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Archaeoastronomy in the Ancient Americas

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Since its popular resurgence in the 1960s, the interdisciplinary field of archaeoastronomy, which seeks evidence from the written as well as the unwritten record to shed light on the nature and practice of astronomy and timekeeping in ancient civilizations, has made ever-increasing significant use of the archaeological record. This essay briefly touches on the origin and history of these developments, discusses the methodology of archaeoastronomy, and assesses its contributions via the discussion of selected case studies at sites in North, South, and Mesoamerica. Specifically, archaeology contributes significantly to clarifying the role of sky events in site planning. The rigorous repetition of axial alignments of sites and individual oddly shaped and/or oriented structures can be related to alterations in the calendar often initiated by cross-cultural contact. Together with evidence acquired from other forms of the ancient record, archaeology also helps clarify the relationship between functional and symbolic astronomical knowledge. In state-level societies, it offers graphic evidence that structures that served as chronographic markers also functioned as performative stages for seasonally timed rituals mandated by cosmic connections claimed by the rulership.

KEY WORDS: archaeoastronomy; archaeology; architecture; orientation (alignment).

HISTORICAL AND THEORETICAL PERSPECTIVE

Most ancient civilizations paid some attention to what goes on in the sky. The periodic cycles of the sun, moon, and planets are the most pristine, predictable, and consequently, the most reliable natural phenomena on which to anchor the counting of the days and the making of the calendar. Celestial observation served to order and formalize the time to plant, to anticipate the monsoon, and, given the tension of anticipation concerning what the future might hold, to fix the ritual celebration of seminal seasonal events such as the first rain and the harvest.

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Because of their stability, the moving lights that traversed the heavens often came to be regarded as ancestor gods. By carefully charting their movements, people would come to know the habits of the cosmic deities, the better to enter into a dialog with them in order to seek omens regarding the course of war, crop yields, even personal affairs. Thus the sky served as a text capable of revealing vital information to diviners skilled at asking the appropriate questions and invoking the proper debt payment. Little wonder that celestial objects appear frequently in oral and written mythologies that tell the story of creation and the descent of humanity and the lineage of the storyteller from the sky (cf. e.g., Freidel *et al.*, 1993; Heidel, 1942; Wasilewska, 2000).

The most reliable evidence attesting to the practice of astronomy in past civilizations comes from the written record, but oral histories, iconography, and the planning and orientation of specialized architecture constitute unwritten texts that supply valuable data regarding the nature and uses of a precise knowledge of the sky. Archaeoastronomy is the study of the practice of astronomy using both the written and unwritten records. It is the interdisciplinary field where these supply lines of information converge and in which the archaeological record has come to play a major role.

Considered historically, archaeoastronomy began as a meeting ground for at least three established disciplines that deal with ancient astronomy:

1. *Astroarchaeology* (Hawkins, 1966) is the now obsolete name given to a field methodology for retrieving astronomical information from the study of alignments associated with ancient architecture and the landscape.
2. *History of astronomy*, a discipline well rooted in the sciences, usually engages only the written record. It is concerned with the acquisition of precise knowledge by the ancient circum-Mediterranean cultures from which modern western science was derived (Crowe and Dowd, 1999).
3. *Ethnoastronomy* is a branch of cultural anthropology that draws its evidence from the ethnohistorical record and ethnographic studies of contemporary cultures. It seeks to develop an understanding of cultural behavior as gleaned from indigenous perceptions of events in the heavens (Fabian, 2001; Farrer and Williamson, 1992).

The involvement of archaeology in archaeoastronomical studies has a curious history of its own. Since ancient civilizations expended considerable effort paying tribute to celestial deities, one should not be surprised to find that, in many instances, astronomical principles played a role in the design of the places where they worshipped their gods. When astronomer Gerald Hawkins wrote his popular *Stonehenge Decoded* (Hawkins, 1964), he rekindled an idea made popular at the end of the nineteenth century by Sir Norman Lockyer (1964) and others (e.g., Somerville, 1927). Hawkins hypothesized that the famous megaliths that had stood for 5000 years on the Salisbury Plain of southern England constituted a calendar in stone. Each component had been situated deliberately and precisely to align with astronomical events that took place along the local horizon. Among these were the extreme rising and setting positions of the sun and the moon, the so-called standstill positions attained once a year by the sun and approximately 18.67 years by the moon.

Hawkins also rekindled a controversy. In the then-established comparative tradition that pitted "less sophisticated" New World astronomers against the text-bound astronomers of the Classical Old World, the scientific community raised inquiries such as the following: Were their astronomers as skilled as ours? Did they too climb a ladder of progress toward great intellectual heights? Where did technology, precision, and scientific theorizing, the hallmarks of Western astronomy, fit into the picture? For the investigator, it seemed relatively simple (especially with the advent of the high-speed personal computer) to acquire the tools and methodology to demonstrate just how precisely a solstice or lunar standstill *could* be marked out on the land and skyscape by a perspicacious nonliterate skywatcher. But *was* it?

Archaeologists reacted with a combination of disinterest and critical disbelief to popular archaeoastronomy's foray onto their turf (Atkinson, 1966; Hawkes, 1967; see also Judge, 1987). Nonetheless, more detailed work (Thom, 1967, 1971) further solidified the agenda of hunting for solar and lunar standstills at archaeological sites. The so-called "Thom paradigm" (Aveni, 1988) was carried over to studies in the New World. Cultural syntheses (Aveni, 1997; Castleden, 1987; MacKie, 1977; Ruggles, 1999) have since sought to solidify the basis of our understanding of ancient megalithic astronomy as a legitimate part of an unwritten record of astronomical achievement by deflating unsupportable claims such as precise eclipse prediction and more fully addressing the uses of architecture as a reflection of seasonal ritual and mortuary practice.

Although the reception of much of the early literature that followed the resurgence of archaeoastronomy had been generally favorable (Krupp, 1978a,b; Willey, 1976), some suspicion about the validity and implications of such interdisciplinary studies was raised by the archaeological community (Baudez, 1987; Rowe, 1979b; see the responses in Aveni, 1979; Aveni *et al.*, 1993; Zuidema, 1979). Meanwhile, the flood of trade and popular works on archaeoastronomy, though useful in bringing new ideas to a wider audience, did little to contribute to its professional status. Although archaeoastronomy has shed much of the burden of the sensationalist baggage it once acquired in the aftermath of the Stonehenge controversy, popular works that advocate an extraordinary and oft-difficult-to-document role for astronomy in shaping human culture still reach the level of trade text publications (e.g., Bauval, 1995; Sullivan, 1996; Ulansey, 1989). Many of these works exhibit both millenarian and deterministic qualities in which seminal cosmic events drive the course of civilization.

In the past two decades more than a dozen international conferences on archaeoastronomy have addressed basic issues, and hundreds of published scholarly reports have appeared, a significant number of them in the Americas coauthored by interdisciplinary teams that include archaeologists. Although a recent quantitative survey is lacking (see Aveni, 1993b, for the most recent one), it seems clear that more and more contributions that carry the label "archaeoastronomy" now appear in disciplinary journals such as *American Antiquity, Latin American Antiquity, Journal of Field Archaeology, Current Anthropology, RES*, and *Arqueología Mexicana*, to name a few. Two journals specialize in disseminating research in archaeoastronomy: *Archaeoastronomy, Supplement to the Journal for the History of Astronomy*, based at Cambridge University in England (discontinued in 2002, with archaeoastronomy papers to appear in the main journal thereafter); and *Archaeoastronomy, the Journal of Astronomy in Culture*, published by the University of Texas Press. The latter is an outgrowth of the *Archaeoastronomy Bulletin and Archaeoastronomy and Ethnoastronomy News* published (until 1999) by the Center for Archaeoastronomy, Washington, DC.

The disciplinary mainstreaming of ancient New World astronomical studies is the result of a significant turning away from ethnocentric "celestial butterfly collecting" (Kintigh, 1992), that is, the tendency to report precise alignments with little analysis of their putative cultural meaning, and toward framing questions that impact current anthropological and archaeological theory (cf. Aveni, 1989a,b, 1992). Freeing archaeoastronomy from its self-styled closed universe of discourse, which for too long had failed to deal with questions that address problems in the social sciences, has been a demanding task, for it requires the investigator to learn the basic tenets of anthropology and archaeology, or at least to work very closely with researchers trained in those fields. This is far more demanding than requiring an archaeologist interested in the sky to learn practical astronomy. Nonetheless, despite some lingering pessimism about what can be revealed (Kintigh, 1992, p. 4), a significant number of archaeoastronomical investigations do begin to tell us a lot about ancient cultures, such as whether the use of astronomical knowledge was public or private, what it signified regarding the hierarchy of rulership, and what role it might have played in the development of the state.

Following McCluskey's charge that the ultimate goal of archaeoastronomy ought to be to deepen one's understanding of culture by attempting to make their observations of the heavens intelligible in terms that are meaningful in that society, (McCluskey, 1996, p. 1), within the past decade archaeoastronomy and ethnoastronomy have begun to be subsumed by the study of what has come to be called cultural astronomy. Cultural astronomy (Ruggles and Saunders, 1993, p. 6) is concerned with the diverse ways in which cultures perceive and integrate the sky and its contents into their worldview. Such a definition, framed largely by the science and history of science communities, seeks to discover links between astronomical practice and the realm of politics, economics, religion, and ideology in general; currently it competes with the title *archaeoastronomy* to describe the same agenda. It is, as Ruggles and Saunders (1993, Ch. 1) characterize it, part of a wider endeavor of investigating and interpreting human culture, an endeavor that incorporates a search for cultural correlates. It attempts to understand the celestial taxonomies of other cultures and the relationship between these taxonomies and earthbound concerns, such as the ordering of the roundhouse (Wilbert, 1981), the arrangement of sacred space (Broda, 1993; Carrasco, 1999), or the delineation of hydrological space (Zuidema, 1964).

Following a very brief synthesis of methodological procedures, I devote the remainder of this survey of the literature on ancient American archaeoastronomy to highlighting the most recent discoveries that bear upon the domain of archaeology. After giving the matter much thought, I have carved up the material regionally, simply because this corresponds best to the way archaeology organizes itself today. Elsewhere others and I have attempted to synthesize the contributions of archaeoastronomy with respect to the study of oral as opposed to written records (Aveni, 1989a, Ch. 2), sedentary versus semisedentary groups (Williamson, 1984), state versus nonstate societies (Aveni, 1997), and Old versus New World cultures (Aveni, 1993a, 2001; Krupp, 1997).

FIELD METHODOLOGY

Although archaeoastronomy begins with hypotheses and evidence derived from the cultural record, for those who would pursue it in the field, a basic knowledge of the heavens gleaned with the naked eye is indispensable. A number of texts and overview articles offer basic lessons in sky orientation and motion, together with lists of objects, cycles, and phenomena that might come to one's attention (e.g., Aveni, 1981a, 1997, 2001; Krupp, 1978a, Ch. 1); in Aveni (2001) see especially the appendices at the end of Chapter III and the list of references on pp. 124–126 that deal with field techniques and relevant special calculations. These include methods for computing positions of celestial bodies, tabulations of celestial position and sky simulation programs, archaeoastronomy websites, and star maps). Of special importance in the study of building orientation is a knowledge of the rising and setting points of celestial objects, which exhibit dramatically different perspectives when viewed from tropical as opposed to temperate latitudes (Aveni, 1981b).

For want of space the field procedures are only outlined here; readers may refer to the aforementioned references for a more thorough treatment. Essential equipment consists of a surveyor's transit (or theodolite) with altitude and azimuth readouts, and an accurate watch. The watch may be set by time signals emanating from a reliable source, such as the radio station of the National Bureau of Standards, WWV (transmitting at 2.5, 5.0, 10.0, 15.0, and 20.0 MHz), or from the on-line time service of the US Naval Observatory (tycho.usno.navy.mil). The watch is necessary because the most reliable method of determining alignments involves getting a "sun fix," that is, determining the relative azimuth, or angle, measured along the horizon between the sun and a wall, for example, or perpendicular to a doorway. This necessitates not only an accurate measure of the time of day but also a knowledge of the position of the sun in the sky. Using magnetic north to fix azimuth is fraught with difficulties (Aveni, 1975, p. 165, 2001, Appendix E, pp. 118–119). Precise latitude and longitude coordinates available either from a reliable map or via on-site GPS measurements also are required. Other useful tables are provided by Aveni (1972), while software packages are listed in Aveni (1997, Appendix C). For an example of how to reduce these data, see Aveni (2001, Appendix G, pp. 120–124). Useful guidelines for the procurement and analysis of data relating to the archaeological record are given by Hawkins (1966, pp. 5–9). They include (my comments added) the following:

1. *Construction dates should not be determined from alignments.* Under certain circumstances this can be attempted. At the very least, construction dates determined from archaeoastronomical dating can be contrasted for consistency with those determined by other techniques, for example, dendrochronology, radiocarbon dating, or ceramic seriation.
2. *Alignments should be restricted to man-made markers.* In some instances there may be evidence that natural horizon features served as astronomical pointers (cf. e.g., Parsons, 1936, on the astronomical observations of the Hopi).
3. *Alignments should be postulated only for a homogeneous group of markers and all possible alignments at a site must be considered.* For example, if four standing stones are in place, one can generate $4 \times 3 = 12$ possible directions, all equally valid. In cases where other evidence obtains, one can go farther; for example, if this method of reasoning were applied at many Mesoamerican sites, one would need to be aware that alignments from such places as doorways ought to be given added weight since such a sighting technique has already been proposed on the basis of the analysis of "eye and stick" iconography in Mixtec codices (Hartung, 1975, 1977a; for a full discussion, see Aveni, 2001, pp. 19–21; Jansen and Aurora, 1983; Smith, 1973a,b).
4. *All related celestial positions should be included in the analysis.* Again, the written record or special geographic conditions might motivate the investigator to break or at least bend this rule. For example, for a site location in the tropics the rising or setting position of the sun on zenith passage dates might be given special importance (Aveni, 1981b; Bricker, 1983; Milbrath, 1999).

To these propositions I would add that when collecting field data, it is unnecessary and perhaps even misleading to take one's precision beyond the limits of detectability (Aveni and Hotaling, 1994, p. S37). The investigator should set as a goal the identification of those celestial bodies that possess azimuths corresponding to the alignments determined from a set of measurements taken on original standing structures to a precision no greater than could have been attained by the builder with the unaided eye (Schaefer, 1993). Rarely will such precision require azimuth measurements to an accuracy of less than $\pm 1/2^{\circ}$. Hartung (1975) offers further rules about astronomical alignments that may be applied specifically to standing architecture. Other discussions on the acquisition of data in the field are provided by Dow (1967), Ruggles (1999), Reyman (1975), and Schaefer (1986, 1987a,b). Reyman is particularly emphatic about the need to offer hypotheses to be tested prior to making *any* observations, a view that seems somewhat unrealistic in practice. Lastly, one needs to be aware that astronomy is hardly the only reason for orienting a building—even one of peculiar shape and/or orientation relative to those around it (for a discussion of diverse orientation motives, see Aveni, 2001, pp. 217–218).

Finally there is the issue of statistical rigor in the assessment of archaeoastronomical data. How does one know whether astronomical alignments are simply due to coincidence? In an overview (Aveni, 1989b) of the two proceeding volumes that resulted from the first international archaeoastronomy conference held at Oxford in 1981 (Aveni, 1982; Heggie, 1982), I noted a marked dichotomy between Old and New World archaeoastronomical studies. Following the Levi-Straussian raw-cooked metaphor, I characterized Old World studies, which dealt largely with statistical precision of alignments between standing stones as “green archaeoastronomy” (conveniently, after the color of the cover of that volume), while I labeled the more broadly based New World archaeoastronomy “brown archaeoastronomy” (again by dint of coincidence that volume’s color turned out to fit the metaphor perfectly). Papers in the latter volume dealt largely with astronomy and calendar in the context of ethnohistoric, iconographic, and written records; they incorporated the study of alignments where necessary or helpful in framing and testing hypotheses. I suggested that green archaeoastronomy, basing itself solely on the existence of standing stones, needed to rely solely on statistical tests as a way of confirming astronomical orientation hypotheses, but that such results could be misleading. I offered examples of studies in Mesoamerica to illustrate that had one employed only building orientations one might grossly misinterpret what archaeological “ground truth” really had to say about astronomical practice (the case of the Templo Mayor, to be discussed in the next section, serves as an illustrative example).

Responding to my analysis, Ruggles (1984) and Ruggles and Saunders (1993) noted that emphasizing the ethnographic and ethnohistoric record is no excuse for abandoning statistical rigor. I agree that in any case study the issue of whether proposed astronomical alignments are not merely due to randomness needs to be addressed. Where applicable, there are statistical methods for doing so (cf. e.g., Ruggles, 1999, Ch. 3); addressing the problem quantitatively, however, is difficult when nonquantitative information enters the picture.

MESOAMERICAN ARCHAEOASTRONOMY

León-Portilla (1989, p. 225) has written that one's very existence in Mesoamerica depended upon observing the sky: "Without skywatchers the ethos of this people, its distinguishing spirit, it's own genius would not have developed." Mesoamerican architecture constitutes one form of expression of the intense focus on time's cycle, especially the notion of completion of time's round evident in the literary and iconographic record from which León-Portilla draws his conclusion about the extraordinary premium placed upon a knowledge of the sky in this culture. Here I look first at the role of astronomy in city planning and then focus on studies of astronomically oriented, specialized buildings and assemblages of buildings.

Celestial considerations have been found to play a role in defining and designing the urban condition all over the world (cf. e.g., Carrasco, 1999; Wheatley, 1971; Wilson, 1988). Since the flow of heavenly motion pivots about the north–south axis, we might expect urban planners to exhibit a desire to orient their cities on the cardinal directions in order to reflect the harmony of the world and the fixity of the rulership about a stable cosmic axis. Mesoamerican cities exhibit significant variations on this theme.

The Aztecs said of Teotihuacan that it was the place where time began: ". . . there in Teotihuacan, they say, is the place; the time was when there still was darkness. There all the gods assembled and consulted among themselves who would bear upon his back the burden of rule, who would be the sun" (Sahagún, 1978, p. 1). That Teotihuacan culture possessed an abiding interest in celestial symbolism is well documented. It is the likely place of origin of the star motif depicted on ceramics and in mural paintings (Baird, 1989). From Teotihuacan this symbol, which has been associated with water and fertility, warfare, and in some instances with the planet Venus, spread to highland Cacaxtla (Baird, 1989, pp. 112–114; Carlson, 1993) and as far as the Maya area (Baird, 1989, pp. 114–120; Fash and Fash, 2000; Schele and Freidel, 1990, pp. 159–164; Stuart, 2000; Taube, 2000).

A mass grave excavated at the center of the Temple of Quetzalcoatl (on the east side of the Ciudadela and dated to A.D. 150–450) revealed a four-directional patterning of burials consisting of decapitated warriors clustered in groups of 18, 20, and 26 ($= 2 \times 13$), all of which are numbers of calendrical significance (López Austin *et al.*, 1991). Whether the deceased were loyal Teotihuacanos laid away to guard the tomb of a great leader or sacrificed war captives is not yet clear. The feathered serpents that adorn the Temple of Quetzalcoatl bear the headdress of Cipactli (Crocodile, also called Alligator), the first day in the Mexica 260-day count and consequently a symbol of its initiation. Therefore, this building is believed to have been dedicated to the myth of the origin of structured time and calendrical succession—the place where time began. Further attesting to order and precision in Teotihuacan architecture, Sugiyama (1993), O'Brien and Christiansen (1986), and Drewitt (1987), all have proposed the use of basic Mesoamerican measuring units that underlie its construction. Calendrically significant multiples (e.g., 20, 260, 584) of some of these units are thought to have been employed in the layout of the city.

The rectangular grid structure of Teotihuacan exhibits ordered harmony and precise planning that may find its roots in the cosmos. As Millon (1973) and his co-workers demonstrated, the streets of the ancient city align in one of two directions, a north–south orientation $15^\circ 28'$ east of north and an east–west orientation $16^\circ 30'$ south of east, both of which run against the natural trend of the landscape. The archaeological evidence suggests that the deviation of 1° from a perfect right angle between the two is probably not accidental.

Teotihuacan is an instructive example to discuss in the context of this review essay because there is no shortage of hypotheses to explain its orientation (Aveni, 2001, pp. 226–235; Millon, 1992). One of them (Dow, 1967) implicates the Pleiades, a conspicuous group of stars that set within 1° of the imaginary line between a pair of pecked crosses (Aveni *et al.,* 1978), possible architectural bench-marks and calendrical counters carved on rocks and in the floors of buildings at Teotihuacan. Coggins (1980), Aveni and Hartung (1989), and Aveni *et al.* (1982) argue that these devices were similarly used elsewhere in Mesoamerica (see also the case of Uaxactún below).

The control of time lies at the basis of this particular orientation hypothesis. The Pleiades underwent heliacal rising or first annual predawn appearance on the same day as the first of the two annual passages of the sun across the zenith, a day of great importance in demarcating the seasons (the date is approximately May 18). Thus the appearance of the Pleiades may have served to announce the arrival of this important day, when the sun at high noon cast no shadows. Furthermore, the star group itself also passed close to the zenith of Teotihuacan. This could have served as an ideal sun-star timing device incorporated into the clockwork fabric of the city itself.

The sun sets along this same $15^\circ 28'$ north of west alignment on April 29 and August 12, which offers a second astronomical hypothesis to account for the orientation (Aveni, 2000, p. 254). These dates may have been meaningful because they are separated by a period of 260 days, during which interval the sun passes to the south of that alignment; during the remaining 105 days it passes to the north. Moreover, this city axis also marks sunsets 40 days after the vernal equinox and 20 days before first zenith passage (the intervals are reversed when the sun returns toward the south). A number of investigators have posited that 20-day solar periods were configured into horizon observational astronomy across Mesoamerica (e.g., Aveni *et al.*, 1988; Aveni *et al.*, in press; Tichy, 1976).

Sprajc (2000a) extends the axial alignment eastward to a prominent peak on the eastern horizon. He argues that this was another deliberate Teotihuacan orientation, to sunrises on February 11 and October 29, which also are 260 days apart. Furthermore, he proposes that the location of the Pyramid of the Sun itself was determined so that observations made from its summit marked sunrises at quarter-year intervals. Like Sprajc, Drucker (1977) also had proposed that local topographic features along the east–west horizon may have been a determining factor in the city's orientation; he argued, however, that the ritualistic 260-day cycle betrayed its Maya origin via a Teotihuacan orientation to the rising and setting points of the sun on the days when it passes the zenith of Copán, which lies in the region where some investigators (e.g., Malmström, 1978, 1997) have suggested that the 260-day calendar originated. (The sun crosses the zenith of Copán and Izápa at 260- and 105-day intervals.) For a critique of this theory, see Aveni (2001) and Henderson (1974). Both Drucker's and Sprajc's arguments rely on a decidedly subjective element, namely the recognition of "conspicuous natural landmarks" along the horizon.

Nonastronomical factors also have been posited as having contributed to building placement and orientation at Teotihuacan. Heyden (1975) suggested that the location of the Pyramid of the Sun was determined by the multichambered flower-shaped cave that lies beneath it. Its axis opens to the west along the east–west orientation axis of the city. That this cave has been demonstrated to be artificial (Manzanilla, 2000) does not rule out Heyden's hypothesis. Nor does Tobriner's theory that the approximate alignment of the Street of the Dead with the prominent mountain Cerro Gordo diminish either the cave or sky explanations (Tobriner, 1972). I agree with Millon (1992) that whatever motivated Teotihuacan city planners, the ideology involved was less practical and more inclined to religious thinking—the need to fix the place of the gods to be in total harmony with all aspects of their power. This may well have entailed a constellation of orientation motives. The *cosmovisíon* (Broda, 1982) that undergirded the Teotihuacan urban arrangement would have posed difficult problems to reconcile for the designers of the great city where time was born (Millon, 1992, p. 35), where cave, mountain, sky, and time all needed to be brought together harmoniously. On the other hand, some critics of this view (Rowe, 1979b, pp. 227–229) insist that a single explanation for the orientation will suffice. Regardless of how to explain it, the influence of Teotihuacan upon its neighbors was made manifest in the duplication of its basic orientation at other sites in highland Mexico, noted long ago (Aveni and Gibbs, 1976). This urbanistic mimicry emerges as one example of Teotihuacan's influence upon the rest of Mesoamerica.

Although it dates to several centuries later, the Aztec capital of Tenochtitlan also exhibits cosmic order in its plan. As stated earlier, there is good evidence that the Templo Mayor was aligned with the rising sun at the equinox. The main pyramid of the Templo Mayor is crowned with a pair of temples dedicated to two of the primary Aztec gods: Huitzilopochtli and Tlaloc. The west-facing temple and its plaza served as a backdrop for the conduct of the rituals, among them that of the sacrifice of children to the rain god in the Aztec month of Atlcahualo, leading up to the rainy season (Aveni, 1991; Sahagún, 1981, p. 1).

Written shortly after the conquest, a text attributed to the chronicler Motolinía (1903) states that the festival celebrating the Aztec month of Tlacaxipeualiztli took place there "when the sun stood in the middle of [the Temple of] Huitzilopochtli, which was at the equinox, and because it was a little out of line, [King] Moctezuma wished to pull it down and set it right" (see Aveni *et al.*, 1988, for a full discussion of this interesting passage). Evidently the priest and worshippers faced east to view the sun rise in the gap between the twin temples. In the wet season the sun passed to the side of Tlaloc's temple atop the Templo Mayor and dwelled in his domain of rain and fertility; in the dry season it rose on the side of Huitzilopochtli, whose temple was tied to warfare, fire, and the sun itself (Miller, 2001, pp. 205–206).

One might expect from Motolinía's remarks about the equinox that modern measurements of the remains of this structure would show that its axis aligned exactly east–west when the sun stood in the middle, to register sunsets on March 20 and September 22. To the contrary, measurements and analysis (Aveni *et al.*, 1988) show that all six of the excavated facades of the structure are directed approximately 7.5° south of east. But here the apparent conflict between historical and archaeological evidence is resolved by a careful consideration of how the crucial equinox observation could actually have been made.

A ground-level observer situated in the plaza below could look over the terrace between the twin temples to view the appointed sunrise between them, but a skew of 7.5° south of east would have been necessary, because as it gains elevation the sun moves toward the southeast on a slanted path to an altitude of about 20° above the astronomical horizon before it can actually be seen in the notch on the day of the equinox. Pinning down the alignment with greater precision is difficult because one cannot be sure exactly where the observer stood. Rowe (1979b, p. 229) has pointed out that one possible reason for Motolinía's statement is that with repeated building, the structure apparently attained a height great enough to begin to throw the traditional observation out of line. In any event, such a key alignment would have sealed the workings of the cosmos into the architectural fabric and sacred space of the city. The sun's appearance at the appointed time would have validated the ritual procedure that took place at the temple.

Maya cities offer a striking contrast to the uniform grid-type structure evident at most sites in the Mexican highlands. Although little has been done with the study of mensuration (cf. the work of Powell cited in Schele and Matthews, 1998, pp. 34–36), there is abundant data on building orientation. Histograms showing the distribution of site alignments exhibit specific azimuthal concentrations that seem to evolve through time with shifting calendrical interests (Aveni and Hartung, 1986), and that strongly suggest calendar reform. Overall only 16% of the alignments fall west of the north–south line, while 84% lie to the east. The dominant group falls in a zone 8–18° east of north, peaking at about 14°; another peak occurs at 25°. There is no conceivable way of establishing such systematic building orientations over a widespread area without recourse to celestial observation. The latter orientation (25°) likely reflects orientations to the solar standstills (solstices). Chronologically, it was already present in late Formative/early Classic architecture (see Aveni and Hartung, 1986, fig. 86c; also Aveni and Hartung, 2000), and it persisted into the Late Classic period, vanishing by the Postclassic period. On the basis of glyphic and ethnohistoric evidence, Bricker (1982) has argued that the solar calendar was first employed by the Maya about 500 B.C., that is, during the Middle Preclassic period. Moreover, her suggested arrangement of month names according to the seasonal year implies that the winter solstice was originally chosen as the starting point of the year count. Yet, by the time the Puuc style of architecture had developed in northern Yucatán, some 1300 years later, a decidedly different orientation principle seems to have been at work.

It has long been argued that the general flow of goods and ideas that characterize the Classic Maya civilization moved from south to north. Architectural principles devised in the south were carried forward in time and northward in space (Gendrop, 1983), as were so many other skills, styles, and traditions in Mesoamerica. The record in the monumental inscriptions shows that the calendar was no exception. We have proposed (Aveni and Hartung, 1986) that the 14° peak in the Puuc alignments constituted an attempt to spatially transform a temporal idea inherited from the earlier Petén calendar on the basis of the pivoting of the 20-day months about the passage of the sun across the zenith. Sprajc (1990) also has found many of these same uinal-based horizon alignments in a single disoriented structure with sighting chambers located at Oxkintok.

The highly replicative nature of Puuc site plans (Pollock, 1980, p. 652) argues for an all-pervading ideology (and rules for its practice) that tied people together regardless of how dispersed the social order might have become. In the Terminal Classic Puuc sites, the separateness implied in the “feudal order” (Willey, 1977) in the development of individual complexes, consisting of buildings that look to the center of their own particular grouping, is counterbalanced by the overall unity of the site displayed in the careful and deliberate planning and orientation of these complexes around a basic axis. The hierarchical unity proceeds to an even higher order when one finds nearly identical plans and orientations over a range of widely separated cities. There is little doubt that a state calendar, built along the lines suggested earlier, played a role in certain stages of site planning. Sharp (1978, p. 169) views great art as “a form of communication that brings together people who are otherwise separated by social, economic, and political barriers.” Thus the abstract knowledge of the elite given, say, in the Dresden Codex, could be shared with the commoner though rudimentary calendars expressed via the orientation of and decoration on monumental architecture. The shift from a more sacred to secular based society begun during the Late Classic period would have motivated such a dispersion of knowledge.

Ashmore (1989, 1991) has singled out five cosmologically related components of a model or template of the architectural setting of the Classic Maya city that illustrate its role in politicoreligious statements. The principal components of the pattern are (1) a strongly marked north–south axis; (2) mutually complementary functional dualism for construction and spaces at north and south ends of that axis, in which north stands for the celestial supernatural sphere and south for the underworld or worldly; (3) the appendage of subsidiary eastern and western units to form a triangle with the north; (4) the common but not invariant presence of a ballcourt as mediator between north and south; and (5) the frequent use of causeways to underscore the linkage between various elements, and thereby stress the symbolic coherence of the whole (see M. Smith for a critique.)

Tikal's twin pyramid groups provide the best example to illustrate some of the features of Ashmore's template. Their quadripartite plan invites comparison with the cosmogram on page 1 of the Codex Féjérvary-Mayer (Seler, 1901 [c. 13th century]) and its counterpart in the Madrid Codex (Anders, 1967 [c. 15th century]), pp. 75–76. Each complex (dated ca. A.D. 600) comprises two large pyramids positioned on the dominant east–west axis of a plaza, with smaller structures on the opposing north–south axis: an unroofed enclosure on the north and a small range building on the south. A stela and altar pair positioned in the north building, which also symbolizes the "up" direction, the access point to the afterworld, provides information about the ruler who commissioned the complex, usually to celebrate the katun period ending in which he claims to have ruled. This building is open to the zenith, whence he derives his power. The southern ("down") structure consists of nine doorways, the same as the number of levels of the underworld.

In part inspired by Coggins (1967, 1980), Ashmore notes similar cosmograms in many of Tikal's larger complexes, as well as in a major portion of Copán's ruins. Fash and Fash (2000) have characterized the great Copán Acropolis as a sacred geography in itself. A walk through each component of it traces successive steps in the creation story told in the Popol Vuh (Stuart, 1997).

The Maya polity often employed specialized assemblages or individual buildings with unusual shape and/or orientation as a way of mapping time and expressing its derivative astronomical knowledge. Like the twin pyramid groups, Group E at Uaxactún has long been recognized to have a cosmic component. It was first proposed as an astronomically oriented complex by Ricketson (1928). From the top of Building E-VII sub, a radial pyramid, one looks out toward the east over an open plaza. In the foreground lie the remains of three small buildings constructed on a single platform, the outside ones (E-I and E-III) equidistant to the north and south of the central building (E-II). Measurements at Uaxactún (Aveni and Hartung, 1989) revealed that the sun as viewed from a point just above the middle stairway of E-VII sub would have risen over the three buildings to the east at the June solstice, the equinoxes, and the December solstice, respectively.

Valdes and Fahsen (1995) have used archaeological data to establish that during the Tzakol 2 phase (A.D. 300–378) Uaxactún's early power center was transferred from the perfectly cardinally aligned Group E complex to Group A several hundred meters to the southwest. Interestingly, a pecked cross of the type referred to above at Teotihuacan is carved in the floor of Str A–V (Ic) (Smith, 1950).

An analysis of the count of peck marks on this artifact has led to the conclusion that a Teotihuacan calendar based on dividing the seasonal year into 20-day units may have been adopted in the Maya world at this time (Aveni *et al.*, in press; see also Coggins, 1979). Surveys of 12 other sites containing assemblages with the Group E form reveal alignments that seem to center on solar positions that mark whole multiples of 20-day intervals measured from the first annual passage of the sun across the zenith. A significant number of these alignments match dates that fall in the midst of the dry season, the most logical points in time to conduct rituals pertaining to the anticipation of the forthcoming crop. A similar correlation has been posited in central Mexico (Sprajc, 2000a,b, 2001).

There is a tendency to believe Uaxactún's Group E was the earliest of its kind because of the preciseness of fit with astronomical data (Ruppert, 1940); Chase and Chase (1995) and LaPorte and Fialko (1990), however, have found antecedents of its general form that can be dated archaeologically to the transition period between Preclassic and Early Classic (c. A.D. 300) (E-VII sub is Late Preclassic, A.D. 0–200). The standardization of the Group E complex found in Uaxactún coincides with the time (A.D. 150–250) when Maya chiefdoms developed into state-level civilizations. Burials and caches at many Group E complexes, accompanied by the development of the open E-Group plaza, have been taken to imply that this architectural form evolved into a place for the emerging ruling elite to perform ancestral rituals (Chase and Chase, 1995, p. 100).

The oddly shaped Caracol round tower at Chichén Itzá (Aveni *et al.*, 1975; Ruppert, 1935) and the radically disoriented House of the Governor at Uxmal (Aveni, 1975; Sprajc, 1993a,b) exemplify two more well-studied examples of specialized astronomically oriented Maya architecture. Both are unusual in that they incorporate Venus alignments. The latter case is especially convincing owing to the appearance of numbers and hieroglyphic symbols identical to those found in the Venus table in the Dresden Codex (Aveni, 2001, pp. 273–279). A zodiacal frieze has recently been deciphered in the iconography that appears on this building (Bricker and Bricker, 1996).

The last decade witnessed a number of publications that stress the real-time astronomical content of the codices (cf. e.g., Bricker *et al.*, 2001; V. and H. Bricker 1986a,b,c, 1988, 1992, 1997; H. and V. Bricker, 1997). These studies serve both as a testimony to the extraordinary effort paid by the Maya to charting the periodicities of celestial bodies and as a basis for formulating chronologically specific hypotheses regarding building orientations. Thus the recent decipherment of almanacs in the Madrid Codex (Hernández and Bricker, in press) that deal with the planting season helps explain alignments at the contemporary site of Mayapán that correspond to seasonal dates in that range (Aveni *et al.*, in press).

Alignment studies at Dzibilchaltún (Coggins and Drucker, 1988) and at Chichén Itzá (Milbrath, 1988) have been specifically tied to associated building iconography. In both studies iconographic interpretations have been employed to generate astronomically related hypotheses. Studies of astronomically aligned buildings elsewhere in Mesoamerica have focused on Monte Albán's Building J (Aveni and Linsley, 1972; Peeler and Winter, 1995), Copán (Closs *et al.*, 1984), and Malinalco (Galindo, 1990).

Hierophanies constitute the most difficult cases of alleged astronomically oriented buildings to appraise. Eliade (1959) defines a hierophany as a revelation of the sacred in an object or event of the otherwise profane world. In Maya architecture this translates into light and shadow phenomena in architectural space dedicated to enhancing public rituals. The most famous case is the serpent hierophany at Chichén Itzá (Rivard, 1970). Late in the afternoon on the equinox, one views seven diamonds of light (resembling the design on the back of the diamondback rattlesnake) on the west side of the northern balustrade of the Temple of Kukulcán (the Castillo) at Chichén Itzá, produced by the shadow cast by the northeast edge of the building (for detailed descriptions, see Aveni, 2002; Krupp, 1982).

The modern re-creation of the descending serpent myth as a device for celebrating Mexican patriotism, which has had a largely negative effect on the contemporary local populace (Castañeda,1996), is reminiscent of the many incidents of the exploitation of the archaeological record by forces driven by contemporary social necessity (Fowler, 1987). Today tourists connect with their own version of an ancient Mesoamerican past by turning out in droves at Teotihuacan, Dzibilchaltún, and even remote Alta Vista (Chalchihuites) on equinox day. Hierophanies also have been proposed at Palenque, involving the Temple of the Inscriptions and the tower of the Palace Group (Schele, 1977), and at Tikal in connection with Temples I and II (Hartung, 1977b).

In sum, there are at least five reasons to establish astronomy as one among a number of factors affecting Mesoamerican city planning:

1. Evidence from ethnohistoric texts and codices strongly implies the existence of astronomically oriented structures.
2. Much Mesoamerican ceremonial architecture can be interpreted as an ideological "text" that makes manifest in the work of people the observed principles of cosmic, ancestral order to which they responded by conducting rituals in the outdoor environment surrounding their temples. In this sense one might also think of Uaxactún's Group E as performative rather than practical, a theater rather than a laboratory, a planetarium rather than an observatory.
3. Alignment studies reveal a widespread pattern of systematically deviated orientations. The confinement of alignments to particular ranges of azimuths is well established all over Mesoamerica. There is evidence that changes in the basic pattern of orientations through time may have corresponded both to local sky conditions and to changes in ideology.
4. Specialized assemblages of buildings, some oddly shaped and radically skewed from the prevailing grid, often can be explained by resorting to astronomical principles.

5. Finally, there must be an underlying empirical basis for the precise calendars that appear in almanacs in the codices and dates in Maya monumental sculpture. Astronomical alignments offer a rational, concrete basis for documenting these calendars at an early time.

The overwhelming attention to timekeeping, calendar, and astronomy manifested in the inscriptions, supported by alignment studies and still extant in contemporary culture (e.g., Gossen, 1974a,b; McGee and Reilly, 1997; Tedlock, 1992, 1999; Vogt, 1964; 1985, 1997), reflects the force of León-Portilla's statement about the upward-looking nature of the Mesoamerican people.

ARCHAEOASTRONOMY IN THE ANDEAN WORLD

Cuzco, the ancient Inca capital, like Teotihuacan and Tenochtitlan in Mexico and Cahokia in the US heartland, was the quintessential meeting place of the social, the natural, and the supernatural worlds. Carrasco (1989, p. 9) has called such cities the *imago mundis* or crystallized images of all the institutions that constituted the state, a lasting expression of *cosmovisión*. Perhaps more than anywhere else, in Cuzco the ethnohistoric record and archaeoastronomical fieldwork help reveal insights into Andean astronomy, calendar, and worldview. I have characterized the alignments as part of an Inca strategy of binding together center and periphery (Aveni, 1989c).

Cuzco was built to conform to an elaborate plan that was intimately tied to concepts of Inca sociopolitical organization. In his *Historia del Nuevo Mundo*, chronicler Cobo (1956) states that some 400 sacred shrines called *huacas* were scattered in and about the city. Cobo's definition of a *huaca* leaves little doubt that he was talking mostly about specific places in the environment—springs, mountains, rock outcrops, caves, etc.: "On each one of those ceques were arranged in order the *guacas* [*huacas*] and shrines which there were in Cuzco and its region, like stations of holy places, the veneration of which was common to all. Each *ceque* was the responsibility of the partialities and families of the city of Cuzco, from within which came the attendants and servants who cared for the *guacas* of their ceque and saw to offering the established sacrifices at the proper time" (p. 169) (translated by Rowe, 1979a, p. 15). Many of these *huacas* were positioned along lines known as *ceques* (*raya* in Spanish). Most of the 41 (or 42 depending upon how one counts them) *ceques* emanated from the centrally located Coricancha, or Golden Enclosure. While they served the primary purpose of dividing the city into irrigation zones and kin-related work groups (*ayllus*), according to Zuidema (1977) there are reasons to believe that some of the *ceques* also may have possessed an astronomical function. Certain of these *huacas* were related to the solar horizon pillars discussed by a number of chroniclers (e.g., Cieza de León, 1973; Garcilaso de la Vega, 1961). They lie on specific *ceque* lines, as Cobo (e.g., 1956, p. 172) tells us; for example, one of Chinchaysuyu's (the northwest sector of Cuzco) *ceques* has 11 *huacas*, the 9th of which, counting radially outward from Coricancha, was named Quiangalla, "which is on the Yucay road. On it were two markers (*mojones*), or pillars, which they regarded as indication that, when the sun reached there, it was the beginning of the summer" (Rowe, 1979a, p. 25). References to "markers" can be found in other quarters of the city, although they are more difficult to document archaeologically.

The spatial domain of Cuzco is divided by an east–west line into an upper (northern) and lower (southern) moiety, each of which was halved to produce four quarters or *suyus*. The suyus possessed an ordered number of *ceque* lines (usually arranged in groups of three). Zuidema (1964) contends that 328 *huacas* were part of the *ceque* system of Cuzco, which also functioned as a calendar (the number 328 may have represented a 12 sidereal lunar month cycle). (See also Rowe [1979b, p. 231], who agrees with the general idea of an association between *huacas* and the calendar.)

One of the most important alignments in Cuzco demarcating the solar year employed as a backsight the *sucanca*, four pillars situated on Cerro Picchu overlooking Cuzco on the northwest. It centered on the place where the sun set on the day of passage through the antizenith. An anonymous chronicler (Maurtua, 1906) tells us that from the *ushnu*, a pillar of well-worked stone said to have been located in the colonial Plaza de Armas not far from the Coricancha, the observer could view the four pillars marking the solar course at the start of the planting season. On the calendar date opposite the passage of the sun in the zenith, the so-called antizenith sunset day (18 August specifically in the latitude of Cuzco), the sun set over the western horizon at a point about 180° opposite the sunrise point on the day of zenith passage. As in Mesoamerica, the importance of the passage of the sun through the zenith is mentioned frequently in the chronicles (see, e.g., Garcilaso de la Vega 1961). The zenith–antizenith alignment in Cuzco may have been one form of expression of the symbolic vertical dualism so prominent in the Andean worldview (Isbell, 1978; Murra, 1972). It also is consistent with statements made by Guaman Poma (1936, ff. 883–884) that the earth opens up (to be penetrated by the plow) in February and August, the zenith–antizenith sun dates. (See also Salomon and Urioste's [1991, pp. 1–24] discussion of the pervasive theme of complementary dualism in Andean lifeways.)

Discovering the sites of astronomical *huacas* in the city and landscape of Cuzco is a classic example of the gathering together of evidence from diverse "texts," both written and unwritten that has become the hallmark of archaeoastronomical method. By employing ethnohistoric evidence, astronomical arguments, and architectural and topographic data gathered in the Cuzco environment, various investigators (Aveni, 1981c; Bauer and Dearborn, 1995; Dearborn and Schreiber, 1986; Zuidema, 1981, 1982) have attempted to map their locations. Bauer and

Dearborn have concentrated their efforts on seeking the archaeological evidence for astronomical *huacas*. Their search has met with some success, although they have not yet managed to locate the *sucanca*. More recently, Bauer (1998) has produced a lengthy work giving the location of all extant *huacas*. His research methodology (pp. 31–33) involved archaeological survey accompanied by archival work and interviews with locals to secure toponyms. Bauer finds that the *ceques* are anything but straight in the actual landscape. Niles (1987) corroborates this conclusion. On the other hand, despite fundamental differences regarding the organization of the *ceque* system, Bauer's discoveries do not substantially alter either the astronomical or calendrical conclusions already reached regarding the *ceque* system by Zuidema and Aveni (Aveni, 1996, summarizes). Bauer and Dearborn (1995, Ch. 4) find support in the archaeological record for most of Aveni's and Zuidema's findings; however, they have been particularly critical of those that involve the antizenith sun and the equinox (see pp. 94–98).

These studies are at odds over two fundamental ideological and methodological differences, one having to do with what sort of knowledge holds primacy, the other with which form of a fundamental concept matters most. First, it must be understood that Zuidema's work uses the ethnohistoric record to generate astronomical hypotheses concerning the *ceque* system. Bauer and Dearborn, while relying on ethnohistorical data (and not being ethnohistorians), tend to take statements by the chroniclers in a literal manner. Moreover, they regard the existence of archaeological remains as the ultimate litmus test for proving the existence of an astronomical *huaca*. Not having located the *sucanca*, which the chronicler Garcilaso de la Vega (1961, pp. 116–118) himself says were destroyed in his lifetime, is therefore reason enough for them to deny the existence of the zenith–antizenith alignment and its role in the calendar.

The second difference (also based on a literal interpretation of the chronicles) revolves around the issue of the straightness of the *ceque* lines. "Let's draw a line across the world. I'll go into this space and you go into the other," says the highland trickster Cuni Raya in the Huarochiri creation myth (Salomon and Urioste, 1991, p. 89). A *ceque* has the sense of a line, boundary, or limit, but often was employed to mean "a schematic line in ideal space" (note 382). A temporal example from our own culture helps elucidate this Andean spatial conundrum. Conceptual *ceque* lines are not unlike our months, which were at one time observationally based on the lunar synodic period (29.53 days). In practice, however, the moon's phase cycle has been culturally corrupted, largely by the vagaries of Roman politics (see Aveni, 1989a), into an irregular sequence of 31-, 30-, and 28- or 29-day periods that comprise our contemporary calendar. What matters is that *ceque* lines are radial in their conceptualization, and their *huacas* were intended to function in part to delineate an orientation calendar. Distant reflections of the astronomical underpinning of the ceque system are echoed in various forms of the historical record (both written and unwritten) that survives them. Although the Inca empire was short lived, Cuzco's plan, like that of Teotihuacan, was rigorously duplicated elsewhere in the empire, especially at Inkawasi (Hyslop, 1985) and Huánuco Pampa (Morris, 1985).

Another critique of Zuidema's approach by Ziolkowski (1989) focuses largely upon interpretations of the calendar, questioning his proposed positions of the sun pillars on the Cuzco horizon. Ziolkowski argues that the calendar of the Inca state consisted of 12 lunar synodic months tied to a tropical year, with the count beginning at one of four different moments of the cycle. On the other hand, Zuidema, drawing on Cobo's description of the *ceque* system and other chroniclers, argues that the calendar was a far more complicated instrument consisting of sidereal months counted in one part of the year and synodic in the other. Both Ziolkowski and Bauer and Dearborn seem to be wedded to the primacy of a solar-based year consisting of lunar months and an intercalation process, a western tradition since Caesar that influenced the way the chroniclers—and possibly modern investigators—tend to think about the calendar. For example, Ziolkowski is concerned with the "empty time" of 37 days that would be needed to fill out the native calendar of 328 days proposed by Zuidema to make a full solar cycle of 365 days (cf. Ziolkowski, 1989, p. 207). But Roman, Trobriand, and Maya calendars all once operated on temporal baselines that fell well short of a tropical year (Aveni, 1989c, pp. 174–176), and this may well have been the case for the Inca. It is fair to say that, at this writing, the whole problem of the nature of Inca calendrics remains open.

Dearborn *et al.* (1998) have discovered a set of possible solar markers on a hillside overlooking the Island of the Sun in Lake Titicaca, the place where the sun first emerged from the earth according to Inca myth. Near the time of the Inti Raymi festival (the June solstice), westward-looking observers situated in the central plaza of an island site (called the Sacred Rock in historical sources) fronting the city of Copacabana would have been confronted with a view quite similar to the description given by the anonymous chronicler of sunsets with respect to the *sucanca* in Cuzco. Bauer and Stanish (2001, pp. 207–212) argue that the physical arrangement was sufficient to accommodate lesser nobility and commoners who, viewing the June solstice sunrise together, acquired a participatory role in the state-operated ritual.

One of the most intriguing specialized buildings that incorporates Inca astronomical orientations is the Torreón of Machu Picchu, a site more well known for its hypothetical astronomical sun stone or Intihuatana. (Aside from its shape, which resembles that of a gnomon, there is no evidence that this stone was ever used to measure time via shadow casting.) Viewed aerially, the Torreón is a P-shaped structure built on a natural outcrop. Three trapezoidal apertures overlook spectacular vistas that include the Urubamba River. The northeast window centers on the June solstice, which Dearborn and White (1983, 1989) propose had some connection with the way the window and the carved rock at the center of the floor of the structure on which the former's shadow falls were modified to create a precise marking device to register the event. The upper surface of the interior "altar" stone is cut into a flat vertical surface perpendicular to the window. These investigators fastened a wooden frame to carved knobs located on the outside corners of the window. From it they suspended a plumb line that recorded the shadow cast by the solstice sunrise. They argue that the Inca likewise could have employed a similar technological device to acquire greater precision; there is no evidence, however, that wooden frames ever were hung on windows of Andean buildings, and adequate explanations for the such knobs in Andean stone facing already exist.

Alignment studies in the Andes provide good lessons for future investigations in archaeoastronomy. One should assume that neither fundamental Western astronomical percepts necessarily have counterparts in other cultures nor any such percept in another culture need also be present in our own. Moreover, it is well known among ethnohistorians that when it comes to interpreting Native American astronomical and cosmological concepts, the Spaniards, given the Western view of the universe imparted to them via their own Renaissance education, were often confused and biased.

The study of astronomical alignments in the *ceque* system also offers an object lesson in the danger of employing statistical methods, a habit one often encounters in "green archaeoastronomy." Thus, if one had disregarded the written record provided by the Spanish chroniclers and set out to test the straightforward astronomical hypothesis by measuring the alignments of the directions to the horizon indicated by the *ceque* lines (the only admissible way to begin according to Rowe [1979b, p. 232]), feeding the data into a computer, and then attempting to correlate the alignments with astronomical phenomena of conceivable significance at the horizon, one would not have the slightest chance of arriving at conclusions that turn out to be consistent with the ethnohistorical record (see Aveni, 1981a, for a summary).

Ethnoastronomical studies frequently bridge gaps to the sister interdiscipline of archaeoastronomy in South America. Urton's study of the cosmology and astronomy of contemporary Misminay reveals that a number of Inca celestial concepts survive in the contemporary culture (Urton, 1982). Elsewhere, contemporary Warao cosmology attests to the significance of the zenith. The Warao, who live in the Orinoco delta of Venezuela, visualize the world as a flat disk afloat on a world sea. The sky, which surrounds all, has the shape of a bell, which begins to narrow to a point where the noontime sun passes; the zenith thus serves as one end of the principal world axis. According to Wilbert (1981), shamans in nicotine-induced trances ascend vertical columns of rising tobacco smoke to feed the gods in the zenith so that they may acquire sacred medicine from them. The Desana (Reichel-Dolmatoff, 1971) and Yekuana (Wilbert, 1981) cosmologies also emphasize the zenith–antizenith axis by virtue of their locations in tropical latitudes, although the Bororo, who also incorporate astronomy in their site planning (Fabian, 1992), do not. In the case of the Yekuana, the residence itself is patterned after the basic structure of the tropical sky (Aveni, 1981b, summarizes a number of examples).

Other collections of essays and conference proceedings on South American archaeoastronomy include contributions by Arias de Greiff and Reichel (1987) and Ziolkowski and Sadowski (1989).

ARCHAEOASTRONOMY IN NORTH AMERICA

One of the major differences between archaeoastronomical studies in North America and elsewhere in the New World is that the cultures in the north were largely non- or semisedentary, with different demands for calendar keeping. Moreover, there is little in the way of iconographic and written data that is found with the state-level cultures to the south, which further constrains the hypotheses one can make and the firmness of the conclusions one can draw regarding astronomical practice.

The earliest study of astronomically oriented remains in North America involves the Big Horn medicine wheel in Wyoming. Named for the resemblance of its circular plan to the medicine lodge, Big Horn is one of several dozen spoked wheels fashioned out of chains of large boulders. Dating mostly from the last half millennium, these curious earthworks are located on mountaintops along the Rocky Mountains of Wyoming, Montana, Alberta, and Saskatchewan. Typically 5–15 m in diameter, medicine wheels display a circular pattern along the periphery of the spokes; some exhibit stone cairns at the center or along the axes. As stone structures in the round, medicine wheels bear a recognizable relation to Stonehenge, the early historical archetype for astronomical orientation studies.

Eddy (1974) views Big Horn as a site where monthly rituals, demarcated by alignments during the summer season, were conducted. He has argued that sight lines between cairns at Big Horn were deliberately oriented to the bright stars, Rigel, Aldebaran, and Sirius. All three made their first annual appearance (heliacal rise) at key dates in the predawn summer sky, the only time the wheel was available for ritual purposes; raging snow storms plague the Big Horn Mountains during the remainder of the year. Perhaps significantly, the heliacal risings of these stars also occurred at 1-month intervals; therefore, taken in turn, they could have been used to mark the three "warmest moons" following summer solstice. In this scenario, the first predawn appearance of Sirius, last of the three stars to rise, would have served as a warning for the people to leave the mountain, for soon the last moon before the start of winter would make its appearance.

The functional astronomical hypothesis for the Big Horn medicine wheel is further strengthened by two additional facts. First, one of the alignments points to the position of sunrise at the summer solstice, and second, the 28 spokes of the wheel are equivalent to the number of visible moons in a lunar synodic month. Eddy and Kehoe (Eddy, 1977) later explored the Moose Mountain Medicine Wheel in southeastern Saskatchewan, discovering that it registers the same astronomical events as does the Big Horn. They also found that the Fort Smith (Montana) Medicine Wheel, though much smaller and containing fewer spokes, is astronomically oriented as well. Its longest spoke also points to the summer solstice sunrise point.

The theory of medicine wheels as astronomical time markers has been criticized by Ovenden and Rodger (1981), Zuiderwijk (1984), and Haack (1987a,b). The most thorough review of the data is by Vogt (1993). He offers a composite medicine wheel alignment distribution diagram, which portrays Eddy's alignments dissolving into a general sort of randomness. He has also criticized the accuracy of Eddy's calculations. Nonetheless, Vogt concludes that while one cannot gauge the level of precision or identify the astronomical objects associated with medicine wheel alignments, astronomical interest still remains the most viable explanation lying at the root of the orientations (p. 191). Other critics of the astronomical hypothesis concerning medicine wheels have suggested that the primary and perhaps the only, function of the wheels was purely geometrical or that their form might have symbolized the concept of a "world center" (Hall, 1985), a mountain top enclosure containing symbolic "rain roads" that direct water toward various pueblos. A medicine wheel hypothesis that reflects both geometrical and astronomical as well as symbolic truths seems quite consistent with what we know about the integrative nature of the pre-Columbian worldview.

Alignments also can be seen in the plan of earth lodges, which for the Skidi Pawnee reflect their view of the cosmos. The vaulted dome of the lodge represents the celestial sphere, while its circular plan imitates the horizon. Posts supporting the dome were implanted in the semicardinal directions, each symbolizing a directional star god; they were often painted in the different directional colors, thus reflecting the habits of their Mesoamerican neighbors. The doorway to the lodge was so arranged that the rising sun at the equinox would illuminate an altar at the rear of the lodge.

Chamberlain's detailed calculations on model lodge geometry suggest that the structure was not designed so much as an observatory, but rather as a kind of classroom in which the importance of directions and stars viewed through the various openings could be learned and appreciated as reminders of astronomical knowledge and belief (Chamberlain, 1982). These included the solstices, Polaris, Sirius, and the stars of our Corona Borealis (the so-called Chiefs in Council), all of which are prominently mentioned in the ethnographic record (Williamson and Farrer, 1992). The latter functioned together with the Pleiades as a way of dividing the sky into male and female sectors among Algonkian people (Mann, 2000).

Part of the Adena-Hopewell culture, Cahokia contains the largest earthworks in North America. There is good evidence that its builders had planned and organized this state-level center according to astronomical principles, and that they were particularly concerned with registering the position of the sun at the equinoxes and solstices. Huge burial mounds on the north, south, and west mark the periphery, and archaeological evidence would appear to support the notion that major rituals were conducted there (Pauketat, 1998). Monk's Mound, the 25-m-high, four-terrace earthwork at the center dominates the landscape. Mound 72, an elaborate burial site containing the remains of a pair of prominent individuals flanked by those of some 300 people of lower status, along with exotic trade items, is of special interest. It aligns 30° south of east to 30° north of west and might have been deliberately skewed out of line with Cahokia's quadripartite plan to align with the solstices, Krupp (l977) argues.

Most of Cahokia's 100 or so mounds are oriented on the cardinal directions; however, Pottery Mound, located 1,000 m southeast of the center site, is skewed 30° off the east–west line, its axis again aligning with the December solstice sunrise–June solstice sunset axis. Large elevated mounds mark the vertices of the diamond-shaped plan enclosing the ruins at three of the four cardinal points. The north–south axis cuts through Monk's Mound, which also serves as the focal point of a geometrical arrangement of nearby mounds set out on corners of an equilateral triangle. The ancient marking of Cahokia vertices is reminiscent of stations assigned to the four directions and visited by processions on key dates in the Maya calendar (Tedlock, 1982, Ch. 4).

Accurate astronomical observations were a prime concern of the Pueblo-Anasazi of the U.S. southwest. Short growing seasons, minimal erratic rainfall, and the need to pinpoint the times of planting and harvesting offered a number of motives for these agriculturally based societies to keep a close watch on the sky. Zeilik (1985a), in reviewing the ethnoastronomy associated with the historic pueblos, discusses its role in setting times for ritual planting and for hunting and gathering. Zeilik (1989, p. 145) also cites the establishment of sacred directions, shrines, and cosmic mythology as part of Anasazi astronomy. The main task of calendar watchers seems to have been to anticipate the dates of festivals. McCluskey (1990), who provides a detailed discussion of the precision of solstice watching in the US Southwest, doubts that these observations served so practical a need; rather he sees them as having functioned more as hierophanies.

In addition to employing a solar horizon calendar, light and shadow schemes involving wall markers also may have served to keep track of the sun's course. The Anasazi Hovenweep Castle and similar tower structures (Williamson, 1984) survive as working examples. Their precise operation in regulating the planting seasons is described in the diary of an early visitor to Zuni pueblo:

> Nor may the sun priest err in his watch of time's flight; for many are the houses in Zuni with scores on their walls of ancient plates imbedded therein, while opposite a convenient window or small porthole lets in the light of the rising Sun, which shines but two mornings in the three hundred and sixty-five on the same place. (Cushing 1941, p. 40)

Zeilik has given a detailed list of horizon (1989, pp. 149–151) and light and shadow (pp. 151–152) situations for this area.

Claims of calendrical precision (Sofaer *et al.*, 1979) have made the three-slab construction atop Fajada Butte in Chaco Canyon, New Mexico, known in the popular literature as the "sun dagger," perhaps the most controversial site in the US Southwest. Here a luminous dagger formed by sunlight penetrating the spacing between the slabs, and said by these investigators to have been placed there deliberately, marks solar noon at the equinoxes and solstices. Lunar standstills also have been posited (Sofaer *et al.*, 1982). Zeilik (1985b) and Carlson (1987) have challenged these conclusions, noting that the entire situation likely resulted from a natural rockfall. One is inclined to believe that while the site may not have been functional as a precise observatory it could have been a shrine. Light and shadow phenomena also have been reported among the Chumash of California (Benson and Hoskinson, 1985; Hudson and Underhay, 1978).

Petroglyphs that represent astronomical phenomena have been cited. Most well known are the several possible depictions of the Crab Nebula supernova explosion of A.D. 1054 that have been suggested (e.g., Brandt *et al.*, 1975; Brandt and Williamson, 1977; Miller, 1955), though not without criticism. For example, Ellis (1975) argues that these petroglyphs are better explained as crescent moon and evening/morning star views, which not only happen with greater frequency but also are more likely to have been recorded by native calendar keepers known to have focused more upon cyclic than cataclysmic events.

Finally, regarding archaeoastronomy in the US Southwest, Young (1989) has addressed the question of cultural continuity from Puebloan to Anasazi to the present-day historic pueblos. She has sought a cultural context for the astral symbolism inferred in rock art by placing the petroglyphs on a comparative level with ceramics and sand paintings. Young points to an overemphasis upon the petroglyphic studies relative to other media in which astronomical knowledge might have been expressed. At the same time, Reyman (1987) has discussed Puebloan astronomy as a mechanism for socioceremonial control in nonegalitarian society, and Wilcox (1987) has dealt with archaeoastronomical data specifically in the context of Hohokam ceremonial systems. He argues that the metastructure of cosmological beliefs has Mesoamerican parallels. I also have offered a detailed assessment of archaeoastronomy in the US Southwest (Aveni, 1987).

As at Monte Albán and Chichén Itzá in Mesoamerica, strange geometry often implies astronomy. Such is the case of the curious Ohio earthworks attributed to the Hopewell culture and dated to c. 1–500 A.D. Most famous among the odd juxtapositions of circles and octagons that constitute these earthworks is that located in Newark. Its 0.6-ha space is encompassed by walls several meters high pierced by gaps at the vertices of the octagon. Like Chichén Itzá it too has been appropriated by the modern state. It once served as a 19th-century county fairgrounds, and today it achieves popular appeal in the form of a golf course. The High Bank earthworks 100 km distant has an almost identical form. Extensive survey work by Hively and Horn (1982, 1984) at both sites demonstrates the precision of their layouts and establishes the use of a basic measuring unit of 321.3 m. On the basis of his study of a large number of circles and octagons, Romain (2000) favors a much smaller common unit of 25.272 in. (0.642 m), derived from the length of the typical adult male Hopewell arm. Both Hively and Horn and Romain suggest that alignments to the lunar standstills were incorporated into the plans of Hopewell sites, although the choice of numerous backsights and foresights makes it difficult to determine whether the results are fortuitous. Lepper's review of native American sources corroborates the importance of the moon and its dominance over the sun in a number of native traditions of that area (Lepper, 1998). I have recently reviewed the archaeoastronomy of this area (Aveni, in press) and made the point that more attention ought to be paid to the possibility that seasonal events in the riparian environment of these sites might have been expressed via alignments.

Little archaeoastronomical field study has taken place in the southeastern United States. Benchley (1970) has examined intermound alignments on maps of 32 Mississippi valley sites. She finds solstitial orientations at 29 of them, with multiple orientations to the solstice at most sites. Although no transit measurements were taken in connection with this project, her results appear to be statistically significant; they suggest that accurate field surveys need to be carried out. Her analysis reveals that the solstice orientation is the most common alignment employed, occurring with four times the frequency of equinoctial alignments.

The much earlier (c. 1000 B.C.) Adena Poverty Point site in northeast Louisiana also appears to exhibit geometrical and astronomical principles (largely solstitial) in its layout (Brecher and Haag, 1980; Purrington, 1983; Purrington and Child, 1989). It consists of concentric ridges averaging 33 m apart forming a large (1.2-km diameter) horseshoe pattern segmented by four aisleways that divide it into five sections, each of which once housed residences along the ridges; a more recent detailed plan (Kidder, 2002), however, reveals that the site is not as symmetric as it seems from aerial photos on which earlier plans were based. These new results may necessitate a reevaluation of the archaeoastronomical hypothesis.

For other reviews of North American archaeoastronomy, see Williamson (1984), Chamberlain (1982), Zeilik (1985a,b, 1988, 1989), Carlson and Judge (1987), and McCluskey (1990). For pan-American citations that appear in world conferences on archaeoastronomy, consult the recent updated bibliography in Aveni (2001).

SUMMATION

Archaeoastronomy addresses the question of who controls time and how the material record evidences the way various control mechanisms are expressed. It also lies at the foundation of assessing human existential questions such as who we are as a culture, how we came into being, and how we seek to participate in the cosmologies we create. This is the ultimate rationale for divining the firmament. The sky is the primary place to seek order amidst the chaos that surrounds us.

Together with mountains, water, plant, and animal life, it forms a template that guides creation narratives. We see it reflected in pictorial and written divinatory almanacs and cosmograms, and we find it microcosmically in the layout of the shaman's table in Mesoamerica (Sosa, 1989; Tedlock, 1982) and Peru (Sharon, 1978). Archaeoastronomy touches upon questions of interest to the archaeologist especially when it addresses the macrocosm or the places one inhabits: the realm of the archaeological site. *Huacas*, earthworks, ceremonial centers, and cities—all are places in which time was used as a mechanism to control and unify people, where the cosmos was employed as a means of validating ritual performance. Celebrating the completion of one cycle of time and the beginning of another, Hopewellian octagon mounds, Cuzco's *suyus* and *ceques*, Teotihuacan's grid, all incorporate, to one degree or another, cosmically derived elements in their highly ordered plans. As we have seen, many of these sites exhibited a template that gave rise to a kind of site mimicry. Teotihuacan's orientation and calendar is duplicated at sites in highland Mexico as well as in the distant Maya world; Cuzco's layout is mimicked in Inkawasi and Huánuco Pampa; and Hopewellian site geometry seems to radiate out and back to the Adena culture. The archaeological record helps inform to what degree this deliberate duplication occurred in states ranging from tributaries to those beyond the periphery of immediate influence.

Archaeoastronomy also addresses problems of cultural change. The Maya solar observatory at Uaxactún may have been a passing fancy, its tripartite elements having been ingeniously fashioned in the Late Preclassic to mark the solstices, then reenvisioned at more than a dozen early Classic Petén sites to reckon 20-day months centered in the planting season, a consequence of calendar reform that likely accompanied the Teotihuacan entrada. It has been suggested (Fialko, 1988) that the last forms of Group E, complexes in the area were mere reflections of the sun clocks they once were, like the Skidi Pawnee lodge, astronomically commemorative structures dedicated to symbolizing a belief system. The absence of a deciphered written record and the brevity of the Inca empire leaves a gap in our understanding of elements of cultural change that might be accessible there through a study of archaeoastronomy. The same problem plagues North American studies, although one wonders whether the rich ethnographic record of early visitors to the southwest has been sufficiently mined.

I believe the archaeological record shows that the practical and performative elements of cosmically based architecture should not be isolated. Our modern penchant for precision tends to bias us toward regarding Maya Group E complexes, Chichén Itzá's Castillo, Newark's Octagon Mounds, Machu Picchu's Torreón, and Copacabana's Island of the Sun as temporal referential devices, that is, clocks or observatories. In many cases, however, the evidence shows that these sacred places were part of a ceremonial landscape, serving as stages upon which seasonally timed rituals were carried out as a part of normal social life. Indeed for the Group E's and Copacabana, and probably for the Castillo, public access space was provided for viewing the attendant astronomical phenomena. At the appropriate time, these sites must have constituted a powerful mandate for the cosmic connection to the power of the rulership. Descendants of cultures of temperate climes can easily lose sight of the efficacy of practicing one's form of religious worship outdoors. What the interior of Chartres Cathedral was to the Medieval French peasant, so was the exterior plaza fronting the Templo Mayor of Tenochtilan to the Aztec commoner.

Judge (1987, p. 5) once stated that archaeoastronomy could succeed as a truly integrated interdiscipline only "when astronomers deal more with the cultural context of sites in an area and when archaeologists deal more with the ritual aspects of the same sites." Kintigh (1992) has echoed much the same opinion. Although the archaeologists who made these assessments operate under different paradigms and pose different research questions than astronomers, I believe that, especially in the last decade or so of Americanist studies, there has been a gradual convergence of scholarly agendas along the desirable lines they have suggested. Archaeoastronomy has passed beyond the stage of simply collecting facts about solstices, equinoxes, and lunar standstills in relation to building alignments and calendrical calculations to be handed over to historians of culture to do with as they will.

Still lacking in archaeoastronomical studies, however, are attempts to address the ways in which ancient cultures might have integrated the schedules of other entities in the natural environment into the clockwork sky that overlay them. Urton's study of the correlation between the appearance and disappearance times of Andean black cloud constellations and key moments in the life cycles of the terrestrial animals they represent is exemplary (Urton, 1981). What of the natural events in the riverine environment of the Hopewellian mounds, or the coming and going of the rainy season in the Petén? Notwithstanding, the necessary effort involved in stretching one's horizon of inquiry associated with doing rigorous fieldwork in archaeoastronomy is now well under way, and the prospects for continuity seem secure in an age in which problem solving appears to be more firmly directed along interdisciplinary lines than it was two decades ago.

As the attached general bibliography, which concentrates on the past 20 years (and covers a number of important case studies that were not discussed in the essay for want of space), will demonstrate, more works are now coauthored by experts from diverse fields working closely with one another and more results appear in the archaeologically based journals. Also, more students enter our graduate institutions in history of science, archaeology, anthropology, art history, and comparative religion with the intention to write archaeoastronomy theses and dissertations under the direction of supervisory boards whose members come from more than a single discipline. Finally, the contributions of archaeoastronomy to the mainstream textbook literature in allied fields are now clearly evident (Carrasco, 1990; Coe, 2001; Hammond, 1993; Henderson, 1997; Milbrath, 1999; Miller, 2001; Moseley, 2001; Sabloff, 1989; Sharer, 1994; Weaver, 1993). Comparing the old with the new editions of these basic texts is testimony to the progress achieved in this growing interdisciplinary field.

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