ARCHAEOMAGNETIC ANALYSIS OF KILNS AT MARFIELD QUARRY EXTENSION, MASHAM

A PROGRAMME OF RESEARCH CARRIED OUT
ON BEHALF OF

MAP ARCHAEOLOGICAL CONSULTANCY LTD

By

GeoQuest Associates

INTRODUCTION

During January 1996, excavations were carried out by MAP Archaeological Consultancy Ltd on the site of a proposed extension to Marfield Quarry at Masham (SE2085 8290). The study area is situated approximately 2km NW of Masham village and comprises a field under arable cultivation. The excavations investigated a number of intense geomagnetic anomalies and found that these were associated with several substantial, well-preserved lime kilns of uncertain date.

The aim of this study was to obtain oriented samples from three of these kilns in order to attempt archaeomagnetic dating for the times of last firing (MAP Kilns 1 , 2 and 4).

The research was funded by Redland Aggregates Ltd and carried out in accordance with instructions supplied by Anne Finney, Project Director for MAP Archaeological Consultancy Ltd. The principles of the archaeomagnetic dating technique are described in Appendix A.

SAMPLING

Archaeomagnetic sampling was carried out on 21st January 1996 during the final stages of the excavation when each kiln had been fully exposed and recorded. These impressive structures were found to be constructed of large cobbles of sandstone and limestone set in a matrix of fired clay with ashy debris. It was decided that, wherever possible, samples would be recovered from the stone blocks since this would provide the best assurance that the material was firmly *in situ* with minimal post-firing rotation.

All surfaces were first brushed clear of loose material and oriented samples then recovered using the *button method* devised by Clark, Tarling & Noel (1988). This technique employs a 25mm, flanged plastic disc to act as a field orientation reference, sample label and specimen holder inside the laboratory magnetometer. Buttons were glued in position using a fast setting epoxy resin (Devcon Rapid) with their surfaces set horizontal with a spirit level. Small beads of plasticene beneath the buttons held them steady while the resin cured. Finally, geomagnetic orientation arrows were marked using a Nautech fluxgate compass, along with a specimen code. The set of orientation arrows were finally checked for parallelism to test for errors due to the bulk magnetisation within each feature; no significant flux distortion was detected.

The specimens were slowly dried over several days and then consolidated by impregnation with a dilute solution of PVA in acetone. Finally, the samples were cut with a diamond saw until each button retained a volume which fitted the standard 25x25mm specimen holder inside the archaeomagnetic magnetometer.

MEASUREMENT

The natural remanent magnetisation (NRM) of all the samples was measured in a Molspin fluxgate spinner magnetometer (Molyneux, 1971) with a minimum sensitivity of around $5 \times 10^{-9} Am^2$. Remanence directions were corrected for the local geomagnetic variation using data published by the British Geological Survey and the vectors plotted on the stereograms of Figures 1-3 and listed in Table 1.

Generally, the NRM of an archaeological material will comprise a primary magnetisation, (in this case presumed to be of thermal origin), together with secondary components acquired in later geomagnetic fields due to diagenesis or partial reheating. Usually, a weak viscous magnetisation is also present, reflecting a tendency for the remanence to adjust to the recent field. If the secondary components are of relatively low stability, then removal by partial demagnetisation will leave the primary remanence of archaeological interest. A pilot specimen with typical NRM characteristics from Kiln 4 was demagnetised incrementally, up to a peak alternating field of 30mT and the changes in remanence recorded in order to identify the components of archaeomagnetism and their stability (Figure 4).

From a study of the pilot sample behaviour, an alternating field of 2.5mT was chosen which would provide for the optimum removal of secondary components of magnetisation in the remaining samples. After partial demagnetisation in this field, sample remanences were remeasured and the results are shown on the stereograms of Figures 5 to 7.

RESULTS AND DISCUSSION

General

Intensities of natural remanent magnetisation in the kilns were found to be strong but inhomogeneous, with measured magnetic moments ranging from 4.0 to 10612.0 $mAm^{-1} \times 10^{-3}$ in a typical 1ml specimen, reflecting variation in the efficiency of the thermoremanent magnetisation and uneven concentration of the ferrimagnetic remanence-carrying mineral in the construction materials.

Kiln 1 (Context 1150: Figures 1, 4 and 5)

Samples from this feature have produced a very tight cluster of archaeomagnetic vectors (Figure 1) providing good evidence for consistent heating and remagnetisation during use, with negligible disturbance during burial. Only one sample was anomalous and was therefore rejected from the subsequent analysis (MAR19: Table 1). The pilot sample demagnetisation tests indicate a very good stability of the remanence and the archaeomagnetic vectors retain their excellent grouping after partial demagnetisation in a field of 2.5mT (Figures 4 & 5).

Kiln 2 (Context 2150: Figures 2 and 6)

This kiln was located approximately 100m SW of Kiln 1 and was the best preserved of the three structures. The results (Figure 2) again show an exceptionally consistent group of archaeomagnetic vectors which indicates that little relative movement has occurred within this structure. The remanence vectors remain well grouped after magnetic cleaning in an alternating field of 2.5mT (Figure 6).

Kiln 4 (Context 4150: Figures 3 and 7)

This kiln was situated at the extreme western end of the archaological evaluation area and, in common with the other structures, was formed of substantial stone blocks bedded in fired clay and ash. The direction of natural remanent magnetisation are tightly clustered and this good grouping is maintained after partial demagnetisation in an alternating field of 2.5mT.

Relative Dating

A standard correction was used to convert the mean archaeomagnetic vector for all three contexts to Meriden, the reference locality for the British Master Curve (Noel & Batt, 1990). Figure 8 then compares the new vectors and their associated error envelopes to the Master Curve segment 600AD-2000AD. It can be seen from the circular standard error bars in the diagram that the three vectors are indistinguishable. Indeed, by comparing the mean vectors and their alpha 95 uncertainties (Table 1) it is evident that the times of last firing are identical at the 95% level of confidence.

Absolute Dating

It is interesting to note that the three archaeomagnetic vectors closely approach, but do not overlap, the archaeomagnetic curve for the period after 1600AD (Figure 8). This divergence cannot be due to an error in the UK curve which, for this period, has been based on direct and accurate historic observations (Clark, Tarling & Noel, 1988). The most probable explanation for the disparity between these vectors and the curve is a shallowing of the geomagnetic field by the kiln materials whose magnetic susceptibilities will have been enhanced by oxidation. Such an effect has recognised in a wide variety of fired structures and often referred to as 'archaeomagnetic refraction'.

For the purpose of dating these structures it has therefore been assumed that the geomagnetic declination has been accurately recorded with error present only in the inclination due to 'refraction'. A mean date can then be derived from the closest approach of the group of vectors with the UK Master curve (red lines in Figure 8). The following date range is thus inferred:

KILNS 1, 2 AND 4: 1650-1740 AD

CONCLUSIONS

The results of this research can be summarised as follows:

1 An archaeomagnetic study has been carried out of three lime kilns uncovered during excavations in advance of a proposed extension to Marfield quarry at Masham. Each was found to contain a thermoremanent magnetisation providing a high quality record of the ancient geomagnetic field. All contexts were judged to be excellent candidates for an analysis aimed at establishing the time of last firing.

2 The dates of last firing of the three kilns were indistinguishable on the basis of their archaeomagnetic analyses.

3 Comparison of the mean archaeomagnetic vectors in the three kilns with the UK Master Curve indicates that the features were last in use at some time during the period 1650-1740 AD.

REFERENCES

Clark, A.J., Tarling, D.H. & Noel, M., 1988. Developments in archaeomagnetic dating in Britain, *Archaeometry*, 15, 645-667.

Molyneux, L., 1971. A complete result magnetometer for measuring the remanent magnetisation of rocks, *Geophys. J. R. astr. Soc.*, 24, 429-433.

Noel, M. & Batt, C.M., 1990. A method for correcting geographically separated remanence directions for the purpose of archaeomagnetic dating, *Geophys. J. R. astr. Soc.*, **102**, 753-756.

Credits
Sampling, analysis & report: M.J. Noel PhD, FRAS
Date: 13/2/96

FIGURE 1

Directions of natural remanent magnetisation in samples from Kiln 1 shown on an equal area stereogram. In this representation, declination increases clockwise while inclination increases from zero at the equator to 90 degrees at the centre of the projection.

KILN 1, NRM

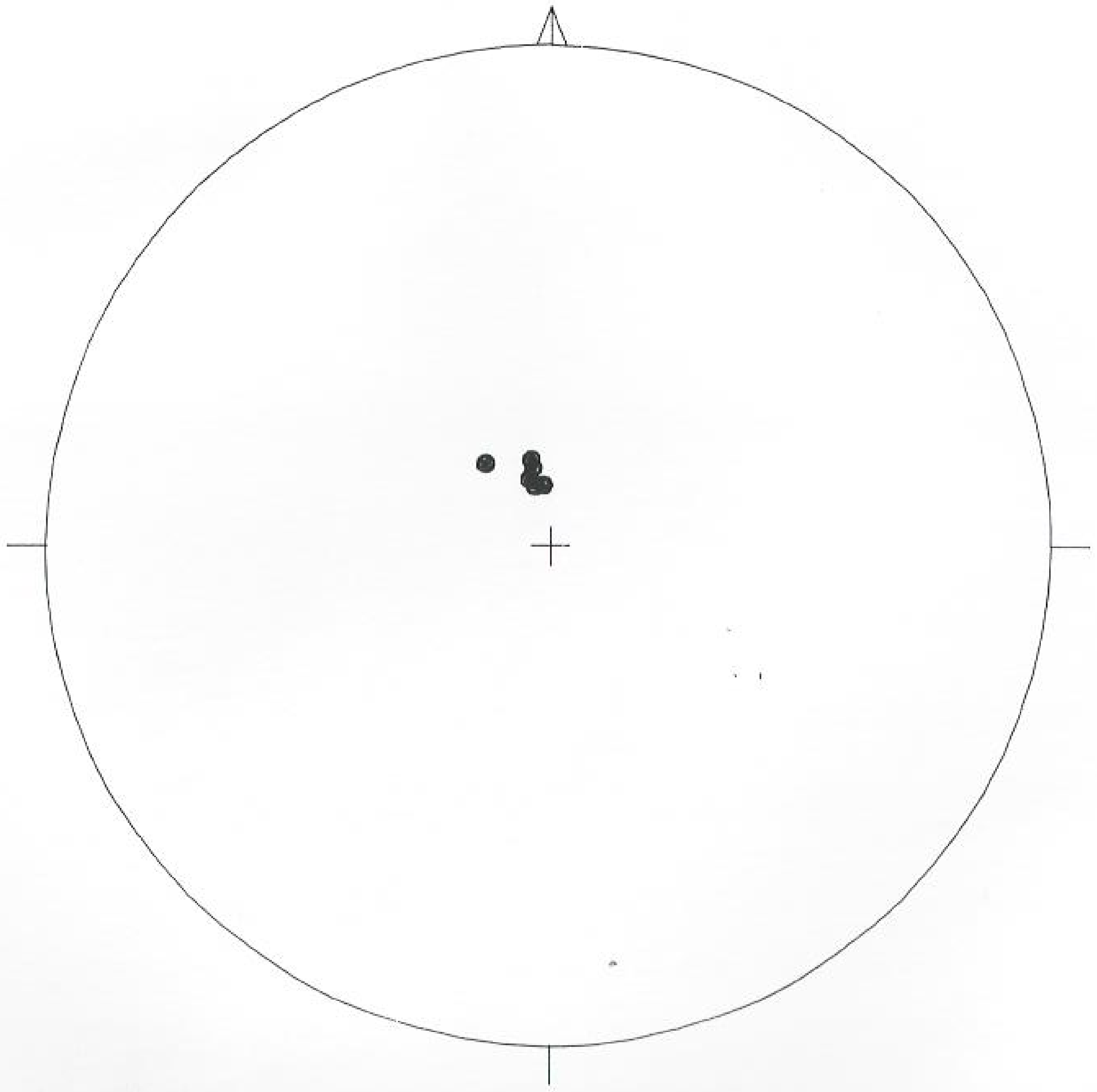

FIGURE 2

Directions of natural remanent magnetisation in samples from Kiln 2 shown on an equal area stereogram. In this representation, declination increases clockwise while inclination increases from zero at the equator to 90 degrees at the centre of the projection.

KILN2, NRM

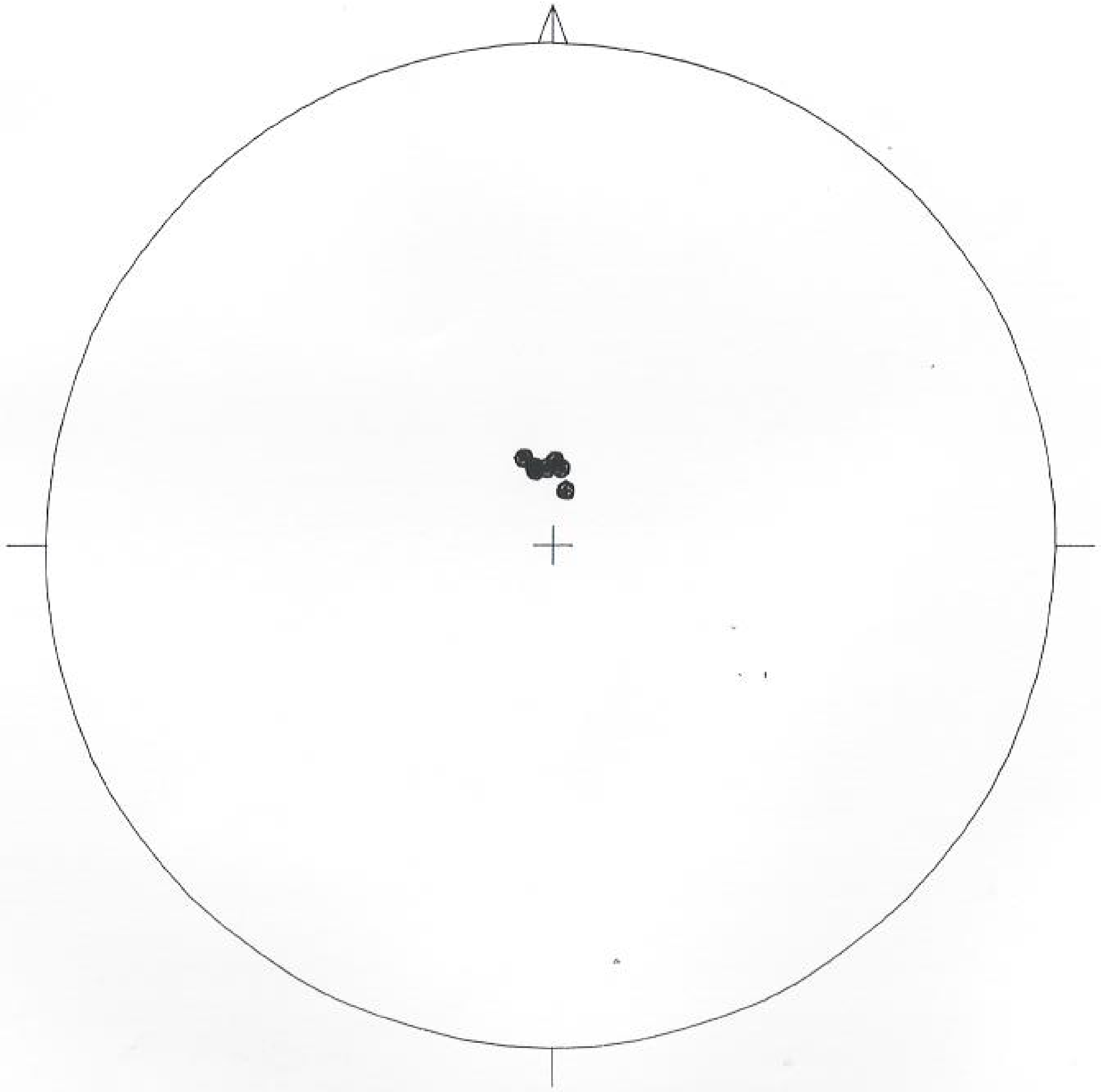

FIGURE 3

Directions of natural remanent magnetisation in samples from Kiln 4 shown on an equal area stereogram. In this representation, declination increases clockwise while inclination increases from zero at the equator to 90 degrees at the centre of the projection.

KILN 4, NRM

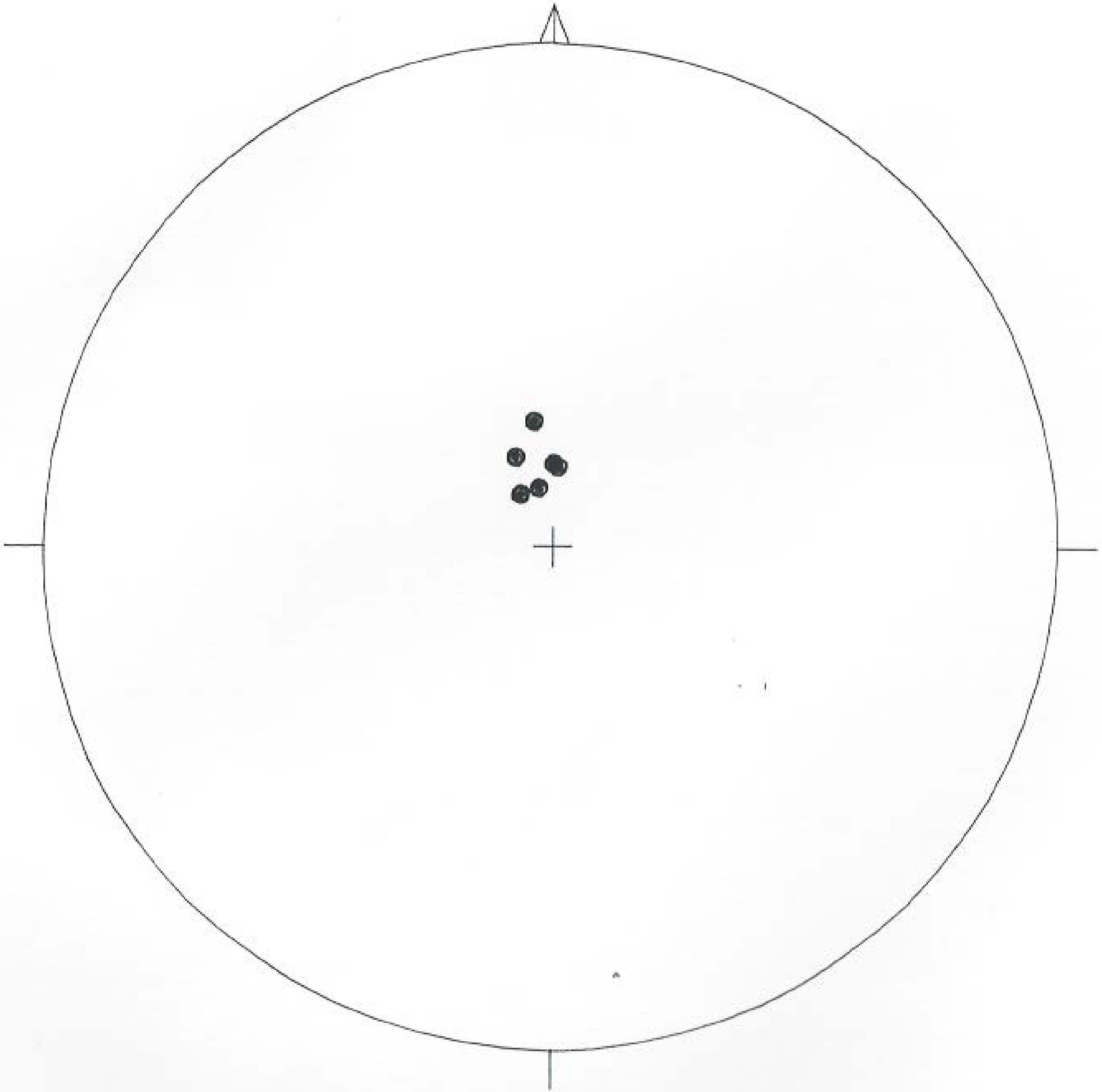

FIGURE 4

Changes in the direction and intensity of remanent magnetisation in a test sample from Kiln 4 during stepwise demagnetisation by alternating magnetic fields.

MAR6

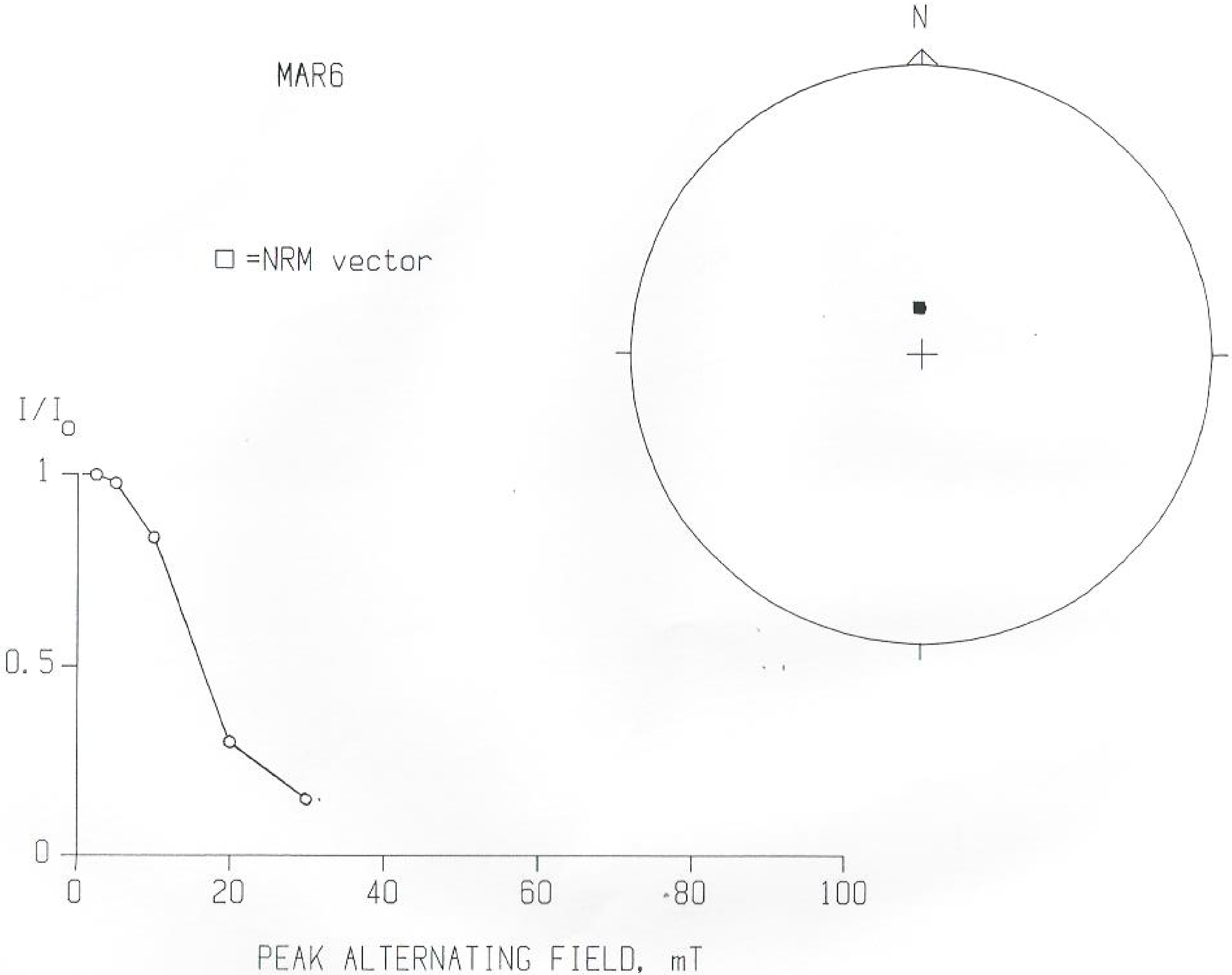
□ =NRM vector
N
I/I$_0$
1
0.5
0
0
20
40
60
80
100
PEAK ALTERNATING FIELD, mT

FIGURE 5

Directions of remanent magnetisation in samples from Kiln 1 after partial demagnetisation in an alternating field of 2.5mT

KILN 1, 2.5mT

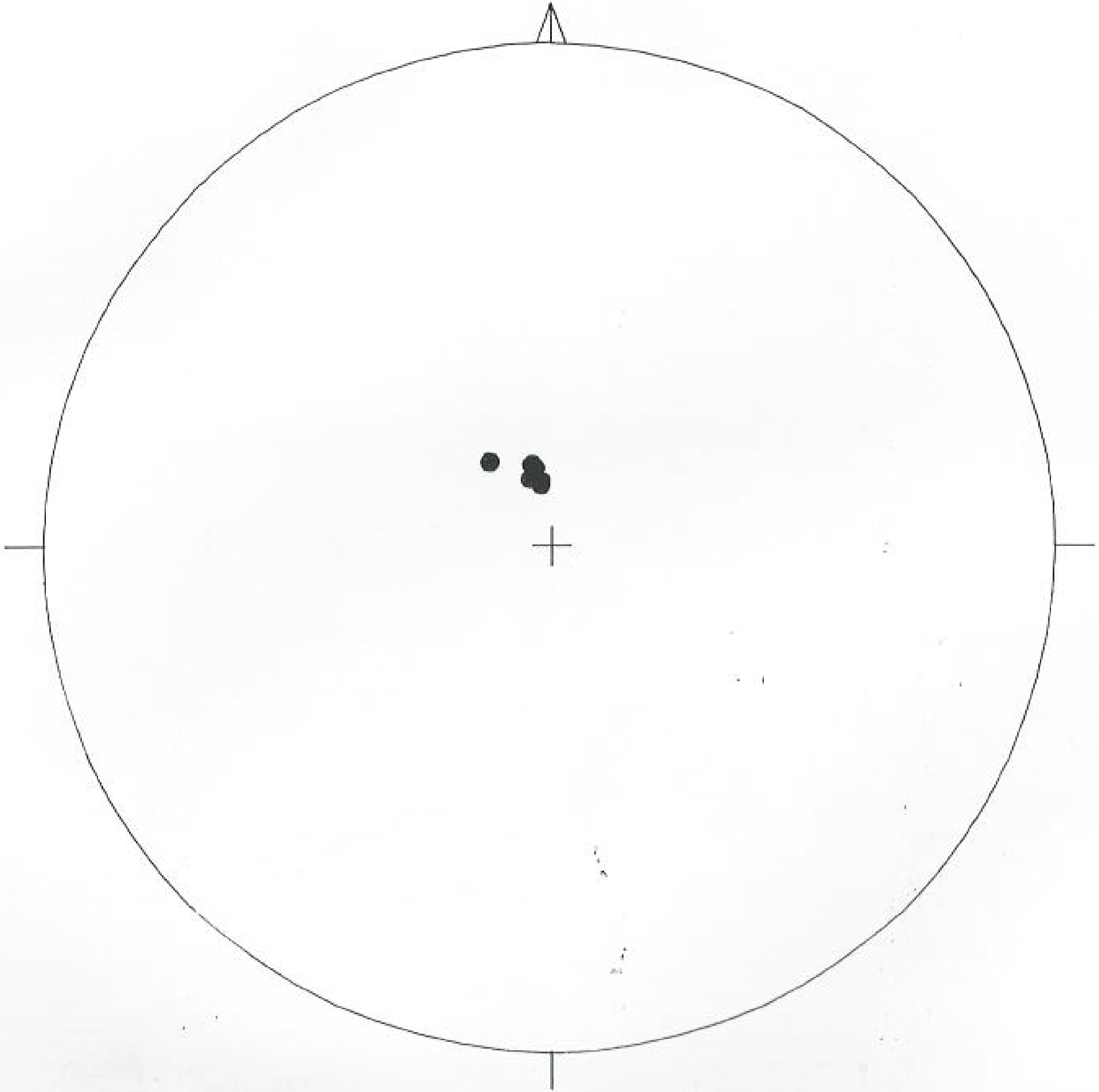

FIGURE 6

Directions of remanent magnetisation in samples from Kiln 2 after partial demagnetisation in an alternating field of 2.5mT

KILN 2, 2.5mT

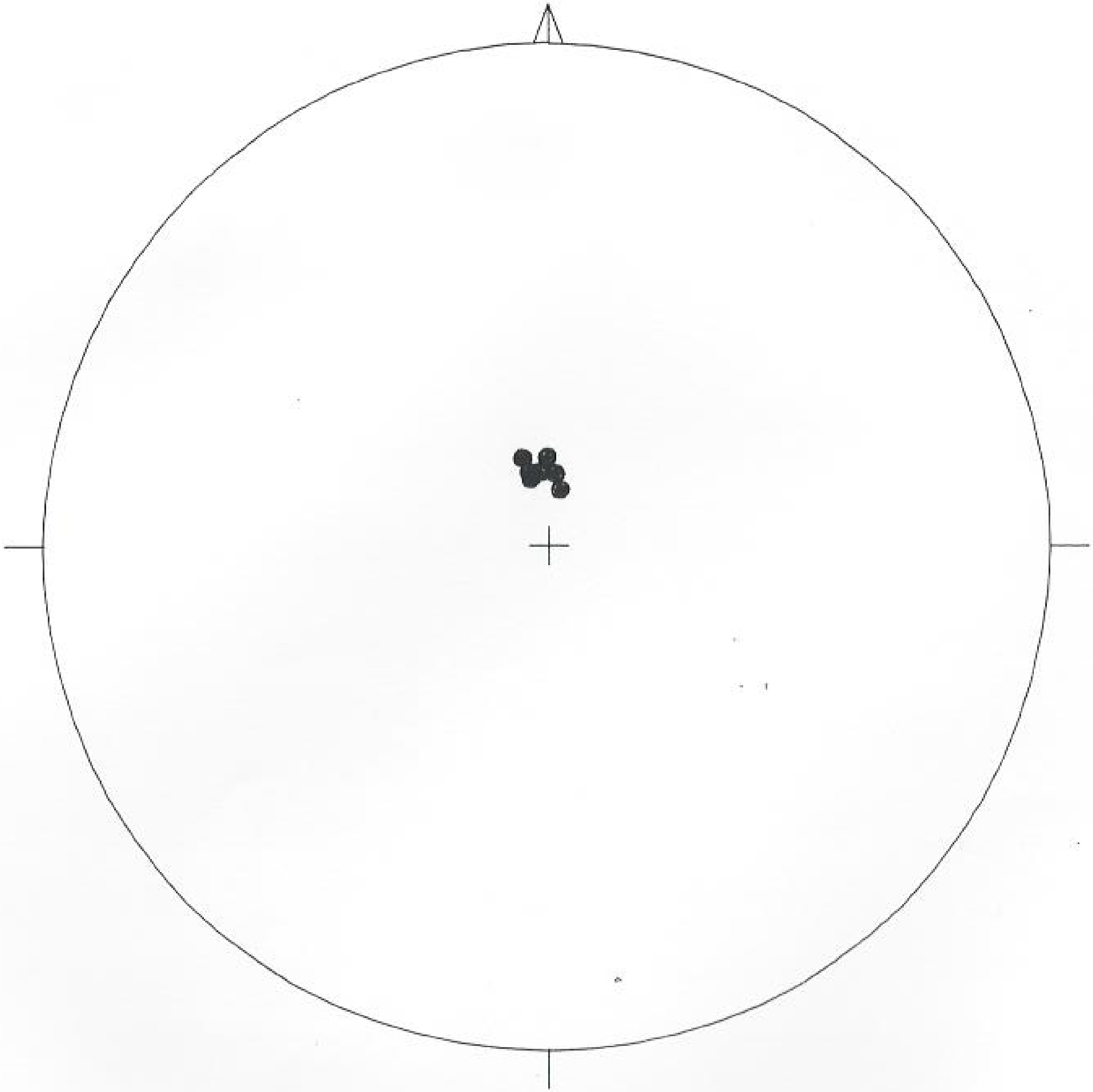

FIGURE 7

Directions of remanent magnetisation in samples from Kiln 4 after partial demagnetisation in an alternating field of 2.5mT.

KILN 4, 2.5mT

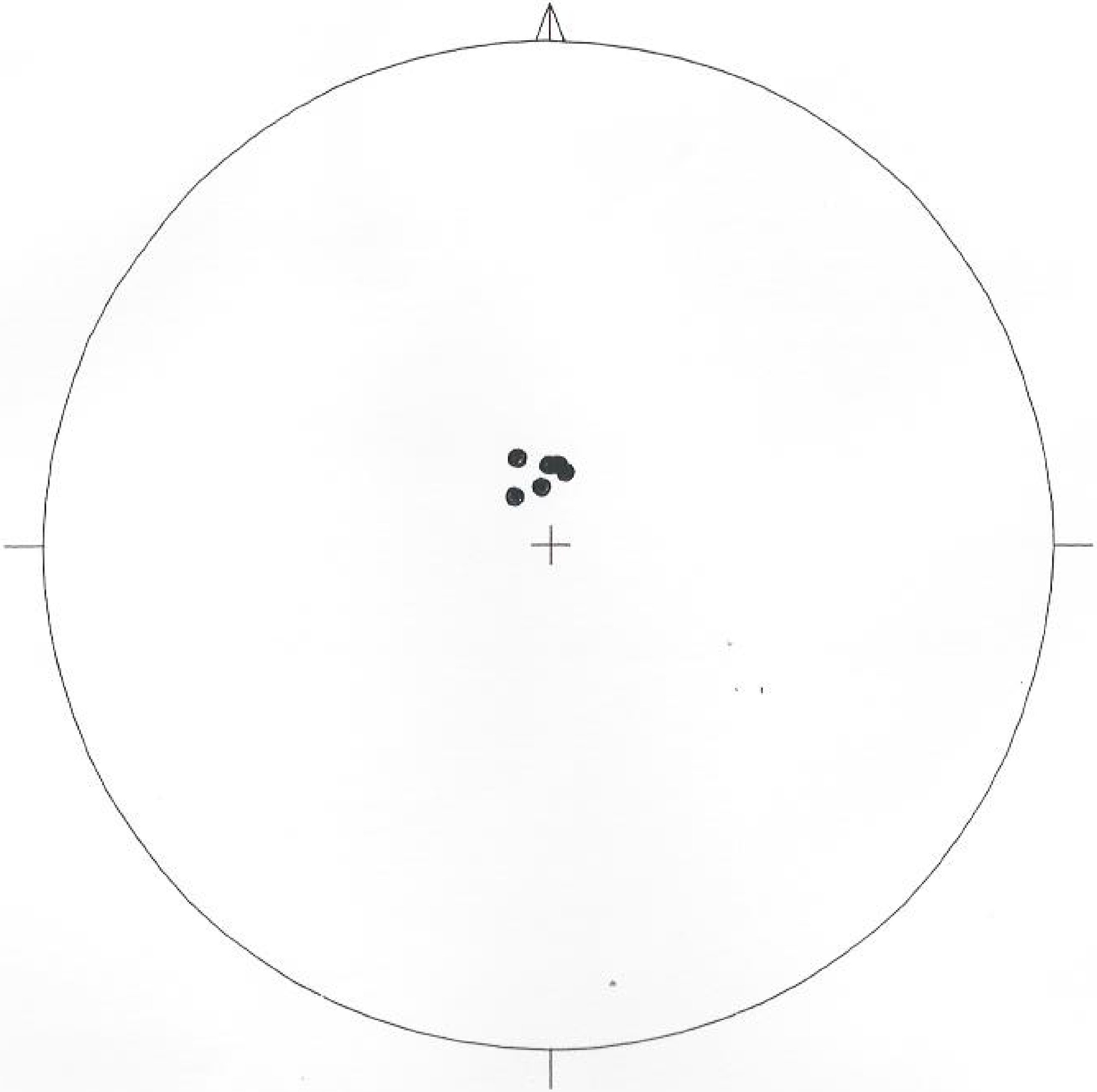

FIGURE 8

Comparison between the mean archaeomagnetic vectors in the three kilns, corrected to Meriden, with the UK Master Curve. Numbers refer to the time in centuries.

MARKFIELD
QUARRY

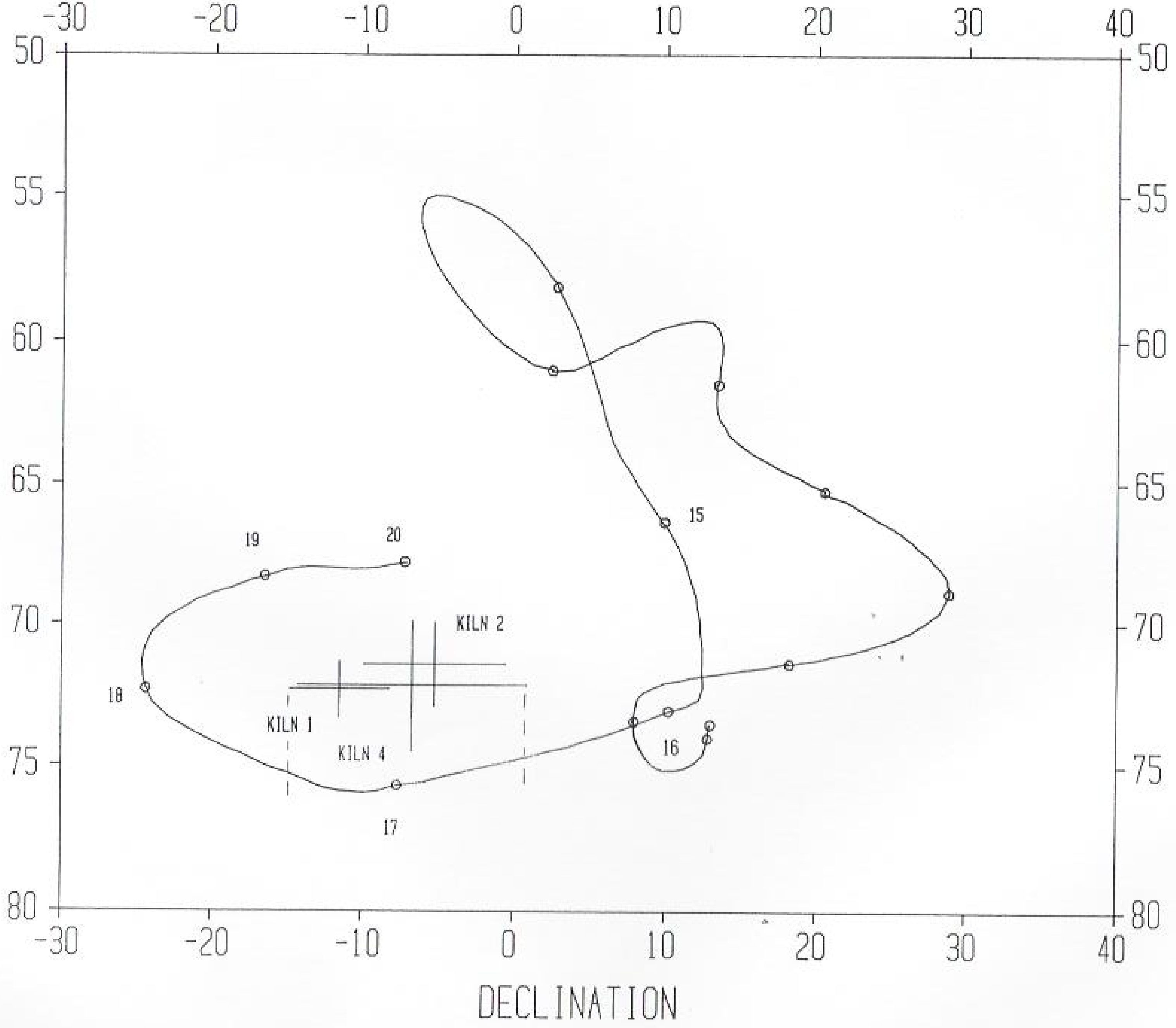

TABLE 1
ARCHAEOMAGNETIC RESULTS FROM MARFIELD QUARRY EXTENSION

Sample	LITH	J	D	I	A.F.	D	I
Kiln 4: Context 4150							
MAR1	BST	4.0	351.8	62.0	2.5	11.5	72.7
MAR2	BST	726.3	347.1	76.5	2.5	351.9	76.3
MAR3	BST	TOO SMALL					
MAR4	BST	264.0	337.7	68.5	2.5	340.0	68.7
MAR5	BST	TOO SMALL					
MAR6	BST	747.5	1.2	71.4	2.5	359.3	71.5
MAR7	BST	286.5	4.6	72.1	2.5	5.6	71.5
MAR8	BST	3155.6	328.9	76.9	2.5	324.4	76.2
Mean of Feature						352.9	73.4
					alpha95=4.8		k=199.1
						c.s.e.=2.3	
AT MERIDEN			**-6.7**	**72.2**			
Kiln 2: Context 2150							
MAR9	TOO SMALL						
MAR10	BST	840.8	6.2	72.4	2.5	5.3	73.1
MAR11	BST	8751.7	342.0	69.3	2.5	344.1	68.9
MAR12	BST	426.1	346.7	71.7	2.5	346.1	72.3
MAR13	BST	228.4	347.4	72.6	2.5	345.8	73.9
MAR14	BST	1024.7	356.0	72.4	2.5	354.2	72.8
MAR15	BST	10612.0	1.9	71.0	2.5	359.6	69.4
MAR16	BST	TOO SMALL					
MAR17	BST	TOO SMALL					
MAR18	BST	2164.3	14.0	77.1	2.5	11.4	76.5
Mean of Feature						354.5	72.6
					alpha95=3.0		k=401.5
						c.s.e.=1.5	
AT MERIDEN			**-5.2**	**71.4**			
Kiln 1: Context 1150							
MAR19	BST	120.9	322.4	66.5	2.5	324.2	66.6
MAR20	BST	1407.2	348.0	71.8	2.5	348.3	71.9
MAR21	BST	1092.9	345.8	75.8	2.5	350.7	75.8
MAR22	BST	215.8	342.9	73.9	2.5	342.8	74.0
MAR22	BST	TOO SMALL					
MAR23	BST	TOO SMALL					
MAR24	BST	761.5	353.8	76.1	2.5	351.4	74.9
MAR25	BST	347.5	347.7	69.9	2.5	347.0	70.9
Mean of Feature						347.9	73.5
					alpha95=2.1		k=1287.9
						c.s.e.=1.0	
AT MERIDEN			**-11.5**	**72.3**			

NOTES: LITH=Lithology, 'BST'=burnt red stone. D=declination, I=inclination, J=intensity in units of mAm^{-1}x10^{-3}. A.F.=peak alternating demagnetising field in milliTesla. alpha95 is the semi-angle of the 95% cone of confidence, c.s.e. is the circular standard error and k is the precision parameter.

APPENDIX A

Principles of Magnetic Dating

Magnetic dating is based on comparing the remanent magnetisation in an archaeological structure with a calibrated reference curve for the geomagnetic secular variation. Two distinct methods have evolved. The *intensity* technique relies on obtaining estimates of the past strength of the Earth's magnetic field while *directional* magnetic dating uses archaeomagnetic measurements to derive the orientation of the geomagnetic vector in antiquity. Intensity dating can only be applied to fired materials which have acquired a thermoremanent magnetisation upon cooling from high temperatures (>600°C) while the directional method enables the age of a broader range of archaeological materials to be determined. For example, sediments and soils may have acquired a dateable 'detrital remanence' if magnetic grains had been aligned by the ambient field during deposition. The growth of magnetic minerals during diagenesis or as a result of manufacturing processes can also give rise to a magnetisation which may enable materials such as iron-rich mortars, for example, to be dated. However hearths, kilns and other fired structures are the most common features selected for magnetic dating primarily because their thermoremanence is generally strong, stable and sufficiently homogeneous that the ancient field can be determined with sufficient precision from a small set of specimens. An analysis of dated archaeomagnetic directions, largely from fired structures, together with lake sediment and observatory records has enabled a master curve for the UK region to be synthesised for the period 2000 B.C. to the present (Clark, Tarling & Noel, 1988).

For directional magnetic dating it is essential to obtain specimens of undisturbed archaeological material whose orientation with respect to a geographic coordinate frame is known. A number of sampling strategies have evolved, enabling specimens to be recovered from a range of archaeological materials with orientations being recorded relative to topographic features, the direction of the sun, magnetic or geographic north. For this feature the miniaturised 'button method', illustrated overleaf, was employed. Modern archaeomagnetic magnetometers are sufficiently sensitive that only small volumes of material (~1ml) are required for an accurate remanence measurement. This has the advantage of reducing the impact of sampling on archaeological features - of particular significance if they are scheduled for conservation and display.