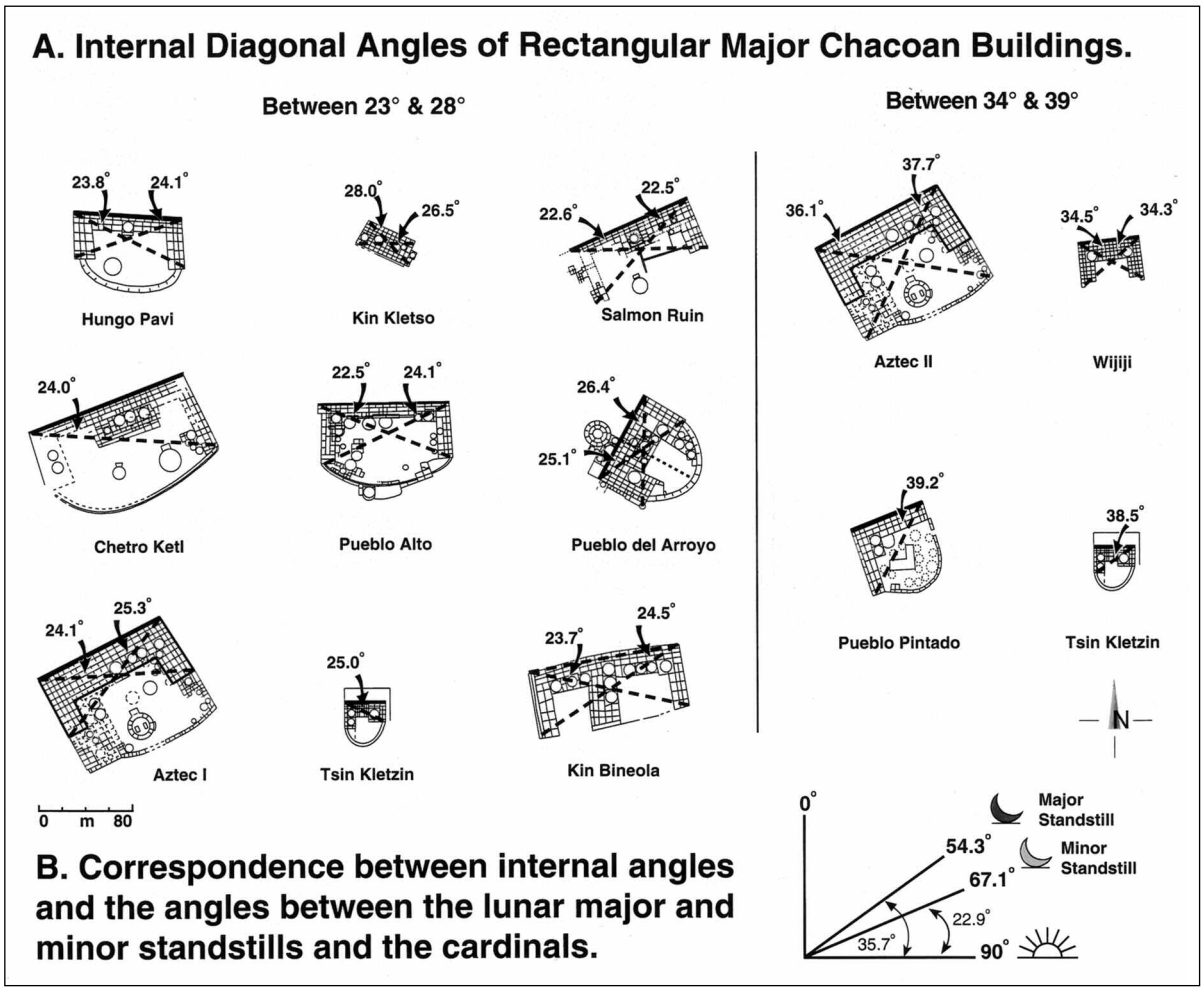

FIGURE 9.8. (A) The eleven rectangular major Chacoan buildings, showing their diagonals and internal diagonal angles. (Two building phases at Aztec are shown.) (B) The correspondence of these angles to the angles between the lunar standstill azimuths and the cardinal directions. (Suzanne Samuels, By Design Graphics; © 1995 by The Solstice Project)

then asked if there were other such relationships between the major buildings.

As Table 9.3 and Figures 9.9 and 9.11 show, numerous bearings between thirteen of the fourteen major buildings align with the azimuths of the solar and lunar phenomena associated with the individual buildings.[21] Only one major building, Salmon Ruin, is not related in this manner to another building. In questioning the extent to which these astronomical interbuilding relationships were intentionally developed by the Chacoans, the Solstice Project examined the pattern formed by them. In a manner similar to the central cardinal patterning, the bearings between the lunar-oriented buildings and other buildings appear to form lunar-based relationships that are symmetric about the north-south axis of the central complex (Figure 9.11).

The two isolated and remote outlying buildings, Pueblo Pintado and Kin Bineola, 27 km and 18 km, respectively, from the canyon center, are located on lines from the central complex that correspond to the bearings of the lunar minor standstill. As in the cardinal patterning, these lunar-based interbuilding relationships are underscored by the fact that they involve buildings that also are oriented individually to the lunar standstills (for one example see Figure 9.12a). Specifically, Chetro Ketl, Pueblo del Arroyo, and Kin Kletso—the three buildings in the central complex that are oriented to the lunar minor standstill—also are related to Pueblo

Table 9.3. Astronomical Bearings between Astronomically Oriented Buildings (Positive azimuths are east of north; negative azimuths are west of north)

Astronomically Oriented Buildings	Astronomical Bearings to Other Buildings			
	Buildings	Azimuth (degrees)	Differences between astronomical azimuth and interbuilding bearings (degrees)	Distance (km)
Cardinal Buildings associated azimuths 90°/0°				
Pueblo Bonito	Chetro Ketl	-88.7	-1.3	0.72
	Aztec	-2.2	2.2	86.3
Pueblo Alto	Tsin Kletzin	0.6	-0.6	3.7
	Aztec	-2.5	2.5	86.0
Hungo Pavi	- -	- -	- -	- -
Tsin Kletzin	Pueblo Alto	0.6	-0.6	3.7
	Aztec	-2.3	2.3	89.0
Solstice Building associated azimuth ±60.4°				
Aztec	- -	- -	- -	- -
Lunar Minor Buildings associated azimuth ±67.1°				
Chetro Ketl	Kin Bineola	69.3	-2.2	17.1
	Pueblo Pintado	-69.9	2.8	27.2
	Kin Kletso	-69.9	2.8	1.5
Pueblo del Arroyo	Hungo Pavi	-69.3	2.2	3.4
	Kin Bineola	67.8	-0.7	16.2
	Wijiji	-65.9	-1.2	8.4
Salmon Ruin	- -	- -	- -	- -
Pueblo Pintado	Chetro Ketl	-69.9	2.8	27.2
	Pueblo Bonito	-70.3	3.2	27.9
	Peñasco Blanco	-68.6	1.5	32.1
	Pueblo Alto	-68.0	0.9	27.8
	Kin Kletso	-69.9	2.8	28.7
Kin Kletso	Chetro Ketl	-69.9	2.8	1.5
	Pueblo Pintado	-69.9	2.8	28.7
	Wijiji	-64.5	-2.6	9.0
	Pueblo Alto	65.8	-1.3	1.3
	Kin Bineola	65.9	-1.2	16.0
	Hungo Pavi	-65.2	-1.9	4.0
Lunar Major Buildings associated azimuth ±54.3°				
Peñasco Blanco	Pueblo Bonito	-55.9	1.6	4.2
	Pueblo del Arroyo	-55.8	1.5	4.1
	Una Vida	-56.7	2.4	9.8
	Kin Bineola	55.0	0.7	14.3
Una Vida	Chetro Ketl	-51.3	-3.0	4.8
	Pueblo Bonito	-55.8	1.5	5.4
	Peñasco Blanco	-56.7	2.4	9.8
	Pueblo del Arroyo	-55.8	3.0	5.7
	Kin Kletso	-55.8	1.4	6.3

Pintado and Kin Bineola on bearings oriented to the lunar minor standstill. It is of interest that Pueblo Pintado also is oriented to the lunar minor standstill (Figures 9.11 and 9.12a).[22] In addition, two major buildings, Wijiji and Hungo Pavi, located outside of the central complex but within the canyon, also are on the bearing from the central complex to Pueblo Pintado and to the lunar minor standstill (Figure 9.11).[23]

The relationship of the central complex to Pueblo Pintado (southeast of the canyon) is to the rising of the southern minor standstill moon; the relationship of the central canyon complex to Kin Bineola (southwest of the canyon) is to the setting of this same moon. Thus the north-south axis of the central complex is the axis of symmetry of this moon's rising, meridian passage, and setting, as well as the axis of the ceremonial center and of the

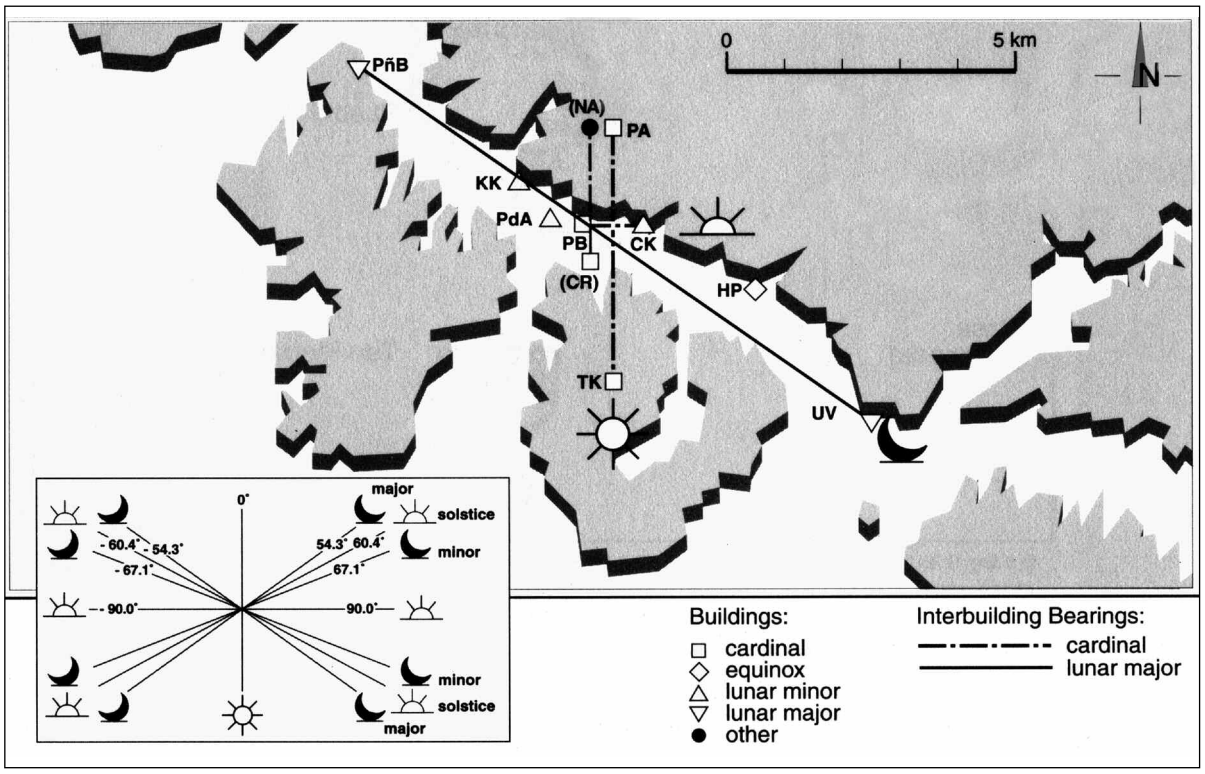

FIGURE 9.9. The locations and orientations of the buildings in Chaco Canyon. The diagram shows the bearings between buildings that correlate with the orientations of individual buildings to the cardinal directions and to the lunar major standstill azimuths. (Fabian Schmid, Davis, Inc.; © 1995 by The Solstice Project)

relationships of these significant outlying structures to that center.

It is of further note that Pueblo Pintado and Kin Bineola are regarded as having particularly significant relationships with the buildings in the canyon. One archaeologist reports that these two buildings are more like the canyon buildings than they are like other outlying buildings, and he suggests, because of their positions to the southeast and southwest of the canyon, that they could be viewed as the "gateway communities" (Michael P. Marshall, personal communication 1990).

This lunar-based symmetrical patterning about the north-south axis of the central ceremonial complex also is expressed in the relationships of the lunar major–oriented buildings, Una Vida and Peñasco Blanco, to that complex (Figure 9.9). Without knowing the astronomical associations of these buildings, other scholars had observed the symmetrical relationship of Una Vida and Peñasco Blanco to the north-south axis, as described above, between two major buildings in the central complex, Pueblo Alto and Tsin Kletzin; and one of these scholars described this relationship as, along with the cardinal relationships of the central complex, "establishing the fundamental symmetry of the core development of Chaco Canyon" (Fritz 1978; Stein and Lekson 1992).

From the central complex, bearings to the major standstill moon are also the bearings to Una Vida and Peñasco Blanco, the only major Chacoan buildings that are oriented to the lunar major standstill (Figure 9.12b). This correspondence of the interbuilding relationships with the individual building orientations is again what is found with the cardinal and lunar minor relationships of the major buildings. Here it also is striking that the two buildings are equidistant from the north-south axis of the central complex. It is of further interest that the bearing from Peñasco Blanco to Kin Bineola also corresponds with the bearing to the lunar major standstill (Figure 9.11).[24] Una Vida, Peñasco Blanco, and Kin Bineola, along with Pueblo Bonito, share the earliest dates among the major

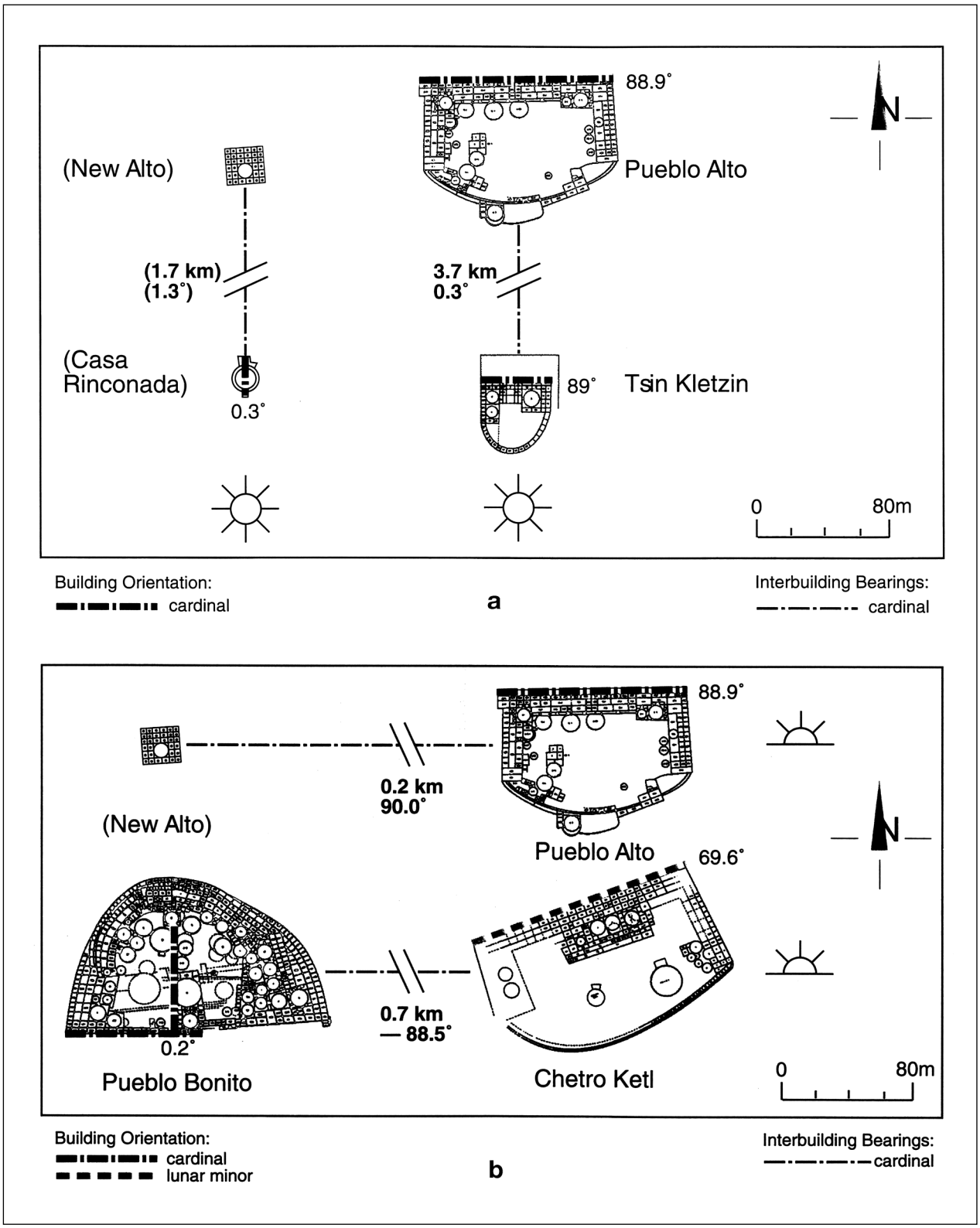

FIGURE 9.10. The relationships between pairs of Chacoan buildings in the central complex that are connected by astronomical bearings: (a) north-south connections, and (b) east-west connections. (Fabian Schmid, Davis, Inc.; © 1995 by The Solstice Project)

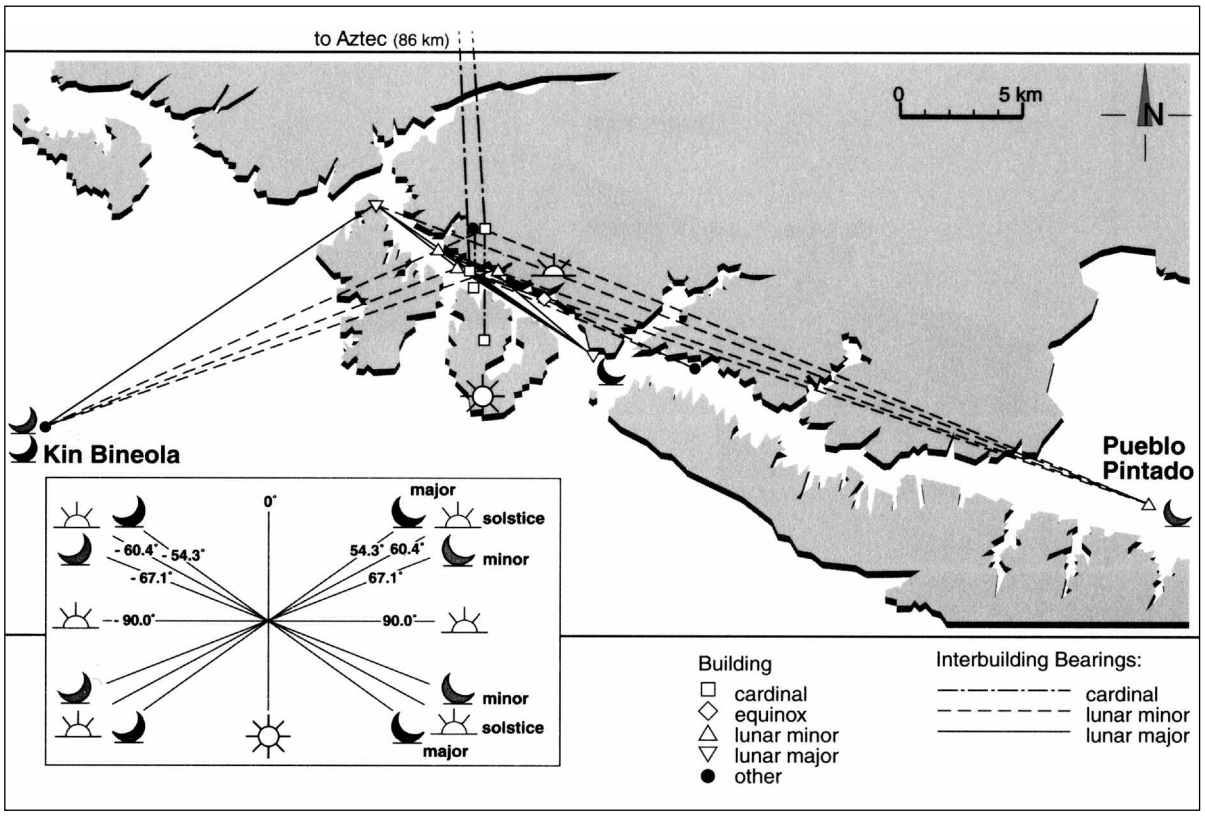

FIGURE 9.11. The locations and orientations of twelve of the major Chacoan buildings, including Kin Bineola and Pueblo Pintado outside the canyon. The diagram shows bearings between buildings that correlate with the orientation of the individual buildings to the cardinal directions and the lunar major and minor standstill azimuths. (Fabian Schmid, Davis, Inc.; © 1995 by The Solstice Project)

Chacoan buildings (Lekson 1984; Marshall et al. 1979).

Thus, from the central complex of Chaco Canyon, in the year of the major standstill moon, there was a relationship to that moon, as it rose farthest south in its full cycle, that also incorporated a relationship to Una Vida; and, in that same year, as the moon made its excursion to setting farthest north in its full cycle, it was on a bearing from the central complex that incorporated a relationship with Peñasco Blanco. Furthermore, in that year, the southern major standstill moon that rose on the bearing from Peñasco Blanco to Una Vida and the central complex would set on the bearing from Peñasco Blanco to the outlying major building, Kin Bineola. This phenomenon may have been intended to draw Kin Bineola into a lunar major relationship with Peñasco Blanco and with Peñasco Blanco's lunar major connection with Una Vida and the central canyon complex.[25]

At the other end of the lunar standstill cycle, nine to ten years later, in the year of the minor standstill moon, two outlying buildings, Kin Bineola and Pueblo Pintado, would be drawn into relationship with the central complex by their locations on bearings from the central complex that are to the rising and setting of the southern minor standstill moon.

Finally, in the face of the evidence that the Chacoans oriented and proportioned their major buildings in relationship to the solar and lunar cycles—and also interrelated their cardinally oriented buildings in a cardinal and symmetrical pattern—it is difficult to dismiss as coincidental the lunar-based interbuilding relationships, which are based on the same principles.[26] The recurring correlation of the interbuilding lines with the astronomical phenomena associated with the individual Chacoan buildings, and the centrally and symmetrically organized design of these lines, suggest that

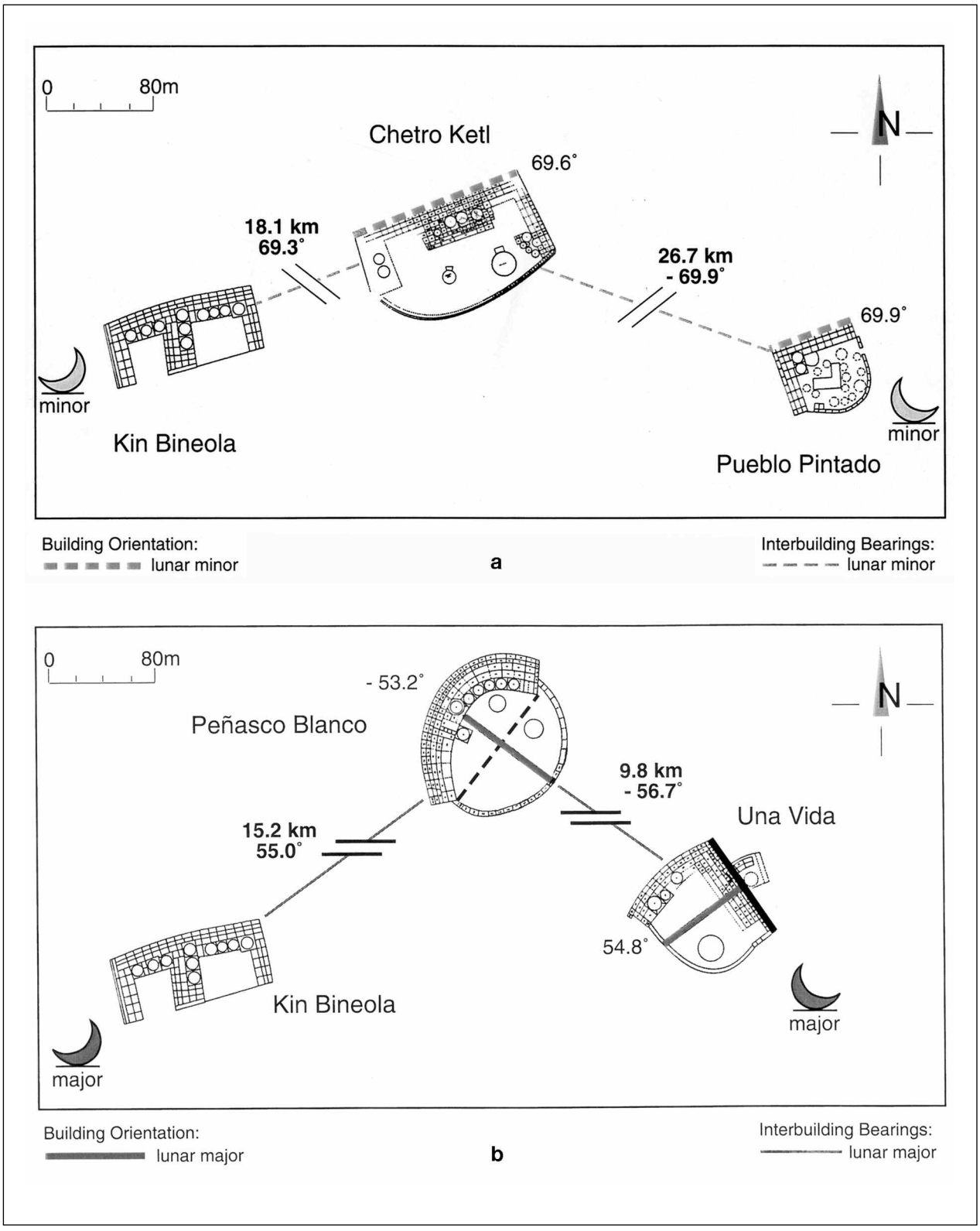

FIGURE 9.12. The relationships between two groups of three major Chacoan buildings connected by astronomical bearings aligned to (a) the lunar minor standstill and (b) the lunar major standstill. (Fabian Schmid, Davis, Inc.; © 1995 by The Solstice Project)

the Chacoan culture coordinated the locations and orientations of many of its major buildings to form an interbuilding regional pattern that commemorates and integrates the cycles of the sun and the moon.[27]

Most of the buildings related by astronomical interbuilding lines are not intervisible. In general, this is because the canyon and other topographic features block the views between the buildings, especially those related over long distances. Thus the astronomical interbuilding lines could not have been, in general, used for astronomical observations or predictions.[28] It is of interest that the Chacoan roads, which are typified by their rigorous straight course, frequently appear to ignore topographic obstacles and connect sites that are great distances apart and are not intervisible.

Consideration of the Evolution of Astronomical Expression in Chacoan Architecture

The evidence of a conscious effort by the Chacoans to orient and interrelate their buildings on astronomical bearings raises a number of questions for further study. Were the building locations selected because they fell on astronomical bearings from other buildings? Were the interbuilding bearings developed from a plan? Were some buildings originally located for reasons other than astronomy and later drawn into the astronomical regional pattern?

It will probably never be known how great a role astronomy played in the decisions regarding the placement of the Chacoan buildings. Nor does it appear possible to know the extent of planning that preceded the development of the astronomical expressions in Chacoan architecture.[29] The data presently available on the chronology of the construction of the major buildings, however, do provide some insight into the history of the development of astronomical orientations and interrelationships among the major Chacoan buildings.

These data show that astronomical orientation appears to have played a part in Chacoan architecture from the earliest to the latest phases of its construction. Pueblo Bonito's north-south axis was incorporated in a major interior wall in the building's earliest design in the late 800s (Stein, Suiter, and Ford 1997), and this north-south axis was extended and elaborated in the construction of the primary interior wall during the building's last phase of construction, in the late 1090s. The cardinal orientations of Pueblo Alto and Tsin Kletzin were developed in the early 1000s and the early 1100s, respectively. The lunar orientations were developed from the mid 900s (in Una Vida) through the early 1100s (in Kin Kletso).

Available data on the evolution of individual buildings show that, for most of the fourteen major buildings, the walls that are revealed today—and that were the subject of this study—are the original walls of these buildings, or that they follow closely the orientation of the buildings' prior walls. These data indicate that the orientation of two of the fourteen buildings changed significantly from one building phase to another.

It is also of interest that three of the four buildings in which the earliest dates were found among the fourteen major buildings (Peñasco Blanco, Una Vida, and Kin Bineola) are involved in the lunar major standstill interbuilding bearings. (Curiously, Peñasco Blanco is one of the two buildings that shifted from an earlier orientation [of −67°, in 900–915] to a later orientation [of −53.2° in 1050–1065].)

With further dating information it may be possible to know more of the evolution of astronomical expression in the Chacoan buildings. Such information could also shed light on the intriguing possibility that there may be, as there was found to be at Chimney Rock, correlations between the building phases of the major Chacoan buildings and the astronomical cycles (Malville and Putnam 1989).

Speculations on the Chacoans' Experience

Many of the major buildings appear to incorporate interesting views and experiences of the sun and moon at the extremes and mid-positions of their cycles. For example, each day at meridian passage of the sun, the mid-wall which approximately divides the massive structure of Pueblo Bonito casts no shadow. Similarly, the middle of the sun's yearly passage is marked at Pueblo Bonito as the equinox sun is seen rising and setting closely in line with the western half of its south wall. Thus, the middle of the sun's daily and yearly journeys are visibly in

alignment with the major features of this building, which is at the middle of the Chacoan world.[30]

From many of the other major buildings, the sun and moon at the extreme positions of their cycles would be seen rising and/or setting along the long back walls or across the plazas at angles perpendicular to the back walls. In buildings oriented in their facing directions to the lunar standstill azimuths, the rising or setting moon, near its extremes, would be framed strikingly by the doorways (Figure 9.7).

Also visually compelling would have been the view from Peñasco Blanco of the moon rising at the major standstill position. This building is located 5.4 km northwest of Pueblo Bonito near the top of West Mesa. From it, one would view the southern major standstill moon rising in line with the mid-axis of the building's crescent, and also on a bearing to Pueblo Bonito and to the central complex of the canyon. The bearing would appear to continue through the valley of the canyon to the rising moon on the horizon. This event marked the time when the moon rises farthest south in its full cycle, once every eighteen to nineteen years.

This dramatic view of the major standstill moonrise also embodied astronomical and symmetrical relationships to nonvisible objects. Out of sight, but on the alignment between the viewer at Peñasco Blanco and the rising moon, is Una Vida, the one other of the Chacoan buildings that is oriented to the major standstill moon. Some viewers would likely have known of this nonvisible building's position on the bearing from Peñasco Blanco to the major rising moon, and they may also have known of Una Vida's and Peñasco Blanco's symmetrical relationship with the north-south axis of the central complex—in other words, that the two buildings are located the same distance from the north-south axis. Seeing the southern major standstill moon set over the mesa rise behind Peñasco Blanco would have conveyed to some Chacoans that as it set, out of view, on the sensible horizon it was on a bearing with Kin Bineola, out of view, 14.3 km to the southwest. Thus the experience of viewing the moon rising and setting at its southern major standstill from Peñasco Blanco would have involved seeing certain visible—and knowing certain nonvisible—aspects of the building's relationships with astronomy and with other major Chacoan buildings.

In the sculptured topography of the southern Rockies, at a location 150 km north of Chaco, the Chacoans witnessed a spectacular view of the moonrise at its major standstill. From their building situated high on an outcrop at Chimney Rock, once every eighteen to nineteen years, the Chacoans watched the moon rise between two nearby massive stone pillars.

Thus, while certain aspects of Chacoan architecture embed relationships on astronomical bearings to nonvisible objects, others appear to have been designed and/or located to frame, or to align to, bold displays of astronomy. Furthermore, some Chacoan astronomical expressions are on bearings that ignore topographic features, while others use topography dramatically to reinforce the visual effects of the architectural alignments to the sun and moon.

Concluding Discussion

Peoples throughout history and throughout the world have sought the synchronization and integration of the solar and lunar cycles. For example, in times and places not so remote from Chaco, the Mayas of Mesoamerica recognized the 19-year metonic cycle—the relationship of the phase cycles of the moon to the solar cycle—and noted elaborately, in the Dresden Codex, the pattern of lunar eclipses (Aveni 1980).[31] The Hopi, a Pueblo people living today in Arizona, are known to have synchronized the cycles of the sun and moon over a two-to-three-year period in the scheduling of their ceremonial cycle (McCluskey 1977). At Zuni Pueblo in northwestern New Mexico, the joining of Father Sun and Mother Moon is sought constantly in the timing of ceremonies (Tedlock 1983).

Each of the Chacoan expressions of solar and lunar cosmology contains within it this integration of the sun and the moon. For example, at the three-slab site on Fajada Butte, the sunlight in a dagger-like form penetrates the center of the large spiral at summer solstice near midday, the highest part its cycle (Sofaer, Zinser, and Sinclair 1979); and, as though in complement to this, the moon's shadow crosses the spiral center at the lowest point of its cycle, the minor standstill (Sofaer, Sinclair, and Doggett 1982). In the same way, the outer edges of the spiral are marked by the sun in light patterns at

winter solstice, and the moon's shadow at its maximum extreme is tangent to the left edge.

This integration of the sun and the moon is in the three expressions of solar-lunar cosmology in Chacoan architecture. Five major buildings commemorate the solar cycle: three in their cardinal orientations, one in its equinox orientation, and one in its solstice orientation. Seven of the other nine major buildings commemorate the lunar standstills: five the minor standstill, and two the major standstill. And the overall patterning of the buildings joins the two sets of lunar-oriented buildings into relationship with the cardinal-solar center in a symmetrically organized design. The geometry of the rectangular buildings again expresses the joining of sun and moon; the internal angles related to the cardinal and lunar azimuths bring a consciousness of each of these cycles into the layout of the buildings.

Commemoration of these recurring cycles appears to have been a primary purpose of the Chaco phenomenon. Many people must have been involved over generations in the planning, development, and maintenance of the massive Chacoan constructions. The work may have been accomplished in relatively short periods of time (Lekson 1984) and perhaps in episodes timed to the sun and moon. This activity would have unified the Chacoan society with the recurring rhythms of the sun and moon in their movements about that central ceremonial place, Chaco Canyon.[32]

There are many parallels to the cosmological patterning of the Chacoan culture in the architectural developments of the Mesoamerican cultures. These developments occurred in the region to the south of Chaco, for several centuries before, during, and after Chaco's florescence.

It is observed that "the coordination of space and time in the Mesoamerican cosmology found its expression in the orientations of pyramids and architectural complexes" (Broda 1982) and in the relationships of these complexes to outlying topography and buildings (Broda 1993). Ceremonies related to the dead and timed to the astronomical cycles occurred in Mesoamerican centers (Broda 1982). In central structures of the ceremonial complexes, light markings commemorated the zenith passage of the sun (Aveni 1980). Certain of the ceremonial centers were organized on axes close to the cardinal directions (Aveni 1980; Broda 1982). It is stated that cosmological expression in Mesoamerica "reached an astonishing degree of elaboration and perfection," and that its role was "to create an enduring system of order encompassing human society as well as the universe" (Broda 1993). A Mesoamerican archaeoastronomer comments that "a principle of cosmic harmony pervaded all of existence in Mesoamerican thought" (Aveni 1980).

The parallels between Mesoamerica and Chaco illustrate that the Chacoan and Mesoamerican peoples shared common cultural concerns. In addition, the several objects of Mesoamerican origin that were found in Chacoan buildings indicate that the Chacoans had some contact with Mesoamerica through trade.

In the complex cosmologies of the historic Pueblo peoples, descendants of the Chaocans, there is a rich interplay of the sun and moon.[33] Time and space are integrated in the marking of directions that order the ceremonial structures and dances, and in the timing of ceremonies to the cycle of the sun and the phases of the moon. The sun and the moon are related to birth, life, and death.[34] Commemoration of their cycles occurs on some ceremonial occasions in shadow-and-light patterns. For instance, sunlight or moonlight striking ceremonial objects or walls of ceremonial buildings may mark the solstices, as well as the meridian passage of the solstice sun and the full moon, and time the beginning and ending of rituals.

In many Pueblo traditions, the people emerged in the north from the worlds below and traveled to the south in search of the sacred middle place. The joining of the cardinal and solstice directions with the nadir and the zenith frequently defines, in Pueblo ceremony and myth, that sacred middle place. It is a center around which the recurring solar and lunar cycles revolve. Chaco Canyon may have been such a center place and a place of mediation and transition between these cycles and between the worlds of the living and the dead (F. Eggan, personal communication 1990).[35]

For the Chacoans, some ceremonies commemorating the sun and the moon must have been conducted in relatively private settings, while others would have been conducted in public and monumental settings. A site such as the three-slab site

would have been visited probably by no more than two or three individuals, who were no doubt highly initiated, specialized, and prepared for witnessing the light markings.[36] By contrast, the buildings would have been visited by thousands of people participating in ceremony.

The solar and lunar cosmology encoded in the Chacoans' massive architecture—through the buildings' orientations, internal geometry, and geographic relationships—unified the Chacoan people with each other and with the cosmos. This order is complex and stretches across vast reaches of the sky, the desert, and time. It is to be held in the mind's eye, the one that sees into and beyond natural phenomena to a sacred order. The Chacoans transformed an arid empty space into a reach of the mind.

Acknowledgments

The generous help and disciplined work of many individuals made possible the research presented here. We are particularly indebted to Rolf M. Sinclair (National Science Foundation) for his help in the rigorous collection and reduction of large amounts of data, for his thoughtful analysis of naked-eye astronomical observations, and for his help in organizing numerous and complicated surveying trips. We most especially appreciate his dedication to pursuing the truth through thousands of hours of discussion and analysis of the Chacoan material.

We wish to express a special thanks to John Stein (Navajo Nation) for sharing with us, over fifteen years, his many insights to the nonmaterial side of the Chaco phenomenon. To our knowledge, John was the first scholar to speak of Chacoan architecture as "a metaphoric language" and to express the view that the Chacoan roads were built for purposes other than utilitarian functions. He early on saw geometric complexity in the individual buildings and their interrelationships.

Phillip Johnson Tuwaletstiwa (the Hopi Tribe), the late Fred Eggan (Santa Fe), and Jay Miller (Chicago) helped us move from the confines of an engineering and surveying perspective to think of the rich and complex dualities of Pueblo cosmology and their analogies with the Chacoan developments. The late Alfonso Ortiz (University of New Mexico), when first viewing our material on the patterning of Chacoan roads and major buildings, observed that these complex constructions were developed as though they were to be seen from above.

Tuwaletstiwa was also responsible for initiating the surveys that form the basis of our studies. Most of the surveys were carried out by Richard Cohen (National Geodetic Survey), assisted by Tuwaletstiwa, and supplemented by William Stone (National Geodetic Survey). Other surveys were conducted by Robert and Helen Hughes and E. C. Saxton (Sandia National Laboratories); C. Donald Encinias and William Kuntz, with the cooperation of Basil Pouls (Koogle and Pouls Engineering, Inc.); James Crowl and associates (Rio Grande Surveying Service); Scott Andrae (La Plata, NM), assisted by Dabney Ford (National Park Service) and Reid Williams (Rensselaer Polytechnic Institute); and William Mahnke (Farmington, NM).

Michael Marshall (Cibola Research Consultants) shared with us his comprehensive knowledge of Chacoan archaeology, and his keen insights into the Chacoans' use of topography. Stephen Lekson's (University of Colorado) extensive knowledge of the major buildings in Chaco Canyon was invaluable to us. We also benefited from many helpful discussions regarding Chacoan archaeology with John Roney (Bureau of Land Management), Dabney Ford, and Thomas Windes (National Park Service). LeRoy Doggett (U.S. Naval Observatory), Bradley Schaefer (Goddard Space Flight Center), and the late Gerald Hawkins (Washington, DC) assisted with a number of points concerning the naked-eye astronomical observations. Crawford MacCallum (University of New Mexico) photographed the moonrise under unusual lighting conditions.

We thank J. McKim Malville (University of Colorado) for a number of interesting discussions and a tour of several northern prehistoric puebloan building complexes, where he has identified astronomical building orientations and interbuilding relationships, and Murray Gell-Mann (Santa Fe Institute) for joining us for a tour of several major Chacoan buildings and contributing stimulating and encouraging comments on our early analysis of possible astronomical significance in the Chacoan architecture.

William Byler (Washington, DC) once more gave us extremely generous and thoughtful assistance in editing the final manuscript that was published in Morrow and Price's 1997 edited volume by the University of New Mexico Press. The graphics were prepared by Suzanne Samuels (By Design Graphics) and by Fabian Schmid with the cooperation of Davis, Inc. (Washington, DC).

The fieldwork in Chaco Canyon was done with the helpful cooperation of former superintendents, Thomas

Vaughan and Larry Belli, with the thoughtful guidance of National Park Service archaeologist Dabney Ford, and with the generous assistance of many other staff members of Chaco Culture National Historical Park.

Notes

1. For convenience the reader can find most of these papers on the Solstice Project's website: www.solsticeproject.org.

2. The long back walls of five of the ten major buildings located in Chaco Canyon are somewhat parallel to local segments of the north canyon wall. Since there are innumerable locations along this canyon wall where significantly different orientations occur and where these buildings could have been placed, this approximate parallel relationship does not appear to have been a constraint on the orientations of these five buildings.

3. In the literature of Chacoan studies, we find one suggestion of a utilitarian reason for the location of the major buildings, and it applies to only one building. Specifically, it has been suggested that Tsin Kletzin was placed to optimize the direct sight lines to six other buildings (Lekson 1984:231). A suggestion by Judge (1989) that three major buildings "functioned primarily as storage sites to accompany resource pooling and redistribution within the drainage systems they 'controlled'" locates them only generally.

4. For an example of a nonutilitarian Chacoan road, see Dabney Ford's finding of a road connecting the canyon floor with the three-slab site on Fajada Butte (Ford 1993).

5. In addition, the relationship of Pueblo Bonito's design to the solar cycle appears to be symbolically represented in a petroglyph on Fajada Butte in Chaco Canyon. (Sofaer and Sinclair 1989:499; Sofaer 2006).

6. "Sensible horizon" describes the circle bounding that part of the earth's surface if no irregularities or obstructions are present. "Visible horizon" describes the horizon that is actually seen, taking obstructions, if any, into account.

7. It would seem unlikely that the Chacoans, who incorporated cardinal orientations in their architecture, and who also marked the equinoxes and meridian passage in light markings, did not associate the north-south axis with the sun's meridian passage and the east-west axis with the sun's rising and setting positions at equinox.

8. See also Lekson 1991: "Using intrinsic criteria, one could argue that only the Big Four (Salmon Ruin, Aztec, Pueblo Pintado, and Kin Bineola) . . . were identical to Pueblo Bonito and Chetro Ketl." Eventually, the Solstice Project will also study the "medium-size" (Powers et al. 1983) and the more remote Chacoan buildings for possible astronomical significance.

9. In most cases the longest wall is obvious. For the orientation of Pueblo Pintado, values were taken for the longer of the two walls and the perpendicular to it. For Kin Kletso, the orientations of the two long walls of equal length, which differed in orientation by only 0.8°, were averaged. Kin Bineola's principal wall is not a straight wall, but three sections, which vary by several degrees. The sections were averaged in the value given here, and the error quoted (±3°) reflects the differences in the sections.

10. The Solstice Project notes that other scholars have described the cardinal orientation of Pueblo Bonito by the direction of this primary interior wall and the direction of the western half of the south wall (Williamson et al. 1975, 1977). The eastern half of the south wall, which is not perpendicular to the primary interior wall and is oriented to 85.4°, is a curious departure from these perpendicular relationships.

11. The orientation of Hungo Pavi as reported here corrects an error in an earlier paper (Sofaer, Sinclair, and Donahue 1991). The orientations of nine other major Chacoan buildings are also reported here with slightly different values than those reported in the earlier paper. These changes are the result of certain refinements in a further reduction of the Solstice Project's survey data. The changes, unlike in the case of Hungo Pavi, are so slight (from 0.1° to 0.7°) that they do not affect the conclusions.

12. It is of interest that a unique and extensive construction of the Chacoan culture, the Chetro Ketl "field," which is a grid of low walls covering more than twice the land area of the largest Chacoan building, appears also to be oriented to the azimuth of the lunar minor standstill. This construction was reported to have an orientation of –67° (Loose and Lyons 1977). It should be further noted that the Solstice Project's survey found that the orientation of the perpendicular of Kin Klizhin, a tower kiva located 10 km from Chaco Canyon, is –65°, an azimuth also close to the azimuth of the lunar minor standstill.

13. In certain of the Solstice Project's earlier studies of Chacoan constructions, an emphasis was given to substantiating claims of accurate alignments. The author

believes that this focus sometimes blinded us in our search for the significance of the orientations and relationships developed by this prehistoric and traditional society, to whom symbolic incorporation of astronomical relationships would have been at least as important as the expression of optimal accuracy. In addition, in several instances, the Project's studies have shown that alignments (such as the north orientation of the Great North Road) are adjusted off of precise astronomical direction in order to incorporate other symbolic relationships (Sofaer, Marshall, and Sinclair 1989).

14. The preliminary results of the Solstice Project's study of elevated horizons that are near certain of the major buildings show that from eight of these eleven buildings both the rising and setting astronomical events occur within 1° to 3° of the building orientations.

15. The preliminary results of the Solstice Project's current study show that none of the other thirteen buildings is oriented, as Hungo Pavi is, to an astronomical event on only the visible and not the sensible horizon.

16. The Solstice Project finds that the orientation of Wijiji, which is approximately 6.5° off of the cardinal directions, is also close to the orientation of New Alto, Aztec East, and the east and north walls of the great kiva of Pueblo Bonito, as well as the orientation of several interbuilding relationships. Although there is no obvious astronomical reason for the selection of this azimuth for building orientations and interrelationships, its repetition indicates that it may have been significant to the Chacoans. In addition, at Wijiji at winter solstice the sun is seen rising in a crevice on the horizon (Malville 2005:75). The Solstice Project survey shows that the alignment from Wijiji to this event is also the diagonal of the building. Other instances of astronomical orientation of the diagonals of the buildings are discussed in the next section of this chapter.

17. Because of the deterioration of one of its short walls, Chetro Ketl has only one measurable diagonal angle.

18. The Chacoans may have had additional reasons to consistently choose angles of approximately 23° and 36°. It has been suggested that these angles were also used by a Mesoamerican culture (Clancy 1994; Harrison 1994).

It is of interest that only at locations close to the latitude of Chaco Canyon (i.e., 36°) do the angles of 23° and 36° correspond with the relationships of the cardinal directions and the lunar major and minor standstill azimuths. In addition, at the latitude of 36° at solar noon on equinox day, the shadow of a stick or other vertical object cast on a flat surface forms a right angle triangle that has the internal angles of 36° and 54°. The correspondence of the internal angles of the major Chacoan buildings with angles apparently favored by a Mesoamerican culture, as well as with the angles evident in the solar and lunar astronomy that occurs only close to the latitude of Chaco, raises intriguing questions. It may be that Chaco Canyon was selected as the place, within the broader cultural region of Mesoamerica, where the relationships of the sun and the earth, and the sun and the moon, could be expressed in geometric relationships that were considered particularly significant.

Of further interest is one archaeologist's discussion of the location of Chaco Canyon and Casas Grandes, a postclassic Mesoamerican site, on the same meridian. He suggests that this correspondence may have been an intentional aspect of the locating of Casas Grandes (Lekson 1996). Casas Grandes is 630 km south of Chaco Canyon.

19. The Solstice Project's further study of the internal design of the major Chacoan buildings suggests that one of the solar-lunar angles found in the rectangular buildings, 36°, is also incorporated in the design of three other major buildings (Pueblo Bonito, Peñasco Blanco, and Una Vida) and that Kin Bineola's design (like Aztec I and II) incorporates 36° as well as 24°. In addition, in several of these buildings the solar-lunar geometry is combined with orientational relationships to both the sun and the moon (Sofaer 1994). It also is of interest that three great kivas in Chaco Canyon are organized in geometric patterns of near-perfect squares and circles. This further geometric study of Chacoan architecture will be presented in work that is in preparation by the Solstice Project.

20. The Solstice Project also found that cardinal interbuilding lines relate two minor buildings located in the central canyon to each other and to one of the major central buildings involved in the central cardinal patterning. The line between Casa Rinconada, the cardinally oriented great kiva, and New Alto aligns closely with the north-south axis of Casa Rinconada, and New Alto lies directly west of the cardinally oriented Pueblo Alto (Figures 9.2, 9.3, 9.9, and 9.10). An internal feature of Casa Rinconada appears to mark the kiva's north-south relationship with New Alto. The south stairway of Casa Rinconada is positioned slightly off the axis of symmetry of the kiva, and this stairway is also offset in the south doorway. The effect of the offset placement of this stairway is that from its center one

sees New Alto over the center of the north doorway on a bearing of 1.3°. (Although the construction of Casa Rinconada was completed before the construction of New Alto, it is possible that the position of the stairway within the south doorway of Casa Rinconada was modified at the time of New Alto's construction.)

Three long, low walls extending from Pueblo Alto (surveyed by the Solstice Project) are also cardinally oriented, and they appear to further elaborate the cardinal pattern of the central complex (Windes 1987).

21. The astronomical interbuilding bearings shown in Table 9.3 and in Figures 9.9 and 9.11 are defined as the bearings between two buildings that align (within 3°) with the rising or setting azimuths of the astronomical phenomena associated with one of the two buildings.

The Solstice Project identified the locations of the fourteen major buildings from the coordinates of the 7.5' topographic survey maps of the U.S. Geological Survey. The relative locations of certain of the central buildings were confirmed by direct surveying and by the use of existing aerial photography. The bearings of the interbuilding lines were taken from the estimated centers of the buildings. (The close relationship of two very large buildings, Pueblo Bonito and Chetro Ketl, introduced the only uncertainty. In this case, however, it was observed that each point in Chetro Ketl is due east of each point in Pueblo Bonito.) The relative locations of the buildings could be identified to within 15 m on the maps. The Solstice Project estimates that its measurements have a typical uncertainty in the bearing of an interbuilding line of 0° 12' at an average separation of 4.7 km for the ten buildings within the canyon, and much less uncertainty in the bearings of interbuilding lines extending outside the canyon.

22. The orientation of the perpendicular of Pueblo Pintado is to the azimuth that corresponds with a bearing to Salmon Ruin, 85 km from Pueblo Pintado; furthermore, the azimuth of the orientation of the perpendicular of Salmon Ruin also corresponds with this bearing. Perhaps these relationships were deliberately developed by the Chacoans to join two outlying major buildings that are oriented to the minor standstill moon on a bearing perpendicular to the azimuth of the minor standstill moon and to draw Salmon Ruin into connection with the central complex of Chaco Canyon, to which Pueblo Pintado is related by lunar minor standstill relationships (as is suggested elsewhere in this chapter).

23. It is of interest that the two other Chacoan constructions, the Chetro Ketl "field" and Kin Klizhin (a tower kiva), that are oriented to the lunar minor standstill are also on the lunar minor standstill interbuilding bearings from the central complex to Kin Bineola and to Pueblo Pintado, respectively (see note 12).

24. The Solstice Project's preliminary investigations of several C-shaped, low-walled structures (Windes 1978) and three sets of cairns located in and near Chaco Canyon show that the bearings between these sites are oriented to the lunar major standstill. It is also of interest that several recent findings by others suggest astronomical relationships among sites within prehistoric pueblo building complexes, including one Chacoan building complex, in southwestern Colorado (Malville et al. 1991; Malville and Putnam 1989).

25. It is of interest that Ron Sutcliffe documented another interbuilding bearing: Peñasco Blanco to Casa Rinconada on the alignment to the rising of the southern major standstill moon, June 11, 2006.

26. Certain of the astronomical interbuilding relationships within the canyon, such as that between Una Vida and Peñasco Blanco, appear to correspond roughly with the topography of the canyon. While this correspondence suggests the possibility that the relationship between these buildings could have fallen into lunar alignment by coincidence, it does not explain the other interlocking aspects of these buildings, which suggest an intentional marking of the lunar major relationship between them. The relationships of the central complex to Pueblo Pintado and Kin Bineola on the lunar minor bearings are not affected by the canyon topography because these buildings are located beyond the canyon. The lunar minor relationships of the central complex to Hungo Pavi and Wijiji could have been affected in part by accommodation to the canyon topography. This would not discount the possibility that these relationships had lunar significance for the Chacoans.

27. Although the Solstice Project cannot be certain that all of the astronomical interbuilding bearings that are shown in Table 9.3 and Figure 9.11 were intentionally developed by the Chacoans, it seems important at this stage in our study to present all the interbuilding bearings that meet the criterion described above (see note 21).

One astronomical interbuilding bearing which has not been discussed in the text deserves particular note. Aztec, 86 km north of Pueblo Bonito, is located on a bearing from the central complex of Chaco that could have been regarded by the Chacoans as a continuation of the north-south axis of the central buildings and their interbuilding relationships (Table 9.3 and Figure 9.11). Certain

analysis suggests that the north-south bearing between Chaco and Aztec had particular significance to the Chacoans. Aztec, itself a massive architectural complex, is regarded as an important late center of the Chacoan culture. An architectural study shows that Aztec appears to be "modeled on standards fixed in Pueblo Bonito" (Stein and McKenna 1988). An author of this latter study further notes that the core activity of the Chacoan culture moved in the late 1100s from Chaco Canyon to Aztec (Fowler and Stein 1992), and that this center maintained an active relationship with the canyon through the 1100s and 1200s (John Stein, personal communication 1996). Furthermore, another study suggests that a north-south alignment between Chaco Canyon and Casas Grandes, a Mesoamerican site 630 km south of Chaco, developed in the 1300s, extended the earlier north-south axis from Aztec through Chaco (Lekson 1996).

28. Preliminary results of the Project's study of elevated horizons in the views to astronomy from certain major buildings suggest that the orientations of most of the interbuilding bearings to astronomical events on the sensible horizon (as shown in Table 9.3) are within 3° of the same astronomical events on the visible horizon. Exceptions to this generality appear to be the interbuilding bearings from Pueblo del Arroyo and Peñasco Blanco to Kin Bineola, from Kin Kletso to Pueblo Alto, and from Chetro Ketl to Kin Kletso.

29. In regard to the techniques used for orienting and interrelating buildings on astronomical bearings, the Solstice Project's experiments have shown that the cardinal directions can be determined with shadow and light to within one quarter of a degree (Solstice Project, prepublished report 1988; see also Williamson 1984:144). Recordings of the shadows cast by a vertical object onto a flat surface during several hours of the sun's midday passage indicate the cardinal directions. If this were done at a site with flat horizons toward the lunar standstills, at the time of the lunar standstills on that same surface where the cardinal directions would be recorded, the azimuths of the rising and setting standstill moons could also be recorded. It is possible that the Chacoan architects and planners used such a recording of the solar-lunar azimuths for incorporating lunar orientations in their buildings and in the interrelationships of their buildings, instead of waiting for the recurrence of the lunar events on the local horizons. The wait for the recurrence of the lunar major standstill would be 18 to 19 years. The Solstice Project has also shown that interrelating the buildings which are not intervisible could have been done with quite simple intersite surveying techniques.

30. See note 5.

31. It has been suggested that the Mayas' interest in the lunar eclipse cycle may have involved knowledge of the lunar standstill cycle (Dearborn 1992). Floyd Lounsbury (personal communication 1982) expressed a similar opinion a number of years ago.

32. W. J. Judge and J. M. Malville speculate on Chaco as a center for lunar eclipse prediction (1993), and the Malvilles suggest that ceremonial pilgrimage to Chaco Canyon was scheduled to the solar and lunar cycles (Malville and Malville 1995).

33. For ethnographic reports on the cosmology of the historic Pueblo Indians, see Sofaer, Marshall, and Sinclair (1989); Sofaer and Sinclair (1987); Sofaer, Sinclair, and Doggett (1982); Sofaer, Zinser, and Sinclair (1979); and Williamson (1984).

34. M. C. Stevenson (1894:143): "The moon is father to the dead as the sun is father to the living."

35. Fred Eggan's studies of the Hopi "roads" suggested to him several parallels with the Chacoans' use of roads. Eggan noted that at Hopi the spirits of the dead emerge from the world below and travel on symbolic roads to visit with the living, and that the Great North Road of Chaco appears to have been built to join the ceremonial center symbolically with the direction north and with the world below (Fred Eggan, personal communication 1990).

36. Alfonso Ortiz, *The Sun Dagger* film (The Solstice Project 1982).

References

Ahlstrom, Richard Van Ness
1985 *Interpretation of Archeological Tree-Ring Dates*. Ph.D. dissertation, University of Arizona, Tucson.

Aveni, Anthony F.
1980 *Skywatchers of Ancient Mexico*. University of Texas Press, Austin.

Broda, Johanna
1982 Astronomy, *Cosmovisión*, and Ideology in Prehispanic Mesoamerica. In *Ethnoastronomy and Archaeoastronomy in the American Tropics*, edited by Anthony F. Aveni and Gary Urton, pp. 81–110. Annals of the New York Academy of Sciences.
1993 Archaeoastronomical Knowledge, Calendrics, and Sacred Geography in Ancient Mesoamerica. In *Astronomies and Culture*, edited by C. Ruggles and N. Saunders, pp. 253–295. University Press of Colorado, Niwot.

Clancy, Flora S.
1994 Spatial Geometry and Logic in the Ancient Maya Mind. Part 1: Monuments. In *Seventh Palenque Round Table, 1989*, Merle Greene Robertson, gen. ed., Virginia M. Fields, vol. ed., pp. 237–242. Pre-Columbian Research Institute, San Francisco.
Cordell, Linda S.
1984 *Prehistory of the Southwest*. Academic Press, Orlando.
Crown, Patricia L., and W. James Judge, Jr.
1991 Synthesis and Conclusions. In *Chaco and Hohokam: Prehistoric Regional Systems in the American Southwest*, edited by Patricia L. Crown and W. James Judge, Jr., pp. 293–308. School of American Research Press, Santa Fe.
Dearborn, David D.
1992 To the Limits. *Archaeoastronomy and Ethnoastronomy News: Quarterly Bulletin of the Center for Archaeoastronomy* 3:1, 4.
Ford, Dabney
1993 The Spadefoot Toad Site: Investigations at 29SJ629. In *Marcia's Rincon and the Fajada Gap Pueblo II Community, Chaco Canyon, New Mexico*, edited by Thomas C. Windes, Vol. I, Appendix H. Reports of the Chaco Center 12. National Park Service, Albuquerque.
Fowler, Andrew P., and John Stein
1992 The Anasazi Great House in Time, Space, and Paradigm. In *Anasazi Regional Organization and the Chaco System*, edited by David E. Doyel, pp. 101–122. Maxwell Museum of Anthropology, Anthropological Papers 5. University of New Mexico, Albuquerque.
Fritz, John M.
1978 Paleopsychology Today: Ideational Systems and Human Adaptation in Prehistory. In *Social Archeology, Beyond Subsistence and Dating*, edited by Charles L. Redman et al., pp. 37–59. Academic Press, New York.
Harrison, Peter D.
1994 Spatial Geometry and Logic in the Ancient Mayan Mind. Part 2: Architecture. In *Seventh Palenque Round Table, 1989*, Merle Greene Robertson, gen. ed., Virginia M. Fields, vol. ed., pp. 243–252. Pre-Columbian Research Institute, San Francisco.
Hawkins, Gerald S.
1973 *Beyond Stonehenge*. Harper and Row, New York.
Judge, W. James, Jr.
1984 New Light on Chaco Canyon. In *New Light on Chaco Canyon*, edited by David G. Noble, pp. 1–12. School of American Research Press, Santa Fe.
1989 Chaco Canyon—San Juan Basin. In *Dynamics of Southwest Prehistory*, edited by Linda S. Cordell and George J. Gumerman, pp. 209–262. Smithsonian Institution Press, Washington, DC.
Judge, W. James, Jr., and J. McKim Malville
2004 Calendrical Knowledge and Ritual Power. In *Chimney Rock: The Ultimate Outlier*, edited by J. McKim Malville, pp. 151–163. Lexington Books, Lanham, MD.
Kincaid, Chris, editor
1983 *Chaco Roads Project Phase I: A Reappraisal of Prehistoric Roads in the San Juan Basin*. Bureau of Land Management, Albuquerque.
Lekson, Stephen H.
1984 *Great Pueblo Architecture of Chaco Canyon*. National Park Service, Albuquerque.
1991 Settlement Patterns and the Chacoan Region. In *Chaco and Hohokam: Prehistoric Regional Systems in the American Southwest*, edited by P. L. Crown and W. J. Judge, Jr., pp. 31–56. School of American Research Press, Santa Fe.
1996 Chaco and Casas. Paper presented at the 61st Annual Meeting of the Society for American Archeology.
Lekson, Stephen H., Thomas C. Windes, John R. Stein, and W. James Judge Jr.
1988 The Chaco Canyon Community. *Scientific American* (July):100–109.
Loose, Richard W., and Thomas R. Lyons
1977 The Chetro Ketl Field: A Planned Water Control System in Chaco Canyon. In *Remote Sensing Experiments in Cultural Resource Studies*, assembled by Thomas R. Lyons, pp. 133–156. Reports of the Chaco Center 1, National Park Service, Washington, DC.
McCluskey, Stephen C.
1977 The Astronomy of the Hopi Indians. *Journal for the History of Astronomy* 8:174–195.
Malville, J. McKim
2005 Ancient Space and Time in the Canyons. In *Canyon Spirits: Beauty and Power in the Ancestral Puebloan World*, essays by S. H. Lekson and J. M. Malville, photographs by J. L. Ninnemann, foreword by F. C. Lister, pp. 65–86, University of New Mexico Press, Albuquerque.
1993 Astronomy and Social Integration among the Anasazi. In *Proceedings of the Anasazi Symposium, 1991*, edited by Jack E. Smith and Art Hutchinson, pp. 155–166. Mesa Verde Museum Association.
Malville, J. McKim, and Nancy J. Malville
1995 Pilgrimage and Astronomy at Chaco Canyon, New Mexico. Paper presented at the National Seminar on Pilgrimage, Tourism, and Conservation of Cultural Heritage, January 21–23, Allahabad, India.
Malville, J. McKim, and Claudia Putnam
1989 *Prehistoric Astronomy in the Southwest*. Johnson Books, Boulder.

Malville, J. McKim, Frank W. Eddy, and Carol Ambruster
1991 Moonrise at Chimney Rock. *Journal for the History of Astronomy* (Supplement 1b: *Archeoastronomy*) 16:s34–s50.
Marshall, Michael P.
1997 The Chacoan Roads—A Cosmological Interpretation. In *Anasazi Architecture and American Design*, edited by Baker H. Morrow and V. B. Price, pp. 62–74. University of New Mexico Press, Albuquerque.
Marshall, Michael P., and David E. Doyel
1981 An Interim Report on Bis sa'ni Pueblo, with Notes on the Chacoan Regional System. Ms. on file, Navajo Nation Cultural Resource Management Program, Window Rock, AZ.
Marshall, Michael P., John R. Stein, Richard W. Loose, and Judith E. Novotny
1979 *Anasazi Communities of the San Juan Basin*. Public Service Company of New Mexico, Albuquerque.
Morrow, Baker H., and V. B. Price, eds.
1997 *Anasazi Architecture and American Design*. University of New Mexico Press, Albuquerque.
Neitzel, Jill
1989 The Chacoan Regional System: Interpreting the Evidence for Sociopolitical Complexity. In *The Sociopolitical Structure of Prehistoric Southwestern Societies*, edited by Steadman Upham, Kent G. Lightfoot, and Roberta A. Jewett, pp. 509–556. Westview Press, Boulder.
Powers, Robert P., William B. Gillespie, and Stephen H. Lekson
1983 *The Outlier Survey: A Regional View of Settlement in the San Juan Basin*. National Park Service, Albuquerque.
Reyman, Jonathan E.
1976 Astronomy, Architecture, and Adaptation at Pueblo Bonito. *Science* 193:957–962.
Roney, John R.
1992 Prehistoric Roads and Regional Integration in the Chacoan System. In *Anasazi Regional Organization and the Chaco System*, edited by David E. Doyel, pp. 123–132. Maxwell Museum of Anthropology, Anthropological Papers 5. University of New Mexico, Albuquerque.
Sebastian, Lynne
1991 Sociopolitical Complexity and the Chaco System. In *Chaco and Hohokam: Prehistoric Regional Systems in the American Southwest*, edited by Patricia L. Crown and W. James Judge, Jr., pp. 107–134. School of American Research Press, Santa Fe.
1992 Chaco Canyon and the Anasazi Southwest: Changing Views of Sociopolitical Organization. In *Anasazi Regional Organization and the Chaco System*, edited by David E. Doyel, pp. 23–34. Maxwell Museum of Anthropology, Anthropological Papers 5. University of New Mexico, Albuquerque.
Sinclair, Rolf M., and Anna Sofaer
1993 A Method for Determining Limits on the Accuracy of Naked-Eye Locations of Astronomical Events. In *Archaeoastronomy in the 1990s*, edited by Clive Ruggles, pp. 178–184. Group D Publications, Loughborough, UK.
Sinclair, Rolf M., Anna Sofaer, John J. McCann, and John J. McCann, Jr.
1987 Marking of Lunar Major Standstill at the Three-Slab Site on Fajada Butte. *Bulletin of the American Astronomical Society* 19:1043.
Sofaer, Anna
1994 Chacoan Architecture: A Solar-Lunar Geometry. In *Time and Astronomy at the Meeting of Two Worlds*, edited by Stanislaw Iwaniszewski et al., pp. 265–278. Warsaw University, Poland.
1997 The Primary Architecture of the Chacoan Culture: A Cosmological Expression. In *Anasazi Architecture and American Design*, edited by Baker H. Morrow and V. B. Price, pp. 88–130. University of New Mexico Press, Albuquerque.
2006 Pueblo Bonito Petroglyph on Fajada Butte: Solar Aspects. In *Celestial Seasonings: Connotations of Rock Art, 1994 IRAC Proceedings*, Rock Art-World Heritage, edited by E. C. Krupp, pp. 397–402. American Rock Art Research Association, Phoenix.
Sofaer, Anna, and Rolf M. Sinclair
1987 Astronomical Markings at Three Sites on Fajada Butte. In *Astronomy and Ceremony in the Prehistoric Southwest*, edited by John Carlson and W. James Judge Jr., pp. 43–70. Maxwell Museum of Anthropology, Anthropological Papers No. 2. University of New Mexico, Albuquerque.
1989 An Interpretation of a Unique Petroglyph in Chaco Canyon, New Mexico. In *World Archaeoastronomy*, edited by Anthony F. Aveni, p. 499. Cambridge University Press, Cambridge.
Sofaer, Anna, Michael P. Marshall, and Rolf M. Sinclair
1989 The Great North Road: A Cosmographic Expression of the Chaco Culture of New Mexico. In *World Archaeoastronomy*, edited by Anthony F. Aveni, pp. 365–376. Cambridge University Press, Cambridge.
Sofaer, Anna, Rolf M. Sinclair, and LeRoy Doggett
1982 Lunar Markings on Fajada Butte, Chaco Canyon, New Mexico. In *Archaeoastronomy in the New World*, edited by Anthony F. Aveni, pp. 169–181. Cambridge University Press, Cambridge.
Sofaer, Anna, Rolf M. Sinclair, and Joey B. Donahue
1991 Solar and Lunar Orientations of the Major Architecture of the Chaco Culture of New Mexico. In *Colloquio Internazionale Archeologia e Astronomia*, edited by G. Romano and G. Traversari, pp. 137–150. Rivista di Archaeologia, Supplementi 9, edited by Giorgio Bretschneider. Rome, Italy.

Sofaer Anna, Rolf M. Sinclair, and Reid Williams
1987 A Regional Pattern in the Architecture of the Chaco Culture of New Mexico and its Astronomical Implications. *Bulletin of the American Astronomical Society* 19:1044.
Sofaer, Anna, Volker Zinser, and Rolf M. Sinclair
1979 A Unique Solar Marking Construct. *Science* 206:283–291.
Stein, John R.
1989 The Chaco Roads—Clues to an Ancient Riddle? *El Palacio* 94:4–16.
Stein, John R., and Stephen H. Lekson
1992 Anasazi Ritual Landscapes. In *Anasazi Regional Organization and the Chaco System*, edited by David E. Doyel, pp. 87–100. Maxwell Museum of Anthropology, Anthropological Papers 5. University of New Mexico, Albuquerque.
Stein, John R., and Peter J. McKenna
1988 *An Archaeological Reconnaissance of a Late Bonito Phase Occupation near Aztec Ruins National Monument*. National Park Service, Southwest Cultural Resource Center, Santa Fe.
Stein, John R., Judith E. Suiter, and Dabney Ford
1997 High Noon in Old Bonito: Sun, Shadow, and the Geometry of the Chaco Complex. In *Anasazi Architecture and American Design*, edited by Baker H. Morrow and V. B. Price, pp. 133–148. University of New Mexico Press, Albuquerque.
Stevenson, Mathilda Coxe
1894 The Sia. In *Eleventh Annual Report of the Bureau of Ethnology*. Smithsonian Institution, Washington, DC.
Tedlock, Barbara
1983 Zuni Sacred Theater. *American Indian Quarterly* 7:93–109.
Toll, Henry Walcott
1991 Material Distributions and Exchange in the Chaco System. In *Chaco and Hohokam: Prehistoric Regional Systems in the American Southwest*, edited by Patricia L. Crown and W. James Judge, Jr., pp. 77–108. School of American Research Press, Santa Fe.
Vivian, R. Gwinn
1990 *The Chacoan Prehistory of the San Juan Basin*. Academic Press, San Diego.
Williamson, Ray A.
1984 *Living the Sky*. Houghton Mifflin, Boston.
Williamson, Ray A., Howard J. Fisher, and Donnel O'Flynn
1977 Anasazi Solar Observatories. In *Native American Astronomy*, edited by Anthony F. Aveni, pp. 203–218. University of Texas Press, Austin.
Williamson, Ray A., Howard J. Fisher, Abigail F. Williamson, and Clarion Cochran
1975 The Astronomical Record in Chaco Canyon, New Mexico. In *Archaeoastronomy in Pre-Columbian America*, edited by Anthony F. Aveni, pp. 33–43. University of Texas Press, Austin.
Windes, Thomas C.
1978 *Stone Circles of Chaco Canyon, Northwestern New Mexico*. Reports of the Chaco Center No. 5, Division of Chaco Research, National Park Service, Albuquerque.
1987 *Investigations at the Pueblo Alto Complex, Chaco Canyon, New Mexico, 1975–1979*. Vol. 1: *Summary of Test and Excavations at the Pueblo Alto Community*. Publications in Archeology 18F. National Park Service, Santa Fe.
Zeilik, Michael
1984 Summer Solstice at Casa Rinconada: Calendar, Hierophany, or Nothing? *Archaeoastronomy* 7:76–81.