EVIDENCE FOR MINOAN ASTRONOMICAL OBSERVATIONS FROM THE PEAK SANCTUARIES ON PETSOPHAS AND TRAOSTALOS

BY

GÖRAN HENRIKSSON AND MARY BLOMBERG

Abstract

We report the results of investigations made by the archaeoastronomical group at Uppsala University of the peak sanctuaries on Petsophas and Traostalos, in eastern Crete. The results indicate that the Minoans were conducting systematic observations of the sun, the moon and the stars—particularly Arcturus—at the two sites early in the Middle Minoan Period. We propose that there were practical as well as religious reasons for the Minoan interest in the motions of the heavenly bodies: for example the knowledge acquired from the observations contributed to navigation and made possible the regulation of a ritual lunisolar calendar. We supplement our earlier proposal of a Minoan goddess associated with the moon, with the suggestion of a god associated with the star later known as Arcturus.

Since Archaeoastronomy is not well-known in Aegean studies, we introduce our report with a brief account of this discipline.

THE ARCHAEAOASTRONOMICAL BACKGROUND

Investigations of the possible use of pre- and protohistoric monuments for observing the heavenly bodies have resulted in the development of the academic discipline archaeoastronomy. The discipline has been defined as "the study of the practice and use of astronomy among the ancient cultures of the world based upon all forms of evidence, written and unwritten". Archaeoastronomy is thus an interdisciplinary field of research, requiring as a minimum the co-operation of an astronomer and an archaeologist. Iconographical and philological studies may also be necessary in some cases. Research focuses on deliberate orientations of structures to the sun, the moon or the brightest stars, but various types of rock carvings have also been investigated for references to astronomical phenomena. The roots of the discipline reach back into the eighteenth century, when studies of the orientations of prehistoric monuments such as Stonehenge began to appear. This is not the place to go into the stubborn controversy over the astronomical significance of Stonehenge, but it is worth mentioning that the solid results obtained from that long tug-of-war between astronomers and engineers on the one side and archaeologists on the other have made it impossible for any but the most hardened sceptic to discount the evidence that our ancestors in Europe had begun systematic astronomical observations by the Late Neolithic Period.  

Abbreviations


Acknowledgements

This study is one of several planned for the project investigating Aegean astronomy in the Bronze Age. We would like to thank the members of the boards of the following foundations for making our research possible: the Swedish Council for Research in the Humanities and Social Sciences, the Gunvor & Josef Axel Johnson Foundation, the Axel & Margaret Ax:son Johnson Foundation, the Magn. Bergvall Foundation and the Helge Ax:son Johnson Foundation. We are also grateful to the Greek Archaeological Service and the British School at Athens for permission to study the site of Petsophas. We would like to thank as well C. Davaras, former ephor, and N. Papadakis, present ephor of antiquities at Ayios Nikolaos, J.A. MacGillivray, director of the current excavations at Palaikastro, Robin Hägg, Berit Wells, Bodil Nordström of the Swedish Institute and Maria Hielte of the Norwegian Institute at Athens, all of whom have been helpful in furthering our work. We are especially indebted to Maria Papathanassiou, Department of Mathematics at the University of Athens, and the members of the graduate seminar in Classical Archaeology and Ancient History at Uppsala University for their helpful comments and suggestions. We thank also Lennart Bondesson, associate professor in mathematical statistics, Uppsala University, who conducted the statistical evaluation of our measurements. We are also grateful to Lars Bägerfeldt and Petter Lindahl for their generous help with the reproduction of our figures.


A major aim of the discipline is to add to our knowledge of ancient societies through the study of the orientations of their monuments towards the heavenly bodies. Should a monument be found to have an astronomically determined orientation, then the material found in its excavation may also refer to astronomical phenomena. Therefore the study of such material is also proper to archaeoastronomical investigations. Orientations may, of course, be determined by other factors, such as meteorological phenomena, but in archaeoastronomy only alignments of man-made structures towards the heavenly bodies are studied. The presence of such alignments signifies systematic observation of these bodies and, as a likely result, the development of predictive skills concerning the place and time of their appearance in the sky. Thus celestial orientations may reveal not only aspects of a society's cosmology but also its nascent scientific probrings.

Aegean archaeoastronomy has its origins in the study of the theory that Greek and Roman temples were constructed so that the rays of the rising sun would fall upon the cult statue inside on the birthday or festival day of the deity to whom the temple was dedicated. This theory seems to have been first proposed and investigated by Heinrich Nissen in 1869. Soon afterwards a number of scholars had begun similar pursuits.

There is no ancient source for the theory that temples were oriented to sunrise on a festival day. Plutarch and Lucian tell us that temples and other monumental buildings were oriented to the east, whereas Vitruvius wrote that temples should face westward. Vitruvius, however, gave overriding importance to the adjustment of temple orientations to local conditions. There seems to be no ancient textual source for the significance of the festival days of the gods in connection with the alignments of their respective temples.

The basic problem in the Aegean has been to account for the fact that, although the axes of about 73% of the surviving temples are oriented to the east, the spread of these alignments lies between the limits of sunrise during the year. In other words, they lie within the solstitial arc for Greece. They seem not to be directed towards any single sunrise, not towards the sunrise at one of the solstices or at the equinox, for example. This orientation of monuments towards the east is by far the most usual in the Aegean and suggests at first reflection that sunrise was the point of interest, although this is not necessarily the case, as we shall see.

An early ambition of investigators of orientations was to be able to use them in dating monuments. Alignments to the sun, however, provide little help in this respect, in contrast to orientations to the bright stars, as precessional motion affects most noticeably the relationship of the stars to the earth. A principle which could overcome the problem of dating was discovered by the English astronomer Norman Lockyer at the end of the last century. Lockyer pointed out that some Egyptian temples had been built so that their axes pointed to the rising or setting of important stars, especially the heliacal rising of Sirius. He invited Francis Penrose, who had been engaged in measuring the orientations of Greek temples, to join him in an investigation to see if a similar principle had prevailed among the Greeks. Penrose was of the opinion that the differences which could be observed in the orientation of a number of Greek temples built one above another, or next to each other, were due to the need to compensate for the precessional motion of the stars. For example, he referred the difference in alignment of the two temples to Athena on the Acropolis at Athens to the change in position of the heliacal rising of the Pleiades, and the orientations of the two temples at Rhamnus to the precessional movement of Spica.

Penrose suggested that the ceremonies at sunrise on the festival day of the deity would have been preceded by a period of preparation, so that it would have been important to know in advance when the sun would rise in the proper position relative to the temple. He proposed that an appropriate bright star had been chosen such that its heliacal rising, when observed through the entrance of the temple, would give adequate warning of the approach of the sun. In time precession would have invalidated the relationship of the temple to this star. When temples were rebuilt after long intervals, their foundations would have been changed so that the axes would again have the desired orientation to the sun at the time of the foundation or on the festival day of the deity would have been preceded by a period of preparation, so that it would have been important to know in advance when the sun would rise in the proper position relative to the temple. He proposed that an appropriate bright star had been chosen such that its heliacal rising, when observed through the entrance of the temple, would give adequate warning of the approach of the sun. In time precession would have invalidated the relationship of the temple to this star. When temples were rebuilt after long intervals, their foundations would have been changed so that the axes would again have the desired orientation to the sun at the time of the foundation or on the festival day of the deity would have been preceded by a period of preparation, so that it would have been important to know in advance when the sun would rise in the proper position relative to the temple. He proposed that an appropriate bright star had been chosen such that its heliacal rising, when observed through the entrance of the temple, would give adequate warning of the approach of the sun. In time precession would have invalidated the relationship of the temple to this star. When temples were rebuilt after long intervals, their foundations would have been changed so that the axes would again have the desired orientation to the
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warning star. According to this hypothesis, the dates for the construction of such re-aligned temples could be calculated from the rate of precession, if the warning star could be identified.\textsuperscript{12}

Penrose devoted considerable time and effort to making careful theodolite measurements of the axial alignments of Greek temples and he also measured the profile of the landscape or structures opposite their entrances. He then proceeded to the task of identifying the warning stars for the temples and calculating the likely construction dates. Unfortunately, his results were in glaring conflict with the archaeological and historical evidence.\textsuperscript{13}

Even more unfortunately, the serious study of orientation seems to have been discredited by these results to such an extent that no further interest was shown in the Aegean again until the 1930s. We emphasise serious study because there have appeared sporadically all along improbable theories based on exact, inexact, and even hypothetical orientations. We will not go into the publications of these pyramidiots, as they have been called.

The next serious publication dealing with orientation in the Aegean, as far as we are aware, is the article by Spyridon Marinatos which appeared in 1934. Marinatos pointed out what he considered to be the very precise way in which the north-south axes of the three then-known Minoan palaces agreed with respect to their orientations, a circumstance to which Sir Arthur Evans had earlier drawn attention when he compared the palaces at Knossos and Phaistos in his monumental study of the Minoan civilization.\textsuperscript{14} The similarity of the palaces in this respect has been noted repeatedly since Evans' day. Marinatos pointed out that chance is excluded in these alignments since Mallia, which lies in a plain, could have been oriented in any direction, if topography were the only determining factor. There is nothing in the terrain itself which forces any particular placement of that palace. Marinatos went on to state that orientation in an east-west or a north-south direction is exemplified by all Minoan monumental architecture where local conditions permit, for example by the tholoi graves, the country villas and also the town plan of Gournia.

Marinatos compared Minoan orientations with similar phenomena in Assyria and Babylonia. The monuments of Assyria were considered at the time to have been oriented so as to exploit the benefit of the cooling northwestern winds; thus orientation in that area was regarded primarily as practical in intent.\textsuperscript{15} In Babylonia, on the other hand, the intention was considered to be religious and determined by the view of the winds as the breath of the gods. Marinatos' conclusion was that orientation in Crete was of a plainly different character from that in Mesopotamia, as the Minoan buildings were more strictly aligned to the cardinal points. He considered an alignment in the east-west direction to be paramount since nearly all religious rooms have this orientation, with their doors opening to the east. Marinatos concluded that the motions of the sun, moon and stars were doubtless the reason for the Minoan orientations in the east-west direction and that this was due to religious factors.

A few years after Marinatos' article, William Bell Dinsmoor took up again the task of the alignment of the Greek temples.\textsuperscript{19} Impressed by Nissen's data that about 73\% of Greek temples were oriented so that their axes lay within the solstitial arc for Greece, Dinsmoor returned to the theory that the temples had been aligned towards the rising sun on the festival days of their respective deities. He also accepted Penrose's idea that the differences in orientation between earlier and later temples on the same site to the same deity were due to a new orientation of the later temples at the time of rebuilding.\textsuperscript{21} Dinsmoor, however, knew that the differences in alignments could not be explained by precession, as the time intervals between the construction dates could not possibly be so great as some of those which resulted from Penrose's calculations. Astronomy alone could not account for the differences in the orientations.

Dinsmoor's knowledge of the Greek lunisolar calendars suggested to him a new method of investigation that might provide more accurate dates for the temples than the older theory. He presented what he called a "pseudo-algebraic equation" of the following form:

\[ X = Ar + R + C + As, \]

where \( X \) is the unknown date, \( Ar \) the archaeological evidence— in which Dinsmoor included historical data, \( R \) the religious evidence—here knowledge of the deity to whom a temple was dedicated and the deity's festival day, \( C \) "the artificial astronomy of the local calendar"—by which Dinsmoor meant the Greek methods for determining the dates for the various religious festivals, and \( As \) astronomical knowledge.\textsuperscript{22} Knowledge of the local calendars was essential since the festival days of the gods were determined ac-
According to them. The year for the Athenians, for example, seems to have begun at the first appearance of the new moon following the summer solstice.\(^23\) This meant that the festival days of the deities wandered within certain limits from year to year as compared to our calendar. We have a similar situation with the dates of our Easter.

The date in our calendar when the visible sunrise is in line with the axis of any given temple can be calculated, if the necessary information is available. As a check the sunrise can be observed on the calculated date, provided there have been no alterations at the site which would affect the time of the observation. For example, if a wall or other obstacle opposite a temple entrance had influenced the time when sunrise would have been observed within the temple, then the obstacle must still exist, if the observation is to be repeated today at the same time on the calculated date. Also it is necessary to take into account the change in the inclination of the earth's axis.

Dinsmoor tested his method first on the Parthenon, which rests on the foundation of an older temple and has the same alignment. The archaeological and historical data set limits for the first foundation between 490, the year of the battle of Marathon, and 480, the year the Persians destroyed the buildings on the Acropolis.\(^24\) If we assume that the foundations were laid on Athena's birthday, 27/28 Hekatombaion, the only possible time in that decade when the 27/28 Hekatombaion fell on the day when the sunrise is observed along the temple's axis is in the year 488, on the day which would have corresponded to our August 31.\(^25\) This calculation takes into account the height of the foundation of the building, the height of the sun behind Mt. Hymettos when first visible from the temple and atmospheric refraction. Dinsmoor was able to test the correctness of these parameters by witnessing sunrise on the axis of the Parthenon on the day in his time calculated from the same parameters. This occurred on our calendar date of August 23, 1937.\(^26\)

Dinsmoor considered the Parthenon to provide the best information for testing his equation. The data for the Hephaisteion were more difficult to establish and are more problematic. Here the assumed festival date was arrived at from year to year as compared to our calendar. We have a similar situation with the dates of our Easter.

Nearly forty years were to pass before the next serious investigation of Aegean orientation. Joseph Shaw's study of the Minoan Palaces.\(^27\) Shaw's aim was to determine with the aid of a theodolite and sighting on the North Star (Polaris) the exact orientation of each individual palace more accurately than had been done earlier with the magnetic compass. He also wished to explain the reason for the similarity of their alignments, which Shaw termed their "most outstanding and consistent common feature".\(^28\) As Dinsmoor had done, Shaw took into account both astronomy and the archaeology of the palaces; he also considered what was known of Minoan religion. There was at that time almost no knowledge concerning the Minoan calendar, so it could not figure in Shaw's calculations.

In contemplating the cause for the apparent north–south orientation and the rectangular shape of the central courts of the palaces, Shaw considered the possibility that these were the result of the desire to provide maximum light, either for purely practical or for religious reasons.\(^29\) Accepting the identification, on the basis of the archaeological evidence, of the rooms along the western side of the central courts as cult rooms and their provision with an eastern entrance as intentional, Shaw argued that there must have been an important relationship between these rooms and the central courts; otherwise the eastern orientation could have been as well satisfied by placing the rooms in the eastern wings of the palaces.\(^30\) If the cult rooms at Knossos, for example, for some reason had to be placed adjacent to the court and if it had been important to maximise the amount of light reaching them, then they would have been placed at the northern end of the western wing, and the court would have been extended southwards so that these rooms would not lie in the shadow of the south façade in winter time. He thought that the intended orientation was east–west and the greater north–south length due merely to the practical restraints which follow from this. Shaw thus arrived at the same conclusion as Marinatos, but by a somewhat different line of
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We have already noted that the identification of the important palatial cult rooms is not certain. Shaw turned then to the reasons for the east-west orientations. He noted that all of them lie south of due east and all but one, that at Kato Zakros, lie within the range of winter sunrises. Turning to the exception of Kato Zakros, Shaw noted that the area in which the palace is situated is especially affected in the summer by winds from the west and he suggested that this could be a reason for the difference in the orientation of this particular palace. He also mentioned the possibility that the rising or setting moon may have been the determining factor for the alignment and gave the southern limit for moonrise as 36° 48′ south of east (azimuth 126.80° from north. It is not stated whether the calculations refer to the upper limb or to the centre of the moon). We have independently reached a similar conclusion and have studied the relationship of the moon to the palace in detail. The orientation of the northernmost corridor in the west wing of the palace is very close to the azimuth for the northern edge of the cliff (126.49°) visible through the door of the corridor and the door in the east wing opposite. The southern limit of moonrise was, according to our calculations, 126.27° in the year 2034 BC (measuring from the upper limb of the full moon). Minoan interest in the moon, as we point out below, is likely to have had both a practical and a religious aspect-practical for calendric purposes and religious through association with a deity.

Shaw continued in the tradition begun by Dinsmoor of not drawing conclusions beyond what was archaeologically possible. And as Dinsmoor had done, he took us a step forward in our understanding of one of the ancient cultures of the Aegean.

When orientation studies were resumed in the Aegean in the 1930s, we notice an interesting development, the investigators are archaeologists. A further development occurred in connection with the studies of the orientations of the Late Bronze Age graves at Armenoi. Here for the first time we have an interdisciplinary approach engaging a mathematician, an historian of science and an archaeologist. This, we hope, will continue to be the case in future archaeoastronomical investigations in the Aegean. We would also like to see further progress towards realising the ambition stated long ago by Dinsmoor: the use of archaeoastronomical results to illuminate other areas of cultural life.

THE PRESENT ARCHEAOASTRONOMICAL STUDY

Minoan peak sanctuaries have been the subject of many studies since Evans’ first mention of sacred mountains in 1901, but they have never been investigated archaeoastronomically. Our own interest in these sites is based on our hypothesis that at least some of them were used for systematic astronomical observations. The hypothesis is one of several being tested as part of the project investigating whether or not the origins of the Greek calendar and Greek astronomy can be traced in part to the Minoans via the Mycenaeans. It is based on information preserved in Mycenaean, Greek and Roman texts. Astronomical observations would not have been at odds with the religious function of the peak sanctuaries, the only one so far ascribed to them, but rather complementary. To

34 Shaw 1977, 57ff.
35 Shaw 1977, 58. The southern limit for Crete for 2000 BC was estimated to be 29°45′ ± 5′ south of the equinoctial point.
36 Shaw 1977, 59. Shaw’s north-south orientation for the central court at Zakros is 37.55°; our value is 37.57°.
38 Papathanassiou et al. (supra n. 37).
41 The religious function of the Minoan peak sanctuaries is undeniable. For recent references to the extensive literature on the subject see Rutkowski 1991 (supra n. 39), 52-57; N. Marinatos (supra n. 16), 115-123; Peatfield 1992 (supra n. 39), 74-80; M. Blomberg,
what extent astronomical observations may have been regarded as secular, and thus essentially different from the religious activities which took place on the peaks, would be difficult to determine. Also such a distinction is not likely for the period in question, as any activity centred on the sun, moon and stars would probably have been regarded as religious.\textsuperscript{32}

Our first investigation of a peak sanctuary was of Petsophas (H. 255 m), the site just above the important Minoan town which lay near present-day Palaikastro. Preliminary results from our measurements of the orientations of the walls at this site were presented at the Fourth 'Oxford' conference on archaeoastronomy at Stara Zagora, Bulgaria in 1993\textsuperscript{23} and at the workshop in Aegean archaeoastronomy, held at the Swedish Institute at Athens in April of 1994.\textsuperscript{44} Since then we have repeated our measurements on Petsophas and also have measured on two separate occasions the orientations of the walls of one of the small Minoan structures near the highest peak of the Traostalos massif (H. 515 m), about three kilometres north of the palace at Kato Zakros.\textsuperscript{45} Both sites are excellent for the study of the motions of the heavenly bodies. Petsophas has a view of the sea to the north and east whereas the entire eastern horizon is visible from Traostalos in clear weather. They are near important Minoan harbour towns whose inhabitants were probably aware of the utility of the stars for navigation.\textsuperscript{46} Material spanning the periods MM I and LM I (ca. 2100-1500 BC) has been found at both places.\textsuperscript{47}

The results from Traostalos confirm our findings from Petsophas and thus add a crucial link to the chain of evidence for Minoan astronomical observations. As long as the results from Petsophas remained unique, the data on which our conclusions have been based could be suspected of bearing chance correlations with celestial phenomena and our arguments for astronomical observations could be regarded as influenced by subjective factors in our attempts to find an astronomical solution for the orientations. We are in the process of evaluating the measurements of other peak sanctuaries and Minoan buildings in Crete, and reports will appear as they are completed. All dates are before our era.

\textbf{THE ORIENTATIONS (Table 1)}

Petsophas (Fig. 1)

The results from Petsophas which indicate that systematic observations of the celestial bodies took place on the site are the following:

The first astronomically significant factor is that the structure on the site has been placed so that an observer standing near it could have seen the sun setting behind the conical peak Modi exactly on the day of the vernal and the autumnal equinox (Figs. 2, 3). This indicates that the location for the site is likely to have been chosen for the sake of these observations, since the dates would have been shifted by one day for an observer who stood more than 30 metres to the south of the structure. It is not possible to stand more than about 10 metres to the north because of the sheer drop in that direction. Every 19 years, also from near the building, the moon can be observed to set behind Modi once every month for several months in succession, and in some years the new crescent moon and the full moon will set at the equinoxes behind the same peak (Fig. 4). Such lunisolar coincidences are often considered to be significant and may become the starting points for new calendric cycles. We have suggested in an earlier article that the moon was significant in Minoan religion.\textsuperscript{48} It is important to note here that Modi is the only prominent landmark to the west of Petsophas. Had there been several peaks near each other, as there often are in Crete, our results would be less convincing.

The second significant astronomical factor is that the terrace wall CE was oriented to the rising sun at the summer solstice. This means that the long axis of the room QRST was oriented so that the first rays of the rising sun would completely illuminate the western wall RS only at the sum-

'\textit{Cultural continuity and change: the case of the Minoan peak sanctuaries}', in Papers from the Uppsala workshop in cultural continuity and change in antiquity (forthcoming). The possible representation of smoke rising from the peaks of Vigla and Traostalos on the 17th-century Venetian map of the Kato Zakros area, published by C. Davaras, \textit{Guide to Cretan antiquities}, 2nd rev. ed., Athens 1976, 237, suggests the practical function of signalling, e.g., to boats at sea, to the settlements in the area, to more distant parts of the island. Peatfield's suggestion of a network of sacred beacons should perhaps be modified to a network of beacons also for secular purposes, not least military (supra n. 39, 1983, 277).

\textsuperscript{42} S. Marinatos (supra n. 14) wrote already in 1934 on the possible dependence of Minoan orientations on the heavenly bodies and that this almost certainly was due to a religious conception. For other references bearing on the divinity of the heavenly bodies for the Minoans see M.P. Nilsson, \textit{Minoë}, 486 and L. Goodison, \textit{Death, women and the sun} (BICS, Suppl. 53), London 1989.

\textsuperscript{43} Blomberg & Henriksson forthcoming (supra n. 37).

\textsuperscript{44} We would like to thank the Institute's Society of Friends for the grant which made the workshop possible.


\textsuperscript{46} For the use in simple societies of the stars to navigate over enormous landless areas of the Pacific, methods of instruction and attitudes towards the astronomical knowledge required, see D. Lewis, \textit{We, the navigators}, Honolulu 1972.
mer solstice, had there been no impediment in the east. According to Myres the wall DF is later; presumably he meant later than the walls BC and CE. Furthermore, the thick and extensive layer of ashes which Myres observed on the westward side of the wall DF suggests the custom of building fires in this region, making it unlikely that the area QRST had a roof in the Middle Minoan period, when the terrace wall was constructed. A number of the models of walls found at peak sanctuaries have cornices with horns of consecration, also indicating that the structures at such places were used for ceremonial purposes.

49 The orientation of the wall CE is 58.8° ± 0.2° (Table 1).
50 Myres (supra n. 45), 357. For the contemporaneity of the ash layer and the terrace wall, ibid., 358.
places may not have been roofed. This orientation must have been important since the terrace wall CE was not built on the most convenient place, the large, nearly flat plateau to the east and south. Nor was it built parallel to the slope of the hill, but at about 45° to it (Fig. 1). This made it necessary to build up the corner at C about one metre with a massive retaining wall (Fig. 5). As Myres’ plan shows, the site is impractical. Moreover, at the present location the building would have required at least two stories in order for the upper part to have been visible from the town.

The choice of such an impractical location and the unusual layout of the walls of the structure indicate that there

51 Ilse Schoep, “‘Home sweet home”. Some comments on the so-called house models from the prehellenic Aegean', OpAth 20, 1994, 193, figs. 10-12.
52 Peatfield (supra n. 39), e.g. 1990, 119f., stresses the importance of inter visibility between shrine and settlement. At Petsophas, however, only the peak itself is likely to have been visible down in settlement, whereas at Traostalos not even the peak would have been visible from the palace and settlement at Kato Zakros.
Fig. 5. Petsophas. The walls as Myres drew them (based on pl. VII, BSA 9, 1902-1903).

were important specific reasons for them. As there are astronomical observations having calendaric, and very likely religious, significance which can be made from the site precisely because of the characteristics of the structure and its location, these would seem to be the most logical explanation.

In addition to the orientations reported above, we call attention to a number of unusual features of the structure which have no obvious explanation. One is that the walls AA' and AB meet to form an angle of 76°. That is, they deviate considerably from the right angle which would be normal if they had been part of an ordinary room; and there are no traces of any other walls which would have completed a room. These walls, in addition, have an irregular relationship to the rest of the structure, a relationship, furthermore, which has not been dictated by the terrain.

The wall AA' points 37.4° ± 0.6° to the west of north and AB points 38.4° ± 0.8° to the east of north. The horizon can be seen in both directions from the corner at A. We suggest two hypotheses which could account for the orientations of these walls.

On first reflection one might assume that the walls were intended to be symmetrical with respect to the meridian, for example to mark the eastern and western limits of the circumpolar stars for the latitude of Petsophas (35.20°). The excess of ca. 2.2° to the west and ca. 3.2° to the east, however, is disturbingly large for this purpose (Fig. 6).

The second hypothesis assumes that the slightly different orientations of the walls were intentional. In this case AA' can have been aligned to the cosmical setting of Arcturus.

53 The letters designating the walls have been chosen to agree with those on the plan by Myres (supra n. 45), pl. VII, to facilitate comparison. We use the same for the walls of Traostalo (Fig. 8). The measurements were made with the laser theodolite SOKKIA SET 4C on two occasions, and the orientation of the co-ordinate system was obtained from observations of the sun, which are accurate to better than 0.01°. The results from the two occasions are for the present purpose identical, being far more exact than is required. The Minoans could not have arranged their walls with the exactness that we can measure, and the vicissitudes of the intervening years must also be taken into account. The use of an instrument of such precision, however, eliminates the introduction of measurement errors into the computations.
Fig. 6. Orientation of the walls AA' and AB on Petsophas and AA', AB and BY on Traostalos relative to the circumpolar stars. BY has the same orientation as the western limit of the circumpolar stars for the latitude of Traostalos.

Fig. 7. The measured azimuths of the walls AA' and AB on Petsophas and Traostalos and the corresponding optimal years for the observations of the heliacal rising and setting and the acronychal rising and cosmical setting of Arcturus. For every wall there are two possible optimal years, but only the identifications which give the smallest deviations have been accepted. The corresponding years are presented with their mean errors.

The weighted mean of the azimuths of the four walls is 38.3° ± 0.4°. On the assumption that the orientations were specific only for the heliacal rising and setting, the mean construction date would be 1886 BC ± 49 years. Assuming that they were specific only for the acronychal rising and cosmical setting, the date would be 1768 BC ± 49 years. On the assumption that the walls were built at the same time in order to observe all four positions of Arcturus, the weighted mean construction date would be 1827 BC ± 77 years.

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Table 1. Summary of the measured azimuths and mean errors for the walls on Petsophas and Traostalos.

<table>
<thead>
<tr>
<th>Site</th>
<th>Orientation</th>
<th>Azimuth</th>
<th>Mean error</th>
<th>No.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petsophas</td>
<td>AA’</td>
<td>322.6° (-37.4°)</td>
<td>± 0.6°</td>
<td>10</td>
<td>Arcturus' cosmical setting 10/5, optimal for 1865 ± 71 years</td>
</tr>
<tr>
<td></td>
<td>AB</td>
<td>38.4°</td>
<td>± 0.8°</td>
<td>6</td>
<td>Arcturus' heliacal rising 23/8, optimal for 1869 ± 93 years</td>
</tr>
<tr>
<td></td>
<td>CE</td>
<td>58.8°</td>
<td>± 0.2°</td>
<td>8</td>
<td>sunrise at the summer solstice ca 2000, valid for many centuries</td>
</tr>
<tr>
<td></td>
<td>ST</td>
<td>59.1°</td>
<td>± 1.2°</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RQ</td>
<td>60.8°</td>
<td>± 0.4°</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DF</td>
<td>28.8°</td>
<td>± 1.0°</td>
<td>9</td>
<td>later wall according to Myres</td>
</tr>
<tr>
<td></td>
<td>to Modi</td>
<td>269.23° (-90.77°)</td>
<td>± 0.01°</td>
<td></td>
<td>Sunset at the vernal and autumnal equinoxes ca 2000, valid for many centuries</td>
</tr>
<tr>
<td></td>
<td>to Traostalos</td>
<td>179.31°</td>
<td>± 0.01°</td>
<td></td>
<td>true south 180.00°</td>
</tr>
<tr>
<td>Traostalos</td>
<td>AA’</td>
<td>320.6° (-39.4°)</td>
<td>± 0.8°</td>
<td>8</td>
<td>Arcturus' heliacal setting 13/10, optimal for 1762 ± 87 years</td>
</tr>
<tr>
<td></td>
<td>AB</td>
<td>38.9°</td>
<td>± 1.8°</td>
<td>4</td>
<td>Arcturus' acronychal rising 4/2, optimal for 1707 ± 200 years</td>
</tr>
<tr>
<td></td>
<td>BY</td>
<td>325.0° (-35.0°)</td>
<td>± 0.8°</td>
<td>8</td>
<td>Western limit for the circumpolar stars at Traostalos' altitude 324.85° (-35.15°)</td>
</tr>
<tr>
<td></td>
<td>to Modi</td>
<td>320.28° (-39.72°)</td>
<td>± 0.01°</td>
<td></td>
<td>Arcturus' heliacal setting 13/10, 1730</td>
</tr>
<tr>
<td></td>
<td>to Petsophas</td>
<td>359.31° (-0.69°)</td>
<td>± 0.01°</td>
<td></td>
<td>true north 0.00°</td>
</tr>
</tbody>
</table>

optimal for 10 May 1865 ± 71 years, and AB to the heliacal rising of the same star, optimal for 23 August 1869 ± 93 years, dates which agree well with those that have been proposed for the site (Table 1 and Fig. 7). The optimal date calculated from the weighted mean for the two walls is 1866 ± 80 years (Fig. 7); see below, the section on 'Significance of the orientations'. The calendric importance of the risings and settings of Arcturus from at least the time of Hesiod speaks for this alternative. The orientation of a wall, or other device, to the point where a star will be observed to rise or set insures that this event will not be missed in the morning or evening light. This is important in Crete where visibility at the horizon is often low.

Thus the placement of the structure on Petsophas and the orientations of several of its walls would have aided observations of a number of celestial phenomena of major calendric utility as early as the first half of the nineteenth century: the equinoxes, the summer solstice, the heliacal rising and cosmical setting of Arcturus. We know that the calendric use of these risings and settings of Arcturus existed for the Greeks and the Romans from as early as the Archaic period.

Even though the walls AA' and AB are not closely oriented to the limits of the circumpolar stars, they would have been helpful for astronomical observations of the equinoxes, the summer solstice, and the heliacal risings and settings of Arcturus. The errors are the mean errors. In addition to the mathematical margins of error, the physical conditions of observation should also be kept in mind when estimating dates for orientations towards the stars. Due to the precession of the equinoxes, stars change their position by about 1.38° in a century. We do not know with what exactness Minoans made their observations of stars. Proper motion of Arcturus has been taken into account. The apparent positions of Arcturus are meant, on this see West (supra n. 40), 379f. The true or hypothetical risings of a star occur at the same place on the horizon in the east, as do the true or hypothetical settings in the west. However, due to variations in visibility, the apparent positions vary. The hypothetical rising at 0° altitude for Arcturus in the year 1730 is 3.7° to the north of the apparent heliacal rising. The parameters for calculating visibility and the optimum relative positions of Arcturus and the sun have been based on the results of H. Siedentopf, "Neue Messungen der visuellen Kontrastschwelle", Astronomische Nachrichten 271, 1941, 193-203; A. Ljunghall, 'The intensity of twilight and its connection with the density of the atmosphere', Meddelanden från Lunds astronomiska observatorium, ser. 2, vol. 13, no. 125, 1949; J.F. Schmidt, 'Ober die Dämmerung', Astronomische Nachrichten 63, 1865, article no. 1495. We have used Schmidt's visibility calibration for Athens of ca. 1850, our era. The proper motion of Arcturus has been taken into account.
have facilitated the study of these stars, which are useful for navigation.\(^\text{57}\)

In the interest of an evaluation of possible subjectivity in our results, we would like to point out that we made the measurements from which the orientations of these walls have been determined when interpretations of the structure and its finds were in an exploratory phase. In addition, the co-existence on Petsophas of several significant orientations for the same system of walls makes it unlikely that the relationships are chance occurrences.

Traostalos (Fig. 8)

The remains of several ancient structures exist today on the plateau near the central and highest peak of the Traostalos massif. The smallest is immediately to the south of the highest point and may have been a lookout post. There is a similarly located small building on Modi. A building with two rooms lies lower down to the east. To judge from its shape and location it is not the Z-shaped enclosure mentioned by Davaras.\(^\text{58}\) The system of walls described here are those of the peak sanctuary investigated by him.\(^\text{59}\)

We measured the orientations of the walls on two occasions, and in the interval the site was re-excavated because of planned military construction.\(^\text{60}\) Our choice of points on the first occasion had been made with Davaras’ report of levered stones very much in mind.\(^\text{61}\) We chose only stones which seemed to be in their original position. This was not a serious problem when it came to calculating the orientation of the wall AA’. Although the two large stones which stood between the stones c, d and d, e have been thrown out of place and the stone b is cracked and loose, the other stones are \textit{in situ} and provide an adequate number of points for measuring the original orientation. The fact that the wall AA’ is oriented 39.4° ± 0.8° to the west of north, which orientation, considering the margin of error, is that of the direction to Modi (Table 1 and Figs. 8, 9), is further indication that the measured direction is the intended one.

In the case of AB some of the stones were moved in the

\(^{\text{57}}\) See Circe’s sailing advice to Odysseus, \textit{Od.} 5.276f.

\(^{\text{58}}\) Davaras 1978 (supra n. 45), 393.

\(^{\text{59}}\) Davaras 1963 and 1978 (supra n. 45).

\(^{\text{60}}\) The measurements on the first visit, in November 1994, were made with a Kern DKM I theodolite, as only two persons were available to carry the equipment. Weather conditions were so poor that a desirable number of points were not measured. Also, at the time we did not realise that AA’ and AB on Petsophas were oriented towards Arcturus, although we were aware from earlier magnetic compass estimations that the corresponding walls on Traostalos might have a similar alignment to those on Petsophas. When evaluation of the measurements indicated the significance of the pairs of orientations, we measured again in October of 1995 with the SOKKIA laser theodolite. The results from the common points measured on two occasions agree to within 1 cm and to 0.02°. Therefore it is justifiable to combine the measurements in calculating the orientations. See also Blomberg & Henriksson 1996.

\(^{\text{61}}\) Davaras 1978 (supra n. 45), 393.
interval between our visits in 1994 and 1995. Stone f, for example, was rotated ca. 90°. The solid line shows the position before the stone was moved; the dotted line shows its present position (Fig. 8). We have included in our calculations only the measurements made from stones in the same position in 1994 and 1995, a, h and i. There are fragmentary foundation stones in the empty area on the south–east side of AB which indicate that the wall began at A. The orientation measured is 38.9° ± 1.8° to the east of north (Table 1 and Fig. 8). As on Petsophas, the horizon is visible in both directions from the corner at A. The palace and settlement at Kato Zakros are not visible.

AA' can have been oriented to the heliacal setting of Arcturus, optimal for 13 October 1762 ± 87 years and AB to the acronychal rising of the same bright star, optimal for 4 February 1707 ± 200 years (Table 1 and Fig. 7). The optimal date calculated from the weighted mean of the two walls is 1752 ± 138 years. The poor condition of the wall AB and the evidence that some of the stones have been moved must be given due consideration in the evaluation of the accuracy of the orientation of this wall. One must also weigh in the balance the close correspondence to the relationship to Arcturus provided by the other three walls at the two sites.

The wall BY, which has no counterpart on Petsophas, is oriented to the western limit for the circumpolar stars for the latitude of Traostalos (35.15°). The existence of the means for a precise definition of the circumpolar stars on Traostalos, and the absence of obvious orientations towards the sun and the moon, may indicate that the site was specialised to the study of the stars for navigation. The location of the site on the highest peak by the sea and with an unobstructed view of the entire eastern coast of the island makes it especially suitable for such study.

The structure on Traostalos is not as well preserved as the one on Petsophas. Nevertheless it seems from the plan and location that it can not have been built for any ordinary purpose (Fig. 8). The site chosen is an awkward one and is exposed to the wind. The ground slopes downward and eastward from H, giving a difference in altitude of about 1.5 m within the 6 m from the highest to the lowest part, whereas the large plateau to the east is relatively flat. We think that the orientations to Modi and Arcturus must have been important factors in the choice of the location on Traostalos, just as they were in the case of Petsophas. The high rocks from H to A', which have been roughly worked to form walls, would have helped to screen off the light from the sun in the evening, increasing the visibility of Arcturus as it set.

Our view is that the structure was intended primarily for observations of the stars and that one of the other buildings nearby could have served for any other activities which may have taken place on the mountain.

**SIGNIFICANCE OF THE ORIENTATIONS**

Lennart Bondesson, associate professor in mathematical statistics at Uppsala University, conducted Student's T-test on our measurements of these walls, with pooled variance. The orientations were calculated by orthogonal regression. According to the results the walls AA' and AB on Petsophas do not differ significantly in their north–south orientation. This means that they can have been built symmetrically with respect to north. Bondesson also determined that the orientations of the walls AN on Petsophas and Traostalos are not significantly different, even if the result here is not entirely convincing. This means that their azimuth difference of 2.0° can be explained as a chance variation in our estimations of the orientation of eroded walls towards the same object. In this particular case we can show that the object was Arcturus at its heliacal and cosmical settings. At the time in question there was only 0.9° difference between these two settings. An interval of 112 years corresponds to a difference in orientation of only 1°, as the result of precession. Bondesson's results indicate that it is feasible to test the hypothesis that all four walls were built at the same time and were oriented on each site symmetrically with respect to north. The weighted average of the deviation of all four walls from the north–south direction is 38.3° ± 0.4°. The weighting has been done with respect to the inverse variances. The conclusion from the statistical analysis of our measurements is a 90% probability that the orientations of the walls were intended to be the same.

If we assume that the walls AN and AB on both Pet-
sophas and Traostalos were oriented towards Arcturus, we can conclude that they were built at the same time, 1827 BC ± 77 years, to facilitate observation of the four risings and settings of that important star. Because of the slow rate of precession the walls would have continued to be useful for the same purpose for most of the Middle Bronze Age. After that period the effects of precession would have become more and more appreciable.

The focus on Modi and Arcturus at both sites suggests an important role for this particular mountain and star either in the religion of the area or in Minoan religion in general. The lofty conical peak of Simodi (422 m), which lies between Petsophas, Modi and Traostalos, seems not to have been of interest. The two sites of Petsophas and Traostalos are close to the same meridian, the azimuth from Petsophas to Traostalos being 179.31°. The sum of the evidence indicates a close intentional relationship in function between the sites and is a persuasive argument in favour of our interpretation.

We do not propose that astronomical observations were the only function of the Minoan peak sanctuaries, but that they were a very important one. The religious functions which have been posited for peak sanctuaries are not at odds with the use of the sites as astronomical observatories. In fact, our interpretation of the most frequently occurring type of female figurine on Petsophas as representing a goddess associated with the moon and the mountain Modi supports the proposed Minoan worship of a goddess with a wide variety of associations to the world of nature. Our interpretation is based partly on the fact that the unusual shape of the heads of these figurines, as they are turned, suggests the phases of the moon, while the conical skirt suggests the shape of Modi (Fig. 4). In his discussion of the female figurines, Myres remarked upon their "very peculiar ... and quite unparalleled" head-gear, pointing out that normally there is no demarcation between the hat and the head. To our knowledge all figurines of this type have been found at peak sanctuaries. More than thirty have been found on Petsophas.

If we look for an analogous association for Traostalos, then our attention rests on the relationship of Modi to Arcturus, a star designated by a male name in Greece as early as the Archaic period. The name, which means bear guardian (from ἄρκτος and οὐρος), is related to two other constellations, the Arktoi, for whom there is a mythical link to Crete and the Cretan Zeus in Aratos. The association of a female and male with a mountain calls to mind the famous impressions "Mother of the Mountain", found at Knossos, and the

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63 Supra n. 41.
64 E.g. M.P. Nilsson, MMR², 65-71; B.C. Dietrich, 'Peak cults and their place in Minoan religion', Historia 18, 1969, 257-275, esp. 271-273; N. Marinatos (supra n. 16), 147.
65 Blomberg & Henriksson 1996, 36, fig. 6. Our interpretation is built also on linguistic arguments. There seems to have been a moon goddess mentioned in the tablets from Knossos, a fact which suggests Mycenaean continuation of a Minoan cult. See Diccionario Micénico 1, 434, s. v. me-na and R. Palmer, Wine in the Mycenaean palace economy (= Aegaeum 10), Liège & Austin 1994, 125-128.
66 Myres (supra n. 45), 370f. For other examples of the type see Rutkowski 1991 (supra n. 39), pls. 29, 32, 35 and 37. The line formed by the arms and the collar suggests the crescent moon; however none of the figurines was found with the lower arms intact.
67 Aratos (supra n. 40), 26-35. Arcturus is part of the constellation Arctophylax, which name also means bear guardian.
"Master Impression", found at Khania. The great majority of the male figurines found on Petsophas hold their arms in the same way, symmetrical with respect to the axis of the figure (Fig. 11), a position unique to eastern Crete as far as we have been able to ascertain. Many parts of male figurines were also found on Traostalos, but most are so fragmentary that the positions of their arms can no longer be determined.

Assuming that the walls AA' and AB were built at the same time and intended to be useful for observing all four positions of Arcturus, the significance of these positions is likely to have been the following: The heliacal rising (24/8) would have been especially useful, as it occurred one lunar month before the autumnal equinox. This means that the Minoan year may have begun already in the Middle Bronze Age at the first visibility of the new moon following the autumn equinox. If the Minoans had used a lunisolar calendar, the heliacal rising of Arcturus would not only have signalled the approaching new year, but the appearance of the star relative to the phases of the moon would have indicated when an intercalary month was needed to compensate for the incommensurate motions of the moon and the sun, thereby keeping the months in the correct seasons. This would have been of great importance for a religious calendar with seasonal ceremonies. We have presented elsewhere our arguments for the Bronze Age origins of the later Greek lunisolar calendar. The acronychal rising (2/2) occurs midway between the winter solstice and the vernal equinox. This may indicate that there was also a division of the solar year into eight equal parts. Such a year would have been practical for farmers, whereas the lunisolar calendar would have been necessary for religious observances. The cosmical setting (11/5) and the heliacal setting (13/10) would have been appropriate for indicating the limits of the sailing season in the Middle Bronze Age, and there are traces of the use of stars for the same purpose in the Archaic period. Arcturus was later associated with storms by seamen, but this may have been a superstitious survival from the Bronze Age when the settings and risings of this star were signals of the beginning of stormy weather and, consequently, the limits of the sailing season. As to Arcturus’ heliacal rising and setting, acronychal rising and cosmical setting in the Classical period, none would have been appropriate for determining the season for sailing.

For recent discussions of these representations and their relationship to the peak sanctuaries see the articles by Davis, Marinatos, and Krattenmaker, in The role of the ruler in the prehistoric Aegean (supra n. 39). As N. Marinatos has suggested (supra n. 16), 119, different deities may have been worshipped on the peaks of different areas, as was the case in later Greek religion.

For a similar, although later, procedure in the east see M.E. Cohen, The cultic calendars of the Ancient Near East, Bethesda 1993, 5f.

Blomberg & Henriksson 1996. 

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75 M. Guarducci, ‘Note sul calendario cretese’, Epigraphica 7, 1945, 79, suggested that in the historical period the year at Knossos may have begun with the autumnal equinox. See also A.E. Samuel, Greek and Roman chronology (Handbuch der Altertumswissenschaft, 1,7), München 1972, 17, 134-136.

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82 For a similar, although later, procedure in the east see M.E. Cohen, The cultic calendars of the Ancient Near East, Bethesda 1993, 5f.

83 Blomberg & Henriksson 1996.
The fact that there seem to be no orientations towards the moon and the sun from Traostalos may mean that stellar observations for the sake of navigation were the focus of the astronomical interest at that site, which has a view of the entire eastern horizon. Petsophas could have been specialised towards maintenance of the calendar. The two places are within sight of each other and near enough to have had a close functional relationship; the linear distance between them is about 7 km. There may also have been political and religious reasons for a close association.

SUMMARY

The sum of the evidence indicates that a major function of the sites on Petsophas and Traostalos was to keep track of the motions of the heavenly bodies and that some of the walls at each place were designed specifically for this function. The orientation to the heliacal rising of Arcturus would have been very useful for regulating a lunisolar calendar. The existence of such a calendar to determine the proper times for religious observances is well attested in Greece for the historical period and there is accumulating evidence that the Mycenaeans may have had a similar calendar. As we have argued elsewhere, if the Mycenaeans used a lunisolar calendar, their source is likely to have been the Minoans.

The orientations to the three other positions of Arcturus may indicate that Minoans also had a secular solar-stellar calendar, which would have been more convenient for farmers and sailors, for example.

The positioning of a structure with respect to a distant horizon marker so that the sun is observed to set behind the marker at the equinoxes from the structure requires considerable knowledge of the sun’s motion. The equinoxes would have had to be arrived at empirically and this would have required a long tradition of observations. Thus the relationship of Petsophas to Modi such that the sun sets behind Modi at the equinoxes to an observer no more than 30 meters from the structure requires back perhaps several centuries before the relationship was established, unless astronomical knowledge had been acquired elsewhere.

In the Early Minoan period, when hills and peaks may already have had a religious function, favourable conditions would have existed for this tradition of observations to have developed.

Since the motions of the heavenly bodies are regular, observation over a sufficient period of time is likely to lead to the understanding of the laws governing these motions. If knowledge of the motions of the heavenly bodies were acquired at the peak sanctuaries and if this knowledge had important consequences for religion (cult calendar) and the economy (agriculture, navigation), then it is also likely to have affected other areas of society in significant ways. The implications for religious and political stability could have been considerable, as the dawning understanding of the laws behind natural phenomena can either constitute a challenge to authority or be exploited to its advantage. The orientation of walls and the siting of structures as aids to astronomical observations on the peaks near two important Minoan centres indicates that just such acquisition of knowledge was under way on those peaks early in the Middle Minoan Period and that it was encouraged by locally powerful groups.

Somewhat different purposes for the peak sanctuaries is also suggested by the finds of large numbers of phalli from Atsipadhes, Peatfield (supra n. 39), 1992, 74f.

The study of the celestial bodies in Mesopotamia and Egypt was already underway in the Middle Bronze Age. In Egypt the heliacal rising of stars seems to have been the basis of a calendar at least as early as the ninth dynasty (ca. 2150). See O. Neugebauer & R.A. Parker, *Egyptian astronomical texts I. The early Decans*, London 1960.

The hypothesis of a long period of observations before the system of walls was built provides an explanation for the ash layer under the floor at Petsophas. The accumulated ashes from fires used for warmth, and perhaps for signalling, in the years before the walls were built could have been part of the material used to level the area chosen for the structure.

For a discussion of the Minoan association of peaks, palaces and power, for example, see most recently Krattenmaker (supra n. 39); also Blomberg & Henriksson 1996.

Only a few of the peak sanctuaries so far known have remains of Minoan structures. See Rutkowski (supra n. 39), 1986, 96-98.