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ASTRONOMICAL ALIGNMENTS AT THE TEMPLO MAYOR OF TENOCHTITLAN, MEXICO

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Introduction

Systematic archaeoastronomical research carried out during the last few decades has revealed that architectural orientations in Mesoamerica exhibit a clearly non-random distribution and that civic and ceremonial buildings were mostly oriented on the basis of astronomical considerations, particularly to the sun's positions on the horizon on certain dates of the tropical year.[1] While the alignments to sunrises and sunsets on the solstices and equinoxes have been found on various archaeological sites, the most frequent orientational groups correspond to other dates whose significance is less obvious. According to various hypotheses put forward thus far, the solar dates recorded by the orientations can be interpreted in terms of their relevance in the agricultural cycle and in the 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,[2] who contends that these dates mark intervals of 13 and 20 days and multiples thereof; on the other hand, he also suggests that the orientations are spaced in accordance with a geometrical system based on a 4.5° angular measurement unit. Some authors 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.[3]

In order to test such hypotheses, I undertook precise measurements of alignments at 37 Preclassic, Classic and Postclassic archaeological sites in central Mexico. This involved measuring not only the orientations of civic-ceremonial structures but also the alignments to prominent mountains on the local horizon, placed within the angle of annual movement of the sun. The analyses of the data obtained show that the dates of sunrises and sunsets both along the architectural orientations and above the prominent hills on the local horizon exhibit consistent patterns, being separated by intervals that are predominantly multiples of 13 and 20 days and are, therefore, significant in terms of the Mesoamerican calendrical system. Furthermore, the most frequently recurrent dates, registered at a number of sites, apparently marked crucial moments of a ritual agricultural cycle. The regularities detected strongly suggest that the important ceremonial structures were constructed on carefully selected places, in order to employ certain surrounding peaks as natural markers of horizon calendars. Both the orientations embodied in the monumental architecture of a particular site — occasionally dominating the entire urban layout — and the prominent features of the local horizon allowed the use of an observational

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calendar that, in view of the lack of permanent concordance of the calendrical and tropical years, was necessary for predicting important seasonal changes and for an efficient scheduling of the corresponding agricultural activities. It is also obvious, however, that this practical function of observational calendars was deeply embedded in the ritual and intimately related with social organization, religion and political ideology.[4]

The results of my research in central Mexico agree with some general ideas formerly expressed by other authors, but differ in important details which concern the principles underlying the orientational patterns and the use of observational calendars. While some of Tichy's models,[5] for example, do have a real basis — even if his specific hypotheses are not corroborated — his geometrical orientational scheme can hardly be sustained.[6]

The Templo Mayor of Tenochtitlan, one of the structures included in my study, exemplifies the observational and calendrical function of the alignments at central Mexican sites from the Preclassic onwards.

Architecture and Chronology

The remains of the Templo Mayor of Tenochtitlan (Figure 1) are located in Mexico City's historical centre, immediately northeast of the Metropolitan Cathedral (longitude: 99° 07′ 51″ W; latitude: 19° 26′ 03″ N; altitude above sea level: 2240 m[7]). The earliest vestiges of a settlement in the area occupied in later times by the

FIG. 1. Remains of the Templo Mayor of Tenochtitlan, with its various structural phases (view to the north).

TABLE 1. Data on the orientations of the Templo Mayor of Tenochtitlan.

Structure	A	h	δ	Dates
Templo Mayor Phase II	97°42′ ± 30′	2°02′ ± 5′	−6°39′ ± 30′	Mar 3, Oct 10 ± 1^d
	277°42′ ± 30′	2°07′ ± 3′	7°54′ ± 30′	Apr 9, Sep 1 ± 1^d
	6°30′ ± 1°			
Later phases	95°36′ ± 30′	1°55′ ± 5′	−4°43′ ± 30′	Mar 9, Oct 5 ± 1^d
	275°36′ ± 30′	2°22′ ± 5′	6°00′ ± 30′	Apr 4, Sep 7 ± 1^d
	6°40′ ± 30′			

Templo Mayor ceremonial precinct date from the Early Postclassic.[8] However, the greater part of architectural remains discovered so far belong to the Late Postclassic, including the various structural stages of the Templo Mayor, the main building of the sacred precinct of the Mexica capital. Even if there is no agreement about the details concerning the chronological sequence of the Templo Mayor's construction, it seems that Phase II can be dated, according to several propositions, to the fourteenth century;[9] it is thus probable that the earliest temple (nowadays covered by the construction called Phase II) was built in the same century or even in the previous one.

The research accomplished so far[10] has made possible to distinguish seven principal building stages of the Templo Mayor. Each of the known superimposed structures, all of them similar in shape, is characterized by a double stairway on the west side. Upon the platform of Phase II the remains of upper twin sanctuaries are also preserved, dedicated to the gods Tlaloc and Huitzilopochtli. Not only the Contact-period historical sources but also an enormous amount of offerings and other archaeological finds provide information as to the ritual activities and complex symbolism associated with the Templo Mayor.[11]

Architectural Orientations and Alignments to Prominent Horizon Features

The data on architectural orientations at the Templo Mayor of Tenochtitlan are listed in Table 1. The mean east–west and north–south azimuths (with estimated margins of error) appear in the second column (A), whereas the corresponding horizon altitudes are given in the third column (h). The astronomical declinations calculated for each azimuth and horizon altitude, taking into account the effects of atmospheric refraction, appear in the fourth column (δ),[12] while the dates on which the sun had these declinations are listed in the fifth column.[13]

The east–west orientation azimuth of Phase II is based on the azimuth of the narrow passageway that separates the upper twin sanctuaries (Figure 2), because the latter probably reproduces the intended orientation of the temple with particular fidelity: the drawing of the Templo Mayor in the Tenochtitlan map attributed to Cortés shows a face representing the sun flanked by the two upper sanctuaries, thus suggesting that the observations were made precisely along the passage between them.[14] Even if this is not an indisputable proof that the orientation of the passage is the most relevant one, it does seem significant, on the one hand, that other east–west lines measured on the Phase II structure exhibit very divergent azimuths and, on the other, that their mean is very close to the present-day azimuth of the passage (*cf. infra*).

The remains of the various construction stages of the Templo Mayor are nowadays considerably displaced from their original position, due to differential settlements that the architectural complex has undergone through the centuries[15] and which must have also resulted in horizontal movements. At present, the azimuth of the axis of the passageway between the twin sanctuaries of Phase II is 97°32′, but originally it must have been a little larger, because the structure is strongly inclined, its southeast extreme exhibiting the highest elevation. Measuring relative heights of various points on the upper platform,[16] I was able to determine the approximate inclination angles in the north–south and east–west directions and to calculate, on these grounds, the probable magnitude of horizontal movements. The calculations, presented in detail in the Appendix, indicate that a small rotation movement in the horizontal plane must have accompanied the process of settling of the structure and that the east–west architectural alignments originally had slightly greater azimuths than they have nowadays. Since the magnitude of this horizontal skew may have been between 0 and 20 minutes of arc, depending on the sequence of the movements, I added to the measured azimuth of the passage (97°32′) the mean value of 10′. Although the estimated margin of error of the azimuth thus obtained is, according to these calculations, ±10′, it seems reasonable to consider a larger value: on the one hand, the calculations are valid for a rigid body, whereas the building most surely has not

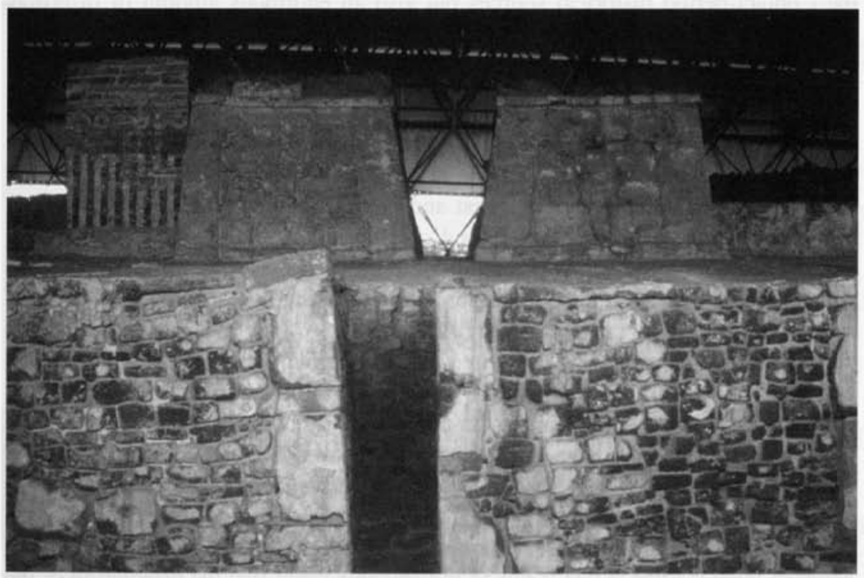

FIG. 2. View to the east along the passageway between the upper sanctuaries of Tlaloc (left) and Huitzilpochtli (right) of Phase II of the Templo Mayor of Tenochtitlan.

moved uniformly in all of its parts; on the other hand, we can suppose that telluric movements, which are so common in the region and whose effects may have been intensified by the characteristics of the swampy ground, triggered some additional and irregular horizontal dislocations that cannot be reconstructed. Furthermore, it should be recalled that the value 97°42′ corresponds to the azimuth measured along the passageway between the twin sanctuaries and corrected for the estimated horizontal rotation, while we have no compelling evidence that this was, indeed, the most relevant alignment for observations. The mean azimuth of all of the east–west lines measured on Phase II is 97°24′; this value is, significantly, very close to the present-day azimuth of the passage, but it also has a margin of error, since the individual azimuths diverge considerably. The margin of error of ±30′ assigned to the east–west orientation azimuth of Phase II of the Templo Mayor (Table 1) is based on these considerations.

Aveni *et al.* and Ponce de León give for the passage of Phase II the azimuths 97°46′ and 97°25′, respectively.[17] Exploring the effects of the structure's sloping, Ponce de León[18] measured the axis of the passage projected to the present ground level, and concluded that the azimuth of 98°48′ he established for this virtual axis must be considered as very close to the original azimuth of the passageway. Even if Ponce de León's analysis is detailed and careful, it should be pointed out that the azimuth obtained by his procedure is most probably too large: by projecting the axis of the passage to the actual ground level, along the plane perpendicular to the upper platform of the structure,[19] we get a line connecting two points which — located on the front and rear façades — originally were not on the same level, if we consider the inclination of the structure, whose southeastern extreme is nowadays its most elevated part. The azimuth of this alignment does not necessarily reproduce the original orientation of the passageway, since it depends on the position of the axes around which the structure rotated and on the sequence of these movements.[20]

The results of my measurements show that the orientation of Phase II, at least in the east–west direction, differs from the one incorporated into the later superimposed structures. Measuring the alignments between the corners of the preserved slanted faces (*taludes*) of the later phases — or between the points near the corners that are not exposed or preserved — I obtained the azimuths shown in Figure 3;[21] the mean values appear in Table 1. The azimuths of the alignments may nowadays, due to settlements, slightly differ from the original ones, but the formula discussed in the Appendix and derived with the purpose of estimating possible horizontal movements of Phase II cannot be applied to the case of later phases, since the latter have not moved as rigid bodies. The degree of subsidence observable at different points is directly proportional to their distances from the central part of the construction mass, which is the most elevated one, because the compressibility of underlying clays was reduced by the pressure of the first superimposed buildings.[22] As it is obvious, therefore, that the settlements did not produce uniform horizontal skews, it can be assumed that by averaging the extant azimuths, the eventual errors of individual values cancel out.

Ponce de León[23] also inferred that Phase II, on the one hand, and the later superimposed buildings, on the other, had different orientations. For the line connecting central points of the stairways of the late phases he obtained the azimuth of 96°02′. Assuming also for these structures a skew similar to the one detected on Phase II, he added to the measured azimuth the value 1°23′ — i.e. the difference between the existing (97°25′) and the original azimuth (98°48′) he determined for the passageway of Phase II — and concluded that the value obtained, 97°25′, must be considered as the original orientation azimuth of the structural phases later than the second one. In view of the argument presented above, however, the conclusion seems hard to accept, both because the correction value determined for Phase II (1°23′) is excessive and because the Phase II structure tilted in a relatively uniform manner, while the differential settlements of subsequent phases caused different parts of the structures to incline in different directions. It can be observed that the azimuth measured by Ponce de León, without correction (96°02′), is quite close to the mean value based on the *taludes* (95°36′: Table 1). However, the line measured along the central points of the stairways of the superimposed buildings does not necessarily reproduce with precision the orientation of each of them, because it could never be visually controlled by the builders. On the other hand, we can recall that the successive stages of the contemporary Tenayuca pyramid share the same orientation, but their central east–west axes move progressively towards the south.[24]

The data displayed in Table 1 show that the north–south azimuths of Phase II and of the late phases are practically equal. Furthermore, the listed values, the result of my own measurements, agree with the mean of 6°42′ ± 23′ established by Aveni, Calnek and Hartung[25] and based on the north–south lines. Observing that the latter do not exhibit notable divergences, Aveni *et al.* concluded that all of the structural stages possessed very similar orientations.[26] However, the east–west azimuths of the late phases are consistently smaller than those measured on Phase II, their mean values being 95°48′ (Phase III), 95°25′ (Phase IV), 95°19′ (Phase IVb) and 95°52′ (Phase VI) (*cf.* Figure 3). Since these values do not differ from each other in a significant and systematic way, it is likely that the mean value based on them and given in Table 1 represents the intended orientation of the late phases of the Templo Mayor with reasonable accuracy.[27] This conclusion is supported by the fact that various adjacent structures contemporary with the last phases of the Templo Mayor[28] exhibit comparable orientations. For example, the azimuths of the east–west axes of Structures C and F, located immediately to the north and south of Phase VI, are 95°47′ and 95°04′, respectively. The pronounced inclinations of both structures suggest that their original orientations were quite similar to those of the late phases of the Templo Mayor: since Structure C, to the north, presents the greatest elevation in its southwest corner, its original east–west azimuths must have been slightly smaller than nowadays, while those of Structure F, alternatively called Red Temple and situated to the south, were probably greater, because the most elevated part of this building is its northwest corner. The east–west azimuth of Structure B located immediately west of Structure C is 95°23′, while the south

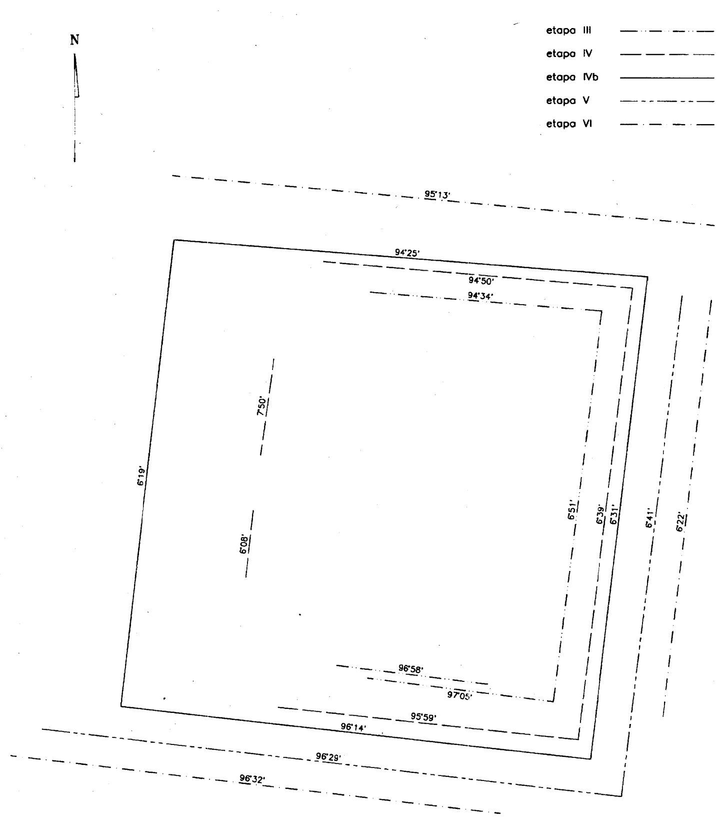

FIG. 3. Azimuths of the lines measured on late phases of the Templo Mayor of Tenochtitlan.

face of Structure E, also known as House of the Eagles and occupying the extreme north of the excavated area, aligns with an azimuth of 95°06′. It seems, then, that the orientation of the Templo Mayor was reproduced in the contemporary neighbouring buildings.

It has been commonly held that the streets in the historical centre of Mexico City follow the orientation of the Templo Mayor and associated structures.[29] This opinion is reflected also in the reconstruction plans of the sacred precinct of Tenochtitlan.[30] It should be pointed out, however, that the orientations of the greater part of the buildings that have been excavated are slightly skewed counterclockwise relative to the present urban layout. As the plan of Vega Sosa shows, the structures excavated in the area of the nearby Metropolitan Cathedral exhibit such a deviation with regard to the ground plan of the church, whose axes agree with the orientation of

TABLE 2. Data on the eastern horizon of the Templo Mayor of Tenochtitlan.

Mountain	A	h	δ	Dates
Cerro Tláloc	93°11′	2°17′	−2°19′	Mar 14, Sep 28
Cerro Tlamacas	74°40′	0°58′	14°40′	Apr 29, Aug 13

the surrounding streets.[31] The fact that the colonial urban layout corresponds rather with the orientation of Phase II of the Templo Mayor[32] suggests that this alignment, even though in later times it no longer prevailed in the ceremonial precinct, had been dominant in the early period of Tenochtitlan and persisted in certain buildings and streets, or even in the greater part of the prehispanic urban layout, until the Conquest, when it was adopted by the colonial town.[33]

Considering that the orientation of the Templo Mayor changed, beginning with Phase III, it can be recalled that the latter, according to various authors, belongs to the reign of Itzcóatl.[34] The modification can thus be understood as a part of the ambitious programme of reforms for which this ruler is particularly well known. The orientations of the structures excavated in the area of the cathedral have not been measured with precision, but Structure A (Temple of Tonatiuh) appears to reflect the same change:[35] while the first construction phase follows the orientation of the cathedral and, therefore, of Phase II of the Templo Mayor, the superimposed buildings exhibit a skew in the same direction (counterclockwise) as the late phases of the Templo Mayor. However, whereas Structure A is late, some other buildings that share the same deviation, notably Structures C and D,[36] belong, according to Vega Sosa,[37] to the early periods of occupation of the site (*c.* A.D. 950–1350). Consequently, it is possible that the new orientation incorporated into the Templo Mayor after Phase III had forerunners, but became dominant in the sacred precinct only in the late periods of Tenochtitlan.

The results of my analysis of the alignment data referred to prominent horizon features at a number of archaeological sites in central Mexico suggest that, in the case of the Templo Mayor of Tenochtitlan, the mountain tops Tláloc and Tlamacas, visible on the eastern horizon, must have been particularly important: they marked sunrises on the dates that, together with those recorded by architectural orientations, composed observational calendar schemes comparable to those reconstructed for other sites.[38] The azimuths (A), altitudes (h), declinations (δ) and sunrise dates corresponding to the two mountains are listed in Table 2.[39]

Observational Calendars

Employing the data presented in Tables 1 and 2, it can be calculated that various dates recorded by architectural alignments and certain mountain peaks on the horizon are separated by intervals that are, or approach, multiples of 13 and of 20 days. Cerro Tlamacas demands particular attention, because the dates it registers divide the year into intervals of approximately 105 and 260 days. The 'ideal' dates would be April 30 and August 13, which are commonly marked by

architectural orientations and prominent horizon features at various sites.[40] In fact, Cerro Tlamacas could have recorded these dates if the last contact of the solar disk with the horizon was observed, i.e. if it was the tangent position of the sun upon the mountain that was relevant for determining the dates corresponding to the alignment. The declination of the sun required for seeing its lower limb aligned with the top of Cerro Tlamacas, when observing at the Templo Mayor, is 14°45′.[41] If for a 4-year period in the mid-fourteenth century — assuming the site for the construction of the Templo Mayor was chosen around that time — we examine solar declinations calculated for the moments of sunrise on relevant dates, we find that Gregorian dates on which Cerro Tlamacas was aligned with the centre of the sun and with its lower limb were those listed in Tables 3 and 4, respectively.[42]

It can be observed that the intervals separating the dates registered by the centre of solar disk behind the summit of Cerro Tlamacas are 105 or 106 and 259 or 260 days. However, if the dates on which the sun's disk was seen tangent to the mountain were relevant, the short interval was 105 or, once in the four years, 106 days, while the long interval was always 260 days.[43] Assuming that the interval of 260 days was particularly important, because it separated the same dates of *tonalpohualli* (the sacred 260-day calendrical count), it can be concluded that *the dates of the observational calendar of the Templo Mayor were recorded by tangent positions of the sun on the horizon along the alignments.*[44]

The interval of 46 days between the dates marked by the Tláloc and Tlamacas peaks also demands attention, because the sunset dates corresponding to the orientation of the Templo Mayor's Phase II subdivide it in intervals of 26 or 27 and 20 or 19 days (*cf.* Tables 1 and 2). In the late fourteenth century, when

TABLES 3 and 4. Dates recorded by the solar disk's centre (Table 3) and lower limb (Table 4) aligned with Cerro Tlamacas, and intermediate intervals, for a period of 4 years in the middle of the 14th century.

	Table 3			Table 4	
Year	Date	Interval (days)	Year	Date	Interval (days)
1341	Apr 29		1341	Apr 30	
		106			105
	Aug 13			Aug 13	
		260			260
1342	Apr 30		1342	Apr 30	
		105			105
	Aug 13			Aug 13	
		260			260
1343	Apr 30		1343	Apr 30	
		106			105
	Aug 14			Aug 13	
		259			260
1344	Apr 29		1344	Apr 29	
		106			106
	Aug 13			Aug 13	
		259			260
1345	Apr 29		1345	Apr 30	
	.	.		.	.
	.	.		.	.
	.	.		.	.

Phase II was probably erected,[45] the sun's lower limb aligned with the Tláloc and Tlamacas mountain tops on March 14 or 15 and April 29 or 30, respectively, but the intermediate interval was predominantly 46 days. Supposing the accuracy of the observational calendar was more important in spring, before the onset of the rainy season, it is likely that the orientation of Phase II recorded sunsets on April 9 or 10, ideally separated by the exact intervals of 26 (2 *trecenas*) and 20 days (1 *veintena*) from those marked by Cerro Tláloc and Cerro Tlamacas, respectively.[46] The structure could have registered these dates if the tangent position of the sun on the horizon was determinant and, moreover, if the original east–west orientation azimuth of Phase II was approximately 97°50′ (declination required: 8°06′), i.e. about 8′ greater than the one given in Table 1 (97°42′). The latter has been determined from assessment of the magnitude of horizontal skew originated by settlements, by adding the mean correction value of 10′ to the present azimuth of the passageway between the twin sanctuaries (97°32′) (*vide supra*, and the Appendix). However, according to the argument presented in the Appendix, the original azimuth could have been, indeed, up to 20′ greater than it is nowadays.[47]

It also seems significant that the interval between the sunrise dates corresponding to the orientation of Phase II approaches 39 days (3 *trecenas*). However, the spring interval (from March 3 to April 9), though presumably the more important, is 37 days. If the original orientation azimuth was about 97°50′, as suggested above, and if the tangent position of the sun on the horizon was observed, the date of sunset along the axis of Phase II was April 9 or 10, while the sunrises occurred on the same date of March 3, which means that the interval between the two dates did not reach 39 days. The 'ideal' date would have been March 1/2, 13 days before the one recorded by Cerro Tláloc, and April 9/10, 20 days before the sunrise above Cerro Tlamacas, but these dates, given the horizon altitudes, could not be recorded by one and the same orientation.[48]

It can be hypothesized that sunrises on March 1 or 2 (13 days before sunrise above Cerro Tláloc and 39 days before sunset in the axis of the temple) were marked by other orientations. While the idea that two slightly different alignments were embodied in the same Phase II of the Templo Mayor is not supported by the measured alignments,[49] it is not impossible that some other neighbouring building(s) recorded the relevant sunrise dates, which composed an observational calendar in combination with the dates of sunset in the axis of the Templo Mayor.[50] The hypothesis obviously has no support until a required orientation is found, incorporated into a structure contemporaneous with Phase II.

The available evidence suggests that the primary concern of the builders of Phase II was to orient the structure toward the point on the western horizon where the sun set 26 days after it had risen above Cerro Tláloc and 20 days before the same phenomenon occurred above Cerro Tlamacas. Table 5 presents the dates and intervals of the observational calendar that could have been in use in the late fourteenth century, if the east–west orientation azimuth of the structure was approximately 97°50′ and if tangent positions of the sun upon the horizon were

TABLE 5. Possible observational calendar related to Phase II of the Templo Mayor, for a 4-year period in the late 14th century.

Alignment	Date	Interval (days)	Date	Interval (days)
	1380		1382	167
Cerro Tláloc, sunrise	Mar 14		Mar 14	
		26		27
Templo Mayor, Phase II, sunset	Apr 9		Apr 10	
		20		20
Cerro Tlamacas, sunrise	Apr 29		Apr 30	
		105		105
Cerro Tlamacas, sunrise	Aug 12		Aug 13	
		19		19
Templo Mayor, Phase II, sunset	Aug 31		Sep 1	
		28		27
Cerro Tláloc, sunrise	Sep 28		Sep 28	
	1381	167	1383	168
Cerro Tláloc, sunrise	Mar 14		Mar 15	
		26		26
Templo Mayor, Phase II, sunset	Apr 9		Apr 10	
		20		20
Cerro Tlamacas, sunrise	Apr 29		Apr 30	
		106		105
Cerro Tlamacas, sunrise	Aug 13		Aug 13	
		19		19
Templo Mayor, Phase II, sunset	Sep 1		Sep 1	
		27		27
Cerro Tláloc, sunrise	Sep 28		Sep 28	
	1382	167	1384	168
Cerro Tláloc, sunrise	Mar 14		Mar 14	

relevant for determining the dates. As one can see, in the spring half of the year the interval between the sunset in the axis of the structure and the sunrise above Cerro Tlamacas is invariably 20 days, while the distance between the sunrise above Cerro Tláloc and the sunset marked by the building is 26 days, except in 1382, when it is 27 days. It may be noted, again, that the long interval separating the sunrises above Cerro Tlamacas is always 260 days. Also significant might be the fact that the long interval between the dates of sunset in the axis of the structure (e.g. from 1380 August 31 to 1381 April 9) is constantly 221 days, i e. 17 *trecenas*.

As for the late orientation of the Templo Mayor, the underlying astronomical and calendrical motives seem to be clear: the intervals composing the observational calendar that can be reconstructed are, or approximate to, multiples of *trecenas*. The shortest intervals between the sunrises and sunsets in the axis of the structure are 26 or 28 days, while the consecutive sunrise/sunset dates are separated by intervals of 155/156 days; furthermore, the sunset dates recorded by the temple's orientation fell 25 days before and after the sunrises above Cerro Tlamacas (*cf.* Tables 1 and 2). An 'ideal' scheme of intervals would have been the one shown in Table 6, where the short intervals between the consecutive dates of both sunrises and sunsets in the axis of the structure are always 156 days (12 *trecenas*), while the spring intervals from the sunrise to the sunset marked by the structure, as well as from the latter to the sunrise above Cerro Tlamacas, are 26 days (2 *trecenas*). Calculations show

TABLE 6. Possible observational calendar related with the late phases of the Templo Mayor of Tenochtitlan.

Alignment	Date	Interval (days)		Date
		156		
Templo Mayor, late phases, sunrise	Mar 9			Oct 4
		26	27	
Templo Mayor, late phases, sunset	Apr 4			Sep 7
		26	25	
Cerro Tlamacas, sunrise	Apr 30			Aug 13
		105		

that this scheme could have been achieved if the declinations corresponding to the east- and west-working orientation of the building were about –4°27′ and 5°55′, respectively. In the fifteenth century, the sun had these declinations when its lower limb 'touched' the east and west horizon of the Templo Mayor at azimuths 95°25′and 275°25′. Consequently, the ideal dates of the observational calendar could, indeed, be recorded by one and the same architectural orientation, but *only if tangent positions of the sun on the horizon were relevant* and, at the same time, if the orientation azimuth was about 95°25′, i.e. 11′ smaller than the one given in Table 1 (95°36′). Since the latter derives from the azimuths measured on the preserved segments of the lowest wall faces of the late structural stages, it is obvious that the margin of error that has to be allowed for exceeds the correction of 11′ necessary for obtaining the ideal value. It is thus very likely that, starting with Phase III, the azimuth of the intended east–west orientation of the Templo Mayor was about 95°25′.[51]

In the light of comparative evidence from other sites it is unlikely that the alignments to the mountains Tláloc and Tlamacas were fortuitous. While information on the eventual importance of Cerro Tlamacas in prehispanic times seems to be lacking, the symbolic and ritual significance of Cerro Tláloc is amply documented in early colonial written sources and corroborated by archaeological remains on the mountain's summit.[52] Several historical sources mention that the selection of the site for the construction of the Templo Mayor was conditioned by the presence of caves, rocks and water springs.[53] On the other hand, Mazari *et al.* and Mazari, analysing the settlements of the Templo Mayor in terms of the soil mechanics, argue that no natural island had ever existed on the spot and that the temple was built upon a huge artificial platform some 11m in height, submerged approximately 6m below the lake surface.[54] This interpretation, if correct, may give further support to the idea that the site, apparently hardly appropriate for building a temple, was chosen on astronomical grounds, because it allowed the use of an observational calendar in which some significant dates were marked by the sun's positions over certain prominent horizon features.

Discussion of Some Previous Hypotheses

Aveni, Calnek and Hartung[55] also ascribe astronomical motives to the location of the Templo Mayor of Tenochtitlan. They observe that the sun rises over the peaks of Telapón and Tepetzinco (Peñón de los Baños) about 20 days before and after,

respectively, the spring equinox.[56] Their inference about the importance of equinoxes is based on indirect data,[57] but it might be significant that the dates of sunrise over Cerro Tepetzinco are close to the sunset dates marked by the orientation of Phase II of the Templo Mayor.[58] Even if Cerro Tepetzinco, with its summit lying below the actual skyline, does not seem appropriate for exact astronomical observations, it may have had a symbolic influence on the location of the Templo Mayor of Tenochtitlan. We may recall the mythical significance of Tepetzinco, the place where Copil's head was deposited, as well as the argument of González Aparicio that this rocky outcrop had an important role in the urban planning of Tenochtitlan.[59]

Aveni *et al.*[60] find allusions to the observation of the sun relative to the mountains in the myth about the founding of Tenochtitlan, as narrated by Alvarado Tezozómoc in his *Crónica Mexicáyotl*. They comment that the scene with the eagle perched on top of a cactus was seen, according to the story, from far away and that the eagle, identical to Huitzilopochtli, must refer to the sun, probably the rising sun. Since the myth also mentions that the Mexica recognized the site prophesied by Huitzilopochtli when they saw rocks and caves to the east and north, Aveni *et al.* conclude that the founding of Tenochtitlan must have been related to the observation of sunrise at a position where relevant alignments to the east and to the north intersected. If the story reflects the importance of the mountains to the east as calendrical markers, the reference to the elevation to the north might be associated with the Guadalupe mountain range and its highest peak, Cerro Cuauhtepec, currently also known as Pico Tres Padres;[61] on the other hand, the text might refer to Cerro Chiquihuite, which for an observer at the Templo Mayor marks the direction to the astronomical north.[62]

Ponce de León[63] mentions another alignment that may have been involved in considerations about the placement of the Templo Mayor of Tenochtitlan: the western extension of the solstitial axis of the pyramid and urban layout of Cholula crosses Cerro Tehuicocone, in the mountain ridge north of Iztaccíhuatl, and reaches the sacred precinct of Tenochtitlan. While Cholula is not visible from the Templo Mayor, the alignment to Cerro Tehuicocone may not be fortuitous: though little prominent, the peak marked winter solstice sunrises.[64]

In his attempt to reconstruct the observational calendar of the Templo Mayor, Drucker suggests that at both Teotihuacan and Tenochtitlan observational schemes composed of 20-day periods were in use, with a "core interval" of 180 days, from September 22 to March 20. Drucker calculates that the Templo Mayor azimuth of 97°06′ (measured by Aveni) corresponded in the mid-fourteenth century to sunrises on March 1 and October 12, and to sunsets on April 8 and September 2, and concludes that these dates, except April 8, represent initial days of three of the 20-day periods composing his observational calendar scheme.[65] Drucker's hypotheses must be rejected because, in the first place, his calculation procedures are erroneous.[66] Therefore, the dates he determines do not correspond to the azimuth of 97°06′ and, even less so, to the azimuths of 97°42′ and 95°36′, which actually represent the orientations of the Templo Mayor (Table 1). Furthermore, to my knowledge there is no unequivocal evidence ascribing a special importance to the dates September 22 and March 20, central dates of Drucker's scheme.

Galindo[67] remarks that, according to Sahagún, the feast of Yoaltecuhtli was celebrated in the sign called Nahui Ollin, which was the day 203 of the count of *tonalamatl*. Considering that Sahagún places the beginning of the prehispanic year on February 2, or February 12 in the present calendar, Galindo observes that the day 203 of the calendar falls exactly on September 2, the day when the sun set in the axis of the Templo Mayor. It must be pointed out, in the first place, that the number "203" represents an inadequate translation of the Nahuatl term used in the *Florentine codex*. Anderson and Dibble corrected the error in their second edition of the work: the text relates simply that the feast was celebrated every *260* days,[68] without mentioning any relationship with the beginning of the calendrical 365-day year. Furthermore, the date September 2 referred to by Galindo is based on the azimuth of 97°25′ determined by Ponce de León[69] for the late phases of the Templo Mayor; as I have argued above, this azimuth approximately corresponds to Phase II, while the superimposed buildings — including Phase VII, i.e. the temple seen by Spanish conquerors — had a different orientation.[70] Likewise, the day March 4 associated by Galindo[71] with sunrises in the axis of the Templo Mayor and with the first day of the month of Tlacaxipehualiztli, according to Sahagún's correlation, corresponds to the azimuth 97°25′ and, therefore, could not be recorded by the orientation of the Templo Mayor at the time of the Conquest.

Galindo[72] also refers to the dates March 27 and December 12 mentioned by Durán and associates the first one with the sunset behind Cerro La Malinche; in Durán's scheme, the two dates correspond to the days 4 Ollin of *tonalpohualli*. However, beside the fact that the coincidence of a certain date of *tonalpohualli* with one and the same date of the tropical year, recurring only at 42-year intervals,[73] can hardly be considered as relevant for explaining the significance of the alignments, it should be recalled that the calendar of Durán is fictitious — or a "model calendar" — because its indigenous year starts arbitrarily with 1 Cipactli and 1 Cuahuitlehua (Atlcahualo), corresponding to March 1 of the Julian calendar.[74]

The Orientation of the Templo Mayor and the Comment of Motolinía

Finally, let us examine the hypotheses that have been put forward with respect to the famous statement of Fray Toribio de Motolinía, that the feast of Tlacaxipehualiztli "fell when the sun was in the middle of *Uchilobos*, which was the equinox".[75] The text, evidently referring to the Templo Mayor of Tenochtitlan, owes its importance to the fact that it seems to be the only documentary reference relating a Mesoamerican temple with astronomical observations. No wonder, then, that there have been various attempts at reconciling Motolinía's comment with the archaeologically attested layout of the Templo Mayor.

Aveni and Gibbs,[76] finding that the temple's orientation does not correspond to the equinox sunrises on the natural horizon, suggested that the observations of the equinoctial sun could have been made at the Temple of Quetzalcoatl, situated, according to some sources, west of the Templo Mayor: due to the height of the latter, the sun would have appeared in the notch between the twin sanctuaries only after having moved considerably southwards on its oblique daily path, and reaching the azimuth corresponding to the orientation of the Templo Mayor.[77]

Aveni, Calnek and Hartung[78] further elaborated the hypothesis, taking into account the most recent archaeological data. They proposed that the Mexica laid out their earliest temple structures in the east–west direction, i.e. to the equinox sunrise, but as the altitude of the successive superimposed buildings was growing, they skewed the orientation to the south, so that the equinoctial sun could be observed along the passageway between the upper sanctuaries from some point located in front of the building and along its extended axis. According to Aveni *et al.*, "the general conformity of the alignments of the later phases, however, may be taken to imply either that the differences of linear height between observer and sun disk were always kept constant in the engineering problem, or that the desire to preserve the equinox orientation, once established, simply was abandoned".[79]

Tichy[80] argues that the hypothesis forwarded by Aveni *et al.* is unlikely and that the orientation of the structure must be explored relative to the sun's positions on the horizon. Even if the possibility that some prehispanic structures contained oblique alignments, referring to astronomically significant positions at considerable altitudes, cannot be discarded, the azimuthal distribution patterns exhibited by Mesoamerican architectural orientations indicate that the latter, indeed, recorded astronomical phenomena on the horizon.[81]

Quoting Motolinía's comment about the coincidence of the feast of Tlacaxipehualiztli with the equinox, Aveni *et al.*[82] mention that the month of Tlacaxipehualiztli began, in Sahagún's correlation, on March 4 of the Gregorian calendar, so that the feast, usually celebrated at the end of the month, would have occurred about March 23, very close to the equinox. Sahagún's correlation, which makes the first day of Tlacaxipehualiztli occur on March 4, Gregorian, is based on information compiled in his time[83] and thus cannot be relevant for interpreting Motolinía's statement, which refers to an astronomical phenomenon related to the Templo Mayor: even if the structure was not destroyed immediately, its ritual and astronomical function did not survive beyond the Conquest. Furthermore, Motolinía says that, when the Spaniards conquered the land, the natives of the New Spain started their year at the beginning of March, the first month being Tlacaxipehualiztli, while Sahagún affirms that the indigenous year began in early February with the month Atlcahualo,[84] so that the first day of the following month Tlacaxipehualiztli, although it coincided with March 4, Gregorian, fell in *February* of the Julian calendar, as Aveni *et al.* also observe.[85] This means that, if we rely on Sahagún's correlation and, at the same time, accept as correct Motolinía's statement about the feast of Tlacaxipehualiztli (last day of the month) falling on or near the equinox, we are forced to reject as false the information given by the same Motolinía about the beginning of the month Tlacaxipehualiztli in March, which seems arbitrary. As can be seen immediately, Motolinía's data quoted above are internally coherent[86] and, moreover, perfectly congruent with the orientation that has been determined for the late phases of the Templo Mayor (Table 1).

Both Motolinía's comment and the drawing of the Templo Mayor in the map of Tenochtitlan attributed to Cortés have been interpreted as references to the observation of *sunrises* between the twin sanctuaries.[87] In fact, Motolinía's text,[88] having it that the feast of Tlacaxipehualiztli "fell when the sun was in the middle of *Uchilobos*", is not explicit and may well refer to the *sunset* in the axis of the building.[89] Indeed, in 1519 the last day of Tlacaxipehualiztli fell, according to the correlation established by Caso,[90] on March 25 of the Julian calendar, equivalent to April 4 of the Gregorian calendar, which was precisely *the date of sunset along the axis of the late stages of the Templo Mayor*. Consequently, Motolinía's statement can be understood as a reference to the sunset in the structure's axis on the specified date. This interpretation agrees not only with Caso's correlation and his argument,[91] based on various sources and supported by Prem,[92] that the main feast of every month was celebrated on its last day, but also with the comment of Motolinía[93] himself that the last day of the month was "solemn and very festive among them".

Even the fact that Motolinía correlates the feast of Tlacaxipehualiztli with the equinox is only apparently contradictory. As mentioned above, in the Julian calendar, which was in use in Motolinía's times (until the Gregorian reform, adopted in Mexico in 1583[94]), the feast (and the sunset in the axis of the Templo Mayor) fell in 1519 on March 25; the friar's information becomes entirely understandable and accurate, if we recall that this day, the Feast of the Annunciation on which Jesus Christ's conception was celebrated, was in the Middle Ages commonly identified with the vernal equinox.[95] It seems, then, that Motolinía did not refer to the astronomical equinox but rather only made note of the correlation between the day of the Mexica festival, which in the last years before the Conquest coincided with the solar event in the Templo Mayor, and the date in the Christian calendar that corresponded to the traditional day of spring equinox.

Considering that the offerings found at the Templo Mayor and other types of data reflect the enormous importance of the ceremonies carried out in Tlacaxipehualiztli,[96] it is not impossible that the temple's orientation had some relationship with this month, though the correspondence was more symbolic than calendrically precise and stable. It can be pointed out that the date of the spring sunset recorded by the late orientation of the Templo Mayor (April 4, Gregorian) fell on a day within the month Tlacaxipehualiztli during a period of some 80 years; even if it may be fortuitous, it is nonetheless a fact that the date of sunset in the axis of the Templo Mayor coincided with the first day of Tlacaxipehualiztli in the late forties of the fifteenth century, i.e. precisely in the period of Itzcóatl, the ruler responsible of the construction of Phase III,[97] which is the first one that has the new orientation. In this context it seems significant that, according to the written sources, the ceremonies of consecration of the *Huey Teocalli*, intertwined with the Tlacaxipehualiztli rites, acquired importance during the reign of Motecuhzoma Ilhuicamina (1440–69), Itzcóatl's immediate successor on the Mexica throne.[98]

Possible Observational Techniques

It seems fairly certain that the Templo Mayor, like other architectural orientations in central Mexico, recorded astronomical phenomena on the horizon, but we can only speculate about the possible observational methods. The sunrises may have been observed along the passageway between the twin sanctuaries (Figure 2), as the drawing in the early colonial map of Tenochtitlan suggests.[99] In this case the dates corresponding to the orientation could have been determined with ease and better precision if the observations were made from a distant point. Moreover, if the observation point was at the natural ground level, it necessarily had to be located relatively far from the temple: as the height of the latter was growing (by each superimposed building), the distance had to increase.[100] If the observations were carried out from the upper part of a building situated along the axis of the Templo Mayor, the distance could have been smaller. For the moment, however, we have no evidence suggesting the location of the eventual observing point.

On the other hand, it is worth noting some architectural elements of Phase II that may have allowed observations of the sun or light-and-shadow effects in the upper sanctuaries. Recalling Hartung's suggestion, based on illustrations in some codices, that astronomical observations could have been carried out from the interior of the temples,[101] I measured the imaginary line connecting the centre of the sacrificial stone, found *in situ* in front of the sanctuary of Huitzilopochtli, and the centre of the small rectangular pedestal built upon the bench abutted to the interior east wall (Figure 4). The alignment does not seem to be astronomically significant, because the corresponding azimuth, 99°37′, coincides with none of the others that have been measured in the building.[102]

Between the jambs of the entrance to the sanctuary of Tlaloc and two abutted pillars there are vertical slits that could have facilitated the observation of solar rays projected upon the interior east wall of the chapel on certain dates, a few moments before the sunset. To the idea expressed by Hartung,[103] that the temples' jambs possibly incorporated astronomical alignments, it can be added that the sufficiently narrow slits, allowing the passage of solar rays on certain dates only, certainly could have served as very appropriate devices for precise astronomical and calendrical observations. However, the slits of the Tlaloc sanctuary would not have allowed high accuracy, because each of the two, defined by rather irregular wall faces, is approximately 1.20m long and between 2cm and 5cm wide. The observational hypothesis is further weakened by the fact that the two slits, one to the north and the other to the south of the entrance (Figure 2), have very divergent azimuths (94°35′ ± 30′ and 98° ± 30′, respectively).

The adjacent Huitzilopochtli's sanctuary has no comparable masonry pillars abutted to the jambs but rather two low walls, which flank the access to the inner sanctum (Figure 4). Vestiges of stucco, framing rectangular spaces upon the two walls, as well as remains of wood found on both of them during excavations, indicate that wooden pillars were placed on top of the low walls and abutted to

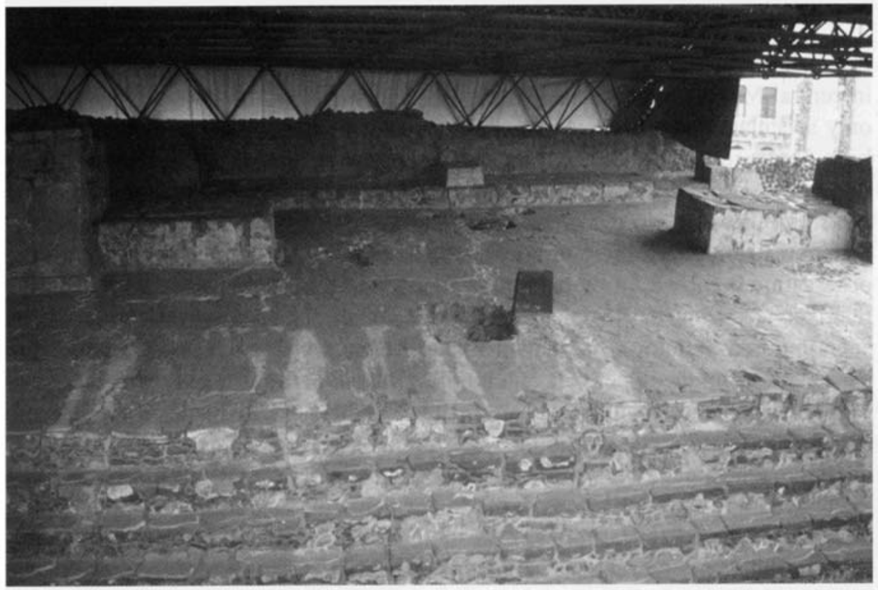

FIG. 4. Sanctuary of Huitzilpochtli on the upper platform of Phase II of the Templo Mayor of Tenochtitlan (view to the east).

the jambs of this sanctuary.[104] It seems significant that the jamb faces are much smoother and more parallel to each other than those of the Tlaloc sanctuary: the azimuths of north and south jambs are 98°48′ ± 30′ and 97°40′ ± 30′, respectively. It should be pointed out, however, that the measured lines are, again, short[105] and that the original azimuths cannot be accurately determined, because their exact values depend on the thickness of the stucco that covered the jambs and which is preserved in fragments. Moreover, the surfaces without stucco on the jambs are of roughly the same width as those on the abutted walls, suggesting that the two wooden pillars were not separated from the jambs.[106] In other words, the idea that slits, comparable to those of the adjacent Tlaloc shrine, existed between the jambs and wooden pillars of Huitzilopochtli's sanctuary must remain, in the light of the currently available evidence, merely a speculation.

Since the alignments discussed differ notably, the corresponding sunset dates would have fallen several days before and after those listed in Table 1 and recorded by the azimuth of the passageway between the twin sanctuaries. Even if the possibility that certain alignments were astronomically significant and intentional cannot be discarded, it would be too venturous to speculate along these lines, because some of the measured azimuths may differ from the original ones, both because it is impossible to reconstruct the original thickness of the stucco layers and because of possible measurement errors arising from the shortness of the lines. Furthermore, no alignments of this type that could serve as comparative data are preserved in other sites.

It is not impossible, of course, that the sanctuaries originally had some architectural elements, now lost, that permitted the observation of the projection of the sun's rays on relevant dates (e.g. openings, such as those of the Temple of the Seven Dolls at Dzibilchaltún, Yucatán[107]). If light-and-shadow effects were observed in the west-facing sanctuaries of the Templo Mayor at sunset, we can suppose that some adjacent buildings, sharing the same orientation but facing east (like Structures C and F, contemporary with the late phases of the Templo Mayor; see above) may have served for observing this type of phenomena in the morning, when the sun rose in the axis of the Templo Mayor.

To conclude this discussion on possible observational practices, let us return, once more, to the quoted statement of Motolinía. Commenting upon the feast of Tlacaxipehualiztli and the associated solar phenomenon at the Temple of Huitzilopochtli, the author adds that the building was a little twisted, and that "*Mutizuma* wanted to tear it down and set it straight".[108] The remark, brief and apparently insignificant, reveals nothing about the observational methods employed, but it does suggest that the orientation of the temple was not merely symbolic but also functional. Considering that the mean east–west azimuths of the late phases do not exhibit significant differences (*vide supra*), the referred imprecision could not be large; if in spite of that it was detected and, moreover, became a matter of concern of the supreme Mexica lord, it seems obvious that the observations were made continuously and that the function of certain structural elements was to mark astronomically relevant alignments with precision. Why was the building twisted? Aveni *et al.*[109] consider that the skew may have been a consequence of the difficulties the architects had to face, as they wished to preserve the equinoctial alignment in different building stages, each one with a greater height (*cf. supra*). Another possible explanation is related with the phenomenon whose effects have been analysed above: the archaeological evidence indicates that settlements represented a serious problem already for the Mexica builders, forcing them continuously to strengthen, correct and re-level their temples.[110] As I have argued, the settlements were accompanied by slight movements of the alignments in the horizontal plane; could not it be that this was the cause of the imperfection that Fr Motolinía alludes to?

Final Remarks

In the light of comparative evidence from other central Mexican archaeological sites,[111] it can be concluded that the Templo Mayor of Tenochtitlan was constructed on a spot that was deliberately chosen, with the purpose of employing some prominent peaks on the local horizon as natural markers of the sun's position on certain culturally relevant dates of the tropical year, whereas the architectural orientations were laid out to pinpoint dates that were in a meaningful relation to those marked by the horizon features. The observational schemes were composed of calendrically significant and, therefore, easily manageable intervals. It is more than likely that observational calendars had practical uses, allowing an efficient scheduling of agricultural and associated ritual activities in the annual cycle. While some dates recorded by the alignments probably marked crucial moments of a canonic or ritualized agricultural cycle, others must have had 'auxiliary' functions. Since the intervals that separated them were multiples of basic periods of the calendrical system, it was relatively easy to predict the most important dates, knowing the sequence of the intervals involved and the mechanics of the calendar: it should be recalled that the days separated by multiples of 13 days had the same *trecena* numeral, whereas the phenomena separated by multiples of 20 days occurred on the dates that had the same *veintena* sign of the 260-day count. This anticipatory aspect of observational calendars must have been of major significance. Important dates, supposing they were related to subsistence activities, had to be announced ahead of time, because the ceremonies officially inaugurating certain stages of agricultural cycle had to be prepared with due anticipation; on the other hand, direct observations on relevant dates may have been obstructed by cloudy weather.[112] Notwithstanding, it should be recalled that astronomical alignments at the Templo Mayor of Tenochtitlan, as well as at other Mesoamerican sites, are associated with the most important civic and ceremonial buildings, obviously revealing that astronomical practices had a paramount role in social, religious and even political life of prehispanic societies.

APPENDIX: POSSIBLE HORIZONTAL SKEWS RESULTING FROM SETTLEMENTS OF PHASE II OF THE TEMPLO MAYOR OF TENOCHTITLAN

The southeast corner of the strongly tilted second structural stage of the Templo Mayor of Tenochtitlan is, at present, its most elevated part. By measuring relative heights of various points on the upper platform, I was able to determine the approximate inclination angles along the north–south and east–west axes of the structure, and to calculate, on these grounds, the magnitude of probable horizontal movements caused by settlements. Though the ground surface supporting the architectural masses of the Templo Mayor is estimated to have undergone settlements of up to 11m,[113] it can be assumed, for the purpose of this calculation, that only west and north parts of the structure subsided. The situation is shown schematically in Figures 5 and 6.

The rectangle outlined in each of these figures with a bold line represents the inclination of the base of Phase II, as observed nowadays, though intentionally exaggerated, in order to facilitate visualization of the movements and to illustrate the derivation of the expression for calculating the range of horizontal skews. We can imagine that the rectangle represents the base of the building, though it may also correspond to the upper platform or to whatever parallel section of the structure, considering that uniform movements that characterize the behaviour of rigid bodies will be assumed. Ideally, the movements that have resulted in the extant inclination of the structure can be separated in two components: those having a horizontal

rotation axis in the north–south direction provoked a greater settlement of the west part, whereas the north part of the structure subsided as a result of the movements around an east–west horizontal rotation axis. The exact location of the axes around which the structure really rotated is irrelevant for the calculation, because the developed expression involves only the inclination angles, which are in any case equal. Supposing these horizontal axes were always placed along the east and south sides of the building's base, two ideal sequences of settlements can be reconstructed.

The first case is illustrated in Figure 5. If the structure first suffered a settlement of its west part (i.e. rotation around the eastern axis) and later of its north part (rotation around the southern axis), we can observe that the north–south azimuths remain equal, while the east–west azimuths diminish to an extent depending on inclination angles (Figures 5(a) and (d)): if the building inclined first by a vertical angle α in the east–west direction and, afterwards, by a vertical angle β in the north–south direction (Figure 5(a)), the azimuths of the east–west lines decreased by a horizontal angle γ (Figure 5(d)). Figure 5(b) shows that

$$x/a = \cos\alpha, \text{ and so } x = a\cos\alpha, \tag{1}$$

and

$$z/a = \sin\alpha, \text{ and so } z = a\sin\alpha, \tag{2}$$

while Figure 5(c) implies that

$$y/z = \sin\beta, \text{ and so } y = z\sin\beta. \tag{3}$$

Eliminating z between (2) and (3), we have

$$y = a\sin\alpha\sin\beta. \tag{4}$$

Since from Figure 5(d) it follows that

$$\tan\gamma = y/x,$$

we have

$$\tan\gamma = (a\sin\alpha\sin\beta)/(a\cos\alpha) = \tan\alpha\sin\beta. \tag{5}$$

The angle γ represents the decrease in the azimuths of east–west lines, if the movements that provoked the inclination of the body occurred as shown in Figure 5(a).

The effects of the inverted sequence of movements are illustrated in Figure 6: if we consider that the first movement, provoking the settlement of the north part, occurred around the south axis and was followed by one around the east axis, resulting in subsidence of the west part of the structure (Figure 6(a)), we can observe that the north–south azimuths increased, while the east–west azimuths remained equal (Figure 6(b)). The increase of the north–south azimuths can be calculated by the same Equation (5), interchanging the values of α and β.

It should be emphasised that these are, of course, two *ideal* sequences of movements. There is no doubt that Phase II of the Templo Mayor subsided gradually; however, particular moving sequences must have been comparable to those described, having combined effects that resulted in the skew of *all* horizontal alignments within the ranges that can be calculated. Equation (5) allows the estimation of the *maximum* values of deviation in the horizontal plane of the lines incorporated into the structure. Since the maximum values of α and β, which define the inclination of the upper platform of Phase II, are approximately 8°30′ and

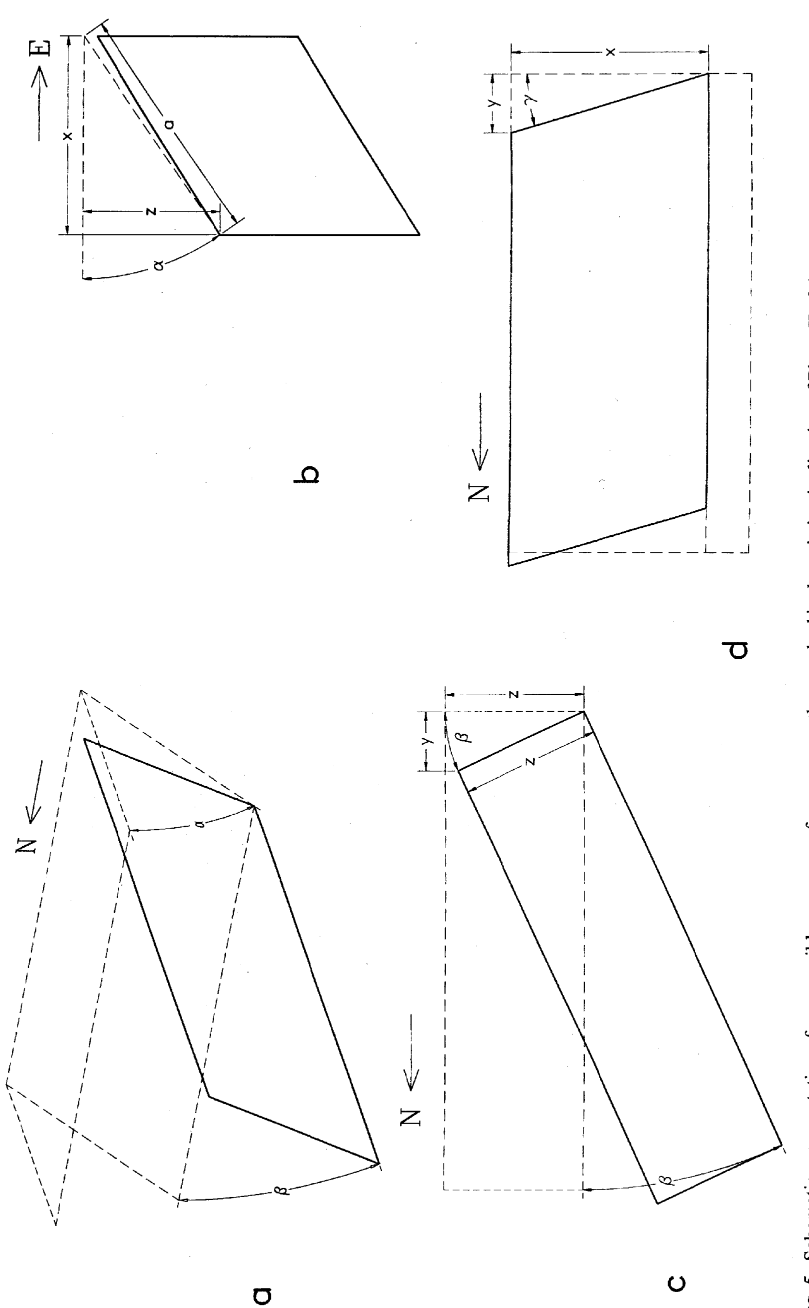

FIG. 5. Schematic representation of one possible sequence of movements that resulted in the existing inclination of Phase II of the Templo Mayor of Tenochtitlan: (a) perspective view to the northeast; (b) side view to the north; (c) side view to the east; (d) plan.

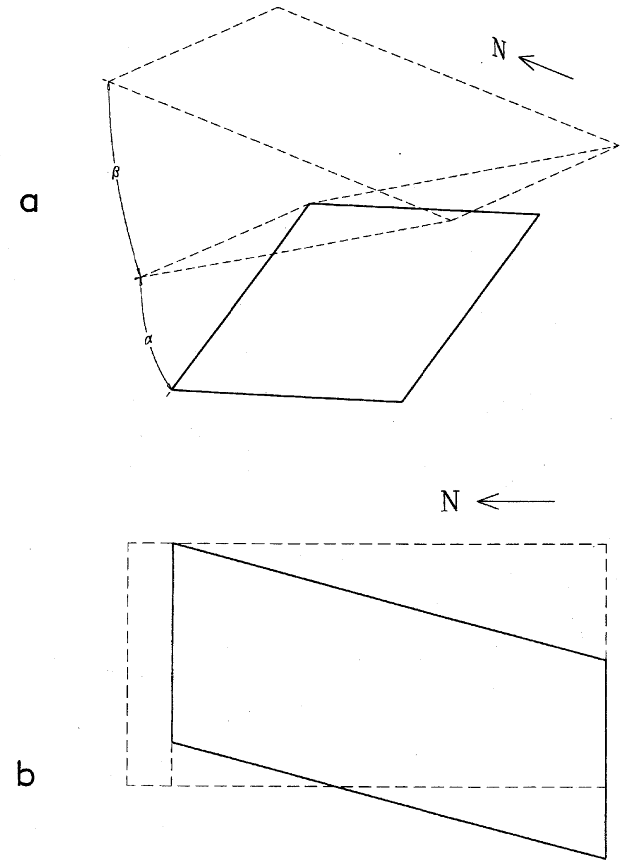

FIG. 6. Schematic representation of another possible sequence of movements that resulted in the existing inclination of Phase II of the Templo Mayor of Tenochtitlan (cf. Fig. 5): (a) perspective view to the northeast; (b) plan.

2°15′, respectively,[114] it follows that the east–west/north–south alignments may have suffered an azimuthal decrease/increase of up to approximately 20′. It should be reiterated that these are the maximum values calculated for one or the other group of alignments, and that gradual settlements with different sequences of the structure's movement may have resulted in slightly smaller azimuthal variations, though both in east–west and north–south alignments. Consequently, the mean correction value of 10′ considered for diminishing/increasing the existing north–south/east–west azimuths measured on Phase II of the Templo Mayor seems to be sufficiently realistic.

REFERENCES

1. Anthony F. Aveni, "Possible astronomical orientations in ancient Mesoamerica", in *Archaeoastronomy in pre-Columbian America*, ed. by A. F. Aveni (Austin and London, 1975), 163–90; *idem*, "Concepts of positional astronomy employed in ancient Mesoamerican architecture", in *Native American astronomy*, ed. by A. F. Aveni (Austin, 1977), 3–19; *idem*, *Skywatchers of ancient Mexico* (Austin, 1980); Anthony F. Aveni and Sharon L. Gibbs, "On the orientation of precolumbian buildings in central Mexico", *American antiquity*, xli (1976), 510–17; Anthony F. Aveni and Horst Hartung, *Maya city planning and the calendar* (*Transactions of the American Philosophical Society*, lxxvi/7; Philadelphia, 1986); Franz Tichy, *Die geordnete Welt indianischer Völker: Ein Bespiel von Raumordnung und Zeitordnung im vorkolumbischen Mexiko* (Das Mexiko-Projekt der Deutschen Forschungsgemeinschaft, 21; Stuttgart, 1991); Ivan Šprajc, "La astronomía en Mesoamérica", in *Historia antigua de México*, 2nd edn, vol. iv, ed. by L. Manzanilla and L. López Luján (Mexico City, in press).
2. Tichy, *op. cit.* (ref. 1).
3. E.g.: Arturo Ponce de León, *Fechamiento arqueoastronómico en el Altiplano de México* (Mexico City, 1982); A. F. Aveni, E. E. Calnek and H. Hartung, "Myth, environment, and the orientation of the Templo Mayor of Tenochtitlan", *American antiquity*, liii (1988), 287–309; Tichy, *op. cit.* (ref. 1), 159ff; Johanna Broda, "Astronomical knowledge, calendrics, and sacred geography in ancient Mesoamerica", in *Astronomies and cultures*, ed. by C. L. N. Ruggles and N. J. Saunders (Niwot, 1993), 253–95, pp. 258ff; Stanislaw Iwaniszewski, "Archaeology and archaeoastronomy of Mount Tlaloc, Mexico: A reconsideration", *Latin American antiquity*, v (1994), 158–76; Jesús Galindo Trejo, *Arqueoastronomía en la América antigua* (Mexico City, 1994), 129ff; Rubén B. Morante L., "Evidencias del conocimiento astronómico en Xochicalco, Morelos" (unpublished M.A. thesis, Mexico City, 1993); *idem*, "Evidencias del conocimiento astronómico en Teotihuacan" (unpublished Ph.D. dissertation, Mexico City, 1996).
4. The detailed argument and the supporting evidence are exhaustively presented in: Ivan Šprajc, "Orientaciones en la arquitectura prehispánica del México central: Aspectos de la geografía sagrada en Mesoamérica" (unpublished Ph.D. dissertation, Mexico City, 1997).
5. Tichy, *op. cit.* (ref. 1).
6. Šprajc, "Orientaciones" (ref. 4), 39ff, 70ff.
7. This altitude above the sea level was reconstructed by Luis González Aparicio, *Plano reconstructivo de la región de Tenochtitlan* (Mexico City, 1973), 17ff, for the level of the lake of Texcoco in prehispanic times; it is thus probable that it approximately corresponds also to the level of the ground on which each of the successive structural phases of the Templo Mayor was built, even if nowadays they are situated at lower and differing altitudes, due to settlements in the marshy subsoil.
8. Constanza Vega Sosa, "La cronología relativa de México-Tenochtitlan", *Mexicon*, xii (1990), 9–14; Leonardo López Luján, personal comm. (May 1997).
9. Leonardo López Luján, *Las ofrendas del Templo Mayor de Tenochtitlan* (Mexico City, 1993), 73–77, Fig. 14.
10. For research history and bibliography, see *ibid.*, 19ff.
11. Ignacio Marquina, *El Templo Mayor de México* (Mexico City, 1960); *idem*, *Arquitectura prehispánica*, 2nd edn (Mexico City, 1964; 1st edn. 1950), 180–204; Eduardo Matos Moctezuma, *Una visita al Templo Mayor de Tenochtitlan* (Mexico City, 1981); *idem* (ed.), *El Templo Mayor: Excavaciones y estudios* (Mexico City, 1982); *idem*, "Los edificios aledaños al Templo Mayor", *Estudios de cultura náhuatl*, xvii (1984), 15–21; *idem*, *The Great Temple of the Aztecs: Treasures of Tenochtitlan* (London, 1988); J. Broda, D. Carrasco and E. Matos Moctezuma, *The Great Temple of Tenochtitlan: Center and periphery in the Aztec world* (Berkeley, Los Angeles and London, 1987); Elizabeth Hill Boone (ed.), *The Aztec Templo Mayor* (Washington, 1987); López Luján, *Las ofrendas del Templo Mayor* (ref. 9).
12. The refraction factors used in these calculations (taken from: Gerald Hawkins, "Astro-archaeology", *Vistas in astronomy*, x (1968), 45–88, p. 52, Table 1; A. Thom, *Megalithic lunar observatories* (Oxford, 1971), 28ff, Table 3.1; Aveni, *Skywatchers* (ref. 1), 128) were corrected for the altitude above the sea level, employing Formula (7) of Hawkins (*op. cit.*, 53).
13. The dates are given in the (proleptic) Gregorian calendar, which provides the closest approximation to the tropical year. Due to precessional variations in the obliquity of the ecliptic, on the one hand, and in the heliocentric longitude of the perihelion of the Earth's orbit, on the other (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 (Gregorian) year. The dates in Table 1 have been determined on the basis of the sun's positions given in the tables of Bryant Tuckerman, *Planetary, lunar, and solar positions: A.D. 2 to A.D. 1649* (Philadelphia, 1964) (the procedure is described in detail in: Šprajc, "Orientaciones" (ref. 4), 30f); the dates corresponding to Phase II and to later phases are valid for the fourteenth and fifteenth centuries, respectively.
14. *Cf.* Marquina, *El Templo Mayor* (ref. 11), 30, 113, Fig. 1; *idem*, *Arquitectura prehispánica* (ref. 11), 183, Fig. 6 bis; Aveni and Gibbs, *op. cit.* (ref. 1), 514, Fig. 3; Matos, *The Great Temple* (ref. 11), 146, Fig. 115.
15. Marcos Mazari, Raúl J. Marsal and Jesús Alberro, "Los asentamientos del Templo Mayor analizados por la mecánica de suelos", *Estudios de cultura náhuatl*, xix (1989), 145–82; Marcos Mazari M., *La Isla de los Perros (con un apéndice)* (Mexico City, 1996).
16. I am grateful to Leonardo López Luján for his help in these measurements, as well as in other works I carried out at the Templo Mayor. I also wish to thank Eduardo Matos Moctezuma, director of the Museo del Templo Mayor, who kindly authorized all the measurements I made on various occasions at this archaeological site.
17. Aveni, Calnek and Hartung, *op. cit.* (ref. 3), 296; Ponce de León, *op. cit.* (ref. 3), 54.
18. Ponce de León, *op. cit.* (ref. 3), 54ff, Plates 12 and 13.
19. *Cf. ibid.*, Plates 12 and 13.
20. The alignment described and measured by Ponce de León would correspond to the one originally incorporated into the passageway only if the existing inclination of the structure were the result of two successive rotations only: the first around a north–south axis and the second around an east–west axis. There is no doubt, however, that the movements were gradual and in different directions; after the first subsidence of the northern part of the building, any subsequent settling of its western part — the structure rotating around a horizontal north–south axis — increased the azimuth of all of the east–west lines projected to the horizontal plane along the planes perpendicular to the base (already inclined) of the structure. Considering that the tilt of the building is particularly pronounced in the east–west direction, it is highly probable that the azimuth of the virtual axis measured by Ponce de León exceeds the original azimuth of the passageway.
21. I am indebted to José Guadalupe Orta B. and Pascual Medina M., topographers of the Dirección de Registro Público de Monumentos y Zonas Arqueológicos, INAH, Mexico, who kindly helped me in these measurements, carried out with a total station and GPS receivers.
22. Mazari, Marsal and Alberro, *op. cit.* (ref. 15), 169f; López Luján, *Las ofrendas del Templo Mayor* (ref. 9), 70; E. Ovando-Shelley and L. Manzanilla, "An archaeological interpretation of geotechnical soundings under the Metropolitan Cathedral, Mexico City", *Archaeometry*, xxxix (1997), 221–35, pp. 224f.
23. Ponce de León, *op. cit.* (ref. 3), 31, 56f, Pl. 13.
24. Marquina, *Arquitectura prehispánica* (ref. 11), 168, Plates 49 and 50; Šprajc, "Orientaciones" (ref. 4), 230ff, Fig. 5.16.
25. Aveni *et al.*, *op. cit.* (ref. 3), 294, Table 2.
26. *Ibid.*, 295.
27. The mean value 95°36′ given in Table 1 has been calculated on the basis of the mean east–west azimuths of Phases III, IV, IVb and VI; because on Phase V only the south face could be

measured (*cf.* Fig. 3), its azimuth has not been taken into account in this calculation.

The azimuth 97°06′ obtained by Aveni (*Skywatchers* (ref. 1), 314; Aveni and Gibbs, *op. cit.* (ref. 1), 512, Table 1) was not measured on Phase VII (Aveni *et al.*, *op. cit.* (ref. 3), 294) but rather at the southwest extreme of Phase IV, which had been exposed before the extensive excavations directed by Eduardo Matos Moctezuma began in the area (Leonardo López Luján: personal comm., June 1997). The azimuth exceeds considerably the mean given in Table 1, most probably because it was measured along a relatively short section of the south face's west part: due to differential settlements, the preserved faces or *taludes* are nowadays slightly convex; moreover, the azimuths of the south faces are consistently greater than those of the north faces (see Fig. 3).

28. Matos, *Una visita* (ref. 11), 37, 41; *idem*, "Los edificios aledaños al Templo Mayor" (ref. 11); López Luján, *Las ofrendas del Templo Mayor* (ref. 9), 78ff.
29. *Cf.* Ponce de León, *op. cit.* (ref. 3), 30f, Photo 7; Aveni *et al.*, *op. cit.* (ref. 3), 303.
30. E.g. Marquina, *Arquitectura prehispánica* (ref. 11), 185, Plate 54; Alejandro Villalobos Pérez, "Consideraciones sobre un plano reconstructivo del recinto sagrado de México-Tenochtitlan", *Cuadernos de arquitectura mesoamericana*, no. 4 (1985), 57–63, p. 62, Fig. 5.
31. Constanza Vega Sosa, "El Templo del Sol, su relación con el glifo chalchíhuitl; el Templo de Ehécatl-Quetzalcóatl", in *El recinto sagrado de México-Tenochtitlan: Excavaciones 1968–69 y 1975–76*, ed. by C. Vega Sosa (Mexico City, 1979), 75–86, Plan 1. These skews have been corroborated by recent explorations (Alvaro Barrera: personal comm., May 1997).
32. For example, the azimuth of Calle Guatemala is approximately 97°20′, whereas the streets Tacuba and Donceles have azimuths around 98°10′ (*cf.* similar values in Aveni *et al.*, *op. cit.* (ref. 3), 296, Table 3).
33. George Kubler, *Mexican architecture of the sixteenth century* (Westport, Conn., 1972; 1st edn, 1948), 102, mentions that Mexico City still reveals the form of the Aztec capital and that many central streets follow the pattern of prehispanic canals. In fact, the archaeological information about the course of prehispanic avenues in the immediate vicinity of the Templo Mayor is lacking, so that we do not know for sure whether parts of urban layout of Tenochtitlan are, indeed, preserved in modern streets (and, if so, to what extent and how accurately). To give a concrete example, some archaeological data support the opinion first expressed by Marquina (*El Templo Mayor* (ref. 11), 32) that the modern street of Tacuba, assumed to be a survival of the easternmost part of the causeway to Tlacopan, actually runs a trifle south of the latter: Margarita Carballal: personal comm., June 1997; Margarita Carballal Staedtler and María Flores Hernández, "Las *calzadas* prehispánicas de la *Isla de México*: Algunas consideraciones acerca de sus funciones", *Arqueología: Revista de la Dirección de Arqueología del INAH*, 2a época, no. 1 (1989), 71–80, p. 76.
34. Matos, *The Great Temple* (ref. 11), 73; López Luján, *Las ofrendas del Templo Mayor* (ref. 9), 73ff, Fig. 14.
35. Vega Sosa, "El Templo del Sol" (ref. 31), Plan 1.
36. It must be pointed out that here we are dealing with the structures excavated in the area of the cathedral, because the same letters were assigned to other buildings in the immediate neighbourhood of the Templo Mayor.
37. Vega Sosa, "La cronología relativa de México-Tenochtitlan" (ref. 8), 13f.
38. Šprajc, "Orientaciones" (ref. 4).
39. The data on the rest of the prominent features on the horizon of the Templo Mayor are given in Šprajc, "Orientaciones" (ref. 4), 305f, Tables 5.4.20.2 and 5.4.20.3. As for the methodological criteria employed for the selection of the horizon features considered in my comparative analyses, see *ibid.*, 16f. The dates in the last column of Table 2 are valid for the fourteenth century (*cf. supra*: ref. 13), because it was probably at that time that the place for the construction of the Templo Mayor was selected.
40. Šprajc, "Orientaciones" (ref. 4), 74ff.

41. *Cf. ibid.*, 27, 94ff.
42. The dates listed in Table 3 are those on which the sun's declination at sunrise was equal or closest to 14°40′, required for the centre of solar disk to be aligned with Cerro Tlamacas (*cf.* Table 2), while on the dates in Table 4 the declination of the sun was closer or equal to 14°45′, necessary for the alignment of the mountain top with the sun's lower limb.
43. It may be worth noting that the interval from 1343 August 14/13 to 1344 April 29, in Tables 3 and 4, is 259/260 days, because 1344 was a leap year; in other years the interval between the same dates is one day shorter.
44. It should be pointed out that the four-year patterns of exact dates of solar phenomena (i.e. of certain declinations of the sun) exhibit gradual variations through time (of ±1 day) which derive from the system of intercalations used in the Gregorian calendar. However, the patterns of intervals remain constant during longer periods. In Tables 3 and 4 the dates for a 4-year span in the mid-fourteenth century are given, but the schemes of intervals would be practically identical if reconstructed for the thirteenth or fifteenth century. The dates registered by tangent positions of the sun would always tend to separate 260-day intervals. Even though the interval of 260 days, too, would sometimes inevitably diminish or increase for 1 day, the 'irregularities' of this kind would be much less frequent than in the scheme of the dates recorded by the centre of solar disk.
45. López Luján, *Las ofrendas del Templo Mayor* (ref. 9), 73ff.
46. Spanish terms *trecena* and *veintena* are commonly employed for basic 13-day and 20-day periods, respectively, of Mesoamerican calendar.
47. As shown in Appendix, the horizontal skew of the east–west lines could have reached the maximum value if the structure suffered, first, a major subsidence of its west part and, afterwards, minor settlements of the north part. Indeed, such sequence of movements is likely, considering that the most intensive settlements of the Templo Mayor seem to have been provoked by the weight of the stairways: *cf.* Mazari *et al.*, *op. cit.* (ref. 15), 168f, 178f; López Luján, *Las ofrendas del Templo Mayor* (ref. 9), 70.
48. The dates March 2 and April 10, separated by 39 days, could have been registered with an azimuth of approximately 98°05′, which is, however, hardly reconcilable with the argument concerning the probable effects of settlements, because it implies a horizontal skew of more than $\frac{1}{2}$° (recall that the existing azimuth of the passageway between the twin sanctuaries is 97°32′), whereas the results of calculations make values in excess of 20′ unlikely (see Appendix). Furthermore, the alignment of 98°05′ actually would not have provided a basis for an ideal observational calendar: since the date of sunset at the azimuth of 98°05′ would have been, in the late fourteenth century, invariably April 10, while the sunrises above Cerro Tlamacas ocurred on April 29 or 30, the interval between the two phenomena would have varied from 19 to 20 days; on the other hand, the sunrise above Cerro Tláloc, falling predominantly on March 14, would not have subdivided the 39-day span between the dates of sunrise and sunset in the axis of the structure in ideal intervals of 13 and 26 days.
49. The east–west lines of the northern half of the building have smaller azimuths than those of the southern half. However, since the alignments on each of the two halves do not tend to be parallel to each other (instead, the azimuths increase progressively from north to south, the extreme values being 94°08′ and 100°00′), it seems that this peculiarity of construction was not a result of the purpose of incorporating two different orientations into the same building. It may also be mentioned that the twin sanctuaries of Structure I of Teopanzolco, which is the only comparable case known at the moment, evidently share the same orientation.
50. This is the way the orientations of the Templo Mayor and the Calendrical Temple of Tlatelolco, on the one hand, and of Structures I and II of Teopanzolco, on the other, seem to have functioned: Šprajc, "Orientaciones" (ref. 4), 268ff, 291ff.
51. Significantly, the declinations (dates) corresponding to the orientation of the church of San Luis at Huexotla (Edo. de México), apparently built upon the ruins of the main temple of the prehispanic town, are almost identical: Šprajc, "Orientaciones" (ref. 4), 249.

52. Aveni *et al.*, *op. cit.* (ref. 3), 298ff; Johanna Broda, "Las fiestas aztecas de los dioses de la lluvia: Una reconstrucción según las fuentes del siglo XVI", *Revista española de antropología americana*, vi (1971), 245–327, pp. 277ff; *eadem*, "Cosmovisión y observación de la naturaleza: El ejemplo del culto de los cerros en Mesoamérica", in *Arqueoastronomía y etnoastronomía en Mesoamérica*, ed. by J. Broda, S. Iwaniszewski and L. Maupomé (Mexico City, 1991), 461–500, pp. 475f; *eadem*, "The sacred landscape of Aztec calendar festivals: Myth, nature, and society", in *To change place: Aztec ceremonial landscapes*, ed. by D. Carrasco (Niwot, 1991), 74–120, p. 95; Stanislaw Iwaniszewski, "La arqueología de alta montaña en México y su estado actual", *Estudios de cultura náhuatl*, xviii (1986), 249–73, pp. 256f, 260; *idem*, "Archaeology and archaeoastronomy of Mount Tlaloc" (ref. 3); Šprajc, "Orientaciones" (ref. 4), 255ff.
53. López Luján, *Las ofrendas del Templo Mayor* (ref. 9), 88ff; Ovando-Shelley and Manzanilla, *op. cit.* (ref. 22), 222. While vestiges of water springs have, indeed, been found in the area of the Templo Mayor ceremonial precinct (López Luján, *op. cit.*, 88f; Ovando-Shelley and Manzanilla, *op. cit.*, 222, 232), the allusions to caves and large rocks are not reconcilable with the geological and geomorphological lacustrine environment (Ovando-Shelley and Manzanilla, *ibid.*, 232f).
54. Mazari *et al.*, *op. cit.* (ref. 15), 155, 168, 177; Mazari, *op. cit.* (ref. 15), 11ff.
55. Aveni *et al.*, *op. cit.* (ref. 3).
56. *Ibid.*, 302; Anthony F. Aveni, "Mapping the ritual landscape: Debt payment to Tlaloc during the month of Atlcahualo", in *To change place: Aztec ceremonial landscapes*, ed. by D. Carrasco (Niwot, 1991), 58–73, p. 67.
57. Aveni *et al.*, *op. cit.* (ref. 3), 289f, 304f, 307.
58. *Ibid.*, 302; *cf.* Galindo, *Arqueoastronomía* (ref. 3), 166.
59. Aveni *et al.*, *op. cit.* (ref. 3), 292, 302; Broda, "The sacred landscape" (ref. 52), 86ff; González Aparicio, *op. cit.* (ref. 7), 47f, 53.
60. Aveni *et al.*, *op. cit.* (ref. 3), 292f.
61. *Ibid.*, 304. Aveni, "Mapping the ritual landscape" (ref. 56), 63, mentions various archaeological sites that seem to exemplify the symbolic importance of the mountain located to the north of a ceremonial centre. It may be added that the north–south axes of the structures examined at central Mexican archaeological sites align in more cases with a mountain to the north than to the south: Šprajc, "Orientaciones" (ref. 4), 38.
62. Ponce de León, *op. cit.* (ref. 3), 58.
63. *Ibid.*
64. Šprajc, "Orientaciones" (ref. 4), 313f.
65. R. David Drucker, "A solar orientation framework for Teotihuacan", in *Los procesos de cambio (en Mesoamérica y áreas circunvecinas): XV Mesa Redonda*, ii (Guanajuato, 1977), 277–84, pp. 281ff, Fig. 3.
66. To obtain the date corresponding to a certain declination of the sun in the past, Drucker (*ibid.*, 278) multiplies the present declination value with a constant derived from de Sitter's formula. However, the formula developed by de Sitter for calculating the obliquity of the ecliptic in any epoch (Thom, *op. cit.* (ref. 12), 15), while it makes possible to determine the maximum/minimum declinations of the sun (attained at solstices), is not sufficient for establishing the *exact dates* on which the sun, in a given period, had certain declinations, since the corresponding moments of the year depend not only on the obliquity of the ecliptic but also on the length of the seasons, which varies as a function of the secular movement of the perihelion–aphelion line of the Earth's orbit: *cf.* Šprajc, "Orientaciones" (ref. 4), 30f. Moreover, the declinations and dates determined by Drucker (*op. cit.*, 282) as corresponding to the azimuth 97°06′, allowing for the horizon altitude of 2°10′ (both for east and west), actually do not derive from the formula presented by himself (*ibid.*, 278).
67. Galindo Trejo, *Arqueoastronomía* (ref. 3), 166f.
68. Arthur J. O. Anderson and Charles E. Dibble, *Florentine Codex: General history of the things of New Spain: Fray Bernardino de Sahagún. Book 2 — The ceremonies*, 2nd edn, revised (Monographs of the School of American Research, no. 14, Part III; Santa Fe, 1981), 216. I am indebted to Leonardo López Luján and Alfredo López Austin for calling my attention to this fact.

69. Ponce de León, *op. cit.* (ref. 3), 31.
70. The orientation of Phase VII has not been determined directly by measurements, but the remains of this structure clearly show that it was erected on top of the former Phase VI, preserving its orientation: López Luján, *Las ofrendas del Templo Mayor* (ref. 9), 72, and personal comm., June 1997.
71. Galindo Trejo, *Arqueoastronomía* (ref. 3), 167.
72. *Ibid.*, 167.
73. Elzbieta Siarkiewicz, *El tiempo en el tonalámatl* (Warsaw, 1995), 94.
74. *Cf.* Hanns J. Prem, "Das Chronologieproblem in der autochthonen Tradition Zentralmexikos", *Zeitschrift für Ethnologie*, cviii (1983), Heft 1, 133–61, pp. 143ff, Table 3.
75. Fray Toribio de Benavente o Motolinía, *Memoriales o libro de las cosas de la Nueva España y de los naturales de ella*, ed. by E. O'Gorman (Mexico City, 1971), 51.
76. Aveni and Gibbs, *op. cit.* (ref. 1), 513ff.
77. *Ibid.*, 515, Fig. 4; Aveni, *Skywatchers* (ref. 1), 245ff, Fig. 81.
78. Aveni *et al.*, *op. cit.* (ref. 3), 294ff.
79. *Ibid.*, 297.
80. Tichy, *op. cit.* (ref. 1), 94.
81. Šprajc, "Orientaciones" (ref. 4), 9; *idem*, "La astronomía en Mesoamérica" (ref. 1).
82. Aveni *et al.*, *op. cit.* (ref. 3), 291.
83. Šprajc, "Orientaciones" (ref. 4), 106f. In fact, this correlation appears only in the *Florentine codex* and *Historia general*; in his other texts, Sahagún gives slightly different correlations: Renate Bartl, Barbara Göbel and Hanns J. Prem, "Los calendarios aztecas de Sahagún", *Estudios de cultura náhuatl*, xix (1989), 13–82.
84. Motolinía, *op. cit.* (ref. 75), 44f; Fray Bernardino de Sahagún, *Historia general de las cosas de Nueva España*, 6th edn (Mexico City, 1985), 77ff.
85. Aveni *et al.*, *op. cit.* (ref. 3), 291.
86. It should be clarified that the data relevant in the present context and quoted above are coherent, but apparently do not belong to the same author: Motolinía (*op. cit.* (ref. 75), 44f) himself mentions that the year began in March with the month of Tlacaxipehualiztli and that the feasts took place on the last day of each month, whereas the reference to the solar phenomenon in the Templo Mayor is part of an interpolation that does not pertain to the text of *Memoriales* (*ibid.*, 50).
87. *Cf.* A. Maudslay, "A note of the position and extent of the Great Temple", in *Trabajos arqueológicos en el centro de la Ciudad de México*, 2nd edn, ed. by E. Matos Moctezuma (Mexico City, 1990; orig. publ. in 1912), 269–72, p. 272; Aveni and Gibbs, *op. cit.* (ref. 1), 513; Aveni, *Skywatchers* (ref. 1), 248.
88. *Op. cit.* (ref. 75), 51.
89. The fact that Marquina, *El Templo Mayor* (ref. 11), 113, paraphrasing Motolinía, mentions the sun "in front of Huichilobos" shows clearly that the text is ambiguous.
90. Alfonso Caso, *Los calendarios prehispánicos* (Mexico City, 1967), 58, Table IV.
91. *Ibid.*, 39, 51.
92. Hanns J. Prem, "Los calendarios prehispánicos y sus correlaciones: Problemas históricos y técnicos", in *Arqueoastronomía y etnoastronomía en Mesoamérica*, ed. by J. Broda, S. Iwaniszewski and L. Maupomé (Mexico City, 1991), 389–411, p. 395.
93. *Op. cit.* (ref. 75), 45.
94. Caso, *op. cit.* (ref. 90), 98f.
95. Robert R. Newton, *Medieval chronicles and the rotation of the Earth* (Baltimore and London, 1972), 27; Stephen C. McCluskey, "The mid-quarter days and the historical survival of British

folk astronomy", *Archaeoastronomy*, no. 13 (1989), S1–19, p. S2; *idem*, "Astronomies and rituals at the dawn of the Middle Ages", in *Astronomies and cultures*, ed. by Ruggles and Saunders (ref. 3), 100–23, pp. 110f, 114. Even if the canonical date of ecclesiastical equinox established in A.D. 325 by the Council of Nicaea was March 21, the Roman tradition correlating the equinox with March 25 (VIII Kal. Aprilis) survived, as well: Newton, *op. cit.*, 22–27. Newton mentions two medieval calendars — one of them recorded by Bede — which attest to the coexistence of both traditions, because in each of them the equinox is annotated for both 21 and 25 of March (*ibid.*, 26f). Incidentally, Bede is one of the authors Motolinía (*op. cit.* (ref. 75), 46) quotes in his discussion on various calendars.

96. Johanna Broda, "Tlacaxipeualiztli: A reconstruction of an Aztec calendar festival from 16th century sources", *Revista española de antropología americana*, v (1970), 197–274; López Luján, *Las ofrendas del Templo Mayor* (ref. 9), particularly pp. 270–89.
97. Matos, *The Great Temple* (ref. 11), 73; López Luján, *Las ofrendas del Templo Mayor* (ref. 9), 73ff, Fig. 14.
98. López Luján, *Las ofrendas del Templo Mayor* (ref. 9), 272.
99. *Cf.* Marquina, *El Templo Mayor* (ref. 11), 30, Fig. 1; *idem*, *Arquitectura prehispánica* (ref. 11), 183, Fig. 6 bis; Aveni and Gibbs, *op. cit.* (ref. 1), 514, Fig. 3; Matos, *The Great Temple* (ref. 11), 146, Fig. 115; Aveni, *Skywatchers* (ref. 1), 247, Fig. 81b.
100. For example, if the upper platform of the last structural phase was about 30m high (*cf.* Marquina, *El Templo Mayor* (ref. 11), 44), the observer had to stand at a distance of more than 800m if he wanted to see the sunrise on the natural horizon and, at the same time, between the two upper sanctuaries.
101. Horst Hartung, "A scheme of probable astronomical projections in Mesoamerican architecture", in *Archaeoastronomy in pre-Columbian America*, ed. by A. F. Aveni (Austin and London, 1975), 191–204, p. 193, Figs 3 and 4.
102. It could be speculated that, a few moments before sunset on certain dates, the sacrificial stone's shadow was observed, projected onto the pedestal, which probably supported a statue of Huitzilopochtli (López Luján, *Las ofrendas del Templo Mayor* (ref. 9), 71). However, as the pedestal is wider than the sacrificial stone, the phenomenon would have occurred on several consecutive days. Particular dates could have been determined if the pedestal or the bench had had some markings, no traces of which, however, have been detected.
103. Hartung, *op. cit.* (ref. 101), 196.
104. Francisco Hinojosa: personal comm., May 1997.
105. The inner face of each jamb is trapezoidal, being its maximum width, which diminishes upwards, about 185cm (along the intersection with the upper horizontal face of the abutted wall).
106. I am indebted for this caution to Francisco Hinojosa, May 1997.
107. *Cf.* Ivan Šprajc, "El Satunsat de Oxkintok y la Estructura 1-sub de Dzibilchaltún: Unos apuntes arqueoastronómicos", in *Memorias del Segundo Congreso Internacional de Mayistas* (Mexico City, 1995), 585–600.
108. Motolinía, *op. cit.* (ref. 75), 51.
109. Aveni *et al. op. cit.* (ref. 3), 297.
110. López Luján, *Las ofrendas del Templo Mayor* (ref. 9), 70; Francisco Hinojosa: personal comm., May 1997.
111. Šprajc, "Orientaciones" (ref. 4).
112. Šprajc, "Orientaciones" (ref. 4), 114ff; *cf.* Michael Zeilik, "The ethnoastronomy of the historic Pueblos, I: Calendrical sun watching", *Archaeoastronomy*, no. 8 (1985), S1–24.
113. Mazari *et al.*, *op. cit.* (ref. 15), 155.
114. Relative heights of different points on the platform do not render in all parts exactly the same inclination angles α and β, which indicates that the structure, undergoing differential settlements, has not moved strictly as a rigid body.