Journal of Radioanalytical and Nuclear Chemistry, Vol. 247, No. 3 (2001) 609–619

Archaeoastronomy: New trends in the field, with methods and results from studies in Minoan Crete

M. Blomberg,* G. Henriksson**

* *Department of Archaeology and Ancient History, Uppsala University, St. Erik's Torg 5, SE-753 10 Uppsala, Sweden*
** *Astronomical Observatory, Uppsala University, P.O. Box 515, SE-751 20 Uppsala, Sweden*

(Received August 25, 2000)

We describe briefly new trends in archaeoastronomy and present results from our studies on Crete to show what this field can contribute to archaeological investigations in the Bronze Age Aegean. Our basic method is the study of orientations, but contemporary Linear A texts, finds from the sites, and later Mycenaean and Greek texts have proved to be important supplementary sources. In broadest terms the results show systematic observation of the heavenly bodies from the end of the early Minoan period (ca. 2000 BCE) and the use of the knowledge obtained to regulate a lunisolar calendar and to navigate.

Introduction

The theory and methodology of archaeoastronomy are developing rapidly today and this is due largely to the annual meetings of the "European Society for Astronomy in Culture" and the triennial meetings of the "Oxford International Conferences on Archaeoastronomy", where these aspects have received emphasis from the beginning.[1] Improvements in the measuring and computational equipment have now reached the point where the orientations of ancient structures to celestial bodies and the horizon profiles opposite the structures can be measured with extreme precision. With modern computers and programs the exact appearance of the sky can be quickly recreated with a high degree of accuracy for any place on the globe and for several thousand years in the past. Thus the mechanical side of archaeoastronomy is completely under control. Interest has consequently widened from determining orientations – still the basic method of archaeoastronomy – to comprehensive studies of what orientations reveal about the astronomical interests of a society and of how astronomical knowledge contributed to the society's cultural development. It should be kept in mind that in ancient times there was usually a religious dimension to interest in the celestial bodies. This aspect, however, is difficult to penetrate without supplementary sources of information.

New trends

Three recent trends in archaeoastronomy are especially noteworthy: one is the increasing application of statistical analysis to orientations, another is the stress placed on having more than one example of an orientation, and the third is the growing appreciation of a holistic approach to the evaluation of data in that many kinds of information about a society, including its iconography and the nature of its influence on later cultures, have been found to be valuable sources of information for archaeoastronomical studies.

The first of these new trends, statistical analysis, gives the probabilities that an orientation is intentional and not a random occurrence. In the case of major celestial events, for example sunrise and sunset at the solstices and equinoxes, such analysis has shown that close orientations are unlikely to be random. As the diameter of the sun is about half a degree, or ca. 1/720th of the horizon, the probability of an orientation to sunrise at the summer solstice is thus roughly 1 in 720. If there are several monuments of a culture with identical orientations, within reasonable margins of error, the probabilities of intentional arrangement are, of course, greatly increased. Moreover, if the orientation of a monument is underscored by a marker at the horizon, then the probability of deliberate choice is further increased. Such markers are known as foresights and may be either natural – for example a mountain peak, or man-made – such as a stone pillar. In Great Britain some scholars hold that there must be a foresight, and preferably a man-made one, if an orientation is to be accepted as intentional, and a case has been made for reserving the term alignment, as opposed to orientation, for such an arrangement.[2] Fortunately, those orientations on Crete which do not make use of a foresight are so specific and the same kinds occur so frequently that the probabilities of deliberate choice are large enough to be convincing in themselves, without the presence of foresights.

In the case of the second trend, emphasis on the existence of more than one monument in a culture with a given orientation, this has also become a requirement for

* E-mail: mary.blomberg@antiken.uu.se
** E-mail: goran.henriksson@astro.uu.se

0236–5731/2001/USD 17.00

Akadémiai Kiadó, Budapest
Kluwer Academic Publishers, Dordrecht

some archaeoastronomers if they are to accept an orientation as intentional. It seems to us, however, that this is the lingering influence of the study of British monuments, which are often rather approximately oriented and frequently badly preserved. We do not think this should be a general stipulation, but would require instead that the effort be made to identify and include in a study as many monuments of the same type as possible. A unique orientation, however, should definitely not be excluded if it can be adequately explained in terms of the monument itself or the culture. The orientation of the palace at Knossos, presented below, is a case in point.

The third notable trend, the holistic approach to the evaluation of orientations, is becoming more and more an integral part of archaeoastronomical studies. Its importance is indicated by the decision to include the words Astronomy in Culture in the name of the European Society for Astronomy in Culture. The intention is that not only celestial orientations but also other topographical relationships should be considered, as well as contemporary social, economic, and religious factors which may illuminate, and also be illuminated by, the orientations of the monuments of a society. It is not assumed, unless indicated by other evidence, that the members of early societies distinguished between the importance of the earth around them and the sky above. In most early cultures, all of nature was thought to be inhabited and controlled by supernatural beings and this made the entire world a sacred place. The careful study of this world in its entirety was important to many spheres of life. However, since astronomy is an exact science, the study of the celestial bodies can have an awesome consequence, it can lead to increasing comprehension not only of the laws accounting for the unique regularity of the motions of these bodies but also of the valuable practical uses to which such knowledge can be put. The dawning understanding of natural laws may well promote that dynamic interaction between humans and their environment which leads to what RENFREW has called the multiplier effect.[3] This seems to have happened at a very early date in the eastern Mediterranean where astronomical knowledge became essential not only for secular daily life but also for the proper exercise of religion. It made possible ritual calendars and stellar navigation with far-reaching consequences for the society as a whole. Because of the awareness of the significance of astronomical knowledge for these broader cultural aspects, archaeoastronomers no longer focus exclusively on the orientations of a monument to celestial events, but consider many different sources of information. This is opening new doors to cultural understanding, especially where written documents are limited or nonexistent.

Methods used on Crete

We use the following methods in our investigations of Minoan astronomical study. We select appropriate monuments on the basis of location, size and any other indications of archaeoastronomical significance. Using the least-square method, we determine the orientations of walls from a large enough number of points to suffice for a statistical evaluation. We also measure the parameters necessary to create a three-dimensional model of the site and its horizon. We use a digital theodolite for the measurements and our own computer program for the astronomical calculations. The program includes stringent formulas for visibility, atmospheric refraction, precession of the equinoxes, change in the obliquity of the ecliptic, parallax of the moon and the sun, and the proper motion of each star. Where indicated we calculate with statistical methods the probability of chance occurrences with respect to the orientations. All other archaeological evidence from the sites is also included in our study. This has been especially informative in the case of the many small terracotta figurines found at the peak sanctuaries. Finally we interpret the significance of the orientations in the context of what we know of Minoan culture, its contemporary contacts with Egypt and the Near East, and its influence on the Mycenaeans and later Greeks. We justify the use of later sources by the fact that the astronomical traditions which grow up around a culture's interest in the heavens have an extremely tenacious hold on the imaginations both of the members of the culture which create them and also of those that inherit them. We have only to recall to mind that we still use all of Ptolemy's 48 constellations and with the same names or the Latin translations. Also, we still use the calendar of Julius Caesar, with the minor modification made by Pope Gregory XIII in 1582. The vitality of the memory which the Mycenaeans and the later Greeks retained of the Minoans is attested in many areas, both in the archaeological and in the textual remains.

General results from Crete

We have found that sixteen of the seventeen certain Minoan monuments which we have measured are oriented to the east within the limits of sunrise and most seem to be to sunrise at the major calendar events, the equinoxes or the solstices.[4] This is true for the palaces at Knossos and Phaistos, the large houses at Ayia Triada, Gournia, Tylissos, Vathypetra, the Royal Villa and the South House at Knossos, the peak sanctuaries of Petsophas, Traostalos, Jouktas, Pyrgos, Gonies, Vrysinas and the one near Mallia, and finally the Royal Temple Tomb. The exception is the palace at Zakros which is

oriented to moonrise at its southernmost limit. There are also in the settlements at Ayia Triada, Mallia, and Gournia three small shrines which are oriented to sunset, rather than sunrise, at the summer solstice. These shrines, however, date to the period of the Mycenaean hegemony on Crete and their deviation from the Minoan custom of eastern orientations is therefore of great interest.

Our results are in good agreement with those obtained by PAPATHANASSIOU and HOSKIN in their study of the graves at Armenoi and with GOODWIN's study of those in the Mesara Valley, 87% of which are oriented within the limits of sunrise.[5] Since the entrances to nearly all monuments can still be determined, we can say definitely that the orientations are to sunrise and not to sunset, except in the case of a few graves at Armenoi which lie within the limits of moonrise. In the case of the peak sanctuaries on Gonies and Pyrgos, we can not be sure about the main entrance, but the long axis of each building is generally east-west and is exactly to the solstices at Pyrgos.

Results

Results from Petsophas

As examples of what may be achieved through the application of archaeoastronomical methods, we present in greater detail the results from two of our sites: the peak sanctuary on Petsophas and the Central Sanctuary Area of the palace at Knossos.

We began our project on Crete with the peak sanctuaries since they are so eminently suitable for studying the celestial bodies, and we measured the six which have remains of walls. The one on Petsophas is directly above the important Minoan town which was located near modern Palaikastro at the eastern edge of the island. The small structure was built near the beginning of the Middle Minoan period, about 2000 BCE, and the axis of the main room was oriented to sunrise at the summer solstice at that time (Fig. 1). From the benches which were found at the western end of the room, the sun on this important calendaric day would have been seen to rise just south of the highest peak of Karpathos, which thus functioned as a foresight (Fig. 2). The map shows the relationship of Petsophas to the peak on Karpathos (Fig. 3).

Moreover, looking to the west from the near vicinity of the building, the sun would have been seen to set behind the isolated conical-shaped mountain Modi at the equinoxes (Fig. 4). Here again we have a natural foresight in the peak of Modi. These alignments to major celestial events are sufficient to place beyond doubt the question of intention at this site. There is, in addition, a further set of orientations which tell us something quite specific about the Minoan calendar. The two walls AA' and AB (Fig. 1) were oriented to the cosmical setting and the heliacal rising, respectively, of the bright star Arcturus, which was an important calendar star already in the earliest Greek literature.[6] Here on Petsophas the heliacal rising of Arcturus in the years when the sanctuary was in use, took place one moon month before the autumn equinox. This coincidence provided a simple method for regulating a lunisolar calendar that began in connection with the autumn equinox.

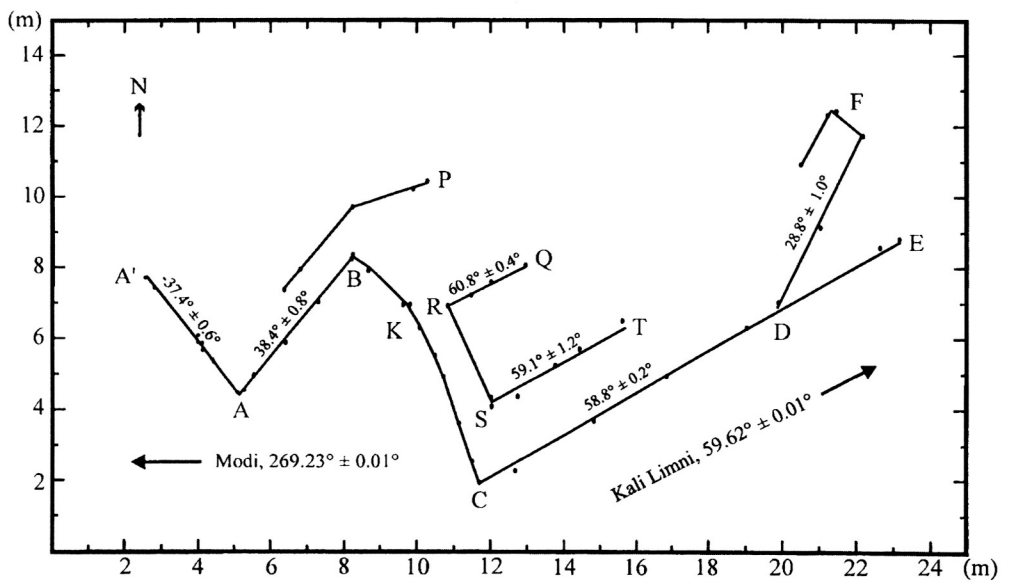

Fig. 1. Petsophas. Orientations of the walls

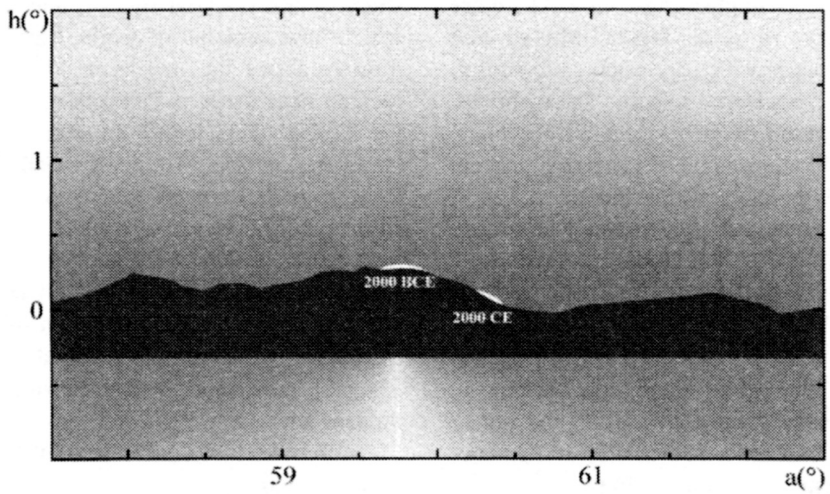

Fig. 2. Theoretically calculated position of sunrise at the summer solstice above Kali Limni, Karpathos' highest peak (1215 m), 23 June 2000 BCE, 04.39.35 o'clock local mean solar time (sun on the left), as it would have been observed from the peak sanctuary on Petsophas (H. 255 m). The orientation of the sanctuary's axis of symmetry is 60.4°±1.0° which, in view of the margin of error, coincides with the orientation to sunrise at the summer solstice (59.86°) when the sanctuary was built. Karpathos' profile has been digitised from a photograph that was calibrated with theodolite measurements

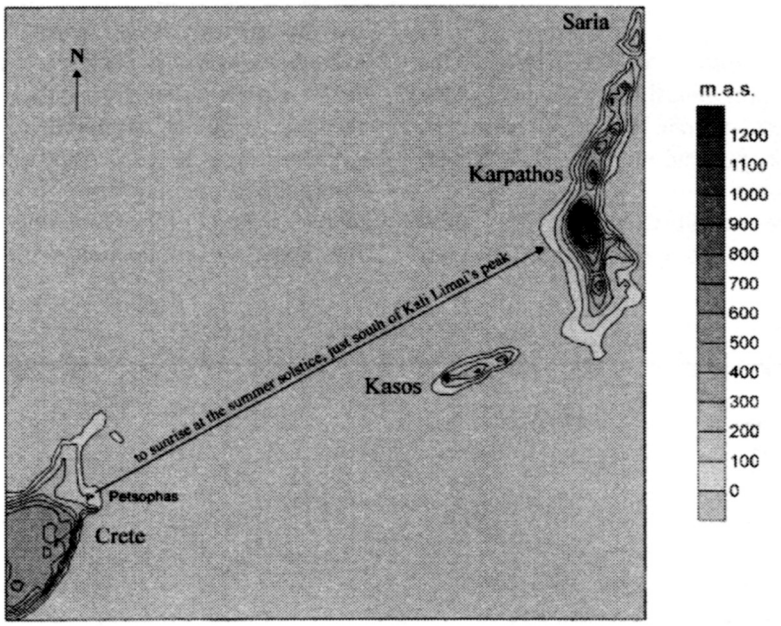

Fig. 3. Eastern Crete and Karpathos (distance from Petsophas to Kali Limni ca. 90 km)

We have other evidence that the Minoan year began at that time,[7] and the day of the equinox was given by the placement of the sanctuary with respect to the peak of Modi. Since 12 synodic months are 11 days shorter than a solar year, the calendar could have been regulated with a rule of thumb that can be formulated as follows, 'whenever the new crescent moon appears in the evening sky on one of the 11 days following the heliacal rising of Arcturus, it signals the beginning of an intercalary month'. The new moon will appear in this interval three times in eight years and seven times in nineteen years.

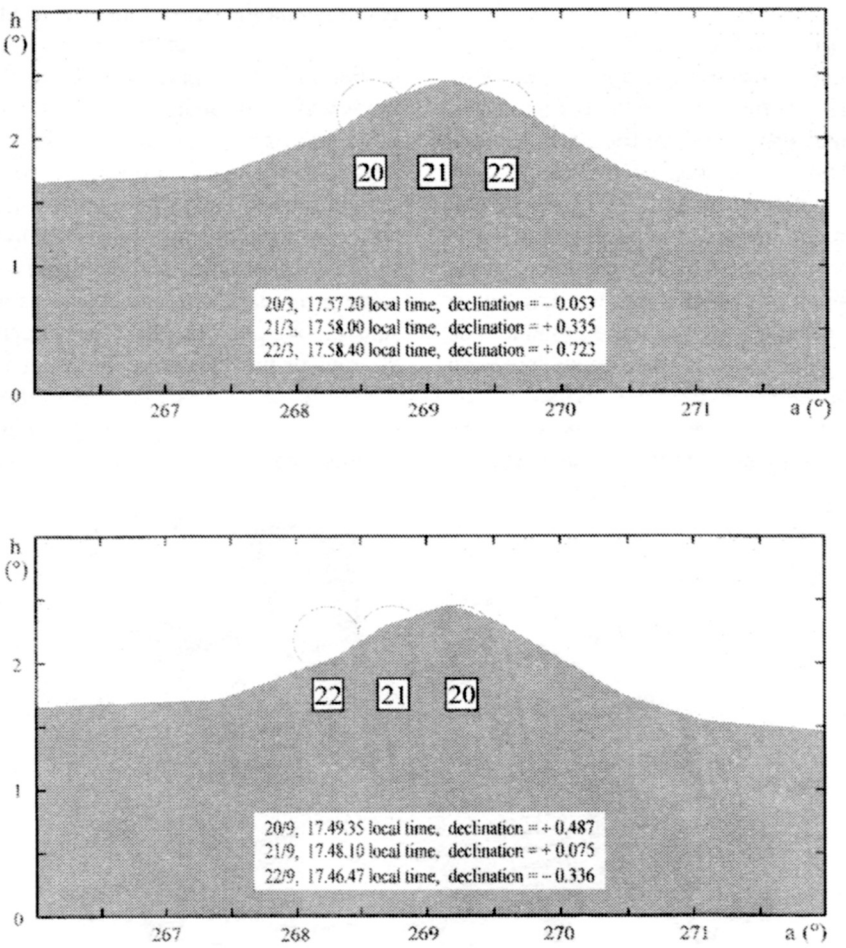

Fig. 4. Sunset behind Modi at the equinoxes in the year 1997 BCE as seen from Petsophas (refraction for t = +10 °C). The relationship is valid for many centuries

Thus the application of the rule by the insertion of a month will keep the months, and the feast days in honor of the gods, in their proper seasons. Similar rules of thumb were used in both Egypt and the Near East where intercalations were being made as early as the third millenium.[8]

These orientations to Arcturus are also found at the nearby sanctuary on Traostalos (ca. 7 km due south), and we had a statistical evaluation made of the two sets of orientations using Student's *t*-test with pooled variance. The conclusion was a 90% probability that the orientations of the walls at the two sites were intended to be the same. The only way to achieve such a set of similar orientations at different sites is by sighting on the same objects, and in the present case only the rising and setting of the same star would provide the necessary object.

When the small terracotta figurines and anatomical parts, found exclusively in connection with peak sanctuaries, were considered in the light of our proposed use of the sites as observatories, it was found that more than 90% of them could be explained as representations of constellations or their parts.[9] It has therefore been proposed that these objects were used to teach stellar positions in much the same way as ARATOS uses similar figures in his Phainomena to describe the risings and settings of the constellations.[10] They had earlier been connected to the interpretation of the sanctuaries as centres of healing cults and cults for the kinds of fertility useful to farmers and pastoralists. That interpretation had become widely accepted despite the early opposition by the great historian of Greek religion Martin P. NILSSON, for whom there were "unsurmountable difficulties" in that the small finds were very different from those usually found in connection with such cults.[11]

Results from Knossos

At Knossos the orientation of the Central Sanctuary Area in the west wing of the present building is 10.4° south of due east and it is the same as that of an earlier underlying monumental structure from the Early Minoan period (Fig. 5).[12] This is the area of the well-known pillar crypts and the generally recognized center of cult for the palace. We have found that the deviation of 10.4° from due east can be explained by the presence of the Ailias ridge in that direction, which shifts the azimuth of sunrise at that particular place by the same amount. The sun appears at the equinoxes in the upper northern corner of the eastern entrance to the Corridor of the House Tablets where the ridge intersects with the doorframe as seen from a conspicuous concave stone in the southwest corner of the corridor (Figs 6–8). The result is that the rays of the sun reach the stone only on a few specific days at the equinoxes. The corridor was earlier an integral part of the Central Sanctuary room and there was no door in its southern wall. The shape of the bowl and its position in the darkest part of the sanctuary suggested the use of a reflection for observing sunrise at the equinoxes, as we know that reflections were used in antiquity to avoid the danger of looking directly at the sun.[13] Furthermore, a reflection is an excellent method since it appears instantaneously as a sharp clear sign of sunrise. We get a bright clear reflection at *A* the moment the rays of the sun strike the water in the stone at *B*. We observed further that the upper edge of the shadow just touches the upper edge of a double axe at *C* on the southern wall of the corridor (Figs 9 and 10).

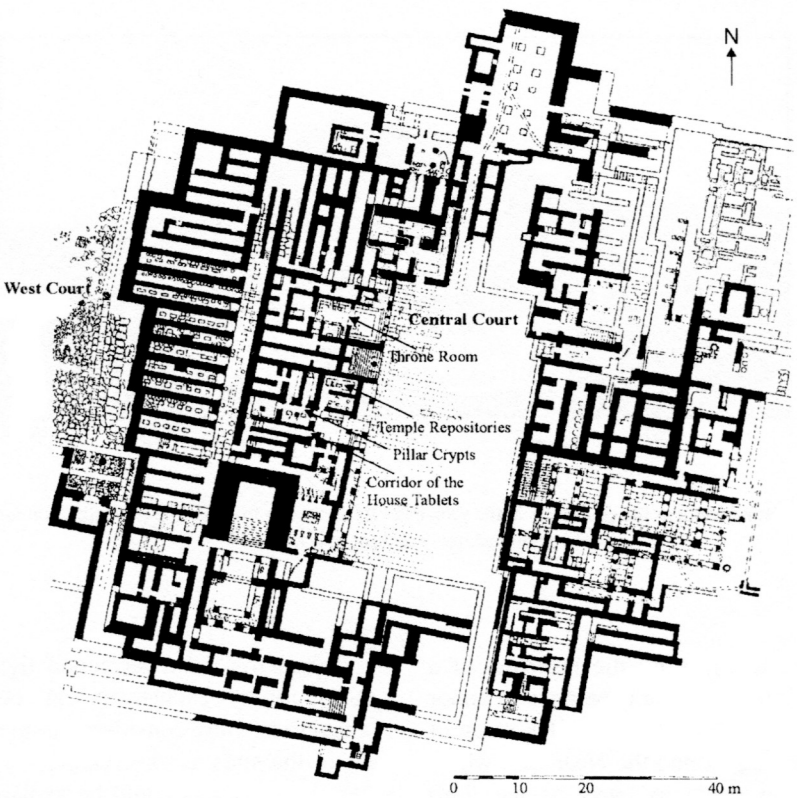

Fig. 5. Plan of the palace at Knossos. Orientation 10.4° for the western side of the Central Court.
With permission of the editors of "The Aerial Atlas of Ancient Crete"

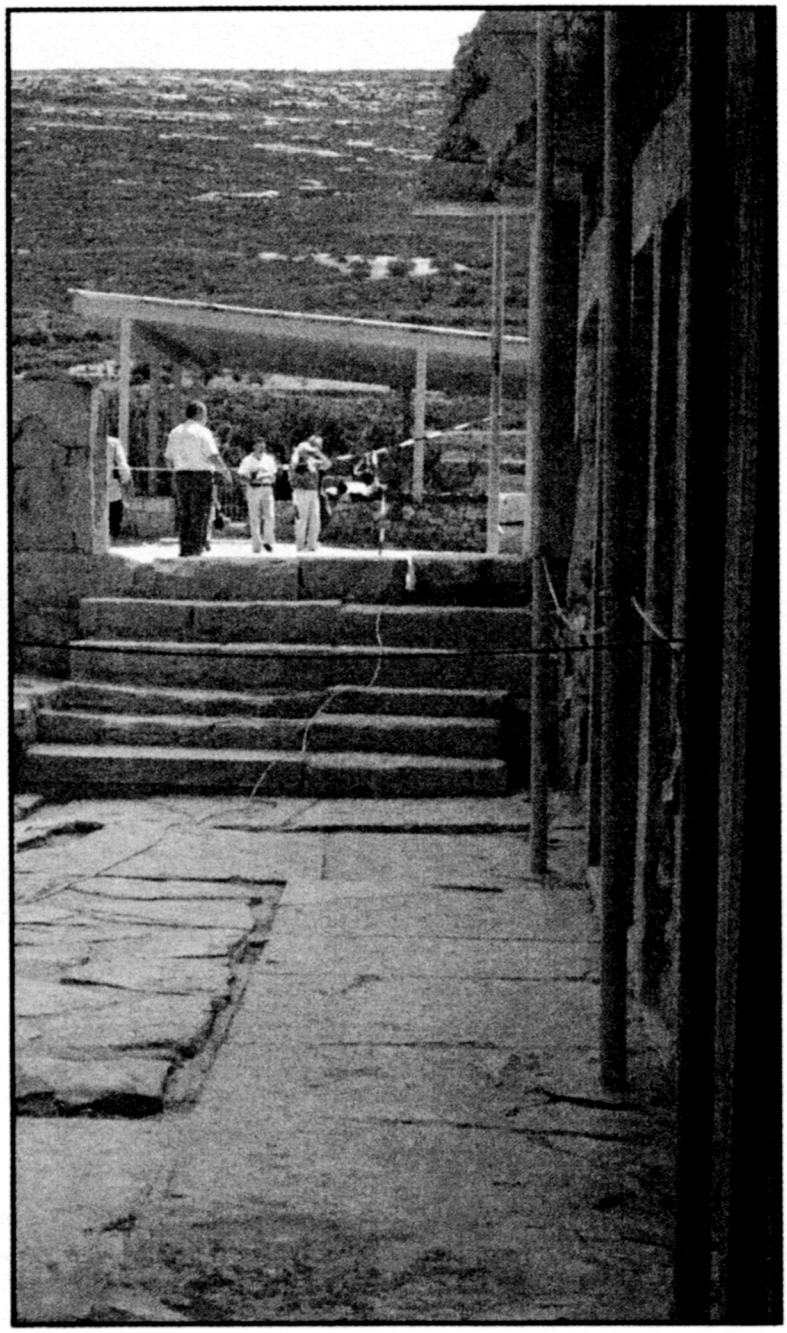

Fig. 6. Corridor of the House Tablets in the palace at Knossos, eastern doorway toward the Ailias ridge. The width and height of the door correspond to 4 and 8 Minoan feet, respectively

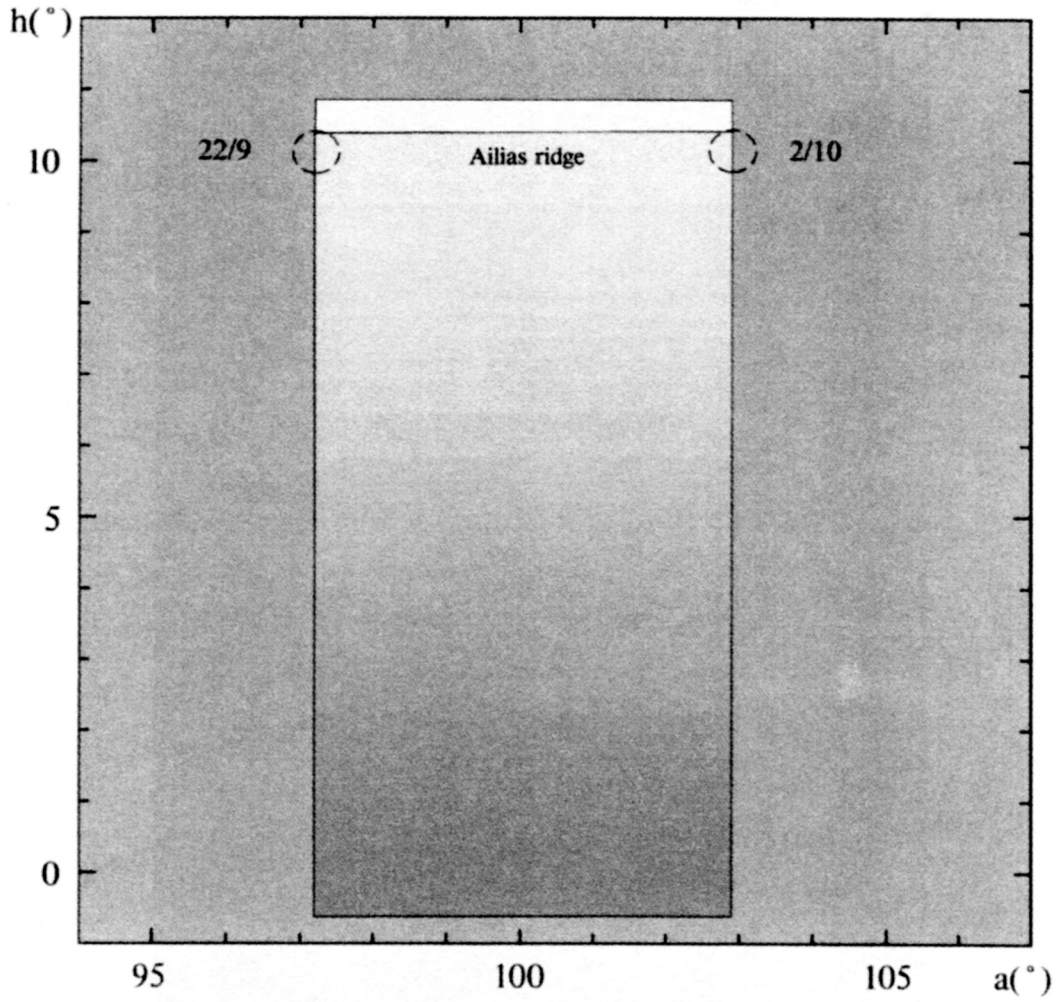

Fig. 7. The position of the sun relative to the Ailias ridge and the eastern door of the Corridor of the House Tablets on the morning of the equinoxes (upper left) and 11 days after the autumn equinox (upper right). These positions are still valid

The sun appeared, and still appears, at the upper northern edge of the doorway on the morning of both equinoxes and at the upper southern edge 11 days after the autumn equinox (Fig. 7). This gives a parallel to the arrangement on Petsophas in that a similar rule of thumb can be used to regulate a lunisolar calendar which began in connection with the autumn equinox: for example 'when the new crescent moon appears in the evening in the 11-day interval between the appearance of the morning sun at the two sides of the doorway, it signals the beginning of an intercalary month'. Also the phase of the moon on the eleventh day following the autumn equinox will be the same as on the day of the autumn equinox of the next year. This could have had considerable ritual significance. The situation is not the same at the spring equinox.

Thus we have at Knossos, as at Petsophas, a brilliant yet simple method for regulating a lunisolar calendar. It is scarcely possible to overestimate the practical and religious value of such a system in the Bronze Age. There is not space here to present all of the archaeological details which must tally in order for the method to have functioned as we propose, nor the additional refinements of the system. These will be presented in a separate article. We would like to accentuate, however, that there is no archaeological evidence which speaks against the existence of this method for regulating the calendar whereas there are a number of surviving details which support it. Furthermore what was happening astronomically at Knossos is in good agreement with developments in contemporary Mesopotamia and Egypt.

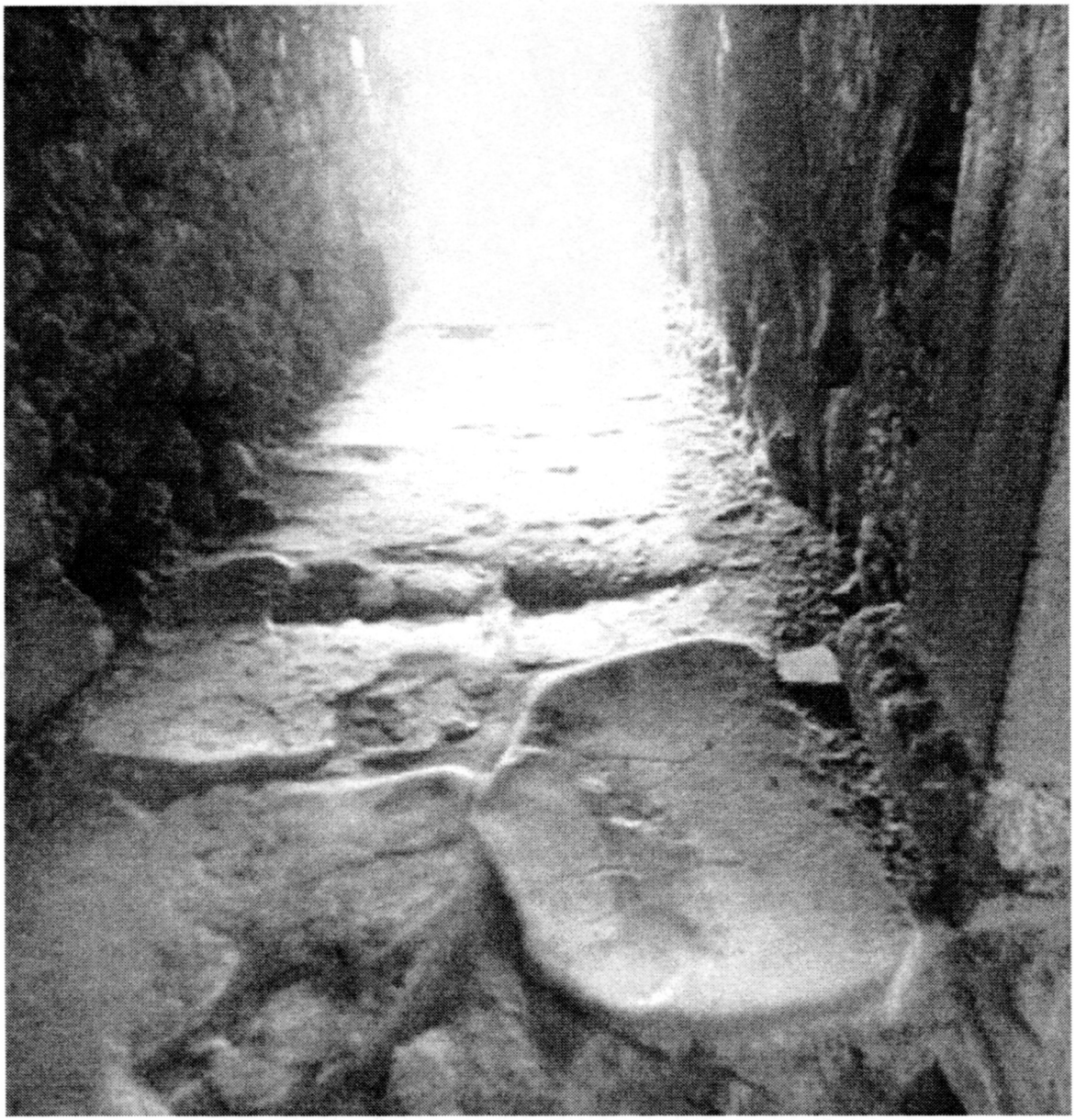

Fig. 8. The bowl-like stone at the western end of the Corridor of the House Tablets

Fig. 9. The reflection (A) cast on the western wall of the Corridor of the House Tablets by the first rays of the sun as they strike the surface of the water in the concave stone (B) on the morning of the autumn equinox. At the same time the shadow cast on the wall by the upper door frame just touches the upper edge of the inscribed double axe (C)

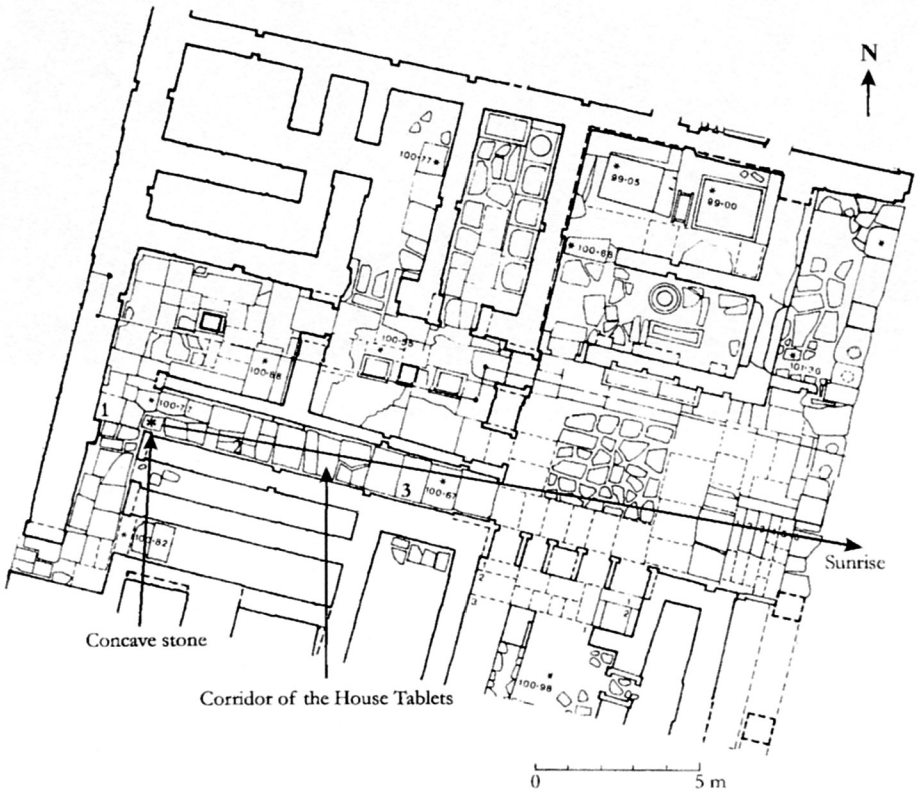

Fig. 10. Corridor of the House Tablets at Knossos. The asterisk marks the position of the concave stone and the numbers give those of the inscribed double axes. (Plan courtesy S. HOOD and W. TAYLOR, reproduced with permission of the British School at Athens)

Concluding remarks

We hope that the results which we have presented from our investigations of Minoan monuments has shown the importance of the routine use of archaeoastronomical methods in archaeological excavations. Early recognition of the function of a site not only leads to the formulation of relevant hypotheses and comprehensive explanatory models but also prevents incorrect hypotheses from becoming entrenched. The explanation of the small finds from peak sanctuaries as pedagogical aids in the learning of the positions of the constellations, for example, is not likely to have occurred unless the function of the sites as astronomical observatories had been proposed. Another important consequence is that ignorance of the function of the sites as astronomical observatories had blocked one avenue of approach to the study of the origins of Greek astronomy, that of Minoan influence. This indicates the need for a re-evaluation of the generally accepted model of Greek dependency on Babylonian astronomy. At the time when the history of Greek astronomy was being written, the possible role of the Minoans, and also of the Mycenaeans, was unsuspected.

References

1. The following proceedings have appeared:
   D. C. HEGGIE (Ed.), Archaeoastronomy in the Old World, Cambridge University Press, Cambridge 1982;
   A. F AVENI (Ed.), Archaeoastronomy in the New World, Cambridge University Press, Cambridge 1982;
   A. F. AVENI (Ed.), World Archaeoastronomy, Cambridge University Press, Cambridge 1989;
   C. L. N. RUGGLES (Ed.), Archaeoastronomy in the 1990s, Group D Publications Ltd., Loughborough 1993;
   C. L. N. RUGGLES, N. J. SAUNDERS (Eds), Astronomies and Cultures, University Press of Colorado, Niwot 1993;
   V. KOLEVA, D. KOLEV (Eds), Astronomical Traditions in Past Cultures, Sofia 1996;
   Proc 2nd SEAC Conference, Bochum, August 29-31, 1994, Bochum 1996.
2. E. W. MACKIE, Maeshowe and the Winter Solstice: Ceremonial Aspects of the Orkney Grooved Ware Culture, Antiquity 71 (1997) 340.
3. C. RENFREW, The Emergence of Civilisation, the Cyclades and the Aegean in the Third Millennium B.C., Methuen, London, 1972, p. 27.
4. The following reports have been published:
   M. BLOMBERG, G. HENRIKSSON, Minos Enneoros, Archaeoastronomical Light on the Priestly Role of the King in Crete, in: Religion and Power in the Ancient Greek World. Proc. Uppsala Symp. 1993 (=BOREAS. Uppsala Studies in Ancient Mediterranean and Near Eastern Civilizations, 24), P. HELLSTRÖM and B. ALROTH (Eds), Uppsala, 1996, p. 27;
   G. HENRIKSSON, M. BLOMBERG, Evidence for Minoan astronomical observations from the peak sanctuaries on Petsophas and Traostalos, Opuscula Atheniensia 21 (1996) 99;
   G. HENRIKSSON, M. BLOMBERG, Petsophas and the Summer Solstice, Opuscula Atheniensia 22-23 (1997–1998) 147.
5. M. PAPATHANASSIOU, M. HOSKIN, H. PAPADOPOULOU, Orientations of tombs in the Late-Minoan cemetery at Armenoi, Crete, Archaeoastronomy, 17 (1992) S43-S55;
   M. PAPATHANASSIOU, M. HOSKIN, H. PAPADOPOULOU, Orientations of tombs at Armenoi, Crete: Addenda, Archaeoastronomy, 18 (1993) S54;
   M. PAPATHANASSIOU, M. HOSKIN, The Late Minoan Cemetery at Armenoi: A reappraisal, J. History of Astronomy, 27 (1996) 53;
   M. GOODWIN, The Archaeoastronomy of early Minoan Crete, Master's Thesis, presented at Bryn Mawr College, 1998.
6. M. L. WEST (Trans.), Hesiod: Theogony and Works and Days, Oxford University Press, Oxford 1988, p. 54-55 (lines 566, 610).
7. M. GUARDUCCI, Note sul calendario Cretese, Epigraphica, 7 (1945) 79 and our results from Knossos.
8. R. A. PARKER, Ancient Egyptian Astronomy, Phil. Trans. Royal Soc. London, A276 (1974) 52;
   H. HUNGER, E. REINER, A Scheme for Intercalary Months in Babylonia, Wiener Zeitschrift für die Kunde des Morgenlandes, 67 (1975) 21.
9. P. E. BLOMBERG, An astronomical interpretation of the finds from Minoan Crete, in: Astronomy and Cultural Diversity, Proc. Oxford VI Intern. Conf. in Archaeoastronomy, J. A. BELMONTE and C. E. LÓPEZ (Eds), in press.
10. D. KIDD (Ed. & Trans.), Aratus: Phaenomena, Cambridge University Press, Cambridge, 1997.
11. M. P. NILSSON, The Minoan-Mycenaean Religion and its Survival in Greek Religion, 2nd rev. ed., Biblo and Tannen, New York, 1971, p. 69.
12. H. W. CATLING, Archaeology in Greece, 1973–74, Archaeological Reports, 1973-74, p. 34;
    J. W. SHAW, The Orientation of the Minoan Palaces, Antichità Cretesi, 1 (1977) 48. We are very grateful to Mr. Sinclair Hood for pointing out to us the course of this wall.
13. PLATO, Phaedo, line 99D.