WERE ANCIENT MESOAMERICAN BUILDINGS ORIENTED TO MAGNETIC NORTH ?

by

TIMOTHY JOHN CARROLL

Submitted in Partial Fulfillment of
of the Requirements for the
Degree of Bachelor of Science

at the

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Thesis Supervisor

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Chairperson, Departmental Committee on Theses

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Abstract

The orientations of buildings at the ancient Mesoamerican temple centers of Teotihuacan, Tula, Chichen Itza, Palenque, Tikal, Copan, and Monte Alban were plotted against the past magnetic declination for that region to test the possibility that they were constructed to align with magnetic north. Archaeomagnetic data did not extend back far enough for a check of Olmec buildings, the most likely candidates. Although the possibility still exists for the Olmec, it was concluded that the ancient Mesoamericans did not align their buildings to magnetic north. An astronomical explanation is most likely for the asymmetrical east of north orientation noted for Mesoamerican centers.

Thesis Supervisor: Kenneth Brecher
Title: Associate Professor of Physics

Acknowledgements

I would like to thank my thesis advisor, Kenneth Brecher. Although he wouldn't know it, he is my inspiration.

Special thanks to Lori for getting me up for practice.

"They are ill discoverers that think there is no land,
when they can see nothing but sea."
—Francis Bacon

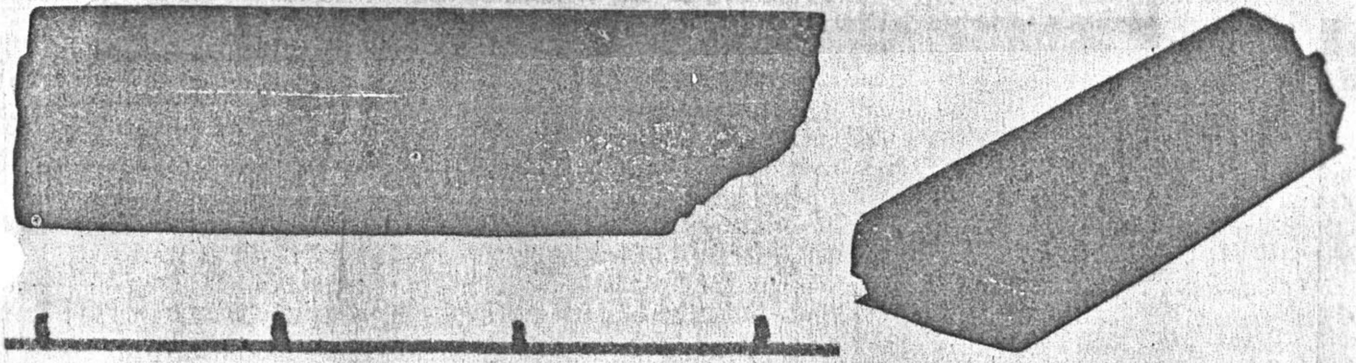
Introduction

In 1967 archaeologist Michael D. Coe uncovered a rectangular worked fragment of hematite at the Olmec site of San Lorenzo (1500-900BC). Fuson (1969) recounts how the object's general appearance suggested to Coe that it might serve as part of a compass. Accordingly, Coe tested the possibility: he placed the object on a piece of cork and floated it in a bowl of water. The "pointer" consistently aligned itself slightly west of magnetic north. Flipped over, the object pointed somewhat east of north. This was a very provocative result, but Coe took the issue no further.

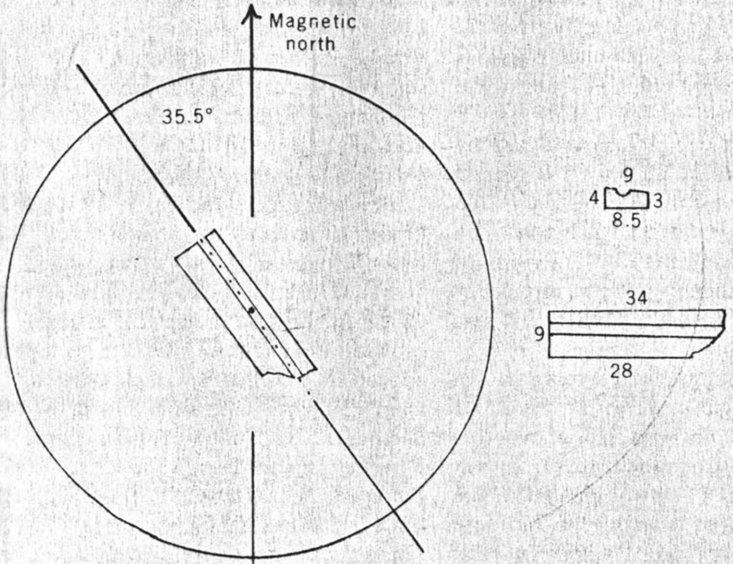
Not until 1973 did the object, designated artifact M-160 (see fig.1), receive the attention it deserved. In that year, John B. Carlson of the University of Maryland undertook a thorough multidisciplinary analysis of M-160 which he reported in Carlson (1975). He repeated the flotation experiment and found a consistent orientation 35.5° west of magnetic north. The magnetic moment was measured in a spinner magnetometer and found to lie close to the flotation plane. This property is important for maximum sensitivity to the magnetic field declination.

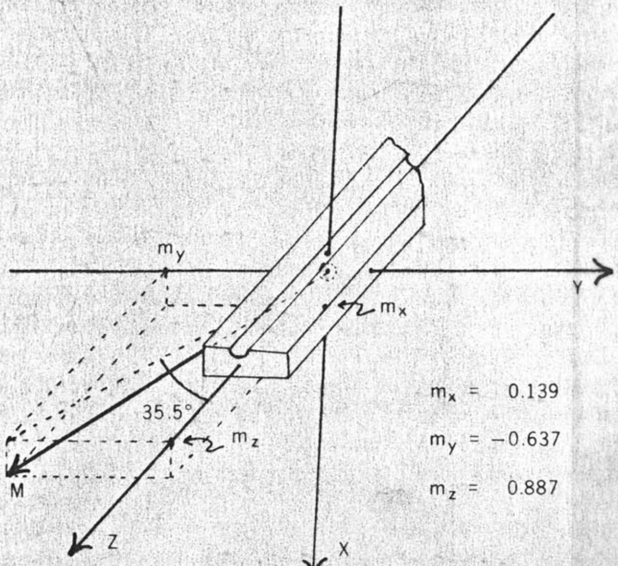
The spinner magnetometer also provided an explanation for the large deviation of the "pointer" from magnetic north. M-160 was broken into two fragments during the investigation. Determined separately, the magnetic moments of each fragment differed by 40.5° in azimuth, a huge difference! M-160 itself is just a part of a larger piece. If fully assembled, M-160 could well have pointed accurately toward magnetic north. If this statement seems presumptuous, note that the directive property of M-160 is remarkable in itself.

The Olmec possessed the rudiments of a magnetic compass by 1000BC, whether or not they realized the implications. Evidence that they did understand its magnetic properties was



[redacted]. Photographs of M-160. The scale is marked in centimeters.





F (left). Top face and cross section of M-160 (dimensions in millimeters) and diagrammatic representation of the floater experiment showing the ed orientation 35.5° west of magnetic north. Fig. 6 (right). Total magnetic moment vector **M** and components of M-160. The direction of **M** is that of the north-seeking pole, *y-z* is the floating plane of M-160, and the *z*-axis is parallel to the incised groove. The artifact is not drawn to scale or exact proportion.

figure 1 (after Carlson,1975)

found by Vincent Malmstrom (1976) while working at the site of Izapa on the Pacific coast of Chiapas, Mexico. He discovered a boulder carved as the head of a turtle which strongly deflected the needle of a nearby compass. No matter where the compass was placed along the perimeter of the sculpture, it always pointed to the turtle's snout. No other rock with such magnetic properties was discovered at the site.

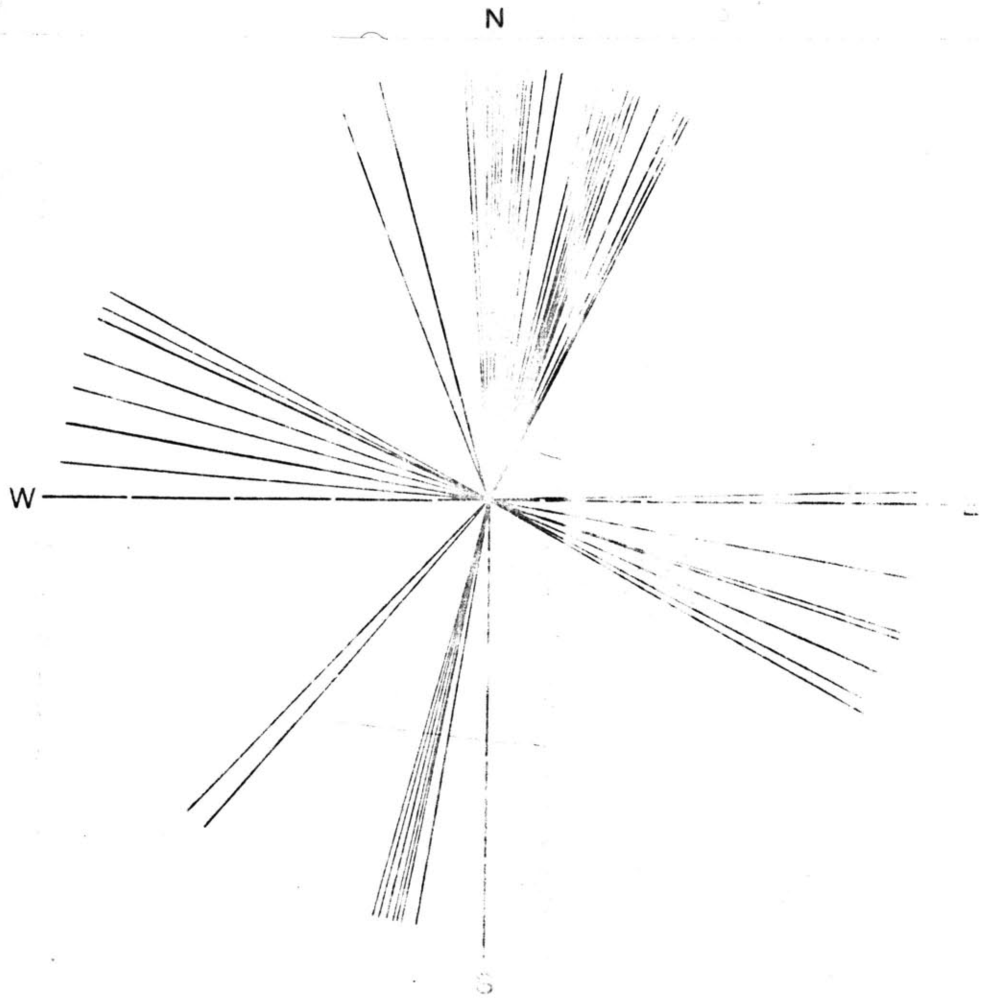
Considerable knowledge of the directive properties of magnetism would have been required of artisans in order to manipulate the magnetic material so carefully. Izapa, as an archaeological site, was contemporary with San Lorenzo and contains more evidence of Olmec influence than any other Mesoamerican site outside of the Olmec heartland. Cross cultural exchange is clearly indicated, and knowledge as remarkable as magnetism would surely have been shared.

The Olmec knew how to make a compass. But for what purpose did they and their descendents use it? Carlson (1975) has drawn attention to several similarities between the Chinese and Olmec cultures and suggested that the geomantic use of the compass by the Chinese was paralleled in ancient Mesoamerica. Paul Wheatley (1971) essayed on the geomantically inspired orientation of the ancient Chinese city to the four cardinal directions. He described it as a "cosmo-magical symbol", a cosmological representation on earth. Such cosmological symbolism was certainly as important to the Mesoamericans (Thompson,1970). A magnetic compass could have provided the Olmec and their successors with a cosmologically signifigant direction.

Kenneth Macgowan (1945) was the first to note a systematic east of north orientation for Mesoamerican cities and buildings. He cautiously hinted that this may indicate an alignment with magnetic north. Anthony Aveni discussed the astronomical possibilities of this pattern (Aveni,1977) and made a plot of the major axes of many Mesoamerican sites which is shown in figure 2. The sites do cluster near, but not on, true north. For the Chinese, Polaris represented the primary direction of their cosmology. Not so for the Mesoamericans. A motivation for their habit must be found elsewhere.

Astronomical explanations abound and will be reviewed later, but several writers have followed Macgowen and suggested a magnetic orientation (Fuson,1969; Carlson,1975; Evans,1977; Dupas,1977). Only recently has the necessary data been made available for a preliminary test of this hypothesis. Using the new information, this paper will investigate the coincidence of building orientation with magnetic declination through time in hopes of deciding whether the ancient Mesoamericans used their compass in laying out their cities.

Lest this seem nothing but an academic excercise the reader is referred to the abstract of a paper written in Japanese by K. Hirooka (1976) about his work in Japan:



[redacted]. *Polar diagram showing the distribution about astronomical north of the axes of ceremonial centers in Mesoamerica.*

figure 2 (after Aveni,1977)

> The directions of horizontal axial lines of about 60 ancient and Middle Age (500-1200AD) Buddhist temples were determined, and it was concluded that the temple buildings were built in line with the magnetic north shown by a compass at that time.

With such a precedent, let us proceed.

Geomagnetism

The feasibility of this investigation depends upon a precise knowledge of the past behavior of the Earth's magnetic field. We will first describe the properties of this field and then go on to discuss the ways in which this information can be retrieved.

The Earth is a giant though weak magnet. As it spins on its axis 366 1/4 times per year, the Earth's molten iron outer core is sloshed about in such a manner as to produce the familiar dipolar magnetic field. Fundamentally, this field is produced according to the same principle by which modern electrical generators operate; a good conductor (i.e. iron) moving in a magnetic field will induce a current which in turn generates a new magnetic field. If no electromagnetic energy is dissipated, the exchange can continue indefinitely.

This mechanism, generally known as a magneto-hydrodynamic self-exciting dynamo, requires the coupling of a coaxial rotation of the conducting fluid with some complicated turbulence so as to produce the observed poloidal field. The precise nature of these extra motions is undetermined, but Strangway (1970) lists several probable processes which could produce them:

1) Radioactivity in the core could cause heating and

hence convective motion in the fluid.

2) If the solid inner core is growing as the Earth cools down, it would release latent heat of melting and could thereby cause heating.
3) Pieces of the solid mantle could break off and cause stirring as they settled through the liquid core.
4) The ellipticity of the fluid core is known to be different from that of the whole Earth. It might, therefore, precess with a different period, this differential motion causing turbulence.

Whatever the exact mechanism, the theory is sufficiently complete to show that convoluted motions of the fluid core <u>could</u> give rise to the Earth's magnetic field as we see it. To its credit, also, the random nature of this field source can help to rationalize the field's erratic secular variability, of interest to this paper. For a more complete intuitive explanation of the dynamo mechanism see W.M. Elsasser's Scientific American article (Elsasser,1958).

The magnetic field of the Earth is not precisely a dipole, nor is it exactly aligned with the rotation axis. In addition to the main dipolar field there are other weaker components which cause local variation in field strength and direction. A contour map of this nondipole field is pictured below for the year 1945 (fig.3). The average deviation amounts to only about 5% of the main field strength (~.5 gauss) although departures as great as

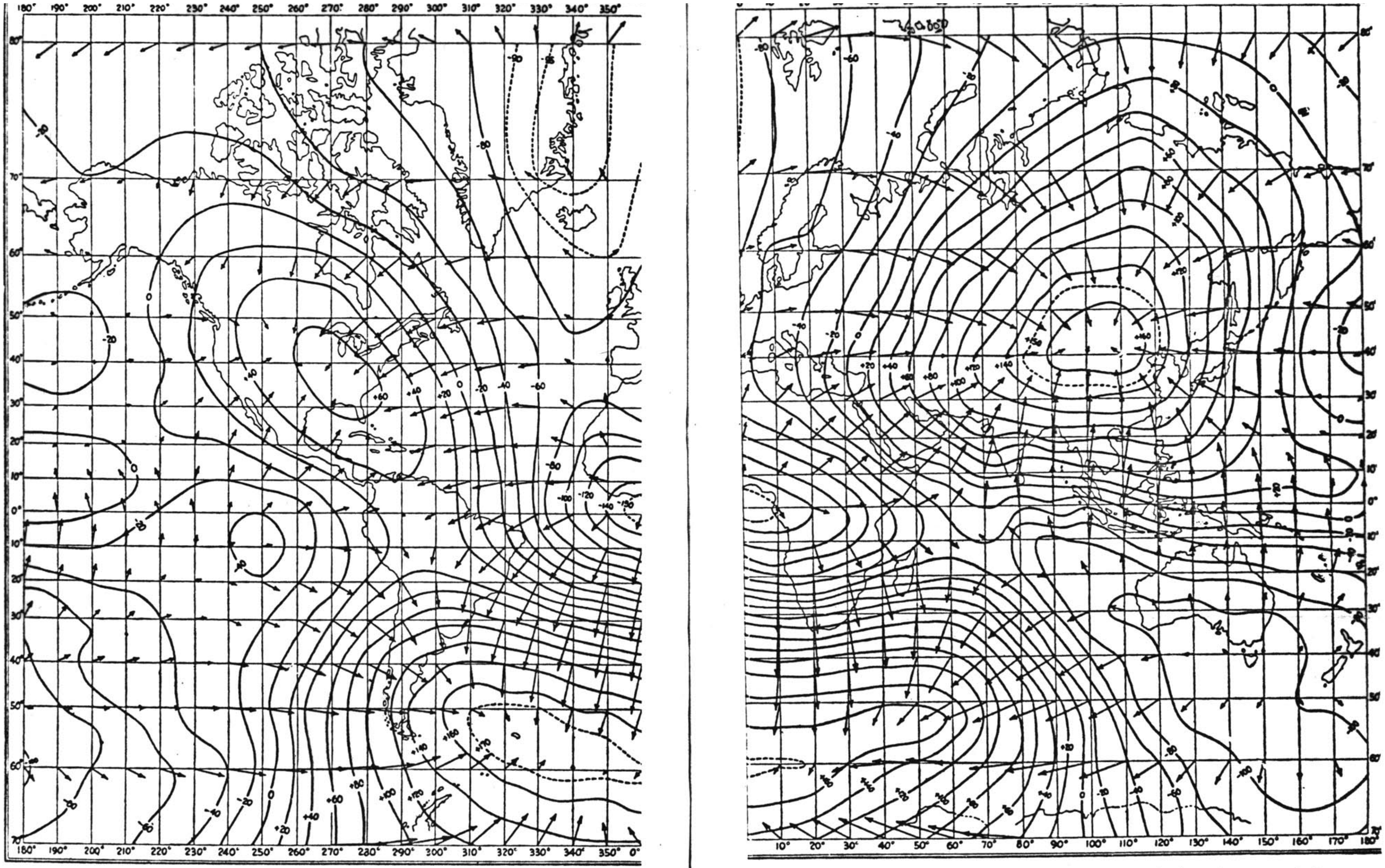


FIGURE [redacted] Nondipole field for 1945. Vertical field intensity with contour intervals at 0.02 gauss. Arrows give horizontal component [from Bullard, Freedman, Gellman, Nixon, *Phil. Trans. Roy. Soc.* (London), A, 243:67–92 (1950)].

figure 3 (after Strangway,1970)

.18 gauss exist. Additionally, the pole of the magnetic field does not quite align with the pole of the Earth's rotation. The relative inclination varies but is presently about 11 1/2°.

The most interesting and potentially informative aspect of the Earth's magnetic field is its time variability. For reasons not well understood but intricately tied up with the variable nature of the source mechanism, the field exhibits irregular secular changes in intensity and direction. Historical records of the magnetic field have produced plots such as those given in figures 4 and 5 which show the marked variation.

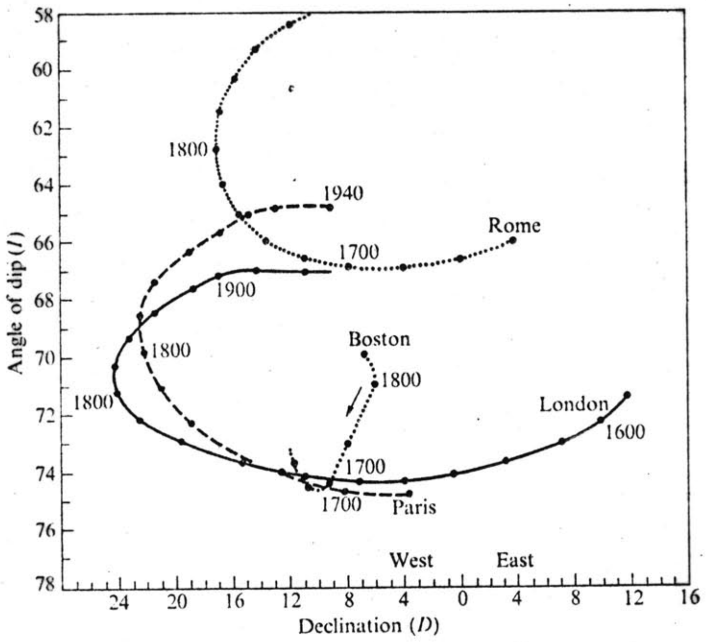


FIG. [redacted]. Secular variation from historical records—London, Paris, Rome, and Boston. The time scale is indicated by dots at 20-year intervals. Prior to 1900 the curves shown are those obtained by Bauer (1899) using recorded observations to determine an empirical formula; Bauer's extrapolations into periods when only declination was measured have been omitted.

figure 4 (after Aitken,1974)

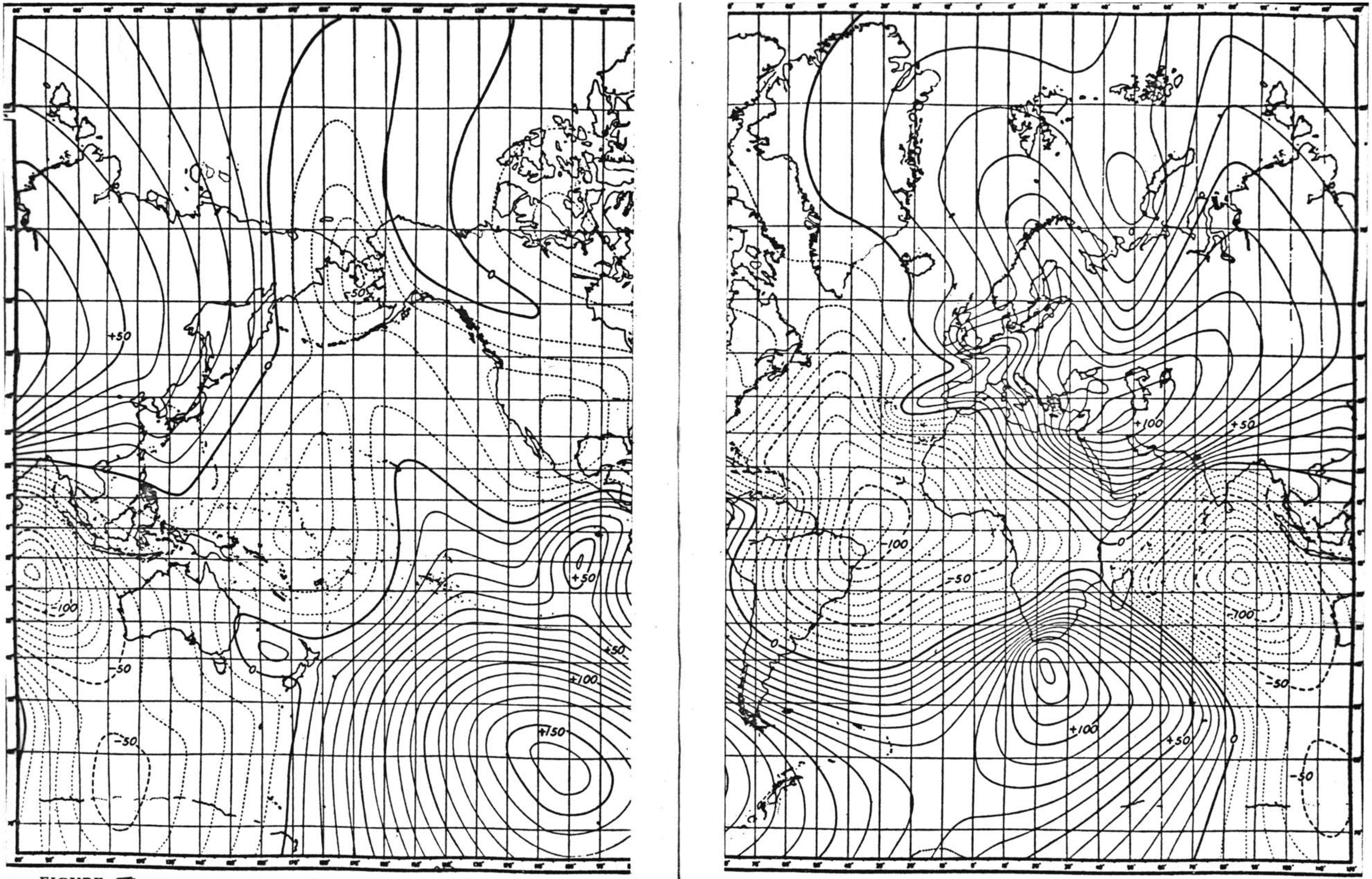


FIGURE ■ Geomagnetic secular change in gammas per year for period 1940 to 1945. (From Vestine, Laporte, Cooper, Lange, and Hendrix, Carnegie Institution Publications, p. 578, 1947.)

figure 5 (after Strangway,1970)

Owing to the magnetic properties of geologic materials, the history of these changes is also preserved in crystallized rocks, sediments and baked clays. The unravelling of this sequence from such evidence constitutes the science of paleomagnetism. For more recent periods, the specialized term archaeomagnetism has been applied.

An explanation of the way that this information is stored in rocks lies hidden in the quantum mechanical theory of matter. Weiss' theory of ferromagnetism (1911) was given quantum mechanical interpretation by Heisenberg in 1928 (Heisenberg,1928). J.G. Konigsberger, however, was the first to systematically apply the principles of crystal physics to understanding the magnetic behaviors of geologic materials. His two articles, titled "Natural Residual Magnetism of Eruptive Rocks" (Konigsberger,1938), served as the starting point for subsequent work in the field.

The elemental building block of all minerals and rocks is the atom. Although chemically distinct, different atomic species are all composed of the same three fundamental units, in varying proportions: the charged nuclear proton, the oppositely charged orbiting electron, and the aptly named neutrally charged neutron.

Elementary electrodynamics says that a moving charge will produce a magnetic field. Atoms are electrically neutral, so their motion cannot account for rock magnetism. For minerals, the atomic nuclei are locked into a lattice; they cannot move and therefore create no magnetic field either. The whirling electrons, however, are highly mobile in the vicinity of their owning atoms. Normally their motions are random; one electron cancelling the magnetic field of an oppositely directed one. But if they are somehow forced to move coherently, a substantial net field will result.

There are three ways in which the magnetic nature of electrons can be harnessed. The weakest is called diamagnetism. For this case, the application of a magnetic field to a material is seen as a changing magnetic flux by the orbiting electrons. In response, an orbital current is induced to oppose the applied field. A weak magnetism results. Oppositely directed to the applied field, the effect disappears once the field is removed. All atoms are diamagnetic.

A second phenomenon is termed paramagnetism. Owing to their spin, electrons have an inherent magnetic dipole moment. These dipoles will align parallel to an applied magnetic field. Thus, in this case, the external field is enhanced. Only atoms with unpaired electrons can exhibit paramagnetic behavior. Otherwise, the paired spins will cancel one another. This effect usually predominates over the coexisting diamagnetism, and likewise disappears upon removal of the field.

The third mechanism, ferromagnetism, is the only one which yields a permanent magnetization. Ferromagnetism gives a rock its memory.

For ferromagnetism, as for paramagnetism, unpaired electron spins produce a net dipole moment. For some atoms (Fe, Co, Ni, Gd, Dy), however, there is a special interaction between electrons which favours their parallel alignment, without the influence of an outside field. This interaction is purely quantum mechanical in nature and cannot be explained on classical grounds. In quantum systems, the indistinguishability of particles provides an additional stabilizing energy term in the wave equations called the exchange energy. This energy is important only for a narrow range of atomic separation distances. If far apart, the electrons are distinguishable and the term goes to zero. If too close, the Coulomb repulsion dominates, and electrons will pair up. Although only five elements qualify, many alloys and compounds do meet this exacting criterion, including several common minerals. Magnetite (Fe_3O_4) and hematite (Fe_2O_3) are the most important.

But if parallel alignment is favoured, why don't ferromagnetic minerals commonly occur in nature as permanent magnets? The answer is simple: without a preferred direction (as defined by an applied field), thermal motion during crystallization is enough to randomize the spins. The quantum effect is still pronounced enough, however, to produce small micron sized regions of common spin called domains. If subjected to a strong field, these domains can shift with respect to one another and give a net magnetization. The domains are then locked in their new position with an acquired dipole moment. That is how you make a magnet!

We know that natural magnets are uncommon; a magnetic field is needed to order the domains. At room temperature the domains are hard to move, too tough for the Earth's weakling field. At higher temperatures, however, the crystal loosens up due to thermal motion and ordering can occur. The permanent magnetization acquired by a mineral upon cooling from such a temperature in the Earth's field is termed thermo-remanent magmetization (TRM). This magnetization is, in general, precisely coincident with and proportional to the external field. This property, as well as its great stability, provides the basis for paleo- and archaeo-magnetic research.

There are other natural processes by which a rock can be magnetized. Chemical change in a rock owing to weathering or metamorphism can form magnetic minerals. As these new minerals grow, ferromagnetic atoms will be added somewhat aligned with the prevailing field direction. The resulting magnetization (CRM) is as stable as TRM and cannot be separated from it. Since such chemical change can take place long after a rock's formation, the two field directions will be confused. Therefore, care must be taken to find unaltered 'fresh' samples for measurement.

Detrital remanent magnetization (DRM) is produced by the partial alignment of magnetic particles as they settle through calm water into a sediment bed. When the sediments are processed to form a rock, the net magnetization remains. Although this recorded direction can be altered by CRM, cores from deep sea sediments have been successfully used to determine geomagnetic reversals. An archaeomagnetic application of DRM has been recently reported by Turner and Thompson (1979).

Random thermal fluctuations in a magnetic mineral can lead to a small magnetization as grains occasionally acquire enough energy to break through the domain walls and align with the ambient field. This process is akin to the evaporation of a liquid below its boiling point; molecules randomly are given above average kinetic energy due to collision and thereby escape from the liquid's surface. The magnetization acquired in this way, called viscous remanent magnetization (VRM), is a complication which can be eliminated by laboratory cleaning techniques. By the same mechanism, VRM, more permanent remanent magnetizations can decay.

Two final types of magnetism called, respectively, isothermal and anhysteritic remanent magnetization (IRM and ARM) are usually unimportant for geologic materials. In the former case, a strong applied field (~300 oe) may exceed the coercive force of some grains and cause them to align. For the latter, a strong alternating field in the presence of a small constant field will leave a net magnetization along the weak field direction. In both cases, such strong fields are not normally found in nature. An exception has been found, however, for rocks struck by lightning. Such a large current is accompanied by powerful magnetic fields capable of inducing both IRM and ARM. Like VRM, IRM can be removed, but ARM is more stable and will complicate measurements of the true historical field direction.

The principles of geomagnetism have been cursorily examined. For a more complete and technical coverage of the magnetic theory of geologic materials see Nagata (1961).

But how is the record of the Earth's past magnetic field extracted from these rocks? That is the domain of the science of archaeomagnetism.

Archaeomagnetism

The primary material of interest for archaeomagnetic research is the baked clay from ancient kilns and hearths which has acquired a stable TRM. Lavas from documented flows have sometimes been used (Chevallier,1925; Brynjolfsson,1957; Tanguy,1970), but baked clays are more readily available. They are also more surely dated by radiocarbon techniques applied to associated ash and charcoal.

The first problem faced by the archaeomagnetist is sample collection. He must be certain that the clays have not been disturbed since the time of their last firing, either by chemical weathering or by physical movement such as kiln wall fallout. Weathered material is visually obvious and can be avoided. As for shifts in position, samples taken from the floors or lower walls should be most reliable as opposed to those taken from the kiln superstructure.

Even with such precautions, scatter among samples is commonly found to be on the order of 5-10°. The most obvious cause is due to irregular subsidence of the supporting ground. There is some evidence, however, that the magnetic properties of the structure itself may distort the geomagnetic field and produce scatter (Aitken and Hawley,1971). To remedy this situation, a dozen or so samples must be taken from each structure and their average taken.

The precise procedure for removing a sample and preserving its relative orientation has been described by Wolfman (1973) whose data will be used here:

> A small column of fired clay approximately 1¼in. in diameter and 1¼in. high is carved from an <u>in situ</u> fired clay feature and a small amount of modelling clay is placed around the base of the column. A brass mold in the form of a cube 1.7 inches on a side and open on top and bottom is placed over the column of fired clay and squeezed into the clay until it is level, which is determined using a cross-test level. The mold is filled with plaster and when the plaster is hardened, the direction along one edge of the mold is measured with a Brunton compass. The specimen is then cut from the ground, the top is leveled and marked with per-

tinent data, and the bottom is cleaned and filled with plaster to completely encase the specimen. When the plaster on the bottom is hard, it is leveled and the specimen is removed from the mold.

Before measurement of the remanent magnetism of a sample can be meaningful, all magnetic components other than the TRM must be removed. This procedure is termed 'cleaning' and is accomplished in two different ways, each appropriate for different types of remanence.

The first technique is essentially a reversal of the TRM process. The sample is heated up to a temperature sufficient to overcome the 'hardest' secondary component, and then cooled in a zero field. Cancellation of the Earth's field is accomplished by a set of Helmholtz coils aligned along the field direction. The necessary current is pumped through the coils in order to reduce the field to less than 1% of its normal value. VRM can be erased in this manner.

The second process is much more effective for removing IRM and ARM than is thermal demagnetization. The Earth's field is annulled as before, and the sample is subjected to a strong alternating magnetic field which is smoothly and slowly reduced to zero. This randomizes domains having a coercive force less than the maximum value of the alternating field. Care must be taken in this case since an ARM may be <u>induced</u> if the Earth's field is not cancelled exactly.

Usually the above two procedures are accomplished in progressive increments of temperature or alternating field strength until no further change in remanent direction is observed. The remaining remanence should be due to the TRM induced by the ancient geomagnetic field at the time of last heating.

Once cleaned, one of two different machines is used to measure the remanent magnetization of a given sample. The simplest is known as the astatic magnetometer, schematically shown in figure 6. It consists essentially of two oppositely oriented bar magnets separated by a short rigid rod. This arrangment is suspended from a fine fiber of phosphor-bronze or quartz. Since the two magnets are antiparallel, the net torque due to the Earth's field is zero. The torque on the lower magnet due to the lower sample, however, is greater than that on the upper due to the differential distance. This produces a deflection proportional to the strength of the sample's magnetism. For a point source, measurement in three mutually perpendicular directions of the sample is sufficient to determine the remanent direction. But they are not point sources, so measurements are taken with the sample cube in all 24 possible orientations and the results averaged.

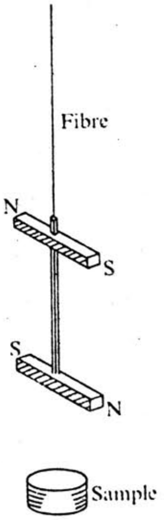


FIG. [redacted]. Principle of the astatic magnetometer. The restoring torque due to the earth's field is eliminated by using magnets of exactly equal moment. There is a net torque due to the sample because it is nearer to the lower magnet than to the upper one.

figure 6 (after Aitken,1974)

Thellier (1938) developed a second magnetometer based on electromagnetic induction. A magnetized sample spun between two Helmholtz coils will induce a voltage. The amplitude of this voltage determines the component of TRM in the plane of rotation and its phase with respect to the driving shaft yields the azimuth of that component. Theoretically two mutually perpendicular measurements are sufficient, but again the remanent direction is averaged over all orientations to compensate for sample irregularities. Modern 'spinner magnetometers' utilize complicated systems of coils to eliminate outside interference effects. A simple example of such a system is shown in figure 7.

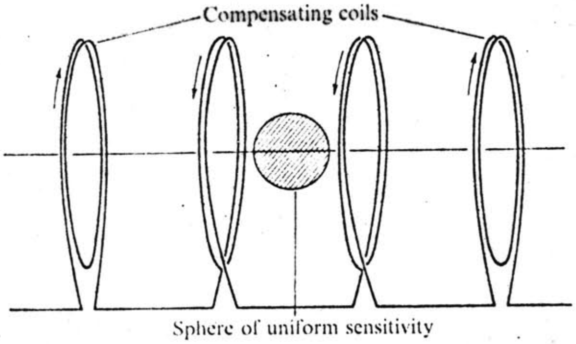


FIG. [redacted]. Simple compensated Helmholz coil system for spinner magnetometer. The outer pair of coils is wound in opposite sense to the inner pair thus eliminating the effects of uniform magnetic disturbances and of non-uniform disturbances of constant horizontal gradient.

figure 7 (after Aitken,1974)

When the remanent magnetization direction of each sample has been determined, they are averaged to obtain the most likely declination and inclination for the ancient geomagnetic field. This averaging is accomplished using the statistical model devised by R.A. Fisher (1953) expressly for treating paleomagnetic data. His model assumed the specimen vectors to be distributed symmetrically about the mean direction and specified that the density of vectors decrease normally with increasing angular distance from the mean. He was then able to show that the best estimate of the true sample mean direction was the vector sum of the specimen vectors. His analysis also provided a precision parameter, alpha-95, expressed as the half angle of a circular cone centered on the mean. There is a 95% chance that the true field direction lies within that cone.

The resultant geomagnetic field directions are coupled with dates obtained by either stratigraphy or radiocarbon to yield a plot of declination and inclination vs. time similar to that in figure 5. A more interesting plot, however, is known as a polar data representation curve (PDRC). It traces the wanderings of the virtual geomagnetic pole (VGP) over the surface of the Earth. The VGP does not necessarily represent the'true'dipolar magnetic pole, but instead locates a pole corresponding to the measured declination (D) and inclination (I) assuming they belong to a purely dipolar field. Two PDRC's for the same time period are given in figure 8. One is from data taken in England, the other from Japan. Obviously the two do not coincide, and this is due to the vagaries of the nondipolar components. Note that the wandering pattern is similar, however.

Although VGP's from opposite sides of the world are clearly not superimposable, Aitken (1974) suggests that a given PDRC is valid for a region several hundred miles across – the size of Mesoamerica.

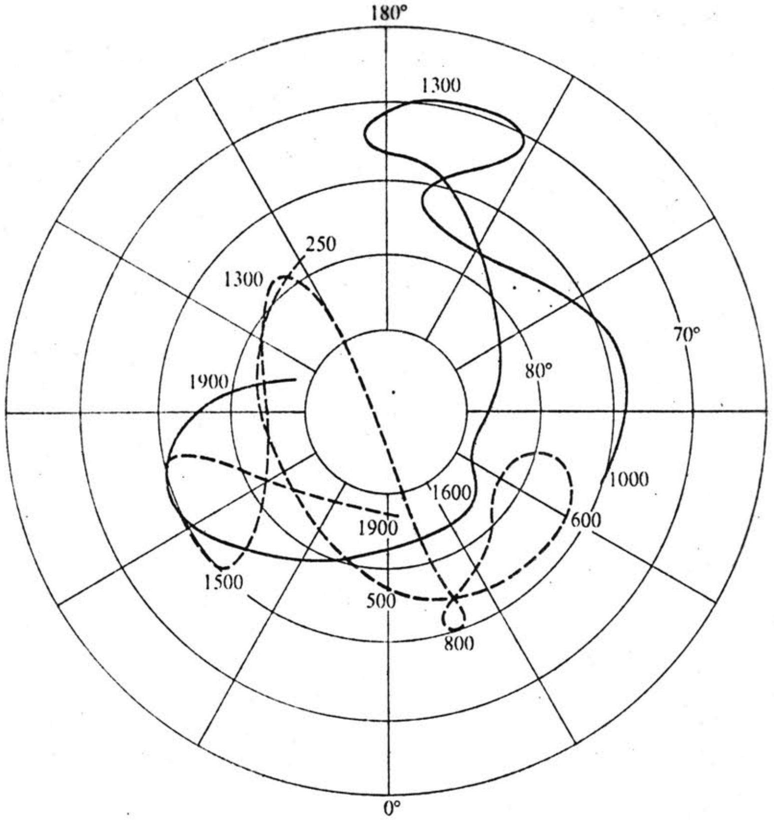


FIG. [redacted]. Virtual pole positions derived from archaeomagnetic data for England (solid line) and for Japan (dashed line). The virtual pole for an observing station is the orientation of a dipole at the centre of the earth such that the magnetic field would have the values of *I* and *D* observed at the station. Although the pole positions do not superimpose, it is to be noted that there is a broad similarity in the movement. Data used are from Aitken (1970) and Hirooka (1971).

figure 8 (after Aitken,1974)

The VGP for a given D and I is obtained from the following equations:

$$\cot(p) = \tfrac{1}{2}\tan(I)$$
$$\sin(A') = \sin(A)\cos(p) + \cos(A)\sin(p)\cos(D)$$
$$\sin(B'-B) = (\sin(p)\sin(D)) \, / \, \cos(A')$$

where A' and B' are the latitude and longitude of the VGP, and A and B are those of the sampling site.

The 95% cone of confidence can also be transformed according to the above formulas. It is projected on the Earth's surface as an oval about the VGP with its semi-minor axis along the line connecting the sampling site with the pertinent VGP. This oval of confidence increases in size with decreasing latitude.

The above discussion should be sufficient for an understanding of the principles of archaeomagnetism. For additional coverage see Aitken (1974), Michels (1973), Tite (1972), and Bucha (1971).

Archaeology

The Olmec civilization was only the first of a series of brilliant Mesoamerican cultures. In the wake of the Olmec decline, about 400BC, was planted the seeds of some of the world's most remarkable civilizations. Perhaps Olmec influence directly stimulated this fluorescence, or the Olmecs may simply have been the most precocious in a wider cultural awakening. This question bears on the problem of determining which cultures could have inherited the knowledge of an Olmec compass.

Evidence exists that the Olmec did have a wide ranging influence. Carlson's Mossbauer analysis of M-160 showed that the hematite probably originated in the valley of Oaxaca. Other workers have definitely placed the source of Olmec magnetite mirrors there (Carlson,1975). Recall, also, Malmstrom's discovery, implying that the Olmecs explicitly shared their knowledge of magnetism, as well as artistic styles, far down the Pacific coast at Izapa.

To put the geographic relationships among the various cultures into better perspective, Richard Adams (1977) has divided Mesoamerica into nine major cultural regions:

1) The Northeast: the Huasteca
2) The Northwest Frontier
3) Western Mexico
4) Mesa Central: the Basin of Mexico, and the surrounding Valleys of Morelos, Puebla, and Toluca
5) Puebla-Oaxaca Highlands
6) Oaxaca, Central Valley, and Pacific Coast
7) The Isthmian zone: Gulf Coast Veracruz, Tehuantepec Isthmus, and the Guatemalan Pacific Plain
8) The Maya lowlands
9) The Maya highlands: Chiapas and Guatemala

These regions are delineated and identified in figure 9. Each represents a major physiographic zone or center of major cultural development.

Between AD1 and AD650, three major civilizations reached their peak and then suddenly, by 900AD, disappeared. Much has

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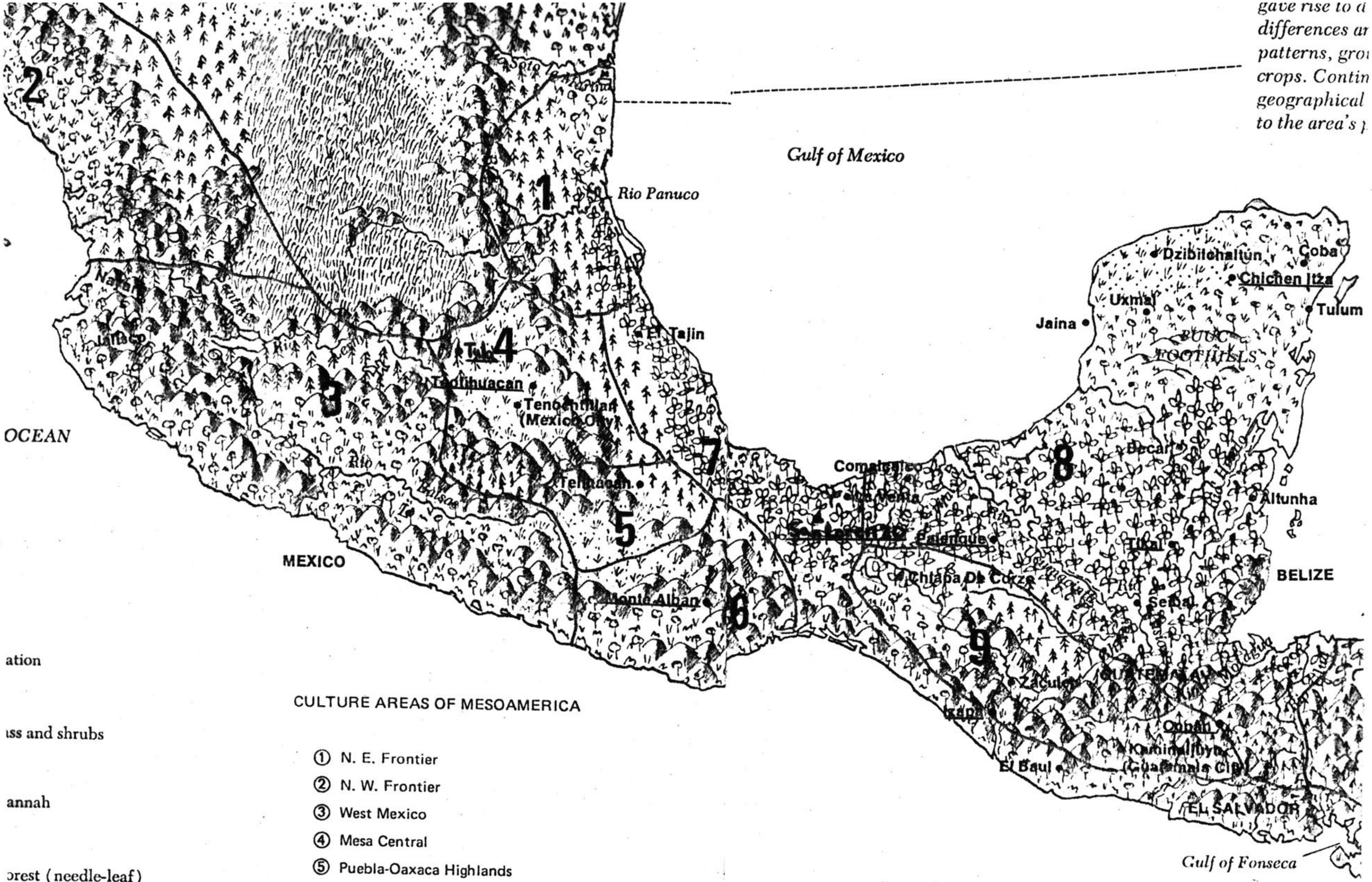

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CULTURE AREAS OF MESOAMERICA

① N. E. Frontier
② N. W. Frontier
③ West Mexico
④ Mesa Central
⑤ Puebla-Oaxaca Highlands
⑥ Oaxaca Central Valley and Pacific Coast
⑦ Isthmian & Coastal Zones
⑧ Maya Lowlands
⑨ Maya Highlands

figure 9 (after Adams,1977)

been written about this precipitous decline, but it will not concern us. Our investigation does not extend beyond the healthy period of fervent building activity.

These three cultures are known as Teotihuacan, Monte Alban, and Maya. They occupy respectively Adam's areas four, six, and both eight and nine. Following their demise, the Teotihuacan group was succeeded by a people known as the Toltecs who restored some of the grandeur of bygone days until they too passed away in 1200AD.

All these peoples were highly skilled in the art of dressing stone for building purposes. They built magnificent temple centers replete with paved courtyards, palace residences, and ceremonial ballcourts. These temple centers, often inaccurately referred to as cities, served as the unifying cultural force behind every Mesoamerican civilization. It was their signifigance as religious centers which attracted local inhabitants and assured their loyalty.

Such a mystical bond is a very fragile thing and needs to be constantly reinforced. Ritual in the form of public pageantry, divination, and even human sacrifice serves this purpose well. Perhaps ritual also dictated the alignment of buildings along a special geomantic direction, that determined by a magnetic compass.

It will be assumed here that if such a practice existed, it would certainly be evident at the most important temple centers. Armed with this rationalization, the orientation of buildings at the one or two largest centers in each cultural region will be investigated.

Among their many great achievments, the Maya developed a highly accurate calendar. Their 'long count' system functions similarly to the modern astronomical Julian date. The Mayan day count, however, is broken down into a hierarchy of vigesimal units as follows:

1 kin = 1 day
1 uinal = 20 kins = 20 days
1 tun = 18 uinals = 360 days
1 katun = 20 tuns = 7200 days (~20 yrs.)
1 baktun = 20 katuns = 144,000 days (~400 yrs.)

Thompson (1960) gives a comprehensive discussion of Maya calendrics and their astronomical applications.

This type of Maya date was recorded on many stelae, altars, and buildings. A modern decimal notation has been developed to express them. For example, 9.13.2.0.0 means nine baktuns, thirteen katuns, two tuns, zero uinals, and no kins.

Like the Julian Day date, the Mayan calendar originates its count from some mythical creation date. The placement of this date in the Christian calendar, however, has been a sticky problem for archaeologists. A summary of the dating problem and a bibliography of recent work pertaining to it is given by Ralph (1965). Two correlations are presently in contention. That of Spinden (1924) sets the calendar origin date at 3373BC. The Goodman-Martinez-Thompson (GMT) correlation places it 260 years later. The GMT is currently favoured by most archaeologists.

Where possible, inscribed dates will be used for this archaeomagnetic correlation. Both GMT and Spinden dates will be plotted as a superficial test of their relative validity.

The archaeology of Mesoamerica is fascinating in its own right. Two classic books on the subject are Thompson (1966) and Morley (1956). For the most recent developments see the highly readable accounts of Weaver (1972) and Adams (1977). They have been of especial value to this paper.

Site Data

As explained above, only the major sites from each cultural region were chosen for this study. For each temple center, the orientations of all major structures were measured with a protractor on maps drafted by the chief excavating archaeological team. Only orientations within 17° of true north were eventually plotted, but all buildings with wall directions in this range were included, irrespective of absolute facing. Several of the maps had grids aligned to magnetic north. Adjustment to true north was effected using the magnetic declination provided by the respective archaeologists. Estimated datings were quoted from project archaeologist's reports, and, where appropriate, inscribed dedicatory dates of buildings were taken from Morley (1937-38).

The collected data appears in the following table. References to the associated maps are given in parentheses following the name of each site. If different, sources for the estimated datings are listed second.

SITE DATA

Site/Building	Orientation	Est.Date	Inscr.Date(GMT/Spinden)
Chichen Itza(Ruppert,1952)			
Monjas	8°30′ EN	600-800	10.2.10.11.7(878/618)
Casa Colorada	12 45 EN	600-800	10.2.0.15.3 (869/609)
Temple of Initial Series	16 45 EN	600-800	10.2.9.1.9 (877/617)
Sacbe no.1	6 30 EN	900-1050	
Great Ballcourt	17 00 EN	1050-1200	
Copan(Stromsvik,1947; 1952)			
1st Ballcourt	4 00 WN	500-600	9.4.0.0.0 (513/253)
2nd Ballcourt	9 00 WN	600-750	9.13.10.0.0(701/441)
3rd Ballcourt	4 00 WN	700-850	9.17.4.0.0 (774/514)
Main Court	5 00 WN	500-600	
Reviewing Stand	4 00 EN	700-850	9.17.0.0.0 (770/510)
Mound 16	5 00 EN	700-850	
Mound 18	2 15 EN	700-850	
Temple 22	6 00 EN	700-850	9.17.0.0.0 (770/510)
Temple 11	1 00 EN	700-850	9.14.15.0.0(725/465)
Mound 26	0 45 EN	700-850	9.16.5.0.0 (755/495)
Monte Alban(Acosta,1965)			
Central Pyramid	2 45 EN	700-900	
Plataforme Este	4 30 EN	700-900	
Ballcourt	3 30 EN	700-900	
Danzantes	3 15 EN	500BC-0	
N.Platform Court	3 30 EN	700-900	
System IV	9 15 EN	700-900	
Mound o	7 00 EN	700-900	
S.Platform	3 30 EN	200-600	
(Blanton, 1978)			
House Mounds	within 2 of 8 EN	300BC-200AD	
House Mounds	within 3 of 1 EN	200-700	

SITE DATA cont.

Site/Building	Orientation	Est.Date	Inscr.Date(GMT/Spinden)
Palenque(Lhuillier Ruz,1952,1956,1961)			
North Group	16°15' EN	600-800	
Temple 10	16 45 EN	600-800	
Ballcourt Plaza	14 15 EN	600-800	
Ballcourt	12 45 EN	600-800	
Tikal(Carr and Hazard,1961;Coe,1965)			
Temple I	11 45 EN	600-900	9.13.3.0.0(694/434)
Temple II	11 30 EN	600-900	
Temple IV	12 00 EN	600-900	9.16.0.0.0(750/490)
Temple V	8 00 EN	600-900	
Temple of Inscriptions	9 15 EN	600-900	
North Acropolis	10 30 EN	100BC-200AD	
5D22	8 00 EN	300-500	
Teotihuacan(Millon,1973)			
Street of the Dead	15 30 EN	1-150	
Ciudadela Compound	17 00 EN	150-200	
Tula(Acosta,1957)			
Adoratorio	15 30 EN	1000-1200	
Ballcourt no.1	16 30 EN	1000-1200	
Temple of Quetzalcoatl	17 00 EN	1000-1200	
Building C	17 00 EN	1000-1200	
Museo	12 45 EN	1000-1200	

Archaeomagnetic Data

The archaeomagnetic data for Mesoamerica was taken from the unpublished dissertation of Daniel Wolfman (1973). His work in the University of Oklahoma Archaeomagnetism Laboratory provided 41 VGP's for the time period between 35BC and 1065AD. His PDRC is given as three plots in figures 10 and 11.

The magnetic declinations at each archaeological site were recovered from Wolfman's calculated VGP's through use of the formulas given previously. These declinations and his ascribed dates are given in the following table.

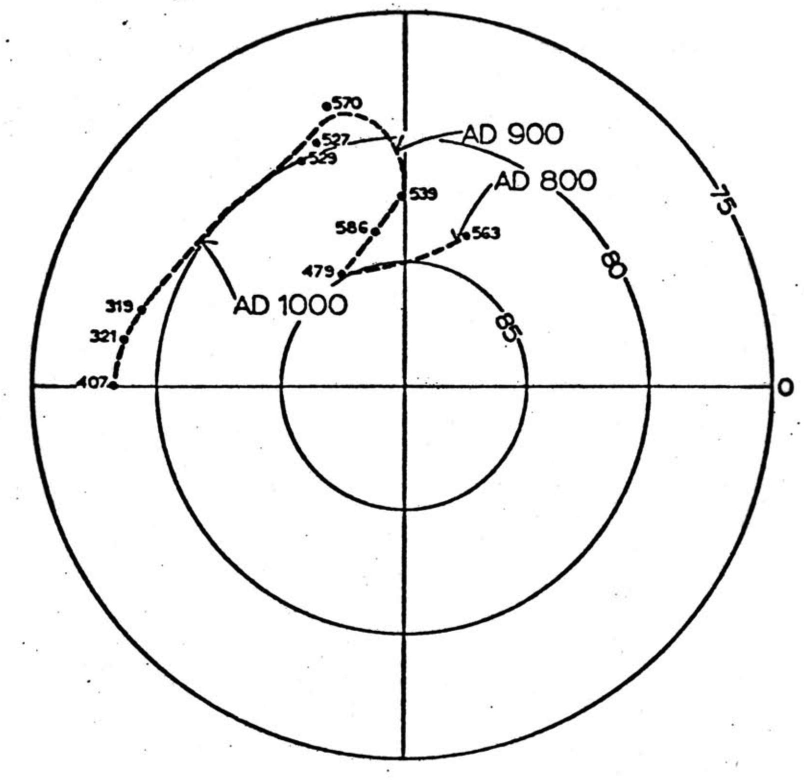


Fig. [illegible]. Mesoamerican Polar Data Representation Curve, A.D. 800-1050.

figure 10 (after Wolfman,1973)

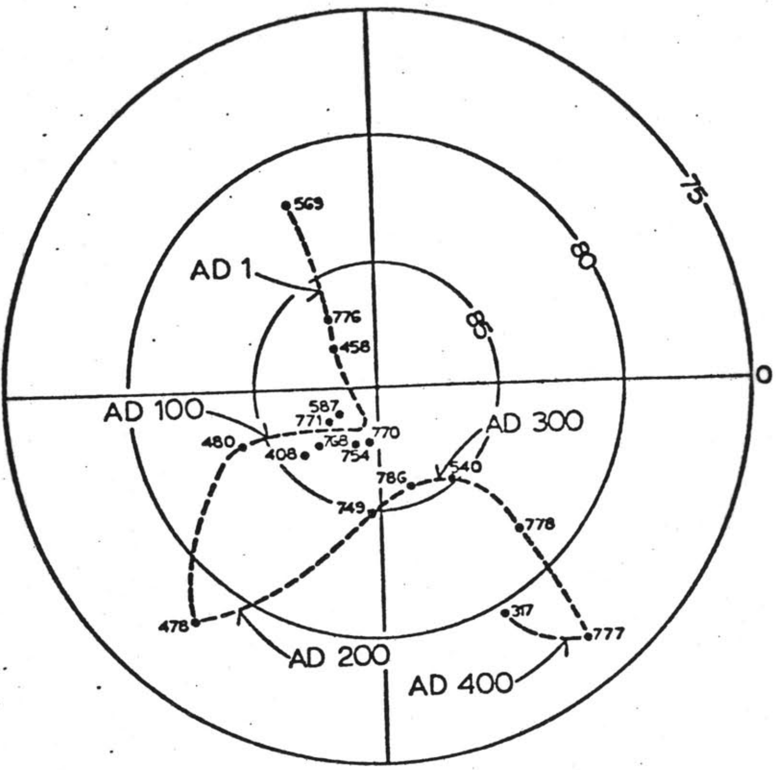


Fig. [redacted]. Mesoamerican Polar Data Representation Curve, A.D. 1-400.

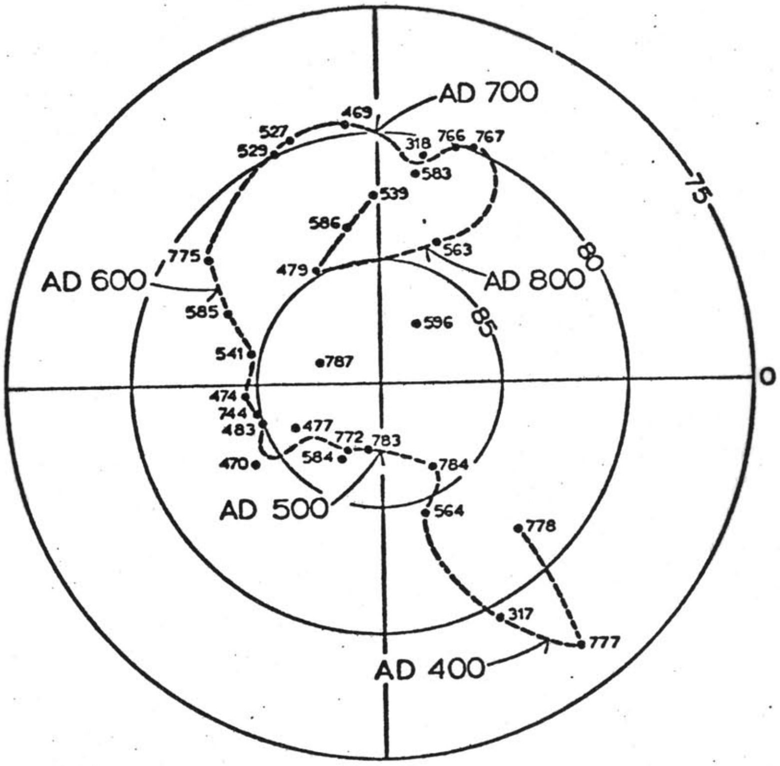


Fig. [redacted]. Mesoamerican Polar Data Representation Curve, A.D. 350-900.

figure 11 (after Wolfman,1973)

ARCHAEOMAGNETIC DECLINATION

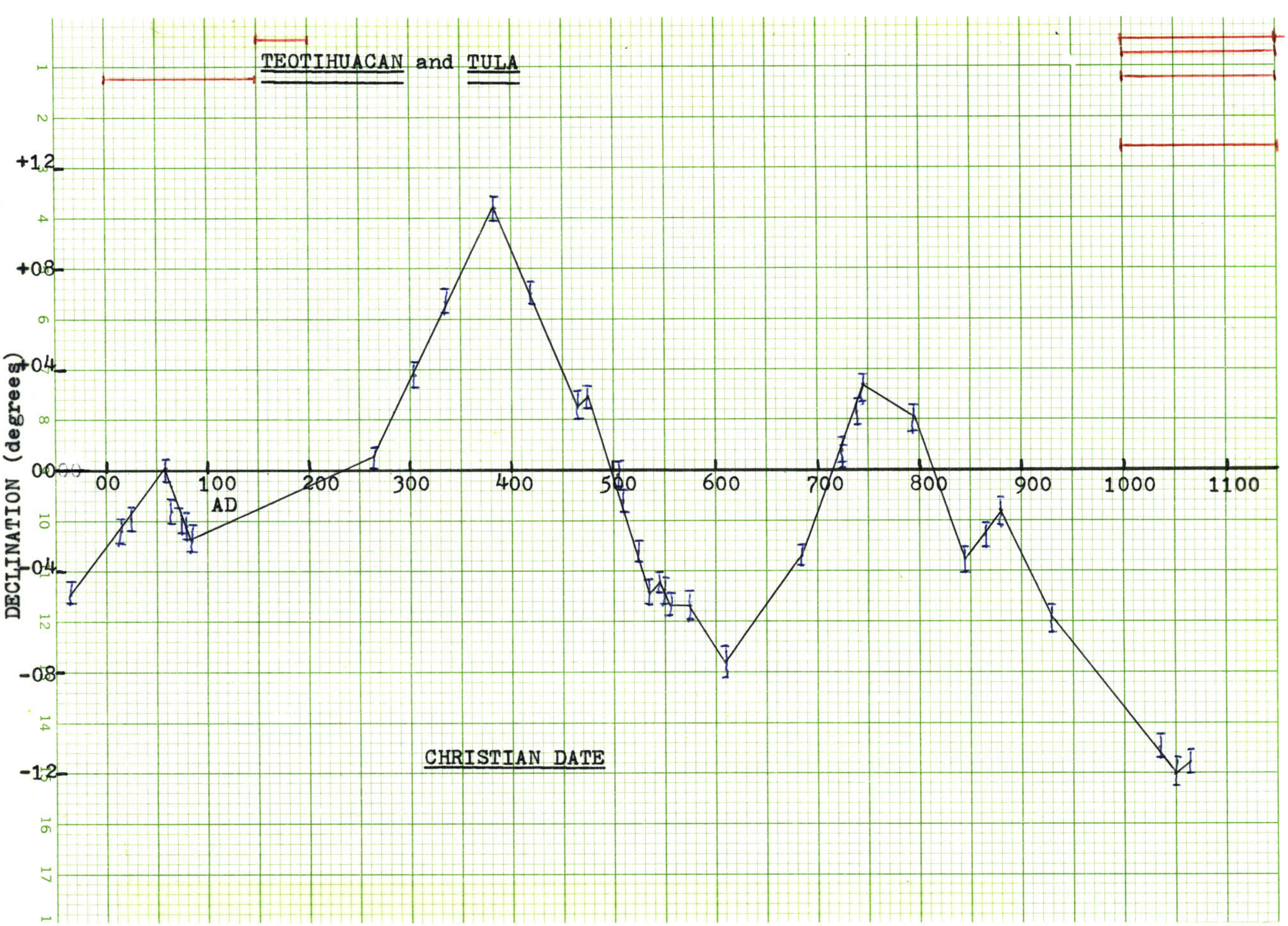
	Teotihuacan/ Tula	Chichen Itza	Copan	Tikal	Palenque	Monte Alban
lat.A :	19.70°	20.67°	14.87°	17.22°	17.51°	17.00°
long.B:	-98.85°	-88.53°	-89.17°	-89.40°	-91.98°	-96.70°
Date		Declination				
420	7.04°	5.45°	6.08°	5.88°	6.26°	6.98°
725	0.78	2.83	3.04	2.84	2.30	1.31
1035	-11.04	-10.39	-10.43	-10.43	-10.58	-10.83
1050	-11.95	-11.24	-11.15	-11.21	-11.37	-11.64
1065	-11.57	-12.11	-11.82	-11.96	-11.93	-11.62
85	-2.71	-3.11	-3.32	-3.15	-3.05	-2.88
25	-1.86	-1.66	-1.75	-1.72	-1.77	-1.85
685	-3.35	-0.98	-1.29	-1.27	-1.90	-3.04
535	-4.83	-5.27	-5.35	-5.29	-5.18	-5.01
555	-5.28	-5.64	-5.49	-5.53	-5.46	-5.32
525	-3.19	-3.44	-3.47	-3.45	-3.39	-3.28
845	-3.50	-2.77	-3.07	-2.97	-3.15	-3.47
545	-4.45	-4.75	-4.72	-4.71	-4.65	-4.53
880	-1.59	0.18	0.08	0.04	-0.44	-1.30
305	3.78	3.26	3.50	3.42	3.54	3.76
575	-5.37	-5.05	-5.04	-5.05	-5.13	-5.25
795	2.07	3.28	3.53	3.36	3.04	2.48
465	2.64	1.54	1.81	1.74	2.03	2.55
-35	-5.12	-3.82	-4.30	-4.15	-4.47	-5.06
930	-5.87	-3.64	-4.25	-4.09	-4.66	-5.70
725	0.47	2.38	2.56	2.38	1.87	0.94
510	-1.30	-1.82	-1.95	-1.87	-1.73	-1.49
590	-6.42	-6.00	-6.11	-6.08	-6.17	-6.34
865	-2.58	-1.23	-1.49	-1.42	-1.79	-2.44
65	-1.59	-1.74	-1.77	-1.75	-1.71	-0.77
550	-4.74	-5.06	-5.02	-5.02	-4.95	-4.82
265	0.56	-0.67	-0.68	-0.61	-0.28	0.32
65	-0.58	-1.06	-1.14	-1.08	-0.95	-0.73
740	2.33	4.30	4.65	4.39	3.88	2.94

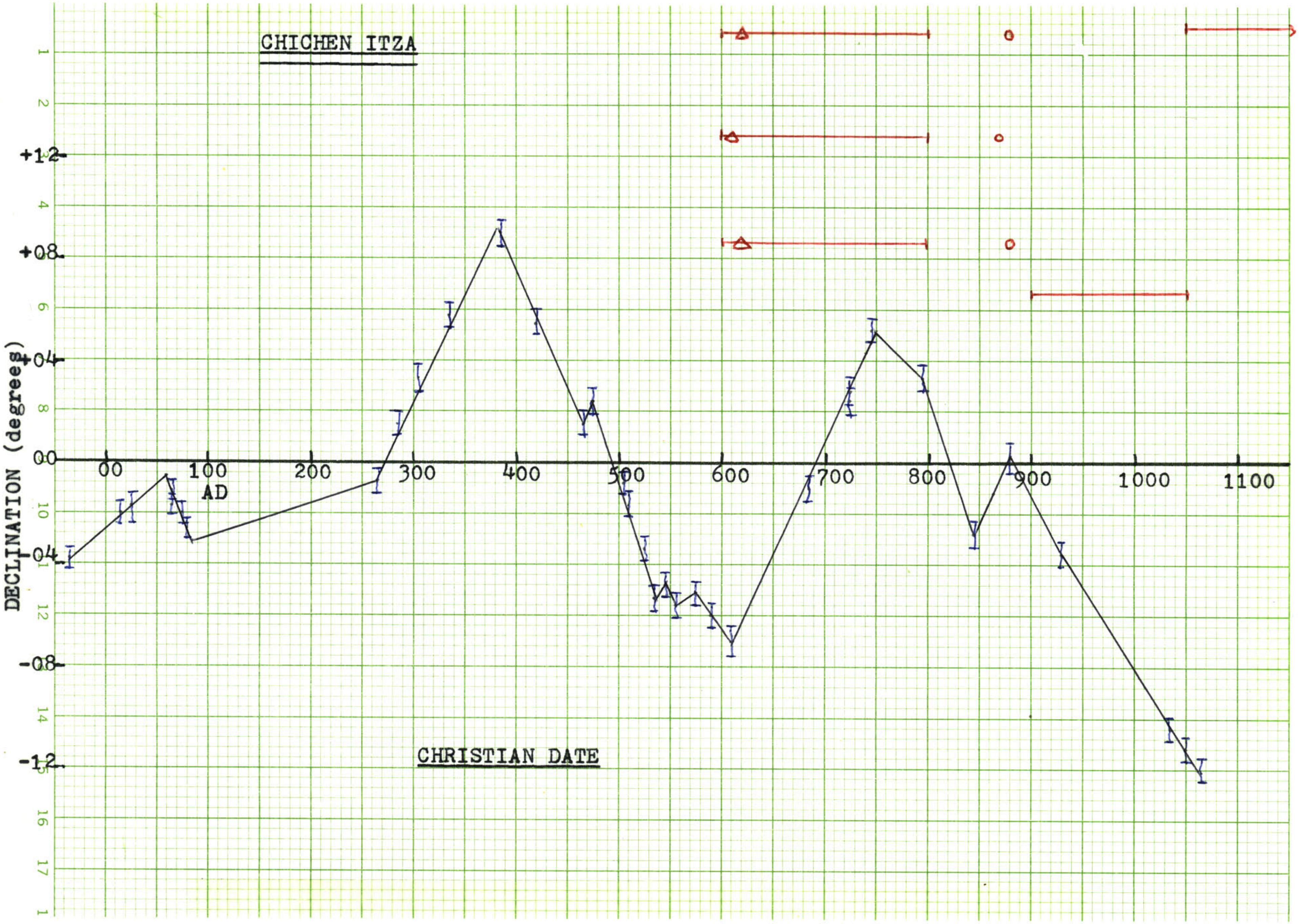
ARCHAEOMAGNETIC DECLINATION cont.

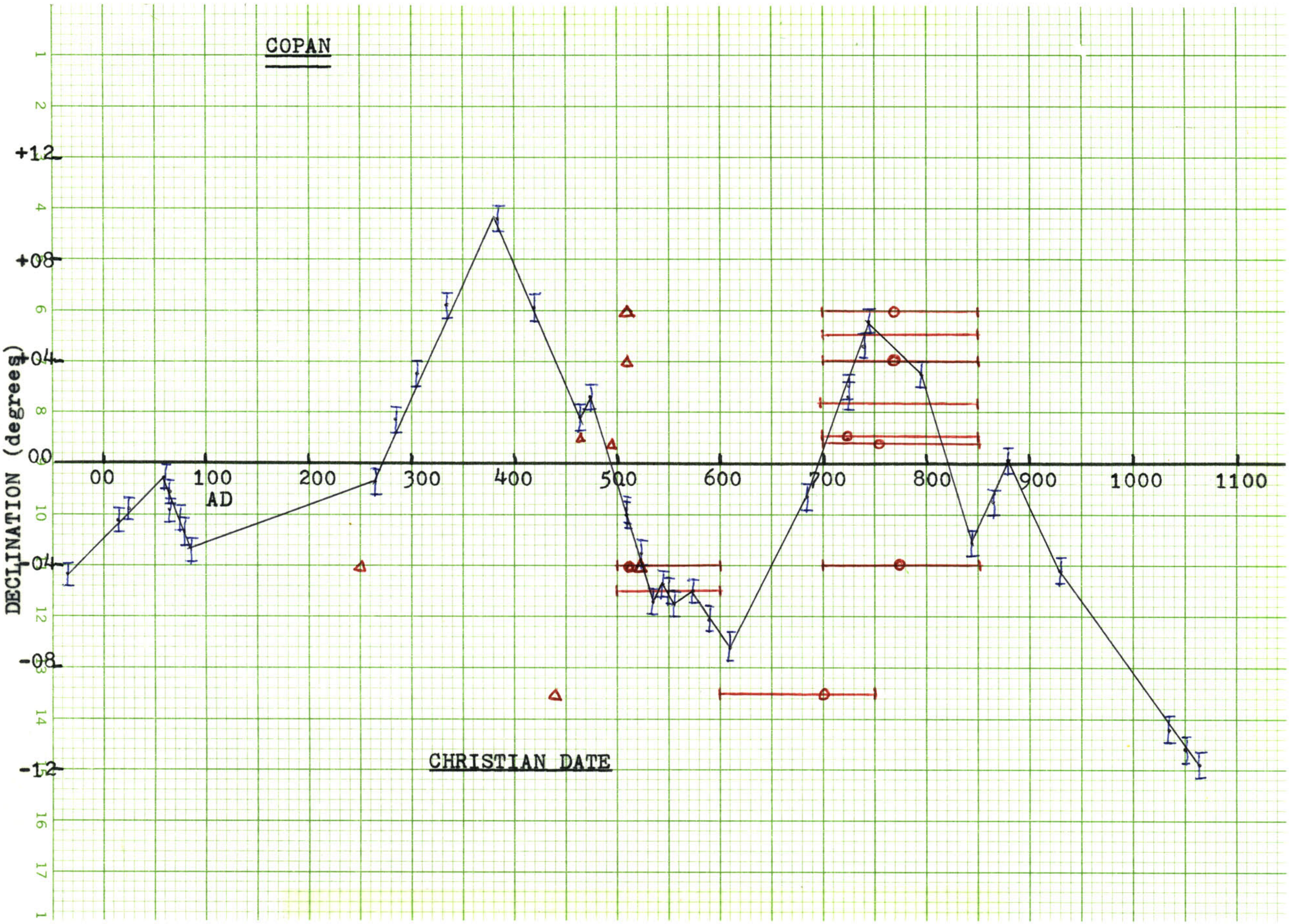
Date	Teotihuacan/ Tula	Chichen Itza	Copan	Tikal	Palenque	Monte Alban
745	3.37°	5.21°	5.60°	5.33°	4.85°	3.99°
80	-2.24	-2.56	-2.66	-2.60	-2.52	-2.38
60	0.05	-0.48	-0.51	-0.47	-0.33	-0.07
75	-1.85	-2.04	-2.08	-2.05	-2.01	-1.93
510	-1.15	-1.68	-1.80	-1.72	-1.59	-1.34
610	-7.62	-6.98	-7.24	-7.15	-7.29	-7.56
15	-2.40	-1.97	-2.16	-2.10	-2.20	-2.38
385	10.40	8.95	9.63	9.40	9.73	10.36
335	6.65	5.87	6.24	6.11	6.29	6.63
505	-0.16	-0.77	-0.83	-0.77	-0.61	-0.31
475	2.90	2.39	2.61	2.54	2.66	2.89
285	2.30	1.50	1.73	1.67	1.87	2.25

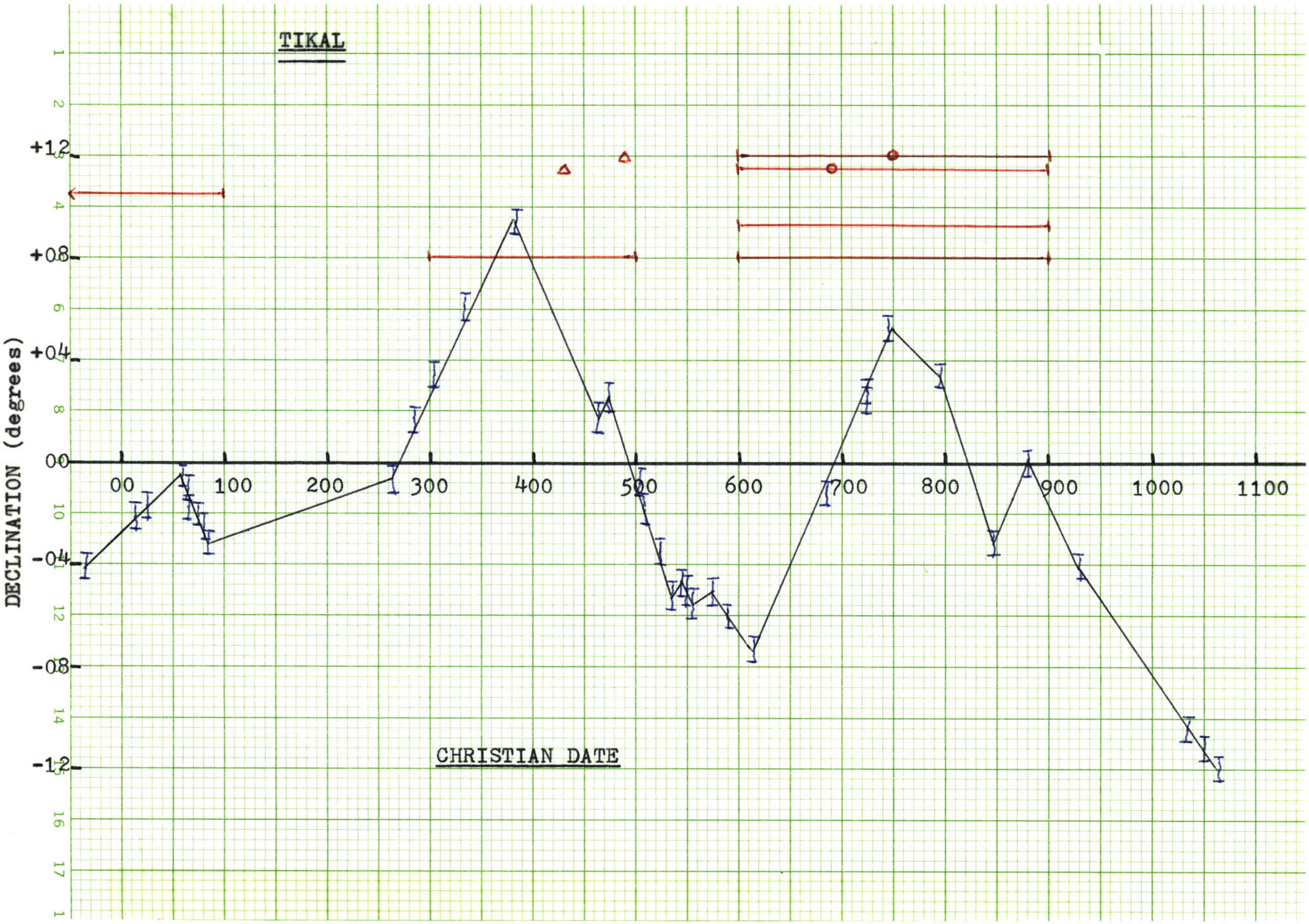
Correlation Plots

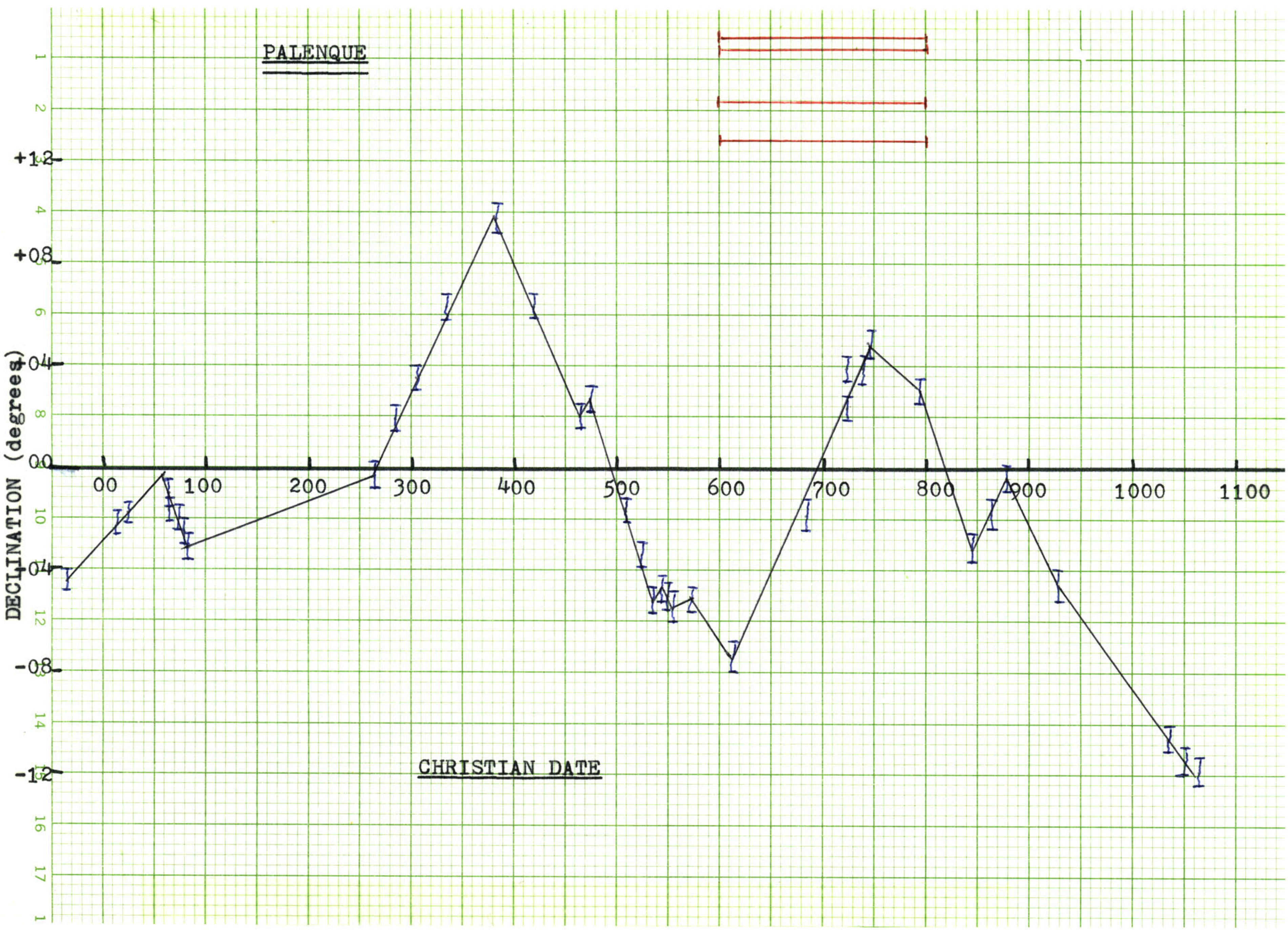
The above data was plotted for each site. Building orientations and age ranges are in red. The recovered declinations are indicated by blue error bars. Interpolated points are indicated by the black trace connecting them. The plots are given here and will be analyzed in the next two sections.

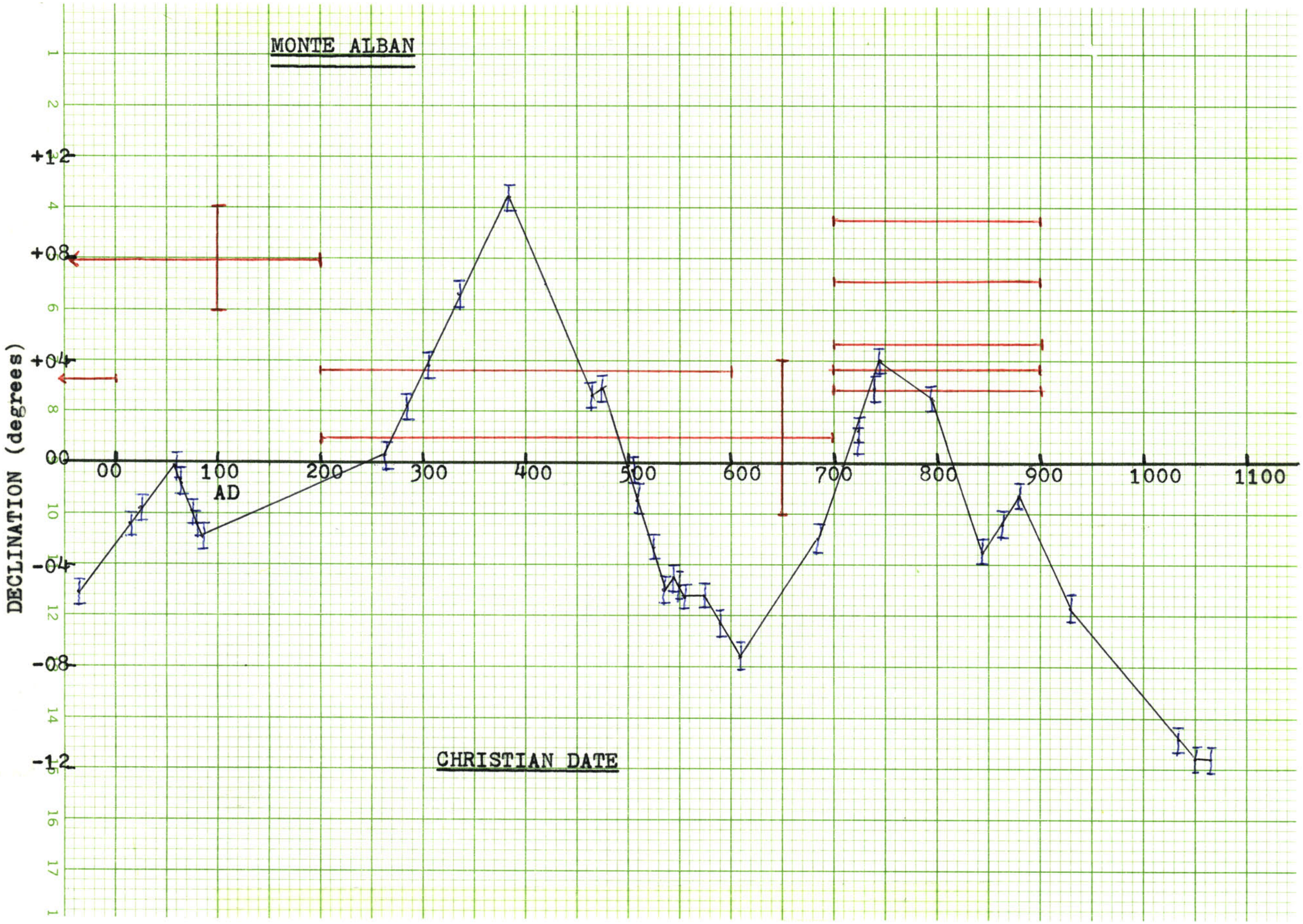

TEOTIHUACAN and TULA
DECLINATION (degrees)
+12
+08
+04
00
-04
-08
-12
00
100
AD
200
300
400
500
600
700
800
900
1000
1100
CHRISTIAN DATE


CHICHEN ITZA
DECLINATION (degrees)
+12
+08
+04
00
-04
-08
-12
00
100
AD
200
300
400
500
600
700
800
900
1000
1100
CHRISTIAN DATE


COPAN
+12
+08
+04
0.0
-04
-08
-12
DECLINATION (degrees)
00
100
AD
200
300
400
500
600
700
800
900
1000
1100
CHRISTIAN DATE


TIKAL
DECLINATION (degrees)
+12
+08
+04
00
-04
-08
-12
00
100
200
300
400
500
600
700
800
900
1000
1100
CHRISTIAN DATE


PALENQUE
DECLINATION (degrees)
+12
+08
+04
00
-04
-08
-12
00
100
200
300
400
500
600
700
800
900
1000
1100
CHRISTIAN DATE


MONTE ALBAN
+12
+08
+04
00
-04
-08
-12
DECLINATION (degrees)
00
100
AD
200
300
400
500
600
700
800
900
1000
1100
CHRISTIAN DATE

Error

No correlation is meaningful without a reliable estimate of the error inherent in the data. Wolfman (1973) gave an ample account of his experimental uncertainties, so only his final estimates will be quoted. Wolfman applied Fisher's statistical analysis, explained above, to minimize the effects of random scatter. This method also provided him with a 95% confidence interval, alpha-95. He found that VGP's having an alpha-95 greater than four degrees were unreliable. Therefore, he retained only those points having better precision than this. The four degree alpha-95 value roughly transforms (it depends on the latitude and longitude of both the VGP and the observing site) to a declination uncertainty of $\pm\frac{1}{2}^\circ$. This range is indicated by blue error bars on the correlation plots. Wolfman also estimated a dating error of ±40 years. Since this uncertainty is quite negligible in comparison to that of the building ages, these error bars were omitted.

The accuracy of measured building orientations was limited by the precision of a protractor. These measurements could be checked to within $\frac{1}{4}^\circ$. Inaccuracies in the maps could increase this to $\frac{1}{2}^\circ$.

As noted before, several maps required transformation from a magnetic to a true north oriented grid. This was necessary for the sites of Palenque and Tikal. The magnetic declination used for the corrections were probably not accurate to better than $\frac{1}{2}^\circ$. This raises the orientation uncertainty for these two sites to 1°.

The age ranges for various structures were adopted from the estimates of expert archaeologists. No improvements can be suggested by this author. One exception to this sorrowfully poor precision is the use of inscribed dedicatory dates. These should be exact within the framework of a given correlation. Which correlation seems to fit the archaeomagnetic data best will be checked.

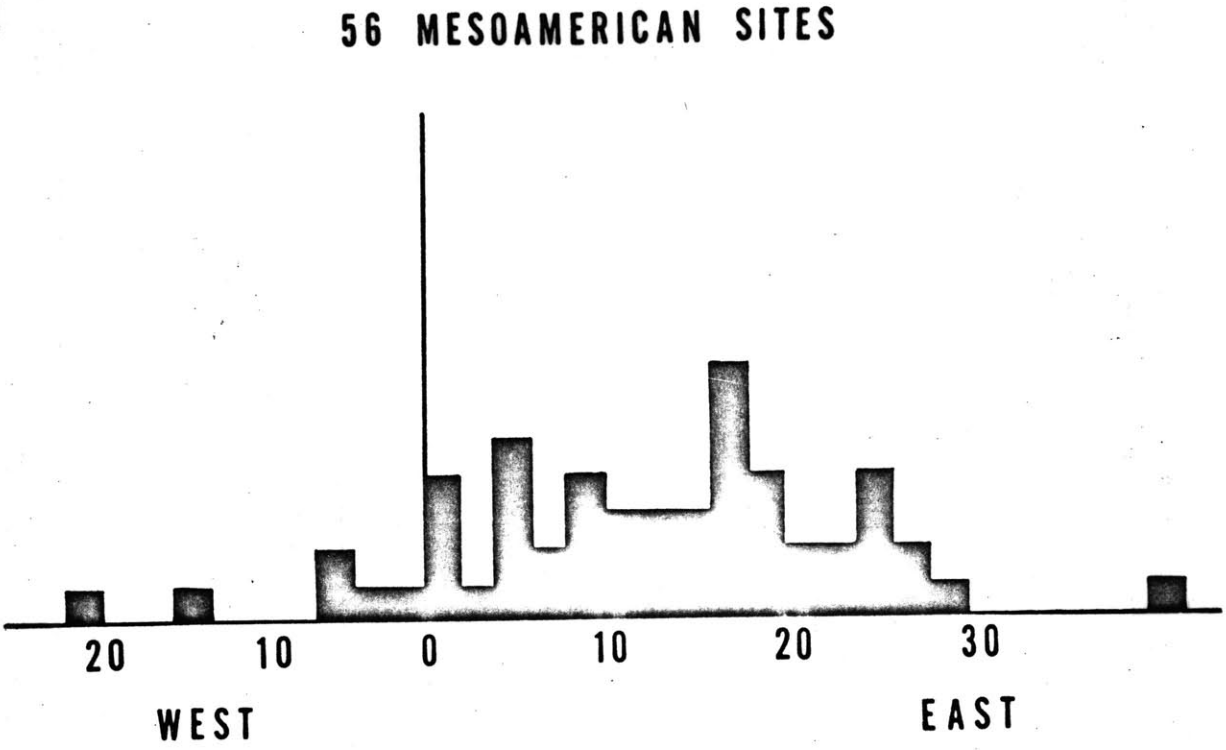
Age ranges for each structure were graphed on the correlation plots as red error bars. For the sake of neatness, orientation error bars were left off. Since they are constant, however, they can be judged by eye using the above estimates.

Results and Conclusion

There is a definite asymmetry in the distribution of axial directions about true north for ancient Mesoamerican sites. Could the practice of aligning buildings to magnetic north account for it? The plots of magnetic declination vs. time show that the compass needle spent as much time west of north as it has to the east. If ancient Mesoamericans aligned their cities to magnetic north, they could not have done it consistently through history. East of north orientations would only be possible between 250-500AD and between 700-850AD.

The Olmec alone seem to have had a preferential orientation west of north. Their possession of a compass marks them as the most likely adherents to this practice. Unfortunately, the archaeomagnetic data does not extend back far enough to allow a check of this possibility. It is suggestive, however, that the declination at 35BC is emerging from an excursion into the west. Such an excursion could have lasted 400 years back into the Olmec period (1500-400BC).

The declination plots show also that at no time has the declination deviated more than 10° east of north. In his letter, Macgowen (1945) noted two distinct families in the observed east of north pattern, one at 7°EN and another at 17°EN. Aveni (1975) reviewed this observation and found only a 17° family. His histogram plot of the major axes for 56 Mesoamerican sites is shown in figure 12. A truly preferential direction does not exist, but the greater proportion of alignments do lie more than 10°EN. Obviously, they could not have been pointed at magnetic north.



1 *Axial Distribution*

figure 12 (after Aveni,1975)

An assumption was made for this study that the practice of magnetically orienting buildings would be apparent at the major site of a culture area. If this is truly valid, then the correlation plots indicate that only the highland Maya (Copan) and the Monte Alban culture (Monte Alban) could have done so. Orientations at the other test sites (Teotihuacan, Tula, Chichen Itza, Palenque, and Tikal) fall so far east of north that they are definitely excluded. The Teotihuacanos, lowland Maya or Toltecs did not orient their buildings to magnetic north.

Copan is a Maya site, but it lies at some distance from the Maya heartland in the highland region of Guatemala. The correlation appears very good; the building orientations even follow the declination into the west. It is fortunate that this site had more inscribed dates available than any other. Since the dates are exact, the deviance of these points from an exact fit to the declination curve is given simply by the difference in y-coordinates(declination). For the GMT correlation, only one building orientation out of ten falls within range of experimental error (1°) of the curve; the Spinden correlation yields three. If these dates can be taken as the time of <u>construction</u>, then the case for magnetic orientation is not as good as it looked. More buildings fit for the Spinden correlation, but the average deviation for all inscribed structures favours the GMT (4.4° to 4.5°). In any case, neither correlation indicates a habitual magnetic orientation.

The case for Monte Alban is even weaker than that for Copan, especially in view of the uncertain datings. A point of support is that Monte Alban, lying in the Valley of Oaxaca, was subject to Olmec influence in its early history. But again, magnetic alignment was clearly not the only determining factor in aligning Monte Alban structures.

If the ancient Mesoamericans did not point their buildings to magnetic north, what did motivate their predilection for east of north orientations? Many workers have investigated the possibilities of astronomical orientation. The most obvious possibility is to turn our attention 90° to various special risings and settings of the sun. The men who built Stonehenge were impressed with the peculiarities of this event, enough to construct a huge stone monument to record them. There are other possibilities; James Dow (1967) has suggested that the rising of the Pleiades cluster provided the baseline for Teotihuacan. Astroarchaeology is a whole field in its own right so no more will be said here. Aveni's two books (Aveni,1975 and 1977) as well as his article in Krupp (1978) serve as a good starting point for further reading.

The results of this investigation have shown that buildings in ancient Mesoamerica were most probably not aligned with magnetic north. The one saving fact for this hypothesis is that the orientations may have been determined using a 'broken' compass, one which did not point to magnetic north. M-160, itself, does not now indicate magnetic north, although it may have originally. If this were the case, then 'magnetic north' would not be a well defined direction, and it is difficult to see how such a possibility could be tested. Perhaps further investigation in the Valley of Oaxaca and down the Pacific coast is warranted, but this author is convinced that the ancient Mesoamericans did not align their buildings with magnetic north.

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A list of all works cited in this paper follows. To complete the bibliography on archaeomagnetism, the list from Aitken (1974) should be consulted for an exhaustive reference to earlier works.

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