



ORIENTATIONS OF MINOAN BUILDINGS ON CRETE MAY INDICATE THE FIRST RECORDED USE OF THE MAGNETIC COMPASS

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ABSTRACT

Archaeomagnetic research has enabled the determination of the secular variation record of the past geomagnetic field and has been used as a tool for absolute and relative dating. The archaeomagnetic secular variation of declination can be used in conjunction with architectural building plan orientation angles (strike directions) to establish, whether or not, a magnetic compass was possibly used to align buildings. Until now, it has been speculative as to, how or why, Minoan buildings were orientated in an approximate North-South direction or at 'askew' angles to one another. Here, it is observed, that, the orientation angles, of some significant Minoan buildings on Crete which have been compared to the archaeomagnetic (secular variation of declination) reference curve record (Bulgaria) for that period, are consistent with the possible use of a magnetic compass. Four of the six main Palaces and other significant buildings may have been oriented using this method. This may indicate the first recorded use, by the Minoans of a magnetic compass. These findings have archaeological implications (chronology) and are of significant interest architecturally. They are also relevant to Minoan religious and cult studies and may have implications for Minoan maritime navigation studies.

KEYWORDS: Minoan, Archaeomagnetism, Declination, Magnetic Compass, Building Orientations, Navigation

INTRODUCTION

The purpose of this study is not to specifically date Minoan archaeological sites but to show that some building orientations are broadly consistent with the ambient declination angle which may indicate that building lay-outs were made using a magnetic compass. Minoan archaeological site locations in Central/Eastern Crete and some schematic building orientations are shown in Fig. 1.

The Declination Angle is the angle between Magnetic North (horizontal component direction as shown by a magnetic compass) and True North. It has a different value from one geographical location to another and also changes with time moving East or West of True North, thus the term secular variation. It is one of the three magnetic parameters of the Geomagnetic field (Declination, Inclination and Intensity or strength) (Tarling, 1983).

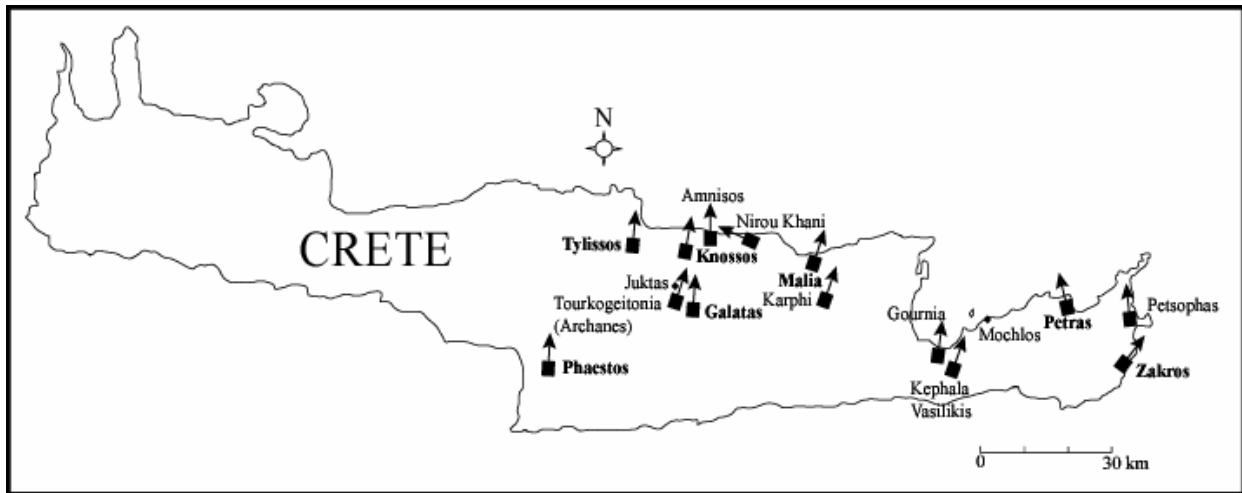


Figure 1: Map of Crete, site locations and schematic building orientations

The Protopalatial period (MMI - MMII) (Middle Minoan) is reported to have lasted from ca. 1900 BC to 1750 BC, about 150 years and over the course of this period the construction of the first Minoan Palaces at Phaestos, Knossos and Malia transformed the Island's history (MacEnroe, 2010).

The angle orientations between the main Minoan Protopalatial Palace's (Central Court long axes) are significantly different but there was no apparent reason to suspect that the orientations were not simply "random", or approximating North-South to facilitate passive heating/cooling, or for some other reason, possibly religious or astronomical.

Liritzis and Vassiliou (2006a) report that Ancient Greeks saw the Aurora Borealis strongly enough to associate it with particular Gods (hyperborean Apollo) and to build temples of unusual orientation. As such, 14 oriented temples of Apollo from ancient Greece and its colonies have been identified. Liritzis (1988) also has

used aurorae and inclinations for archaeomagnetic dating. Although astronomical targets may have been only one amongst several factors that determined the orientation of ancient buildings, arguments drawn from ancient literature support contemporary archaeomagnetic research on virtual pole shift, that points to intentional orientation towards a celestial phenomenon, either aurorae or sunrise. Liritzis and Vassiliou (2006b), also, report that, in a study of 12 Greek Byzantine churches, orientation is towards the east in relation to the day of sunrise. Taking into consideration the Gregorian and Julian calendars, orientation of the nave towards spring and/or autumn (ie) around the two equinoxes were found for most churches, with orientations towards the summer solstice and the name day of the Saint, as well.

It has been suggested that the orientations of Minoan Palaces were deliberately oriented towards the 'East' and the rising sun and that the rough North-South orientation of the Palaces

were connected to the function of the Central Court or were aligned to solar and lunar orientations (Shaw, 1977). Orientation explanations in the literature have referred to, “rising sun at equinoxes and solstices”, (Blomberg and Henriksson, 2001) and “N-S, NE-SW, rough N-S, arbitrary N-S, E-W orientation” (MacEnroe, 2010). However, orientations are, in fact, clearly different and specific. Location or position relative to the points of the compass has been demonstrated by the construction of early Churches in Denmark (Abrahamsen, 1991) and England (Searle, 1974). Practical constraints on some sites, however, may take priority over religious or astronomical orientation preferences and govern orientations. It is important to note that magnetic compass orientations are not universal. Minoan building orientations range from East to West of North through an angle of $\sim 103^\circ$ as indicated, for example, by the ‘extreme’ orientations of Kato Zakros (Central Court long axis), $+37^\circ$, (+ sign denotes, East of North) and Nirou Khani (Minoan Hall/forehall long axis), -66° , (- sign denotes, West of North) (Fig. 1).

METHODS & ORIENTATIONS

Use of Archaeomagnetic Secular Variation

Archaeomagnetic secular variation curves for the past geomagnetic field are established by measuring appropriate materials from the pre-historic past, including, burnt mud brick walls, baked clay from oven plasters, kilns, burnt floor layers subjected to ancient fires, (Kovacheva et al, 1998), (Tarling, 1983), (Xanthakis and Liritzis, 1991). It must be noted, however, that in general, archaeological sites suffer from the absence of precise dating because of the problems of contradictions within the calibrated ^{14}C dates (Boyadziev, 1995), (Kovacheva, 1995). Declination values obtained from ‘in situ’ structures are the most reliable as tilting effects on kilns, in particular, are more likely to affect inclination (Kovacheva et al, 1998). Material containing suitable magnetic grains after being subjected to heating above, about 700°C , record, on cooling the ‘elements’ (Declination, Inclination and Intensity or strength) of the ambient geomagnetic field (Tarling, 1983).

In an attempt towards alternative archaeomagnetic dating, time-series statistical (periodic) analysis and correlation with solar-terrestrial parameters have been reported. Liritzis (1982), Liritzis and Petropoulos (1986) and Xanthakis and Liritzis (1989), published the first results concerning the maximum entropy and power spectrum analyses that revealed different periods in the archaeomagnetic data (intensity and inclination). In these papers, the 200 yr period is compared with different solar-terrestrial phenomena. Xanthakis and Liritzis (1991) also compared the results from archaeomagnetic time series data (intensity, declination and inclination) with those obtained from British lake sediments.

The angular deviations from True North of some Minoan buildings were compared to the Age-Declination [Archaeomagnetic secular variation of declination Reference Curve (ARC)], magnetogram, for Bulgaria (Kovacheva et al, 1998), with particular interest in any meetings (intersections) of the ARC by building orientations from the period between ~ 2400 BC and ~ 900 BC (Fig. 2). The older archaeomagnetic data from 0 – 6000 BC is arguably the best secular variation record in the world (Kovacheva et al, 1998). Bulgaria, which is due north of Crete has currently a declination difference between the two locations of less than 1° and the use of the Bulgarian ARC for comparisons with Cretan building orientations, presumes, that, the declination difference, during the ‘period of archaeological interest’ was of a similar value. A magnetogram for the secular variation of declination in Greece has also been constructed by Evans (2006) but unfortunately only a few data points fall within the archaeological “period of interest” of this study. It is broadly consistent, however, with the Bulgarian dataset.

Inspection of the Bulgarian ARC shows a large and rapid declination amplitude swing of about 16° , from ~ 1850 BC, Declination = $+18.56^\circ$ to ~ 1770 BC. Declination = $+2.58^\circ$ (Kovacheva et al, 1998). A total declination change of $\sim 56^\circ$ over the period 6000 BC to present day was obtained by averaging declination values using a 100 year non-overlapping window (Kovacheva et al, 1998). The mean of the ARC to which intersections of building orientations are made

gives a high 'probability density' at a 95% confidence level for dating (Kovacheva et al, 2004). The uncertainties within the ARC for the Protopalatial 'period of interest', particularly from about $+12^{\circ}$ to $+3^{\circ}$ (~1820 BC to ~1765 BC) are very low. Unfortunately, the section of the ARC between ~1400 BC and ~1150 BC, has not yet been completed in the Bulgarian record but the trend has been tentatively been 'inferred-in' by Evans (2006) (Fig. 2). The rapid westerly shift in declination at this time is confirmed by data from archaeomagnetic directional analyses on 'fired' materials from Crete involved in the Late

Minoan (LM) destruction period (Declination = -4.5° Inclination = 58.7° [α_{95} Fisher (1953) = 2.1°] (Downey and Tarling, 1984). Liritzis, (1985), however, expresses some reservations, in regard to this directional result. The Cretan directional values are both consistent with the Bulgarian inferred directional reference curves, within error. Liritzis and Thomas (1980) work on LM kilns confirms the high value of inclination $\sim 58^{\circ}$ at this time but no declination value is given. On the basis of this Late Minoan directional data, an alternative inferred section is given (Fig. 2).

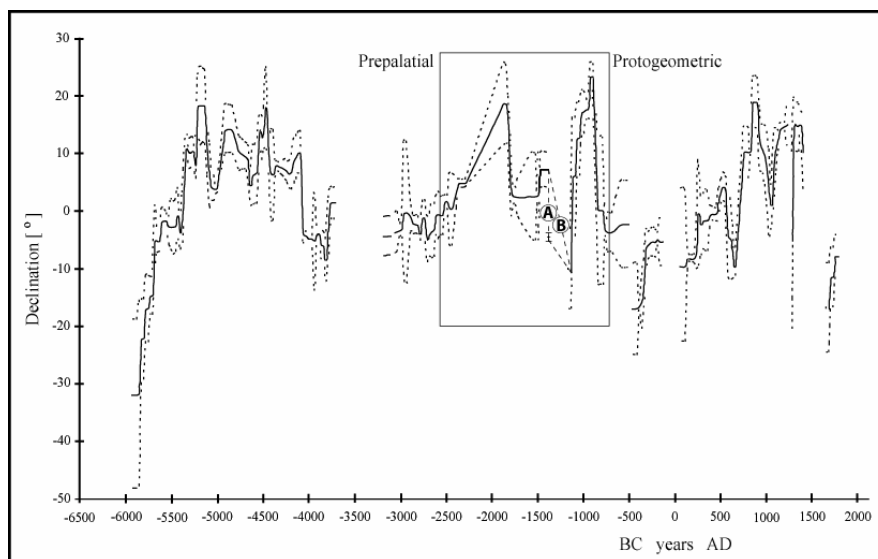


Figure 2: ARC (Secular Variation, Declination) for Bulgaria, from present to 6000 BC (reproduced, after Kovacheva et al, 1998.). Boxed area indicates the archaeological 'period of interest'. Circled letters A (Downey and Tarling 1984) and B (Evans 2006) indicate inferred sections of the ARC between ~1400 BC. to ~1150 BC

Minoan Building Orientations

The long-axes orientations of the Central Courts of the six main Palace sites and the 'N-S' walls within other sites were measured and their orientations compared to True North. Orientations of buildings are taken from published sites plans (MacEnroe, 2010), (MacGillivray, 1994), (Levi, 1976), (Van Effenterre, 1980), (Pendlebury, 1954) and (Poursat, 1978). Reference to 'True North' or 'Grid North' are rarely specified on site plans, however, using the Redfearn (1948) calculation, the grid convergence for sites in Central and Eastern Crete was shown to vary by less than 1° . An 'error' of $\pm 0.5^{\circ}$ is assigned to each building orientation and satellite imagery

was also used, where possible, to confirm orientations.

The orientations of the Central Courts' long axes for the main Palace sites which meet the mean of the [Archaeomagnetic secular variation of declination Reference Curve (ARC)], magnetogram, for Bulgaria, Kovacheva et al (1998), (Fig. 2) are shown in (Figs. 3 and 4) and listed in Table 1. The Protopalatial Palace at Knossos is oriented at $+10^{\circ}$ and this angle meets the ARC at two points (example Fig. 3), firstly at ~2120 BC. It must be noted, that, at Knossos, there is an EM III (Early Minoan), (Late Prepalatial) facade beneath the later Protopalatial Palace, aligned in the same orientation as the Protopalatial walls (MacEnroe, 2010).

Table 1: Comparisons of Archaeological and Archaeomagnetic Dates. Building site orientations (Declination) in degrees East (+) or West (-) of True North and Archaeological Dates, (in McEnroe 2010), unless otherwise indicated. Archaeomagnetic Dates obtained from the intersection of the building orientation angles with the ARC mean. * dates are those obtained from within the inferred sections of the ARC.

Archaeological Site	Building Orientation (degrees, +E, -W)	Archaeological Date	Archaeomagnetic Date (BC), using mean of ARC
Knossos , Protopalatial Palace (Central Court long axis)	+10	MM IB - MM IIB	2120 or 1810 (or date uncertain)
Malia , Protopalatial Palace (Central Court long axis)	+18	MM IB - MM IIB	1900 or 1840
Quartier Zeta Gamma ('N-S' walls of rooms 1-6)	+18	EM III - MM IA	1900 or 1840
Quartier Mu (Building A) ('N-S' walls of Lustral Basin, rooms 10-13, Magazines)	+3	MM I - MM IIB	1765 or 1490
Quartier Nu (West area, main room)	0(N)	LMIII	(1380 or 1280)* or 1120
(East area, main rooms)	-7	LMIII	(1350 or 1180)* or 1130
Phaestos , Protopalatial Palace ('N-S' West wing walls)	+3	MM IB - MM IIB	1765 or 1490
Galatas Palace (Central Court long axis)	+4	MM IIIB - LM IA	1790 or 1485
(West area buildings)	+6	MM II	1800 or 1475
Kato Zakros Palace (Central Court long axis)	+37	LM IA - LM IB	(No date)
Petras Palace (Central Court long axis)	-13	MMIIA	(No date)
Tourkogeitonia (Archanes) 'Palace' (Central Court long axis)	+18	MM I - MM II	1900-1840
Mochlos , Artisans' Quarter (Building A, East walls of rooms 1,4 and 10)	+18	Neopalatial	1900 or 1840
(Building B, West walls of Rooms 1,2 and 7-12)	+6	Neopalatial	1800 or 1475 or 1380
Tylissos (site plan, Sakellarakis and Sapouna-Sakellarakis,1997)			
Houses:- A	+7	LMIA-LMIB	1805 or 1470
B	+4	//	1790 or 1485
C	+3	//	1765 or 1490
Amenospilia Sanctuary ('N-S' walls of rooms 1-5)	+6	MM II-MM III	1800 or 1475 or 1380
Amnisos (main room A, 'N-S' West walls)	0(N)	LM III	(1380 or 1280)* or 1120
Mt. Juktas Peak Sanctuary ('N-S' East walls of rooms I - IV)	-6	MM - LM	(1340 or 1200)* or 1130
Petsophas Peak Sanctuary ('N-S' West walls, rms.1,2 and 4)	-6	//	(1340 or 1200)* or 1130
Kephala Vasilikis ('N-S' walls, rooms 1 - 3)	+25	LM IIIC - Proto-geometric	920 ± 40
('N-S' West walls, rooms 5 and 6)	+19	//	940 or 890
Karphi ('N-S' West walls of rooms 2,3,4,6 and 7)	+19	LM IIIC	940 or 890
'Barracks', (rooms 135 – 140)	+19	LM III - Proto-geometric	940 or 890
Great House ('N-S' walls, rooms 8 and 9)	+8	//	1070 or 870
Temple ('N-S' walls, room 1)	+4	//	1120 or 850
Gournia Civic Shrine ('N-S' long axis)	+7	LMIII	1080 or 860

These walls “represent only a small part of a grand undertaking.... at the heart of the settlement, much of the hill was leveled and a terrace, as massive in scale as the corresponding section of the later Palace, was constructed” (MacEnroe, 2010). This indicates the lengths, to which, architects and builders would go to, in order to achieve the preferred orientation. This orientation suggests that a magnetic compass may have been used during the late EM III period, or alternatively, the building was intentionally aligned towards the vicinity of Mt Juktas. It has been suggested that there was a special relationship between Knossos and Mt. Juktas (Evans, 1921). The second, $+10^{\circ}$ intersection with the ARC is at ~ 1810 BC. The Protopalatial Palace, however, may logically have been constructed on the already existing substantial underlying buildings as was the case with Neopalatial constructions which followed the same pattern of the Protopalatial lay-outs. If the Protopalatial lay-out followed the alignment of the former EM III buildings, then the date of its construction is uncertain as the later ($+10^{\circ}$) intersection of the ARC becomes redundant. It is however possible that, the Protopalatial construction was commenced at ~ 1810 BC when the declination was coincident with that at ~ 2120 BC. If this was the case, it would suggest that the Protopalatial Palace at Knossos was laid out later than the Protopalatial Palace at Malia.

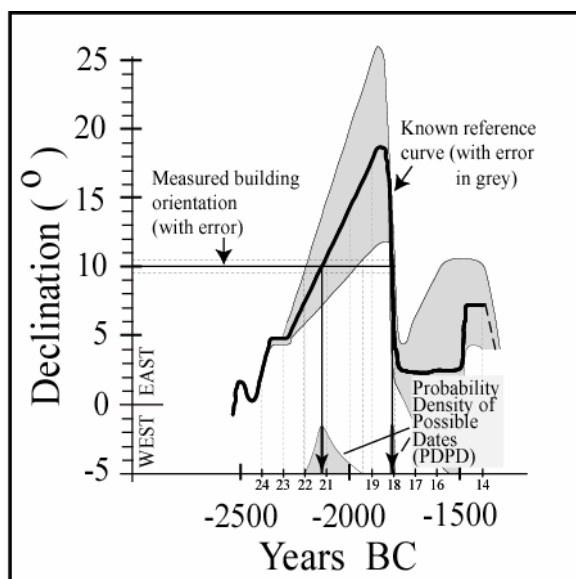


Figure 3: Enlarged section of the ARC showing age determination method

The orientation of the Central Court of the Palace at Malia is oriented at $+18^{\circ}$ and intersects the ARC in the ‘period of interest’ at two points (Fig. 4a), giving possible dates of ~ 1900 BC and ~ 1840 BC, both of which, it could be argued, are plausibly within the reputed archaeological time-frame. “The extraordinary EM III – MM IA buildings at Malia encourages one to question the assumption that the first Minoan Palace had to have been built at Knossos. Malia is at least, as likely a candidate” (MacEnroe, 2010). The foundations of the Protopalatial Palace have been dated, to the end of MM IA (Warren, 1987). The Protopalatial Palace at Phaestos is oriented at $+3^{\circ}$ and this intersects the ARC twice, firstly at ~ 1765 BC (MM II) (MacEnroe, 2010), in archaeological context, possibly the most likely date and again at ~ 1490 BC. Interestingly, to allow for the preferred orientation, “for the old Palace at Phaestos, an arbitrary N–S, E–W orientation was imposed on the site and much of the ridge was completely reshaped and geometrically ordered to accommodate it” (MacEnroe, 2010).

The buildings to the west of the main Palace at Galatas are oriented at $+6^{\circ}$, intersecting the ARC at ~ 1800 BC, the most likely date in archaeological context and again at ~ 1475 BC. (Fig. 4d). These buildings have been dated as MM IIA (MacEnroe, 2010). The $+4^{\circ}$ orientation of the main Palace’s central court, intersects the ARC at two points (Fig. 4c), firstly at ~ 1790 BC and again at ~ 1485 BC. The Palace at Galatas is dated to MM IIB – LM IA (MacEnroe, 2010). The orientation of the Palace at Petras (Tsiropoulou, 2003) is -13° and does not meet the ARC in the archaeological ‘period of interest’. Constraints on its orientation may have been imposed by the hill site on which it was built. The Central Court long axis of the Palace at Kato Zakros is orientation at $+37^{\circ}$ (MacEnroe, 2010) which is radically different from any of the other Palace sites and does not meet the ARC at any point. Other factors may have influenced the orientation of this site. Perhaps, significantly, both the sites at Petras and Kato Zakros are in Eastern Crete (Fig.1) and for some reason, a magnetic compass was not used at their time of construction.

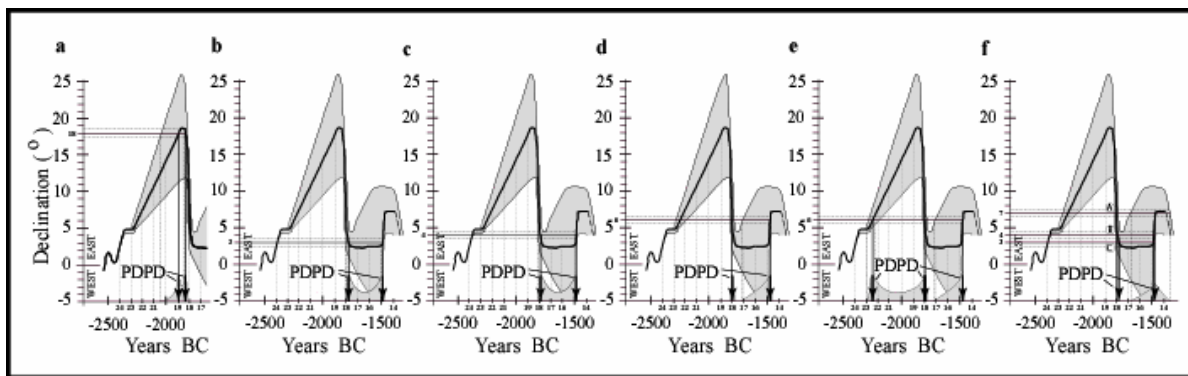


Figure 4: Enlarged sections of the ARC for earlier ‘period of interest’ Intersections of 14 building orientation angles (Central Court long axes for Palaces) with the ARC are shown with possible dates indicated for:
a, Malia :- Protopalatial Palace, Quartier Zeta Gamma (rooms 1-6), Quartier Mu (Potter’s workshop).
 Tourkogeitonia (Archanes). Mochlos (Artisans’ Quarter, Building A, ‘N-S’ East walls of rooms 1,4 and 10).
b, Phaestos, Protopalatial Palace. Malia:- Quartier Mu, Building A, (‘N-S’ walls of Lustral Basin, rooms 10-13),
 Magazines. **c,** Palace at Galatas. **d,** Galatas (West area). **e,** Mochlos (Artisan’s Quarter, Building B, ‘N-S’ 12 West
 walls of rooms 1,2 and 7-12). Amenospilia Sanctuary (‘N-S’ walls of rooms 1-5). **f,** Tyliisos (‘N-S’ long axes of
 Houses A, B and C).

OTHER SITES

Orientations of other significant Minoan building sites throughout Central and Eastern Crete (Fig. 1), that appear to have been oriented using a magnetic compass, are listed (Table 1) and shown (Figs 4 and 5). Some building orientations suggest construction contemporaneity (Fig. 4a) for example and perhaps significantly, the Protopalatial Palace at Malia, Quartier Zeta Gamma (rooms 1-6) dated EM III – MM IA (MacEnroe, 2010) and the ‘Palace’ at Tourkogeitonia (Archanes) dated MM I - MM II (Schoep., 2006).

Mochlos (Artisan’s quarter workshops)

Buildings A and B at this site are dated as Neopalatial (MacEnroe, 2010). However, the ‘N-S’ east walls of rooms 1, 4 and 10, (Building A), (Fig. 4a) if a magnetic compass was used, are oriented at $+18^{\circ}$, the same orientation as the Protopalatial Palace at Malia. It may be worth noting that, “The Artisans’ Quarter at Mochlos is somewhat reminiscent of the Protopalatial artisans’ buildings in Quartier Mu at Malia” (MacEnroe, 2010).

For Building B, the ‘N-S’ west walls of rooms 1,2 and 7-12 are oriented at $+6^{\circ}$ showing intersections with the ARC at ~ 1800 BC and at ~ 1475 BC (Fig. 4e) the latter date, in this case, being consistent with the Neopalatial archaeological date.

Tyliisos

The site plan taken from Sakellarakis and Sapouna-Sakellarakis (1997) indicates that the “askew” Houses A, B and C are respectively orientated at, $(+7^{\circ}, +4^{\circ}$ and $+3^{\circ})$ and have been dated from 1700 BC to 1500 BC. (Warren and Hankey, 1989), however, the intersections of the house orientations with the ARC suggests somewhat earlier dates, between ~ 1805 BC and ~ 1765 BC. These earlier dates suggest that the building order was, firstly House A, then B followed by C. Other intersections of the orientations with the ARC give dates between ~ 1490 BC and ~ 1470 BC, but the construction order at this later time is:- C, B, A.

Amenospilia Sanctuary

The “N-S” parallel walls of rooms 1 to 5 are oriented at $+6^{\circ}$, giving possible dates at ~ 1800 BC and ~ 1490 BC. The site is dated MM IIB – MM III (MacEnroe, 2010) which is consistent with the earlier archaeomagnetic date.

Quartier Mu (Malia)

The Protopalatial building A, is described as the “grandest structure known from the Protopalatial period” (MacEnroe, 2010) and is oriented at $+3^{\circ}$, the same orientation as the Protopalatial Palace at Phaestos. The angular difference between the Protopalatial Palace at Malia and Building A, is 15° suggesting that building

A was constructed ~75 years after the lay-out of the main Palace. The Potters Workshop (Quartier Mu) is oriented at $+18^{\circ}$, the same as the Protopalatial Palace (Fig. 4a).

Amnisos

“The Late Minoan settlement at Amnisos was built over the course of many years, beginning with the best-built, room A and is dated to LM III” (MacEnroe, 2010). It has an orientation of 0° (North) and can only be tentatively matched, at its first intersection with the inferred section of the ARC at ~1380 BC, ~1280 BC and at ~1120 BC (Fig. 5a). The exact date is therefore uncertain but the archaeomagnetic dates fall broadly within archaeological context.

‘Palace’ at Gournia

The long axis of the main court ‘Palace’ is oriented at -18° and does not meet the ARC at any point, however, the archaeomagnetic record for this later period is not yet complete. The ‘N-S’ walls of the Civic Shrine at Gournia are oriented at $+7^{\circ}$ and intersect the ARC at ~1080 BC (ie. LM IIIC, Warren and Hankey, 1989) and ~860 BC (Fig. 5h), the former date, being just later than the reputed archaeological date of LM IIIB (MacEnroe, 2010).

Peak Sanctuary (Mt. Juktas)

The ‘N-S’ east wall of ‘storage’ building rooms I – IV are oriented at -6° , giving possible dates ~1340 BC and ~1200 BC (taken from the inferred section of the ARC) and later, at ~1140 BC (Fig. 5c). The site is dated MM – LM (MacEnroe, 2010) and although it was probably occupied at an earlier time, the building’s orientation indicates that, the most likely archaeomagnetic date for these particular walls is Late Minoan.

Petsophas Peak Sanctuary

This site is dated from Protopalatial to Neopalatial (MacEnroe, 2010). The ‘N-S’ west walls of rooms 1, 2 and 4 are orientated at -6° , giving dates at ~1340 BC and ~1200 BC (from the inferred section of the ARC) and later, at ~1140 BC (Fig. 5c), suggesting that it was probably of Late Minoan construction. However, it should be noted that, “a small building was placed over the earlier votive deposit, but

very little material of LM date was found in association with the building” (MacEnroe, 2010). Interestingly, the earlier sites in Eastern Crete (Katro Zakros and Petras) do not appear to have been oriented using a magnetic compass.

Kephala Vasilakis (Building E)

The ‘N-S’ walls of rooms 1, 2 and 3 are oriented at $+25^{\circ}$ at the extreme easterly maximum of the declination (within error) giving a date at $\sim 920 \pm 40$ BC (Fig. 5d). The ‘N-S’ west walls of rooms 4, 5 and 6 are oriented at $+19^{\circ}$ and intersect the ARC at ~940 BC and again at ~890 BC (Fig. 5e). It is therefore uncertain as to the relative times of construction of rooms (1, 2 and 3) and rooms (4, 5 and 6). The complex was not laid out at one time but was constructed over the course of many years from LM III C – Protogeometric (MacEnroe, 2010).

Karphi

The ‘N-S’ rooms (135 – 140) of the large axial houses to the east and the so-called “Barracks” rooms (3 – 7) are oriented at $+19^{\circ}$ giving an archaeomagnetic date at ~940 BC and ~890 BC (Fig. 5e). The ‘Great House’ (N-S. walls 8 and 9) are oriented at $+8^{\circ}$ intersecting the ARC at ~1070 BC and at ~870 BC (Fig. 5f). The Temple (north of site, room 1) is oriented at $+4^{\circ}$ and intersects the ARC at ~1120 BC and ~850 BC (Fig. 5g). The sites are dated LM III – Protogeometric (MacEnroe, 2010). It is interesting to note that, rooms (58 – 61), described as ‘non-axial’ buildings were laid out as the topography and existing buildings allowed (MacEnroe, 2010).

A comprehensive survey of the orientations of all Minoan and Mycenaean sites, including, small settlements, houses, villas, peak sanctuaries, temples, cemeteries, tombs etc, was unfortunately beyond the scope of this initial report. It is important to note that, there is always the possibility that building lay-outs were not made using a magnetic compass and, that, their orientations were simply coincident with the ambient declination. This may give rise to a misinterpretation of age. Future improvements in the archaeomagnetic secular variation record for Greece will allow for more accurate dating and for the identification of other magnetically oriented sites.

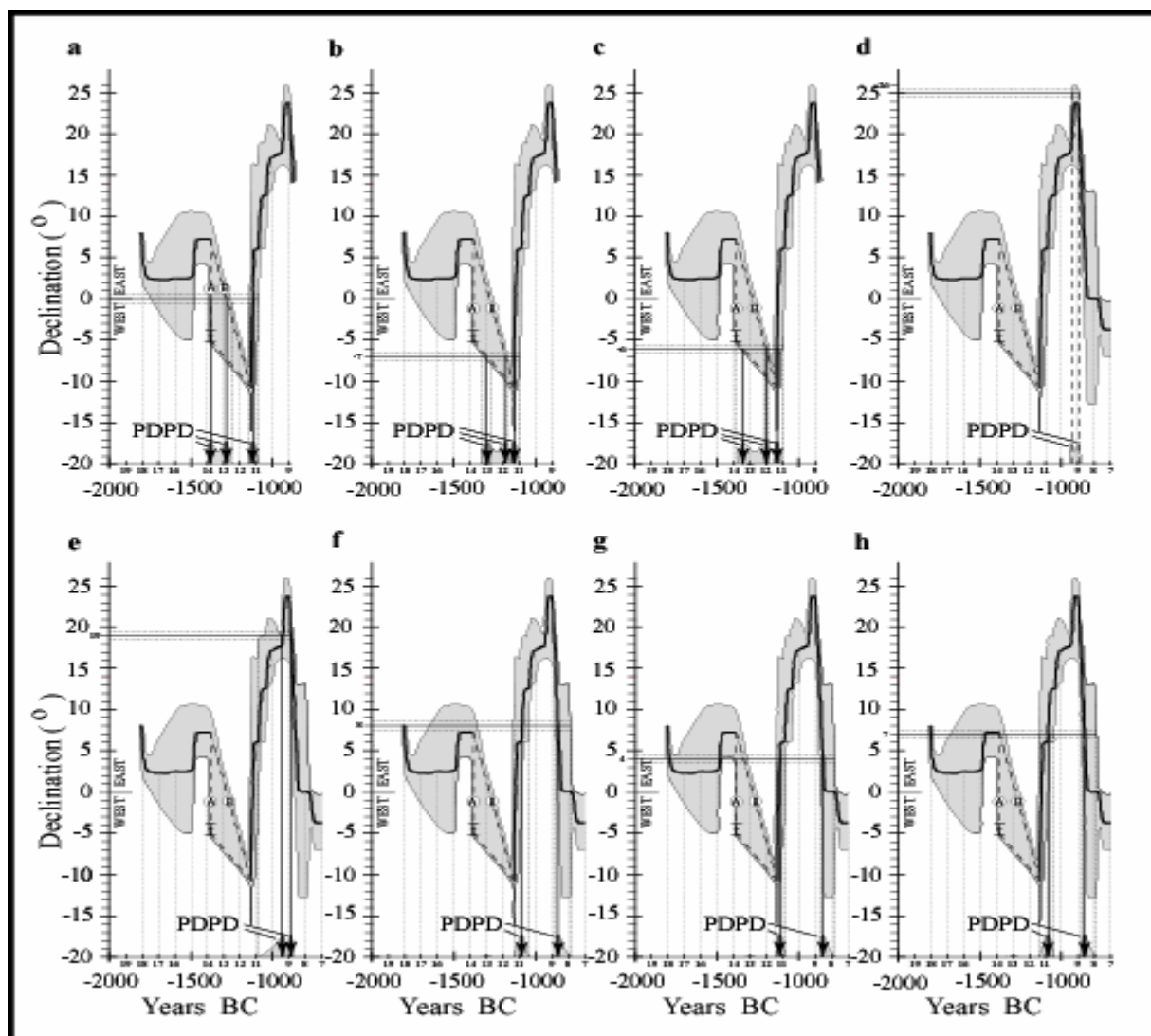


Figure 5: Enlarged sections of the ARC for later 'period of interest' Intersections of 12 building orientation angles with the ARC are shown with possible dates indicated for:- a, Malia, Quartier Nu (West area, main room). Amnisos (room A), b, Malia, Quartier Nu (East area, main rooms). c, Mt. Juktas Peak sanctuary ('N-S' East walls of rooms I – IV). Petsophas Peak sanctuary ('N-S' West wall of rooms 1,2 and 4). d, Kephala Vasilikis ('N-S' walls of rooms 1-3). e, Kephala Vasilikis ('N-S' West walls of rooms 5 and 6). Karphi :- ('N-S' West walls 17 of 'axial' houses, rooms 135-140), ('Barracks' rooms 2,3,4,6 and 7). f, Karfi (Great House, 'N-S' walls of rooms 8 and 9). g, Karfi, Temple 'N-S' walls, room 1. h, Gournia shrine, 'N-S' long axis

Minoans and their use of the Magnetic Compass

The observations suggest that a magnetic compass may have been used for some building orientations which invites the question, as to, how the Minoans became aware of the magnetic properties of materials and their uses. The answer, can only be, at best, speculative at this stage, because of the absence of direct archaeological evidence. A primitive functional magnetic compass can be made simply by taking a small sliver of lodestone (magnetite), magnetiz-

ing it, by stroking it with another lodestone and then placing it onto a small floating cork. In addition to its use for building orientations, it may have been used as a navigational aid at sea. In 'The Ship Procession in the Miniature Fresco' (west house, south wall, room 5) Akrotiri, Thera, specific emblems decorate the prow and stern, hull mast-top and dress-ship lines. An emblem of a 'star/rosette' was emphasized on the hull of the Flag-ship and on all the prows of the large ships (Morgan Brown, 1978) (Fig. 6). This depicted circular object has specifically sixteen pointers with dots between them

around the circumference, more or less symmetrically disposed. Could this artist's crude representation, be that of a magnetic compass, more likely to be (or exclusively) used by the larger 'Ocean-going' ships?

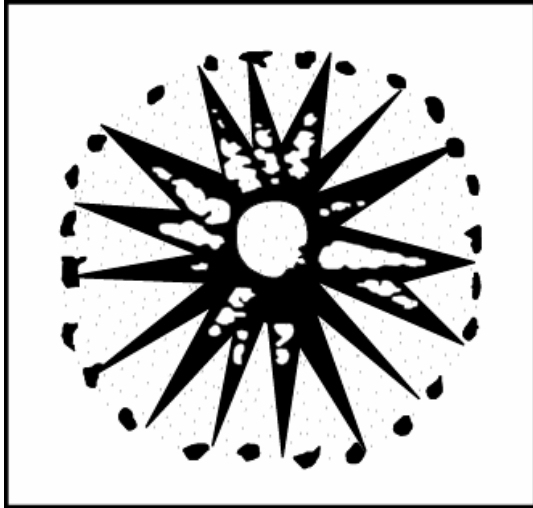


Figure 6: Fig. 6 Star/Rosette 'insignia/emblem'. Sixteen pointed 'Insignia' as depicted on Flag Ship and Larger ships. In:- 'The Ship Procession in the Miniature Fresco' (west house, south wall, room 5) Thera, (reproduced, after Morgan Brown 1978).

CONCLUSION-DISCUSSION

In conclusion, the archaeomagnetic record (Bulgaria), for the past 8000 years, as used in this study, is based on a carefully compiled and comprehensive dataset. This has allowed for the comparison of some Minoan Cretan buildings' orientations with the secular variation of decli-

nation reference curve which may indicate that a magnetic compass was used for orientation and the inevitable acquisition of approximate dates. The approximate dates obtained for the Protopalatial Palaces at Malia, Phaestos and perhaps Knossos and the Palace at Galatas are consistent, within error, with the reputed archaeological dates. The incompleteness of the record in the crucial period from ~1400 BC to ~1150 BC has hampered archaeomagnetic dating but nevertheless, the approximate dates obtained for this period are also broadly consistent with the reputed archaeological dates, within error. Later building orientations, as late as the 10th Century BC also intersect the ARC in the approximate archaeological time-frame. It would appear, that a magnetic compass may have been used for some building orientations over a considerable time period, possibly from Late Prepalatial to Protogeometric. Not all Minoan buildings were oriented using a magnetic compass, as was shown to be the case in other building orientation studies in Europe. If building orientations indirectly recorded the ambient declination, the question remains, as to how the Minoans became aware of magnetism and its uses. In addition to its use for surveying, a magnetic compass could have been used as a navigational aid at sea. If this simple, logical step was made, it would have allowed for 'all year-round' trading, leading to Maritime superiority in the Eastern Mediterranean.

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