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Palaeointensity and thermoluminescence measurements on Cretan kilns from 1300 to 2000 BC

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The strength of the geomagnetic field in Crete during Minoan times has been determined using kiln wall samples from three Minoan palaces, Faistos, Aghia Triada and Kato Zakros, from the Minoan village at Stylos Hania and a Roman kiln at Kalo Horio. The samples have been dated by thermoluminescence measurements providing absolute dates for the construction of a palaeointensity curve. Without the thermoluminescence dates it would have been necessary to use the archaeologists' estimates of the kiln ages, one of which is shown here to be in error by 500 yr.

Kiln material was used because: (1) pottery was not readily available; (2) it was hoped that both palaeointensity and palaeodirection results could be obtained; and (3) the last firing events which were related to the destruction of the Minoan palaces could be dated by thermoluminescence measurements.

The samples, from the kiln floor, walls and heat channels, consist of a fired calcareous mud, varying in appearance from the extremes of a well fired vesicular slag (Aghia Triada and site (1) Faistos) to orange, porous, friable, less well-fired, samples with a fine mud matrix containing fragments of shells, rocks and pottery (site 1 of Kato Zakros, Stylos Hania and site 3 of Faistos); the remaining samples (Kalo Horio and site 1 of Faistos) contain a mixture of both types. Kato Zakros (2) is a brick fragment and Kato Zakros (3), a tile fragment.

The palaces sampled were of middle and late Minoan age. The earliest palace site sampled was Faistos. Kiln FS (3) belongs to the first palatial period (~2000–1700 BC) which ended when the palace was destroyed by earthquakes in about 1730 BC (ref. 1). The palace was subsequently rebuilt but in about 1500 BC it was destroyed by earthquakes or, according to some authors, by the effects of a volcanic eruption of Santorini (refs 2–5). Kiln FS (1) belongs to this second palatial period. The palace of Aghia Triada was built to replace the second palace at Faistos and probably lasted to 1400 BC (ref. 6).

The palace at Kato Zakros is thought to date from 1700 to 1400 BC. Platon (personal communication) believes that it was not rebuilt or inhabited after the catastrophic earthquake which occurred between 1450 and 1400 BC. The kiln at Stylos Hania is believed to be of late Minoan age[7] (~1300 BC); no pottery was found in the kiln but the nearby village is of that age. Kalo Horio, a Roman kiln was believed to date from ~50 BC.

Table 1 Thermoluminescence ages (yr BP)

Site	Age of sample	Estimated % error	Average site age	Estimated % error
Stylos Hania	3,882	6	3,828	4
	3,840	6		
	3,763	7		
Faistos (1)	3,466	6	3,466	6
Faistos (3)	3,806	5	3,784	4
	3,762	6		
Aghia Triada	3,545	6	3,508	4
	3,472	5		
Kato Zakros	3,370*	5	3,303	2
	3,199*	5		
	3,139*	6		
	3,289	5		
	3,519	5		
Kalo Horio	2,126	7	1,960	5
	1,795	7		

* These samples are tiles, all other samples are from kilns.

The thermoluminescence (TL) method used was the quartz inclusion technique described by Fleming[8]. TL dates can only be produced from well-fired materials so the number of dates produced was limited because of vitrification or weathering of the samples. Sample preparation and the determination of the total archaeological dose is described elsewhere[9]. The crystal sensitivity change due to heating to 500°C varied between 5 and 40%. The final total dose error was that derived from the 'dose plateau' tests, the average total doses from two or three peaks only being taken when there was good agreement between them. The β dose rates were measured in two ways, using thermoluminescent dosimetry and also using an α counting and potassium content method. The evaluation of environmental γ radiation was made on site by a portable NaI (T1) scintillometer. Results are presented in Table 1.

Table 2 Results using Shaw's method

Site	No. of results	Range of uncorrected palaeointensities (Oe)	Range of corrected palaeointensities (Oe)	Mean and error of palaeointensities (Oe)
Aghia Triada	3	0.369–0.497	0.560–0.590	0.580 ± 0.034
Stylos Hania	5	0.572–0.422	0.365–0.479	0.423 ± 0.035
Faistos (1)	3	0.259–0.786	0.249–0.519	?
Faistos (3)	4	0.776–0.330	0.395–0.333	0.351 ± 0.037
Kato Zakros (1)	5	0.499–0.791	0.474–0.557	0.542 ± 0.058
Kato Zakros (2)	1	ARM and TRM plots nonlinear		
Kato Zakros (3)	3	0.485–0.788	0.512–0.560	0.540 ± 0.048
Kalo Horio	7	0.581–0.887	0.416–0.645	0.505 ± 0.066

One disadvantage of using kiln material in palaeointensity work is that it was not originally selected by a potter and so is more inhomogeneous and complex mineralogically than pottery. Assessment of the mineralogical state of kiln wall material is complicated by the possibility that it has been repeatedly fired and cooled in various gaseous environments.

Attempts were made to determine the palaeointensities by two methods, that described by Shaw[10] and a modified Thellier method[11]. Alteration of one sort or another occurred in all samples used in Shaw's method. For most of the samples < 10% of the NRM remained after demagnetisation at the peak a.c. field of 900 Oe. The ARM2 versus ARM1 gradients were generally <1, except for samples from Aghia Triada, in many cases they had several linear portions of differing gradients. The TRM versus NRM graphs often showed similar features to the ARM2 versus ARM1 graphs, and where this was the case the correction suggested by Kono[12] was applied to portions of the graph with more than six points. The scatter of results was greatly reduced and for most sites the results were self consistent (Table 2). This method does not always yield reliable results[12] so it was checked using Coe's modified version of Thelliers' method[11]. Alteration of the samples during heating was again a problem and most sites showed a wide scatter of results. The only sites for which useable results were obtained, Kalo Horio (0.506 ± 0.110 Oe) and Kato Zakros 1 (0.484 ± 0.082 Oe), back up the results obtained using Shaw's method with Kono's correction.

The thermoluminescence results agree with the archaeologists' preferred chronology for the major sites. The result obtained for the less well known site of Stylos Hania suggests that it is older than was previously thought. The thermoluminescence results reinforce the suggested absolute chronology of the Minoan period but cannot rival the detail of relative chronologies deduced by the archaeologists.

The palaeointensity results in Table 2 are compared with those of Walton in Fig. 1. The age error bars on the palaeoin-

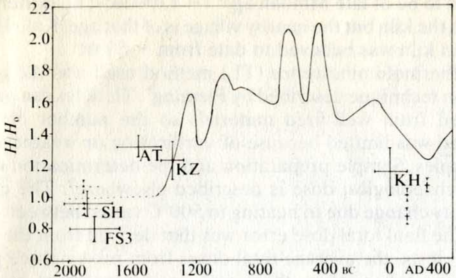

Fig. 1 The change in the ratio of the ancient geomagnetic field intensity H to the present day value, H_0 (0.44 Oe) in Crete. Each point represents several palaeointensity determinations on kiln wall material from one site. The errors are the combined errors from all determinations. The curve produced by Walton[13] is shown for comparison. The Cretan points are labelled, AT, Aghia Triada; KZ, Kato Zakros; SH, Stylos Hania; FS3, Faistos site 3; KH, Kalo Horio. Walton's points which lie away from the smoothed curve are shown by dotted lines.

tensity curve are naturally larger than those of Walton's curve for which the relative ages of the samples are well known. It is unlikely that so precise a curve as Walton's can be extended further back in time, either using archaeological dating or absolute dating which is not yet capable of yielding the necessary precision.

Crete and Athens are $\sim 3°$ latitude apart; differences in geomagnetic field intensity in the two areas are therefore to be expected. The present value for this difference is 0.01 Oe which is smaller than the errors on the palaeointensity determinations. The maximum difference in geomagnetic field intensity, at present, for sites located at the latitudes of Crete and Athens is 0.03 Oe, so it is to be expected that the palaeointensity results for Crete and Athens will agree within experimental error. This is the case for Stylos Hania and Kato Zakros. The Kalo Horio datum falls at a time where Walton seems to have ignored some data points when constructing his palaeointensity curve. If the Kalo Horio result is to be compatible with Walton data then it is necessary to postulate a fairly rapid change in the geomagnetic field strength.

The palaeointensity results reinforce the thermoluminescence date obtained for Stylos Hania, a palaeointensity of 0.42 Oe being unlikely for a sample aged 1250 BC.

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