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ARCHAEOMAGNETIC DATING OF FURNACES AND OTHER FEATURES EXCAVATED AT HAGG END AND EWECOTE, BILSDALE, NORTH YORKSHIRE

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ABSTRACT

This report describes the archaeomagnetic investigation of the furnaces and other features excavated at Hagg End and Ewecote in Bilsdale, North Yorkshire. A total of 52 samples were taken from furnace lining and heat affected clay material associated with these features, using the standard disc method. All except one set of the samples showed a stable magnetisation and variously a wide range of magnetic intensities and some scatter in magnetic direction. With one exception which could not be dated, the excavated areas are shown to be medieval, spanning the late 12th Century to the early 15th Century. Although not substantiated archaeologically, there is the possibility of Romano-British dates for three of these areas.

An introduction to archaeomagnetic dating and an explanation of the technical terms used in this report can be found in Appendix 1. The detailed measurements and statistical analyses can be found in Appendix 2.

INTRODUCTION

Oriented archaeomagnetic samples were taken from heat affected material located in two excavated areas at Hagg End and two at Ewecote.

The objectives were:

- to investigate the suitability of fired material from these areas for archaeomagnetic dating,
- to provide a date for the last use of each of these areas.

The sampling and measurement was undertaken by Alan Powell at the request of Dr. Gerry McDonnell as part of the continuing study into the iron smelting activities in Bilsdale.

ARCHAEOLOGICAL CONTEXT

The iron smelting activities of the Cistercian monks from Rievaulx Abbey is well documented. The Hagg End and Ewecote sites were excavated during July, 2003, as part of a University of Bradford undergraduate field school investigating evidence of further smelting and other activities shown through geophysical surveys of the area carried out in 2002 and 2003. In particular, the survey of the Ewecote site indicated not only an iron smelting furnace but also a single high value magnetic anomaly which was interpreted as a possible glass working furnace.

The Hagg End site is located at SE56859260 on a flood bank 20 m west of the R. Seph and approximately 2 km NNE of Laskill Farm off the B1257 Helmsley to Stokesley road. Ewecote is situated about 1½ km N of Laskill Farm on the 165 m contour above and to the west of the same river; Trench 1 furnace feature is at SE56459207 and Trench 2 iron smelting furnace is next to Lincoln Slack at SE56459215. Figure 1 is a map of Bilsdale showing the location of the two sites, and Figures 2 to 5 are photographs showing where the samples were taken for archaeomagnetic dating.

SAMPLING

A total of 52 samples were taken from cleaned horizontal surfaces within the excavated areas listed in Table 1 using the standard disc method (see Appendix 1):

Hagg End — HE03 Trench 1 contexts 135-141: 9 samples each from furnace lining material and heat affected clay (Figure 2);

HE03 Trench 1 context 104: 9 samples from heat affected clay (Figure 3);

Ewecote — EC03 Trench 1: 4 samples from vitrified lining material and 6 from heat affected clay (Figure 4);

EC03 Trench 2: 4 samples from furnace lining material and 11 from heat affected clay (Figure 5).

Samples were north-oriented using a magnetic compass; none of the samples were observed to have a localised magnetic anomaly within the sample material which would have deflected the magnetic compass needle away from the geomagnetic field.

MEASUREMENT

The direction of remanent magnetisation of all samples was measured using a Molspin fluxgate spinner magnetometer and listed in Appendix 2 as the natural remanent magnetism (NRM) measurements. The stability of the magnetisation of the samples from each feature was investigated by the stepped alternating field (a.f.) demagnetisation of pilot samples in fields of 2.5, 5, 7.5, 10, 15, 20, 30, 40, 60, 80, and 100 mT (peak applied field), with the remanence being measured after each step (Appendix 2). These pilot samples, 13 in total, were chosen for three reasons: their declination and inclination values represented the spread of magnetic directions exhibited by all the samples in each set, their initial magnetic intensities were sufficiently high enough to obtain meaningful results and they were spread physically over each of the areas under investigation. From a study of the pilot sample behaviour, specific alternating fields were chosen to provide a series of data for each sample set which when analysed would give the optimum removal of the less stable components, leaving the magnetisation of archaeological interest. The sample remanences were remeasured in turn after partial demagnetisation (Appendix 2).

RESULTS

The results of the magnetic properties analysis are summarised in Table 1.

The intensity of NRM varied considerably across the four excavated areas, possibly reflecting the variation in sample size, inhomogeneous firing or varying concentrations of remanence-carrying minerals. All samples had a strong enough magnetisation to be measurable.

The stepped a.f. demagnetisation of the pilot samples demonstrated that all the heat affected material sampled had some viscous remenance in addition to a single component probably associated with the geomagnetic field at the time of the materials' last cooling. The intensity spectra (Appendix 2) are all similar in shape, except for HE03 Trench 1 context 104 samples 2 and 4, and EC03 Trench 1 sample 9 (which is probably due to local inconsistencies in the remanence-carrying material), but have varying median destructive fields (mdf) ranging from 8 to 34 mT with an average value of 17 mT, suggesting materials which could be regarded generally as being magnetically "soft".

The stability index (SI), as defined by Tarling and Symons (1967), was calculated for all the pilot samples; the results suggest that the heat affected material across the site was on the whole was magnetically stable, with only one sample showing poor stability.

The initial sample scatter plots (Appendix 2) indicate a wide variation of individual sample magnetic directions. Each of the pilot samples was subjected to the full range of a.f. demagnetisation fields, and both intensity spectra and Zijderveld plots constructed (Appendix 2). The reasons for the magnetic behaviour of each pilot sample are speculative and may be difficult to explain, but could include variations in the mineral content of the basic clay material and the way it has reacted to the heating/cooling cycles to which it was subjected.

Scatter plots were constructed to show the clustering of samples after demagnetisation (the applied fields varied according to the sample set). In three of the four sets of data, the scatter of the magnetic directions reduced. For HE03 Trench 1 context 104, the very wide initial scatter did not improve with demagnetisation. Mean values of declination and inclination, and the errors at both the 68% and 95% confidence levels, (α_{68}) and (α_{95}), were calculated for all sets of demagnetisation data.

Comparison of corrected mean values of declination and inclination and α_{95} for all sets of demagnetisation data indicated the most appropriate demagnetisation results to be used in providing the optimum α_{95} for each of the excavated areas.

DATING OF MAGNETIC DIRECTION

The mean declination and inclination for each of the excavated areas were corrected to Meriden, the reference locality for the British calibration curve, using the standard method (Noel and Batt, 1990). The corrected mean site directions were then dated by comparison with the Clark calibration curve in the conventional manner (see Appendix 1) and shown in Figures 6 to 8. A summary of the results is given in Table 2.

In archaeomagnetic dating it is often necessary to give multiple possible date ranges as the earth's magnetic field has had the same direction at different times in the past. The corrected mean directions can be applied to both upper and lower calibration curves. Although there is a possibility that HE03 Trench 1 iron smelting furnace and EC03 Trenches 1 and 2 excavated areas are Romano-British in date, it is unlikely given the archaeological evidence from the site.

Two medieval date ranges at α_{95} are shown for the HE03 Trench 1 iron smelting furnace: 1160 to 1320 and 1380 to 1470. Both the mean corrected direction mid-point of 1270 and the archaeological evidence suggest that the 1160 to 1320 date range is the more probable.

As the α_{95} for HE03 Trench 1 context 104 demagnetisation results had not improved sufficiently compared to the original NRM α_{95}, remaining high and well outside the acceptable gradings defined by Tarling and Dobson (1995), it is not possible to apply the corrected mean directions of this area to the Clark calibration curve and produce a reliable date range.

The optimum α_{95} of ±6.33° for EC03 Trench 1, being just above the Tarling and Dobson (1995) acceptable grading level, results in data which is not reliable enough to produce a date range. The corresponding α_{68} of ±3.29° indicates medieval date ranges of 1260 to 1330 and 1370 to 1430.

A single wide medieval date range at α_{95} of 1250 to 1430 is derived for the EC03 Trench 2 iron smelting furnace, with a mid-point of 1390. The corresponding α_{68} ranges are shown as 1320 to 1330 and 1370 to 1420. Comparison of the date ranges indicates that the EC03 furnace features could be contemporary.

SUMMARY AND CONCLUSIONS

- All of the samples were measurable and exhibited a wide range of magnetic intensities.
- In general, stable magnetism was recorded, consistent with previous heating above the Curie temperature.
- The results showed the heat affected material was suitable for archaeomagnetic dating and did provide a record of the geomagnetic field at the time of last cooling, with one exception.
- This exception is HE03 Trench 1 context 104. It is considered that the material from this area is either the remains of an *in-situ* but highly disturbed hearth or the deposited remains of a furnace and/or heat affected clay, and as such is undatable.
- The data for HE03 Trench 1 and EC03 Trench 2 iron smelting furnaces indicate multiple date ranges. Given the archaeological evidence from furnace construction and slag morphology, it is probable that these areas are medieval in date, spanning the periods 1160 to 1320 and 1250 to 1430, respectively. The mid-point dates show a century difference between the operation of these two features, but the multiple date ranges suggest contemporary use.
- Although it is not possible to date EC03 Trench 1 reliably, there is the possibility that it is contemporary with its neighbouring Trench 2.

- HE03 Trench 1 iron smelting furnace and the EC03 features may be Romano-British, although this is unlikely due to the lack of archaeological evidence.

SITE CONTACT

Dr. Gerry McDonnell,
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University of Bradford.

EXCAVATED AREA	MAGNETIC PROPERTIES SUMMARY
Hagg End HE03 Trench 1 Iron smelting furnace Contexts 135-141	18 samples. Magnetic intensities: range 14.3 to 1991.5 mA m^{-1}, 8 values up to 100 mA m^{-1}, 3 over 1000 mA m^{-1}, mean 530.1 mA m^{-1}. 4 pilot samples. Some evidence of viscosity. Intensity spectra similar: average mdf = 16 mT. Material magnetically relatively "soft", one pilot sample material "harder". Stability Index: material stable to very stable. Initial plot shows some scatter particularly in inclination, with one outlier. A.f. demagnetisation in 2.5, 5 & 7.5 mT fields; 2.5 mT data chosen for final calculations with one exception (7.5 mT data). α_{95} optimised to ±3.88°, with 4 samples excluded.
Hagg End HE03 Trench 1 Hearth/burnt material feature Context 104	9 samples. Magnetic intensities: range 13.5 to 1313.2 mA m^{-1}, majority of values less than 100 mA m^{-1}, 3 values over 200 mA m^{-1}, mean 170.0 mA m^{-1}. 3 pilot samples. Evidence of viscosity. Considerable differences between intensity spectra: 8 to 34 mT, average mdf = 22 mT. Material magnetically mixed relatively "soft" to "hard". Stability Index: material poorly stable to stable. Initial plot shows a wide variation in scatter. A.f. demagnetisation in 2.5, 5, 7.5 & 10 mT fields; 2.5 mT data chosen for final calculations. α_{95} optimised to ±34.33°, with 4 samples excluded.
Ewecote EC03 Trench 1 Furnace feature Contexts 104, 124-127	10 samples. Magnetic intensities: range 7.2 to 971.0 mA m^{-1}, mean 304.5 mA m^{-1}. 3 pilot samples (3, 6 & 9). Some evidence of viscosity in samples 3 & 6; sample 9 appears to be unstable. Intensity spectra of samples 3 & 6 very similar; spectrum of sample 9 different possible due to unstable magnetic material: average mdf = 14 mT. Material magnetically relatively "soft". Stability Index: samples 3 & 6 material very stable, sample 9 material poorly stable. Initial plot shows wide scatter particularly in inclination, with 2 outliers. A.f. demagnetisation in 5, 7.5 & 10 mT fields; 5 mT data chosen for final calculations. α_{95} optimised to ±6.33°, with 5 samples excluded.
Ewecote EC03 Trench 2 Iron smelting furnace	15 samples. Magnetic intensities: range 5.1 to 945.2 mA m^{-1}, 4 values over 100 mA m^{-1}, mean 122.6 mA m^{-1}. 3 pilot samples. Evidence of viscosity. Intensity spectra similar: average mdf = 18 mT. Material magnetically relatively "soft" to "hard". Stability Index: material stable to very stable. Initial plot shows wide scatter in both declination and inclination. A.f. demagnetisation in 5, 7.5 & 10 mT fields; a combination of demagnetisation data chosen for final calculations. α_{95} optimised to ±4.50°, with 7 samples excluded.

Table 1. Summary of magnetic properties analysis.

EXCAVATED AREA	CONFIDENCE LEVEL		MEAN CORRECTED		DATE	
			DECLINATION	INCLINATION	MID-POINT	RANGE
Hagg End HE03 Trench 1 Iron smelting furnace Contexts 135-141	α_{95}	±3.88°	6.88°	60.10°	**1270** 270	**1160 - 1320** 1380 - 1470 200 - 400
	α_{68}	±2.30°			1270 270	1230 - 1300 1400 - 1440 260 - 290
Hagg End HE03 Trench 1 Hearth/burnt material feature Context 104	α_{95}	±34.33°	16.21°	52.45°	**-**	-
	α_{68}	±17.63°			-	-
Ewecote EC03 Trench 1 Furnace feature Contexts 104, 124-127	α_{95}	±6.33°	2.59°	57.54°	1400 240	1160 - 1460 160 - 400
	α_{68}	±3.29°			 1400 240	1260 - 1330 1370 - 1430 210 - 280
Ewecote EC03 Trench 2 Iron smelting furnace	α_{95}	±4.50°	1.20°	57.01°	**1390** 240	**1250 - 1430** 200 - 280
	α_{68}	±2.59°			1390 240	1320 - 1330 1370 - 1420 220 - 270

Table 2. Summary of dating results, with the most probable date range at a 95% confidence level shown in bold for each excavated area, where appropriate.

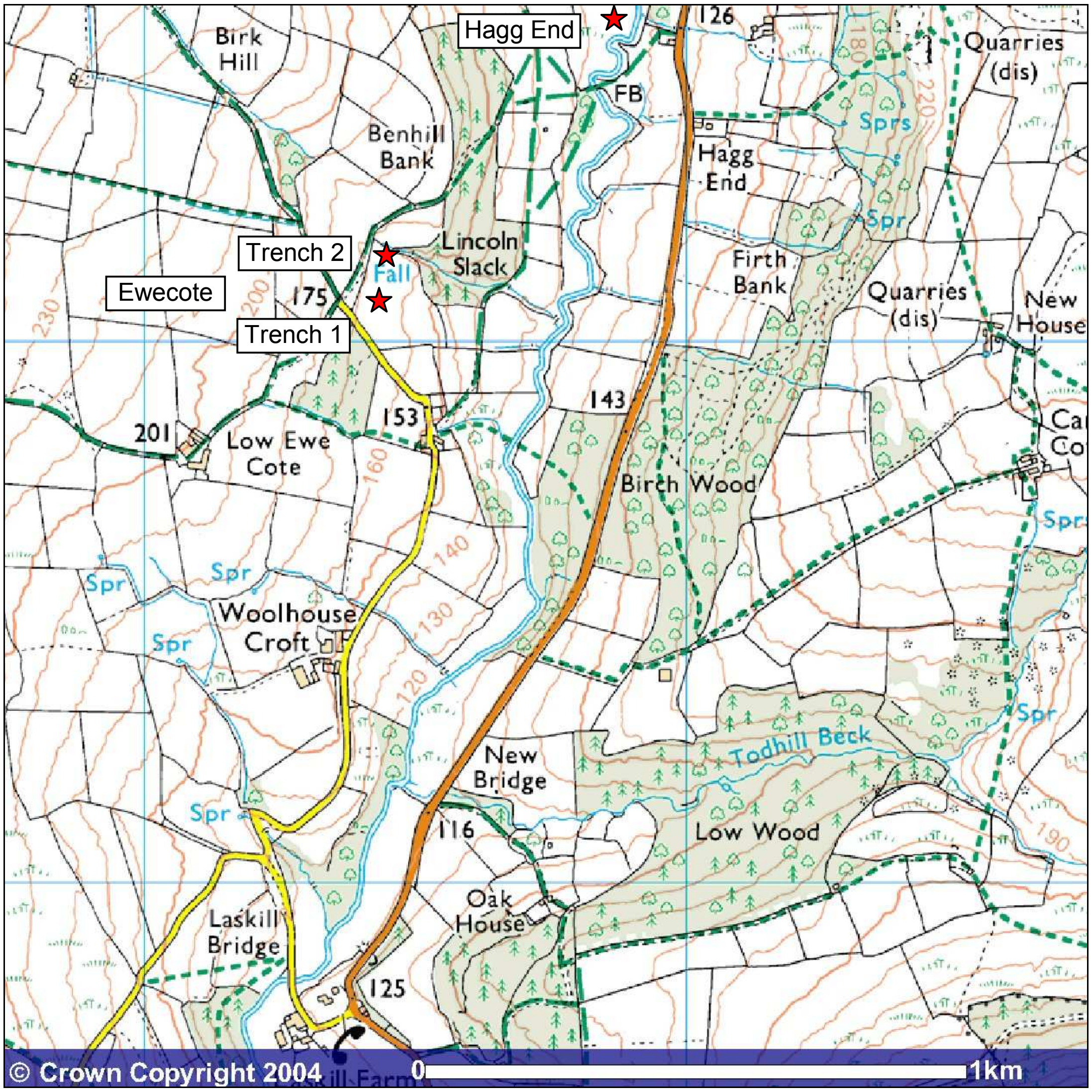

Figure 1. Location of the Hagg End and Ewecote sites in Bilsdale, N. Yorkshire.

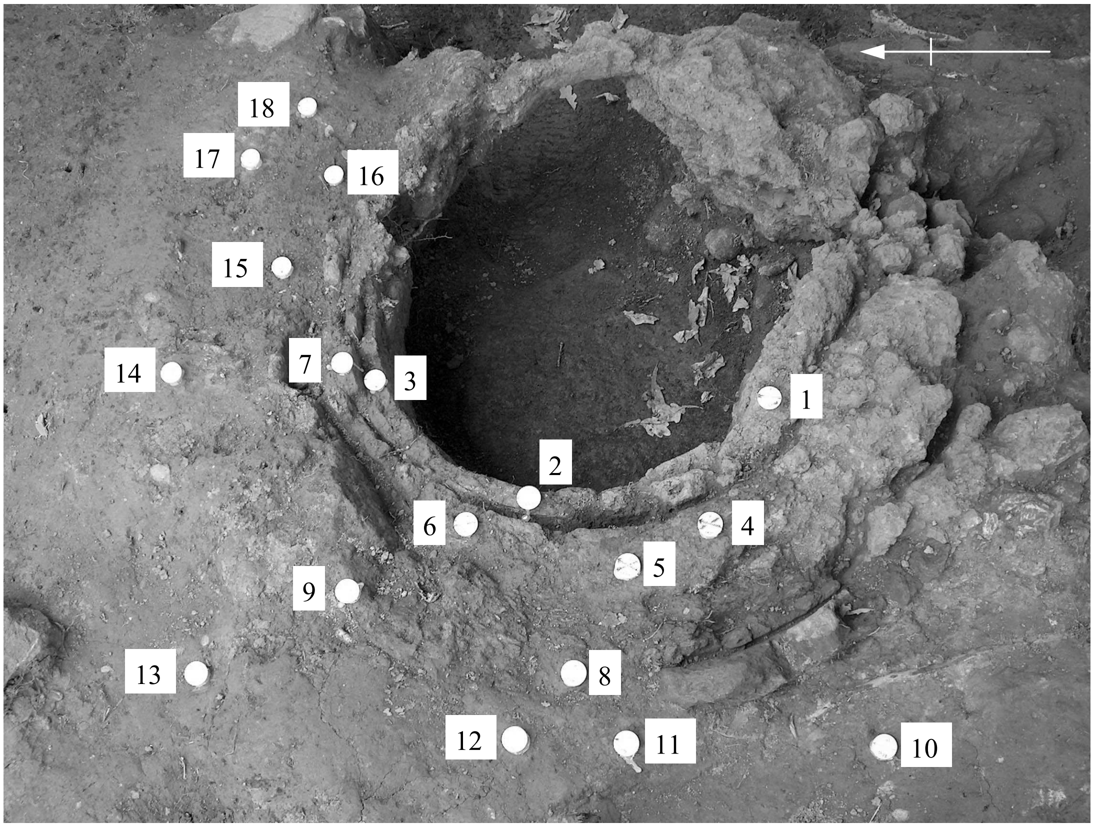

Figure 2. Hagg End, Bilsdale, N. Yorks.: Trench 1 iron smelting furnace (contexts 135 to 141) archaeomagnetic dating sampling points.

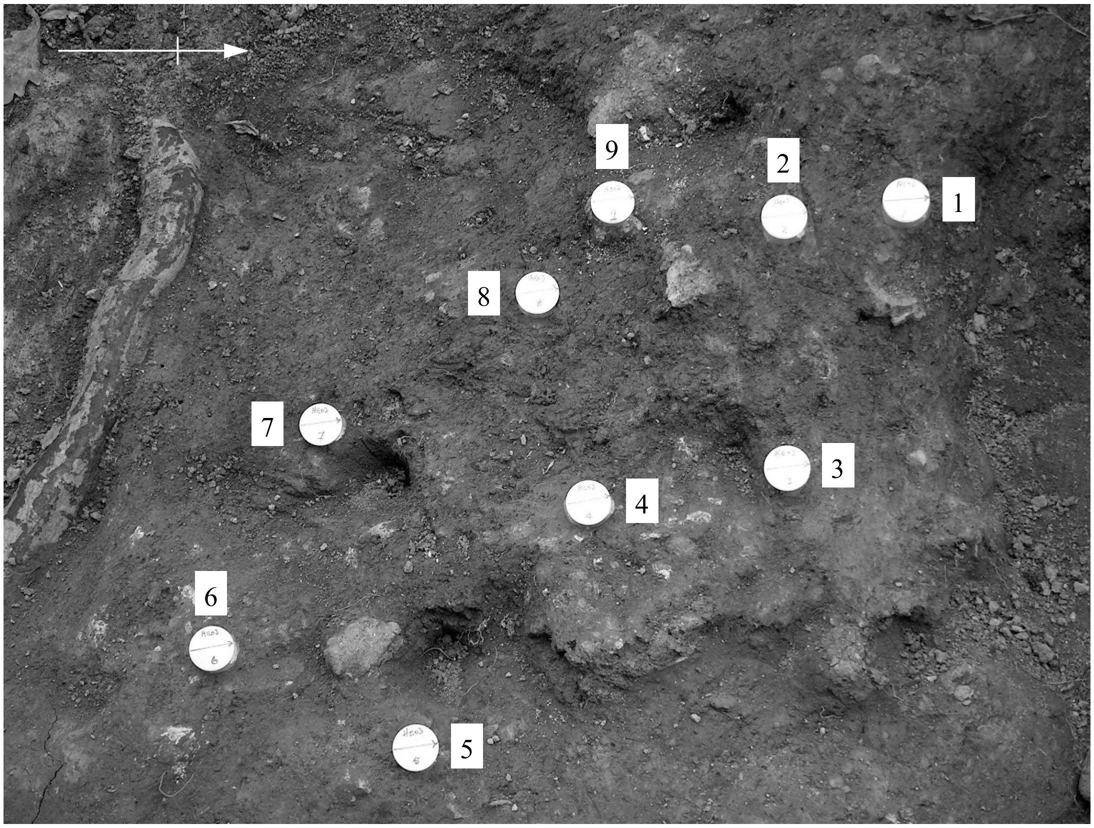

Figure 3. Hagg End, Bilsdale, N. Yorks.: Trench 1 hearth feature (context 104) archaeomagnetic dating sampling points.

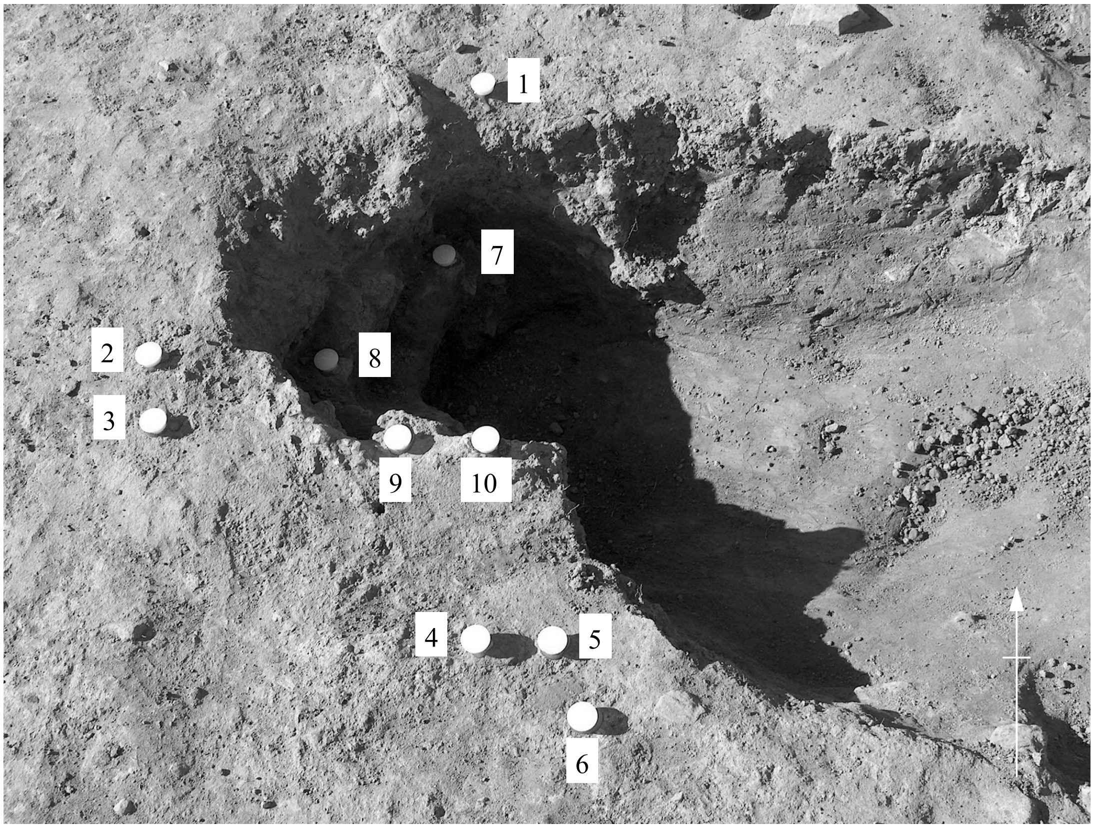

Figure 4. Ewecote, Bilsdale, N. Yorks.: Trench 1 furnace feature archaeomagnetic dating sampling points.

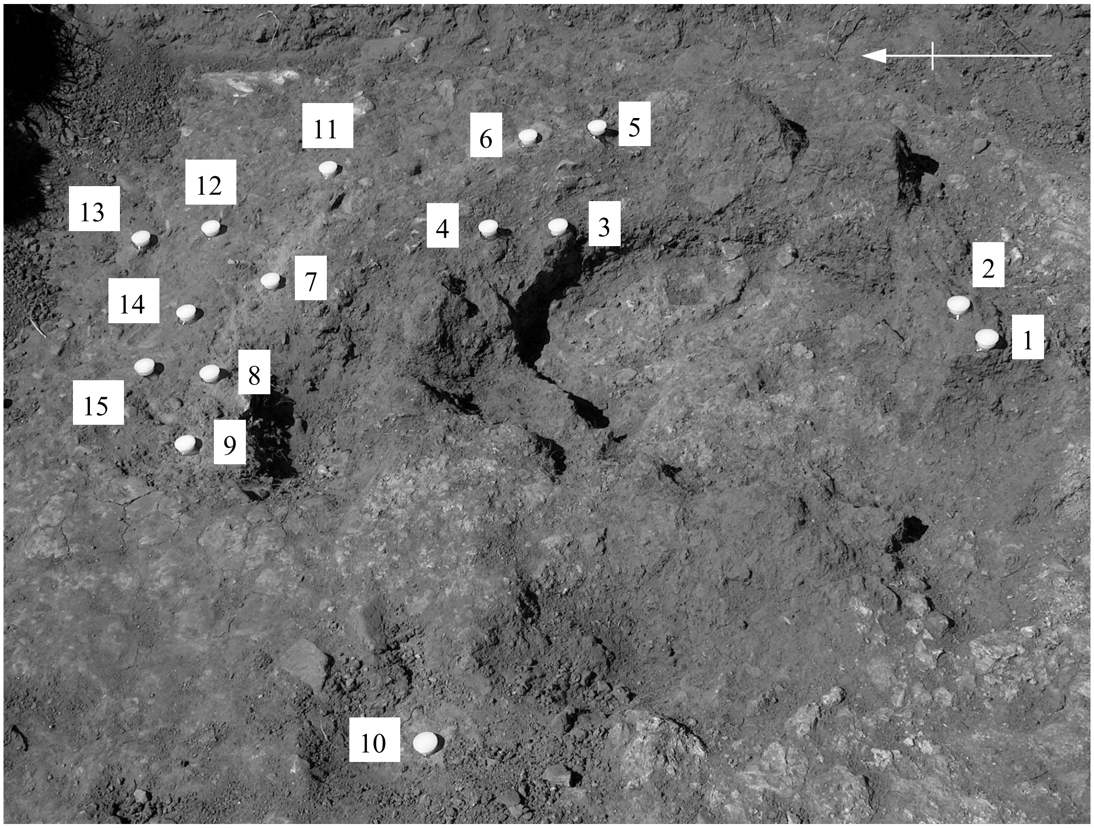

Figure 5. Ewecote, Bilsdale, N. Yorks.: Trench 2 iron smelting furnace archaeomagnetic dating sampling points.

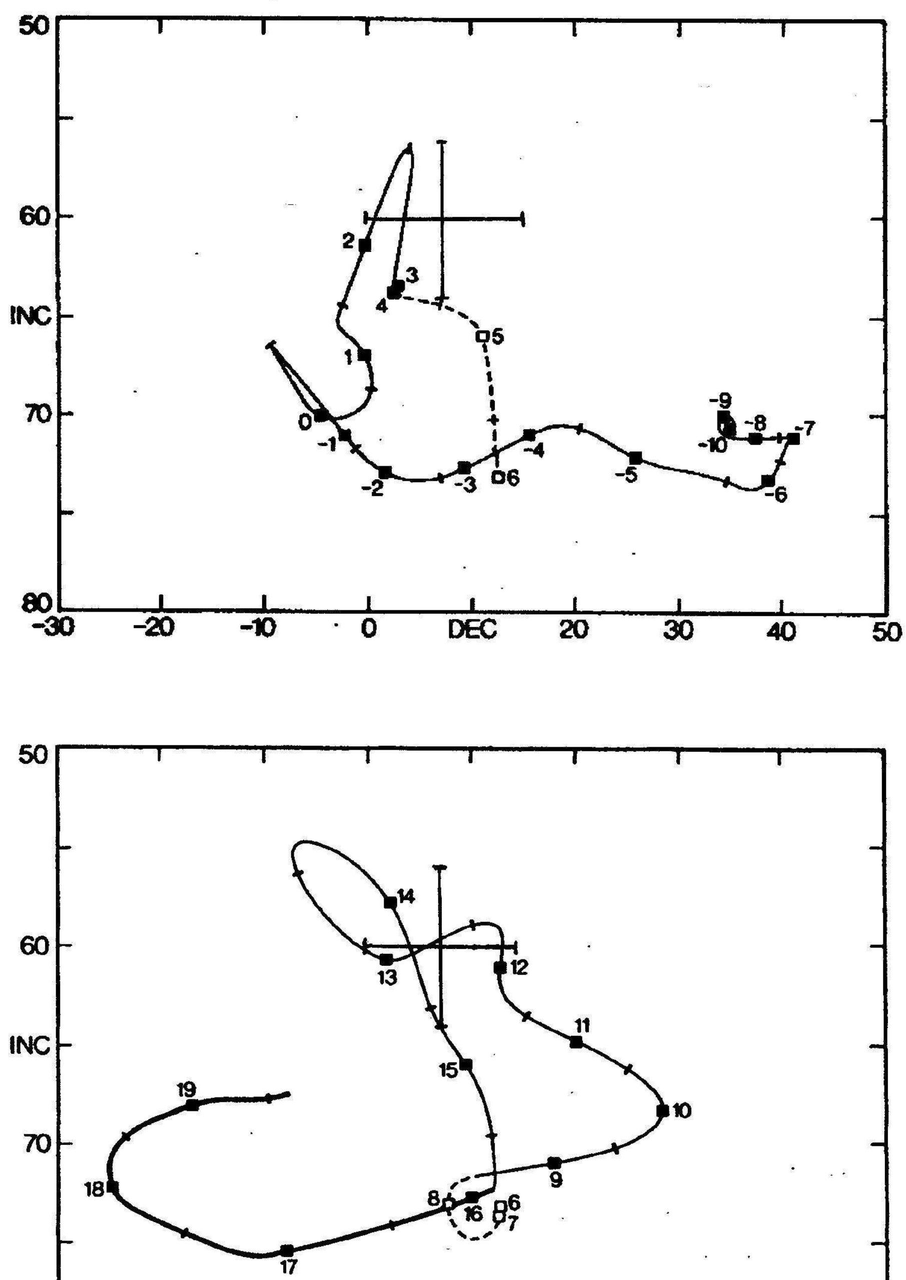

Figure 6: Corrected mean remanence vectors for the Hagg End HE03 Trench 1 iron smelting furnace together with 95% confidence level errors, superimposed on the British archaeomagnetic calibration curve (Clark *et al.*, 1988), normalised to Meriden, showing (upper) 1000BC-AD600 and (lower) AD600-AD1975.

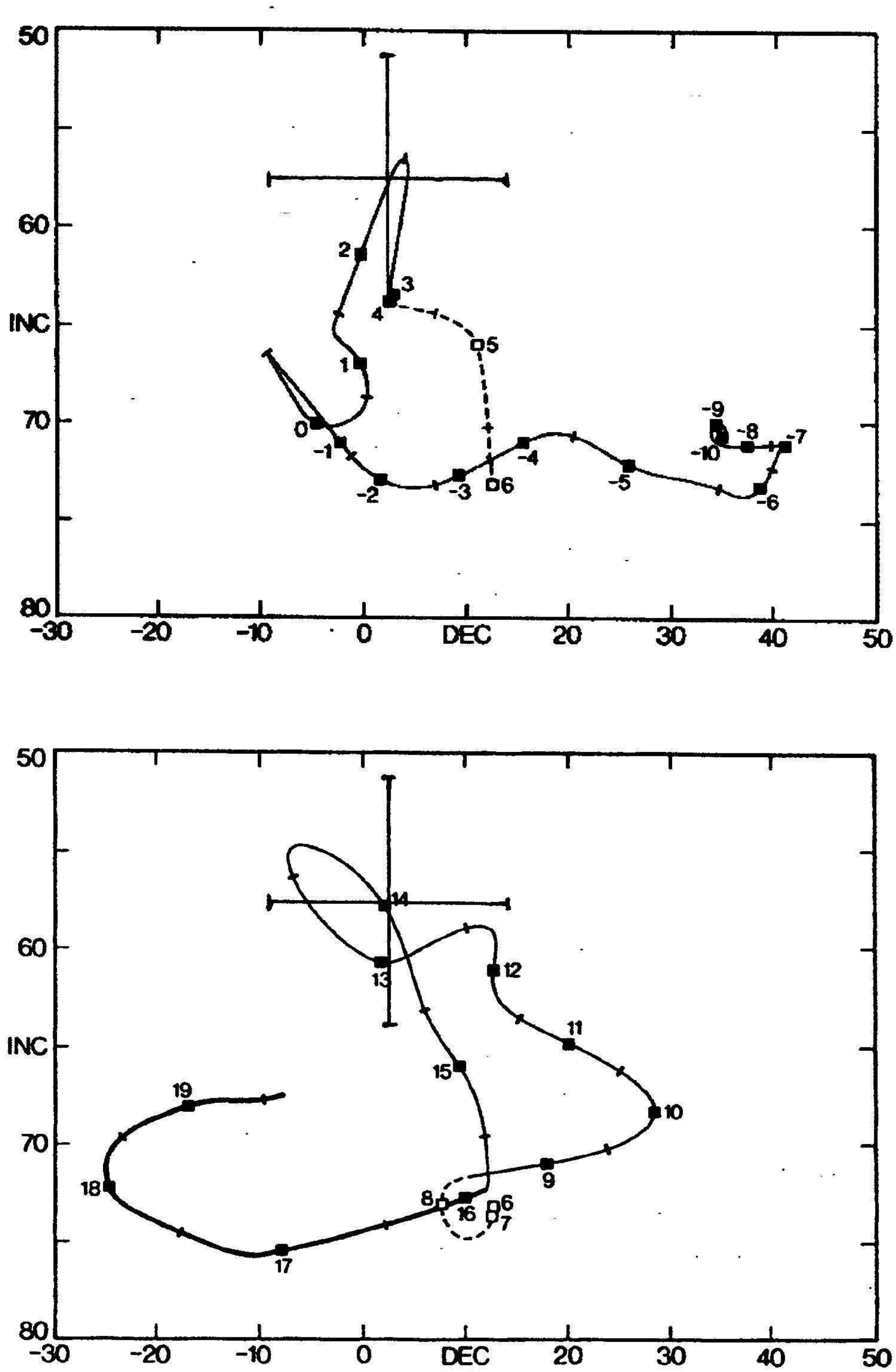

Figure 7: Corrected mean remanence vectors for the Ewecote EC03 Trench 1 furnace feature together with 95% confidence level errors, superimposed on the British archaeomagnetic calibration curve (Clark *et al.*, 1988), normalised to Meriden, showing (upper) 1000BC-AD600 and (lower) AD600-AD1975.

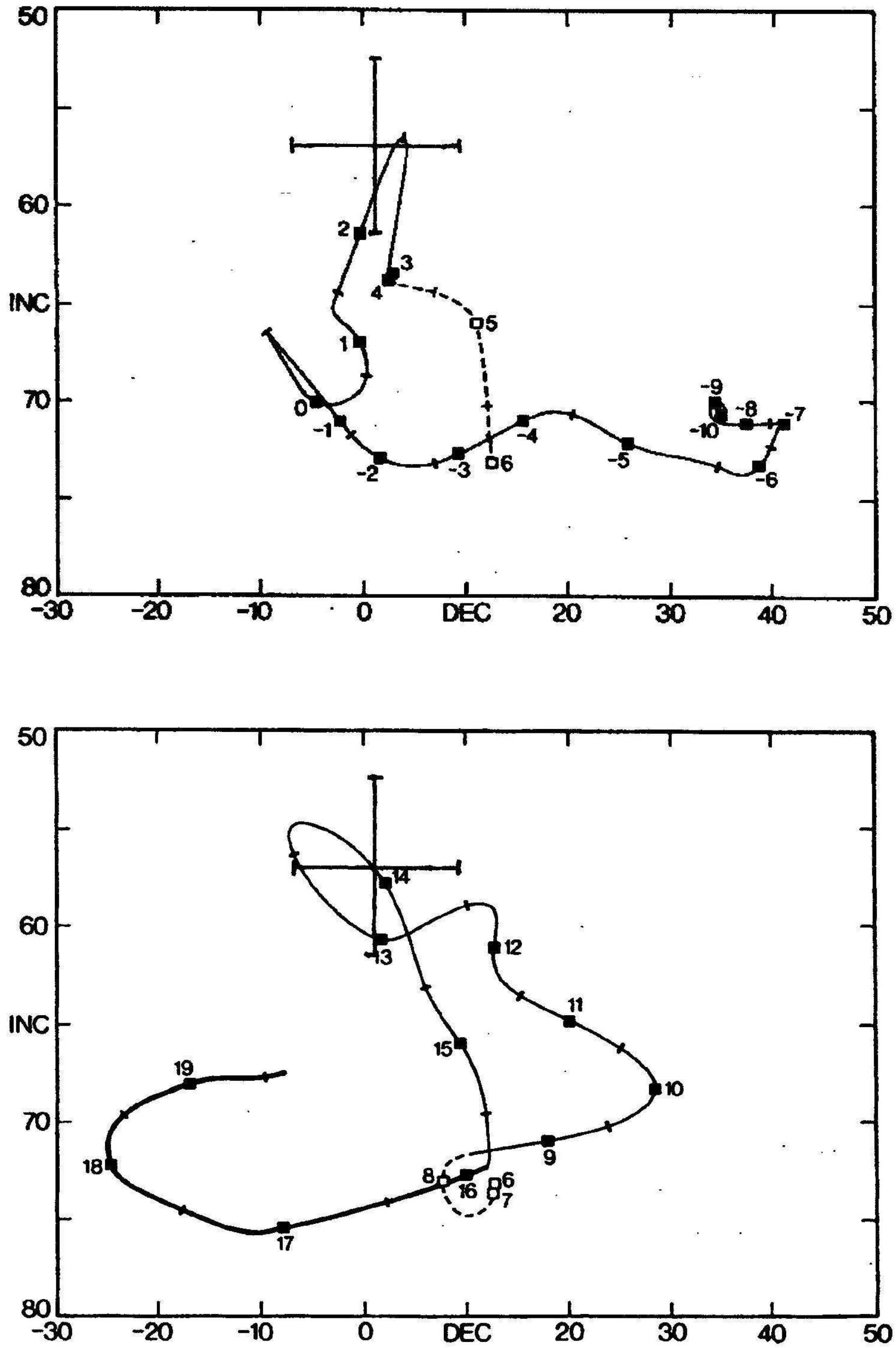

Figure 8: Corrected mean remanence vectors for the Ewecote EC03 Trench 2 iron smelting furnace together with 95% confidence level errors, superimposed on the British archaeomagnetic calibration curve (Clark *et al.*, 1988), normalised to Meriden, showing (upper) 1000BC-AD600 and (lower) AD600-AD1975.

APPENDIX 1: AN INTRODUCTION TO ARCHAEOMAGNETIC DATING

PRINCIPLES

Archaeomagnetic dating is based on a comparison of the ancient geomagnetic field, as recorded by archaeological materials, with a dated record of changes in the Earth's field over time in a particular geographical area. The geomagnetic field changes both in direction (declination and inclination) and in strength (intensity) and archaeomagnetic dating can be based on either changes in direction or intensity or a combination of the two. Dating by direction requires the exact position of the archaeological material in relation to the present geomagnetic field to be recorded, and so material must be undisturbed and sampled *in situ*. Dating by intensity does not require *in situ* samples but is less precise and experimentally more difficult. The laboratory at Bradford uses archaeomagnetic dating by direction.

SUITABLE MATERIALS FOR DATING

For an archaeological material to be suitable for dating using magnetic direction, it must contain sufficient magnetised particles and an event must have caused these particles to record the Earth's magnetic field. Many geologically derived materials e.g. soils, sediments, clays, contain sufficient magnetic minerals. There are primarily two types of archaeological event which may result in the Earth's magnetic field at a particular moment being recorded by archaeological materials: heating and deposition in air or water.

If materials have been heated to a sufficiently high temperature (>600°C) they may retain a thermoremanent magnetisation (TRM) which reflects the earth's magnetic field at the time of last cooling. Suitable archaeological features would include hearths, kilns and other fired structures.

Sediments may acquire a datable detrital remanent magnetisation (DRM) from the alignment of their magnetic grains by the ambient field during deposition. Such an effect allows deposits in wells, ditches and streams to be dated. However, this aspect of archaeomagnetic dating is still under development, as factors such as bioturbation and diagenesis, can cause post-depositional disturbance of the magnetisation.

Archaeomagnetic dating can be applied to features expected to date from 1000BC to the present day, as this is the period covered by the calibration curve. However, as discussed below the precision of the date obtained will vary according to the period being dated.

SAMPLING

Samples of robust fired materials are taken by attaching a 25mm diameter flanged plastic reference disc to a cleaned, stable area of the feature using a fast setting epoxy resin (Clark *et al*, 1988). The disc is levelled, using a bubble spirit level, and held in place with a small bead of plasticine while the resin sets. The direction of north is then marked on using a magnetic compass, sun compass or gyrotheodolite and the disc removed with a small part of the feature attached to it. In the laboratory, samples are trimmed and if necessary consolidated with a solution of 10% polyvinylacetate in acetone. Sediments and friable fired materials are sampled by insertion of a 2 cm diameter plastic cylinder, onto which the direction of north is marked. Magnetometers used are sufficiently sensitive for only small samples (c. $1cm^3$) to be required; approximately 12 to 15 samples are needed from each feature and it may be possible to select sampling location to minimise the visual impact, if the feature is to be preserved.

LABORATORY MEASUREMENTS

In the laboratory a spinner magnetometer is used to measure the remanent magnetisation of each sample (Molyneux, 1971). This measurement indicates the relative strength and direction of the magnetic field of the sample. The stability of this magnetisation is then examined by placing the sample in alternating magnetic fields of increasing strength and removing the magnetisation step-by-step. The demagnetisation measurements allow removal of any less stable magnetisations acquired after the firing or deposition event, leaving the magnetisation of archaeological interest. The magnetic stability of a sample can be demonstrated by a demagnetisation curve (intensity spectrum) or a Zijderveld plot. The results of measurements of the direction of magnetisation of a group of samples are represented on a stereographic plot, which shows declination as an angle measured clockwise from north and inclination as a distance from the perimeter; alternatively the results can be shown on a scatter plot of the angles of declination and inclination for each sample.

STATISTICAL ANALYSIS

The magnetic directions from a number of samples expected to have the same date are combined to give a mean direction, the precision of which is defined using Fisherian statistics (Fisher, 1953). α_{95} represents a 95% probability that the true direction lies within that cone of confidence around the observed mean direction, and would be expected to be less than 5° for dating purposes. A value larger than this indicates that the magnetic directions of the samples are scattered and therefore do not all record the same magnetic field. The stability of magnetisation of an individual sample on demagnetisation is quantified using the Stability Index (Tarling and Symons, 1967). For a stable magnetisation this value would be expected to be greater than 2.5, a value less than this would indicate that the recorded magnetisation was not reliable for dating purposes.

CALIBRATION OF DATES

Once a stable, mean magnetic direction has been obtained this is dated by comparing it with a calibration curve showing changes in the Earth's field over time. The calibration curve is compiled from direct measurements of the field, which extend back to AD1576 in Britain, and from archaeomagnetic measurements from features dated by other methods. Because the geomagnetic field changes spatially, data for the calibration curve can only be drawn from within an area approximately 1000km across and all magnetic directions must be corrected mathematically to a central location (Noel and Batt, 1990). There is a single calibration curve for England, Scotland and Wales and directions are corrected to Meriden (52.43°N, 1.62°W). Conventionally British archaeomagnetic dates are calibrated by visual comparison to the calibration curve produced by Clark *et al*. (1988). However, this method takes no account of the errors in the calibration curve itself and an alternative method is also used (Batt, 1997). The latter method gives a larger error margin on the date but is a better reflection of the actual error.

PRECISION OF DATES

There are a number of factors that will influence the error margins of the dates obtained:

- differential recording of the field by different parts of the feature
- disturbance of the material after firing / deposition
- uncertainties in sampling and laboratory measurements
- error margins in the calibration curve itself
- uncertainties in the comparison of the magnetic direction with the calibration curve
- spatial variation of the geomagnetic field

The precision of the calibration curve varies according to the archaeological period and so the precision of the date obtained will depend on the archaeological date. As the geomagnetic field has occasionally had the same direction at two different times, it is also possible to have two or more alternative dates for a single feature. In most cases the archaeological evidence can be used to select the most likely.

Given the number of different factors it is not possible to give a general figure for the precision of archaeomagnetic dates but there will be an error margin of at least ±25 years. It is important to note that, since the method relies on the reliability of previously dated sites, the calibration curve can be improved as more measurements become available.

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Tarling, D.H. and Symons, D.T.A. (1967). A stability index of remanence in palaeomagnetism. *Geophys. J. R. astr. Soc.* **12**, 443-448.

FURTHER READING

For general information on scientific dating methods:

Aitken, M.J. (1990). *Science-Based Dating in Archaeology.* London: Longman.

For details of wider applications of magnetic studies:

Oldfield, F. (1991). Environmental magnetism - a personal perspective. *Quaternary Science Reviews* **10**, 73-85.

For an international perspective on archaeomagnetic dating:

Eighmy, J.L. and Sternberg, R.S. (1990). *Archaeomagnetic Dating.* Tucson: The University of Arizona Press.

For details of the principles and geological applications:

Tarling, D.H. (1983). *Palaeomagnetism*. London: Chapman and Hall.

APPENDIX 2: DETAILED MEASUREMENTS AND STATISTICAL ANALYSES

INCORPORATES:

- Site information
- Magnetic measurements
- Statistics for NRM
- Statistics for partial demagnetisation
- Statistics for corrections, final result and errors
- Scatter plots for NRM and demagnetised samples
- Pilot demagnetisation measurements and plots

FOR EACH OF THE FOLLOWING EXCAVATED AREAS:

- Hagg End HE03 Trench 1 contexts 135-141: iron smelting furnace
- Hagg End HE03 Trench 1 context 104: hearth/burnt material feature
- Ewecote EC03 Trench 1 contexts 104, 124-127: furnace feature
- Ewecote EC03 Trench 2: iron smelting furnace