RESEARCH DEPARTMENT REPORT SERIES no. 88-2008 ISSN 1749-8775

RINGLEMERE FARM, WOODNESBOROUGH, KENT ARCHAEOMAGNETIC DATING REPORT, OCTOBER 2004

Paul Linford and Louise Martin

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

RINGLEMERE FARM, WOODNESBOROUGH, KENT

ARCHAEOMAGNETIC DATING REPORT, OCTOBER 2004

Paul Linford and Louise Martin

NGR: TR 293 569

ISSN 1749-8775

The Research Department Report Series incorporates reports from all the specialist teams within the English Heritage Research Department: Archaeological Science; Archaeological Archives; Historic Interiors Research and Conservation; Archaeological Projects; Aerial Survey and Investigation; Archaeological Survey and Investigation; Architectural Investigation; Imaging, Graphics and Survey, and the Survey of London. It replaces the former Centre for Archaeology Reports Series, the Archaeological Investigation Report Series and the Architectural Investigation Report Series.
Many of these are interim reports which make available the results of specialist investigations in advance of full publication. They are not usually subject to external refereeing, and their conclusions may sometimes have to be modified in the light of information not available at the time of the investigation. Where no final project report is available, readers are advised to consult the author before citing these reports in any publication. Opinions expressed in Research Department reports are those of the author(s) and are not necessarily those of English Heritage.

Requests for further hard copies, after the initial print run, can be made by emailing:
Res.reports@english-heritage.org.uk
or by writing to:
English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD
Please note that a charge will be made to cover printing and postage.

SUMMARY

During excavations following the discovery of a Bronze Age gold cup at Ringlemere Farm near Woodnesborough in Kent in 2001a hearth thought to date from the late Neolithic or early Bronze Age was discovered. The English Heritage Geophysics Team was asked to sample this feature to test its suitability for archaeomagnetic dating and analyses showed that the hearth did retain a stable remanent magnetisation. While standard archaeomagnetic calibration curves for the UK do not extend back in time further than the Bronze Age, it has been possible to deduce an approximate date range for the last firing of the hearth during the 4th millennium BC using an international geomagnetic reference curve. This date is earlier than that of other material from the site so far submitted for scientific dating and further investigation is required to ascertain whether this discrepancy is due to deficiencies in the calibration curve resulting from the current paucity of UK archaeomagnetic reference data for the prehistoric period.

CONTRIBUTORS

All fieldwork, laboratory analyses and reporting were carried out by Louise Martin and Paul Linford.

ACKNOWLEDGEMENTS

The authors are grateful to Keith Parfitt of Canterbury Archaeological Trust for bringing the Ringlemere hearth to their attention and inviting the Geophysics Team to sample it.

ARCHIVE LOCATION

Fort Cumberland

DATE OF FIELDWORK AND REPORT

The fieldwork was conducted on 7th October 2004 and the report was completed on 19th November 2008

CONTACT DETAILS

Geophysics Team, English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD.
Paul Linford; Tel: 023 9285 6749; Email: paul.linford@english-heritage.org.uk

CONTENTS

INTRODUCTION

Following the discovery of a Bronze Age gold cup by a local metal detectorist at Ringlemere Farm, Woodnesborough in Kent in 2001, various archaeological investigations were conducted around the find spot. These included an initial geophysical survey and excavation in 2002 funded by English Heritage followed by more detailed investigations funded by the British Museum being carried out between 2002 and 2006. The excavations, conducted by Canterbury Archaeological Trust, revealed a large ditched henge enclosure, a central barrow mound, numerous 5th century Anglo Saxon graves and, more unusually, cremations and a later 7th century sunken-floored building (Parfitt and Needham 2007). A central pit, believed to have contained the gold cup, also contained flint work and a rare Early Bronze Age amber pendant (Parfitt and Needham 2007, 44). Elsewhere on the site Grooved Ware and Beaker Pottery was discovered, with one pit containing the former being dated using ^{14}C to 2890-2600 cal BC.

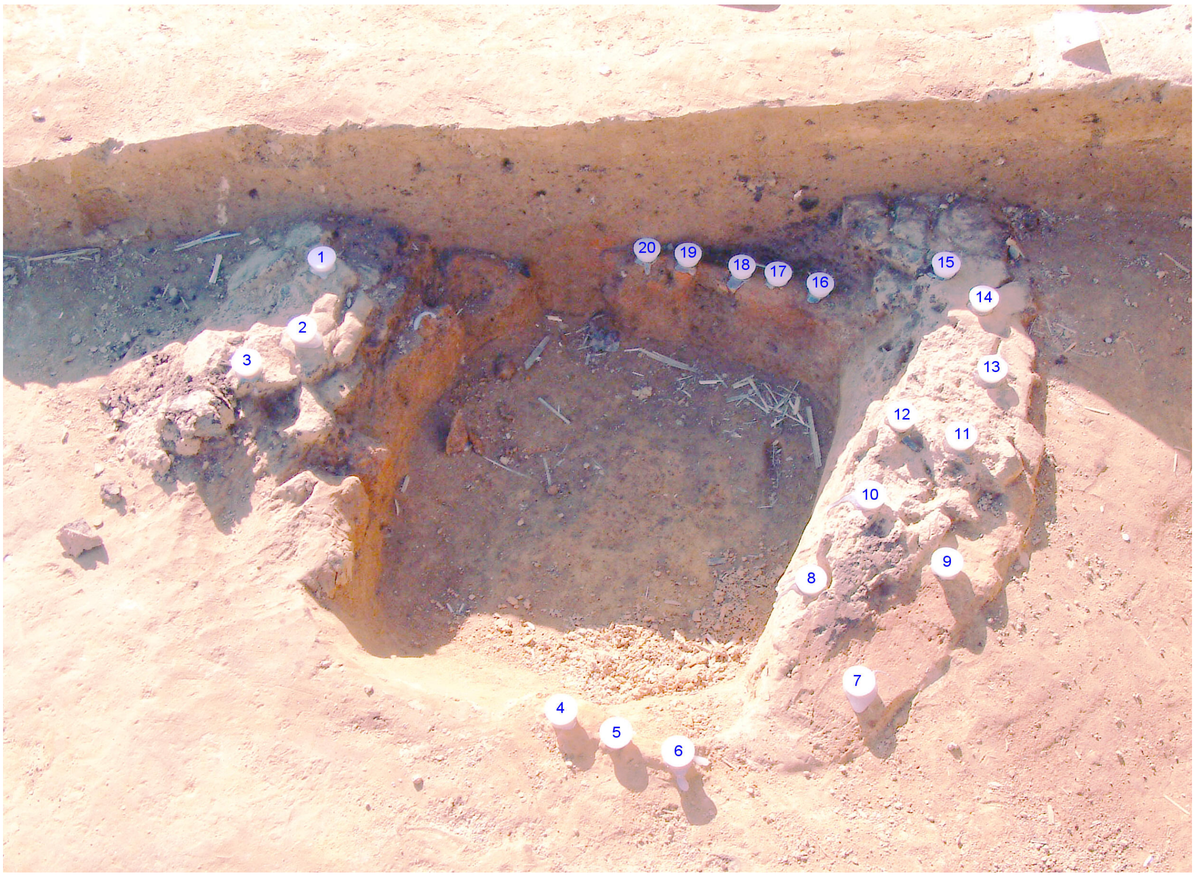


Figure 1: Photograph of the hearth remains looking south west and showing the locations of the numbered archaeomagnetic sampling discs.

Beneath the central barrow mound a hearth was revealed (Figure 1) which, given its context, was likely to date from the early Bronze Age or late Neolithic periods. Although this era predates the time for which detailed archaeomagnetic calibration material is available for the UK, the discovery of a well fired feature of such an early date in association with Grooved Ware pottery and material that could be dated using other scientific techniques offered a rare opportunity to obtain reference material to enhance the UK archaeomagnetic calibration database. The hearth was constructed of clay and differences in the colour and texture of this material suggested that parts of it, at least, had been exposed to temperatures high enough for a thermoremanent magnetisation to be acquired.

The hearth was brought to the attention of the authors by Keith Parfitt of Canterbury Archaeological Trust. In consultation with the English Heritage Inspector of Ancient Monuments for the region, Peter Kendal, it was agreed that the English Heritage Geophysics Team would provide archaeomagnetic analysis of the remains. The authors, who visited the site on 7th October 2004 to collect samples for this purpose, also performed all subsequent measurement and analysis.

METHOD

All samples were collected using the disc method (see appendix, section 1a), orientated to true north using a gyro-theodolite and given the archaeomagnetic sample prefix code RM. On inspection the hearth appeared to be composed of two types of fired clay: a dark brown/black very well-fired layer from which samples 01-03 and 10-15 were taken and a lighter sandy orange layer, which in places appeared to underlie the dark layer, and from which the remaining samples were extracted. The distribution of sample discs around the hearth is shown in Figure 1. Nineteen samples were recovered (sample RM05 became detached during sample extraction) and were consolidated in the laboratory using a Vinamul 40224 solution prior to magnetic analysis.

The magnetic analyses conducted on the Ringlemere samples were first to measure their mass specific magnetic susceptibility, then to measure their directions and strengths of natural remanent magnetisation (NRM). The ratio of remanent magnetisation intensity to magnetic susceptibility is known as the Königsberger ratio (Collinson 1983, p35) and gives an approximate indication of the stability of remanent magnetisation within a sample. Measurements of the mass specific magnetic susceptibility, NRM intensity and Königsberger ratio of the Ringlemere samples are listed in Table 1 and the measured NRM directions are listed in Table 2.

Further analysis of the remanent magnetisation recorded by each sample was then carried out. The natural remanent magnetisation measured in archaeomagnetic samples is assumed to be caused by thermoremanent magnetisation (TRM) created at the time when the feature of which they were part was last fired. However, a secondary component acquired in later geomagnetic fields can also be present, caused by diagenesis or partial reheating. Additionally, the primary TRM may be overprinted by a viscous component, depending on the grain size distribution within the magnetic material. These secondary components are usually of lower stability than the primary TRM and can thus be removed by partial demagnetisation of the samples.

To isolate these different components, each sample is partially demagnetised. This involves tumbling the sample in an alternating magnetic field of fixed peak strength and measuring the resulting changes in its magnetisation. This AF demagnetisation removes the contribution of the most weakly magnetised particles within the sample (those with the lowest coercivities). The higher the peak field strength that is applied, the greater the proportion of the sample's magnetisation that is removed. The procedure is repeated with increasing peak field strengths to build up a complete picture of the coercivity spectrum (or demagnetisation curve) of the sample.

For the Ringlemere samples, RM01 was first incrementally demagnetised to 100mT and, based upon the results of these measurements, it was determined that the remaining samples did not need to be demagnetised beyond 50mT after which less than 10% of the initial magnetisation typically remained. The majority of the samples were demagnetised with a full set of AF demagnetisation increments: 1, 2.5, 5, 7.5, 10, 15, 20, 30 and 50mT. However, it was eventually possible to determine the range of demagnetisation increments that were most likely to isolate the primary TRM component and so samples RM06-09, RM14, RM17-18 and RM20 were demagnetised using only the subset of AF increments: 7.5, 10, 15 and 20mT. Measurements of the remaining TRM after each partial demagnetisation increment are listed for all the Ringlemere samples in Tables 3 to 9.

Principal components analysis can be used to determine the various linear segments present within the sample's demagnetisation curve (Kirshvinck 1980). In the ideal case, each linear segment will correspond with one of the magnetisation components described above. Linearity is determined using the Maximum Angular Deviation (MAD) statistic (see Kirshvinck 1980 for definition). The smaller this statistic the better and, as a rule of thumb, sets of measurements with a MAD of <= 2.0° are considered acceptably linear. Once the linear segment corresponding to a sample's primary magnetisation direction has been identified, its principal component is taken as the characteristic direction of remanent magnetisation (ChRM) recorded by that sample. The results of this analysis for the Ringlemere samples are listed in Table 10 where the range of demagnetisation increments for which each sample showed the highest linearity is recorded along with the corresponding MAD angle and calculated mean direction of magnetisation.

Once the ChRM direction for each sample from a fired feature has been determined, a mean ChRM direction can be calculated for it. Some samples may be excluded from this calculation if their ChRM directions are so anomalous as to make them statistical outliers from the overall distribution. The mean direction is then adjusted according to the location of the feature relative to a notional central point in the UK (Meriden), so that it can be compared with standardised archaeomagnetic calibration data to produce a date of last firing for the feature. Notes concerning the mean calculation and subsequent calibration can be found in sections 3 and 4 of the appendix. The Ringlemere hearth is known to be older than the earliest date covered by the standard UK calibration database and so an international calibration curve was used. This is described below along with the implications for the dating of the feature.

RESULTS

It can be seen from Table 1 that the samples from the Ringlemere hearth taken from the darker clay all have Königsberger ratios greater than 4.0 whilst none of the lighter orange clay samples have a ratio above 3.3. Although the Königsberger ratio is less diagnostic for complex sedimentary materials such as clays where the particles contributing to the magnetic susceptibility are not necessarily the same as those carrying magnetic remanence, these results do suggest a difference in magnetic properties between the two materials. It is likely that the darker clay contains a higher proportion of titanomagnetite whilst in the lighter orange clay haematite or maghaemite is likely to occur in greater abundance. The partial demagnetisation results listed in Tables 3-9 also suggest that the darker clay samples carry more stable remanent magnetisation directions which require higher demagnetisation fields to remove. Figures 2 and 3 depict the typical remanence properties of the two clay types graphically, Figure 2 showing the results from sample RM11 (darker clay) and Figure 3 showing sample RM16 (lighter orange clay). The higher stability of remanence in the former is borne out by the stability of its remanence direction even at high coercivities and its higher median destructive field, 16.2mT as opposed to 9.7mT for sample RM16.

In archaeological terms, this suggests that the dark clay layer, occupying the higher areas around the outside of the feature was probably subjected to higher temperatures (and possibly multiple heating events), perhaps in a reducing atmosphere. By contrast the lighter orange clay, which occurred at lower levels around the central depression, appears to have experienced a lower maximum heating temperature, possibly in a more oxidising environment.

Whilst the darker clay samples clearly carry the most stable remanence, it was decided to fully analyse all the samples collected from the Ringlemere hearth as many of the lighter orange samples still appeared to carry an acceptably stable remanence. The NRM measurements and primary ChRM directions of each sample are tabulated in Table 2 and the directions are depicted graphically in Figure 4. It is clear from the change in the scatters of sample directions between Figures 4a and 4b that the NRM directions were overprinted with a viscous component which partial demagnetisation has removed. Consulting Table 10, principal components analysis suggests that the primary ChRM directions in most of the samples were acceptably linear (MAD angle < 2.0) with the exception of samples RM06-07, RM13, RM19 and RM20. A mean ChRM direction was thus calculated for the hearth excluding these five samples then recalculated also omitting sample RM18 which had a remanence direction which appeared to be a statistical outlier (*sensu* Beck 1983):

At site:	Dec = -7.6°	Inc = 62.3°	α_{95} = 3.2°	k = 169.8 N=13
At Meriden:	Dec = -8.3°	Inc = 63.4°		

Calibration of this mean direction is complicated because the feature is known from its stratigraphic position to predate the Bronze Age barrow which overlies it. The standard archaeomagnetic calibration curves for the UK (Clark *et al.* 1988; Batt 1997; Zananiri *et al.* 2007) only contain calibration evidence going back to 1000BC, hence the global geomagnetic reference curve, CALSK7K (Korte and Constable 2005), was instead used.

From this mean direction, the date for the last firing of the hearth was deduced to be:

4060 to 3300 BC at the 63% confidence level.
4500 to 3170 BC at the 95% confidence level.

CONCLUSIONS

Archaeomagnetic analysis of the remains of the Ringlemere hearth indicates that it had been heated sufficiently in antiquity to acquire a stable thermoremanent magnetisation. Of the two distinct layers sampled, the darker brown/black clay appears to have recorded the strongest and most stable magnetisation directions although consistent magnetisations were observed in the majority of samples from both materials. It was thus possible to determine a mean ChRM direction of reasonable precision which could be compared with calibration data.

The hearth was located in a context known to date from the Bronze Age or late Neolithic periods and, unfortunately, the standard archaeomagnetic reference curves for the UK do not extend this far back into prehistory. For this reason, it was necessary to use the global reference curve of Korte and Constable (2005), CALSK7K, built up from archaeomagnetic observations made on materials dating from the last seven millennia taken from many different locations around the world. However, while this curve provides an adequate description of variations of the main geomagnetic dipole over this period, it will by its nature tend to smooth out regional variations in the geomagnetic field. These more local, secular variations are caused by interactions at the Earth's core-mantle boundary and perturb the main dipolar field, typically over regions about 500 km in diameter. Archaeomagnetic dating depends for its accuracy and precision on this regional detail, so calibration using the CALSK7K curve will tend to provide broader date ranges indicative of the general period when a feature was last fired rather than a precise date.

In the present case this accounts for the relatively broad date range of ~1300 years despite a mean ChRM direction of reasonable precision (3.2 °). It may also explain why the archaeomagnetic date, in the 4th millennium BC, is somewhat earlier than other material found on the site – the Neolithic Grooved Ware pottery for example, appears to date from the early 3rd millennium BC. The archaeomagnetic analysis certainly demonstrates promise that features of this antiquity are suitable for dating using the technique. However, given the present relative paucity of calibration material for early prehistory, the quoted date should be treated as a broad indication only. Comparison with other chronological information for the site would be valuable, both to refine the date of the hearth feature and to help improve archaeomagnetic calibration for the prehistoric period.

ARCHAEOMAGNETIC DATE SUMMARY

Archaeomagnetic ID:	RM
Feature:	Clay hearth, Ringlemere Farm, Kent
Location:	Longitude 1.29°E, Latitude 51.27°N
Number of Samples (taken/used in mean):	19/13
AF Demagnetisation Applied:	0-50mT (see text and Table 10)
Distortion Correction Applied:	None
Declination (at Meriden):	-7.6° (-8.6°)
Inclination (at Meriden):	62.3° (63.4 °)
Alpha-95:	3.2°
k:	169.8
Date range (63% confidence):	4060 BC to 3300 BC
Date range (95% confidence):	4500 BC to 3170 BC
Independent date estimate:	Late Neolithic to early Bronze Age

TABLES

Table 1: Magnetic properties of samples taken from the Ringlemere hearth. NRM = strength of natural remanent magnetisation, MS = volume magnetic susceptibility in SI units measured in a 100cc bench sensor; Q = Königsberger ratio derived from the previous two quantities after correcting MS for sample volume; MCI = Tarling and Symons' Maximum Consistency Index take from Table 10; and MAD = Kirshvink's maximum angular deviation also from Table 10. The latter two statistics both attempt to quantify consistency in the direction of remanent magnetisation as a sample is partially demagnetised and, as a general rule, MCIs > 2.0 and MAD angles <= 2.0 both indicate acceptably linear primary magnetisation components. Rows shaded in grey indicate samples taken from the dark brown/black very well fired layer which exhibit consistently higher Q values.

Sample	NRM (mAm^{-1})	MS (SI $\times 10^{-5}$)	Q	MCI	MAD°
RM01	3602.0	147.7	7.7	9.9	1.7
RM02	3214.5	155.4	6.5	29.4	0.6
RM03	2346.4	88.8	8.3	38.2	0.6
RM04	72.8	28.2	0.8	29.5	0.9
RM06	12.6	1.4	2.7	2.0	3.0
RM07	5.4	0.5	3.3	3.7	12.8
RM08	27.0	4.9	1.7	4.2	0.6
RM09	29.5	4.9	1.9	6.5	0.8
RM10	191.0	13.9	4.3	30.5	0.7
RM11	410.7	25.8	5.0	21.6	0.3
RM12	517.7	36.7	4.4	38.4	0.7
RM13	893.1	32.9	8.5	22.8	2.5
RM14	53.8	3.6	4.7	7.3	1.9
RM15	3384.7	138	7.7	26.2	1.2
RM16	63.3	15.9	1.3	3.8	1.3
RM17	21.5	4.2	1.6	4.2	1.4
RM18	47.3	9.8	1.5	5.8	1.8
RM19	32.8	5.0	2.1	8.6	3.2
RM20	10.6	2.6	1.3	0.8	5.7

Table 2: NRM measurements of samples and measurements after partial AF demagnetisation for feature RM. J = magnitude of magnetisation vector; AF = peak alternating field strength of demagnetising field; R = sample rejected from mean calculation.

Sample	NRM Measurements				After Partial Demagnetisation				
	Material	Dec°	Inc°	J(mAm⁻¹)	AF(mT)	Dec°	Inc°	MAD°	R
RM01	Clay	-18.9	59.0	3602.0	100.0	-16.5	60.6	1.7	
RM02	Clay	-0.7	66.9	3214.5	50.0	-2.0	61.7	0.6	
RM03	Clay	-7.8	62.0	2346.4	50.0	-7.3	60.6	0.6	
RM04	Clay	-13.6	61.9	72.8	50.0	-20.6	61.9	0.9	
RM06	Clay	33.9	49.3	12.6	20.0	33.6	61.1	3.0	R
RM07	Clay	34.7	51.8	5.4	20.0	-85.3	61.2	12.8	R
RM08	Clay	-16.2	62.8	27.0	20.0	-25.8	62.1	0.6	
RM09	Clay	-13.7	76.7	29.5	20.0	-20.7	69.0	0.8	
RM10	Clay	-18.7	62.8	191.0	50.0	-8.6	59.6	0.7	
RM11	Clay	3.8	68.5	410.7	50.0	11.8	64.3	0.3	
RM12	Clay	-26.7	65.0	517.7	50.0	-16.0	60.9	0.7	
RM13	Clay	22.7	71.6	893.1	50.0	16.5	72.6	2.5	R
RM14	Clay	4.8	66.3	53.8	20.0	-7.4	63.5	1.9	
RM15	Clay	6.3	62.9	3384.7	50.0	4.2	61.6	1.2	
RM16	Clay	-13.7	63.0	63.3	50.0	-4.1	57.9	1.3	
RM17	Clay	19.9	57.6	21.5	20.0	11.5	59.7	1.4	
RM18	Clay	-5.4	76.5	47.3	20.0	17.5	73.7	1.8	R
RM19	Clay	5.2	65.1	32.8	30.0	19.5	59.8	3.2	R
RM20	Clay	-3.9	72.8	10.6	20.0	-108.4	68.2	5.7	R

Table 3: Incremental partial demagnetisation measurements for samples RM01, RM02 and RM03.

AF(mT)	RM01			RM02			RM03		
	Dec°	Inc°	J(mAm⁻¹)	Dec°	Inc°	J(mAm⁻¹)	Dec°	Inc°	J(mAm⁻¹)
0.0	-17.4	59.5	3645.4	0.1	65.4	3207.2	-5.9	61.2	2354.2
1.0	-17.6	59.5	3628.7	-4.3	65.6	3211.5	-5.8	60.8	2281.1
2.5	-17.2	58.6	3545.6	-2.3	65.0	3101.2	-6.4	60.6	2181.7
5.0	-19.3	57.6	3261.0	0.3	63.4	2812.2	-6.4	59.9	1979.8
7.5	-20.8	59.5	2876.2	-0.7	62.7	2440.8	-6.8	59.9	1744.1
10.0	-18.7	57.6	2372.2	0.1	62.7	2081.5	-6.1	60.0	1498.7
15.0	-20.1	57.3	1593.9	0.6	63.4	1364.1	-5.8	59.0	1058.8
20.0	-21.1	53.4	1015.7	-0.2	63.0	854.2	-5.9	59.6	732.0
30.0	-13.5	61.6	454.5	-4.0	66.8	365.6	-1.5	57.0	370.1
50.0	-11.5	60.5	146.4	8.7	63.8	146.9	-1.6	50.3	137.5
75.0	-50.8	61.8	92.4	-	-	-	-	-	-
100.0	27.7	-7.2	39.6	-	-	-	-	-	-

Table 4: Incremental partial demagnetisation measurements for samples RM04, RM06 and RM07.

AF(mT)	RM04			RM06			RM07		
	Dec°	Inc°	J(mAm^{-1})	Dec°	Inc°	J(mAm^{-1})	Dec°	Inc°	J(mAm^{-1})
0.0	-14.6	60.7	69.6	11.2	63.0	9.9	38.6	58.1	3.8
1.0	-16.6	61.4	69.1	-	-	-	-	-	-
2.5	-19.0	61.9	66.2	-	-	-	-	-	-
5.0	-20.6	62.4	58.5	-	-	-	-	-	-
7.5	-21.7	62.3	49.2	-5.6	62.4	6.4	44.5	48.1	3.2
10.0	-20.9	62.9	41.6	-9.0	61.4	5.1	50.8	42.9	3.3
15.0	-	-	-	40.2	36.6	7.4	49.1	39.2	2.8
20.0	-21.3	63.0	22.9	43.0	35.2	5.3	53.7	39.4	2.7
30.0	-21.5	67.3	17.2	-	-	-	-	-	-
50.0	-11.1	65.4	13.6	-	-	-	-	-	-

Table 5: Incremental partial demagnetisation measurements for samples RM08-10.

AF(mT)	RM08			RM09			RM10		
	Dec°	Inc°	J(mAm^{-1})	Dec°	Inc°	J(mAm^{-1})	Dec°	Inc°	J(mAm^{-1})
0.0	-5.8	60.2	26.0	-8.3	69.7	25.5	-10.4	60.0	190.1
1.0	-	-	-	-	-	-	-9.4	60.3	189.1
2.5	-	-	-	-	-	-	-9.0	60.3	186.7
5.0	-	-	-	-	-	-	-9.4	60.0	170.0
7.5	-4.4	57.3	19.6	-2.3	70.1	16.6	-7.7	60.0	154.0
10.0	-1.5	56.1	17.1	5.0	69.3	12.6	-8.1	59.8	138.9
15.0	4.9	53.3	12.7	1.0	69.6	9.6	-6.9	60.3	101.9
20.0	10.3	47.7	9.7	27.3	51.1	6.0	-8.8	60.2	68.5
30.0	-	-	-	-	-	-	-4.1	61.0	35.2
50.0	-	-	-	-	-	-	-0.5	62.1	15.9

Table 6: Incremental partial demagnetisation measurements for samples RM11-13.

AF(mT)	RM11			RM12			RM13		
	Dec°	Inc°	J(mAm^{-1})	Dec°	Inc°	J(mAm^{-1})	Dec°	Inc°	J(mAm^{-1})
0.0	11.8	66.3	413.8	-16.7	61.9	522.9	21.6	71.8	883.0
1.0	12.9	65.6	409.5	-16.3	61.8	514.1	19.2	72.2	887.5
2.5	9.8	65.6	400.7	-16.9	61.9	503.8	20.1	72.0	868.0
5.0	9.5	65.2	383.7	-15.6	61.5	469.7	20.4	71.8	827.8
7.5	9.9	64.8	352.6	-15.7	61.2	423.3	14.4	71.5	760.5
10.0	9.0	64.7	312.5	-14.7	61.0	378.2	22.6	72.5	695.7
15.0	9.6	64.0	223.4	-14.1	60.6	277.8	23.6	72.4	541.3
20.0	8.9	63.6	153.5	-14.6	60.9	193.2	14.9	70.6	399.5
30.0	5.7	63.3	79.1	-10.6	61.0	109.6	35.7	71.0	231.0
50.0	19.5	63.4	37.9	-19.4	64.5	48.3	30.2	63.8	83.2

Table 7: Incremental partial demagnetisation measurements for samples RM14-16.

AF(mT)	RM14			RM15			RM16		
	Dec°	Inc°	J(mAm^{-1})	Dec°	Inc°	J(mAm^{-1})	Dec°	Inc°	J(mAm^{-1})
0.0	-0.9	63.0	51.4	3.4	61.7	3342.3	-17.4	61.8	67.4
1.0	-	-	-	3.9	61.7	3306.0	-13.6	61.0	63.8
2.5	-	-	-	4.0	61.9	3217.2	-12.8	59.3	59.6
5.0	-	-	-	5.5	61.8	3229.7	-8.3	57.1	51.7
7.5	2.3	61.2	41.7	5.1	61.0	2757.9	-	-	-
10.0	3.4	62.0	37.5	3.8	61.1	2452.6	-0.1	54.2	32.5
15.0	9.0	60.7	27.5	3.7	61.6	1888.8	16.8	54.9	22.6
20.0	12.5	59.9	19.1	7.0	61.1	1291.3	8.8	57.8	15.7
30.0	-	-	-	2.2	63.0	683.0	22.1	56.2	8.3
50.0	-	-	-	10.9	61.9	291.5	29.1	54.8	5.7

Table 8: Incremental partial demagnetisation measurements for samples RM17 and RM18.

AF(mT)	RM17			RM18		
	Dec°	Inc°	J(mAm^{-1})	Dec°	Inc°	J(mAm^{-1})
0.0	23.4	53.4	18.4	17.4	70.2	42.1
7.5	22.3	43.5	12.9	18.5	68.8	26.2
10.0	23.1	40.4	11.1	16.2	66.3	22.8
15.0	25.2	36.4	9.2	17.8	65.8	17.6
20.0	25.3	39.9	5.9	37.8	66.8	13.0

Table 9: Incremental partial demagnetisation measurements for samples RM19 and RM20.

AF(mT)	RM19			RM20		
	Dec°	Inc°	J(mAm^{-1})	Dec°	Inc°	J(mAm^{-1})
0.0	3.3	59.7	31.6	26.7	67.0	7.1
1.0	11.4	61.2	30.0	-	-	-
2.5	13.1	61.9	26.5	-	-	-
5.0	21.5	58.4	21.9	-	-	-
7.5	22.2	61.0	17.0	38.7	48.6	5.8
10.0	20.9	58.7	14.8	39.9	39.1	4.9
15.0	24.4	58.1	10.2	44.4	27.1	4.8
20.0	20.8	57.9	8.3	41.4	14.4	3.9
30.0	26.8	46.5	5.9	-	-	-

Table 10: Assessment of the range of demagnetisation values over which each sample attained its maximum directional consistency and linearity for feature RM. Consistency is calculated using the method of Tarling and Symons (1967) and linearity using the method of Kirshvink (1980). Min and Max indicate the range of demagnetisation values in mT over which each statistic was calculated and N is the number of consecutive measurements this represents. MCI is the maximum value of Tarling and Symons' consistency index found for the sample (over 2 for a stable magnetisation). MAD is Kirshvink's maximum angular deviation (less than 2° indicates linearity). In each case, declination and inclination values are for the mean direction calculated from all demagnetisation measurements in the range indicated.

Sample	Consistency						Linearity					
	Min	Max	N	MCI	Dec°	Inc°	Min	Max	N	MAD°	Dec°	Inc°
RM01	0.0	15.0	7	9.9	-18.7	58.5	10.0	20.0	3	1.7	-16.5	60.6
RM02	5.0	20.0	5	29.4	0.0	63.0	7.5	15.0	3	0.6	-2.0	61.7
RM03	5.0	10.0	3	38.2	-6.4	59.9	5.0	50.0	7	0.6	-7.3	60.6
RM04	5.0	20.0	4	29.5	-21.1	62.7	5.0	20.0	4	0.9	-20.6	61.9
RM06	0.0	10.0	3	2.0	-1.3	62.5	0.0	10.0	3	3.0	33.6	61.1
RM07	10.0	20.0	3	3.7	51.2	40.5	0.0	10.0	3	12.8	-85.3	61.2
RM08	0.0	10.0	3	4.2	-3.8	57.9	7.5	15.0	3	0.6	-25.8	62.1
RM09	7.5	15.0	3	6.5	1.3	69.7	0.0	10.0	3	0.8	-20.7	69.0
RM10	1.0	5.0	3	30.5	-9.3	60.2	7.5	50.0	6	0.7	-8.6	59.6
RM11	5.0	10.0	3	21.6	9.5	64.9	15.0	30.0	3	0.3	11.8	64.3
RM12	10.0	20.0	3	38.4	-14.5	60.8	10.0	30.0	4	0.7	-16.0	60.9
RM13	1.0	5.0	3	22.8	19.9	72.0	1.0	50.0	9	2.5	16.5	72.6
RM14	0.0	10.0	3	7.3	1.6	62.1	10.0	20.0	3	1.9	-7.4	63.5
RM15	0.0	2.5	3	26.2	3.8	61.8	1.0	50.0	9	1.2	4.2	61.6
RM16	15.0	50.0	4	3.8	19.4	56.1	20.0	50.0	3	1.3	-4.1	57.9
RM17	10.0	20.0	3	4.2	24.5	38.9	7.5	15.0	3	1.4	11.5	59.7
RM18	0.0	15.0	4	5.8	17.5	67.8	0.0	15.0	4	1.8	17.5	73.7
RM19	10.0	20.0	3	8.6	22.0	58.2	10.0	20.0	3	3.2	19.5	59.8
RM20	10.0	20.0	3	0.8	42.0	26.9	0.0	15.0	4	5.7	-108.4	68.2

APPENDIX: STANDARD PROCEDURES FOR SAMPLING AND MEASUREMENT

The principles underlying the archaeomagnetic dating method have been described by Linford (2004) and the procedures employed are described in English Heritage (2006). These notes summarise the most important points.

1) Sampling

One of three sampling techniques is employed depending on the consistency of the material (Clark *et al.* 1988; English Heritage 2006):

a) Consolidated materials: Rock and fired clay samples are collected by the disc method. Several small levelled plastic discs are glued to the feature, marked with an orientation line related to True North, then removed with a small piece of the material attached.
b) Unconsolidated materials: Sediments are collected by the tube method. Small pillars of the material are carved out from a prepared platform, then encapsulated in levelled plastic tubes using plaster of Paris. The orientation line is then marked on top of the plaster.
c) Plastic materials: Waterlogged clays and muds are sampled in a similar manner to method 1b) above; however, the levelled plastic tubes are pressed directly into the material to be sampled.

2) Physical Analysis

a) Magnetic remanences are measured using a slow speed spinner fluxgate magnetometer (Molyneux 1971; see also Tarling 1983, p84; Thompson and Oldfield 1986).
b) Partial demagnetisation is achieved using the alternating magnetic field method (Tarling 1983, p91; Thompson and Oldfield 1986, p59), to remove viscous magnetic components if necessary. Demagnetising fields are measured in millitesla (mT), figures quoted being for the peak value of the field.

3) Remanent Field Direction

a) The remanent field direction of a sample is expressed as two angles, declination (Dec) and inclination (Inc), both quoted in degrees. Declination represents the bearing of the field relative to true north, angles to the east being positive; inclination represents the angle of dip of this field.
b) Aitken and Hawley (1971) have shown that the angle of inclination in measured samples is likely to be distorted owing to magnetic refraction. The phenomenon is not well understood but is known to depend on the position the samples occupied

within the structure. The corrections recommended by Aitken and Hawley are applied, where appropriate, to measured inclinations, in keeping with the practice of Clark, Tarling and Noel (1988).

c) Individual remanent field directions are combined to produce the mean remanent field direction using the statistical method developed by R. A. Fisher (1953). The quantity α_{95}, "alpha-95", is quoted with mean field directions and is a measure of the precision of the determination (see Aitken 1990, p247). It is analogous to the standard error statistic for scalar quantities; hence the smaller its value, the better the precision of the date.

d) For the purposes of comparison with standardised UK calibration data, remanent field directions are adjusted to the values they would have had if the feature had been located at Meriden, a standard reference point. The adjustment is done using the method suggested by Noel (Tarling 1983, p116).

4) Calibration

a) Material less than 3000 years old is dated using the archaeomagnetic calibration curve compiled by Clark, Tarling and Noel (1988).

b) Older material is dated using the lake sediment data compiled by Thompson and Turner (Thompson and Turner 1979; Turner and Thompson 1981).

c) Dates are normally given at the 63% and 95% confidence levels. However, the quality of the measurement and the estimated reliability of the calibration curve for the period in question are not taken into account, so this figure is only approximate. Owing to crossovers and contiguities in the curve, alternative dates are sometimes given. It may be possible to select the correct alternative using independent dating evidence.

d) As the thermoremanent effect is reset at each heating, all dates for fired material refer to the final heating.

REFERENCES

Aitken, M J 1990 *Science-based dating in archaeology*, London, Longman.

Aitken, M J and Hawley, H N 1971 'Archaeomagnetism: evidence for refraction in kiln structures'. *Archaeometry*, 13, 83-5.

Batt, C M 1997 'The British archaeomagnetic calibration curve: an objective treatment'. *Archaeometry*, 39, 153-168.

Beck, M E, Jr. 1983 'Comment on `Determination of the angle of a Fisher distribution which will be exceeded with a given probability' by P. L. McFadden'. *Geophysical Journal of the Royal Astronomical Society*, 75, 847-849.

Clark, A J, Tarling, D H and Noël, M 1988 'Developments in Archaeomagnetic Dating in Britain'. *Journal of Archaeological Science*, 15, 645-667.

Collinson, D W 1983 *Methods in rock magnetism and palaeomagnetism: techniques and instrumentation*, London, Chapman and Hall.

English Heritage 2006 Archaeomagnetic Dating: Guidelines on producing and interpreting archaeomagnetic dates. Swindon, English Heritage.

Fisher, R A 1953 'Dispersion on a sphere'. *Proceedings of the Royal Society of London A*, 217, 295-305.

Kirshvinck, J L 1980 'The least-squares line and plane and the analysis of paleomagentic data'. *Geophysical Journal of the Royal Astronomical Society*, 62, 699-718.

Korte, M and Constable, C G 2005 'Continuous geomagnetic field models for the past 7 millennia: 2. CALSK7K'. *Geochemistry Geophysics Geosystems*, 6 (2), Q02H16.

Linford, P 2004 'Archaeomagnetic Dating'. *Physics Education*, 39 (2), 145-154.

Molyneux, L 1971 'A complete result magnetometer for measuring the remanent magnetization of rocks'. *Geophysical Journal of the Royal Astronomical Society*, 24, 429-433.

Parfitt, K and Needham, S 2007 'Amber, Gold and a Bronze Age Barrow'. *Current Archaeology*, 208, 41-46.

Tarling, D H 1983 *Palaeomagnetism: Principles and applications on geology, geophysics and archaeology*, London, Chapman and Hall.

Tarling, D H and Symons, D T A 1967 'A stability index of remanence in palaeomagnetism'. *Geophysical Journal of the Royal Astronomical Society*, 12, 443-448.

Thompson, R and Oldfield, F 1986 *Environmental Magnetism*, London, Allen and Unwin.

Thompson, R and Turner, G M 1979 'British geomagnetic master curve 10,000-0 yr BP for dating European sediments'. *Geophys. Res. Letters*, 6, 249-252.

Turner, G M and Thompson, R 1981 'Lake sediment record of the geomagnetic secular variation in Britain during Holocene times'. *Geophysical Journal of the Royal Astronomical Society*, 65, 703-725.

Zananiri, I, Batt, C M, Lanos, P, Tarling, D H and Linford, P 2007 'Archaeomagnetic secular variation in the UK during the past 4000 years and its application to archaeomagnetic dating'. *Physics of The Earth and Planetary Interiors*, 160 (2), 97-107.

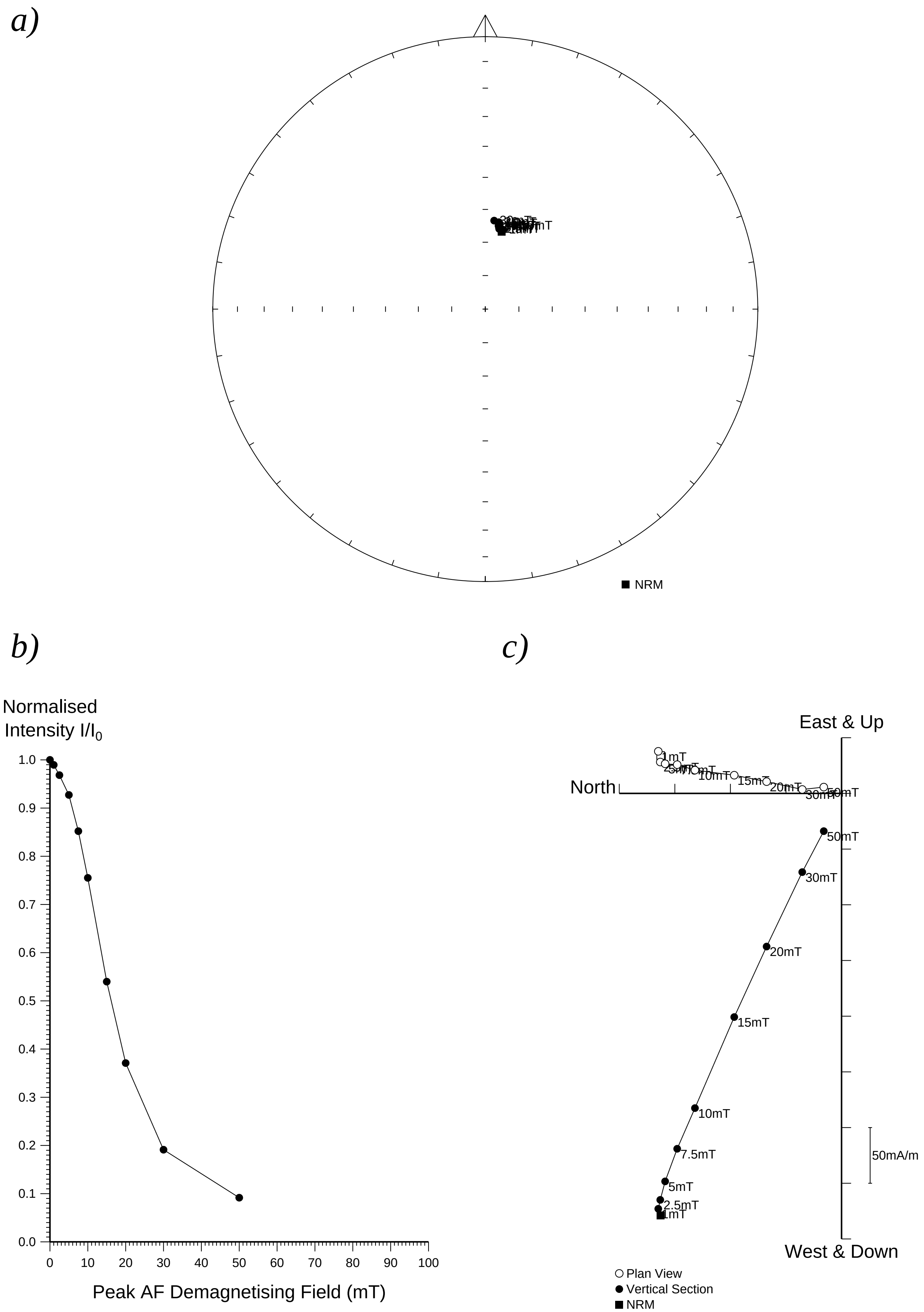


Figure 2: Stepwise AF demagnetisation of sample RM11. Diagram a) depicts the variation of the remanent direction as an equal area stereogram (declination increases clockwise, while inclination increases from zero at the equator to 90 degrees at the centre of the projection); b) shows the normalised change in remanence intensity as a function of the demagnetising field; c) shows the changes in both direction and intensity as a vector endpoint projection.

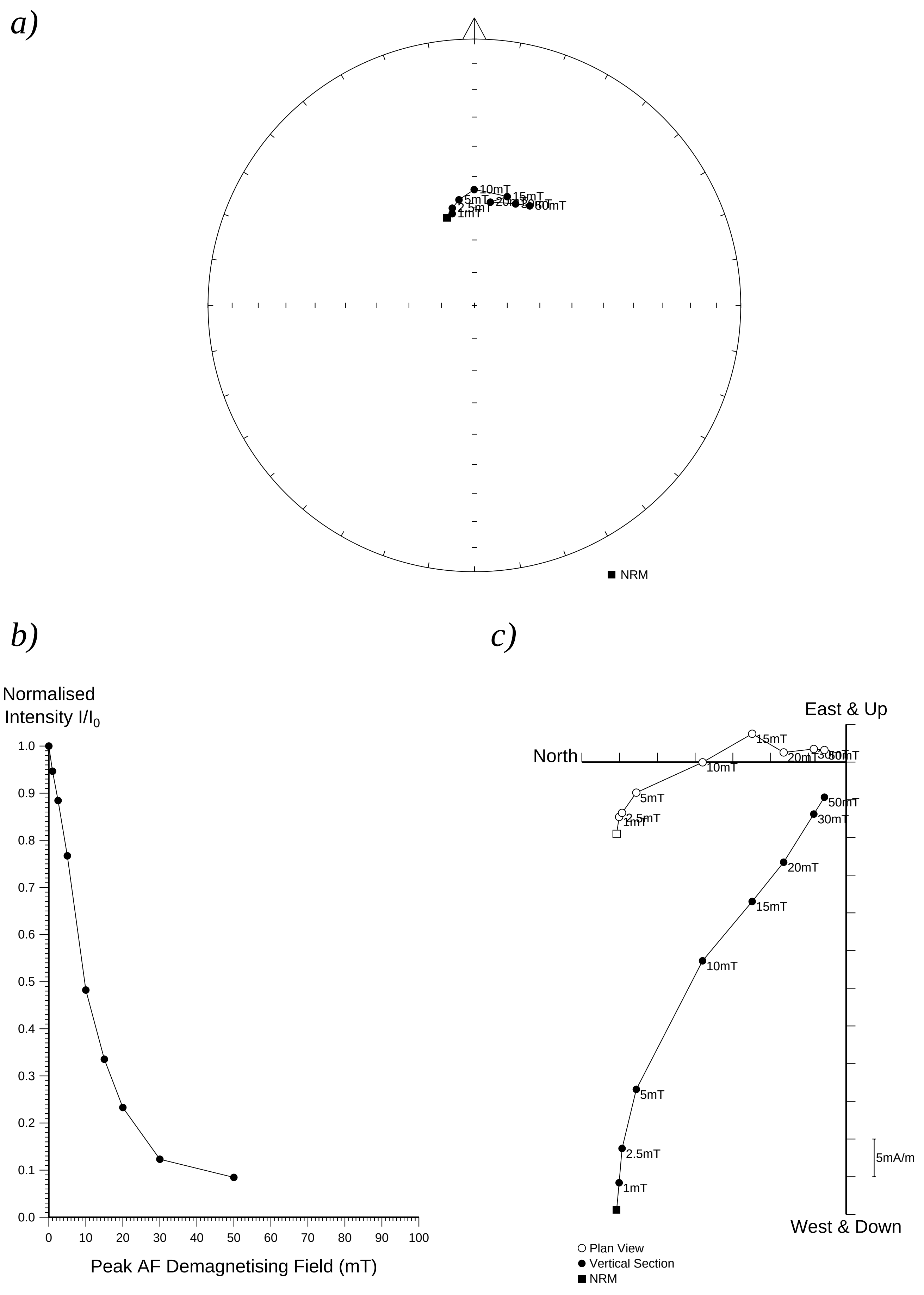
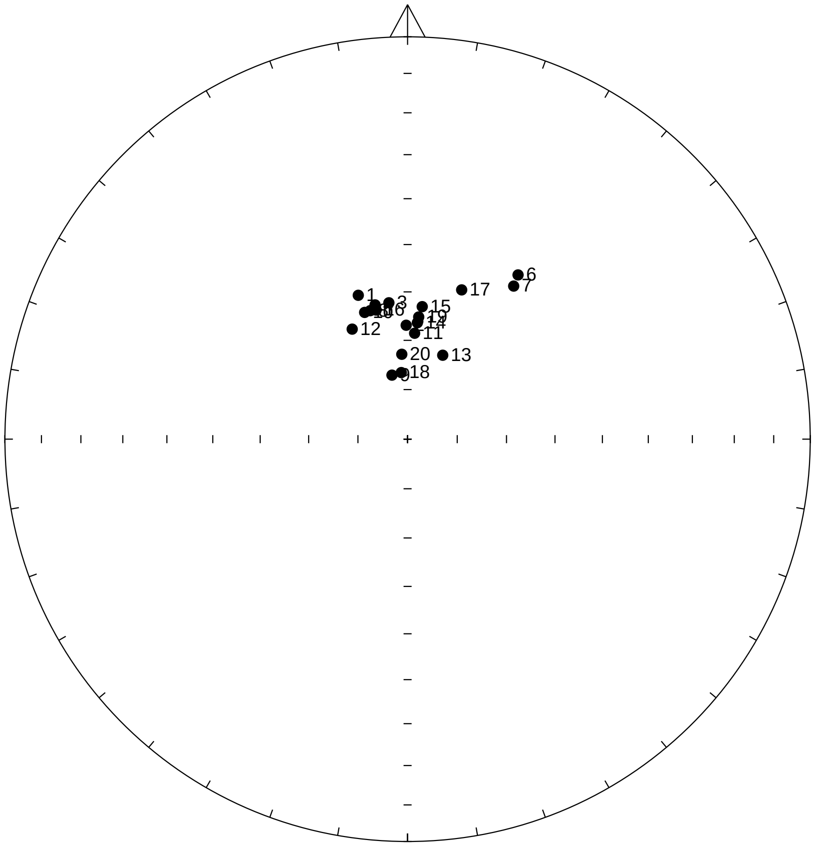


Figure 3: Stepwise AF demagnetisation of sample RM16. Diagram a) depicts the variation of the remanent direction as an equal area stereogram (declination increases clockwise, while inclination increases from zero at the equator to 90 degrees at the centre of the projection); b) shows the normalised change in remanence intensity as a function of the demagnetising field; c) shows the changes in both direction and intensity as a vector endpoint projection.

a)



b)

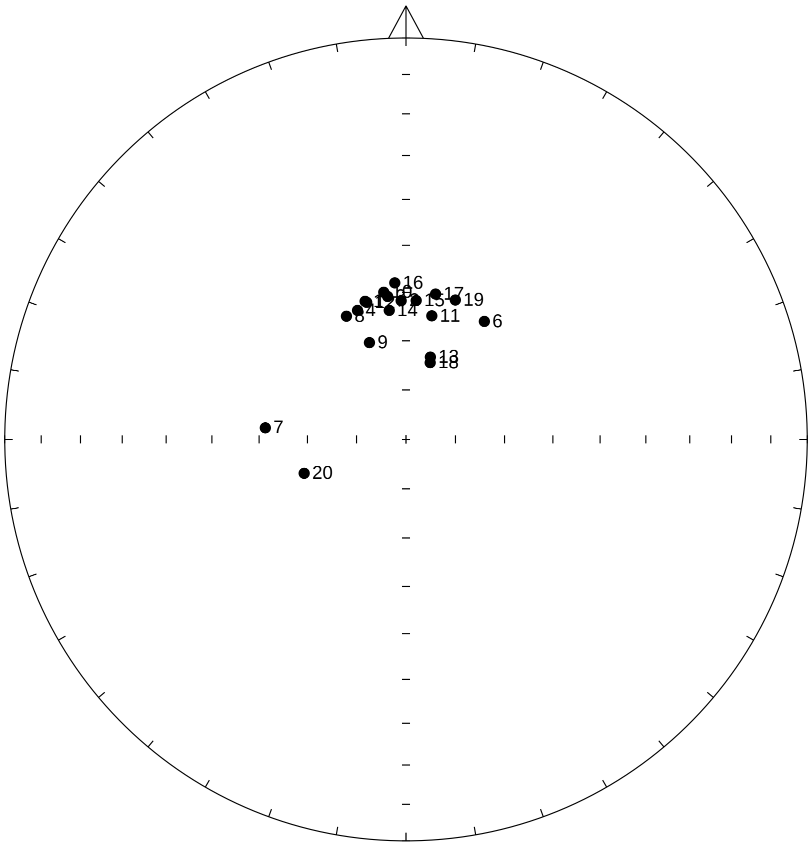
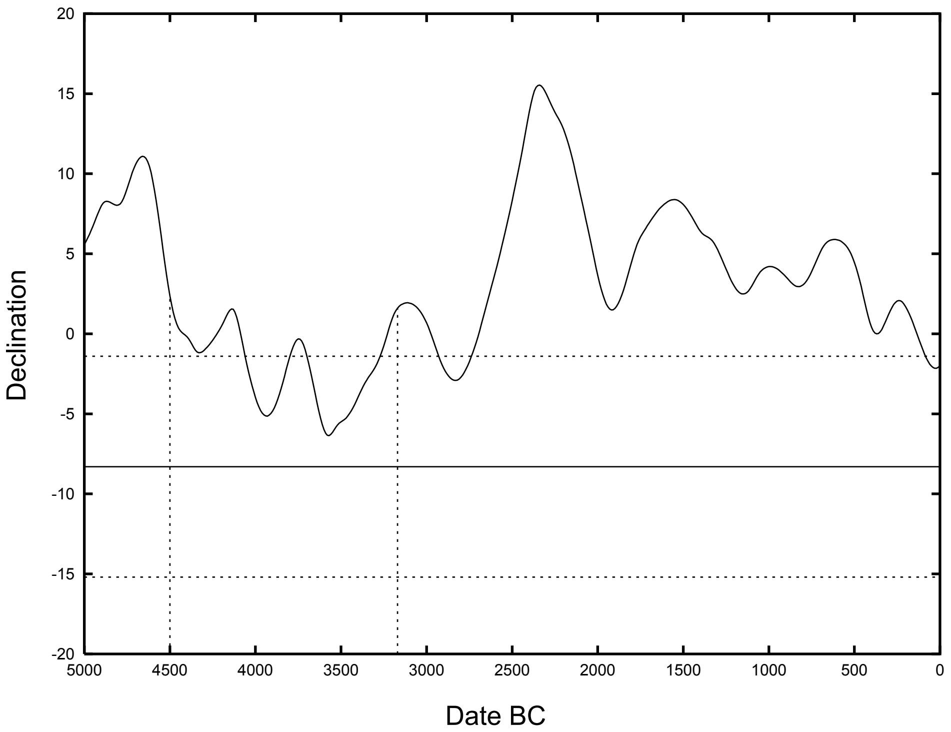


Figure 4: a) Distribution of NRM directions of samples from feature RM represented as an equal area stereogram. In this projection declination increases clockwise with zero being at 12 o'clock while inclination increases from zero at the equator to 90 degrees in the centre of the projection. Open circles represent negative inclinations. b) Distribution of thermoremanent directions of magnetisation of the same samples after partial AF demagnetisation.

a)



b)

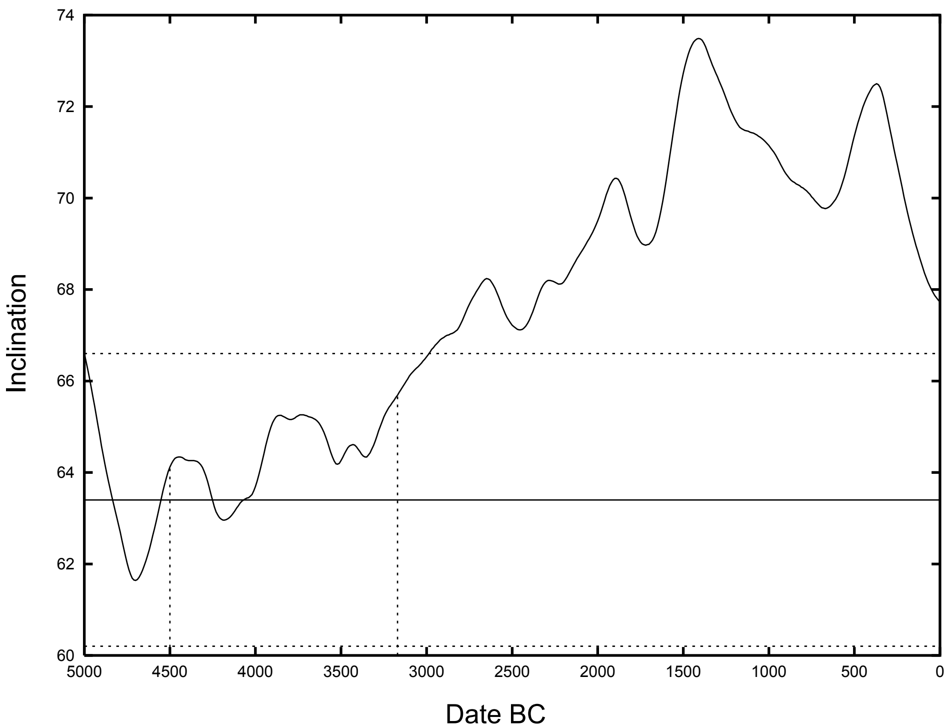
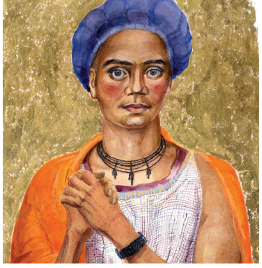


Figure 5: Comparison of the mean characteristic remanent magnetisation direction for the Ringlemere hearth, RM, with the CALSK7K archaeomagnetic reference curve. In plots a) and b) the solid horizontal line shows the mean declination and inclination respectively while the dashed horizontal lines depict the 95% confidence limits. The dashed vertical lines indicate the calibrated date range.



ENGLISH HERITAGE RESEARCH DEPARTMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for sustainable management, and to promote the widest access, appreciation and enjoyment of our heritage.

The Research Department provides English Heritage with this capacity in the fields of buildings history, archaeology, and landscape history. It brings together seven teams with complementary investigative and analytical skills to provide integrated research expertise across the range of the historic environment. These are:

- *Aerial Survey and Investigation*
- *Archaeological Projects (excavation)*
- *Archaeological Science*
- *Archaeological Survey and Investigation (landscape analysis)*
- *Architectural Investigation*
- *Imaging, Graphics and Survey (including measured and metric survey, and photography)*
- *Survey of London*

The Research Department undertakes a wide range of investigative and analytical projects, and provides quality assurance and management support for externally-commissioned research. We aim for innovative work of the highest quality which will set agendas and standards for the historic environment sector. In support of this, and to build capacity and promote best practice in the sector, we also publish guidance and provide advice and training. We support outreach and education activities and build these in to our projects and programmes wherever possible.

We make the results of our work available through the Research Department Report Series, and through journal publications and monographs. Our publication Research News, which appears three times a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities. A full list of Research Department Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

For further information visit www.english-heritage.org.uk

ENGLISH HERITAGE