ARCHAEOMAGNETIC ANALYSIS
OF FOUR FIRED STRUCTURES
AT MALDON, ESSEX

Undertaken by GeoQuest Associates

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5.2 ARCHAEOMAGNETIC ANALYSIS OF FIRED STRUCTURES
By M. J. Noel

This report describes the integrated results of two phases of archaeomagnetic analysis of samples recovered from a total of six kilns at archaeological excavations on the site of a Roman settlement at Heybridge in Essex. The original reports for each phase are held in the paper archive at Colchester Museum.

The research was designed to provide a range of absolute physical dates for the last firing of each feature on the basis of the thermoremanent magnetisation. The structures selected for sampling are listed below:

- Circular pottery kiln 1223, in close association with kiln 1618
- Circular pottery kiln 1618, in close association with 1223.
- Circular kiln 14858, 1.6m in diameter (Group 715, lining 1436, 14725 with well-preserved central pedestal 14601), thought to be a Romano-British pottery kiln.
- A shallow rectangular structure 10906, about 0.9m long, with sides and floor constructed of tegula and fired clay (group number 15518), thought to be a crop-drying structure of Romano-British date.
- Circular pottery kiln 11477, about 2.4m in diameter with well-preserved central pedestal. This kiln is again thought to be of Romano-British date.
- An exceptionally well-preserved pottery kiln 11423 with large central pedestal (11569) and intact flue (Group 693). The original wall (11425) had evidently been repaired several times (11568, 11570). The floor has context number 11601.

The excavations at Heybridge were undertaken by the Archaeology Section of Essex County Council, under the direction of Mark Atkinson, and were jointly funded by Essex County Council, Bovis Homes Ltd and English Heritage who sponsored this research.

SAMPLING
The archaeomagnetic sampling of kilns 1223 and 1618 was carried out on in November 1993 by the AML, but passed to GeoQuest Associates in June 1996 for analysis. The sampling of kilns 14858, 10906, 11477 and 11423 was carried out in October and November 1994 and analysed bt GeoQuest Associates in 1995. Each feature was first carefully examined to identify areas which were evidently *in situ* and where firing had been most intense. Selected surfaces were then brushed clear of loose debris and oriented samples 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 (it was not possible to use a sun compass at the time of sampling). 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 in any of the kilns.

The specimens were slowly dried over several days and then consolidated by impregnation with a 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 5x10-9Am2. Remanence directions were corrected for the local geomagnetic variation using data published by the British Geological Survey and the vectors are listed in Table 1 plotted on the stereograms of Figs 1, 5 and 6.

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 from each kiln, with typical NRM characteristics, was demagnetised incrementally, up to a peak alternating field of 30, 50 or 8OmT and the changes in remanence recorded in order to identify the components of remanence and their stability (Figs 2, 7 and 8).

From a study of the pilot samples' behaviour, an alternating field of 2.5mT or 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 results shown on the stereograms of Figs 3, 9 and 10.

RESULTS AND DISCUSSION

General

Intensities of natural remanent magnetisation in the four structures were found to be intense but inhomogeneous, indicating a variable degree of firing or concentration of the remanence-carrying mineral. The distribution of NRM vectors in each of the structures have clearly been geomagnetically controlled, providing firm evidence that they have indeed been fired to high temperatures (>6800C, assuming titanomagnetite to be the magnetic carrier).

The following are detailed descriptions of the results from each feature:

Kiln 1223 – Samples from this feature produced an exceptionally close grouping of NRM vectors with further improvement produced by partial demagnetisation in an alternating field of 12mT (Fig. 1 and 3). However, three anomalous samples contained vectors which were divergent from the main group (10, 27, 28: bracketed in Table 1. The results from this feature are consistent with the production of thermoremanent magnetisation as a result of heating, with negligible disturbance after burial. The bilot sample demagnetisation tests by the Ancient Monuments Laboratory on Samples 15 and 20 showed that the material has excellent remanence stability.

Kiln 1618 – The nine samples which were analysed from this feature produced a poorer grouping of archaeomagnetic vectors than those recorded from kiln 1223 (Fig. 1). Nevertheless, some improvement was induced by partial demagnetisation in a field of 5mT (Fig. 3) and the results again provide a clear indication for thermoremanaence being generated by heating in the ancient geomagnetic field. Demagnetisation tests on piot sample 1 showed that the archaeomagnetism had good stability (Fig.2). The results from all specimens are included in the subsequent analysis.

Kiln 14858 - All samples from lining 1436, 14725. In the stereogram of Fig. 5 it can be seen that, with the exception of one outlier, the archaeomagnetic vectors in this feature are very well grouped. Stepwise, partial demagnetisation of pilot sample MAL1 (Fig. 7) indicates that the magnetisation comprises a single component which is highly stable. After partial demagnetisation in an alternating field of 5mT, the grouping of the archaeomagnetic vectors changed only slightly (Fig. 9) and one specimen remained as a distinct outlier. The results from this sample have therefore been rejected and it is assumed that the portion of the kiln wall from which the specimen was obtained has suffered disturbance since firing.

Kiln 10906 - Group number 15518: all samples from floor and sides. This structure was formed of relatively mobile tiles and blocks of fired clay. Hence great care was taken during the sampling of this structure to recover material from those areas where internal movement appeared to be least. Nevertheless, the somewhat dispersed NRM vectors seen in the stereogram of Fig. 5 indicates that internal rotation of the hearth components has almost certainly taken place, with 2 specimens having reversed archaeomagnetic declinations. Demagnetisation tests on a sample from this feature shown that the remanence has a very high stability (Fig. 7) and this is confirmed by the negligible change in the vector distribution induced by partial demagnetisation in a field of 5mT (Fig. 9). The two outliers with southerly declinations were rejected from the subsequent analysis.

Kiln 11477 - Context 11409: 5 samples from pedestal; 10 samples from walls. NRM archaeomagnetic vectors in this structure were again found to be rather dispersed with one outlier containing a reversed declination (Fig. 6). Demagnetisation tests on a sample from the kiln wall showed this material to have a high magnetic stability (Fig. 8) implying that the dispersion in NRM vectors is almost certainly due to post-firing disturbance to the structure.

The distribution of vectors after partial demagnetisation in a field of 5mT remained largely unchanged although one specimen was unusual in reversing the remanence inclination (Fig. 10). The results from 2 anomalous samples were rejected from the subsequent analysis.

Kiln 11423 – Group 693, 2 samples from pedestal 11569; 9 samples from wall 11425 and repair 11568,11570. Samples from this well-preserved kiln provided a remarkably well-grouped set of NRM vectors providing excellent evidence for the ancient geomagnetic field direction (Fig. 6). Moreover, the results of demagnetisation tests on a pilot specimen from the kiln wall show that the material has an excellent archaeomagnetic stability (Fig. 8). Negligible change in the distribution of vectors was induced by partial demagnetisation in an alternating field of 2.5mT and the results from all samples were incorporated in the subsequent analysis of this feature (Fig. 10).

Dating

A standard correction was used to convert the mean, partially demagnetised, archaeomagnetic vector of kilns 1223 and 1618 to Meriden, the reference locality for the British master curve (Noel and Batt 1990). Figures 4 and 11 then compares the new vectors and their associated error envelopes to the Master Curve segment 1000BC – 600AD.

The mean archaeomagnetic vectors make closest approaches to the archaeomagnetic curve during the Roman period. A date range has been estimated by considering the extent of overlap between the vectors' circular standard error and the Master Curve. The following date ranges are thus inferred:
Kiln 1223: 140-170 AD
Kiln 1618: 90-210 AD
Kiln 11423: 225-250 AD
Kiln 14858: Either 150-210 AD or 270-400 AD

Comparisons of the mean archaeomagnetic vector in kilns 1223 and 1618 with the UK Master Curve indicates that they were almost certainly contemporaneous and were last in use at some time during the second century AD. Of the samples taken in 1994 only the results from Kilns 14858 and 11423 were judged to be of sufficient quality to warrant an attempt at dating based on the mean remanence vector. It can be seen that the mean vector in Kiln 11423 makes a closest approach to the curve in the 3rd century AD and implies a last-firing date of 225-250AD.

Although the archaeomagnetic vectors in Kiln 14858 were extremely well grouped (with the exception of 1 anomalous sample), it can be seen in Fig. 11 that the mean direction deviates from the Roman segment of the curve by approximately 90 in declination. The kiln vector also does not coincide with the published post-Roman curve portion 600AD-present (Noel & Batt, 1990). If it is assumed that the field orientation of specimens in Kiln 14858 are in error as a result of a local geomagnetic disturbance (for example due to an adjacent pipe or other ferrous object), then an adjustment can be made to the declination in order to converge the result with the

Master Curve. Such an adjustment is shown by the horizontal dotted lines in Figure 713 and the range of possible dates then becomes:150-210AD or 270-400AD.

CONCLUSIONS

The results of this research can be summarised as follows:

1 Four kiln-type structures were found to contain thermoremanent magnetisations of high stability, providing high quality records of the ancient geomagnetic field.
2 The dispersion of archaeomagnetic vectors in several of the kilns provides strong evidence that disturbance to the structures has occurred since their last firing. This may have been caused by tree root activity.
3 Comparison of mean archaeomagnetic vector with the UK Master Curve provides a date range for the last firing in Kiln 1223: 140-170 AD
4 Comparison of mean archaeomagnetic vector with the UK Master Curve provides a date range for the last firing in Kiln 1618: 90-210 AD
5 Comparison of mean archaeomagnetic vector with the UK Master Curve provides a date range for the last firing in Kiln 4 of 225-250AD.
6 After an adjustment has been made to the mean vector in Kiln 1 to compensate for possible orientation error, the archaeomagnetic results implies possible age ranges of 150-210AD or 270-400AD.

Credits
Sampling: M.J. Noel
Analysis & report: M.J. Noel
Date: 28/9/95

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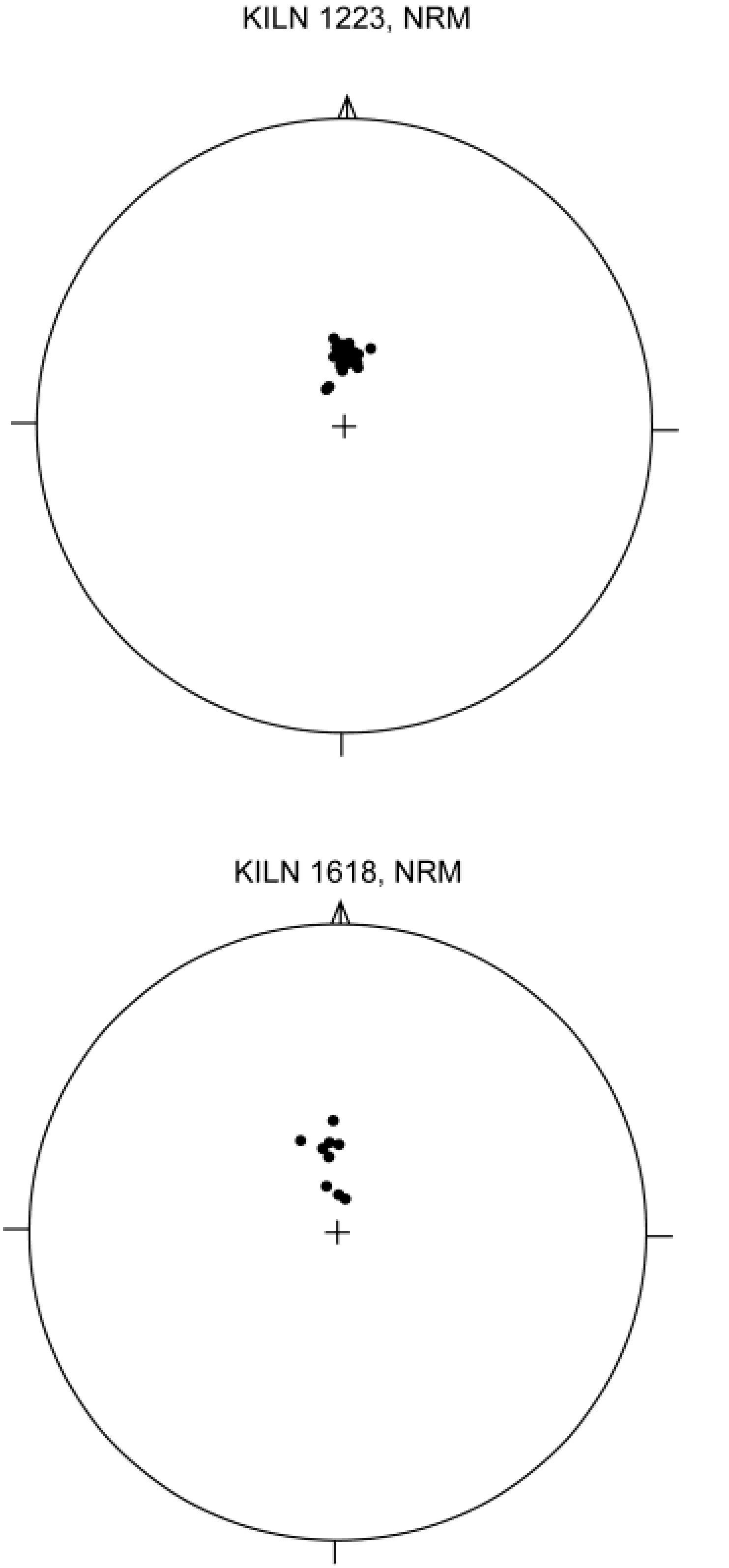
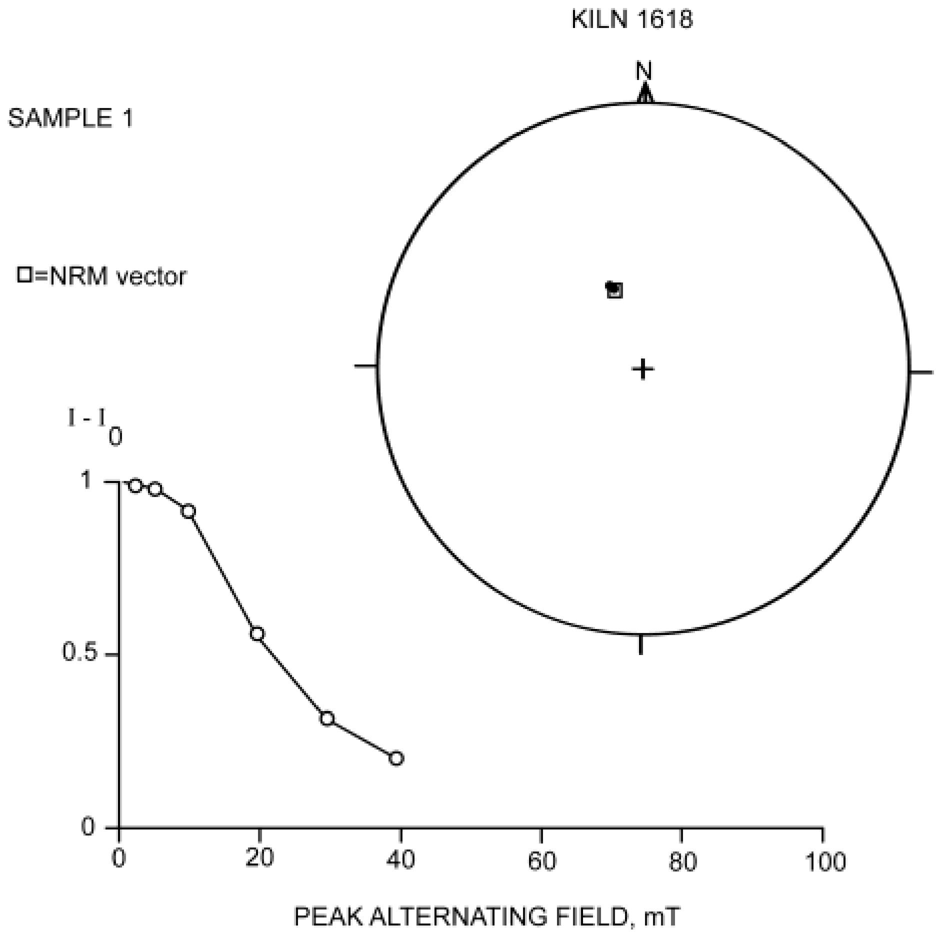


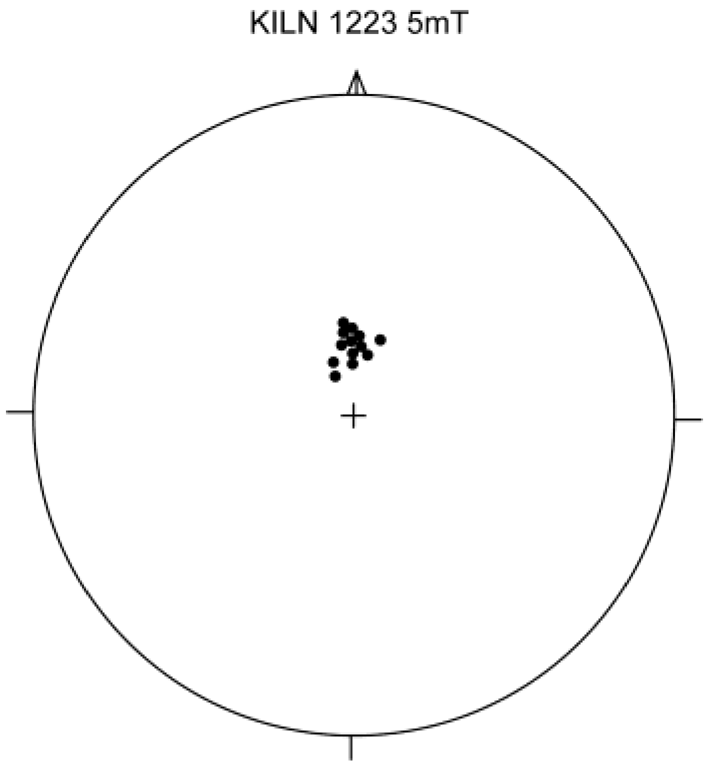
Archaeomagnetic dating - direction of natural remanent magnetisation in samples from kilns 1223 and 1618 shown on equal area stereograms

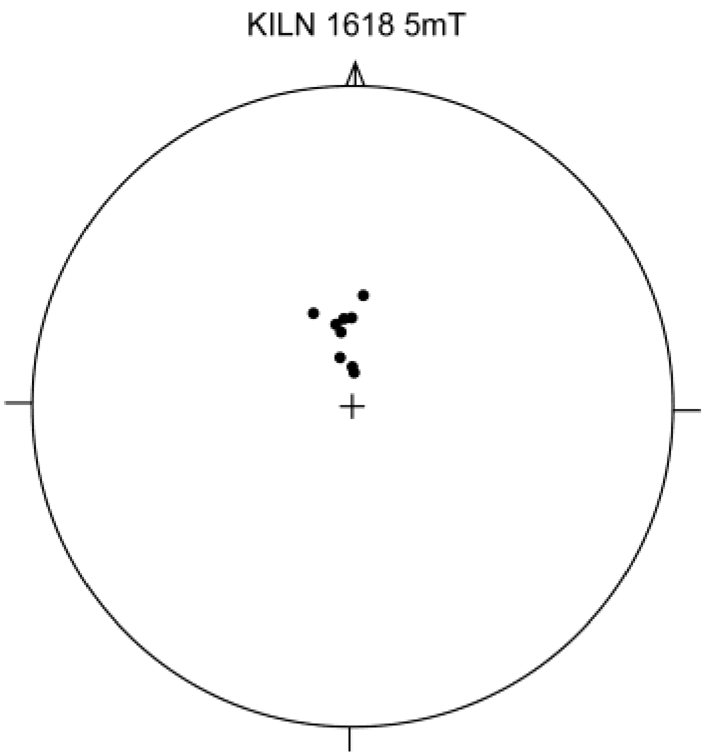
Fig.1



Archaeomagnetic dating - changes in the direction and intensity of remanent magnetisation in a test sample from kiln 1618 during stepwise demagnetisation by alternating magnetic fields

Fig. 2

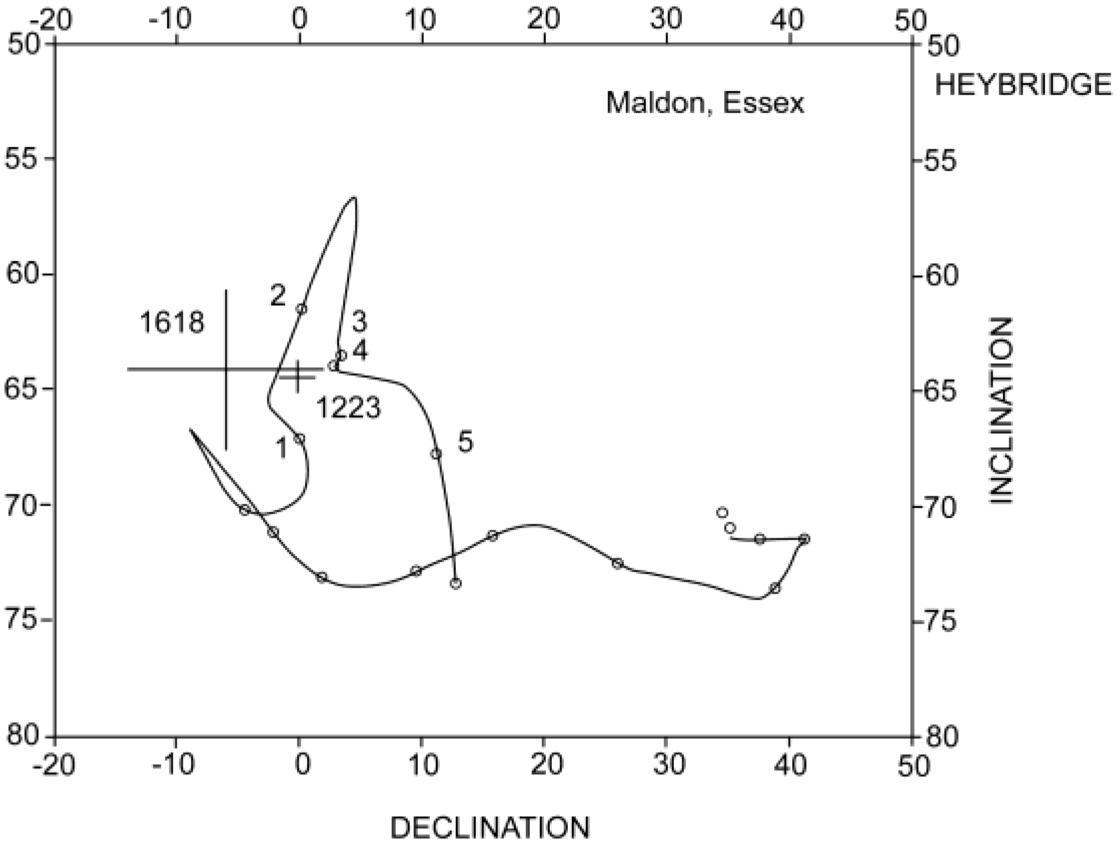




Archaeomagnetic dating - direction of remanent magnetisation in samples from kilns 1223 and 1618 after partial demagnetisation in an alternating field of 12mT

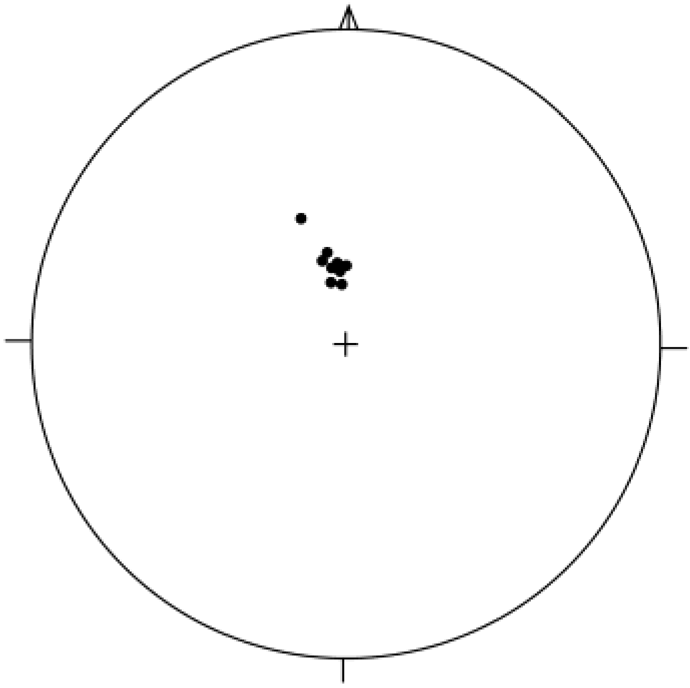
Fig. 3

Fig.4

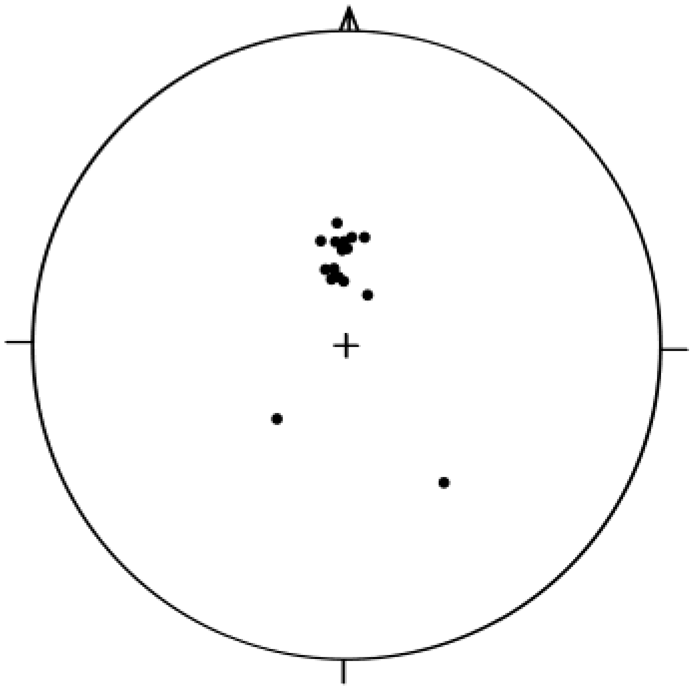


Archaeomagnetic dating - comparison between the mean archaeomagnetic vectors in the kilns, corrected to Meriden with the UK Master Curve

MALDON 14858 NRM

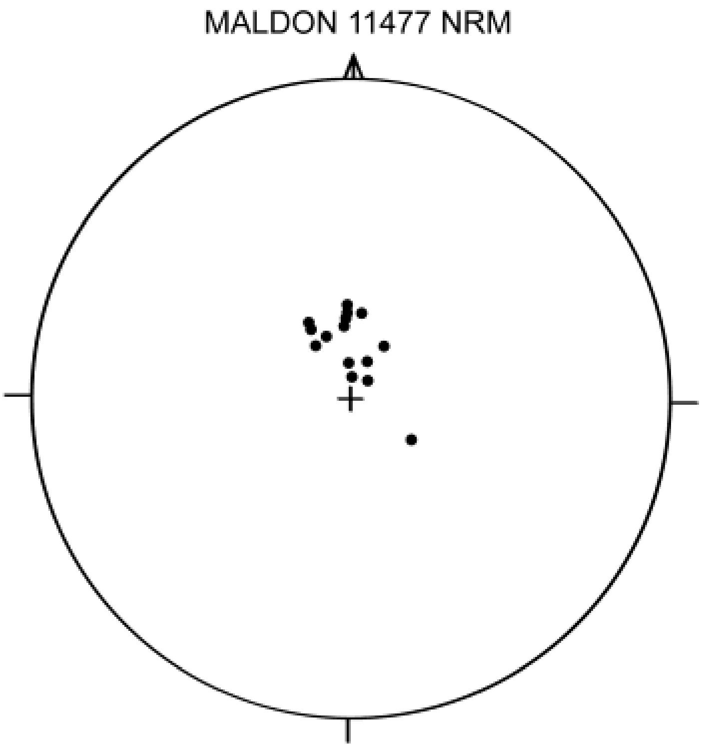


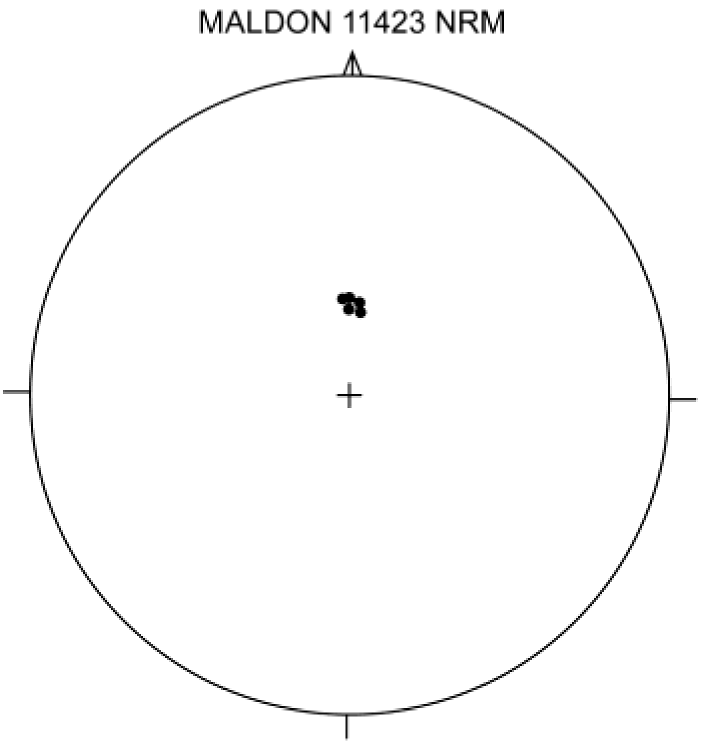
MALDON 10906 NRM



Archaeomagnetic dating - direction of natural remanent magnetisation in samples from kilns 14858 and 10906 shown on an equal area stereogram

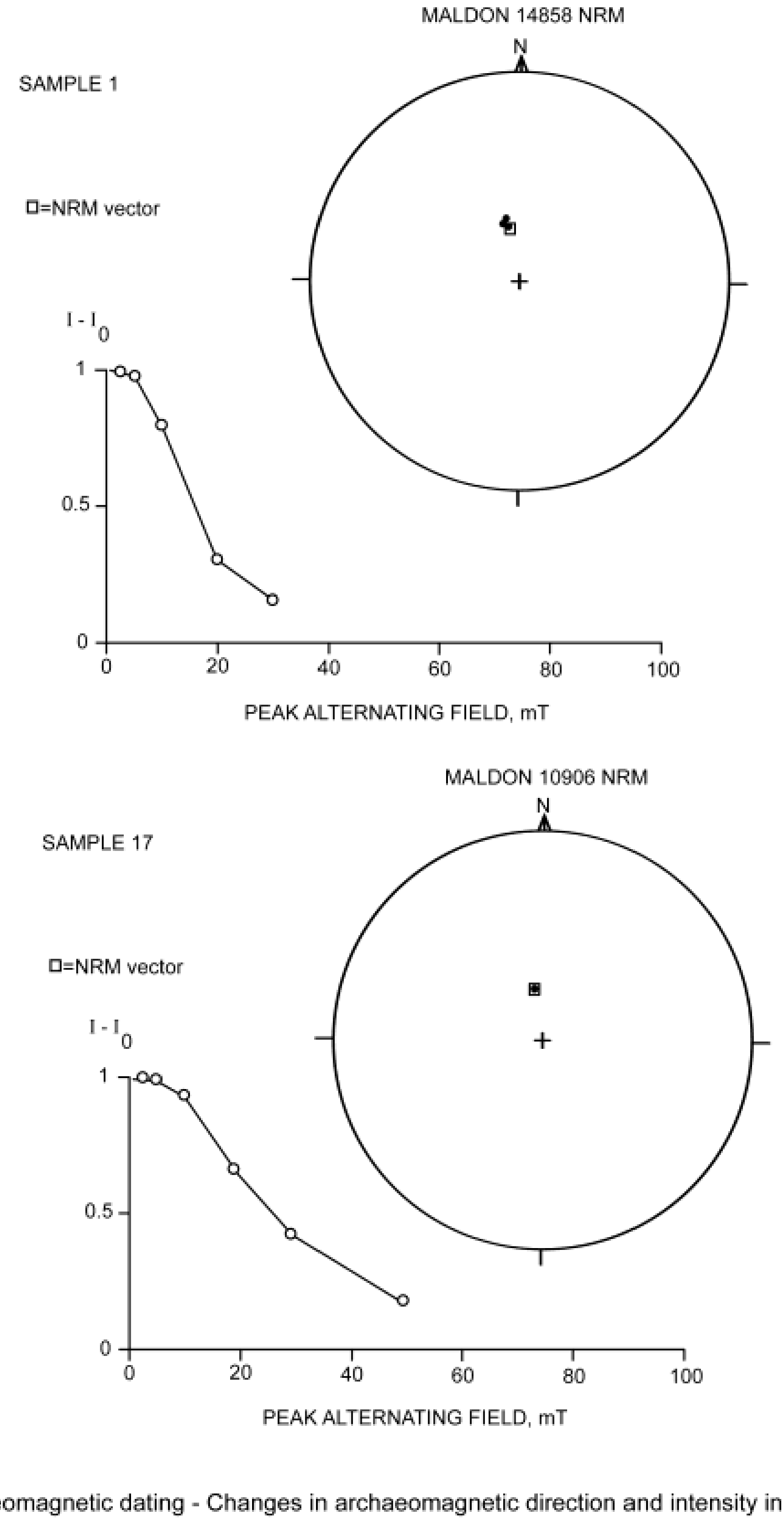
Fig. 5





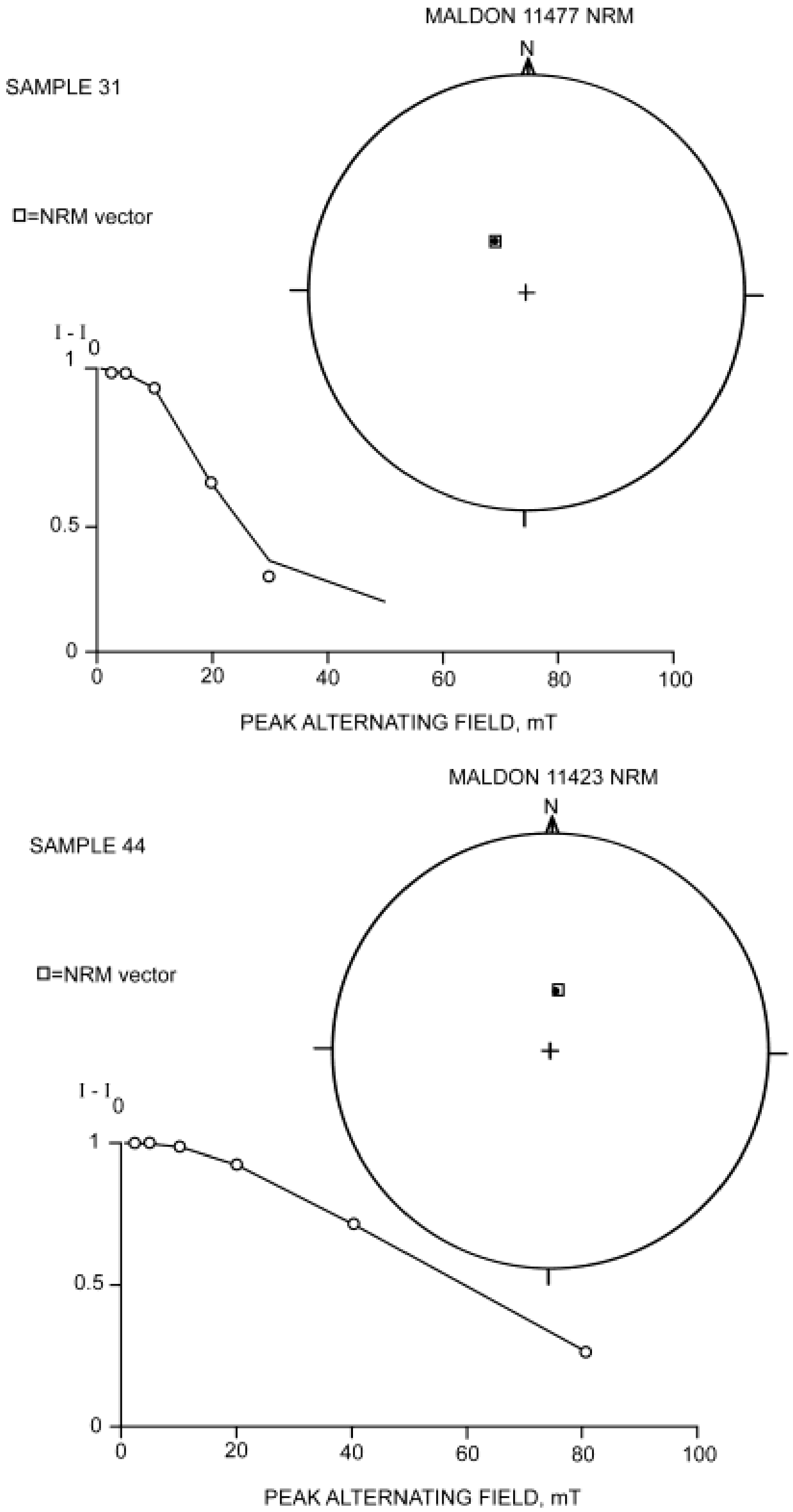
Archaeomagnetic dating - direction of natural remanent magnetisation in samples from kilns 11477 and 11423 shown on an equal area stereogram

Fig. 6



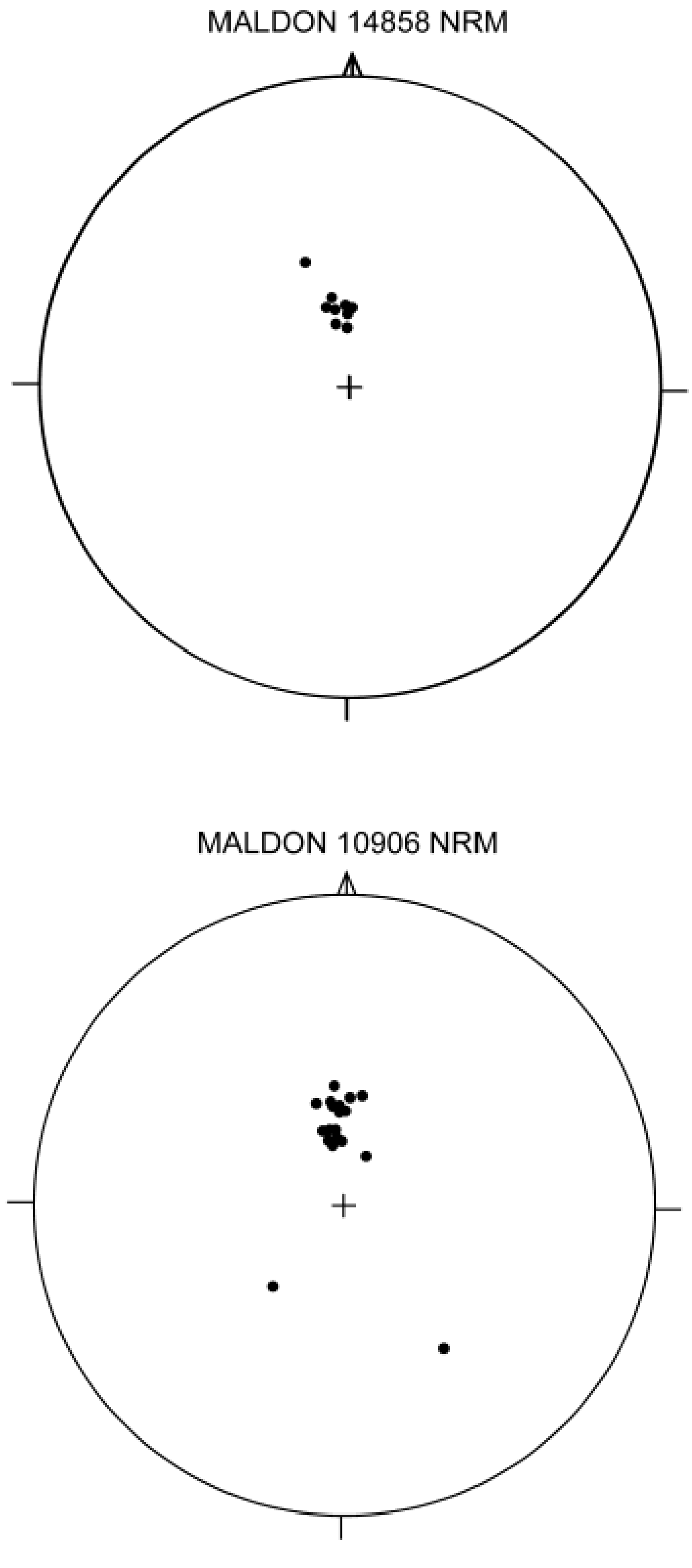
Archaeomagnetic dating - Changes in archaeomagnetic direction and intensity in a pilot sample from kilns 14858 and 10906 during stepwise demagnetisation by alternating magnetic fields

Fig. 7



Archaeomagnetic dating - Changes in archaeomagnetic direction and intensity in a pilot sample from kilns 11477 and 1423 during stepwise demagnetisation by alternating magnetic fields

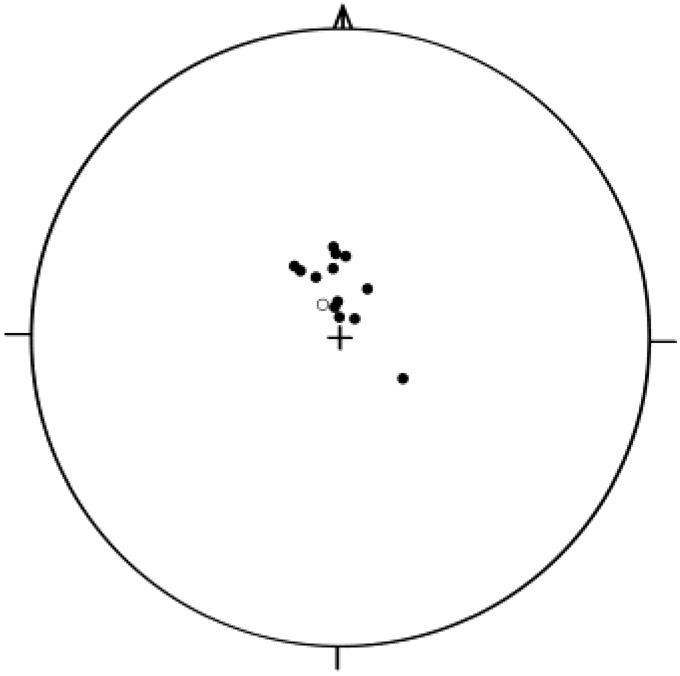
Fig. 8



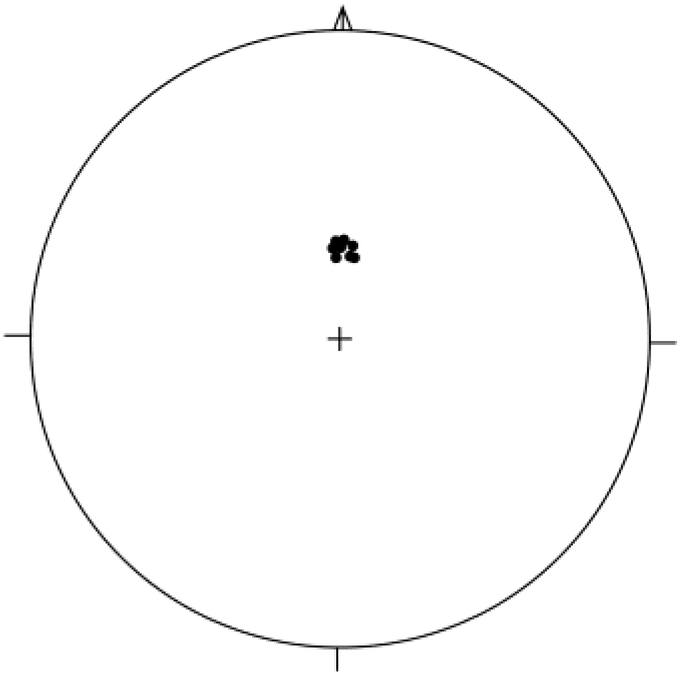
Archaeomagnetic dating - direction of remanent magnetisation in samples from kilns 14858 and 10906 after partial demagnetisation, shown as a stereogram

Fig. 9

MALDON 11477 5mT

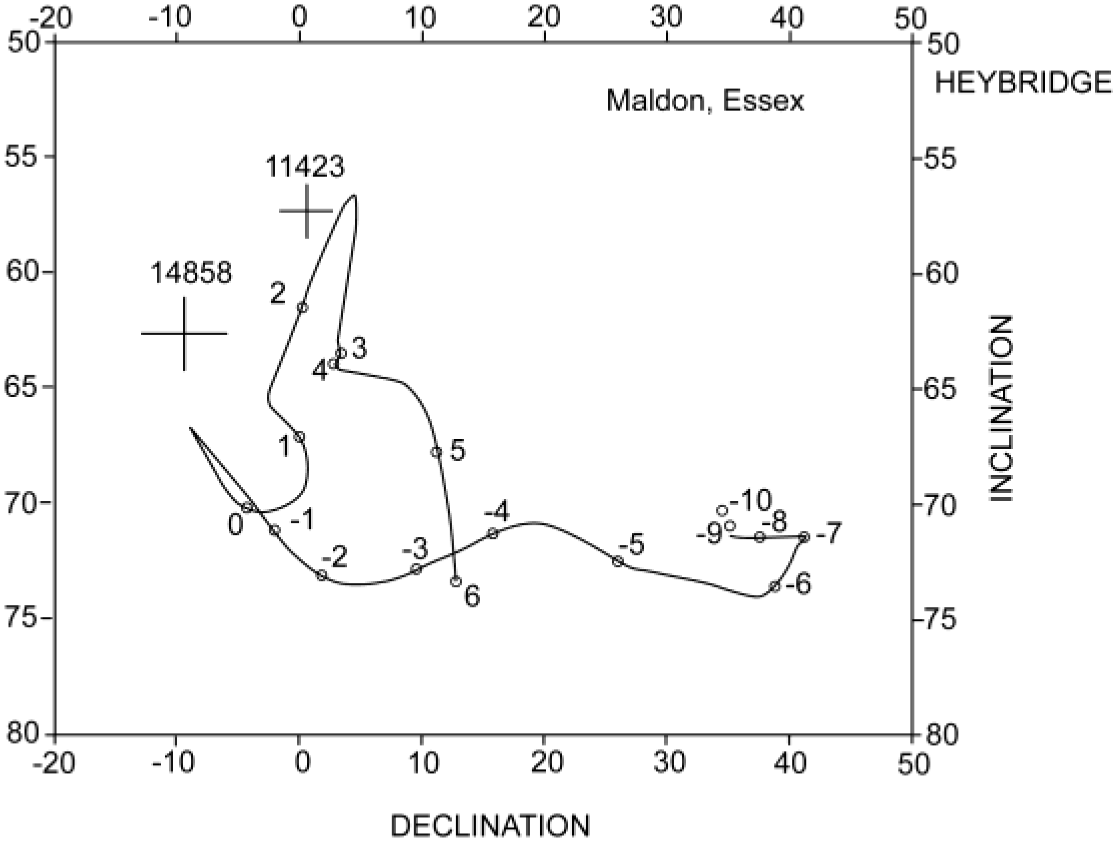


MALDON 11423 2.5mT



Archaeomagnetic dating - direction of remanent magnetisation in samples from kilns 11477 and 11423 after partial demagnetisation, shown as a stereogram

Fig. 10



Archaeomagnetic dating - Mean archaeomagnetic vectors in kilns 14858 and 11423 compared to the uK Master curve for the period 1000BC and 600AD

Fig. 11

Table 195. Archaeomagnetic results from Heybridge, Essex

Sample	LITH	J	D	I	A.F.	D	I
Kiln 1223							
1	FC	3936	355.0	59.5	12	354.6	60.4
2	FC	107	3.1	61.1	12	355.6	63.0
3	FC	380	2.3	59.9	12	357.9	60.9
4	FC	25865	356.8	60.1	12	358.2	58.8
5	FC	9733	353.3	58.0	12	353.6	57.5
6	FC	1528	352.1	64.2	12	352.1	64.9
7	FC	2244	12.6	67.7	12	8.8	67.5
8	FC	99	6.9	65.9	12	4.2	65.5
9	FC	733	6.2	62.6	12	4.9	65.7
10	FC	1090	18.3	60.0	12	[19.5	61.8]
11	FC	2252	356.6	67.3	12	358.4	67.5
14	FC	1641	359.3	63.9	12	0.8	64.9
15	FC	10970	2.7	65.2	12	1.8	63.8
17	FC	590	1.7	64.5	12	1.4	63.3
18	FC	1185	10.4	63.3	12	7.2	65.3
19	FC	3222	10.8	66.5	12	13.0	67.9
20	FC	1498	0.5	62.2	12	0.4	63.2
21	FC	3524	358.1	64.6	12	0.8	64.5
22	FC	6526	5.7	63.0	12	4.3	62.4
23	FC	6558	1.0	62.9	12	358.7	60.2
24	FC	8625	354.7	60.9	12	356.9	59.2
25	FC	13139	2.8	66.9	12	0.0	71.6
26	FC	314	4.0	62.5	12	3.8	64.3
27	FC	214	335.7	74.8	12	[335.2	74.7]
28	FC	865	338.9	74.4	12	[340.4	70.0]
29	FC	6116	357.4	69.5	12	1.2	67.7
30	FC	1345	2.9	60.7	12	0.3	62.9
31	FC	236	356.4	64.5	12	358.3	64.7
32	FC	12713	358.4	65.1	12	358.0	63.2
	Mean of feature		0.8	64.4		0.3	63.9
			alpha95=1.7	k=237.9		Alpha95=1.3	K=457.6
							c.s.e.=0.7
AT MERIDEN						**359.9**	**64.4**

Sample	LITH	J	D	I	A.F.	D	I
Kiln 1618							
1	FC	249	338.7	55.1	5	338.2	54.5
2	FC	42	358.4	50.5	5	6.2	50.6
5	FC	230	0.8	58.5	5	359.9	58.2
8	FC	178	351.0	59.5	5	349.9	59.9
11	FC	323	13.6	77.4	5	7.6	77.2
12	FC	163	355.9	57.7	5	355.4	58.4
15	FC	457	4.9	76.4	5	1.8	75.5
16	FC	254	354.5	62.8	5	352.4	62.7
18	FC	174	348.5	73.1	5	347.4	71.6
	Mean of feature		354.7	63.7		354.6	63.5
			alpha95=6.8	k=58.7		Alpha95=6.6	K=61.1
							c.s.e.=3.5
AT MERIDEN						**354.1**	**64.1**

Sample	LITH	J	D	I	A.F.	D	I
Kiln 14858							
1	FCL		350.4	61.3	5	347.5	60.6
2	FCL		355.3	62.9	5	356.3	63.0
3	FCL		353.7	60.0	5	355.6	60.1
4	FCL		359.6	60.7	5	359.6	60.8

5	FCL		355.5	67.6	5	356.0	67.6
6	FCL		346.9	66.2	5	346.3	65.6
7	FCL		346.8	57.7	5	342.5	59.2
8	FCL		340.8	42.7	5	339.8	43.0R
8a	FCL		348.5	55.6	5	346.8	57.0
	Mean of feature		349.9	59.6		351.1	61.9
Less R(ejects)			Alpha95=5.0	K=105.7		Alpha95=3.1	k=314.4
			c.s.e=2.6				c.s.e=1.6
AT MERIDEN			**-9.6**	**62.6**			
Sample	**LITH**	**J**	**D**	**I**	**A.F.**	**D**	**I**
Kiln 10906							
9	TIL		356.6	66.4	5	356.0	65.5
10	TIL		354.1	53.2	5	352.4	51.8
11	FCL		352.5	65.1	5	353.5	64.4
12	FCL		345.8	62.0	5	345.0	61.6
13	TIL		144.9	32.2	5	145.1	31.7R
14	FCL		349.1	65.2	5	349.3	65.4
15	FCL		349.9	65.6	5	350.1	66.0
16	TIL		357.8	55.5	5	357.4	55.0
17	TIL		350.2	61.8	5	349.9	61.6
18	TIL		359.8	54.9	5	0.4	54.9
19	TIL		222.3	53.1	5	222.4	51.7R
20	TIL		349.4	62.1	5	352.2	61.6
22	TIL		9.5	51.0	5	8.5	49.7
23	TIL		22.8	70.1	5	23.2	69.8
24	TIL		355.4	46.3	5	355.6	46.5
25	TIL		353.6	52.9	5	354.1	53.2
26	TIL		357.5	53.1	5	357.5	53.4
27	TIL		346.1	51.6	5	345.6	51.4
28	TIL		2.3	51.7	5	2.9	50.9
	Mean of feature		355.9	63.9		355.9	58.1
Less R(ejects)			Alpha95=10.3	K=11.6		Alpha95=3.7	k=95.4
			c.s.e=5.4				c.s.e=2.0
Sample	**LITH**	**J**	**D**	**I**	**A.F.**	**D**	**I**
Kiln 11477							
29	FCL		123.7	63.6	5	121.9	62.8R
30	FCL		23.7	74.8	5	26.4	75.3
31	FCL		332.0	59.0	5	328.5	59.0
32	FCL		327.3	67.1	5	334.7	-75.6R
33	FCL		339.2	65.6	5	339.9	65.8
34	FCL		330.9	61.0	5	330.3	61.1
35	FCL		31.6	67.4	5	29.3	68.4
36	FCL		41.4	80.4	5	39.1	80.6
37	FCL		357.6	76.8	5	353.1	77.8
38	FCL		354.4	56.1	5	356.9	56.3
39	FCL		358.1	56.6	5	357.3	58.5
40	FCL		357.1	60.6	5	357.8	75.9
41	FCL		6.9	58.8	5	4.7	59.6
42	FCL		355.4	63.4	5	355.4	63.9
43	FCL		3.1	81.6	5	1.7	81.3
	Mean of feature		359.0	70.1		355.8	69.1
Less R(ejects)			Alpha95=7.5	K=26.6		Alpha95=6.0	k=48.1
			c.s.e=4.1				c.s.e=3.2
Sample	**LITH**	**J**	**D**	**I**	**A.F.**	**D**	**I**
Kiln 11423							
44	FCL		7.7	59.2	2.5	7.2	59.4
45	FCL		7.7	59.3	2.5	9.3	59.5

46	FCL	359.2	55.9	2.5	1.1	53.9
47	FCL	357.4	54.7	2.5	357.6	54.5
48	FCL	5.8	56.3	2.5	7.1	55.5
49	FCL	359.7	58.4	2.5	357.6	59.2
50	FCL	359.4	55.5	2.5	359.5	56.6
51	FCL	357.4	55.4	2.5	357.3	55.4
52	FCL	355.7	54.7	2.5	356.2	55.9
	Mean of feature	0.9	56.7		1.3	56.7
		Alpha95=2.0	K=662.1		Alpha95=2.2	k=536.1
		c.s.e=1.0				c.s.e=1.2

Notes: LITH = Lithology. FC/FCL = fired clay. TIL = Tile. D = declination. I = inclination. J = intensity of measured magnetic moment in units of mAm^{-1} (kiln 1223) and $mAm^{-1}x10^{-3}$ (kiln 1618). 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. Results entered in brackets were not included in the calculation of the archaeomagnetic mean vector.

Table 1