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An updated catalogue of Greek archaeomagnetic data for the last 4500 years and a directional secular variation curve

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Abstract

We present an updated compilation of Greek directional archaeomagnetic data for the last 4.5 millennia. The data set comprises 89 directions from archaeological artefacts and volcanic rocks. Most of the data come from the Late Bronze Age (1700-1400 BC) that is the flourishing period of the Minoan civilization in Crete, while parts of the classical (480-323 BC), Hellenistic (323-31 BC) and Roman (146 BC- 330 AD) periods are also well covered. The dataset has been analysed using the Bayesian approach for curve building and a directional secular variation (SV) curve for Greece is proposed. The Greek curves are well constrained for the periods sufficienty covered by reference data while they are accompanied by large error envelopes for the periods poorly covered by data. Comparisons with regional and global model predictions show a general agreement even though some discrepancies are observed for some time intervals. The new curves together with the previously published intensity SV

curve for Greece , also using the Bayesian approach (De Marco et al., 2008), form a homogeneous set and enrich our knowledge of the full geomagnetic field vector variation in Greece during the last millennia.

Keywords : Archaeomagnetism; secular variation; Greece

1. Introduction

The Secular Variation (SV) of the Earth's magnetic field is the best path for understanding the processes and dynamics responsible for the maintenance of the magnetic field inside the fluid core. At the same time, it can be used to date archaeological material of unknown age by comparing their archaeomagnetic direction and/or intensity with the SV reference curves for a certain region. The precision of the archaeomagnetic dating, thus, highly depends on the reliability of the reference curve used. In order to construct a reliable SV curve, a significant number of well-dated archaeomagnetic data, homogeneously distributed over time and coming from a small geographic region, is necessary. Catalogues of archaeomagnetic data have been recently published for several countries (Schnepp et al., 2004; Gómez-Paccard et al., 2006a; Tema et al., 2006; Kovacheva et al., 2009; Tema, 2011) and have been used for the establishment of the directional variations of the Earth's magnetic field in these countries (Schnepp and Lanos, 2005; Gómez-Paccard et al., 2006b; Tema et al, 2006; Márton and Ferencz, 2006; Zananiri et al., 2007).

In Greece, archaeomagnetic investigations started at the early 60's with the work of Belshé et al. (1963). Since then, various studies have been carried out (i.e. Liritzis and Thomas, 1980; Downey and Tarling, 1984; Papamarinopoulos, 1987; Tarling and Downey, 1989; Spatharas et al. 2000; 2003) but most of them used displaced materials and were thus limited only to archaeointensity determinations. Evans (2006) has published the only, up to now, systematic compilation of 36 Greek directional data, from kilns and baked clay on mainland Greece and on the islands of Crete, Delos, Euboea and Thasos, which he sampled and studied.

Nowadays, global databases including directional and intensity data (Korte et al., 2005; Donadini et al., 2009) are available and mainly used for global modelling the features of the Earth's magnetic field in space and time (Korte and Constable, 2005; Korte et al., 2009). Such large data sets, however, are basically compiled using published regional catalogues of archaeomagnetic data and therefore often miss single publications and data published in journals of national interest. This is the case for Greece where an important number of data have been published in conference proceedings and excavation reports or are included in Master and/or PhD thesis, often written in Greek. Moreover, such large regional and global datasets that report data from different countries cannot always have a direct control on the original data and often problematics related to a single country (such as debated chronological periods) are difficult to be investigated. For this reason, the compilation of local datasets that can be subsequently incorporated into bigger global databases is still very important.

In this study, we present the most now-a-days complete and updated compilation of Greek directional archaeomagnetic data that cover the last 4.5 millennia, from Bronze age to Byzantine times. The data set has been analysed using the Bayesian stochastic approach for curve building and a directional SV curve for Greece is proposed. The Greek curves are compared with regional and global model predictions as well as with SVC curves obtained for several Central Europe countries (Marton, 2010) and compiled ones for the broader Balkan area (Tema and Kondopoulou, 2011). The new curves together with the previously published intensity

SV curve for Greece (De Marco et al., 2008), make reliable archaeomagnetic dating of Greek fired artefacts possible for the periods where the full description of the Earth's magnetic field vector (declination, inclination, intensity) is available.

2. Greek archaeomagnetic directional database

The Mediterranean region (and particularly Greece) possesses a very rich cultural heritage. Archaeological excavations have brought to light a great number of archaeological sites, a lot of which are accurately dated and can provide a detailed record of the variations of the Earth's magnetic field in the past. Nevertheless, although the number of Greek archaeointensity data is impressively high (De Marco et al., 2008; Tema et al., 2012), directional data are much fewer.

A total of 89 directional archaeomagnetic data have been compiled and are now systematically summarized in Table 1. Among them 84 come from dated archaeological artefacts and some volcanic rocks. For the remaining 5, age uncertainty was too big to allow their use as reference points. The database reports the principal information related to each individual study, including site information and geographic location, structure age and dating method, material and sample description, experimental treatment, directional values and statistical information related to number of samples and uncertainties, and the original reference. Only results with cited statistical parameters have been considered.

The geographical distribution of the sites is shown in Fig. 1. An important number of data come from Crete and the area around Thessaloniki (Northern Greece). Some data from Peloponnese (Southern Greece) and the islands of Paros, Delos and Santorini are also available while no data exist for central Greece. The complete absence of data in Eastern Aegean is also noteworthy since it is accentuated by their total lack in Asia Minor-Western Turkey. The data cover the last 4500 years with a high concentration on the Late Bronze Age (1700-1400 BC) that is the flourishing period of the Minoan civilization in Crete. Parts of the classical (480-323 BC), Hellenistic (323-31 BC) and Roman (146 BC- 330 AD) periods are also well covered. On the contrary only few data are available for late Byzantine period and no data exist for the time between the 10^{th} and 6^{th} century BC (Fig. 2a). The latter concerning the Dark Ages and Geometric/Archaic periods is a complicated issue and will be further discussed in the last paragraph. In all cases, the age of the studied structures is based on archaeological evidence and no further age information from independent scientific dating methods (i.e. radiocarbon dating, thermoluminescence) is available.

Important discrepancies between traditional archaeological and more recent, mainly science-based, chronological frameworks regarding the Aegean Late Bronze Age chronology, can be found in the literature (Betancourt, 1987; James et al.,1987; Manning 1999; Dunn, 2002; Manning et al. 2006). Chronologies for Aegean and East Mediterranean cultures during the second millennium BC have been traditionally derived from comparisons of artefacts and style associations with those in the Near East, which can be related to the approximate historical chronologies of Egypt or Mesopotamia. Based on this archaeological evidence, a 'low' chronology was proposed according to which the Minoan eruption of Santorini (Thera) is placed around the mid- to late- 16^{th} century BC (Warren 1987; Tartaron, 2008). On the other part, evidence from ice-cores, tree rings and a large number of radiocarbon datings favours an age for the Thera eruption about 100 years younger (in the second half of the 17^{th} century BC), establishing the 'high' chronology scheme (Friedrich et al., 2006; Manning et al., 2006). This debate is still open and the effort to resolve these differences is a prominent feature of Aegean prehistory for the years to come. In the majority of the Late Bronze Age data included in the Table 1, authors have used the 'low' chronology scheme to date the structures they studied (Belshé et al., 1963; Evans, 2006). To keep uniformity between all data, we have also followed the archaeologically proposed low chronology as found in Tartaron (2008) for the Tarling and Downey (1989) and Tarling et al. (2004) data, where only relative chronology information referring to Early, Middle or Late Minoan periods was included. Nevertheless, one should keep in mind that traditional Cretan chronology is nowadays under re-evaluation and older dates of about a century can not be excluded.

The archaeological structures studied are mainly kilns; some data, however, come from small hearths and burnt walls (Fig. 2b). Data from lava flows from Santorini are also included. Complete stepwise alternating field (AF), partial AF (where only few demagnetization steps are used) and/or thermal demagnetization procedures have been used for the isolation of the characteristic remanent magnetization (ChRM) component and the calculation of the archaeodirections. Directions included in the early archaeomagnetic work of Belshé et al. (1963) were calculated using only NRM measurements. Such data that are not magnetically cleaned should be treated with caution, but considering the strong stability of the baked clay for archaeomagnetic studies (Jordanova et al., 2003) they have been included in the reference dataset. In the majority of cases, the archaeomagnetic directions are well defined characterized by small (< 5^{o}) semi-angles of confidence α_{95} (Fig. 2c).

All data have been relocated to Athens (37.97 ^{o}N, 23.72 ^{o}E) using the virtual geomagnetic pole method (Noel and Batt, 1990) and plotted versus time in Fig. 3. We have illustrated with white color the data that can be evaluated as low quality (based on only NRM measurements or with missing relative information and characterized by α_{95} angle > 5^o) and with black color the high quality data (obtained with thermal/AF cleaning and characterized by low α_{95} angle). No particular discrepancies clearly related to the low quality data are observed, mainly if their error bars are taken in consideration.

The data, even though dispersed for some time periods (i.e. 15th century BC), still succeed to record a clear variation with time. The dispersion might be related to error in the archaeological age and/or to errors associated with sampling and archaeomagnetic measurements. During the Roman period, for which an important number of data is available, declination seems to be quite stable with only small variations. High inclination values (~ 60^o) have been recorded for Minoan times. On the contrary, a clear inclination decrease around 200-400 AD is well documented by the data and a second incilnation low may also be noticed around 1800 BC (Fig. 3).

3. Secular variation reference curve for Greece based on Bayesian statistics

The establishment of a robust SV curve is one of the most complicated tasks in archaeomagnetism, mainly because of the uneven distribution of the reference data both in time and space. Several techniques have been proposed in order to produce reference curves that can describe in the best way all reference data and show in a continuous and smoothed way the variations of the Earth's magnetic field in the past. The most used methods for curve building are the bivariate moving average technique (Le Goff et al., 1992; 2002) and the more recently proposed hierarchical Bayesian approach (Lanos 2004; Lanos et al., 2005). Differences between these methods have been thoroughly discussed in several studies (i.e Lanos et al, 2005, Gómez-Paccard et al., 2006; Márton and Ferencz, 2006). In the present study, the most recent advances of the hierarchical Bayesian modelling for curve building have been used in order to obtain the Greek directional SV curve.

The Bayesian stochastic approach is based on roughness penalty (Lanos, 2004) and allows the fitting of a spherical spline function to the data. It has the advantage, compared to the moving average technique, that the reference points can move within their respective dating errors and measurement uncertainties and the window width can be automatically adjusted to the data density. According to the Bayesian statistics a mean curve is calculated accompanied by an error envelope at a 95% confidence level. This means that the 'real' curve will lie somewhere inside this error envelope.

In order to guarantee the quality of the reference data on which the calculation of a SV curve is based on, several selection data criteria have been proposed and applied by several authors (e.g. Schnepp and Lanos, 2005; Tema and Kondopoulou, 2011). Most of them are based on the experimental precision parameters, usually expressed as semi-angle of confidence α_{95} and precision parameter k, and on the reliability of the archaeological dating of the studied material. Nevertheless, the Bayesian statistical approach takes into consideration both time and measurement uncertainties of each reference point calculating the optimum path that better describes all data with their corresponding errors in a smooth way; the final result is, therefore, not importantly affected by data with large α_{95} angles or large age uncertainties but it mostly depends on the number of reference points (Lanos, 2004). Gómez-Paccard et al. (2006b) have investigated the influence of data with large errors on the construction of the directional SV curve for the Iberian Peninsula using the Bayesian statistics. They first calculated a curve using as reference points the entire dataset (including also data with large errors) and then they calculated it again using only data with age errors ≤ 75 years and $\alpha_{95} \leq 3.5^o$. They obtained in both cases very similar results suggesting that the more numerous complete dataset could be reliably used for the calculation of the Iberian SV curve. Following Lanos (2004) and Gómez-Paccard et al. (2006b) suggestion, no pre selection criteria on the Greek dataset have been applied.

The obtained Greek SV curves for declination and inclination with their 95% error envelopes as calculated by the Bayesian modelling are shown in Fig. 4, plotted together with the raw data. The results obtained (in steps of approximately 25 years) are given in Table 2. It can be observed (Fig. 4) that the raw data are well represented by the smoothed curves and that error margins are much narrower for the periods where many data exist (e.g. Late Minoan or Hellenistic and Roman periods) while the error envelopes are wide for the periods poorly covered by data or where no data exist. In particular, the directional data set still suffers from a limited number of data in various time periods, but mainly during the 1st millennia BC and the 500 AD -1500 AD period, where the lack of data does not allow to draw a firm pattern of the geomagnetic secular variation. Nevertheless, some important geomagnetic features are still clearly evident. A minimum in inclination is recognised around 1800 BC, which is followed by a steep increase in the inclination values in the first half of the 2nd millennium BC, reaching a maximum at around 1400 BC. Eastern declinations are observed around 1000 BC, in spite of the limited number of data. For the 1000BC-500 BC period, no data are available; for this period the curves are characterized by large error bars and should therefore be used with caution. On the contrary, from 400 BC to 400 AD, the curves are well constrained and a well defined inclination minimun can be noticed around 300 AD. Then the inclination is increasing reaching a maximum around 900 AD, that is however calculated based to only three reference points. Declination seems to be constantly increasing from 200 BC till 1600 AD but the dispersion of the declination reference data does not permit the recognition of detailed SV characteristis for the last millennium.

4. Comparison with global and regional geomagnetic field models

During the last 10 years several compilations and models have been published in order to describe the geomagnetic field variations at regional and global scale (Korte and Constable, 2005; Genevey et al., 2008; Donadini et al., 2009; Pavón-Carasco et al., 2009). Korte et al. (2009) have computed 5 global models based on the same modelling principle but using different data compilations (archeological artefacts, lavas, lake sediments). Among these models, Korte et al. (2009) suggest that the ARCH3K.1 (only archaeomagnetic data) global model is the most appropriate for Europe for the last 3000 years. For older times only the CALS7K.2 global model is availabe (Korte and Constable, 2005) that covers the past 7000 years, from 5000 BC to 1950 AD.

An intermediate approach between global models and local secular variation curves is the calculation of regional models. Pavón-Carrasco et al. (2009) proposed a regional archaeomagnetic model that calculates the geomagnetic field variations in Europe for the last 3000 years, modelling together the three geomagnetic elements. This model, SCHA.DIF.3K, was obtained by least sums of absolute deviation inversion of archaeomagnetic data using spherical cap harmonics for the spatial representation of the field and sliding windows in time. In the model's input database (essentially based on the database of Korte et al., 2005) only archaeological material has been used and no lake sediment and lava flow data were considered (Pavón-Carrasco et al., 2009). The SCHA.DIF.3K model directly predicts the geomagnetic field at the site of interest, avoiding, in this way, any eventual relocation error. In order to extend the SCHA.DIF.3K model predictions backwards in time, Pavón-Carrasco et al. (2010) have recently proposed the SCHA.DIF.8K regional model that is based on a selected compilation of both sedimentary and archaeomagnetic data and predicts the geomagnetic field variations from 6000 BC to 1000 BC (Pavón-Carrasco et al., 2010).

Comparison of the Greek SV curves with the models' predictions (Fig. 5) shows generally a good agreement for the periods well covered by data while some differences may be observed for specific time intervals, mainly where only few reference data are available. From 500 BC to around 400 AD the Greek curves for both declination and inclination concide with the global and regional models (Fig. 5). They show that during this period, declination was slightly varying from westward values around 200 BC to eastwards values around 400 AD. For the same time, the Greek inclination curve is in very good agreement with the models showing that inclination was constantly decreasing from 400 BC till around 250 AD when a well defined inclination minimum can be observed. For older times, the Greek SV curve shows a well constrained inclination minimum around 1800 BC, that is not observed either in the global or in the regional models. However, one should take in consideration that both CALS7K.2 and SCHA.DIF.8K include sedimentary records in their reference database and therefore they may suffer from an over-smoothing effect due to the already smoothed raw data and to a possible compaction effect of the lake sediment data. These models may thus miss some short-term variations of the local geomagnetic field and/or record only smooth maximum and minimum variations (Korte and Constable, 2005; Pavón-Carrasco et al. 2010; Tema & Kondopoulou, 2011).

For more recent times, that is from 400 AD to 1600 AD, the Greek curve is based on a very small number of reference data and therefore even though the inclination curves show a general agreement, the greek declination curve does not show the high declination values observed by the global and regional models for the 1000-1200 AD period.

5. Application to archaeomagnetic dating

Two dating examples: Eretria and Avlis

The obtained Greek directional SV curves (Fig. 4 and Table 2) have been used to date archaeological structures of poorly defined age. As an example, we chose to apply the Bayesian dating technique (Lanos, 2004) on two out of five kilns which were cited by Evans, (2006) and are included in our catalogue as “non-dated”, namely Eretria and Avlis.

Inclination and declination were reduced to Athens (lat=37.96°; long=23.79°) using VGP conversion (Noel and Batt, 1990).

a. **Eretria kiln** (site 85-Table 1)

The posterior dating densities were obtained after comparison of the kiln's inclination and declination (acquired during the kiln's last firing) with the greek inclination and declination reference SV curves (Fig. 6a and 6b respectively). The final dating interval was obtained after combination of the separate inclination and declination probability densities (Fig. 6c). Rectangles plotted onto the posterior density represent the highest posterior density (HPD) intervals at 95% confidence level. Such comparison suggests several possible dating intervals: [-2180 ; -1990], [-1665 ; -1550], [-1174 ; -811], [484 ; 1425]. The true dating solution is in one of these intervals. Evans (2006, page 94) "*suggested that this kiln ceased operation in Late Helladic I/II times (~1500 BC)"*. Taking in consideration this archaeological information, the older and/or younger possible dating intervals can be excluded, and thus at 95 % of probability the last firing of the Eretria kiln occured around 1665-1550 BC.

b. Avlis kiln (site 88,Table 1)

The posterior dating densities obtained from inclination and declination are given in Fig. 7a and 7b respectively. As in the previous example, the combined posterior dating density is calculated (Fig. 6c). The possible dating intervals calculated at 95 % of probability are: [-2180 ; -2103], [-1592 ; -1115], [-978 ; -281], [726 ; 1074]. According to Evans (2006, page 94), the kiln is placed in an archaeological context of the fifth century BC *("date of other nearby buildings at the site")*. This means that the true solution probably lies in the interval 978-281 BC. In this case, archaeomagnetic dating, even if in accordance with the archaeological evidence, does not succeed to offer a precise dating and the age interval proposed is very wide. That's probably because for the 1000-400 BC period very limited Greek data are available and the reference curves are accompagnied by large error bars. Moreover for the period around 4-5th BC century the declination of the Earth's magnetic field is very stable and without any important variation as can be also seen in the models (Fig. 5).

To control the dating results obtained by using the Greek SV curves, we have also dated the same sites using the Balkan directional SV curve (Tema & Kondopoulou, 2011) and the regional geomagnetic field models (Pavón-Carrasco et al., 2009; 2010).

In both cases, dating has been performed using the Matlab *archaeo_dating tool* (Pavón-Carrasco et al., 2011).

For Eretria kiln, dating with the Balkan curve shows an age of 1626-1523 BC that is in excellent agreement with the dating interval obtained from the Greek curve (1665-1550 BC, Fig. 6). On the other hand, dating with the SCH.DIF.8K model results in a much wider dating interval (2790-1172 BC). This shows that the models for time periods older than 1000 BC are not detailed enough for dating purposes while the Greek curve can give better results and offer a very useful dating tool for the 1000-2000 BC period.

For Avlis kiln, dating with the Balkan SV curves suggests that the last firing of the kiln occured around 707-246 BC while dating with the SCHA.DIF.3K model results to 496-46 BC dating interval. Again, dating results from the Balkan curve are in good agreement with those obtain from the Greek curve, even though in both cases the obtained dating intervals are quite wide. The age obtained from the SCHA.DIF.3K seems better constrained. However, even if it is slightly less wide than the one obtained by the Greek and Balkan curves, it still cannot guarantee precise dating (almost 400 years wide) and seems to give an age younger than the one proposed by the archaeologists. This shows that for the case of Avlis, no available up to now reference curve can give very satisfactory results, probably because during the 600-100 BC period the declination of the Earth's magnetic field shows very small variations as already discussed.

6. Discussion and Conclusions

The present updated catalog of Greek archaeodirections for the last 4500 years and the calculated greek Bayesian directional SV curve aim to describe, together with the previously published intensity Bayesian SV curve (De Marco et al., 2008), the full geomagnetic field vector variation in Greece and at the same time highlight the potential but also the important limits of archaeomagnetic dating applications in Greece.

All data presented here have been controlled and information about their quality and reliability of the archaeological dating of several time periods has been included, often obtained after personal communication with the original papers authors. Through the whole Greek database, there is a good control on the material selection, sampling procedures and methods of study, as 25% of the data have been obtained by or in presence of researchers and Phd students of the Geophysical Laboratory in Thessaloniki. Prior to this, an additional 20% was obtained with the same protocol and equipment, kindly offered to us later by Prof. Ted Evans. In total, about 50% of the compiled data are therefore characterized by homogeneity in their acquisition procedure.

Based on 84 direction reference data, a directional Bayesian reference SV curve has been calculated. Many of the Greek reference data together with a selection of other data from the Balkan peninsula, have already been previously used for the calculation of the Balkan SV curves (Tema & Kondopoulou, 2011). In the present study our interest has been focused only in Greece. The regional compilations, such as the Balkan one, present the important advantage that they can offer better space and time coverage by sharing data from different countries. On the other hand they fail to clearly display the coverage at the country level and the problems related to local datasets. The Balkan curves have been drawn on the basis of the bivariate extension of the Fisher statistics, while the present Greek ones are established with the Bayesian approach. This allows for easy dating since they form an homogeneous set with the intensity Greek curve (De Marco et al., 2008) also drawn with the Bayesian method (Lanos, 2004).

The obtained Greek curves, even if not detailed for the time periods with limited or no reference data, they succeed to highlight some variations of the Earth's magnetic field that are not observed in the regional and global models, such as the inclination minimum around 1800 BC. This interesting feature of the inclination variation in Greece seems to be also supported by other contemporaneous inclination data from Romania, Bulgaria and Hungary (Tema & Kondopoulou, 2011). More data from well dated archaeological artefacts from this period could offer further information on this very interesting feature.

Apart from the comparison with models in the previous paragraph we proceeded to another one, with the secular variation curves drawn for several Central-Eastern European countries through the Bayesian hierarchical approach for the last 2000 years (Marton, 2010, Fig.4). Considering the same time span, several features are common: the "flatness" of the declination curve between 500BC-500AD for the majority of these countries, while the "sharp increase " up to 1000 AD is appearing rather around 1200 AD, possibly due to uncertainties in ages and reduced number of greek data for this period. Variations in inclination in the greek curves display the same tendancy with the ones reported by Marton (2010) for the overlapping periods, that is a minimum at the third and 13th centuries AD and a maximum around the 8th century AD.

Finally, a cross- check with the Balkan directional SV curve (Tema and Kondopoulou, 2011, Fig. 5a,b) further enlightens the rising pattern of the here presented greek curves. In fact, the gaps around 2000 BC and between 1000-500 BC in the latter are only partly covered by data in South Italy, Serbia and Bulgaria. The minimum in inclination values at 300 AD and 1300 and the maximum at 1000AD are also prominent but further comparisons are hampered by the scarcity of greek data in the time span after 1000 AD.

This study clearly shows that the Greek curves can offer a valuable dating tool for the 2000-1000 BC period for which the global and regional models are mainly based on sedimentary data and show only smooth variations of the Earth's magnetic field. They also can be reliably used for archaeomagnetic dating in the 500 BC-500 AD time span while for the other periods the large error bars present serious limitations on their use for dating purposes. Still great effort should be focused on obtaining more data from Greece in order to improve the Greek SV curves.The number of available data at a certain country, is also in direct relation to the development of civilizations and unearthed vestiges. In Greece, for the 11th - 6th BC centuries period very limited baked clay structures have been found and this creates more problems on filling this gap. Nevertheless, we hope that this study has highlightened the need of more data from well dated archaeological artefacts and the close collaboration with the archaeological society can contribute on the achievement of this goal.

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Table caption

Table 1. Directional archaeomagnetic data from Greece.

Columns: No= site reference number; Location of the sampling sites; Lat /Long= site latitude /longitude; Age range; Mean age; Method of dating (A: archaeological); Material studied; Code name of the structure; laboratory treatment (AF: alternating field demagnetization, pAF: partial AF demagnetization, Th: thermal demagnetization; NRM: natural remanent magnetization); N= number of samples; D, I= declination, inclination; α_{95}= 95% semi-angle of confidence; k= Fisher's precision parameter; D_r , I_r = declination, inclination relocated to Athens (37.97^{o}N, 23.72^{o}E); Reference (demagnetisation technique, k and N values of sites n. 26 & 27 have been provided by Prof. Tarling personal communication).

Table 2. Time: age in years; I (˚) inclination values obtained after the Bayesian modelling, I min (˚) inclination minimum margin, I max (˚) inclination maximum margin; Declination (˚), declination values obtained after the Bayesian modelling, D min (˚) declination minimum margin, D max (˚) declination maximum margin. Data selected every 25 years.

Figure captions

Fig. 1. Geographic distribution of the Greek directional data.

Fig. 2. a) Time distribution of the Greek data; b) pie diagram of the type of material used for archaeodirection determination; c) histogram of the distribution of the α_{95} semi-angle of confidence.

Fig. 3. Greek declination (a) and inclination (b) data plotted versus age together with measurement errors (dD, dI) and age uncertainties. White dots show the data that can be evaluated as low quality and black dots those characterised as high quality (see text for further information). All directions are reduced to Athens (37.97^o N, 23.72^o E).

Fig. 4 Smoothed SV curves for (a) declination and (b) inclination for Greece surrounded by the 95% error envelope as obtained from the Bayesian modelling. Together are plotted the raw data and the historical measurements for the last four centuries. All directions are reduced to Athens (37.97^o N, 23.72^o E).

Fig. 5 The Greek (a) declination and (b) inclination Bayesian SV curves (black dashed curves) accompanied by the uncertainties envelopes (grey bands) plotted together with the predictions of the CALS7K.2 (thick red curve) and ARCH3K.1 (fine red curve) global and SCHA.DIF.3K (green curve) and SCHA.DIF.8K (green open dots) regional geomagnetic field models.

Fig. 6. Dating procedure using the Bayesian dating technique (Lanos, 2004), applied to the site of Eretria (site 32, Evans 2006). The posterior dating densities obtained are presented for both inclination (a) and declination (b). In the upper part of each graph the reference curves for Greece with their error bands (blue) are shown; the mean site

archaeodirection, relocated to Athens are depicted (straight lines) with their analytical errors. In the lower part of each graph, the probability density lines are shown along with their highest posterior density (HPD) intervals at 95% confidence level, represented by the green rectangles. (c). The final posterior dating density was obtained by combining the inclination and declination separate probability densities.

Fig. 7. Dating procedure using the Bayesian dating technique (Lanos, 2004), applied to the site of Avlis (site 88, Evans 2006). As in the previous example (see fig. 6 captions for details), the posterior dating densities are calculated for inclination (a) and declination (b), and (c) the final dating is obtained from the combined posterior dating density.

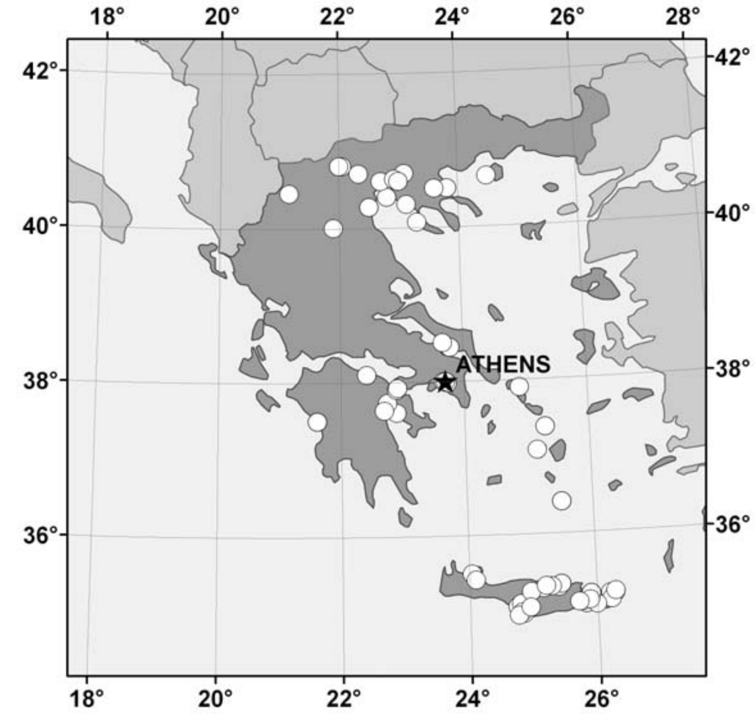
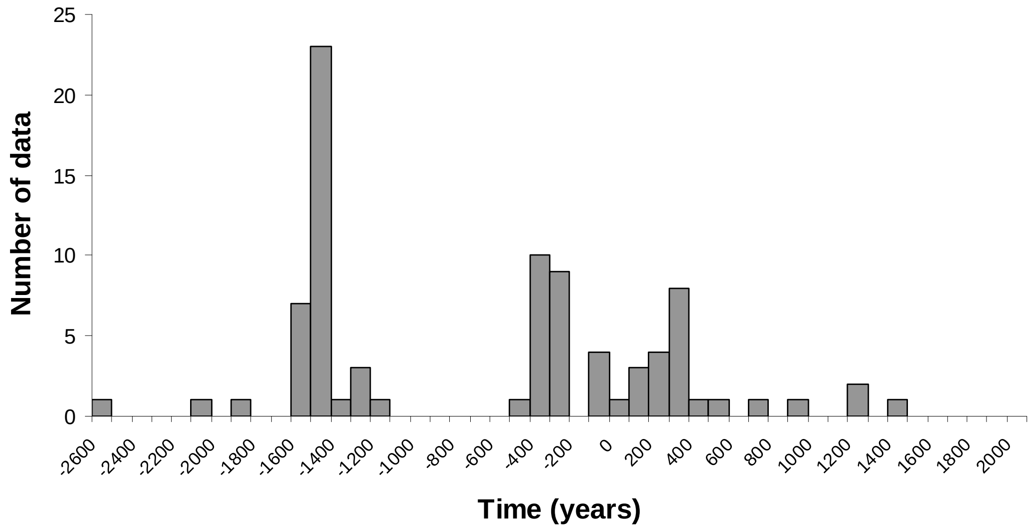


Fig. 1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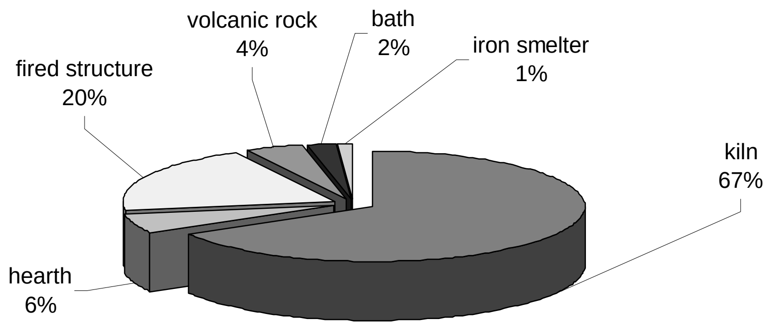
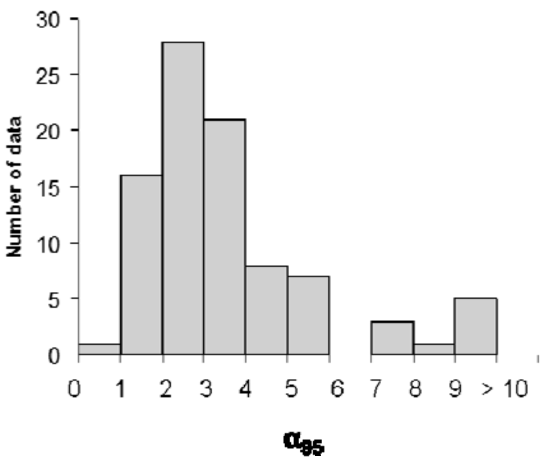
10
15
20
25
-2600
-2400
-2200
-2000
-1800
-1600
-1400
-1200
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time (years)

(a)


volcanic rock
4%
bath
2%
iron smelter
1%
fired structure
20%
kiln
67%
hearth
6%

(b)


Number of data
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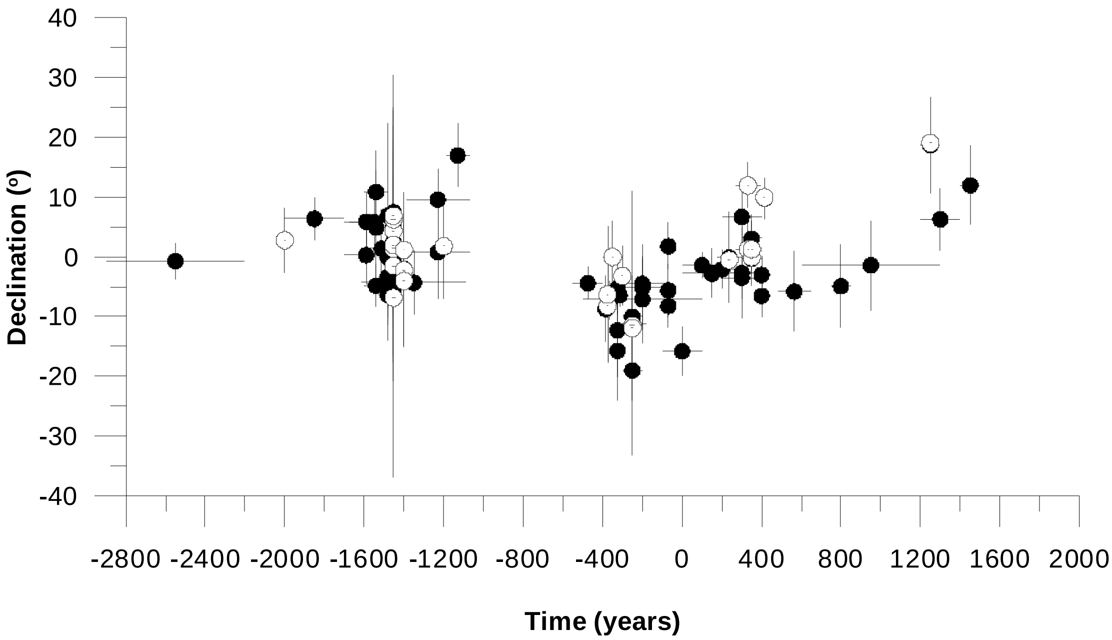
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
> 10
α_{95}

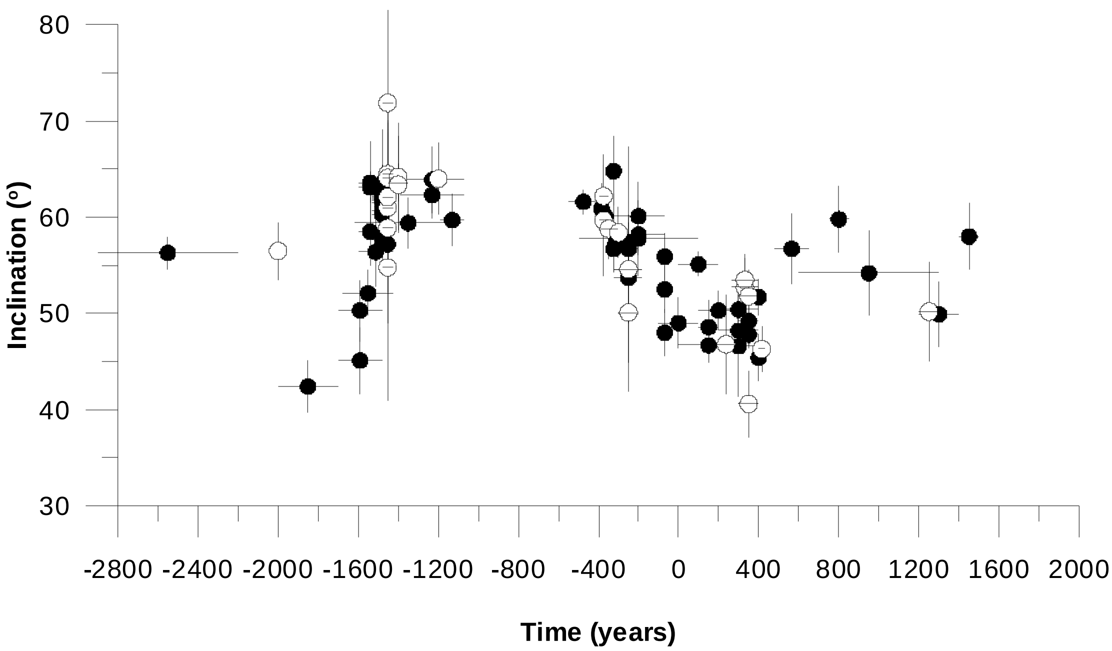
(c)

Fig. 2



40
30
20
10
0
-10
-20
-30
-40
Declination (º)
-2800 -2400 -2000 -1600 -1200 -800 -400 0 400 800 1200 1600 2000
Time (years)

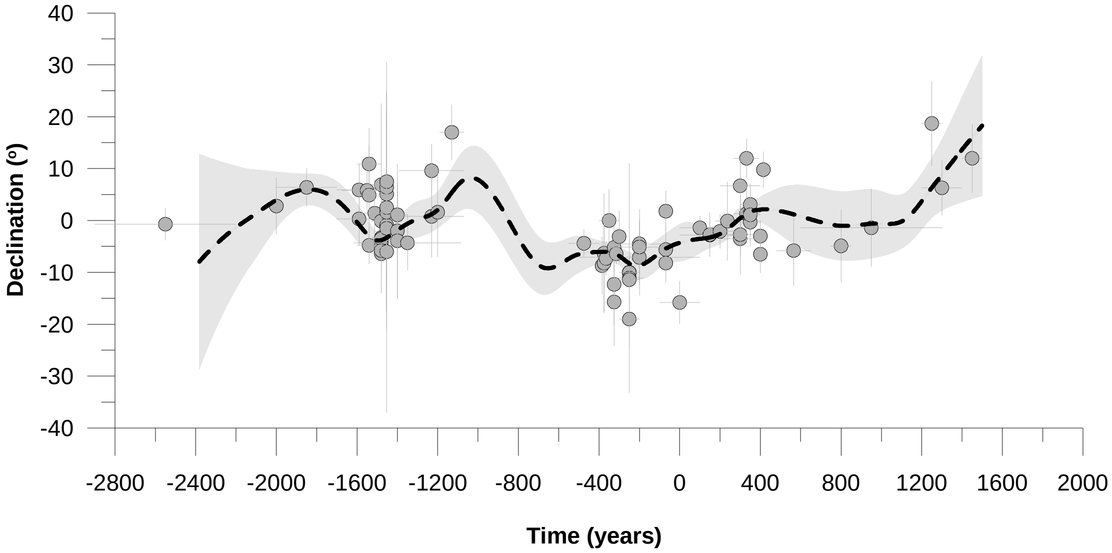
(a)



80
70
60
50
40
30
Inclination (º)
-2800 -2400 -2000 -1600 -1200 -800 -400 0 400 800 1200 1600 2000
Time (years)

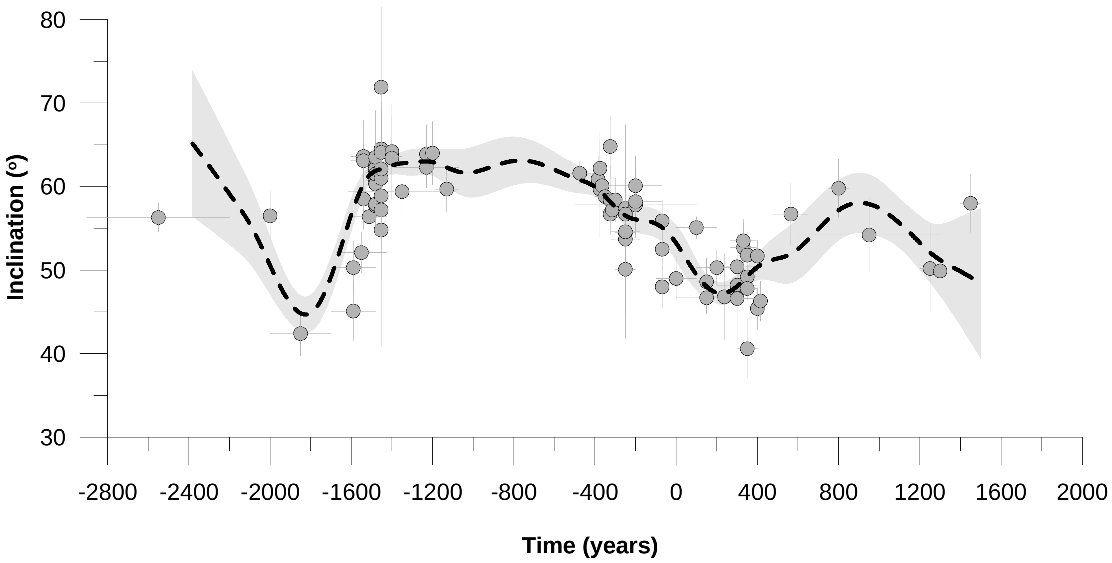
(b)

Fig. 3



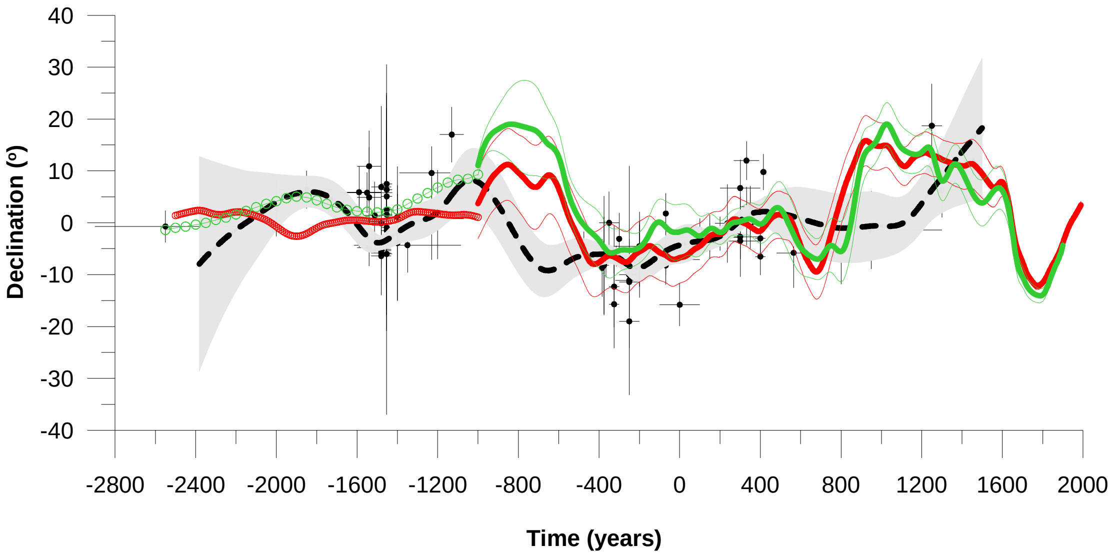
40
30
20
10
0
-10
-20
-30
-40
Declination (º)
-2800
-2400
-2000
-1600
-1200
-800
-400
0
400
800
1200
1600
2000
Time (years)

(a)



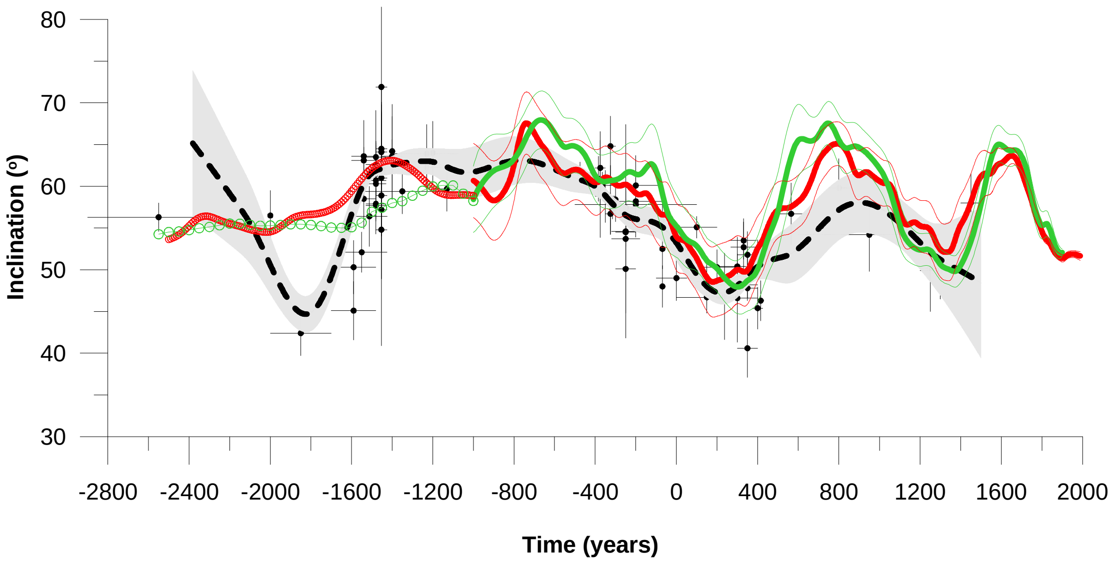
80
70
60
50
40
30
Inclination (º)
-2800
-2400
-2000
-1600
-1200
-800
-400
0
400
800
1200
1600
2000
Time (years)

Fig. 4



40
30
20
10
0
-10
-20
-30
-40
Declination (º)
-2800
-2400
-2000
-1600
-1200
-800
-400
0
400
800
1200
1600
2000
Time (years)

(a)



80
70
60
50
40
30
Inclination (º)
-2800
-2400
-2000
-1600
-1200
-800
-400
0
400
800
1200
1600
2000
Time (years)

(b)

Fig. 5

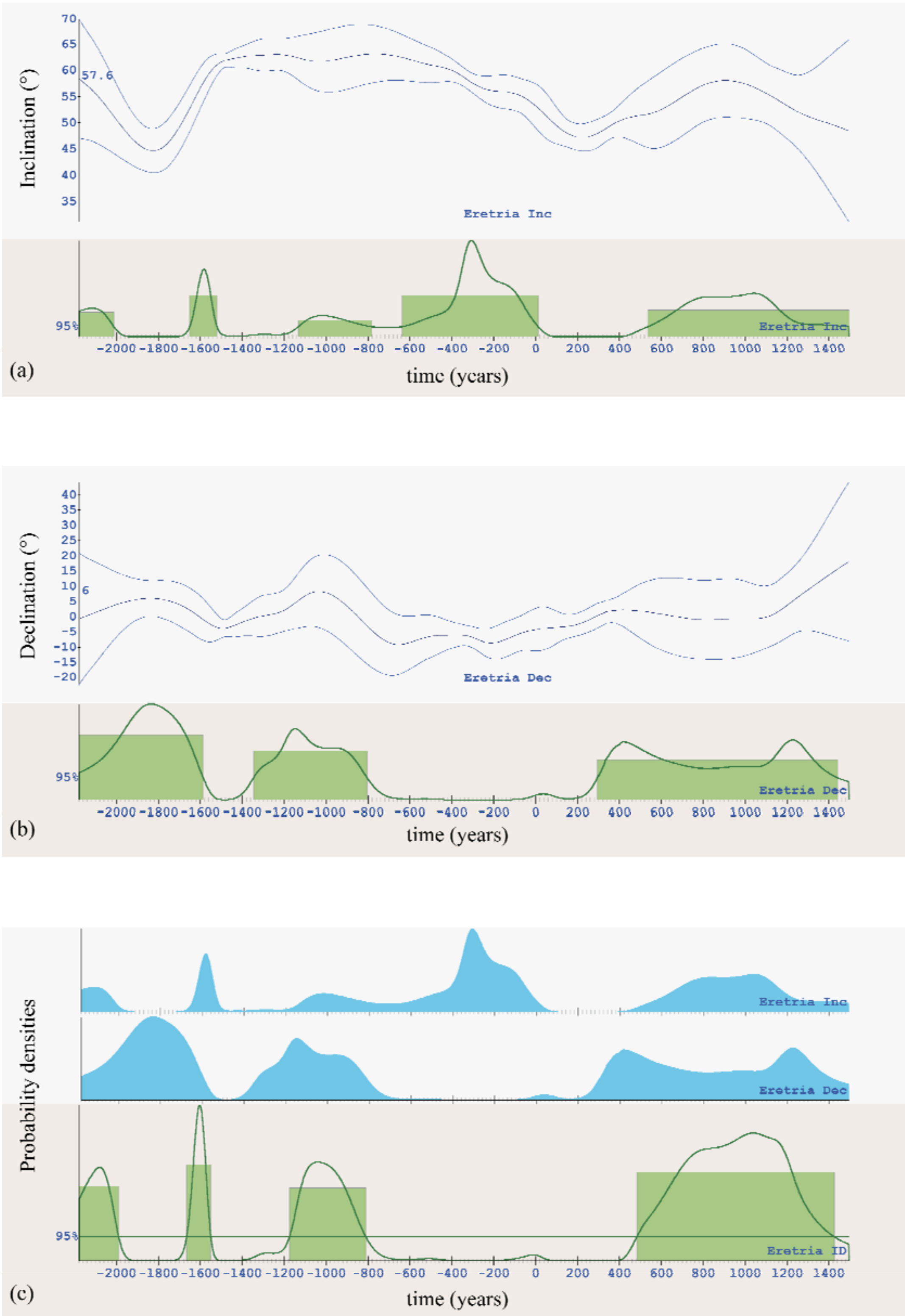

Inclination (°)
57.6
Eretria Inc
95%
(a)
time (years)
Declination (°)
6
Eretria Dec
(b)
Probability densities
Eretria ID
(c)

Fig. 6

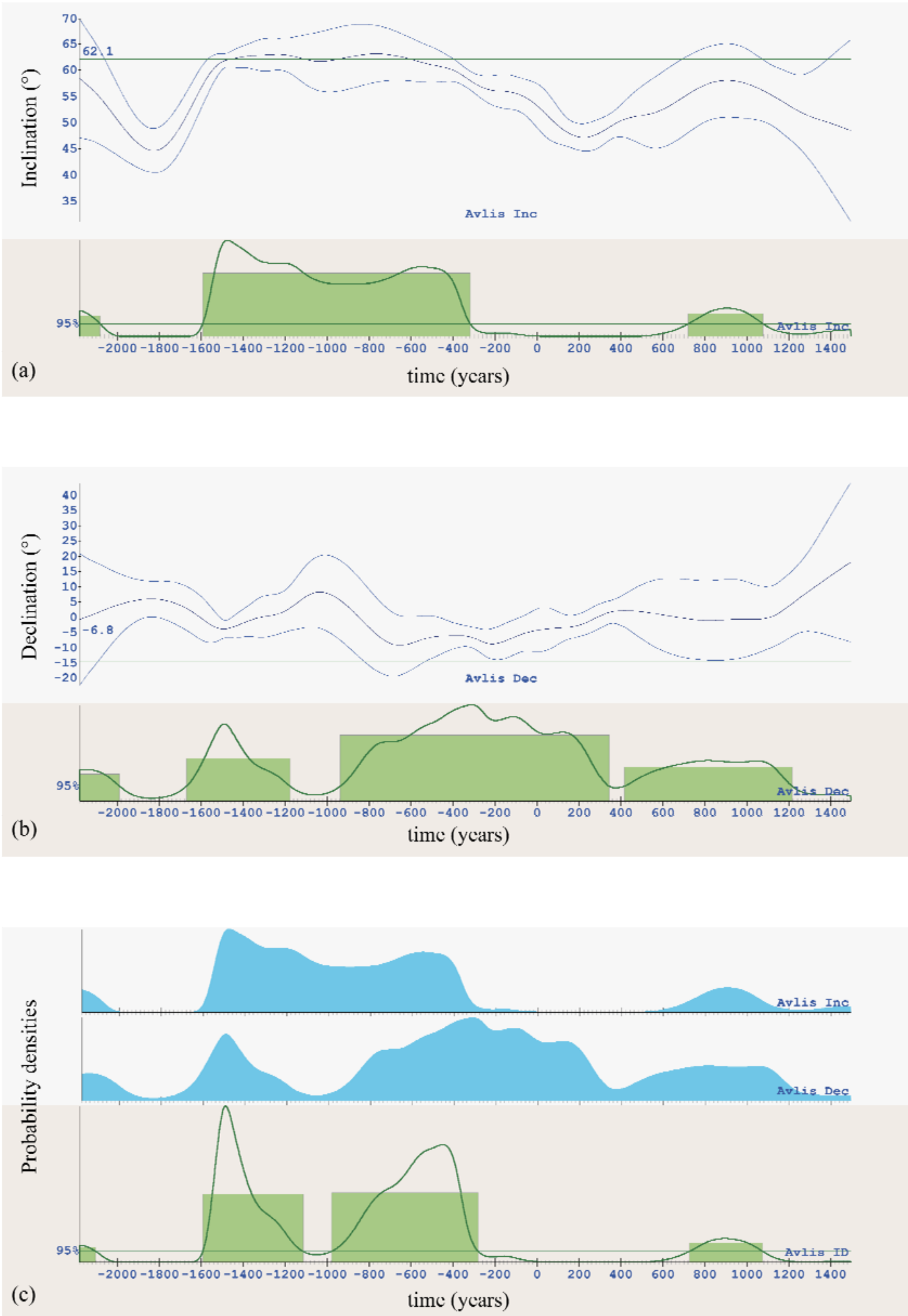

Inclination (°)
70
65
60
55
50
45
40
35
62.1
Avlis Inc
95%
Avlis Inc
-2000 -1800 -1600 -1400 -1200 -1000 -800 -600 -400 -200 0 200 400 600 800 1000 1200 1400
(a)
time (years)
Declination (°)
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-6.8
Avlis Dec
95%
Avlis Dec
-2000 -1800 -1600 -1400 -1200 -1000 -800 -600 -400 -200 0 200 400 600 800 1000 1200 1400
(b)
time (years)
Probability densities
Avlis Inc
Avlis Dec
95%
Avlis ID
-2000 -1800 -1600 -1400 -1200 -1000 -800 -600 -400 -200 0 200 400 600 800 1000 1200 1400
(c)
time (years)

Fig. 7

No	Site	Lat. (°N)	Long. (°E)	t_{min}	t_{max}	t_{mean}	Dating Method	Type of material	Code	Treat-ment	N	D (°)	I (°)	α_{95}	k	Dr (°)	Ir (°)	Reference
1	Vassiliki	35.07	25.82	-2900	-2200	-2550	A	burnt wall		AF, Th	8	359.4	53.4	1.7	839	359.3	56.3	Evans (2006)
2	Vassiliki	35.07	25.82	-2000	-2000	-2000	A	burnt wall	GM	NRM	4	2.8	53.8	3.0	911	2.8	56.5	Belshé et al. (1963)
3	Phaistos	34.97	24.84	-2000	-1700	-1850	A	pottery kiln		AF, Th	8	6.5	38.5	2.7	332	6.4	42.4	Evans (2006)
4	Palaiokastro	35.20	26.20	-1700	-1480	-1590	A	pottery kiln		pAF	18	0.6	47.1	3.2	106	0.3	50.3	Tarling and Downey (1989)
5	Phaistos	35.05	24.78	-1700	-1480	-1590	A	kiln		pAF	5	6.0	41.5	3.5	320	5.9	45.1	Tarling and Downey (1989)
6	Palaikastro	35.20	26.28	-1675	-1425	-1550	A	pottery kiln		AF, Th	13	5.9	49.3	2.4	305	5.8	52.1	Evans (2006)
7	Agia Triada	35.06	24.74	-1600	-1480	-1540	A	kiln		pAF	5	4.5	61.3	4.3	212	4.9	63.6	Tarling and Downey (1989)
8	Knossos	35.29	25.16	-1600	-1480	-1540	A	kiln	Kiln-2	pAF	25	355.2	60.8	1.6	306	355.2	63.1	Tarling and Downey (1989)
9	Akrotiri	36.40	25.50	-1600	-1480	-1540	A	hearth		pAF	17	10.6	57.3	3.6	89	10.9	58.5	Tarling and Downey (1989)
10	Hania A	35.50	24.04	-1600	-1425	-1512	A	hearth		AF, Th	10	1.4	54.0	3.6	147	1.4	56.4	Evans (2006)
11	Agia Triada	35.06	24.74	-1530	-1430	-1480	A	fired wall and floor	Palace	pAF	17	353.8	60.1	2.3	218	353.6	62.6	Tarling and Downey (1989)
12	Santorini (4sites)	36.40	25.50	-1530	-1430	-1480	A	volcanic rock		AF, Th	69	359.8	59.3	2.8	39	359.9	60.7	Tarling and Downey (1989)
13	Gournia	35.10	25.77	-1530	-1430	-1480	A	fired mud bricks	House A, Room 18	pAF	24	356.1	59.5	1.0	817	356.2	62.1	Tarling and Downey (1989)
14	Kato Zakros	35.12	26.22	-1530	-1430	-1480	A	fired mud bricks	Palace	pAF	49	355.8	54.8	1.9	122	355.7	57.7	Tarling and Downey (1989)
15	Makrygialos	35.06	25.99	-1530	-1430	-1480	A	fired mud bricks and charcoal ashes		pAF	32	354.7	57.5	1.4	322	354.6	60.3	Tarling and Downey (1989)
16	Malia	35.34	25.44	-1530	-1430	-1480	A	burnt horizon	Quartier E, room 3, c.2	pAF	15	6.4	59.6	7.4	24	6.9	61.7	Tarling and Downey (1989)
17	Malia	35.34	25.44	-1530	-1430	-1480	A	fired mud bricks	house	pAF	20	356.1	59.6	1.4	500	356.1	61.9	Tarling and Downey (1989)
18	Malia	35.34	25.44	-1530	-1430	-1480	A	fired mud bricks	Maison Da	pAF	22	356.6	59.9	3.2	87	356.7	62.2	Tarling and Downey (1989)

19	Palaikastro	35.22	26.29	-1530	-1430	-1480	A	fired mud bricks	Block N	pAF	59	355.1	55.1	1.8	199	354.9	57.9	Tarling and Downey (1989)
20	Phaistos	35.10	24.80	-1530	-1430	-1480	A	fired mud bricks		pAF	17	356.5	61.1	1.7	399	356.5	63.5	Tarling and Downey (1989)
21	Slavokambos	35.25	24.96	-1530	-1430	-1480	A	fired mub bricks		pAF	16	354.3	59.1	3.9	81	354.2	61.5	Tarling and Downey (1989)
22	Santorini (4sites)	36.40	25.50	-1480	-1425	-1453	A	volcanic rock		AF, Th	70	359.1	55.7	3.2	28	359.1	57.2	Tarling and Downey (1989)
23	Santorini (2 sites)	36.40	25.50	-1480	-1425	-1453	A	volcanic rock		AF, Th	34	358.5	57.4	10.0	7	358.5	58.9	Tarling and Downey (1989)
24	Santorini (2 sites)	36.40	25.50	-1480	-1425	-1453	A	volcanic rock		AF, Th	31	1.4	59.7	8.8	10	1.6	61.0	Tarling and Downey (1989)
25	Mochlos (Chalinomouri)	35.20	25.90	-1480	-1425	-1453	A	kiln	ML 5	AF	13	4.4	62.4	7.3	34	5.1	64.5	Tarling et al. (2004)
26	Mochlos Island	35.20	25.90	-1480	-1425	-1453	A	burnt wall	ML 1	AF	9	2.0	61.9	5.0	37	2.5	64.1	Tarling et al. (2004) & personal comm.
27	Mochlos Island	35.20	25.90	-1480	-1425	-1453	A	burnt wall	ML 2	AF	7	353.2	70.0	9.6	10	354.0	71.9	Tarling et al. (2004) & personal comm.
28	Mochlos	35.20	25.90	-1480	-1425	-1453	A	pottery kiln	ML3, kiln A	AF	5	6.3	52.2	13.9	38	6.4	54.8	Tarling et al. (2004)
29	Mochlos	35.20	25.90	-1480	-1425	-1453	A	pottery kiln	ML4, kiln B	AF	5	6.9	59.9	8.0	92	7.5	62.1	Tarling et al. (2004)
30	Berbati	37.60	22.90	-1450	-1350	-1400	A	pottery kiln		AF, Th	10	1.2	63.3	2.0	490	1.1	63.6	Evans (2006)
31	Nirou Khani	35.30	25.40	-1400	-1400	-1400	A	burnt wall	house, GE	NRM	5	357.8	62.0	5.6	187	358.0	64.2	Belshé et al. (1963)
32	Malia	35.34	25.44	-1400	-1400	-1400	A	burnt wall	Palace, GF	NRM	6	356.0	61.2	5.0	181	356.1	63.4	Belshé et al. (1963)
32	Agia Triada	34.99	24.81	-1600	-1070	-1350	A	pottery kiln		AF, Th	10	355.8	56.6	2.7	320	355.7	59.4	Evans (2006)
34	Kommos	34.95	24.76	-1390	-1070	-1230	A	hearth		AF, Th	8	0.6	61.4	3.5	199	0.8	63.9	Evans (2006)
35	Gouves	35.31	25.29	-1390	-1070	-1230	A	pottery kiln		AF, Th	10	9.0	60.3	2.4	403	9.6	62.3	Evans (2006)
36	Mycenae	37.73	22.75	-1200	-1200	-1200	A	burnt wall	HA	NRM	4	1.8	63.8	3.8	592	1.6	64.0	Belshé et al. (1963)

37	Kavousi	35.12	25.88	-1190	-1070	-1130	A	pottery kiln		AF, Th	17	16.2	57.7	2.7	154	17.0	59.7	Evans (2006)
38	Phari (Thassou)	40.65	24.49	-550	-400	-475	A	kiln		AF, Th	11	355.3	63.7	1.3	1197	355.6	61.6	Evans (2006)
39	Knossos	35.32	25.20	-400	-370	-385	A	kiln		AF, Th	17	351.5	58.4	2.7	171	351.3	60.9	Evans (2006)
40	Athens, Chabrias	38.00	23.70	-400	-350	-375	A	kiln	kiln C	NRM	6	351.8	62.2	4.4	235	351.8	62.2	Belshé et al. (1963)
41	Athens, Chabrias	38.00	23.70	-400	-350	-375	A	kiln	kiln A	NRM	4	353.7	59.7	5.8	251	353.7	59.7	Belshé et al. (1963)
42	Corinth A	37.92	22.92	-400	-330	-365	A	kiln		AF, Th	16	352.8	60.1	1.6	538	352.7	60.1	Evans (2006)
43	Corinth	37.90	22.90	-400	-300	-350	A	tile kiln	GZ	NRM	7	0.0	58.7	3.1	374	360.0	58.8	Belshé et al. (1963)
44	Olimpiada	40.50	23.82	-350	-300	-325	A	kiln	OL1	AF, Th	11	347.2	60.6	4.1	126	347.7	58.4	De Marco (2007)
45	Olimpiada	40.50	23.82	-350	-300	-325	A	kiln	OL2	AF, Th	7	343.5	66.6	3.6	118	344.3	64.8	De Marco (2007)
46	Olympia C	37.50	21.61	-350	-300	-325	A	kiln		AF, Th	7	354.8	56.4	2.5	566	354.8	56.7	Evans (2006)
47	Corinth B	37.92	22.92	-330	-300	-315	A	kiln		AF, Th	11	353.6	57.2	1.1	1726	353.6	57.2	Evans (2006)
48	Pella	40.80	22.00	-300	-300	-300	A	kiln	kiln 2, HO	NRM	4	356.8	61.0	2.6	1220	356.9	58.4	Belshé et al. (1963)
49	Edessa	40.80	22.05	-300	-200	-250	A	kiln	ED	AF, Th	11	349.5	57.4	1.7	701	350.0	54.5	De Marco (2007)
50	Katerini	40.27	22.50	-320	-180	-250	A	kiln	KA 1	AF, Th	16	349.7	59.6	2.8	176	350.0	57.4	De Marco et al. (2008)
51	Katerini	40.27	22.50	-320	-180	-250	A	kiln	KA 2	AF, Th	16	349.6	56.1	4.8	59	350.0	53.7	De Marco et al. (2008)
52	Katerini	40.27	22.50	-320	-180	-250	A	kiln	KA 3	AF, Th	4	348.5	57.0	12.8	52	348.9	54.6	De Marco et al. (2008)
53	Polymilos (2 kilns)	40.00	21.90	-300	-200	-250	A	kiln	ML, SO	AF	14	348.1	52.6	5.3	57	348.6	50.1	Aidona et al. (2010)
54	Pendavrissos (Kastoria)	40.45	21.16	-300	-200	-250	A	kiln	PD	AF, Th	7	340.2	59.5	2.8	451	341.0	56.7	De Marco (2007)
55	Amphipolis	40.50	23.60	-500	100	-200	A	ceramic kiln		AF	7	352.6	60.1	3.9	184	352.9	57.8	Spatharas et al. (2000)

56	Europos	40.80	22.00	-330	-70	-200	A	kiln		AF, Th	8	355.3	60.8	2.2	532	355.5	58.2	Evans (2006)
57	Pella-1	40.70	22.33	-330	-70	-200	A	kiln		AF, Th	10	354.8	62.5	3.6	183	354.9	60.1	Evans and Kontopoulou (1998)
58	Delos A	37.38	25.29	-69	-69	-69	A	kiln		AF, Th	8	354.5	55.2	2.5	476	354.4	55.9	Evans (2006)
59	Delos B	37.38	25.29	-69	-69	-69	A	fireplaces		AF, Th	10	352.1	47.1	2.5	373	351.8	48.0	Evans (2006)
60	Delos C	37.38	25.29	-69	-69	-69	A	burnt wall		AF, Th	5	1.9	51.9	2.4	998	1.8	52.5	Evans (2006)
61	Paros (Parokia)	37.08	25.15	-100	100	0	A	kiln	PAR1	AF, Th	8	344.6	47.6	2.7	428	344.2	49.0	De Marco (2007)
62	Argos	37.63	22.70	0	200	100	A	bath		AF, Th	17	358.6	54.8	1.3	776	358.6	55.1	Evans (2006)
63	Kalo Chorio	35.10	25.71	0	300	150	A	pottery kiln		AF, Th	20	357.7	43.0	1.9	304	357.2	46.7	Evans (2006)
64	Gortys	35.05	24.95	100	200	150	A	bath		AF, Th	13	357.6	45.0	2.8	222	357.3	48.6	Evans (2006)
65	Aegira A	38.10	22.42	100	300	200	A	pottery kiln		AF, Th	30	357.7	50.5	2.1	142	357.9	50.3	Evans (2006)
66	Olympia	37.50	21.61	175	300	237	A	kiln	GU	NRM	4	359.5	46.2	5.2	315	359.9	46.8	Belshé et al. (1963)
67	Vergia	40.30	23.13	200	400	300	A	kiln		pAF	7	6.8	52.8	3.5	307	6.7	50.4	Evans and Kontopoulou (unpublished data)
68	Louloudia	40.40	22.80	200	400	300	A	metal smelter	LM	AF	5	356.2	51.0	2.3	1099	356.5	48.2	Evans and Kontopoulou (1998)
69	Sani, Megali Kipsa	40.07	23.30	200	400	300	A	kiln	SAN8	AF	6	357.2	49.1	5.3	160	357.3	46.6	Aidona et al. (2010)
70	Athens	38.00	23.70	267	395	331	A	kiln	GQ	NRM	6	1.3	52.8	3.4	383	1.3	52.7	Belshé et al. (1963)
71	Athens	38.00	23.70	267	395	331	A	kiln	GR	NRM	4	12.0	53.5	2.2	1169	12.0	53.5	Belshé et al. (1963)
72	Corinth	37.90	24.90	300	400	350	A	tile kiln	GC/2	NRM	4	0.0	40.5	3.5	400	359.7	40.6	Aitken and Hawley (1967)
73	Olympia	37.50	21.61	300	400	350	A	kiln	GT	NRM	4	1.3	51.2	2.8	1108	1.5	51.8	Belshé et al. (1963)

74	Olympia A	37.50	21.61	300	400	350	A	kiln		AF, Th	7	2.8	48.6	2.6	540	3.1	49.2	Evans (2006)
75	Olympia B	37.50	21.61	300	400	350	A	kiln		AF, Th	7	0.7	47.2	1.5	1571	1.1	47.8	Evans (2006)
76	Athens A	37.98	23.73	375	425	400	A	kiln		AF, Th	11	353.5	45.4	2.5	330	353.5	45.4	Evans (2006)
77	Athens B	38.00	23.67	375	425	400	A	kiln		AF, Th	27	357.0	51.7	1.9	220	357.0	51.7	Evans (2006)
78	Corinth-2	37.90	24.90	400	430	415	A	kiln	GC/1	NRM	5	10.0	46.4	2.4	681	9.8	46.3	Aitken and Hawley (1967)
79	Kitros, Louloudia	40.40	22.80	480	650	565	A	kiln	LC	pAF	6	354.0	59.0	3.7	332	354.2	56.7	Evans and Kontopoulou (unpublished data)
80	Thessaloniki, Dioikitirio	40.60	22.70	750	850	800	A	glass kiln	DDI	AF	8	354.9	62.2	3.5	202	355.1	59.8	Spatharas et al. (2011)
81	Thessaloniki, Railway st.	40.70	23.10	600	1300	950	A	kiln	RS1	AF	14	358.5	56.9	4.4	82	358.6	54.2	Aidona et al. (2010)
82	Thessaloniki A	40.60	23.00	1200	1300	1250	A	kiln	TH	AF	9	19.1	52.7	5.2	101	18.7	50.2	Evans and Kontopoulou (1998)
83	Thessaloniki (Melenikou)	40.63	22.93	1200	1400	1300	A	kiln	MK	AF, Th	14	6.4	52.7	3.4	142	6.3	49.9	De Marco (2007)
84	Thessaloniki B	40.60	23.00	1400	1500	1450	A	kiln	MO	AF, Th	10	12.5	60.2	3.5	196	12.0	58.0	Evans and Kontopoulou (1998)
85	Eretria	38.44	23.79	*	*	*		kiln		AF, Th	5	0.6	58.0	3.1	406	0.6	57.6	Evans (2006)
86	Stylos	35.42	24.10	*	*	*		kiln		AF, Th	14	3.5	55.1	2.3	293	3.6	57.5	Evans (2006)
87	Aegira B	38.10	22.42	*	*	*		kiln		AF, Th	9	10.4	65.6	5.4	91	10.1	65.6	Evans (2006)
88	Avlis	38.50	23.67	*	*	*		kiln		AF, Th	6	353.1	62.5	4.5	226	353.2	62.1	Evans (2006)
89	Athens C	38.00	23.70	*	*	*		kiln		AF, Th	11	353.1	58.7	2.9	209	353.1	58.7	Evans (2006)

Table 1

T (years)	I (°)	I_{min} (°)	I_{max} (°)	D (°)	D_{min} (°)	D_{max} (°)
-2180	58.4	52.6	64.2	-0.8	-11.8	10.3
-2155	57.6	52.1	63.0	-0.1	-10.2	10.1
-2130	56.7	51.6	61.8	0.6	-8.8	9.9
-2105	55.8	50.9	60.6	1.2	-7.4	9.8
-2080	54.7	50.1	59.2	1.9	-5.9	9.7
-2055	53.4	49.3	57.6	2.6	-4.5	9.6
-2030	52.2	48.3	56.0	3.2	-3.0	9.5
-2005	50.8	47.3	54.3	3.9	-1.7	9.4
-1980	49.5	46.3	52.7	4.4	-0.5	9.3
-1955	48.3	45.4	51.2	4.9	0.6	9.2
-1930	47.2	44.5	49.8	5.3	1.4	9.1
-1905	46.2	43.8	48.6	5.6	2.1	9.1
-1880	45.4	43.2	47.7	5.8	2.7	9.0
-1855	44.9	42.8	47.1	6.0	2.9	9.0
-1830	44.7	42.6	46.8	6.0	3.0	9.0
-1805	44.8	42.6	47.0	5.9	2.8	9.0
-1780	45.3	43.0	47.5	5.7	2.5	8.9
-1755	46.2	43.9	48.5	5.3	2.0	8.6
-1730	47.4	45.0	49.7	4.8	1.3	8.2
-1705	48.9	46.5	51.2	4.1	0.5	7.7
-1680	50.6	48.2	52.9	3.3	-0.4	6.9
-1655	52.4	50.2	54.7	2.3	-1.4	6.0
-1630	54.4	52.2	56.5	1.2	-2.5	4.9
-1605	56.3	54.3	58.3	0.0	-3.7	3.6
-1580	58.0	56.2	59.9	-1.3	-4.7	2.2
-1555	59.6	58.0	61.1	-2.4	-5.4	0.6
-1530	60.7	59.5	61.9	-3.3	-5.7	-0.9
-1505	61.5	60.7	62.3	-3.8	-5.5	-2.1
-1480	61.9	61.2	62.6	-3.8	-5.2	-2.4
-1455	62.1	61.3	62.9	-3.4	-5.0	-1.7
-1430	62.3	61.4	63.2	-2.7	-4.7	-0.7
-1405	62.5	61.5	63.5	-2.0	-4.3	0.2
-1380	62.7	61.5	63.8	-1.3	-3.9	1.2
-1355	62.8	61.5	64.1	-0.7	-3.6	2.1
-1330	62.8	61.4	64.3	-0.2	-3.4	3.0
-1305	62.9	61.3	64.4	0.2	-3.3	3.6

-1280	62.9	61.4	64.5	0.5	-3.0	3.9
-1255	63.0	61.4	64.5	0.8	-2.7	4.2
-1230	63.0	61.5	64.5	1.2	-2.2	4.6
-1205	63.0	61.4	64.5	1.9	-1.6	5.4
-1180	62.8	61.1	64.5	2.9	-0.9	6.6
-1155	62.6	60.7	64.5	4.1	-0.1	8.3
-1130	62.3	60.1	64.5	5.4	0.7	10.1
-1105	62.0	59.6	64.4	6.6	1.5	11.7
-1080	61.8	59.2	64.4	7.6	2.1	13.1
-1055	61.7	58.9	64.5	8.1	2.3	14.0
-1030	61.7	58.8	64.6	8.3	2.2	14.4
-1005	61.7	58.7	64.7	8.0	1.6	14.3
-980	61.8	58.8	64.9	7.3	0.8	13.8
-955	62.0	58.9	65.1	6.4	-0.2	13.0
-930	62.2	59.1	65.3	5.2	-1.5	11.9
-905	62.4	59.3	65.5	3.8	-3.0	10.5
-880	62.6	59.5	65.7	2.2	-4.5	8.9
-855	62.8	59.8	65.8	0.5	-6.2	7.1
-830	62.9	60.0	65.9	-1.3	-7.8	5.3
-805	63.1	60.2	65.9	-3.0	-9.4	3.4
-780	63.1	60.3	65.9	-4.7	-10.9	1.6
-755	63.1	60.4	65.8	-6.1	-12.1	-0.1
-730	63.1	60.4	65.7	-7.4	-13.2	-1.6
-705	63.0	60.4	65.5	-8.4	-13.9	-2.9
-680	62.8	60.4	65.2	-9.0	-14.3	-3.7
-655	62.6	60.3	64.9	-9.2	-14.2	-4.2
-630	62.4	60.2	64.6	-9.1	-13.8	-4.3
-605	62.1	60.0	64.2	-8.6	-13.1	-4.1
-580	61.8	59.8	63.8	-8.1	-12.3	-3.8
-555	61.5	59.6	63.5	-7.5	-11.5	-3.5
-530	61.3	59.5	63.1	-6.9	-10.7	-3.1
-505	61.1	59.3	62.8	-6.5	-10.1	-3.0
-480	60.9	59.2	62.5	-6.3	-9.6	-3.0
-455	60.6	59.2	62.1	-6.2	-9.1	-3.2
-430	60.4	59.1	61.7	-6.1	-8.7	-3.5
-405	60.1	58.9	61.2	-6.1	-8.3	-3.8
-380	59.6	58.6	60.6	-6.1	-8.1	-4.0

-355	59.0	58.1	59.9	-6.1	-7.9	-4.2
-330	58.3	57.4	59.2	-6.3	-8.0	-4.5
-305	57.7	56.7	58.6	-6.7	-8.4	-4.9
-280	57.1	56.1	58.1	-7.4	-9.3	-5.5
-255	56.6	55.4	57.8	-8.1	-10.3	-6.0
-230	56.3	55.0	57.6	-8.6	-11.0	-6.2
-205	56.1	54.6	57.6	-8.7	-11.3	-6.1
-180	56.0	54.4	57.6	-8.4	-11.2	-5.6
-155	55.9	54.3	57.6	-7.8	-10.8	-4.9
-130	55.8	54.2	57.5	-7.1	-10.1	-4.2
-105	55.6	54.0	57.3	-6.4	-9.3	-3.5
-80	55.3	53.6	56.9	-5.7	-8.7	-2.8
-55	54.8	53.1	56.6	-5.1	-8.2	-2.1
-30	54.2	52.2	56.1	-4.7	-8.0	-1.4
-5	53.4	51.3	55.5	-4.3	-7.9	-0.8
20	52.5	50.3	54.7	-4.1	-7.7	-0.4
45	51.5	49.3	53.8	-3.8	-7.4	-0.3
70	50.6	48.5	52.6	-3.7	-7.0	-0.4
95	49.6	47.8	51.4	-3.6	-6.4	-0.7
120	48.8	47.2	50.4	-3.5	-5.8	-1.1
145	48.1	46.8	49.5	-3.3	-5.4	-1.2
170	47.6	46.4	48.9	-3.1	-5.0	-1.1
195	47.3	46.0	48.6	-2.7	-4.6	-0.8
220	47.2	45.9	48.5	-2.1	-4.1	-0.2
245	47.3	45.9	48.6	-1.4	-3.4	0.6
270	47.6	46.2	48.9	-0.6	-2.6	1.5
295	48.0	46.6	49.4	0.3	-1.8	2.4
320	48.5	47.2	49.8	1.0	-1.0	3.0
345	49.1	47.9	50.4	1.6	-0.3	3.6
370	49.7	48.4	51.1	2.0	-0.1	4.0
395	50.3	48.8	51.8	2.1	-0.3	4.4
420	50.7	48.9	52.5	2.2	-0.6	5.0
445	51.0	48.9	53.1	2.1	-1.3	5.5
470	51.2	48.7	53.7	2.0	-1.9	5.9
495	51.4	48.6	54.2	1.8	-2.6	6.3
520	51.5	48.4	54.6	1.6	-3.3	6.6
545	51.7	48.4	55.0	1.4	-4.0	6.8

570	52.0	48.5	55.5	1.1	-4.6	6.8
595	52.4	48.8	56.1	0.9	-5.1	6.9
620	53.0	49.2	56.7	0.6	-5.6	6.8
645	53.5	49.8	57.3	0.3	-6.1	6.6
670	54.1	50.4	57.9	0.0	-6.5	6.5
695	54.8	51.0	58.6	-0.3	-6.8	6.3
720	55.4	51.7	59.2	-0.5	-7.1	6.1
745	56.0	52.3	59.7	-0.7	-7.3	5.9
770	56.6	53.0	60.2	-0.9	-7.5	5.7
795	57.1	53.5	60.7	-1.0	-7.6	5.6
820	57.5	53.9	61.1	-1.1	-7.7	5.6
845	57.8	54.2	61.3	-1.0	-7.7	5.7
870	58.0	54.4	61.5	-0.9	-7.7	5.8
895	58.0	54.5	61.6	-0.8	-7.6	5.9
920	58.0	54.5	61.6	-0.7	-7.5	6.0
945	57.9	54.4	61.5	-0.6	-7.3	6.0
970	57.7	54.3	61.2	-0.6	-7.1	5.9
995	57.5	54.1	60.9	-0.6	-6.9	5.7
1020	57.1	53.9	60.4	-0.6	-6.7	5.4
1045	56.7	53.6	59.8	-0.7	-6.4	5.1
1070	56.2	53.2	59.3	-0.6	-6.0	4.9
1095	55.7	52.8	58.7	-0.3	-5.5	5.0
1120	55.2	52.2	58.1	0.3	-4.9	5.4
1145	54.6	51.6	57.6	1.1	-4.1	6.3
1170	54.0	50.9	57.1	2.2	-3.1	7.5
1195	53.4	50.2	56.6	3.4	-1.9	8.8
1220	52.8	49.5	56.1	4.7	-0.8	10.2
1245	52.2	48.7	55.7	6.1	0.3	11.8
1270	51.7	47.9	55.5	7.3	1.2	13.5
1295	51.3	47.1	55.5	8.5	1.8	15.3
1320	50.9	46.2	55.6	9.8	2.4	17.2
1345	50.6	45.4	55.8	11.0	2.8	19.2
1370	50.2	44.4	56.0	12.2	3.2	21.3
1395	49.9	43.5	56.3	13.4	3.5	23.4
1420	49.6	42.6	56.6	14.6	3.8	25.4
1445	49.2	41.6	56.9	15.8	4.1	27.5
1470	48.9	40.6	57.1	16.9	4.4	29.5

1495	48.5	39.6	57.3	18.1	4.7	31.4

Table 2