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ANTHROPOLOGICAL NOTEBOOKS V/1

FIELDWORK AND QUALITATIVE RESEARCH IN ANTHROPOLOGY AND BEYOND

Edited by Borut Telban

DRUŠTVO ANTROPOLOGOV SLOVENIJE
SLOVENE ANTHROPOLOGICAL SOCIETY

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Front page: *wunduma*, the carved mask of a female spirit on the men's house in Ambonwari village, Papua New Guinea.
Photo: Borut Telban.

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Aboriginal and non-Aboriginal people, and were suspiciously looked upon. Therefore, she needed to establish her own position as a serious fieldworker, sometimes struggling against mistrust, other times unwillingly changing sides.

*Sociologists **Frane Adam**, **Darka Podmenik** and **Dijana Krajina** (Adam and Krajina are from the Faculty of Social Sciences, University of Ljubljana, while Podmenik is an independent researcher) summarise the history of qualitative methodology used in sociological and social-psychological research in Slovenia over the last twenty-five years. These methods have nonetheless remained marginal mainly, the authors argue, because of the unsystematic use of these methods and lack of epistemological (self)reflection.*

*The last article in this issue by **Borut Telban** is intended to provide a selected bibliography on fieldwork, research methods and ethnography. It does not encompass everything published in this broad field. It could, however, be seen as a guidance for all those who are just beginning to set foot in social and cultural anthropology, as well as a useful aid to those who are eager to penetrate deeper into the field of research methods and the tradition of anthropological fieldwork.*

Editor-In-Chief
Borut Telban

STUDY OF ASTRONOMICAL ALIGNMENTS IN ARCHAEOLOGICAL SITES OF CENTRAL MEXICO: SOME METHODOLOGICAL CONSIDERATIONS

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INTRODUCTION

The alignment studies are the most typical aspect of *archaeoastronomy*, a relatively new anthropological discipline whose endeavors are focused upon those segments of the archaeologically documented societies that have some relationship to the observation of the sky. The object of archaeoastronomical research is not only exact knowledge about celestial phenomena but rather all astronomically-derived concepts and related cultural manifestations. Taking into account concrete environmental peculiarities and geographical location, as well as subsistence strategies, sociopolitical structure and historical antecedents of the society studied, archaeoastronomy searches for responses to a number of questions: What were the social functions of astronomical knowledge? Why did certain astronomical phenomena acquire a prevailing importance? Which were the observational bases of the concepts embedded in myths, iconography, attributes of gods, etc.? What is the nature of the interrelationship between astronomical concepts, natural environment and cultural context? In its attempts to solve such problems, archaeoastronomy participates in the common efforts of anthropological disciplines and contributes to a more comprehensive understanding of ancient societies, as well as of the general processes of cultural evolution.[1]

Important information on past astronomical practices and concepts may be provided by architectural orientations and other alignments recognizable in the spatial distribution of certain archaeological features. It is thus understandable that most archaeoastronomical alignment studies have been so far accomplished in the areas where the remains of this kind

1 Archaeoastronomy thus differs from the *history of astronomy*, which is based primarily on written sources and focused on the development of exact astronomical knowledge, without paying much attention to the natural and cultural circumstances that conditioned particular developments, and to non-scientific concepts. The latter, however, are no less interesting for archaeoastronomy, considering its holistic approach and anthropologically relevant goals: both correct and false ideas are, in a particular social group, normally intertwined, composing a relatively coherent world view, which can be properly understood only if examined as a whole and in the light of the natural, social and historical context. Both "scientific", or exact, and "non-scientific" concepts may thus shed light on a number of aspects of the society being studied (*cf.* Ruggles 1999: 80f, 155). In fact, any attempt to distinguish the two classes of ideas is, to a certain extent, arbitrary and depends on the knowledge and/or beliefs of whoever tries to make such a distinction. It would be illusory to think that our modern scientific criteria are entirely objective: describing the scientific world view, astronomer and historian of science Owen Gingerich (1989: 38f) says: "It is an interlocked and coherent picture, a most workable explanation, but it is not ultimate truth."
General information on the history and theoretical and methodological bases of archaeoastronomy and some related fields of research can be found, for example, in Baity (1973), Aveni (1981; 1989; 1991), Šprajc (1991), Iwaniszewski (1994a; 1995a; 1995b), Ruggles (1999) and several articles in Macey (1994).

are particularly abundant. One of such regions is Mesoamerica, a culturally defined geographical area corresponding to the central and southern parts of modern Mexico and the northern part of Central America, where civilizations with a number of common cultural traits flourished since the 2nd millenium B.C., when the first complex, state-organized societies emerged, until the Spanish conquest in the early 16th century A.D.

Systematic archaeoastronomical research carried out during the last few decades has revealed that Mesoamerican architectural orientations exhibit a clearly non-random distribution and that civic and ceremonial buildings were oriented largely on the basis of astronomical considerations, particularly to the Sun's positions on the horizon on certain dates of the tropical year (Aveni 1975; 1991; Aveni and Gibbs 1976; Aveni and Hartung 1986; Tichy 1991; Šprajc 1997a). According to various hypotheses forwarded thus far, the dates recorded by the orientations can be interpreted in terms of their relevance in the agricultural cycle and in computations related to the calendrical system. It has been suggested, for example, that the dates indicated by the alignments are separated by calendrically significant intervals. The most elaborate model of this type has been proposed by Tichy (1981; 1991), who contends that these dates mark intervals of 13 and 20 days and multiples thereof. Some authors have reconstructed possible horizon calendars for particular sites, on the assumption that prominent peaks of the local horizon served as natural markers of sunrises and sunsets on relevant dates (*e.g.*, Ponce de León 1982; Aveni *et al.* 1988; Tichy 1991; Broda 1993; Morante 1993; 1996; Galindo 1994; Iwaniszewski 1994b).

Since both the accumulated fieldwork experiences and the feedback information generated by interpretational attempts revealed that the available alignment data were neither sufficient nor accurate enough for testing such specific hypotheses, I undertook precise measurements of alignments at 37 Preclassic, Classic and Postclassic archaeological sites in central Mexico,[2] taking into account a variety of facts and circumstances whose relevance had not been recognized before. Not only the orientations of civic-ceremonial structures but also the alignments to prominent peaks on the local horizon, placed within the angle of annual movement of the Sun, were measured. The results of my research agree with some general ideas formerly expressed by other authors, but differ in important details which concern the principles underlying orientational patterns and the observational use of alignments. The general conclusions based on my analyses of the alignment data from central Mexican archaeological sites can be summarized as follows:

(1) The dates of sunrises and sunsets both along architectural orientations and above prominent hills on the local horizon exhibit consistent patterns; at any particular site they are separated by intervals that are predominantly multiples of 13 and 20 days and are, therefore, significant in terms of the Mesoamerican calendrical system.[3]

(2) Since the horizon prominences were measured from the main temple of every site, the patterns of dates and intervals based on these alignment data indicate that the important ceremonial structures were not only oriented towards but also located on astronomical grounds: the places selected for their construction allowed certain surrounding peaks to be employed as natural markers of sunrises and sunsets on culturally significant dates. Furthermore, various structures have been found to be oriented towards prominent peaks on the local horizon.

(3) The relevance of the most recurrent dates, recorded at a number of sites, can be interpreted in terms of their approximate coincidence with important seasonal changes in the natural environment and the corresponding stages of the agricultural cycle. However, the fact that certain series of *exactly* the same dates, separated by multiples of 13 and 20 days, are marked by alignments at a number of sites, even in ecologically different zones, suggests the existence of a *ritual* or *canonical* agricultural cycle: the dates involved must have been canonized precisely because the intervals separating them were easy to handle by means of the sacred 260-day calendar count.[4]

(4) Both the orientations embodied in the monumental architecture of a particular site and the prominent local horizon features allowed the use of an *observational calendar* which, in view of the lack of permanent concordance of the calendrical and tropical years,[5] was necessary for predicting important seasonal changes and for efficient scheduling of the corresponding agricultural activities.

While the results of my study in central Mexico, including the interpretations of the alignment data for particular sites and the supporting evidence, are exhaustively presented in my Ph.D. dissertation (Šprajc 1997b), the purpose of this paper is to focus on some specific methods and techniques that I developed and applied in this research and which, I believe, may be useful in further archaeoastronomical inquiries, both in Mesoamerica and elsewhere.

SELECTION OF ALIGNMENTS

An objective data selection is of foremost importance in the alignment studies: the results of an analysis of a number of alignments will be valid and meaningful only if the sightlines considered have been selected fairly in the first place (Ruggles 1999: 51).

Architectural orientations

The purpose of my research in central Mexico was to explore the orientational rules that reflect astronomical concepts and related aspects of world view and religion. Assuming that such principles were involved particularly in the construction of ceremonial and important civic buildings, only the latter's orientations were included in the study. It is very likely that not only temples but also high rank residences and administrative buildings were oriented in accordance with astronomical principles, because in this way they reproduced and underscored the existing earthly and celestial order, of which the protagonists of the ruling class, normally considered as man-gods, claimed to be responsible (*cf.* Broda 1982: 104ff; 1991: 491; López Austin 1973).[6] The structures whose function cannot be undoubtedly linked to

2 The sites included in the study date to the period from about 500 B.C. to A.D. 1519.
3 One of the important Mesoamerican calendrical cycles was the so-called sacred count of 260 days: since any date of this cycle was a combination of a number from 1 to 13 and a sign in the series of 20, the dates at intervals of 13/20 days had the same numeral/sign. The importance of intervalic time reckoning based on multiples of 13 and 20 days is attested both in the central Mexican (Siarkiewicz 1995) and in the Maya codices (Aveni *et al.* 1995; 1996).

4 *V. supra*: note 3.
5 The Mesoamerican calendrical year had invariably 365 days and thus did not preserve a fixed correlation with the tropical year of 365.2422 days (Šprajc 1998).
6 A convenient example is the Palace of the Governor at Uxmal; this residence of a ruler called Chac was arguably oriented to the

ritual practices and mechanisms of power were not considered in my analyses, because they were probably oriented at random or on essentially different grounds, related to environmental characteristics (topographic and geomorphological features, climatic peculiarities), military considerations or other, more practical motives.[7]

It can be affirmed that the orientations in the Mesoamerican civic and ceremonial architecture were astronomically functional, as a rule, in the east-west direction, referring to the Sun's positions on the horizon on certain dates of the tropical year, because most of the known east-west orientation azimuths[8] fall within the angle of annual movement of the Sun along the horizon (*cf.* Aveni and Hartung 1986: 59-60; Tichy 1991: 117; Šprajc 1997a; 1997b: 9f). Though it is quite likely that *some* structures were oriented to stars or planets (*cf.* Aveni 1991; Šprajc 1993a; 1993b; 1996a; Galindo 1994), the practice could not have been very common: by postulating that stars were primary orientational references, we would be forced to accept that only those rising or setting at azimuths within the angle of annual movement of the Sun, or in perpendicular northerly and southerly directions, were of interest. In view of these facts I have not explored the eventual astronomical potential of the north-south orientation azimuths. Neither have I considered the structures facing north and south, because it is difficult to imagine they facilitated observations of astronomical phenomena on the eastern or western horizon. It is also unlikely, however, that such buildings recorded astronomical events on the northern and southern horizon: since their orientations normally conform to those of the adjacent buildings facing east or west, it was probably the latter (related to the Sun) that dictated the orientations of entire architectural complexes (Šprajc 1997b: 9f, 13ff).

At any site with relatively well preserved architecture we can often find a number of sightlines with possible astronomical significance, connecting diverse architectural elements or even separate buildings and running at different angles with respect to the horizontal (*cf.* Hartung 1975). However, according to the evidence available so far (see above: Introduction), the astronomical basis seems to be indisputable only for the orientations of the main axes of buildings, which can be associated with the phenomena observable on the horizon; therefore, and with the purpose of having a homogenous data sample (*cf.* Hawkins 1968: 49; Ruggles 1999: 51ff), I only considered the alignments indicated by walls, wall faces and other construction elements that make patent the orientation of a structure in the horizontal plane.

Local horizon features

At every site the alignments to prominent horizon features, situated within the angle of the annual movement of the Sun, were also measured, with the purpose of testing the hypotheses about the use of horizon calendars. Though the possibility that prominences beyond this angle also served as markers of certain astronomical phenomena cannot be discarded, the distribution of architectural orientations suggests that the alignments related to the Sun were particularly important.

The readings of the horizon features were taken from the main buildings of every site, mostly temples, assuming they were the most important observing points: if astronomical function is attributed to the orientations of civic and ceremonial structures, it seems logical to suppose that other phenomena on the horizon were also observed from the same buildings.

Although not only peaks but also notches, cuts and similar features (even little prominent) of the local horizon may have served as astronomical markers (*cf.* McCluskey 1990; Zeilik 1985; 1991; Morante 1996: 82), I only took into account prominent and clearly defined hilltops lying on the horizon line. This selection is based on the data about architectural orientations: while a number of buildings are oriented to mountain peaks, none has been found to align with a landmark of any other type. Considering the astronomical basis of architectural orientations, the prominences on the eastern and western horizon to which the buildings are oriented served as exact markers of the phenomena recorded by orientations and, thus, facilitated observations; since the horizon features are in these cases exclusively mountain tops, it can be assumed that other astronomical horizon markers were also of the same kind.

The selection of the mountain peaks considered to be "prominent" was necessarily, to a certain extent, subjective, as Ruggles and Martlew (1992: S4) also admit in a similar case. However, if all conceivably usable prominences had been taken into account, their large number would have introduced too much "noise", making impossible any objective evaluation of their eventual astronomical potential (*cf.* Ruggles 1999: 232, note 83).[9] Though my selection was not biased by pre-existent astronomical hypotheses, the results I obtained do seem meaningful. Similarly, Ruggles and Martlew (1992; 1993), in their study of prehistoric sites on the Isle of Mull in Scotland, identified prominent summits on the local horizon of each site and, plotting their declinations,[10] obtained astronomically significant groups (related to characteristic lunar positions).

MEASUREMENT OF ALIGNMENTS

I employed the alignment data based on my own measurements in field and calculations, because the published information was, for various reasons discussed below, neither sufficient nor reliable enough for the purposes of my research.

maximum northerly extreme of Venus on the western horizon (Šprajc 1993a: 47; 1993b: 272f; 1996a: 75ff; 1996b: 173ff; for different views on the significance of this orientation see Bricker and Bricker 1996, with comments).

7 The selection of structures considered in my study can be justified also by the fact that the hypotheses I intended to verify were all based on orientations of civic and ceremonial buildings. According to the available data (which are admittedly meager), domestic and other structures with secular functions do not seem to have been oriented on astronomical grounds. However, where a single orientation dominates the whole urban layout, as is evident at a few sites, it must have been dictated by the (astronomically functional) orientation of the main temple; this assumption is supported by comparative data from other cultures (*cf.* Wheatley 1971) and also, in the case of Teotihuacan, by internal evidence (Šprajc 1997b: 157ff).

8 The *azimuth* is the angle in the horizontal plane measured clockwise from the north.

9 The situation would have been similar to the one described by Hawkins (1968: 49) in relation with alignments at megalithic sites of western Europe: "as the number of markers increases, the problem rapidly degenerates to the insoluble level".

10 Any object in space (not only celestial bodies but also, for instance, points on the horizon) can be considered as located (or projected) on an imaginary celestial sphere. The *declination* of a point on this sphere is its angular distance from the celestial equator, which can be imagined as a projection of the Earth's equator on the celestial sphere. Declinations are measured perpendicularly to the celestial equator to the north and south (positive and negative declinations). By determining the declination of a horizon point, having its azimuth and altitude measured from a particular spot, one can find out which heavenly bodies rise or set behind it (or did so in the past) and (in the case of the Sun, Moon and the planets) on which dates, because the declinations of celestial objects for particular epochs and dates are known and can be found in astronomical sources (ephemerides, star atlases etc.) (*cf.* Aveni 1981; 1991; Ruggles 1999).

As Reyman (1975: 210) pointed out, the available archaeological site maps are "notoriously inaccurate". The true north is frequently laid out erroneously or confused with the magnetic north, and in many cases it is not even clear which of the two is indicated (Aveni 1975: 164; 1991: 250). It is noteworthy, Hartung (1980: 165) observes, that the first scientific explorers of Maya ruins showed a concern for measuring exact orientations. In 1913, Alfred Tozzer included a chapter on orientation in his study of Nakum and mentioned that this important topic should not be ignored by future researchers working in Central America (*ibid.*: 167, note 11). Indeed, various orientation studies were accomplished in the twenties and thirties of this century, particularly notable being those by Blom, Ricketson and Ruppert on Group E of Uaxactún and the Caracol of Chichén Itzá (*ibid.*: 165; Aveni 1991: 292ff, 314ff). The site maps elaborated in this period are regularly oriented to the astronomical north, indicating the angle of magnetic declination. In the following decades, however, the interest in architectural orientations declined (Hartung 1980: 165); even if the topic regained popularity with the appearance of archaeoastronomy in the sixties, the achievements within the newly consolidated anthropological discipline have not had adequate repercussions in the main-stream archaeological literature. In spite of the evident importance and intentionality of orientations in the civic and ceremonial architecture, the site plans marking true north are still extremely rare.

According to Reyman (1975: 210), even when site maps are very accurate (*e.g.*, Millon *et al.* 1973), they are still unsuitable for archaeoastronomical purposes, because they lack critical data such as the heights of the horizon along the orientation axes. It should be noted, however, that horizon altitudes, indispensable for calculating astronomical declinations and, therefore, for identifying with precision the celestial phenomena the alignments may have referred to, can often be determined on the basis of topographic maps. Accurate site plans can thus be of considerable help, suggesting possible astronomical references of orientations, but there is another problem for which field measurements seem to be inevitable.

Prehispanic buildings in Mesoamerica normally exhibit an orientation (either deliberate or fortuitous) that can be determined, because their ground plans are in most cases roughly rectangular or composed of rectangular elements; in other words, the directions in which the axes of a structure are laid out can be established. Even circular structures or those with a combined ground plan (composed of rectangular and circular elements, *e.g.*, the temples of the wind god Ehécatl) generally possess an orientation, indicated by the stairway of access and other architectural elements. However, the problem consists in the *determination of the exact orientation* of a structure. In the available archaeoastronomical bibliography concerned with Mesoamerican architectural orientations, the azimuth of a line measured at a building is commonly given as representing the orientation of the whole structure. Since the ground plans of most buildings incorporate lines that are roughly parallel and perpendicular to each other, these data have been highly revealing as to the determination of *approximate* orientations, and sufficiently exact to allow the discovery of azimuth distribution patterns and *orientation groups* (*cf.* Macgowan 1945; Aveni 1975; 1991; Aveni and Gibbs 1976; Aveni and Hartung 1986; Tichy 1981; 1982; 1991). However, the azimuths so determined cannot be considered as sufficiently precise for more detailed archaeoastronomical studies, because they do not represent the original and intended architectural orientations with the accuracy required for testing diverse hypotheses that have been forwarded on the basis of these data.

The walls of a structure may appear parallel and perpendicular to each other, but precise measurements reveal that this is frequently not the case (*cf.* Hartung 1980: 155; Ponce de León 1982: 9). Such irregularities are relevant, obviously, only if elements manifesting them are evidently original and *in situ*. Ideally, all reliable lines incorporated in a structure should be measured: if the azimuths of roughly parallel lines do not exhibit systematic variations that can be associated with particular construction phases or architectural elements, such divergences can be attributed to sloppy construction or to the fact that high precision was not aimed at by the builders; the mean value of the measured azimuths is likely to represent the originally intended orientation with reasonable accuracy, since the errors in the orientation of individual lines can be expected to cancel out. In several cases I noted that the walls and wall faces near the upper part of the building tended to be more parallel to each other than in lower sections, which seems understandable: if the orientation of a temple was intentional, it must have been laid out with particular attention in the area of *sancta sanctorum*, *i.e.* in the upper parts of the building. I considered such consistent alignments, if found, as particularly relevant for the determination of a structure's intended orientation.

On the other hand, the lines appearing to be perpendicular to each other often do not intersect at right angles. Ground plans of some buildings are patently rhomboidal (*e.g.*, of the Acropolis and the Pyramid of the Stelae at Xochicalco, or of Structure I at Teopanzolco: Šprajc 1997b: 202ff, 268ff). It is obvious that the orientation of such a structure cannot be described with a single azimuth. I do not believe that north-south lines of a building can be considered as indicative of its orientation in the east-west direction, and vice versa. If, for example, the base of a stairway in the north-south direction is measured, the perpendicular to this line should not be considered as corresponding to the structure's east-west axis, because the latter could be laid out rather by columns, pillars, wall faces or other construction elements that marked the desired astronomical direction with much greater precision than the imaginary perpendicular to the stairway. It thus seems much more natural to relate astronomical events on the eastern or western horizon to architectural east-west lines than to non-existent perpendiculars, whose relationship with these phenomena is not directly manifest or easily observable. The argument is additionally supported by the fact that the mountains to which many buildings are oriented are located along the physically existent architectural lines — as one can verify visually — and not along the imaginary perpendiculars.

As already noted (Reyman 1975: 207; Hartung 1980: 145; Aveni and Hartung 1986: 7, 12), not all of the lines actually incorporated in a building are equally reliable. A number of archaeological structures have been altered during recent excavation, restoration or reconstruction works. In these cases it is necessary to examine the corresponding reports, in order to determine which of the actually manifest lines are original and *in situ* (Hartung 1980: 155); pertinent indications in the field should also be sought (*e.g.*, remains of original stucco or certain characteristics of the construction system). If there is no evidence to this effect, it is recommendable to measure every possible alignment: by averaging various readings, the azimuthal errors originated by recent alterations are likely to be canceled out. However, structures suspected to have undergone drastic modifications should be excluded from considerations. When measurable lines (walls, wall faces etc.) have been considerably altered by deterioration processes, readings should be taken along the lines based on the most reliable elements, *e.g.* corners. Measurements of slanted faces (*taludes*) require particular caution: readings must be taken horizontally, because the azimuths of the lines sighted along the *taludes* at different angles obviously do not reproduce the orientation of the building in the horizontal plane.

Recalling that the Sun disk has a diameter of merely 32 arc minutes, it is clear that measurements must be carried out quite precisely; even if the accuracy which the alignments were intended to have is commonly unknown, reliable evaluations of various hypotheses are possible only if the precision of our data equals or, better, exceeds the one achievable by the builders (*cf.* Aveni and Hartung 1986: 7; Ruggles 1999: 165). In order to determine sufficiently exact azimuths of alignments, it is indispensable to take readings with a theodolite or surveyor's transit, using an astronomical reference, normally the Sun. The techniques that can be employed have been described, for example, by Thom (1971: 119f), Aveni (1981; 1991: 148ff), Šprajc (1991: 45ff) and Ruggles (1999: 164ff), as well as in textbooks on topography and geodesy, and therefore need not be repeated here.

A compass can also be used, but only as an auxiliary instrument and with extreme caution. Directions in the horizontal plane are normally expressed in azimuths, which are angles from 0° to 360° measured from north to the right or, viewed from above, in the clockwise direction. Observing at whatever spot on the Earth, the direction to the astronomical (true) north/south is determined by the vertical plane that contains geographic poles, *i.e.* two points where the Earth's axis of rotation intersects the surface of the globe. Since the apparent rotatory motion of the celestial sphere is centered on the rotation axis of the Earth, it is obvious that the directions in which celestial bodies rise and set depend on the position of this axis in the space. However, the direction to which the magnetic needle points is determined by the position of the Earth's magnetic field, whose poles do not coincide with the geographic poles. Since magnetic azimuths, therefore, differ from astronomical ones, they have no relation to the apparent motion of celestial bodies and, consequently, to their rising and setting points that may have been aimed at by orientations. The angle between the directions to the astronomical and the magnetic north, termed the *magnetic declination*, depends on the location of magnetic poles and thus on the place of observation. Considering that magnetic poles move continuously and unpredictably, any magnetic declination varies irregularly, as a function of both place and time; furthermore, seasonal and daily fluctuations and local anomalies are not uncommon and may result in considerable variations in short time-spans and small areas (*cf.* Aveni 1975: 164; 1991: 62f (note 1), 139f; Ruggles 1999: 165).

In view of these facts, the magnetic compass can be used in archaeoastronomical work only if the local magnetic declination is determined for each site where the measurements are carried out. In order to determine this declination, an observation point must be selected from where both magnetic and astronomical azimuths of several well defined points (*e.g.*, prominent and distant peaks of the local horizon) can be measured. The points located at a short distance are not suitable for such purposes, because even small movements by the observer result in variations of the measured azimuth; walls are even less appropriate, because the sighted point usually is not clearly defined.

Before choosing the spot for these measurements, it is advisable to measure the magnetic azimuth of one and the same reference point on the horizon from various points several metres apart. If the sighted point is sufficiently far away (a few kilometers), its azimuth measured at any one of the observation points should be practically the same; if this is not the case, local magnetic anomalies exist and the use of the compass should be avoided, because it will not render reliable results. The phenomenon is very common in the vicinity of iron elements, though it can also be due to natural properties of the soil or the material employed in ancient constructions.

By taking about ten astronomical and magnetic readings, sufficient pairs of azimuths are obtained for determining the local magnetic declination, if the compass employed allows for distinguishing azimuthal differences of about 1/4°; in my own measurements, a prismatic compass was employed, which is particularly suitable for archaeoastronomical work, both for its size and precision (*cf.* Ruggles 1999: 165). For every alignment measured we determine the astronomical azimuth and its difference with respect to the magnetic azimuth; the mean value of these differences is then calculated. The more readings we have, the more exact the magnetic declination established will be, since the inevitable errors of individual magnetic readings will tend to cancel out.

In sum, only if the local magnetic declination has been determined with sufficient accuracy, can our compass readings be used confidently for determining astronomical azimuths. Measuring architectural alignments, magnetic readings of a single line are recommended to be taken in both directions because, by changing the observation point, possible local anomalies can be detected (Ruggles 1999: 165); if they are absent, the azimuths of one and the same line measured in opposite directions will differ exactly by 180°.[11]

A hand-held compass, if used scrupulously, can speed up field measurements considerably. It is particularly useful if a building preserves a large number of reliable walls that can be measured, since in the mean value based on various azimuths the errors of individual readings will tend to cancel out.

However, the most important and reliable alignments, particularly those that can be determined with high accuracy (*e.g.*, long and straight walls or horizon prominences) should always be measured with a theodolite and astronomical reference. The theodolite is necessary also for measuring altitudes of relevant points of the horizon, albeit a pocket-sized clinometer can also be used for these purposes (Ruggles 1999: 165). Since the orientation of a structure is normally determined by calculating the mean azimuth of readings along various lines, the exact point of the horizon to which the orientation corresponds is often not evident in the moment of measurements. It is thus recommendable to measure azimuths and altitudes of various points along the section of the horizon within which, according to visual estimation, the orientation azimuth of the structure will be located. It is always advisable to sketch relevant sections of the horizon and include the measurement data in these drawings. If the horizon is not visible at present (because of vegetation, modern constructions etc.), the necessary data can be obtained by calculations (*v. infra*).

CALCULATION PROCEDURES

The formulae for calculating azimuths of alignments measured with a theodolite and astronomical fix, and for converting readings of azimuth and altitude into declinations, are given in books on topography and geodesy (*e.g.*, Mueller 1969: 401ff), as well as in specialized archaeoastronomical publications (*e.g.*, Hawkins 1968: 50ff; Thom 1971: 120ff; Aveni 1981; 1991: 140ff; Šprajc 1991: 45ff; Ruggles 1999), and thus will not be repeated here.

11 It may be pointed out that, instead of azimuths, some compasses mark *bearings*, *i.e.* angles from 0° to 90° reckoned from magnetic north and magnetic south towards east and west (*cf.* Somerville 1927: 31, note 1). The values expressed in either system can be easily converted. For example, the bearing of N15°E equals the azimuth of 15°; the bearing of N15°W corresponds to the angle of 15° west of north and, therefore, to the azimuth of 345°, whereas the azimuth of 172° can be expressed as the bearing of S8°E.

The geographic coordinates of each site necessary for these calculations can be taken from sufficiently accurate maps. In my case topographic maps of the Mexican *Instituto Nacional de Estadística, Geografía e Informática* (INEGI; scale 1:50,000) were employed. The values of declination of the Sun and equation of time, necessary for azimuth calculations, were determined for the moment of measurement by interpolation of the values tabulated in ephemerides. Horizon altitudes used when calculating declinations of alignments were corrected for atmospheric refraction factors given by Hawkins (1968: 52, Table 1), Thom (1971: 28ff, Table 3.1) and Aveni (1991: 148). The values tabulated in the quoted works are approximately valid for sea level, the atmospheric pressure of 1002 millibars and the temperature of 10°C. The refraction factors were corrected for altitudes above sea level (taken from topographic maps), employing the formula (7) of Hawkins (1968: 53), whereas corrections for different atmospheric pressures and temperatures (*ibid.*: formula (6)), which are unpredictable variables, were not applied.[12]

At every site I tried to measure all relevant points of the horizon, *i.e.* the horizon altitudes corresponding to architectural orientations, and the azimuths and altitudes of prominent mountains located within the angle of annual movement of the Sun. Occasionally, however, such measurements were not possible, because the view to the horizon is nowadays blocked by modern constructions or trees in the immediate neighborhood, or because there was haze or smog on the days of measurements. The missing data were calculated on the basis of topographic maps: locating the site (observation point) and the point of interest of the horizon on the map, geographic coordinates (longitude λ and latitude φ) and altitudes above sea level of both points were determined. For calculating the azimuth of the visual line from the site, or point 1, to the point on the horizon, or point 2, the following formulae were employed, derived from the relations valid in the spherical triangle (*cf.* Woolard and Clemence 1966: 53ff; Mueller 1969: 37ff):

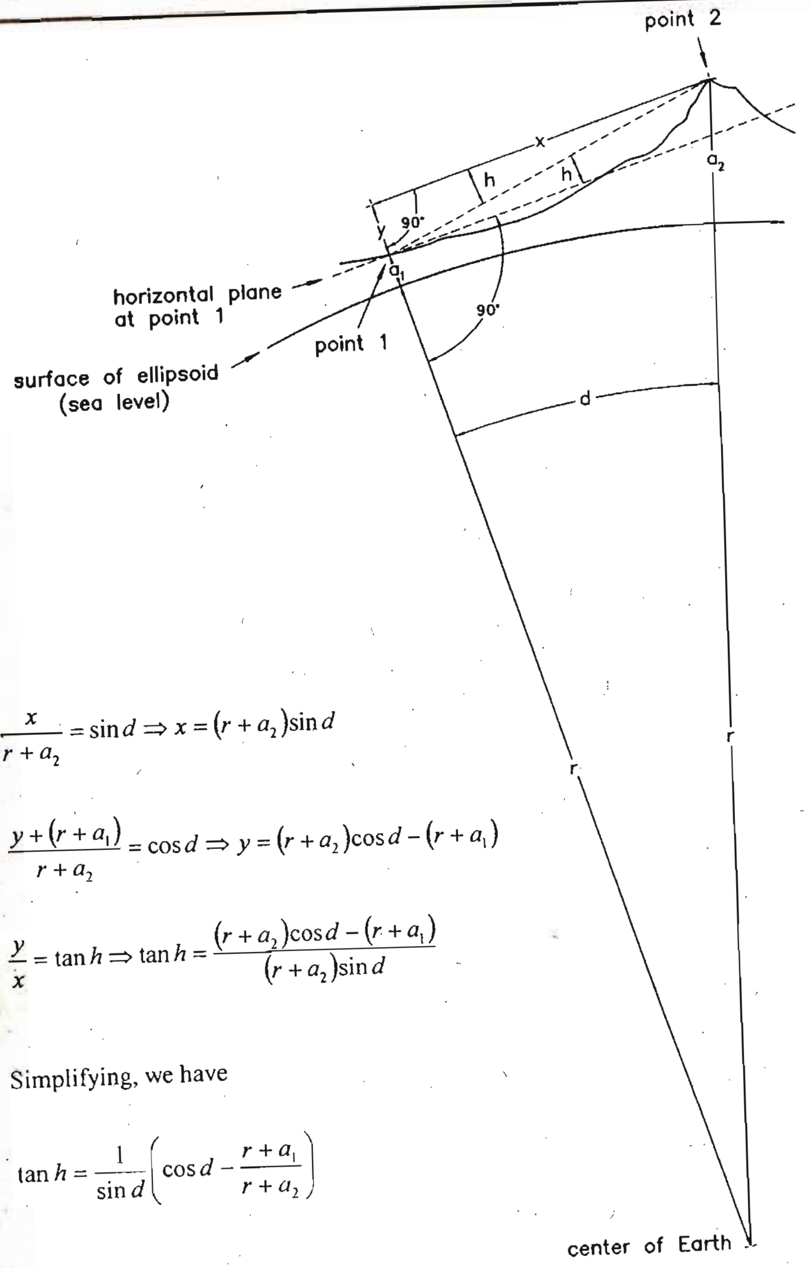
$$\cos d = \sin\varphi_1 \sin\varphi_2 + \cos\varphi_1 \cos\varphi_2 \cos(\lambda_1 - \lambda_2) \quad (1)$$

$$\cos A' = \frac{\sin\varphi_2 - \sin\varphi_1 \cos d}{\cos\varphi_1 \sin d}$$

$$\lambda_1 - \lambda_2 > 0 \Rightarrow A = A'$$
$$\lambda_1 - \lambda_2 < 0 \Rightarrow A = 360° - A'$$

In these formulae λ_1 and φ_1 are the coordinates of point 1, λ_2 and φ_2 are those of point 2, d is the *angular* distance between the two points, and A is the azimuth of alignment, observing at point 1. The formulae are valid for any place on the Earth, if north/south latitudes and longitudes west/east of Greenwich are given positive/negative algebraic signs.

12 For details about refraction near the horizon and the problems relevant to archaeoastronomy, see Schaefer and Liller 1990.



$$\frac{x}{r + a_2} = \sin d \Rightarrow x = (r + a_2)\sin d$$

$$\frac{y + (r + a_1)}{r + a_2} = \cos d \Rightarrow y = (r + a_2)\cos d - (r + a_1)$$

$$\frac{y}{x} = \tan h \Rightarrow \tan h = \frac{(r + a_2)\cos d - (r + a_1)}{(r + a_2)\sin d}$$

Simplifying, we have

$$\tan h = \frac{1}{\sin d}\left(\cos d - \frac{r + a_1}{r + a_2}\right)$$

Figure 1. *Derivation of the formula for calculating the altitude above the horizontal plane of point 2 observed from point 1.*

As a following step, the angle of altitude of point 2 above the horizontal plane, observing at point 1, was calculated. Taking into account the curvature of the Earth's surface, I derived the expression

$$\tan h = \frac{1}{\sin d}\left(\cos d - \frac{r + a_1}{r + a_2}\right) \qquad \textbf{(2)}$$

where h is the altitude of point 2 above the horizontal plane, a_1 and a_2 are the altitudes above sea level of points 1 and 2, respectively, d is the angular distance between both points, and r is the mean radius of the Earth (see derivation of the formula in Figure 1). The approximate value of 6,370,000 m was taken for r in all calculations. Since the shape of the Earth is not spherical but rather ellipsoidal, its dimensions are, in fact, described in terms of its major and minor semiaxes (or equatorial and polar radii); the values assigned to each of the two dimensions vary in accordance with different ellipsoids that have been proposed for defining the Earth's shape (as approximations to the geoid, which is its real form). Consequently, the distance between the center of the Earth and a point at sea level (surface of ellipsoid) varies as a function of geographic latitude and depends, moreover, on the dimensions of the ellipsoid chosen for this calculation. However, the approximate value of r given above is sufficiently exact for our purposes; employing more accurate values of r for each site, the resultant variations in calculated altitudes would be negligible (up to about 5 arc seconds).

It is worth stressing that horizon altitudes should not be calculated without taking into consideration the curvature of the Earth's surface. For small distances, satisfactory results can be obtained by the formula (derived from the relations in the plane triangle)

$$\tan h = \frac{a_2 - a_1}{d} \qquad \textbf{(3)}$$

where h is the altitude of point 2, observing at point 1, a_1 and a_2 are the altitudes above sea level of points 1 and 2, respectively, and d is the distance between both points, *in metres*. However, expression **(3)** will render erroneous results in great many cases, because the relevant points of the horizon are often far away: for example, if the point of the horizon for which the altitude is being calculated is situated at a distance of about 37 km (equal to 20 nautical miles or 20' of angular distance) from the observation point, the difference between the altitudes calculated by formulae **(2)** and **(3)** will be of about 10'. Therefore, the error in altitude calculated by **(3)**, increasing proportionally with the distance, may affect notably the calculation of the declination corresponding to an alignment.

Attention should also be called to the fact that the azimuth and altitude calculations are not reliable when the relevant points of the horizon are situated at a relatively short distance, because the precision of the results depends on the accuracy with which the geographic coordinates and altitudes above sea level can be determined, both for the observation point and the one on the horizon. As the distance between the two points increases, the probable margin of error in the calculated azimuth and altitude diminishes. For example, if the azimuth of a mountain peak located east or west of the site is calculated, an error of 1" (arc second; *ca.* 30 m) in the latitude determined for the site will result in an error of 21' (arc minutes) in the calculated azimuth, if the mountain is 5 km away, and of 5', if it is situated at a distance of 20 km.

For the alignments within the angle of annual movement of the Sun along the horizon I also determined the corresponding sunrise and sunset dates, valid for the epoch of foundation of the site or construction of the buildings in question. Due to precessional variations in the obliquity of the ecliptic and in the heliocentric longitude of the perihelion of the Earth's orbit (the latter element determining the length of astronomical seasons), one and the same solar declination does not necessarily correspond in any time span to exactly the same date of the tropical year (*cf.* Woolard and Clemence 1966: 235ff; Mueller 1969: 59ff; Meeus 1983: 3-1f). In order to determine the exact dates corresponding to the declinations of the Sun in relevant epochs, I employed Tuckerman's (1962; 1964) tables, which give the Sun's positions for the period from 601 B.C. to A.D. 1649; since the positions are given in ecliptic coordinates, the corresponding declinations were obtained by the formula

$$\sin\delta_{\odot} = \sin\varepsilon \sin\lambda \qquad \textbf{(4)}$$

where $\delta_{\odot}$ is the declination of the Sun, ε is the obliquity of the ecliptic and λ is the ecliptic longitude of the Sun.[13] Tuckerman's tables present the Sun's longitudes at 10-day intervals, always for 16:00 hours of Universal Time, taking into consideration the movement of the perihelion and, therefore, the secular variations in the duration of the seasons; the value of the obliquity of the ecliptic was determined, for the epoch corresponding to every particular case, by means of the formula developed by de Sitter (Thom 1971: 15).[14]

Obviously, reliable computer programs can also be employed for calculating positions of the Sun on particular dates in the past.

ANALYSIS AND INTERPRETATION OF THE ALIGNMENT DATA

In order to analyze the alignment data I elaborated a number of histograms which show the distribution of azimuths, declinations and solar dates, and intervals between these dates (Šprajc 1997b: Figures 4.1-4.12). The most important general conclusions of my research in central Mexico (summarized above in Introduction) are supported by the evidently non-random distribution of the plotted values, particularly by the clustering of declinations (dates) and intervals around certain values (Figures 2 and 3).[15] The fact that the data on architectural orientations are combined with those corresponding to horizon features might provoke methodological objections in the sense that heterogeneous elements are compared,

13 In order to evaluate the astronomical significance of alignments, it is necessary to identify the positions on the celestial sphere to which they correspond. Any alignment is defined by its azimuth and altitude above the horizontal plane, which are coordinates of the horizon system, whereas the positions on the celestial sphere can be expressed either by the ecliptic or the equatorial system of coordinates. The astronomical reference of an alignment is indicated by the corresponding declination, which is a celestial coordinate in the equatorial system. If alignments are to be related to celestial positions expressed in ecliptic coordinates, the latter must first be converted into the equatorial system: formula (4) derives from the one used for calculating declination (Mueller 1969: 40), considering that ecliptic latitude β is, in the case of the Sun, always 0°:

$$\sin\delta = \sin\beta\cos\varepsilon + \cos\beta\sin\varepsilon\sin\lambda$$

14 The procedure is described in detail in Šprajc 1997b: 30f.

15 While Figures 2 and 3 show these data for all sites included in my study, histograms presenting them separately for the Preclassic, Classic and Postclassic periods can be found in Šprajc 1997b: Figures 4.6-4.12. A statistical analysis of the alignment data is still planned to be done.

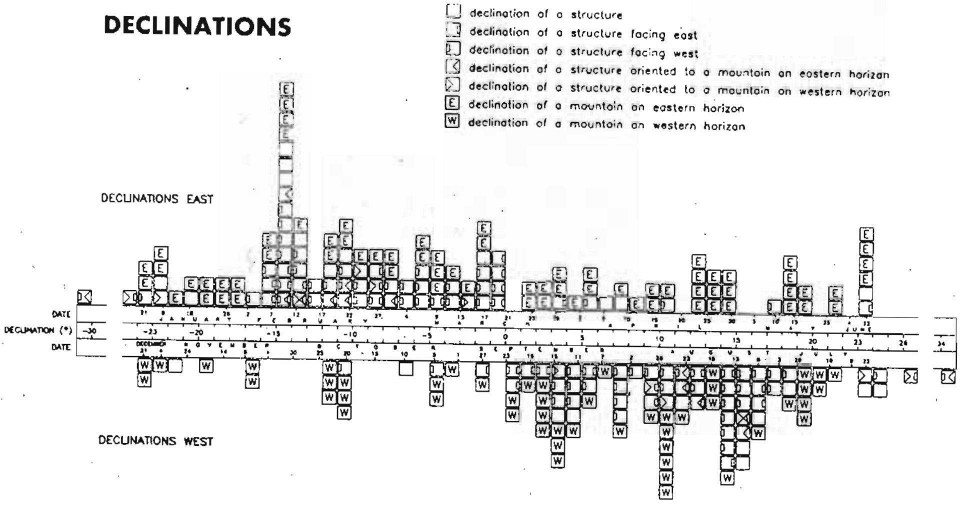


Figure 2. *Distribution of declinations recorded by alignments at central Mexican archaeological sites. Each quadrate represents one declination, corresponding either to a structure or to a horizon prominence; the meaning of signs and letters in the quadrates is explained in the figure. Declination values on the horizontal scale are spaced at 1° intervals; for example, all declinations greater than 15° and smaller than or equal to 16° appear in a single column. The declinations recorded on the eastern/western horizon are plotted upward/downward. For the range of declinations attained by the Sun, the corresponding dates of the year are also shown; winter and spring dates appear above the declination scale and summer and autumn dates below it.*

whose significance was not necessarily comparable (*cf.* Hawkins 1968: 49). It should be pointed out, however, that the alignment data of each type were first plotted separately; only after similar patterns had been obtained in both cases, I proceeded to elaborate histograms combining the two series of data. In fact, the lack of homogeneity is more apparent than real: in both cases we are dealing with alignments associated with phenomena observable on the horizon; furthermore, a generic relationship between the functions of architectural orientations and horizon features is indicated by the buildings oriented to prominent peaks on the local horizon (*cf.* Figure 2). Indeed, the results obtained suggest that architectural orientations served in combination with natural horizon markers, allowing for the use of observational calendars based on calendrically significant intervals.

I hope that the methodological approach employed in my study is free from prejudices that might distort the objectivity of the research results and prevent a global comprehension of the complexity of astronomical factors involved in the orientation and location of civic and ceremonial buildings. As an example of such prejudices, the significance assigned or denied *a priori* to certain dates of the tropical year can be mentioned. In his critique of the hypothesis (first proposed by Morley and later by Aveni) that the alignment from Stela 12 to Stela 10 at Copán was intended to mark sunsets on April 12 and September 1, Köhler (1991: 132) contends that these dates have no particular astronomical

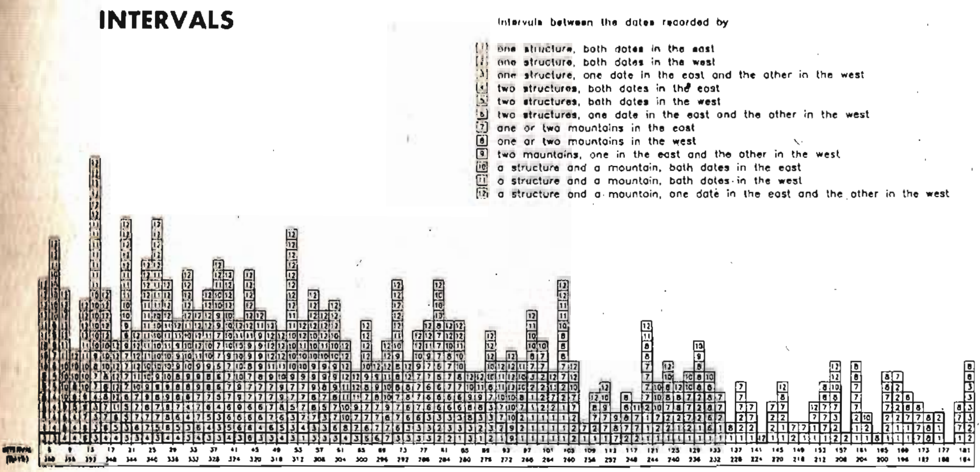


Figure 3. *Distribution of intervals between the dates recorded by alignments at central Mexican archaeological sites. The intervals, each represented by a quadrate, are distances, in days, from any one to any one of the dates recorded at any particular site, both by architectural orientations and by prominences on the local horizon. The meaning of numbers in the quadrates is explained in the figure. Since any (except a solstitial) alignment registers in one and the same direction two dates in a year and, therefore, two intervals whose sum is 365 days, both are represented by a single quadrate: in the upper line of the horizontal scale the shorter intervals are listed and in the lower one their complements to the 365-day year. The columns of quadrates are spaced at 2-day intervals: for example, all intervals in excess of 103 and smaller than or equal to 105 days (greater than or equal to 260 and smaller than 262 days) are included in a single column. The thick line divides the intervals produced by a single architectural orientation (quadrates 1, 2 and 3) from others. If an interval separates the dates recorded by* two *alignments, the latter actually mark* four *dates which, consequently, delimit* two *short intervals; since both are necessarily coexistent and similar (though not always exactly equal, due to the variable speed of the Sun's apparent movement), they are represented by a single quadrate, its location in the histogram being determined by their mean value. Since any (except a solstitial) architectural orientation that is functional in both directions records two dates on the eastern and two on the western horizon, two of the six intervals produced necessarily approach 182 days (half a year); such intervals, even if some of them may have been achieved intentionally (their exact lengths depend on horizon altitudes), are not represented in the histogram, because their high frequency would not reflect their real importance (for details see Šprajc 1997b: 63, 122-124).*

significance. Our still deficient knowledge about the importance of certain dates in the Mesoamerican world view certainly does not warrant such an assertion which, one can suspect, reflects an "application of European concepts", *i.e.* precisely the attitude the same author aptly criticizes in another context (*ibid.*: 133ff). Nor can the requisite be accepted that, for demonstrating the astronomical nature of architectural alignments in a culture it is indispensable, in the first place, to prove with independent data that celestial phenomena were "deified or at least considered to be powerful entities which directly influence the fate of mankind" (*ibid.*: 131); Köhler (*ibid.*) adds that, in the absence of archaeological evidences, the ethnohistoric and ethnographic data from the same cultural area may at least provide some hints. As Aveni (1995: S79) points out, this proposition, refuted by the very emergence and development of archaeoastronomy and its achievements in the second half of this century, "declares that one can discover nothing by beginning with alignments". In terms of general archaeological methodology we could say that, by implementing Köhler's postulate in practice, we would run the risk of neglecting the intrinsic value of archaeological remains and of approaching the attitude criticized by Binford (1972: 86) in relation to inadequate use of ethnographic analogies in archaeology: "Fitting archaeological remains into ethnographically known patterns of life adds nothing to our knowledge of the past." Curiously, however, referring to stellar orientations, Köhler (1991: 131) affirms:

> [...] there is also the possibility of obtaining information on the basis of purely archaeological sources. For example, if the orientation towards the point of rising or setting of a particular star is consistently found in a great number of sites of one area, there is a high probability that this orientation was a deliberate one and quite probably had the aim of being aligned with that particular star. — However, all conclusions based on a single site must remain highly speculative!

This argument, somehow contradictory in comparison with the formerly quoted claims of the same author, is much closer to what I consider to be the proper guidelines for the study of astronomical alignments in general, not only of those related to the stars.

Another example of a methodologically deficient approach is Morante's (1996: 83ss) attempt at identifying horizon markers at Teotihuacan for the dates he assumes to have been relevant. Even if, for the various dates he mentions, we know that they were, indeed, important, this method prevents us from finding other possibly significant dates, *i.e.* it does not allow us to discover anything new, limiting our explanatory endeavors to corroborations of what we already know or suppose (*cf.* Ruggles 1994: 498). These critical remarks notwithstanding, the studies of Xochicalco and Teotihuacan accomplished by Morante (1993; 1996) are important contributions to Mesoamerican archaeoastronomy. It is obvious that a "case study" focused on a single site can hardly detect patterns that would confirm the hypotheses proposed in relation to the alignments at that site. Regularities of this type can only be revealed by comparative research based on a number of sites that manifest some degree of cultural homogeneity, but this approach also involves deficiencies that seem inevitable: when studying diverse sites, it is impossible to pay sufficient attention to the whole complexity of each of them; clearly a detailed research at one site can detect more elements of potential astronomical significance and generate important new hypotheses, but these will have to be verified by comparative investigations. It can be concluded that both approaches are necessary and complementary, each of them having its advantages and limitations.

CONCLUDING REMARKS

The methodological guidelines presented above were developed in the course of my study of alignments in central Mexican archaeological sites. If, as I hope, the results of my

research (summarized in Introduction) contribute to a deeper understanding of the significance of architectural orientations and other alignments incorporated in the cultural landscape of prehispanic central Mexico, the methods and techniques described should be helpful in further archaeoastronomical investigations in Mesoamerica, as well as in other areas with comparable types of archaeological remains.

Since the appearance of the sky and the characteristics of recurrent celestial events can be confidently reconstructed for any place on Earth and any time during the last several millennia, archaeoastronomy largely relies on mathematically exact data and thus has a significant advantage over studies of other aspects of the past (Ruggles and Saunders 1993: 9f; Ruggles 1999: 145). This characteristic of archaeoastronomical research is in keeping with the evident tendency in modern archaeology to employ as many as possible of the techniques, methods and procedures developed by exact sciences, in order to achieve accurate, testable and reliable results. Curiously, however, very little has been done within the main-stream archaeology to include measurements and study of alignments in the excavation process. Architectural orientations represent "attributes of material objects" (Iwaniszewski 1995a: 192) and should be considered as important as any other piece of archaeological evidence:

> Even if the surveyor of a prehistoric structure should be of opinion that there is "nothing in" Orientation, still the direction in which the structure is laid out on the ground should be accurately reproduced in the resulting plan, if only in the interests of scientific completeness. Until this is done, the matter will never be settled as to whether, in fact, there is, or is not Orientation in these structures of antiquity; and if there is, wherein it is expressed. (Somerville 1927: 37)

Unfortunately, this methodological advice, expressed more than seven decades ago, has not had much impact among archaeologists, whose general attitude has not changed substantially even in recent decades, in spite of the indisputable achievements made within the specialized field of archaeoastronomy (*cf.* Ruggles 1999: 1ff). Ideally, architectural orientations and other archaeologically documented alignments with conceivable astronomical significance should be measured in the course of excavation, when the construction elements are still *in situ*, considering that, as a result of later interventions, they are often moved off their original positions or disappear completely (Hartung 1980: 145). Studies of alignments should represent an *integral part* of archaeological research. However, if the place archaeoastronomy deserves within anthropological disciplines, specifically archaeology, is to be secured, the application and continuous development of rigorous and objective methodological procedures is obviously of foremost importance.

POVZETEK

Članek predstavlja nekatere specifične metode in tehnike, ki so bile uporabljene v sistematični arheoastronomski raziskavi orientacij v predšpanski arhitekturi na vrsti predklasičnih, klasičnih in postklasičnih arheoloških najdišč v osrednji Mehiki. Rezultati te raziskave so na kratko podani v uvodu, sicer pa se članek osredotoča na tehnična in metodološka vprašanja, ki so relevantna za arheoastronomska preučevanja nasploh: obravnavajo se kriteriji za izbor linij, ki so bile upoštevane v študiji, pa tudi nekatera tehnična vprašanja, ki zadevajo zbiranje in analizo podatkov o orientacijah.

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