UNIVERSITY OF BRADFORD
DEPARTMENT OF ARCHAEOLOGICAL SCIENCES

ARCHAEOMAGNETIC DATING OF IRON SMELTING FEATURES EXCAVATED AT STINGAMIRES, BILSDALE, NORTH YORKSHIRE

A.J. Powell

Department of Archaeological Sciences
University of Bradford
Bradford BD7 1DP

September 2004

ARCHAEOMAGNETIC DATING OF IRON SMELTING FEATURES EXCAVATED AT STINGAMIRES, BILSDALE, NORTH YORKSHIRE

A.J. Powell
Department of Archaeological Sciences
University of Bradford
Bradford BD7 1DP
Tel. (01274) 233531 Email: a.j.powell3@bradford.ac.uk

ABSTRACT

This report describes the archaeomagnetic investigation of the iron smelting features excavated at Stingamires in Bilsdale, North Yorkshire. A total of 41 samples were taken from the furnace lining material and heat affected clay associated with the features found in Trenches 1 (ore roasting area) and 2 (iron smelting bloomery furnace), using the standard disc method. All of the samples showed a high degree of stable magnetisation, and variously a wide range of magnetic intensities and some scatter in magnetic direction. Both excavated features are dated to the medieval period: Trench 1 to the latter half of the 14th Century, and Trench 2 to the 13th Century.

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 the heat affected material located in two excavated areas at Stingamires: Trench 1 (ore roasting area) and Trench 2 (iron smelting bloomery furnace).

The objectives were to:

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

The sampling and measurement programme 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 Stingamires site was excavated during September, 2004, investigating evidence of further smelting and other activities shown through geophysical surveys of the area carried out earlier in the year. The magnetometry survey in particular indicated two separate high value magnetic anomalies which were interpreted as possible iron smelting furnaces. Excavation of these showed one to be a furnace whilst the other was an ore roasting area.

The site is located at SE56459593, adjacent to Stingamires Gill at approximately 165 m AOD and 1.6 km NW of Fangdale Beck. Excavations were conducted in three trenches and of these Trench 1 revealed the ore roasting area and Trench 2 the iron smelting bloomery furnace. Figure 1 is a map of Bilsdale indicating the location of the site, and Figures 2 and 3 are photographs modified to show where the archaeomagnetic dating samples were taken.

SAMPLING

A total of 41 samples were taken from cleaned horizontal surfaces within the excavated areas listed below, using the standard disc method (see Appendix 1):

SM04 Trench 1: 18 samples from the heat affected clay surface material (Figure 2);

SM04 Trench 2: 14 samples from furnace lining material and 9 from heat affected clay (Figure 3).

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. These pilot samples, 9 in total (4 from Trench 1 and 5 from Trench 2), were chosen for three reasons: their declination and inclination values represented the spread of magnetic directions exhibited by all the samples, 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.

RESULTS

The results of the magnetic properties analysis are summarised in Table 1 and detailed in Appendix 2.

The intensity of natural remanent magnetisation varied across the two 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 remanence in addition to a single component probably associated with the geomagnetic field at the time of the materials' last cooling. The intensity spectra are all similar in shape but have varying median destructive fields (mdf) ranging from 14 to 34 mT and an average value of 22 mT, suggesting materials which could be regarded as being magnetically "hard" in comparison with other Bilsdale sites such as Hagg End and Ewecote.

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 as a whole was magnetically stable.

The initial sample stereoplots indicate a moderate to wide variation of individual sample magnetic directions, with one statistically identified outlier in all 41 samples. Each of the pilot samples was subjected to the full range of a.f. demagnetisation fields, and both intensity spectra and Zijderveld plots constructed. 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. Stereoplots were drawn to show the clustering of samples after demagnetisation (the applied fields varied according to the sample set). In both sets of data there was a reduction in the scatter of the magnetic directions.

Mean values of declination and inclination, and the error at the 95% confidence level (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 determining 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 directions were then dated by comparison with the Clark calibration curve in the conventional manner (see Appendix 1) and shown in Figures 4 and 5. A summary of the results are 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. In both cases the upper curve shows that Romano-British activity is unlikely and this supported by the lack of appropriate archaeological evidence on site.

A single medieval date at α_{95} of 1340 to 1390 is derived for the ore roasting area, with a mean date of 1370. Although the mean date is given as 1200, two date ranges at α_{95} are shown in Table 2 for iron smelting furnace: 1140 to 1300 and 1420 to 1480. The latter range is a consequence of the way the calibration curve is drawn in the medieval period and is considered unlikely.

Summary and Conclusions

- All of the samples were measurable and exhibited a wide range of magnetic intensities.
- Stable magnetism was recorded, consistent with previous heating above the Curie temperature.
- The results demonstrated that the heat affected material in both Trenches was suitable for archaeomagnetic dating and did provide a record of the geomagnetic field at the time of the last cooling.
- Both excavated features are dated to the medieval period: Trench 1 ore roasting area to the latter half of the 14th Century, and Trench 2 iron smelting bloomery furnace to the 13th Century (although there is a low probability of a 15th Century date range).
- For both trenches, a Romano-British date is unlikely due to lack of evidence.

Site Contact

Dr. Gerry McDonnell,
Ancient Metallurgy Research Group,
University of Bradford.

EXCAVATED AREA	MAGNETIC PROPERTIES SUMMARY
SM04 Trench 1 Ore roasting area	18 samples. Magnetic intensities: range 31.7 to 933.8 mA m^{-1}, 2 values less than 100 mA m^{-1}, 3 over 500 mA m^{-1}, mean 339.9 mA m^{-1}. 4 pilot samples. Some evidence of viscosity. Intensity spectra show a range of curves with varying mdf: range 16 to 28 mT, mean = 21 mT. Material magnetically relatively "hard", one pilot sample material "harder". Stability Index: material extremely stable. Initial stereoplot indicates moderate scatter of sample magnetic directions. A.f. demagnetisation in 5, 7.5 & 10 mT fields; a combination of demagnetisation data chosen for the final calculations, but mainly from the 7.5 mT data set. α_{95} optimised to ±2.56°, with 9 samples excluded.
SM04 Trench 2 Iron smelting furnace	23 samples. Magnetic intensities: range 43.3 to 1139.6 mA m^{-1}, 7 values less than 100 mA m^{-1}, 3 values over 500 mA m^{-1}, mean 250.9 mA m^{-1}. 5 pilot samples. Some evidence of viscosity: two of the lining material samples showing large variations in magnetic direction throughout the demagnetisation process. Intensity spectra show a range of curves with varying mdf: range 14 to 34 mT, mean = 23 mT. Material magnetically relatively "hard", two pilot samples material (both from the furnace lining) "harder". Stability Index: material very stable. Initial stereoplot indicates a wide variation in scatter, with one outlier identified by statistical analysis. A.f. demagnetisation in 10, 15 & 20 mT fields; a combination of demagnetisation data chosen for the final calculations. α_{95} optimised to ±3.81°, with 6 samples excluded.

Table 1. Summary of magnetic properties analysis.

EXCAVATED AREA	CONFIDENCE LEVEL		MEAN CORRECTED		DATE	
			DECLINATION	INCLINATION	MEAN	RANGE
SM04 Trench 1 Ore roasting area	α_{95}	±2.56°	-3.99°	55.20°	1370	1340 - 1390
SM04 Trench 2 Iron smelting furnace	α_{95}	±3.81°	10.84°	61.64°	1200	1140 – 1300 1420 - 1480

Table 2. Summary of dating results.

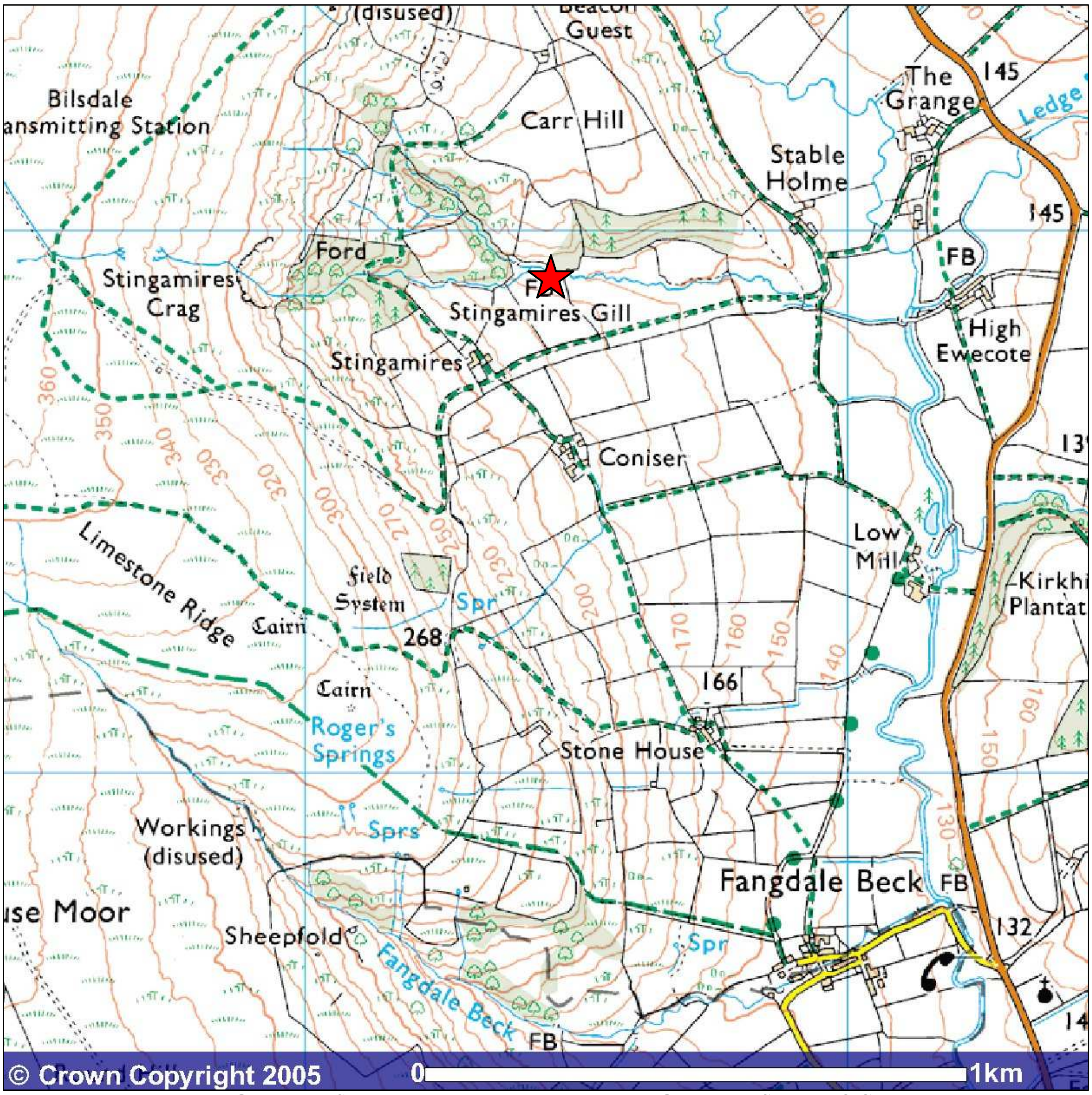

Figure 1. Location of the Stingamires site in Bilsdale, N. Yorkshire.

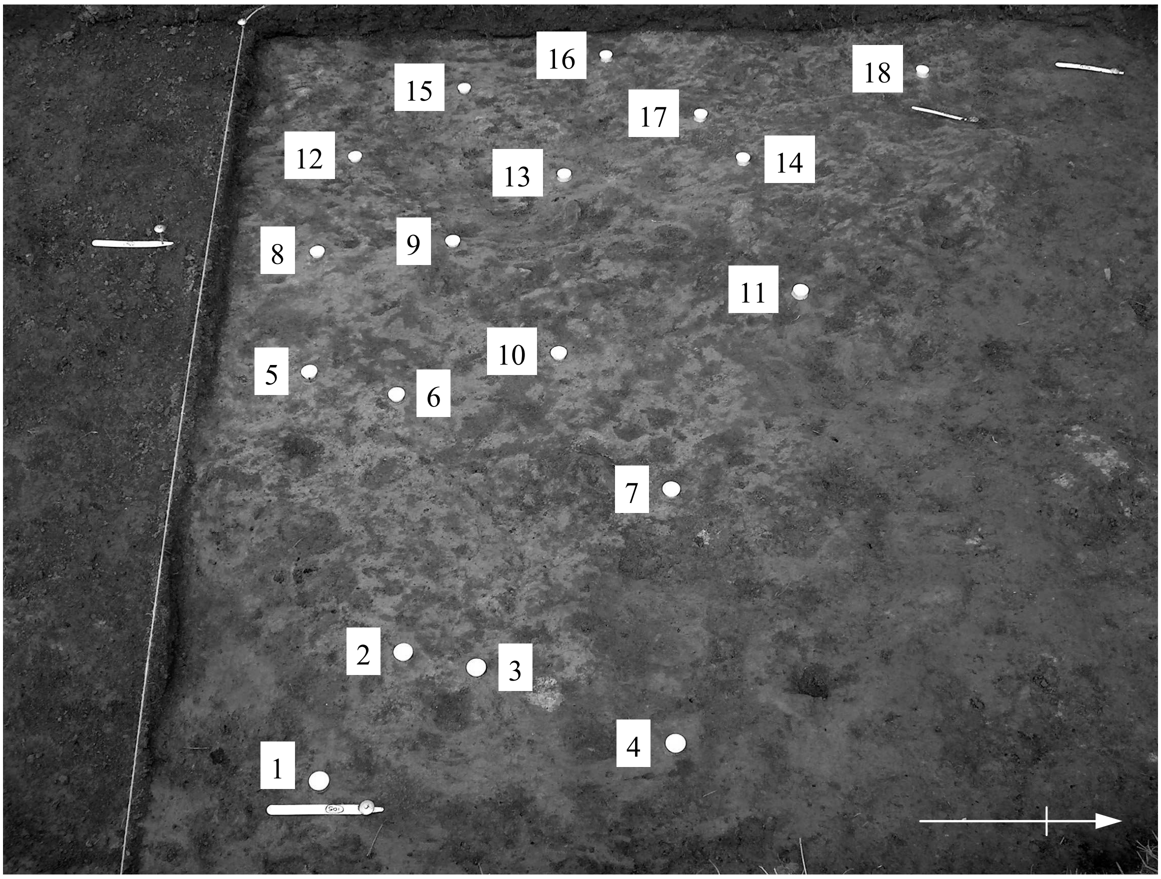

Figure 2. Stingamires, Bilsdale, N. Yorks.: Trench 1 ore roasting area archaeomagnetic dating sampling points.

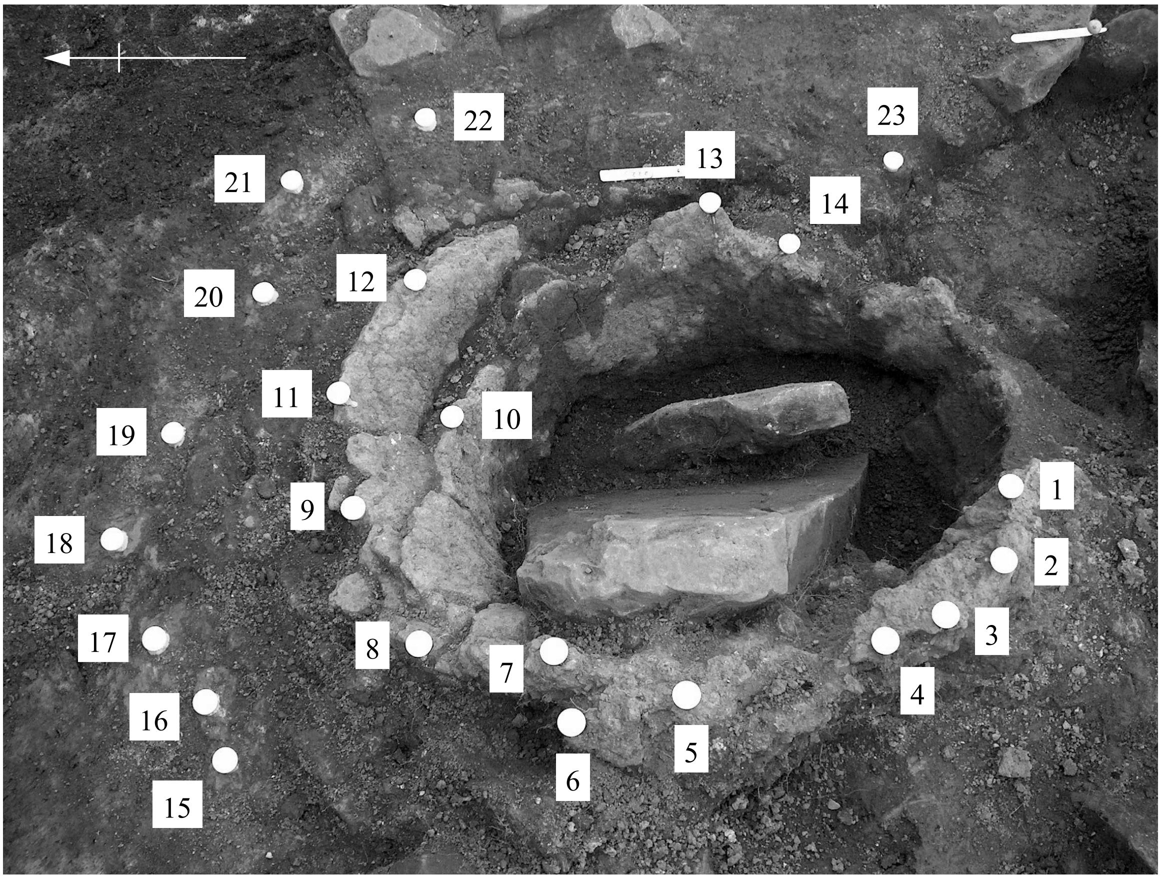

Figure 3. Stingamires, Bilsdale, N. Yorks.: Trench 2 iron smelting furnace archaeomagnetic dating sampling points.

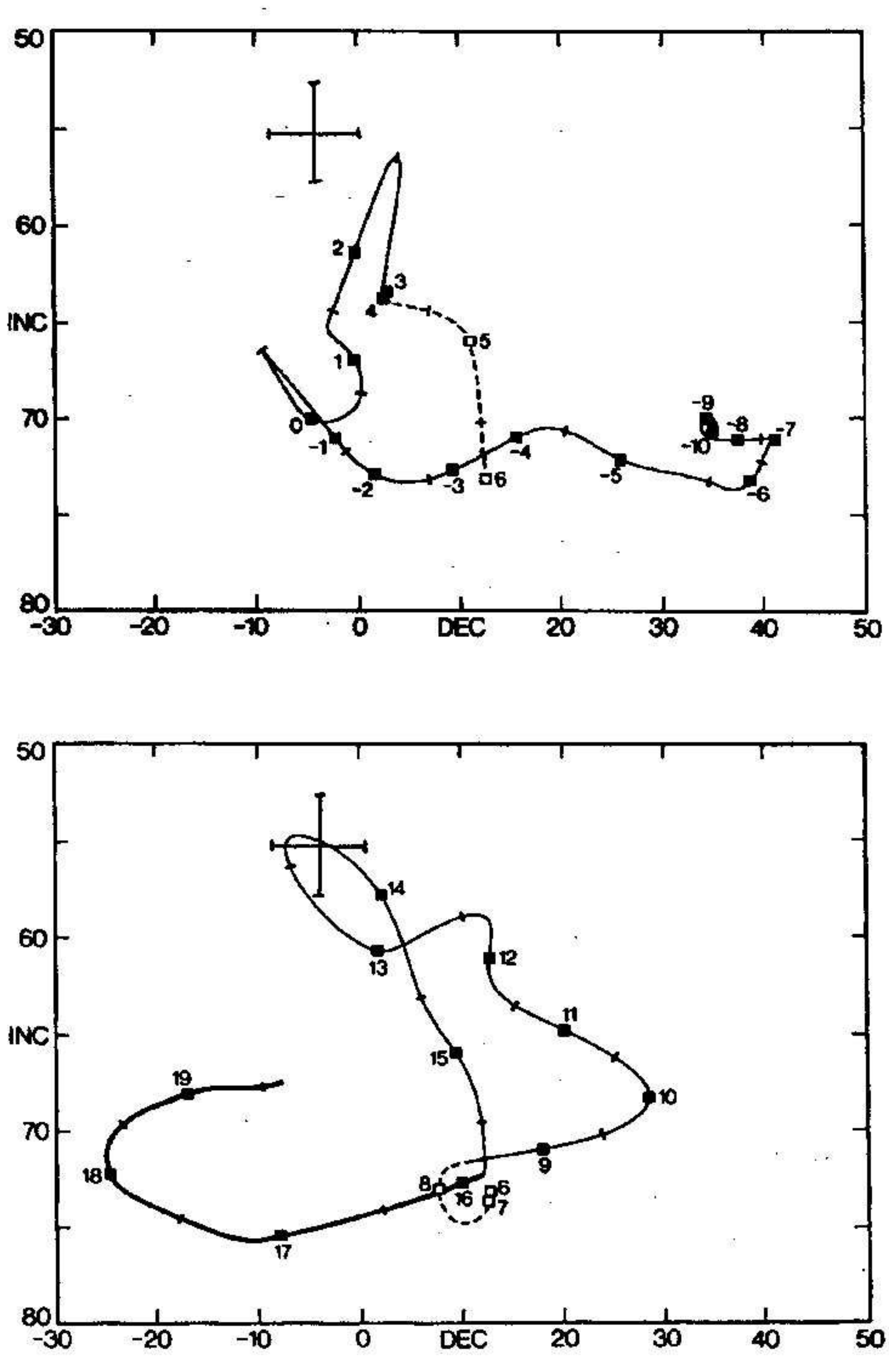

Figure 4: Corrected mean remanence vectors for the Stingamires SM04 Trench 1 ore roasting area together with 95% confidence level errors, superimposed on the British archaeomagnetic calibration curve (Clark *et al.*, 1988), normalised to Meriden, showing (upper) 1000BC-AD600 and (lower) AD600-AD1975.

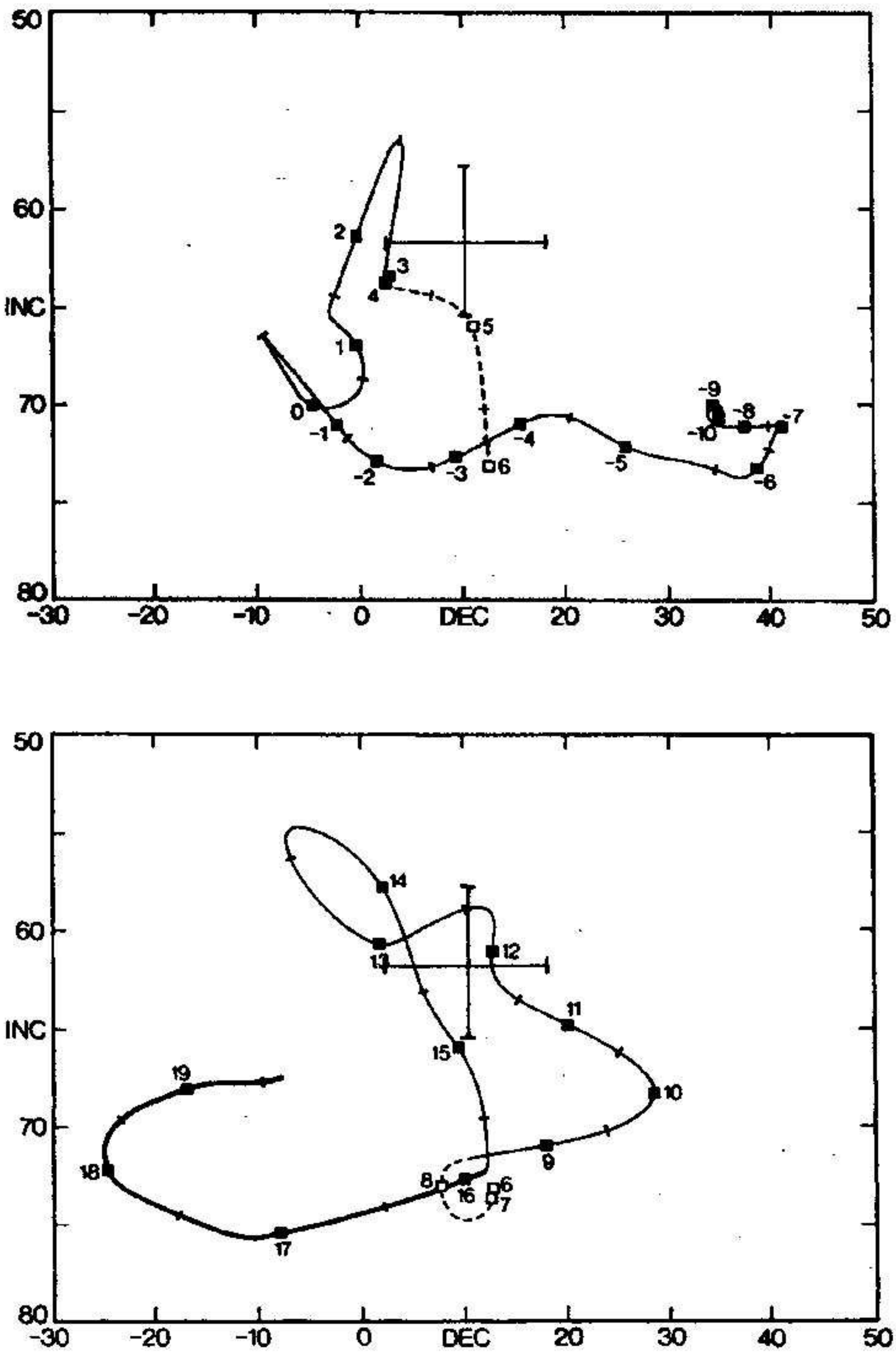

Figure 5: Corrected mean remanence vectors for the Stingamires SM04 Trench 2 iron smelting furnace together with 95% confidence level errors, superimposed on the British archaeomagnetic calibration curve (Clark *et al.*, 1988), normalised to Meriden, showing (upper) 1000BC-AD600 and (lower) AD600-AD1975.

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% polyvinyl acetate 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.

REFERENCES

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

Clark, A.J., Tarling, D.H. and Noel, M. (1988). Developments in archaeomagnetic dating in Britain. *J. Arch. Sci.* **15**, 645-667.

Fisher, R.A. (1953). Dispersion on a sphere. *Proc. R. Soc. Lond.* **A217**, 295-305.

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

Noel, M. and Batt, C.M. (1990). A method for correcting geographically separated remanence directions for the purpose of archaeomagnetic dating. *Geophys. J. Int.* **102**, 753-756.

Tarling, D.H. and Dobson, M.J. (1995). Archaeomagnetism: an error assessment of fired material observations in the British directional database. *J. Geomag. Geoelectr.* **47**, 5-18.

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
- Stereoplots for NRM and demagnetised samples
- Pilot demagnetisation measurements and plots

For each of the following excavated areas:

- SM04 Trench 1: ore roasting area
- SM04 Trench 2: iron smelting bloomery furnace