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SCIENCE

Astronomy, Architecture, and Adaptation at Pueblo Bonito

Exterior corner windows at a Chaco Canyon pueblo may have been aligned to the winter solstice sunrise.

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Of the artifacts that archeologists study, few are as enduring and as tangible as architecture, especially when stone is used in the construction. Furthermore, if one accepts the argument that artifacts embody the cultural systems of the manufacturers (*1*), then architecture is an expression nonpareil of these cultural systems. This idea is hardly novel; for years art historians (*2*) have recognized it, as have many anthropologists (*3*). Whenever architecture is used as a marker for a cultural period or as an indicator of contact between peoples, one makes an implicit assumption about the cultural (behavioral) content of the structures. An excellent example of the ideology underlying the architecture is in the following translation of a passage from Torquemada's *Monarchia Indiana* (*3*, p. 9):

These Indians of New Spain formed and devised the Temple of the Air God also round; and the reason that they gave was to say that thus as the Air moves and surrounds all, thus the house had to be, so that in its form it might reveal its meaning.

Problems

Culture is ultimately an adaptive strategy; any attempt to determine the purpose for a given behavior must include the possibility that the behavior serves a specific adaptive function. Therefore, the basic issue in this discussion involves the adaptive function of architectural features relative to the people who built them (*4*). An understanding of this function, in turn, requires the identification of the affinities and conjunctions that exist between the material results of behavior—architecture—and the natural environment.

In this article, I deal with three specific problems: (i) the interrelations between the prehistoric Anasazi of Chaco Canyon and their environment; (ii) a hypothesis that focuses on one response to that environment; and (iii) a test of the hypothesis for a particular site, Pueblo Bonito (Fig. 1), in terms of specific architectural features—exterior corner windows. I propose that two exterior corner windows, those in rooms 225C and 228C-SE (Fig. 2 and cover), were built to serve a particular adaptive function—to record the winter solstice sunrise. The hypothesis is generated, in part, from the extensive ethnographic data which indicate that Pueblo Indians of the Southwest use architectural features, some similar to those at Pueblo Bonito, to make observations and to record what they see (*5*; *6*, pp. 56 and 265; *7–9*).

Chaco Canyon National Monument lies in the northwest quadrant of New Mexico, about 87 kilometers southeast of Farmington. Its elevation ranges from 1830 to 2065 meters above sea level. Pueblo Bonito is located at 36°03.7′N, 107°57.7′W, as determined from the *USGS 7.5′ Topographic Map, Pueblo Bonito Quadrangle, 1966*, at an elevation of 1866.6 meters.

The Environment

It is often difficult for the present-day visitor at Chaco Canyon to envision that, just 125 years ago, the Chaco Wash was a small, gently flowing stream that meandered along the canyon floor (*10*). Today it is as much as 10 meters deep and 95 meters wide. Although the present arroyo probably began its trenching process between 1860 and 1870 (*11*, p. 17), "many of the tributary canyons, such as Mockingbird, were yet undissected in 1925" (*11*, p. 15).

One effect of the arroyo cutting is to reduce the level of the water table, which, in turn, makes plant growth difficult. The rejuvenation of the land after human occupation takes many years. This is evident in the problems that the National Park Service is experiencing in its attempts to revitalize a former camping area in Gallo Canyon, despite the relatively dense perennial ground cover in this canyon (*12*). Several of the areas farmed in the late 1890's by Richard Wetherill, particularly one near the entrance to Mockingbird Canyon, are now almost devoid of vegetation except for a light cover of strawlike grasses. Add to the lowered water table a mean annual rainfall of less than 255 millimeters (*12*), and it is apparent that the environment is unsuitable for large-scale farming. Nevertheless, modern Navajo cultivation methods suggest "that limited crops could be grown successfully in Chaco Canyon in selected locations by floodwater farming, employing a minimum of temporary ditches, dikes, and other control measures" (*12*, p. 12).

The prehistoric environment, however, was not as marginal. While it is generally agreed that the prehistoric forests adjacent to the canyon were vestigial and were receding long before the Anasazi occupation (*12*, *13*), the rapid increase in the number of large town sites and smaller settlements between about A.D. 850 and A.D. 1125 (*9*, *12*, *14–16*), coupled with the simultaneous development of large-scale water-control systems (*12*, *16*), indicates that both extensive and intensive cultivation were prac-

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ticed. Materials from refuse deposits suggest that foraging activities were important supplements to farming and that natural foodstuffs were available in quantity in the canyon and the immediate vicinity (*12, 17*). In short, "... Chaco Canyon probably represented an oasis of sorts in the Chaco basin and attracted early farming peoples" (*16*, p. 61).

Yet even in the relatively more favorable prehistoric environment, successful farming was not inevitable. To succeed, the Chaco farmers, at the very least, had to anticipate the killing frosts of late spring and early fall; with careful planning, perhaps they usually avoided them. The problem was, and is, how to do this. For example, from 1969 to 1972, the Velarde region along the Rio Grande north of Santa Fe, New Mexico, experienced frequent and serious crop losses as a result of the severe frosts that occurred at both ends of the relatively short growing season.

Adaptation and Methodology

At issue is how the Chacoans coped with frosts and other environmental problems, such as potentially damaging summer rains. Water-control systems help to channel this rainfall and thereby permit use of the water, but a more fundamental concern is prediction of seasonal changes so that seed is planted neither too early nor too late, and so that irrigation ditches, check dams, and reservoirs are cleaned and repaired in time to handle the expected precipitation and runoff. We cannot know with absolute certainty how seasonal predictions were made, but it is reasonable to assume that the Chacoans developed and used one or more calendars. As is the case among the Hopi (*8*) and other Pueblo Indians, environmental changes, such as the flowering of certain plants and the return of particular animals, are also used to predict seasonality. These events serve as a check on the astronomically based calendars. To better understand the Chacoan response to the problem of predicting seasonal changes, I conducted tests that go far toward explaining one technique of prehistoric Chacoan adaptation, the establishment of an accurate solar calendar.

In analysis of this aspect of adaptive strategy I use of the methodology of archaeoastronomy (*18, 19*), the study of prehistoric systems of astronomy (*20*).

> The possibility of astroarchaeology [archaeoastronomy] is based on the fact that people behave in ways which reflect cultural patterns, including belief systems. These may include naive or sophisticated ideas of the real or imagined influences of astronomical events on human affairs. The regulation of daily and seasonal activities by the relative positions of earth and sun is an obvious reality, conditioning a great deal of human behavior. Likewise, the movements of the moon affect the tides, which are a major factor in the lives of coastal dwellers throughout the world and the changing phases which produce dark nights or moonlit nights have affected most of mankind until very recently. In many cul-

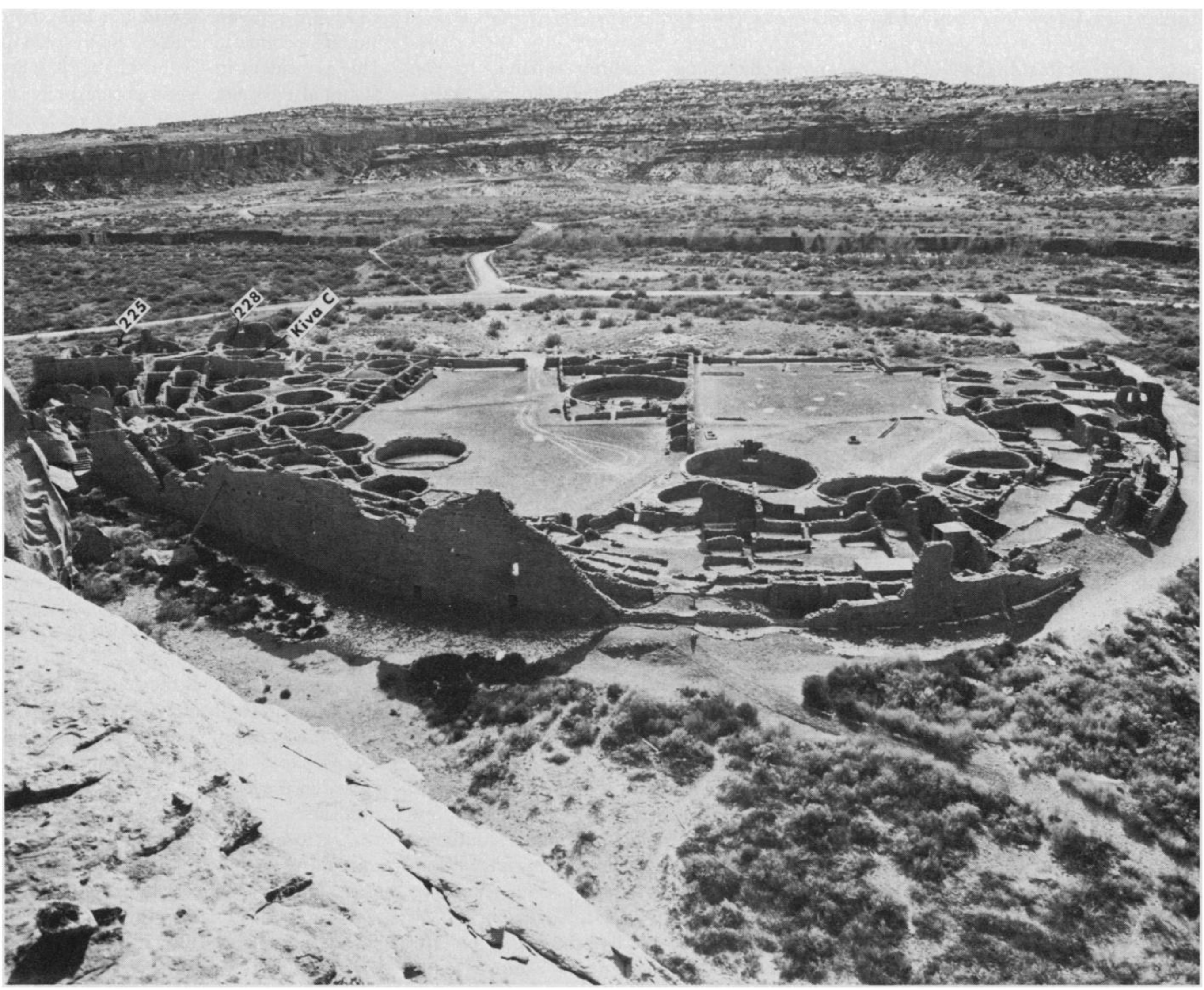


Fig. 1. Pueblo Bonito, Chaco Canyon, New Mexico, as seen from the top of the cliff behind and to the north of the site. The arrows indicate the locations of rooms 225C, 228C-SE, and kiva C.

tures, people postulate a tremendous range of additional effects and partially pattern their behavior to conform to or modify the effects of the postulated influences. To the extent that this behavioral response involves structural patterns or objects which may be recognized or recovered archaeologically, we are dealing with astroarchaeology [archaeoastronomy].

Using Kelley's statement as my basic premise, I formulated a series of three questions as the bases for generating hypotheses and test implications (*18*) concerning Chacoan adaptation. (i) In view of the latitude of the site (or sites) under study and the knowledge of the prehistoric subsistence strategy and technology, what adaptive advantage, in terms of farming, foraging, and so forth, accrues to those who watch the sky and record their observations? (ii) At this latitude, which celestial bodies and astronomical events are most useful in terms of this subsistence strategy? (iii) In view of the technology available to the group, what are the "best" means for recording this information so that one has accurate data for a desired time interval, that is, month, season, or year?

The answers I suggest are as follows: (i) At most latitudes, celestial observations allow the group to predict seasonal changes in order to better plan and implement the sequence of events in the adaptative strategy, be it farming or some other system (*21*). Although such observations do not ensure success every year, if interpreted correctly, careful long-term observations do tend to increase the chances of success. Foreknowledge of the general pattern of seasonal changes is necessary for dealing with the frost problem, and, if the group anticipates the onset of the potentially destructive summer rains, then the water-control systems can be modified and repaired in preparation for them. (ii) The sun, with its apparent yearly south-north-south passage (winter-summer-winter) along the horizons, is the single most reliable celestial body for establishing the calendar on which the understanding of seasonal changes is predicated. Certain stars and constellations (for example, Sirius, Orion, and the Pleiades) and the moon are useful as nighttime checks on the sun's position, particularly when atmospheric conditions like cloud cover and rain temporarily prohibit the direct observation of sunrise and sunset. (iii) While there are a number of possible recording techniques, including the use of shadows (*5*, *6*), the most permanent or reliable technique involves the use of architectural features as sighting devices (*6*, p. 56 and plate 8b; *9; 22*).

Fig. 2. Southeast section of Pueblo Bonito showing the location of the two exterior corner windows: room 225C (right) and room 228C-SE (left).

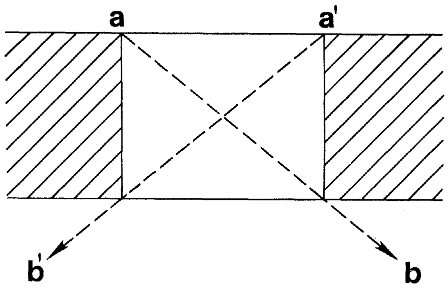
"In cultures in which belief in the importance of astronomical influences upon human affairs has become important, it is usually felt necessary to make more precise observations and it is often possible to find and even, in some cases, to recognize mechanisms and structures used for observation" (*20*). Furthermore, my research indicates that people who astronomically align architectural features usually possess some form of calendar, either written or unwritten [for example, a horizon calendar (see *8*, maps 4 and 12)]. The use of horizon calendars in conjunction with architectural features is especially characteristic of the historic Southwestern Pueblo Indians (*5, 7, 8, 23*).

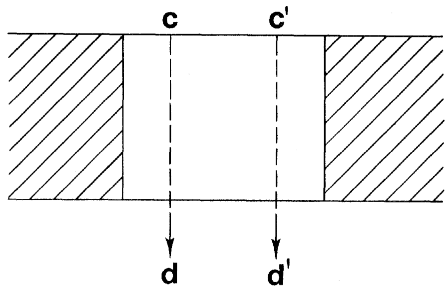
The above questions and answers are valid for most sites. However, the specific hypothesis regarding the exterior corner windows at Pueblo Bonito is suggested by ethnographic data for the Southwestern Pueblo Indians. This material has been discussed at length (*9, 18, 24*); below is a brief summary of the most pertinent points.

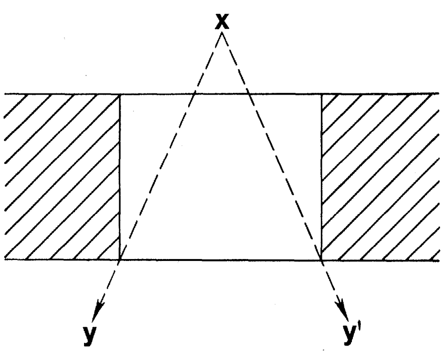
The ethnographic records indicate that, with the exception of Laguna Pueblo, where the practice has ceased (*25*, p. 535), solar observation is the most common and important type of astronomical record-keeping; sunrises and sunsets are observed daily (*8*). Every Pueblo has institutionalized solar observation within the office of sunwatcher (*5*, p. 31). Among the Hopi on First and Third Mesas, the official is called *Ta'wa moñwĭ*—Sun Watcher or Sun Chief (*8*, pp. xxix–xl, 30, 62), for which the equivalent Zuñi position is termed *p̂ekwin*. At Mishongnovi, a Hopi town on Second Mesa, the sunwatching function is performed by the town chief, while among the Keresan and Tanoan Pueblo Indians the *cacique* makes the observations (*5*, p. 31; *6*, p. 56; *25*, pp. 122–123; *26*, pp. 84–85). The ethnographic accounts also indicate that solar, lunar, and stellar observations are made as the bases for, and used in conjunction with, the planning and implementation of the farming system (*6*, p. 322; *8*, pp. 389–390, map 12; *27*, p. 231). From these data and from the fact that much of the Southwest was marginal for cultivation, I assume that careful solar (and other astronomical) observations were important aspects of the farming strategy of the prehistoric inhabitants of Chaco Canyon.

Architecture

From the ethnographic literature it is clear that celestial observation is usually made in conjunction with or from a particular structure or architectural feature (*5; 6*, p. 56 and plate 8b; *7; 8*, pp. 30, 63, 890; *9; 23; 25*, p. 378; *28*, p. 878). Once the pattern of celestial movement is recorded, a permanent record of this passage is usually made by aligning some architectural feature to the path of motion, that is, the sun's apparent movement along the eastern (sunrise) and western (sunset) horizons. Therefore, some architectural feature is astronomically aligned, often with a natural topographic feature as a foresight (*8*, maps 4 and 12). At Zuñi, for example [(*7*), compare (*23*)],







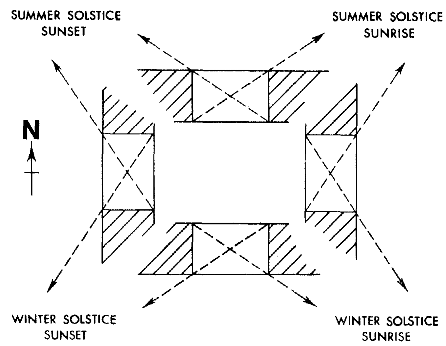


Fig. 3 (top left). Drawing of a diagonal or cross-jamb window alignment, similar to the system presumably in use at Cochiti Pueblo. The observer sights through the window from *a* to *b* and from *a'* to *b'*. Fig. 4 (bottom left). Drawing of a second type of diagonal or cross-jamb alignment. Using this system, the observer would stand at a fixed point (*x*) behind the inside opening of the window and along its center axis and sight to *y* or *y'*. Fig. 5 (top right). Drawing of a parallel-jamb alignment. Using this system, the observer (*c*, *c'*) usually sights along either edge of the window frame or directly through the middle of the window to *d* or *d'*. Fig. 6 (bottom right). Four windows from which two solstice points can be seen. A parallel-jamb sighting in either the east or west window would provide an accurate sighting of the equinox sunrise (east) or sunset (west).

The year begins about the winter solstice. The suntower is used as follows. In winter, they look over a notch in the western wall, over a pillar to the east. When the sun rises over a certain point, there in a line with the pillar, then it is midwinter or the beginning of the year. In summer they look from a pillar in the summar gardens to the sun tower [*sic*]. Sign of the year according to the Zuñi.

A similar system is employed at Cochiti where the sun is observed by the cacique through a window in the top of the east wall of the *Flint–Ku-sha'lī* house (*6*). This sighting is probably made with the use of a diagonal or cross-jamb alignment through the window (Figs. 3 and 4); at Zuñi, however, the two accounts (*7, 23*) indicate that a parallel-jamb technique of sighting and astronomical alignment is used (Fig. 5). Thus it should be evident that, among the present Southwestern Pueblos, certain architectural features serve an adaptive function as devices for recording solar positions (*29*) and essential dates in the farming system with the use of the sun's yearly passage along the horizon. Finally, the structures or architectural features used for this purpose are unusual. The suntower at Zuñi, the placement of the window in the *Flint–Ku-sha'lī* house at Cochiti, and the relative isolation of these buildings with unobstructed views of the horizon (or horizons) are uncommon architectural situations, as are the structures and features employed at other villages.

Fieldwork

The knowledge that the prehistoric inhabitants of the large Chaco Canyon pueblos were farmers and that careful astronomical observations could increase the likelihood of successful crop production, in combination with the relevant ethnographic data, a close examination of the prehistoric architecture, and location of the Chaco sites, led to the formulation of several hypotheses for testing in the field. These hypotheses deal with the relations between architecture and other cultural features—astronomy, farming, and ceremonialism. Predictably, the alignments and types of structures into which the alignments (Fig. 6) are incorporated vary with (i) site location, for example, whether the pueblo is in the canyon or atop the mesa; (ii) the physical relation of the sites to topographic features, such as the canyon walls and the horizons; and (iii) the type of expected alignment, that is, solar, lunar, or stellar. These three factors establish different conditions and architectural requirements that cannot be explained by a single, specific hypothesis.

I hypothesize that the corner windows (Fig. 2 and cover) in rooms 225C and 228C-SE at Pueblo Bonito [according to the numbering system of Judd (*30*)] were used to observe and to record the winter solstice sunrise. These windows are architecturally unusual (*31*) and are situated in the highest part of the south wall of the site. In order to test this hypothesis it is necessary to demonstrate the following. (i) From the windows, one must have a clear view of the eastern horizon (*32*). (ii) Cross-jamb or parallel-jamb sight lines must align to the hypothesized sunrise point within an accuracy of $\pm$ 0.5°. (iii) The alignment is most accurate when the sun's disk is tangent to the observer's horizon. Rounded to the nearest minute and based on the observer's horizon, the azimuth for the winter solstice sunrise at Pueblo Bonito is 119°45'E (29°45'S) (*9*, p. 328). Finally, since the position of the sun has not shifted significantly since the windows were built, at around A.D. 1060 to 1075 (*14*, pp. 180–181), any alignment is still accurate today.

The windows are located in the third stories (*33*) of rooms 225 and 228 (Fig. 2 and cover). Through them one has clear views of the eastern horizon, so the first test implication is met. A glance at Judd's site map (*30*) indicates that there is a row of rooms outside of both room 225 and room 228; these are clearly visible in Fig. 2 and the cover. The existence of a third story on these outside rooms, specifically rooms 173 and 176, would have blocked the view to the horizon, thus invalidating any alignments and changing the identification of these structures from windows to doorways (*30*). In his "Table of room dimensions," Judd (*30*, p. 253) indicates that both exterior rooms (173 and 176) originally were three stories high. However, I am unable to find the evidence for this determination; it is not included in his published excavation notes for these rooms (*30*, pp. 274–275), nor is it in the report on the cultural materials found at Pueblo Bonito (*17*). Early photographs of the site provide no evidence for a third story outside of rooms 225C and 228C-SE. The stabilization report (*34*) for this area of the pueblo gives no indication of a third story for rooms 173 and 176 (*35*). Pepper (*36*), the original excavator of room 176, provides neither written nor photographic evidence for the presence of a third story. Finally, the walls of 173 and 176 now show no traces of third stories, and the outermost walls are no more than two stories high. Nevertheless, because of

Judd's *(30)* report and his indication that rooms 173 and 176 had third stories, the "reality" of the alignments can be questioned.

The windows were tested at sunrise on 21 December 1973 (the winter solstice) and 22 December 1973, and again in 1975. The position of the sun at sunrise does not appear to change for 3 or 4 days around the solstice; thus the 22 December test is valid.

No floor now remains at the third-story level of the window in room 225C, and therefore the usual archaeoastronomical field techniques *(8, 18, 22)* could not be employed to obtain an azimuth reading *(37)*. Instead, it was necessary to position people on the wall opposite, about 6 meters away from the interior opening of the window, and also on a ladder on the south wall alongside the window; both positions allow one to look through the window, although the latter is more accurate. Hand-held, 35-millimeter, single-lens reflex cameras equipped with sun shades and ultraviolet filters, one loaded with color film (Kodachrome II), and the other with black and white (Kodak Plus X), were used to photograph the sunrise.

In room 228, we were able to stand on the unexcavated portion of the room (228C-NW) behind the window. Here, similarly equipped and loaded cameras were set up on tripods to photograph the sunrise through the center axis of the window. Although I predicted a parallel-jamb alignment both for this window and for the window in room 225C *(37)*, preparations were made to photograph both types of alignments for each window. This was necessary, in part, because we were unable to obtain azimuth readings for either window prior to the solstice sunrise *(38)*. Furthermore, any wall markings opposite either window, if such markings existed prehistorically, disappeared long ago when the plaster covering on the walls disintegrated or fell off *(39)*. The condition of the masonry in the window of room 225C also presented problems *(40)*.

Fig. 7. Winter solstice sunrise as seen through the exterior corner window in room 225C, Pueblo Bonito.

Fig. 8. Winter solstice sunrise as seen through the exterior corner window in room 228C-SE, Pueblo Bonito.

Alignment and History of Windows

As the run rose on the winter solstice, it was evident that the predictions were correct. The window in room 225C seems to have a parallel-jamb alignment *(40)* to the winter solstice sunrise at tangency (Fig. 7), and the window in room 228C-SE is also aligned, parallel-jamb, to the winter solstice sunrise, again at the point of tangency (Fig. 8). Thus, the third test is satisfied.

It was impossible to record a precise azimuth reading for the window in room 225C because of the absence of a floor at this level. During the summer of 1974, we planned to erect a scaffold on which to set up the theodolite; however, all available units were in use on a stabilization project in another area of Pueblo Bonito. Therefore, the second test remains unsatisfied for this window, except for the evidence in the photographic record. The same is true for the window in room 228C-SE. It should be possible to obtain the required azimuth readings during the next field session (summer 1976), although the photographs (Figs. 7 and 8) suggest that the second test is likely to be met for both windows.

The fieldwork and photographic records indicate that both windows could have been used to observe and to record the winter solstice sunrise. The problem of the presence of two windows where one would have sufficed still requires resolution. Toward this, one must consider the following data. The building and rebuilding of kiva C (Fig. 1) required room 228 to be divided in quarters and then, later, abandoned and filled in as a buttress for the kiva wall *(30*, pp. 166–167). Thus, the construction of kiva C eliminated the window in room 228C-SE as an observation point and as a solstice recording device. Judd *(30)* notes that rooms 225 and 228 were built during the "late Bonitan" period, but room 225 was built sometime after room 228. Two tree-ring dates suggest a construction date of around A.D. 1061 to 1073 for room 228 *(14*, pp. 180–181). No hard dates exist for room 225; there is only Judd's statement *(30)* that it was built later than room 228.

A possible explanation, therefore, for the presence of two solstice windows is that the window in room 225C was built to replace the window in room 228C-SE after it was realized that the latter's use would be eliminated by the rebuilding and buttressing of kiva C. The two windows were not used concurrently.

This explanation is ex post facto, and it affects the degree of acceptance that one assigns to these possible alignments *(41)*. In view of the archeological situation at Pueblo Bonito, this explanation is not amenable to formulation as a testable hypothesis, nor am I aware of any means for providing a more satisfactory explanation. Nevertheless, my hypothesis—that the windows were used to record the winter solstice sunrise—appears to be confirmed, and the results of the forthcoming summer field session should strengthen this confirmation.

Summary

I propose that architecture and specific architectural features may and sometimes do serve adaptive functions beyond that of shelter. Available evidence supports the hypothesis that two exterior corner windows at Pueblo Bonito were used to record the winter solstice sunrise. The record of this event is necessary for the establishment of a solar calendar, and possession of an accu-

rate calendar increased the Chacoans' chances for a successful harvest. The incorporation of celestial information into architectural features simplifies the observation and recording of astronomical data and, ultimately, increases the adaptive efficiency of the subsistence system.

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29. Lunar, stellar, and Venus positions are also recorded and used; see especially (*8, 9, 24*). For other areas of the world, see (*18*); for Mexico, see (*22*).
30. N. M. Judd, *Smithson. Misc. Collect.* **147**, 1 (1964).
31. Corner windows occur only in the southeastern section of Pueblo Bonito.
32. As Pueblo Bonito now stands, the comparable area on the western side of this site is little more than one story high. If similar windows once existed there, they are no longer extant.
33. This is indicated by the "C" after the room number. The "SE" after 228C indicates that room 228C was divided into four rooms sometime after the initial construction, and the window is in the southeast room.
34. G. Vivian, "Ruins stabilization report" (Chaco Canyon National Monument, typed, 1938).
35. G. Vivian was too competent a field archeologist to have overlooked such evidence.
36. G. H. Pepper, *Anthropol. Pap. Am. Mus. Nat. Hist. 27* (1920).
37. I first thought that the window in room 225C was aligned cross-jamb to the solstice, and this was stated in the original draft of this article. Later fieldwork, however, indicated that the window was probably aligned parallel-jamb, although uncertainty will always exist [see (*40*)].
38. J.E.R. fell from a cliff 2 days later, which precluded an attempt to obtain an azimuth reading for the window in room 228C-SE. In the summer of 1974, we tried to set up the theodolite in the unexcavated portion of the room (228C-NW), but there was insufficient space for secure placement of the tripod. Another attempt to obtain this reading, with the use of a smaller tripod, will be made this summer (1976). Hopefully, a scaffold can be erected as a platform on which to position the theodolite to take the azimuth reading for the window in room 225C. The first attempt to obtain this reading by setting the theodolite on the outermost wall of room 177 was unsuccessful; the wall is not wide enough to permit a solid footing for the theodolite tripod.
39. Such markings, which, for instance, may be on the west wall of the *Flint-Ku-sha'lī* house at Cochiti Pueblo, may have indicated the type of alignment used.
40. However, the walls of the window, especially the north one, are now convex because of the weakness of the masonry. These bulges make it impossible to state absolutely that a parallel-jamb (Fig. 5) alignment was originally used.
41. Most late construction at Pueblo Bonito is on the east side of the town (*30*). This construction completed the "D" shape and was done in apparent conformation with the original town "plan." The east side may have also been the only area available for new construction. In terms of winter solstice sunrise observation, a window location in the northern part of the site probably did not provide a clear view of the eastern horizon.

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