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ARCHAEOMAGNETIC DATING OF A LEAD SMELTING HEARTH EXCAVATED AT PENGUELAN, CWMYSTWYTH

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ABSTRACT

This report describes the archaeomagnetic investigation of the lead smelting hearth PSS4 on the Penguelan site (SN748808) near Cwmystwyth. A total of 14 samples were taken from the furnace, using the standard disc method. All of the samples showed a stable magnetisation but also a low level of magnetic intensity and a considerable amount of scatter in the magnetic direction. Although obviously heat affected, the samples could not be considered to be *in situ* suggesting disturbance since the time of the hearth's last cooling. The effect of these low intensities and wide scatter of declinations and inclinations is a low confidence in the calculated result. Whilst a medieval date is suggested from the mean magnetic direction, no reliable date range can be confirmed.

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 base material of a natural draught lead smelting furnace (bole), on the Penguelan 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, at the request of Dr. Simon Timberlake of the Early Mines Research Group.

ARCHAEOLOGICAL CONTEXT

The Penguelan site is approximately 1.5 km from the hamlet of Cwmystwyth, itself about 25 km inland from Aberystwyth. The site, situated at the base of Copa Hill, lies in an area of prehistoric, medieval and post-medieval mining and smelting activity. Circumstantial evidence suggests that the medieval mining and smelting may have been carried out under the auspices of the Cistercian abbey of Strata Florida around the 12th Century AD (Simon Timberlake *pers. comm.*). Site geology consists of interbedded grey shales and sandstones, with substantial amounts of quartz and feldspar.

The site comprises three or more lead smelting furnaces of which the one under investigation is designated PSS4. The remains of this furnace were no more than 10 cm below ground level, consisting of a reddened heat affected clay/gravel mix hearth surface (context no. 5) surrounded by rocks to form the furnace structure; the rocks appear to be naturally positioned rather than manually placed. Following excavation, approximately one quarter of the hearth remained, with exposed dimensions of 100 cm long by 60 cm wide. The excavations revealed that the furnace had had three base levels, suggesting two occasions of repair or refurbishment; the top (latest) level was to be dated. Figure 1 is a sketch of the hearth, showing the location of the samples taken for archaeomagnetic dating.

SAMPLING

Fourteen samples were taken from cleaned horizontal surfaces within the hearth structure using the standard disc method (see Appendix 1). 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 was investigated by the stepped alternating field (a.f.) demagnetisation of four pilot samples – 1, 6, 9 and 13 - 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 four samples 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 the area of the hearth. 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 (Appendix 2).

Six of the dating samples had sufficient material left over from trimming to allow further magnetic analysis (i.e. mass specific susceptibility and magnetic viscosity measurements) to be carried out in order to assess the amount of heating to which the hearth material had been subjected.

RESULTS

The intensity of natural remanent magnetisation was variable, ranging from 0.6 to 30.5 mA m^{-1} (with a mean of 5.9), 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 but, with four exceptions, did not have magnetic intensities which were high enough not to have been compromised by the noise levels of the spinner magnetometer.

The stepped a.f. demagnetisation of the four pilot samples demonstrated that the hearth material had a small amount of viscous remenance in addition to a single component probably 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 8, 18, 10, and 15 mT respectively. The mean value of 13 mT suggests a material which has a relatively "soft" magnetism.

The stability index (SI), as defined by Tarling and Symons (1967), was calculated for the four pilot samples – 2.8, 3.3, 5.2 and 1.2, respectively. These sample SIs suggested that the hearth material as a whole was magnetically stable. It is, however, possible that the low level of magnetic intensities could have affected the SI calculations.

The initial sample scatter plot (Appendix 2) shows the wide scatter of individual sample magnetic directions. Each of the samples 1, 6, 9 and 13 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 four 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.

Scatter plots were constructed to show the clustering of samples after demagnetisation in 10, 15 and 20 mT peak applied fields. In all cases the scatter of the magnetic directions remained wide. 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.

Comparison of corrected mean values of declination and inclination and α_{95} for the three sets of demagnetisation data showed that there was not much difference between the 10, 15 and 20 mT results; the 10 mT results have been chosen to provide the dating evidence as these gave better α_{95} readings.

The magnetic susceptibility analysis results were compared with those of heat affected clays associated with another high temperature furnace site, Myers Wood near Huddersfield. Mean values of mass specific susceptibility (x 10^{-8} m^3 kg^{-1}): MW heat affected clay = 615, MW burnt clay = 708, PSS4 heat affected clay = 577. The similarities noted lead to the conclusion that the PSS4 hearth material was heat affected but not sufficiently to establish a strong magnetic intensity.

DATING OF MAGNETIC DIRECTION

The mean declination and inclination after demagnetisation in a field of 10 mT were corrected to Meriden, the reference locality for the British calibration curve, using the standard method (Noel and Batt, 1990). As the α_{95} for the demagnetisation results had not improved sufficiently compared to the original NRM α_{95}, remaining excessively high and well outside the acceptable gradings defined by Tarling and Dobson (1995), it is not possible to apply the corrected mean site direction to the Clark calibration curve and produce a reliable date range in the conventional manner (see Appendix 1). Figure 2 shows the (unreliable) data superimposed on the calibration curve. A summary of the results are given in Table 1.

Two levels of confidence errors are shown in Table 1, α_{95} and α_{68} (the error at 68% confidence level). Both are excessively high and may have been caused by a number of factors including mineralogical and magnetic characteristic variations in the hearth material, suggesting that the samples did not respond equally in recording the same geomagnetic field. It is also possible that there has been physical disturbance of the hearth at any time up to excavation, during excavation and during sample acquisition (although in both these cases disturbance is unlikely). The combination of variations and disturbances could account for the NRM scatter noted (Appendix 2).

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 the archaeomagnetic information suggests the remote possibility of a date from the upper curve, it is most unlikely that the hearth is earlier than AD600 given the archaeological and circumstantial evidence.

SUMMARY AND CONCLUSIONS

- All of the samples were measurable but exhibited low levels of magnetic intensity. Stable magnetism was apparent.
- The hearth material appeared to be heat affected, as demonstrated by the comparison of the magnetic susceptibilities from similarly heat affected clays at another high temperature furnace site, but perhaps not enough to establish a sufficiently strong magnetic intensity for measurement purposes.
- A considerable amount of directional scatter was noted from the NRM data, with correspondingly high α_{95}.
- This scatter could have been caused by variations in magnetic characteristics in the hearth material and by the physical disturbance of the hearth structure. The samples could not be considered as being strictly *in situ*, i.e. within 2° of firing position, due to the possible disturbance.
- The consequence of a combination of low intensities and wide directional scatter is a low confidence in the calculated results.
- The hearth material has been shown not to be suitable for archaeomagnetic dating and thus did not provide a record of the geomagnetic field at the time of last cooling.
- Although a medieval date could be inferred from the calculated mean magnetic direction, no reliable date range can be confirmed.

SITE CONTACT

Dr. Simon Timberlake,
Early Mines Research Group.

	Initial NRM measurements	After 10 mT demag.	Final set of 7 samples	Date mid-point	Date range
Declination	-18.1°	-23.2°	-11.2	-	-
Inclination	63.4°	67.7°	56.6	-	-
α_{95}	±30.0°	±31.8°	±19.1°	-	-
α_{68}	-	±18.7°	±10.8°	-	-

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

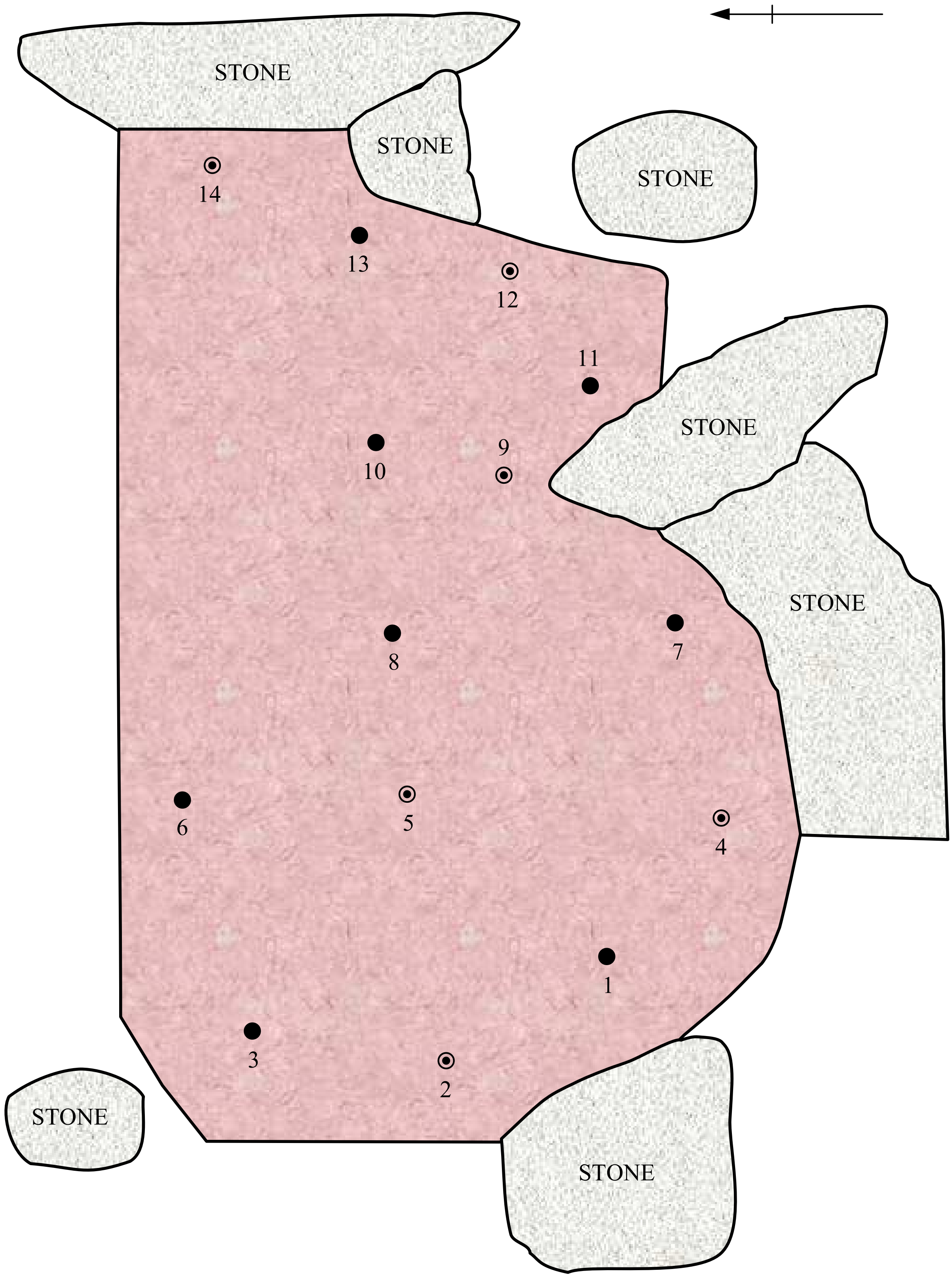

Figure 1: Penguelan PSS4 lead smelting hearth: archaeomagnetic dating sampling points
● sampling points ⦿ sampling points with associated baked clay

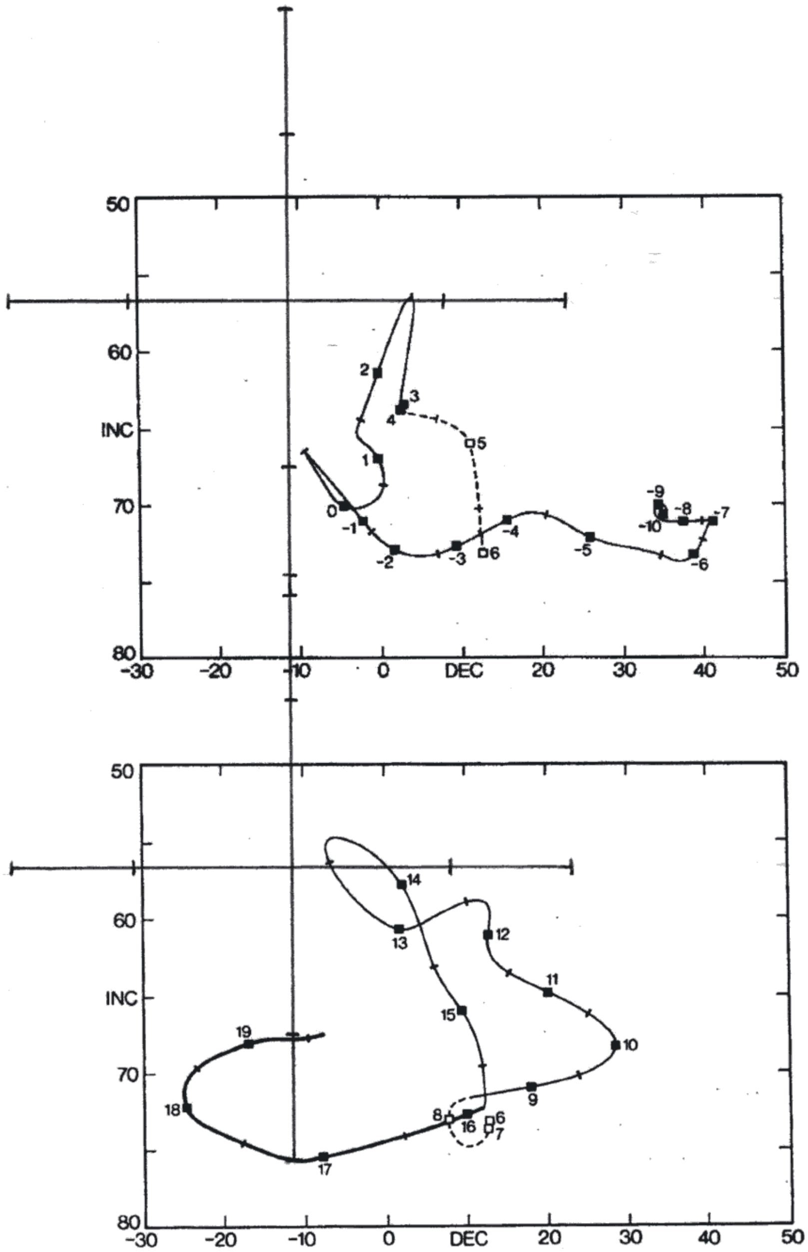

Figure 2: Corrected mean remanence vectors for the Penguelan lead smelting hearth together with 95% and 68% confidence level errors, superimposed on the British archaeomagnetic calibration curve (Clark *et al.*, 1988), normalised to Meriden, showing (upper) 1000BC-AD600 and (lower) AD600-AD1975.

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 10 mT demagnetised samples
- Pilot demagnetisation measurements and plots