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ARCHAEOMAGNETIC DATING OF A FURNACE EXCAVATED AT BOTCHERGATE, CARLISLE

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ABSTRACT

This report describes the archaeomagnetic investigation of the furnace structure 288 on the Botchergate site (L200/151) in Carlisle. A total of 16 samples were taken from the furnace, 12 from the lining material and 4 from the surrounding baked clay support matrix, using the standard disc method. All except 3 of the samples showed a stable magnetisation, which may be indicative of the geomagnetic field in which the structure last cooled. The mean magnetic direction suggested a date for last use of the furnace within the first half of the second century AD.

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 lining and baked clay support material of a high temperature furnace, suspected to be used for lead smelting, on the Botchergate site.

The objectives were to:

- investigate the suitability of fired material from this context for archaeomagnetic dating,
- to provide a date for the last use of the furnace.

The sampling and measurement programme was undertaken by Alan Powell, assisted by Ivan Mack, at the request of Lancaster University Archaeological Unit carrying out the excavation.

ARCHAEOLOGICAL CONTEXT

The Botchergate site is approximately 400m from Carlisle city centre along the A6 road and is being investigated archaeologically before major redevelopment work is carried out. The site comprises of a period of Romano-British industrial activity overlain with and disturbed by Medieval features. Two distinct Romano-British areas of red baked clay are separated by a Medieval ditch.. Finds from the Romano-British layers include a small quantity of lead slag; no iron smelting slag has been found by the time of this investigation. The furnace remains (context no. 288) were discovered close to the modern surface and in remarkably good condition, within the area of activity on the opposite side of the Medieval ditch to where datable artefacts were found. Figure 1 is a sketch of the furnace, showing the location of the samples taken for archaeomagnetic dating. The extant furnace lining material is 2.5 to 5 cm thick, of a light grey/yellow/red appearance with no sign of vitrification. The surrounding support matrix comprises hard, red baked clay.

SAMPLING

Samples were taken from cleaned horizontal surfaces within and adjacent to the furnace structure using the standard disc method (see Appendix 1): 12 samples from the lining material and 4 from the surrounding support matrix (Figure 1). Of the latter, two samples were taken from the baked clay which was exposed after a small area of lining material had been removed. The purpose of the 4 samples independent of the lining was to establish whether the furnace had been operated long enough to heat the surrounding support matrix sufficiently to record the geomagnetic field direction at the time of the last furnace heating/cooling. Samples were north-oriented using a magnetic compass. It was observed that in orienting sample 2 the magnetic compass needle was deflected by about 10° westwards from the general direction of orientation of the other samples. This was seen to be a very localised effect and may have been caused by a high value magnetic anomaly, relative to the geomagnetic field, within the sample material; no other samples affected the compass needle in the same way

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 was investigated by the stepped alternating field (a.f.) demagnetisation of three pilot samples - 6, 7 and 9 - 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 three samples were chosen for two reasons: their declination and inclination values were closest to the mean values of the whole set, and their initial magnetic intensities were sufficiently high enough to obtain meaningful results. From a study of the pilot sample behaviour, alternating fields of 10, 15 and 20 mT were chosen to provide a series of data 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 in each field (Appendix 2).

RESULTS

The intensity of natural remanent magnetisation was variable, ranging from 2 to 442 mA m^{-1} (with a mean of 131), 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 and the strength of magnetisation of all samples was consistent with having been heated.

The stepped a.f. demagnetisation of the three pilot samples (6, 7 and 9) demonstrated that the furnace lining material was magnetically stable comprising a single component associated with the geomagnetic field at the time of the last furnace cooling. The intensity spectra (Appendix 2) are very similar in shape with median destructive fields of 27, 20, and 25 mT respectively. This suggests that the lining material was obtained possibly from the same source.

The initial sample scatter plot (Appendix 2) indicated that there were three samples (1, 2 and 15) which could be considered as outliers. Each of these 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 these three samples 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 of the furnace operation. Sample 2's anomaly indicated by the deviation of the magnetic compass needle was easily removed by the demagnetisation exercise, all trace gone after the application of a 15 mT field, suggesting that there was magnetic material within the sample which may have been affected by a localised magnetisation some time after the furnace had stopped being used.

Scatter plots were constructed to show the clustering of samples after demagnetisation in 10, 15 and 20 mT peak applied fields. In all cases sample 1 remained in an outlying position whilst samples 2 and 15 moved into the main group of samples. Mean values of declination and inclination, and the error at the 95% confidence level (α_{95}) were calculated for the three sets of demagnetisation data including and excluding samples 1, 2 and 15. Although samples 2 and 15 were contained within the main cluster of samples, better results for α_{95} were obtained by excluding all three samples. As a consequence, samples 1, 2 and 15 were defined as outliers and excluded from the final calculations.

Comparison of corrected mean values of declination and inclination and α_{95} for the three sets of demagnetisation data excluding outliers, showed that there was very little difference between the 10 and 15 mT results (variations in the second decimal place) but these were better than the 20 mT results; the 15 mT results have been chosen to provide the dating evidence.

DATING OF MAGNETIC DIRECTION

The mean declination and inclination after demagnetisation in a field of 15 mT were corrected to Meriden (Table 1), the reference locality for the British calibration curve, using the standard method (Noel and Batt, 1990). The corrected mean site direction was then dated by comparison with the Clark calibration curve in the conventional manner (see Appendix 1) and shown in Figure 2. A summary of the results are given in Table 1.

In archaeomagnetic dating it is often necessary to give multiple possible date ranges as the earth's magnetic field has had same direction at different times in the past. The corrected mean directions can be applied to both upper and lower calibration curves. Although a possibility, it is most unlikely that the furnace is modern given the archaeological evidence.

Two levels of confidence errors are shown in Table 1. The first, α_{95}, although acceptable – it is just outside the Grade 3 classification of Tarling and Dobson (1995) – is higher than anticipated. This is possibly caused by mineralogical and magnetic characteristic variations in the furnace lining and support matrix materials, suggesting that the samples did not respond equally in recording the same geomagnetic field; this is indicated by the demagnetised sample scatter plot (Appendix 2). The α_{95} date range lower limit of 100BC is an historic improbability for a Romano-British site. After calculating the α_{68} (the error at 68% confidence), the lower limit of this date range of AD50 is more acceptable but some doubt still remains. At both confidence levels the date range upper limit of furnace operation (end of 2nd./beginning of 3rd. century AD) is feasible.

SUMMARY AND CONCLUSIONS

All of the samples were readily measurable, and appeared to record a stable magnetisation, consistent with previous heating to above the Curie temperature. Despite some evidence for variations in magnetic characteristics in the furnace structure, possibly being the cause of the scatter of the sample magnetic directions, the results showed that the fired material was suitable for archaeomagnetic dating and did provide a record of the geomagnetic field at the time of last cooling.

The date of the last use of the furnace is shown to be in the first half of the 2nd. century AD (around AD135) with the upper date range limit at the end of the 2nd./beginning of the 3rd. century AD. The lower date range limit is uncertain.

In summary:

- The material was suitable for archaeomagnetic dating, both in terms of having been heated to sufficient temperatures and containing appropriate magnetic minerals.
- The furnace and its surrounding support matrix were successfully dated.
- Broad conclusions could be drawn regarding period of use.

SITE CONTACT

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	Initial NRM measurements	After 15 mT demagnetisation	Date mid-point	Date range
Declination	3.2°	-3.5°	-	-
Inclination	65.1°	65.7°	-	-
α_{95}	±21.1°	±5.7°	AD135	100BC – AD210
α_{68}	-	±3.4°	AD135	AD50 – AD180

Table 1: Summary of results. The demagnetised directions are corrected to Meriden.

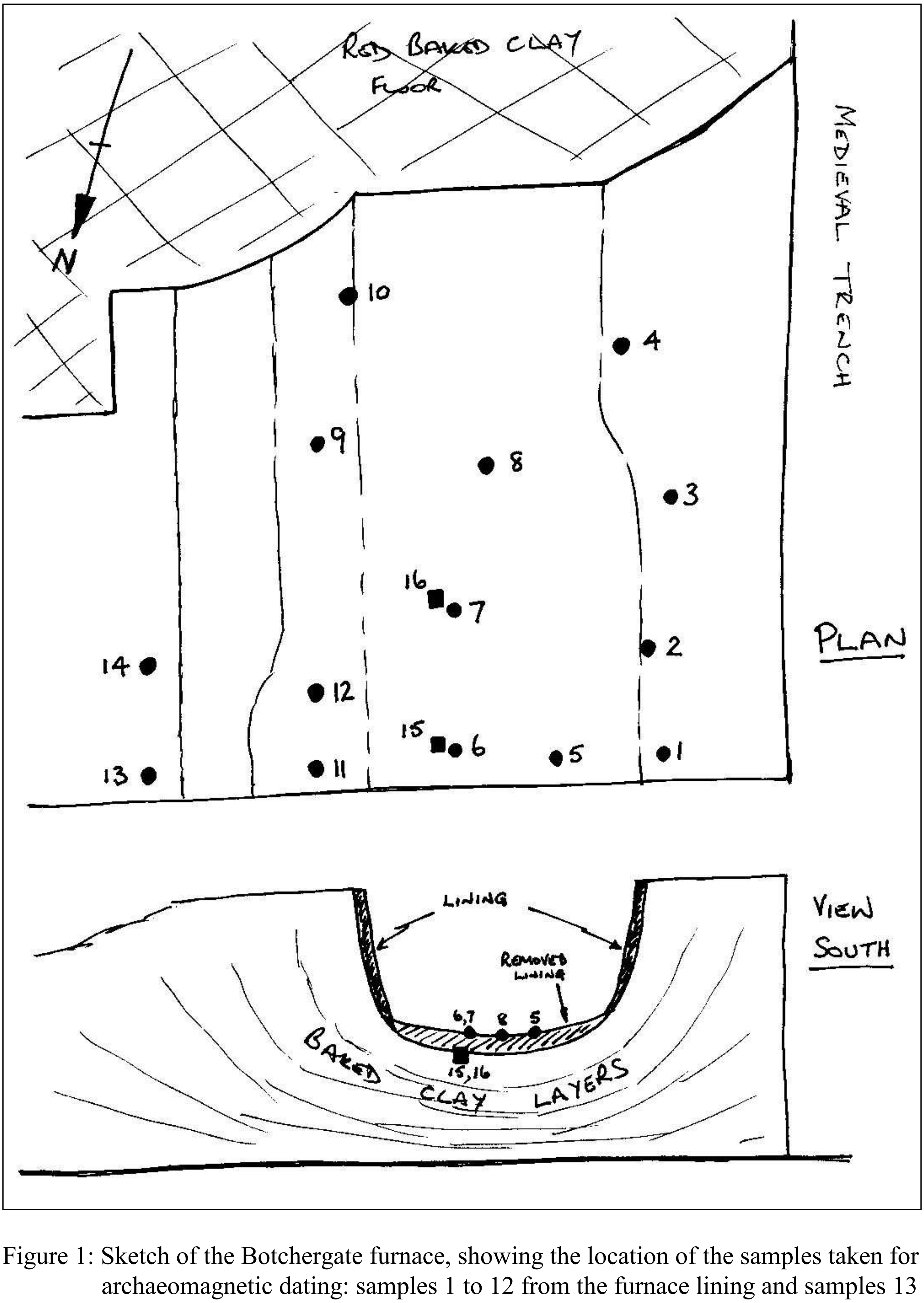

Figure 1: Sketch of the Botchergate furnace, showing the location of the samples taken for archaeomagnetic dating: samples 1 to 12 from the furnace lining and samples 13 to 16 from the supporting baked clay material. Not to scale.

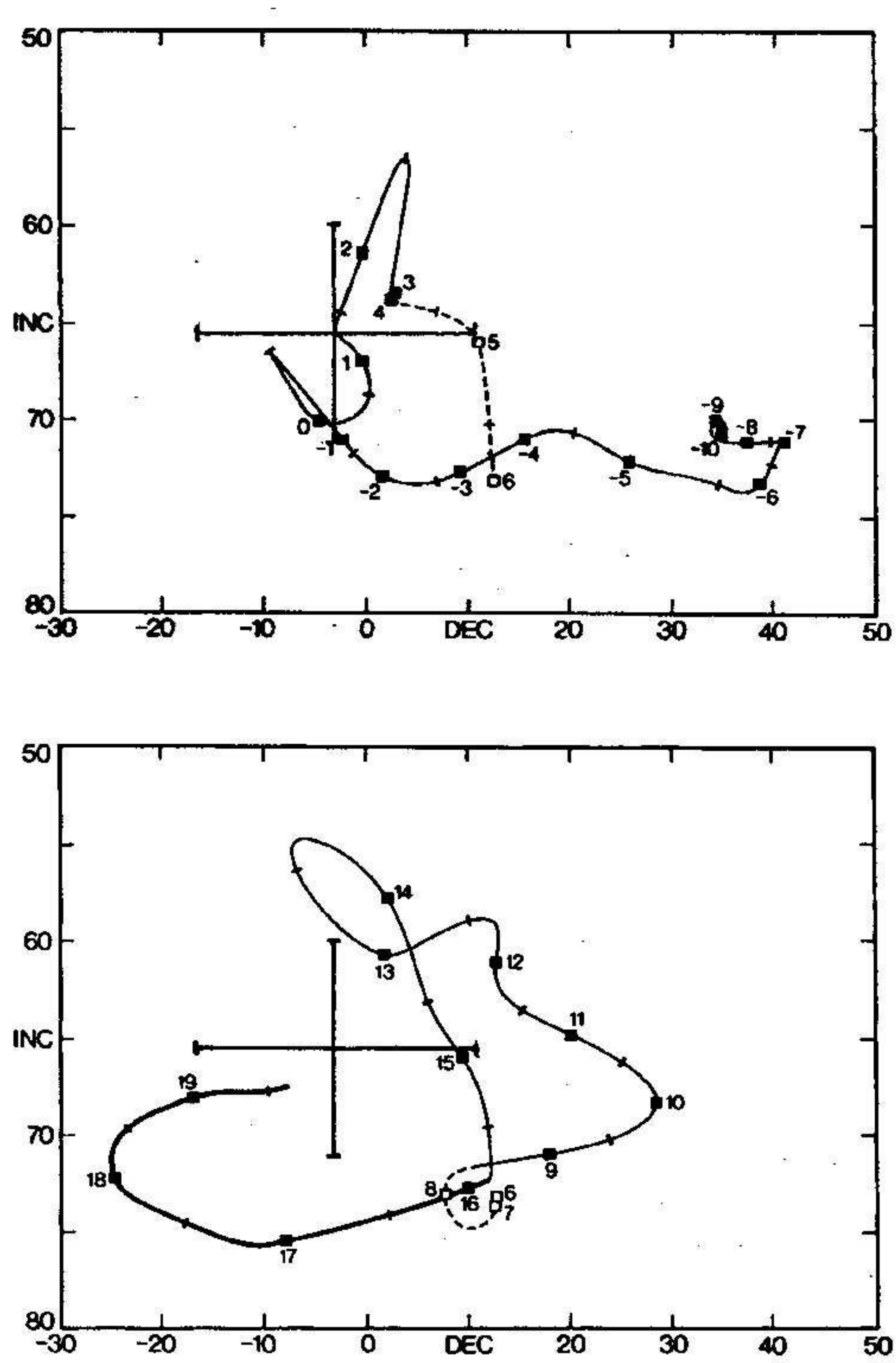

Figure 2: Corrected mean remanence vectors for the Botchergate, Carlisle, furnace together with 95% confidence level errors, superimposed on the British archaeomagnetic calibration curve (Clark *et al.*, 1988), normalised to Meriden, showing (upper) 1000BC-AD600 and (lower) AD600-AD1975.

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 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 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 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 15 mT demagnetised samples
- Pilot demagnetisation measurements and plots
- Outliers demagnetisation measurements and plots