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THE CRETAN MIDDLE BRONZE AGE 'MINOAN KERNOS' WAS DESIGNED TO PREDICT A TOTAL SOLAR ECLIPSE AND TO FACILITATE A MAGNETIC COMPASS

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ABSTRACT

Archaeometry is the application of scientific techniques used to analyze archaeological materials. The Cretan Bronze Age Minoan Kernos, has hitherto, been regarded as a gaming board or for religious purposes. Here, it is shown, that, it was designed, specifically, to predict the occurrence of the 9th. January 1860 BCE Total Solar Eclipse. A prototype magnetic compass was centrally facilitated in a non-magnetic marble structure, whose geomagnetic declination angle, appears to coincide with the Kernos' eclipse prediction-axis orientation. Comparisons of eclipse constructions taken from Kernos measurements, with those of Hipparchus (2nd. c. BCE), appear to be similar, suggesting a common origin. Evidence obtained using a multidisciplinary approach, is testament to the sophistication of Middle Bronze Age science and technology and the ability to create a mathematically-based eclipse predictor and magnetic compass, 3800 years ago and 1700 years before the advent of the Antikythera Mechanism.

KEYWORDS: Minoan Kernos, Archaeoastronomy, Solar Eclipse Predictor, Hipparchus, Prototype Magnetic Compass, Zeus, History of Mathematics.

1. INTRODUCTION

This study is an attempt, using several scientific approaches, to discover why the 'enigmatic' Middle Minoan (MM) II, Minoan Kernos (MK) at Malia (Crete), was constructed. Crete is a Greek island located in the Eastern Mediterranean (Fig. 1, A, B). Here, it is suggested, that the MK was an eclipse predictor, housing for a magnetic compass and had an auxiliary function as an offering table. The findings, suggest that there may be a need to recalibrate the time of arrival of ancient eclipses and also to specify the exact geomagnetic declination angle for this location and time.

Figure 1. Maps of Crete in the Eastern Mediterranean showing the path of the total solar eclipse of 9th January 1860 BCE. (above) Path (west to east) of the total solar eclipse across the Mediterranean (Blue line, central path) (Red lines, extent of totality). (below) Close-up path over Central and part of Eastern Crete and eclipse data for the position of the MK at Malia. Also shown are the general locations of the Psychro and Idaion caves. Map data : Google Imaginery@2014 Terrametrics

The MK pre-dates the Antikythera Mechanism dated between 70-50 BCE (Freeth et al., 2006). This Mechanism is described as a powerful astronomical calculator and could predict the dates of solar and lunar eclipses possibly based on the Babylonian Saros cycle. The much earlier MK, although, not as technologically advanced, has sophisticated functions and is important to our understanding of science and technology in the MM II period. The chronological systems as used in Minoan archaeology are the traditional 'lower' chronology (Warren and Hankey, 1989) and a second modified version of the 'higher' chronology (Manning, 1995).

Archaeoastronomy is the study of how ancient peoples attempted to understand the celestial sky and its role in their cultures and beliefs (Ruggles, 2005). Astronomical principles are shown to underlie the orientations of buildings such as churches (Hoskin, 2001), the Pyramids (Mitchell, 2001)) and using the related discipline of archaeomagnetism, the orientations of Minoan buildings on Crete (Downey, 2011a). There are links with archaeoastronomy and archaeology and cultural anthropology, the history of science and religion and the astronomy of art and literature (McCluskey, 2004). Prehistoric peoples used high-precision 'horizon' astronomy to estimate dates in a year to a specific day (Thom, 1967) and Ancient Greek calendars started with the New Moon (McCluskey, 2000). Historical and ethnographic records have been used to understand ancient calendars and rituals (Aveni, 1986). Myth and cosmology have been shown to reflect astronomical events (Hugh-Jones, 1982).

2. MINOAN KERNOS

The Minoan Kernos is one of many such 'holed stones'. Minoan Kernoi have several names in the archaeological literature: 'stone slabs with depressions'; 'Pierres à cupules' as well as others (Cucuzza, 2010). They have been found in approximately 20 Minoan and Mycenaean sites in central and eastern Crete. Kernoi consist of circular holes cut into the surface of stone slabs and arranged in a circle or oval or arranged in a rectangle, parallel rows, spiral or irregular manner (Cucuzza, 2010).

2.1 Archaeological observations of the Minoan Kernos at Malia.

The MK is located in room XVI in the south west corner of the central court of the Neo-palatial Minoan palace at Malia, Crete (Cucuzza, 2010), (Fig. 2A). It is believed to be originally Middle Minoan (19th.c. BCE) but was retained, in-situ, as an artifact, in the Late Minoan palace (room xvi). Its original location was chosen, to allow for a clear view of the sky's southern horizon. It is described as a circular 'stone' with depressions, (Fig. 2B) and regarded as some sort of gaming board or offering table (Hillbom, 2005). However, it has been suggested that *"from an archaeological point of view, the recognition between religious and gaming activities is very uneasy"* (Cucuzza, 2010).

The MK is oriented along a line joining the (apex) central tip of its protrusion and through the centers of the protrusion depression and the central depression (Fig. 2B). It's axis is, unexpectedly at an angle of ~ 4° to the alignment of a nearby wall to the 'west' which parallels the long axis of the central court of the Palace (18° East of North) (Davaras, 1976), (Fig. 2, A, B and C). The central court's orientation is believed to have been aligned to the geomagnetic field declination angle (angle between magnetic and geographic north at the point of observation), at the time of the initial construction of the Proto-palatial Palace at Malia (~ 1900 BCE) (Downey, 2011a). The MK is currently dipping at an angle of ~5° to the 'Northwest' (Fig. 2C) but is shown, by Chapouthier (1928) to lie horizontally. If reset to the horizontal position the direction of its 'axis' would not be significantly affected.

In detail, the MK is a circular 'stone' of diameter ~ 88 cm and has 33 small and 1 larger depression (No.34) at the 'southern' protrusion end (Chapouthier, 1928). A deeper 'ovoid' central depression is surrounded by a distinct concentric ridge (Fig. 2, D, E) which 'housed' the magnetic compass. This depression is surrounded by a shallow 'flat-bottomed' depression 'cylinder', which in turn, is surrounded by a thin, slightly elevated, 'lip' which would allow liquid to be contained within the depression, to a maximum depth of ~2.8 cm (Fig. 2D). Currently, approximately two thirds of the Kernos' cylinder thickness (36 cm total) is below floor level, however, approximately half of the cylinder is shown to be below floor level when first excavated (Chapouthier, 1928).

Measurements of the MK were made from the published plans/sketches and cross-sections

(Chapouthier, 1928) and from oblique and plan photographs. The distances between the centers of depressions, their diameters, depths, areas and area ratios were measured and computed.

2.2 *Lithology and Provenance*

The rock type from which the Kernos is sculpted, is Plattenkalk marble (Fassoulas et al., 2004) (Fig. 2F). It is possible that, it was quarried from nearby locations to the east or south of Malia (Creutzberg et al., 1977) or from near the Psychro Cave, an ancient Minoan sacred site in the Lasithi district (Jones, 1999) (Fig. 1B). This cave is associated with the reputed birth place of Zeus (Watrous and Blitzer, 1982). Alternatively, the marble could have been sourced from the Idaion Andron Cave at Mt. Ida much further to the west (Fig. 1B), where the Plattenkalk nappe overthusts older limestones at the cave site (Creutzberg et al., 1977). Both caves are believed to have been centers of worship since ca. 2500 BCE (Watrous, 1996; Watrous and Blitzer, 1982).

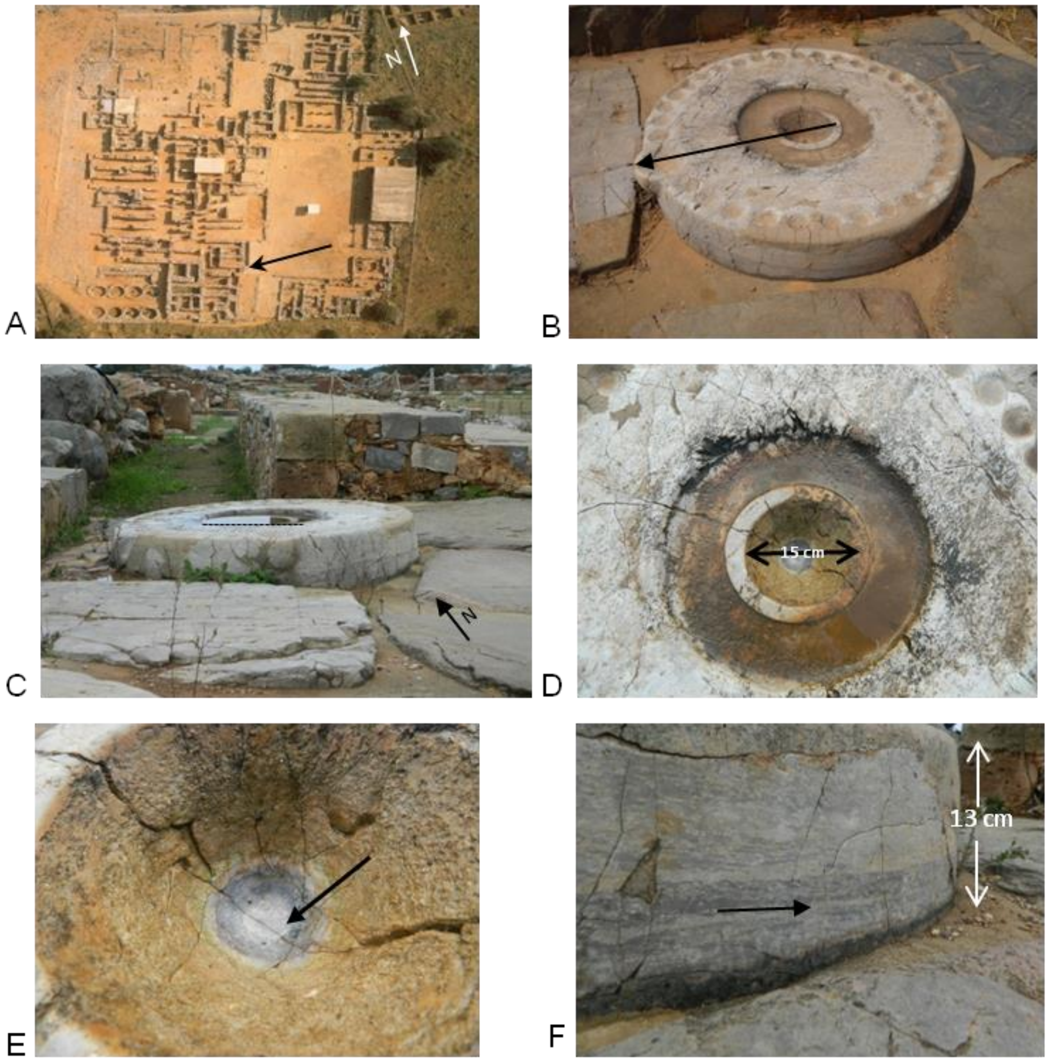

Figure 2. Aspects of the Minoan Kernos at Malia (A-F). Photos (B – F) by Author. (A) Site Plan photo of the Protopalatial palace at Malia (Central Court long axis orientation at18° East of North) with arrow indicating the location of the MK (Google Earth). (B) Oblique photo of the MK (diameter ~ 88 cm) with arrow indicating the direction of the eclipse prediction axis (14° West of South). (C) View of the MK towards the 'North' with rain water defining a current tilt, (dotted line) at ~ 5° to the 'Northwest'. (D) Plan view of the central depression (~ 15 cm diameter) with surrounding ridge and concentric larger shallow depression with elevated 'lip'. (E) Close-up of the central depression with arrow indicating the highly polished lower 'spherical- cap'. The rough sides of the depression are slightly 'convex-upwards'. (F) View of the 'Northeast' quadrant of the upper exposed section (~ 13 cm) of the MK, showing distinct sub-parallel foliation in the Plattenkalk Marble.

It is suggested that, the Plattenkalk marble, with its characteristic, metamorphic pervasive sub-foliation (Fig. 2F), was deliberately chosen for the construction of the Kernos, primarily for its non-magnetic properties but also for its durability and grandeur. Other rock types known to the Minoans for possible use, were not selected (Dierckx and Tsikouras, 2007; Fassoulas et al., 2004). These rock types are often 'magnetic' and can adversely affect the accuracy of a compass. Some coarse- grained igneous and metamorphic rocks contain an induced magnetization related to the magnetic susceptibility of the 'iron' rich minerals. The magnetic susceptibility of Marble (calcite), which is paramagnetic, is negligible. Comprehensive tables of the magnetic susceptibilities for common minerals and rocks are given in (Dunlop and Őzdemir, 1997). Natural Remanent Magnetization is predominant in finer grained rocks such as basalt in which smaller ferromagnetic 'iron' rich minerals may be strongly magnetic. Clays may also contain small strongly magnetic grains (Downey, 2011b). The 36 cm thickness of the marble Kernos is sufficient, to ensure stability in the ground and that any stray magnetic fields produced from within the substrata, would not compromise its accuracy.

2.3 The Magnetic Compass Arrangement: some simple Experimental Archaeology

Simple experiments were carried out using various lodestone (magnetite) masses placed onto the surface (frictional contact) of a proposed, replica wooden 'cone/ovoid' of mass ~ 530g (Fig. 3A). This was initially floated on water in a cylindrical container (keeping it away from the sides to avoid the effect of contact/surface tension forces) and showed that the spontaneous magnetization of a magnetite sliver (mass ~ 25g) was capable of accurately aligning the 'compass arrangement' to magnetic north. The direction was confirmed using a Brunton compass.

The Minoans may have become aware of magnetic properties of iron rich minerals during their preparation of paint pigments in which both organic and inorganic materials were used or from 'iron-included' processes in the production of ceramics (Noll, 1978). 'Iron-filing' sized pieces brushed from 'bearded' lumps of lodestone can be re-attracted and the miniature dipoles observed, with their varying directional properties and degrees of attraction and repulsion (Fig. 3B). The consistent North-seeking phenomenon may have been regarded as significant or even 'magical' as it pointed 'south' to the 'noon' Sun at one end and to the 'north' pole star, at the other end. The axis direction of the MK indicates that the interest at the time was in the southern part of the northern sky.

The compass base may have been made of oak because of its association with Zeus (Thanos, 2005) from the central part 'heart' of the tree trunk or branch and of specific gravity, (SG ~ 0.9). Oak was regarded as the most venerable types of trees in the Ancient Greek World (Gerasimides and Parcharidou-Anagnostou, 2003) with numerous oak species, indigenous to Greece with ancient forests on Crete (Strid and Tan, 1997). Quercusrubra (red oak) is particularly striking with distinctive brown/red and yellow growth rings.

The wooden base was required to support the masses of the magnetite (SG 5.15), together with, some type of directional 'pointer' (Fig. 3C). Middle Bronze Age, thin sheeted double axes with linear ornaments, have been recovered from the Psychro cave (Galanakis, 2013, p. 54, figs. 87,88) and are described as of no practical purpose. Such 'non-functional' axes are made of precious metals (gold, silver), bronze and clay. They are dated MM III – LM (Galanakis, 2013) but may be older (MM II). It is suggested that the thinness of such an axe, with a preference for gold (SG 19.3) up to a thickness of ~1 mm (depending on the chosen area for the axe), would make it an appropriate choice as a 'pointer', positioned and possibly, inlayed, at the top of the wooden base, possibly with a defining burnt surround. It may have been designed, so that the curvature of the axe blades, paralleled the distinctive concentric growth rings of the chosen oak. The doubled axe may have been invested with symbolic function (Herberger, 1972) with symbols related to Lunar phases, Sun, Pole Star, Underworld, 'The Door' and Animals or Mythical creatures which symbolized the seasons. Its choice as a pointer, would be in keeping with the special nature, with which, the compass was regarded and the desire to decorate it, richly and symbolically.

The removal of a volume of wood from the central top surface of the compass cone would be required to ensure that the compasses' final density would allow it to float (Fig. 3D). A cylinder may have been cut/carved (Blitzef, 1995) from its upper surface and covered by a thin lid of the same ring pattern, cut from the same log from which the base was made. The magnetite may have been concealed within this hollow and possibly secured with a combination- adhesive of beeswax and pine resin. The wooden base would likely have been protected from water penetration by the use of a beeswax sealant. The magnetite 'engine' whose crude dipole field as shown in Fig. 3E, should ideally be located at the center of mass (c of m), one quarter from the center of the base to the vertex. The area of the axe, mass of gold, volume of wood excavated, all affect the position of the c of m but can be adjusted accordingly.

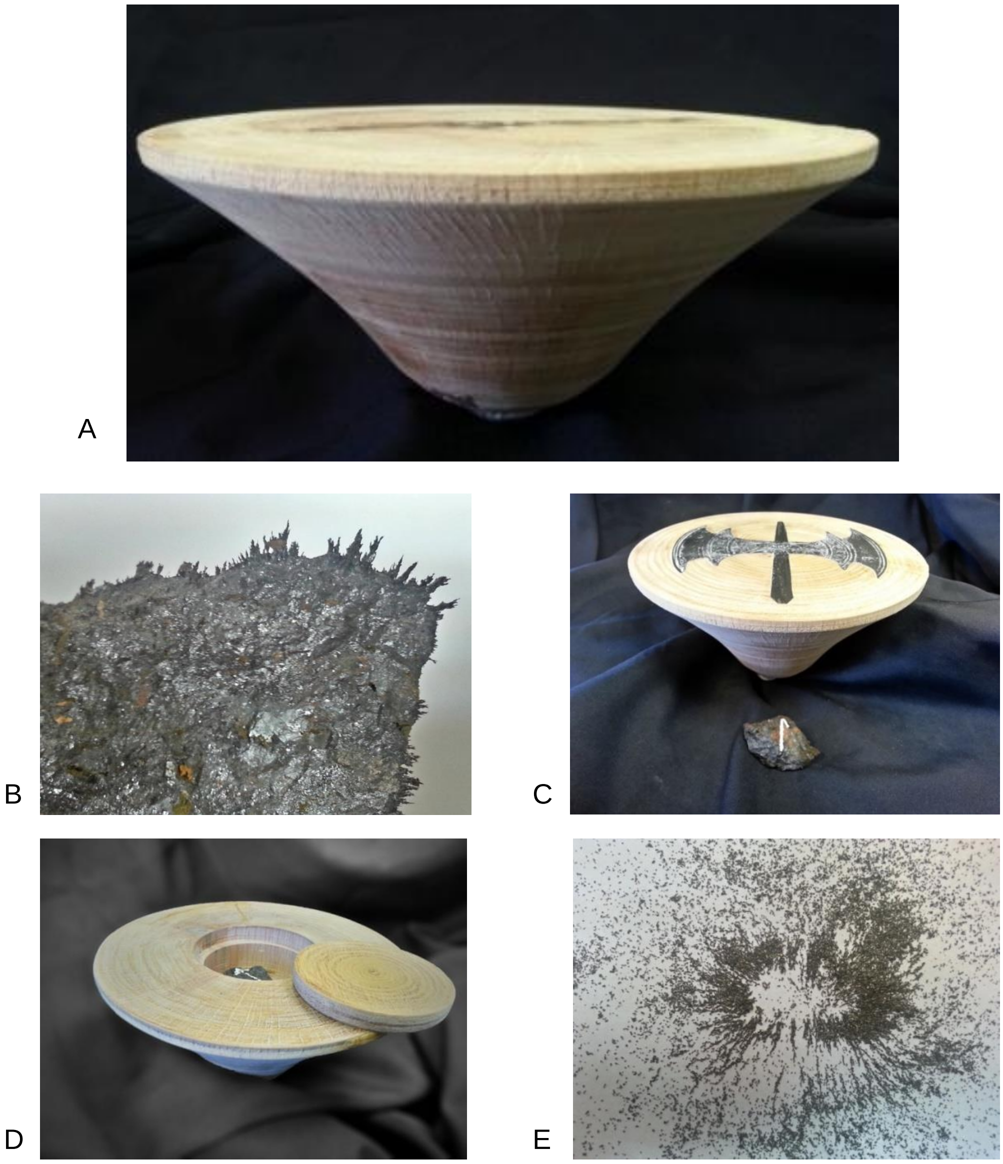

Figure 3. Proposed replica of the Magnetic Compass with lodestone (magnetite) (A – E). (A) Wooden (here Yew, SG 0.9, similar density to Oak) base 'cone' (~ 16 cm diameter, ~ 8.5 cm from base to vertex). (B) Magnetite (lodestone) with 'bearded' small 'dipole' fragments attached. (C) Compass base displaying a proposed 'doubled' axe 'pointer, possibly in thin gold (defined here in black) with 'shaft' in magnetic N-S orientation and coincident with the Kernos' eclipse prediction axis direction. An irregular sliver of lodestone is shown below. (D) Compass base showing excavated portion containing lodestone approximately at the center of mass and a 'concealing' lid which would be of a similar concentric growth pattern. (E) Pattern of the 'crude' (but effective) dipole field, produced by the magnetite sliver with field distribution delineated using iron filings.

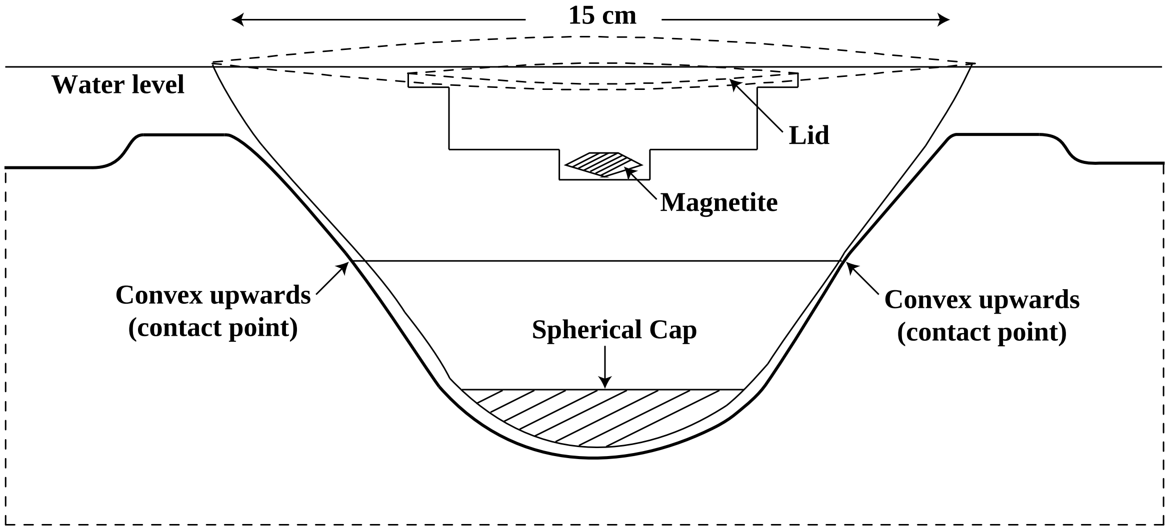

Figure 4. Details of Magnetic Compass. Wooden (oak) ovoid compass with excavated section and lid. Magnetite sliver shown at approximate of c of m. Single perimeter contact point produced by convex upwards nature of the depression sides. Spherical cap section 'fits' polished base of depression. Surrounding ridge is shown below water level. The diameter of the wooden compass base is 16cm, 1cm greater than the ovoid depression (d = 15cm).

2.4 Compass Housing (Central Depression)

The central depression with its surrounding elevated ridge is believed to have facilitated the compass (Fig. 2D), which would have almost completely occupied the space (Fig. 4). The lower part of the depression is highly polished (Fig. 2E) which may have been specifically designed to securely 'cup' the spherical cap at the base of the compass, if liquid was withdrawn and the compass allowed to 'settle' into a fixed position, after the geomagnetic field direction had been established. Significantly, the concentric elevated ridge (height ~ 1.1 cm) surrounding the central depression is at a lower level than the overall platform level of the Kernos. If filled with water, up to the 'lip' level of the larger surrounding 'cylinder', (depth ~2.8 cm), this ridge is below water level by ~ 1.7 cm. It is suggested that the compass's wooden 'cone', confined to the central depression, was designed, only to make underwater contact with the perimeter of the central depression's ridge, or at a 'perimeter' contact point within the depression (~ 4.7 cm below the water surface), created by the slight 'convex-upwards' design of the sides of the depression (Fig. 2E and Fig. 4). This would minimize frictional and surface tension (contact) forces, which would otherwise adversely affect the compass's directional seeking ability. As the wooden compass base was approximately at water level, the surface expression of its disc diameter would be ~16 cm. (~ 1 cm greater in diameter than the depression diameter), obtained by extrapolating and paralleling the curvature of the 'ovoid' depression, upwards to the water surface (Fig. 4). The area of the compass base is taken to represent the Earth's disc.

3. MINOAN KERNOS INTERPRETATION

3.1 The Kernos Geometry

Measurements of the geometry of the MK, suggest that its primary function was that of an eclipse predictor. The distances between depressions and their areas, are assigned to be representative of Earth, Moon and Sun, shown in an eclipse configuration (Fig. 5, A, B). The large surrounding shallower cylinder, concentric to the central depression represents the Sun and has an outer poorly defined and slightly elevated 'lip' ring (Fig. 2, B, D and Fig. 5, A, B) the purpose of which may have been to allow for an increase in water depth and prevent spillage onto the platform of the Kernos. Its ill-defined lateral extent, may be representative of the Sun's corona, as observed during a total solar eclipse. Another representation of the Sun, may be that, of the overall disc of the Kernos with the protrusion's proportion and curvature, consistent with that of the so-called 'diamond ring' phenomenon and the outer perimeter area of the Kernos, also representing a corona.

The thirty-three smaller circular depressions, close to the circumference of the Kernos, are considered, each to represent three of the ninety-nine new moons, of the synodic moon cycle, just over 8 yrs (Fig. 2B and Fig 5A). Each depression would represent a period of ~3 months and would be 'counted-down' prior to the eclipse, from the protrusion-side. A Kernos with 99 moons of the same size as the present 33, would necessitate a diameter of ~ 2.3m and require, an unwieldy, original 'working' marble slab (SG ~ 2.3), of dimensions of the order of (2.5 x 2.5 x 0.5)m and be of mass ~ 7200 kg. Its transport, particularly over a long distance, would be difficult, if not impossible. The present Kernos has a mass of ~ 500 kg and would require an original marble slab of dimensions ~ (1 x 1 x 0.5) m. Furthermore, 99 smaller moon depressions are probably not represented on the present Kernos, as their size would be insufficient, to sensibly hold any significant amount of offerings if indeed, that was there auxiliary design purpose. The Kernos's 33 depressions are shallow and cup-shaped and are clearly designed to hold 'something', as circular grooves would have been adequate to represent the moons of the Synodic moon cycle.

The larger shallow circular depression (No.34) at the 'southern' edge of the Minoan Kernos (Fig. 2B and Fig. 5A) together with its protrusion is regarded as symbolizing the Eclipse position with the depression's area, representing the Moon. Significantly, its area is three times that of one of the 33 small perimeter 'moons'. The area of the protrusion's 'completed' circle (extrapolating the curvature), is identical to the area of the central ovoid depression together with its surrounding ridge.

Circles representing the Earth, Moon and Sun are graphically represented in an eclipse configuration with the Moon positioned, mid-way between the Earth and the Sun; a distance dictated by the geometry of the Kernos (Fig. 5, A, B). The diameter of the Sun is the same distance as that, from the Earth (center of the central depression/compass) to the center of the Moon (Protrusion depression). This eclipse construction allows straight lines (light rays) to be drawn from the top and bottom of the Sun to the top and bottom of the Moon and Earth. No umbra is produced, only what could be interpreted as an Earth-encompassing penumbra (Fig. 5B). The Minoans may have been believed that the Moon was half way between the Earth and the Sun, perhaps not, an unreasonable assumption at the time.

3.2 *Construction of Hipparchus*

Hipparchus (190 – 120 BCE) developed a reliable solar eclipse predictor and confirmed his computations by comparing eclipses from his own period with eclipses from the earlier Babylonian records (Toomer, 1980; Toomer, 1974). Hipparchus presents a construction showing the relative positions of the Sun, Moon and Earth in an 'eclipse' configuration (Toomer, 1984) (Fig. 5C). This construction shows differences in distances between, Sun, Moon and Earth in comparison to that of the 'mid-way' Moon, Minoan construction. For comparison, the Minoan and Hipparchus constructions are normalized (Fig. 5, B, C) and appear to be remarkably similar.

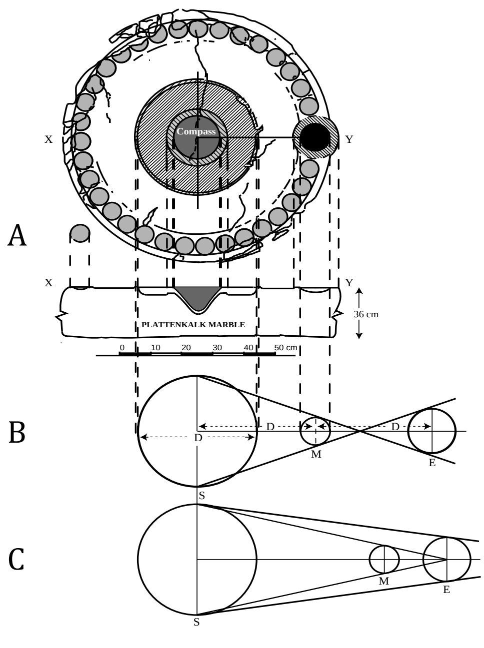

Figure 5. The geometry of the Minoan Kernos and Eclipse configurations. (A) Plan and cross section (X-Y) of the Minoan Kernos, based on Chapouthier, (1928) (16) with central position of the magnetic compass representing the Earth's (E) 'disc' area; concentrically surrounding 'Sun' (S) disc and 'Moon' (black) disc area of depression (34) at the protrusion end. (B) Minoan Eclipse construction based on the Kernos geometry with Moon half way (distance D) between Earth and Sun. (C) Hipparchus eclipse construction (normalized) for comparison.

4. ASTRONOMICAL OBSERVATIONS

4.1 Time and Date of Eclipse Occurrence

A total solar eclipse occurred in Crete on the 9th. January 1860 BCE, (-1860 calendar year), (-1859 astronomical year) (Espenak and Meeus, 2006) (Fig. 1, 2). For more information on solar eclipses see, Fred Espenak's Eclipse Web Site: sunearth.gsfc.nasa.gov/eclipse/eclipse.html

Totality at Malia is reported to have occurred at sun 'azimuth' 183.5° (Espenak and Meeus, 2006) (ie) 3.5° west of south, occurring (local time) just after solar noon. The MK's prediction axis, however, points to ~14° west of south, suggesting that the eclipse occurred approximately 35 minutes later. There is the possibility that the Minoans miscalculated the prediction axis' orientation, or that the Kernos has rotated from its original position since -1860, or that the lunar libration number (ΔT) (Espenak and Meeus, 2006; Morrison and Stephenson, 2004) requires recalculation. Although solar eclipse predictions are based on Terrestrial Dynamical Time of the greatest eclipse (TD), the position of the central eclipse path depends on Universal Time (UT). The parameter ΔT is calculated from the equation: $\Delta T = TD - UT$. Values of ΔT before 1600 CE. pre-date the telescope and are based on historical records of naked eye observations and occultations with simple polynomials used to achieve a best-fit for describing the value of ΔT from ca. 700 - 1600 CE. (Morrison and Stephenson, 2004). However, extrapolated values for ΔT before this time are uncertain. If the MK's eclipse prediction direction is accurate, ΔT would need to be recalculated with a required shift in the longitude position of the TD. Nevertheless, the eclipse axis direction is within the 1σ error of that presented by Espenak and Meeus, (2006).

4.2 Coincidental Alignments

There appears to be an alignment of the ambient Geomagnetic Declination angle and the Eclipse position. The 'swing' of the declination of the geomagnetic field during the period of the 19th c. BCE was relatively rapid (~ 12 minutes of arc/year) from east to west of North (Kovacheva et al., 1998) (Fig. 6). It would appear that the Minoans must have been aware of this westerly drift in declination and that, just over eight years before the eclipse, presumably, when the Kernos was installed (~ 1869 BCE), the compass direction would have been observed to be approximately one and a half degrees to the west of the MK's ('south-pointing') eclipse prediction axis. If the compass was replaced into its housing, periodically (perhaps every two years), during the pre-eclipse period, this would confirm that the magnetic South-seeking pointer was consistently moving at a steady rate towards the east and eventually into alignment with the eclipse predictor's axis on the 9th. Jan. -1860.

With regard to the accuracy of the regional archaeomagnetic reference curve for declination (Kovacheva et al., 1998) (Fig. 6): if the declination of the geomagnetic field obtained from the MK measurement is, in fact, 14° East of North at -1860 at Malia, (obtained without the use of traditional archaeomagnetic methods), it follows that this angle is correct (within any measurement error made at the time).

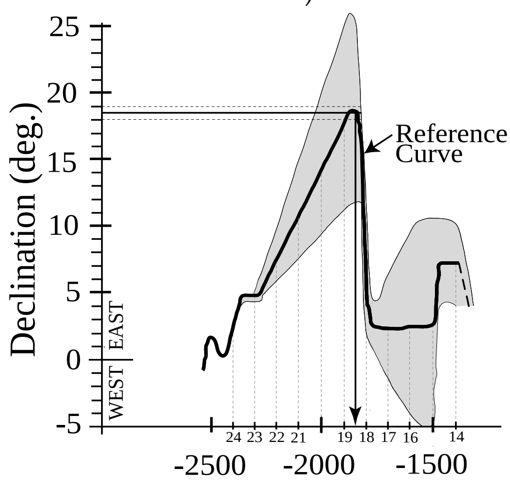

Figure 6. Secular Variation Curve for Declination. Relevant section of the archaeomagnetic reference curve for declination (Bulgaria), modified after Kovacheva et al., (1998), (38) indicating a declination of ~18.5° ± ~ 7° (error, grey shading) East of North at approximately -1860. (14° East of North as defined by the MK is well within error).

4.3 'Pole' Stars

The pole star in the middle of the 19th c. BCE was Thuban (Alpha Draconis, the Snake star) in the constellation of Draconis but it had 'drifted' away from the celestial North pole position since ~27thc. BCE. At the time of the eclipse of -1860 it would have appeared several degrees away from the pole in its circumpolar position due to the rotation of the constellation of Draconis. Thuban was superseded as the pole star by Kappa Draconis at the beginning of the 18^{th}.c BCE but the brighter 'nearby' Kochab in the constellation of Ursa Minor was brighter and may have been effectively regarded as the 'pole star'. In -1860 both Kappa Draconis and Kochab were now much closer to the pole than the weaker magnitude Thuban (Allen, 1899). Delta Draconis (Altias), (apparent visible magnitude ~3.0) was also in close proximity of celestial North. These mythologically significant stars are thus 'grouped' in the northern sky, 'opposite' to the eclipse position and may have been visible to the naked eye, during totality.

5. MYTHOLOGICAL AND ARCHAEOLOGICAL CONNECTIONS

5.1 Calendar (Toreador) Fresco, Knossos

It should be noted, that, the MK was constructed several hundred years before the Late Minoan period but may have some relation to the following comments by Marshack (1974) in relation to the existence of a Minoan calendar (Herberger, 1972) which, *"asserts the discovery of a complex lunar-solar notation in a unique border of the bull-leaping fresco at Knossos. The analysis presupposes an arthimetic, astronomic and notational knowledge for the Late Minoan that is culturally and cognitively complex. The calendar hypothesis is supported by the unbroken clay offering table at Phaistos, ca. 2000-1700 BCE with its intentionally irregular border sequence of sets of symbols, apparently related to various lunar-solar periodicities, the eight year, the longer eighteen year, plus Saros and a possible nineteen year Metonic cycle. However, the date for this knowledge is far too early in the present history of science"*. From the logic that emerges from the 'calendar' Fresco at Knossos, an explanation is offered, as to the meaning of the doubled axe by Marshack (1974). This includes references to the 'Great Year' and all three Minoan sacred beasts (Snake, Bull and Lion) as well as the mythical Gryphon and to astronomical phenomena previously mentioned. As such, the axe may well have been used as a symbolic compass pointer and may have been stored 'out of sight' and brought only into public view during dramatic ritual presentations or 'epiphanies' at least every two-year calendic intervals along the cycle of the 'Great Year Time' before the eclipse occurrence.

5.2 Zeus and some Findings in the Psychro Cave

The Minoan economy was based on agriculture with their arts and icons symbolized the cycles of nature in relation to their farming activities and society's well-being (Hood, 1971). There was probably a fear that an eclipse was a sign that the 'Gods were angry' and was a bad omen (Andrews, 2004) for future harvests. It is logical to think, that the Minoans 'turned' to Zeus (King of the Gods) for help before and during the eclipse.

Together with the thin double axes, previously described, some bronze male and female figurines, recovered from the Psychro cave associated with Zeus, are shown in a variety of gestures which are claimed to suggest an elaborate ritual language based on bodily expressions (Galanakis, 2013, p. 54, Fig.87,88). Some have their hands to their foreheads with faces tilted upwards or their backs slightly bent as if to look skywards at a low angle. The eclipse elevation is reported at ~ 31^{o} (Espenak and Meeus, 2006). These figurines (~ 25 cm tall) are dated, together with the 'non-functional' axes, from MM III to LM (Galanakis, 2013). It is suggested, that they are representations of people, simply viewing the occurrence of the total solar eclipse of -1860 (MM II), shielding their eyes from the sun or looking through their fingers or other improvised 'slits'. The figurines may, therefore be older than the conventional archaeological date assigned; made at the time of the eclipse (MM II), or some time shortly afterwards in MM III or perhaps even later.

6. DISCUSSION

The observations made on the Minoan Kernos suggest that the Minoans in the Middle Minoan II period, had a clear understanding of the use of astronomical observations and were, as master-artisans (Blitzef, 1995) able to, technologically create an eclipse predictor. Their mathematical abilities allowed for the creation of circles of known areas and ratios to each other, as well as specific distances between their centers in order to represent, what they believed related to the sizes and relative positions of the Sun, Moon and Earth to represent an eclipse configuration, albeit, horizontally in stone. The astronomical observations at this time, possibly originated from Sumerian astronomical star charts of which our knowledge is indirect and via the earliest Babylonian star catalogues dating from about ca. 1200 BCE and the fact that many star names appear in Sumerian, suggests a continuity reaching into the Early Bronze Age (Brown, 2000), The remarkable similarities between the two eclipse constructions of the Minoans (19th c BCE) and Hipparchus, some 1700 years later, suggest that both had access to the same or similar astronomical observations. In the case of Hipparchus, they may have been of Babylonian (Chaldean Priestly class) origin (Aaboe, 1991; Aaboe, 1974).

Delta T, the arithmetic difference between Dynamical Time and Universal Time may require recalculation, if the eclipse prediction axis direction of the MK is undisturbed and accurate. This ΔT parameter is the largest uncertainty in eclipse prediction, caused by fluctuations in the Earth's rotation, primarily due to tidal friction of the Moon (Morrison and Stephenson, 2004).

It is likely that the Minoans, at least from the beginning of the 19th c. BCE were already familiar with the use of the magnetic compass and used it for the alignment of some of the Palace central courts (long axes) as well as numerous other significant buildings and probably for marine navigation (Downey, 2011a). The choice of 'non-magnetic' Plattenkalk marble for the construction of the Kernos is also supporting evidence that a magnetic compass was used. The provenance of the Kernos could possibly be determined, as there are variations in metamorphic grade in outcrops from east to west on Crete (Creutzberg et al., 1977; Fassoulas et al., 2004). Initial investigations should focus on marble sourced from within or nearby the sacred cave sites associated with Zeus.

The question remains as to why a magnetic compass was used in conjunction with an astronomical eclipse predictor. The impending, unique coincidence of the directions may have been recognized prior to the eclipse and regarded to be of special significance, in that, the 'magical movement' of the compass pointer (the only 'moving' part of the Kernos), was associated with the 'steering hand' of Zeus. It is also, for this reason that the magnetite may have been deliberately 'secreted' within the compass base and the symbolic labrys pointer, displayed on the surface. It is suggested that, the Kernos was created in the first place because of this unique coincidental alignment. If this is the case, the MK is in situ.

There is no direct physical evidence for the existence of the compass, as the wood has rotted away and the lodestone oxidized to hematite and disseminated into the sediment or blown away. The only indirect physical evidence for the oak magnetic compasses' existence is the presence of the central depression 'housing' and its specific geometry and the possible use of a thin gold doubled axe 'pointer'. The geometry of the Kernos, suggests an eclipse prediction function with indirect support from the 'skyward viewing' figurines at the Psychro cave and the inescapable connection between the Minoans and Zeus. The construction of this unique Kernos is believed to have been motivated by the remarkable coincidence of the geomagnetic field declination angle and the position of the total solar eclipse of the 9th January 1860 BCE.

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REFERENCES

Aaboe, A. (1991) The Culture of Babylonian mathematics, astrology and astronomy. The Assyrian and Babylonian Empires and other States of the Near East, from the Eighth to the Sixth Centuries B.C.E. (Eds.) John Broadman, J.I.E.S Edwards, N.G.L.Hammond, E, Sollberger and C.B.F. Walker. Cambridge University Press.

Aaboe, A. (1974) Scientific Astronomy in Antiquity. *Philosophical Transactions of the Royal Society*, 276, (1257) : 21-42.

Allen, R. H. (1899). Star Names and their Meanings. G.Â.E.Â. Stechert.

Andrews, T. (2004). Wonders of the Sky – Wonders of Nature : Natural Phenomena in Science and Myth, Westport : Libraries Unlimited, 2004.

Aveni, A. F. (1986) Archaeoastronomy: Past, Present and Future. *Sky and Telescope,* 72 : 456-460.

Blitzef, H. (1995). Minoan stone implements and industries. In :- Shaw, J. W. and Shaw, M. C. (eds.), Kommos I. The Kommos Region and Houses of the Minoan Town, I. The Kommos Region Ecology and Minoan Industries. 403-535. Princeton University Press, Princeton.

Brown, D. (2000). Mesopotamian Planetary Astronomy-Astrology, Styx Publications.

Chapouthier. F. (1928). Une Table offandes au Palais de Mallia. *Bull. De Correspondence Hellénique*. Vol. 52, 292-323.

Creutzberg, N., Drooger, C. W., Meulenkamp, J. E., Papastamatiou, J., Sannemann, W., Seidel, E. and Tatares, A. (1977). General Geological Map of the Island of Crete, 1 : 200,000, Institute of Geology and Mineral Exploration, Athens.

Cucuzza, N. (2010). Game boards or offering tables? *Kernos.* Revue du XII[e] colloque du CIERGA (partim), p.133-144.

Davaras, C. (1976). Guide to Cretan Antiquities. Noyes Press, New Jersey.

Dierckx, H. M. C. and Tsikouras, B. (2007). Petrographic characterization of rocks from the Mirabello Bay Crete and its application to Minoan Archaeology: The provenence of stone implements from Minoan Sites. *Bull of Geol. Soc. of Greece*, Vol 40, 1768-1780.

Downey, W. S. (2011a). Orientations of Minoan Buildings on Crete May Indicate the First Recorded use of the Magnetic Compass. *Mediterranean Archaeology and Archaeometry*, Vol. 11, No.1, 9-20.

Downey, W. S. (2011b). Archaeomagnetic Directional Determinations on Various Archaeological Materials from the Late Minoan Site at Malia, Crete. *Mediterranean Archaeology and Archaeometry*, Vol.11, No.1, 21-31.

Dunlop, D. J. and Őzdemir, O. (1997). Rock magnetism : Fundamentals and Frontiers. Cambridge Univ. Press.

Espenak, F. and Meeus, J. (2006). Five Millenium Canons of Solar Eclipses : -1999 to + 3000 (2000 BCE to 3000 CE), *NASA Technical Publication*, 2006-214141. Nasa Goddard Space Flight Center, Greenbelt, Maryland.

Fassoulas, C; Rahl, J. M; Ague, J. and Henderson, K. (2004). Patterns and Conditions of Deformation in the Plattenkalk Nappe Crete, Greece: A Preliminary Study. *Bull. of the Geol. Soc. of Greece*, Vol. XXXVI, 1626-1635.

Fred Espenak's Eclipse Web Site :- "sunearth.gsfc.nasa.gov/eclipse/eclipse.html"

Freeth, T., Bitsakis, Y., Moussas, X., Seiradakis, J., Tselikas, A., Mangou, H., Zafeiropoulou, M., Hadland, R., Bate, D., Ramsey, A., Allen, M., Crawley, A., Hockley, P., Malzbender, T., Gelb, D., Ambrisco, W. and Edmunds, M. (2006). Decoding the ancient Greek astronomical calculator known as the Antikythera Mechanism, *Nature*, 444 Supplement (7119) : 587-91.

Galanakis, Y. (Ed.) (2013). The Aegean World. (A Guide to the Cycladic, Minoan and Mycenaean Antiquities in the Ashmolean Museum.) Ashmolean Kapon Editions.

Gerasimides, A. and Parcharidou-Anagnostou, M. (2003). Oak and Ancients Greeks. 405-414. In: Proceeedings of the 11th Panhellenic Conference of Forestry, Ancient Olympia, Sept.30 – Oct.3, 2003.

Herberger, C. F. (1972). The Thread of Ariadne: The Labyrinth of the Calendar of Minos, New York: Philosophical Library, Wiley, 1972 xi + 158pp

Hillbom, N. (2005). Minoan Games and Game Boards, Lund, 2005.

Hood, S. (1971). 'The Minoans; the Story of Bronze Age Crete, Ancient Peoples and Places, 75. New York : Praeger.

Hoskin, M. (2001). Tombs, Temples and Their Orientations : A New Perspective on Mediterranean Prehistory. Ocarina Books.

Hugh-Jones, S. (1982) "Pleiades and Scorpius in Barasana Cosmology". In :- Antony F. Aveni and Gary Urton. Ethnoastronomy and Archaeoastronomy in the American Tropics. *Annals of the New York Academy of Sciences* 385. New York, New York : New York Academy of Sciences, 183-201.

Jones, D. W. (1999). Peak Sancturies and Sacred Caves in Minoan Crete : Comparison of Artifacts (Studies in Mediterranean Archaeology and Literature). Pub. Coronet Books. Jonsered, Sweden : Paul ÀströmsFörlag.

Kovacheva, M., Jordanova, N. and Karloukovski, V. (1998). Geomagnetic Field Variations as Determined from Bulgarian Archaeomagnetic Data. Part II: The Last 8000 years. *Surveys in Geophysics*, 19, 431-460.

Manning, S. (1995). The Absolute Chronology of the Aegean Early Bronze Age, Sheffield. P 217.

Marshack, A. (1974). Book review:The Thread of Ariadne: The Labyrinth of the Calendar of Minos, New York: Philosophical Library, 1972 by Charles F. Herberger, in: *American Anthropologist*, Vol. 76, Issue 2, 403-405.

McCluskey, S. C. (2004). "The Study of Astronomies in Cultures as Reflected in Discertations and Theses ". *Archaeoastronomy*, 16: 20-25.

McCluskey, S. C. (2000). "The Inconstant Moon: Lunar Astronomies in Different Cultures". *Archaeoastronomy* : the Journal of Astronomy in Culture, 15: 14-31.

Mitchell, J. (2001). A Little History of Arch-Archaeology. Thames and Hudson.

Morrison, L. and Stephenson, F. R. (2004). "Historical Values of the Earth's Clock Error ΔT and the Calculation of Eclipses", *J. Hist. Astron*, Vol. 35, Part 3.

Noll, W. (1978). Materials and Techniques of the Minoan Ceramics of Thera and Crete. Thera and the Aegean World I. London. 1978. C. Doumas and H.C. Puchelt. (Eds.) p. 493-505.

Ruggles, C. L. N. (2005). 'Ancient Astronomy'. ABC-Clio.

Strid, A. and Tan, K. (ed.) (1997). Flora Hellenica, 1. Königstein.

Thanos, C. A. (2005). Theophrastus on Oaks. *Bot. Chron*. 18 (1), 29-36.

Thom, A. (1967). Megalithic Sites in Britain. Oxford: Clarendon Press.

Toomer, G. J. (1984). Ptolemy's Almagest. trans. New York: Springer-Verlag.

Toomer, G. J. (1980). 'Hipparchus' Empirical Basis for his Lunar Mean Motions' *Centaurus*, 24, 97-109.

Toomer, G. J. (1974). 'Hipparchus on the Distances of the Sun and Moon'. *Archives for the History of the Exact Sciences*, 14, 126-142.

Warren, P. and Hankey, V. (1989). Aegean Bronze Age Chronology, Bristol.

Watrous, L. V. (1996). The Cave Sanctuary of Zeus at Psychro : A Study of Extra-Urban Sancturies in Minoan and Early Iron Age Crete (Liège/Austin: Université de Liège / University of Texas at Austin).

Watrous, L. V. and Blitzer, H (1982). "Lasithi: A History of Settlement on a Highland Plain in Crete" *Hesperia Supplements,* 18, 1-22.