ALLEN'S FARM, PLAXTOL, Kent:
Archaeomagnetic Dating Report 2002

Paul Linford

Summary

Earth resistance survey has relocated the remains of a Roman bath house first discovered in the mid-C19th but subsequently lost. At the time of the C19th excavation a piece of inscribed tile was found bearing the name of its manufacturer, one Cabriabanus. Since the rediscovery of the site, more tile of the same type has been found, as has the base of a Roman tile furnace thought to be associated with its production. Archaeomagnetic analysis of the furnace thus provides an opportunity to date the activities of Cabriabanus, and the type of relief patterned tile associated with him. The samples taken from the furnace indicate that its northern end had not experienced particularly intense heating. However, those samples taken from its centre provide a precise date for its last firing, in the mid-C2nd AD.

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Introduction

In 1857 a Roman bath house was excavated at Allen's Farm near Plaxtol in Kent (TQ 615 530, Longitude 0.3°W, Latitude 51.3°N) (Luard 1859) and some fragments of relief patterned tile were found bearing the inscription "*Parietalem Cabriabanu fabricavi*" ["I, Cabriabanus made this wall-tile"] (Haverfield 1910). The location of the bath house was subsequently lost until 2001 when it was relocated, along with an associated Romano-British villa, by an earth resistance survey carried out by Malcolm Davies. The earth resistance survey also detected the remains of a Roman tile furnace, subsequently excavated, in an open field about 130 metres from the bath house. It is conjectured that this furnace may be associated with the construction of the villa and manufacture of the inscribed tile.

Since the rediscovery of the Plaxtol bath house site, a further piece of relief patterned tile has been found there. The same type of tile has also been found at Darenth (Philp 1973, p140) and at a site at Old Broad St. in London (Haverfield 1910), its date of manufacture has been bracketed to the period between 80 to 200 AD. The discovery of the Plaxtol furnace provides an opportunity to date the activities of Cabriabanus more precisely. Further, given that the period of production of this type of tile can be identified with his working life, all three sites where it has been found could potentially be dated by association to a relatively short time span. In view of this significance, Peter Kendal, the English Heritage Inspector of Ancient Monuments for Kent requested that the Centre for Archaeology (C*f*A) provide archaeomagnetic analysis of the furnace. It was sampled for this purpose on the16th October 2002 by the author who also performed the subsequent measurement and analysis.

Method

The tile furnace was given the C*f*A archaeomagnetic feature code PLX. Samples were collected using the disc method (see appendix, section 1a) and orientated to magnetic north using a compass. Subsequently the International Geomagnetic Reference Field (IGRF 2000) was used to establish that magnetic north was 2.6° west of true north at the site on the date when the samples were taken and the sample orientations were corrected accordingly.

Sixteen samples were recovered (samples 02 and 09 fragmented during extraction) with the following compositions:

- 01-04: From a light orange tile, at the base level of the feature.
- 05-08: From a second light orange tile, on top of a stack.
- 10-11: From a third tile at the same level as the 01-04.
- 12: Red fired clay from a raised part of the furnace.
- 13-14: From a large raised mass of fused vitrified grey tile.
- 15-16: From a smaller piece of grey vitrified tile on the edge of a flue.
- 17-18: Red fired clay from the base level of the feature.

The relative positions of these samples are depicted in Figure 1. It is presumed that the grey tiles had turned that colour owing to the extreme heat that they had been exposed to during the operation of the furnace: certainly they had fused together and become vitrified in places. Due to its size, the fused mass of tiles containing samples 13 and 14 was sub-sampled in the laboratory to provide seven extra samples numbered 13.1 to 13.7.

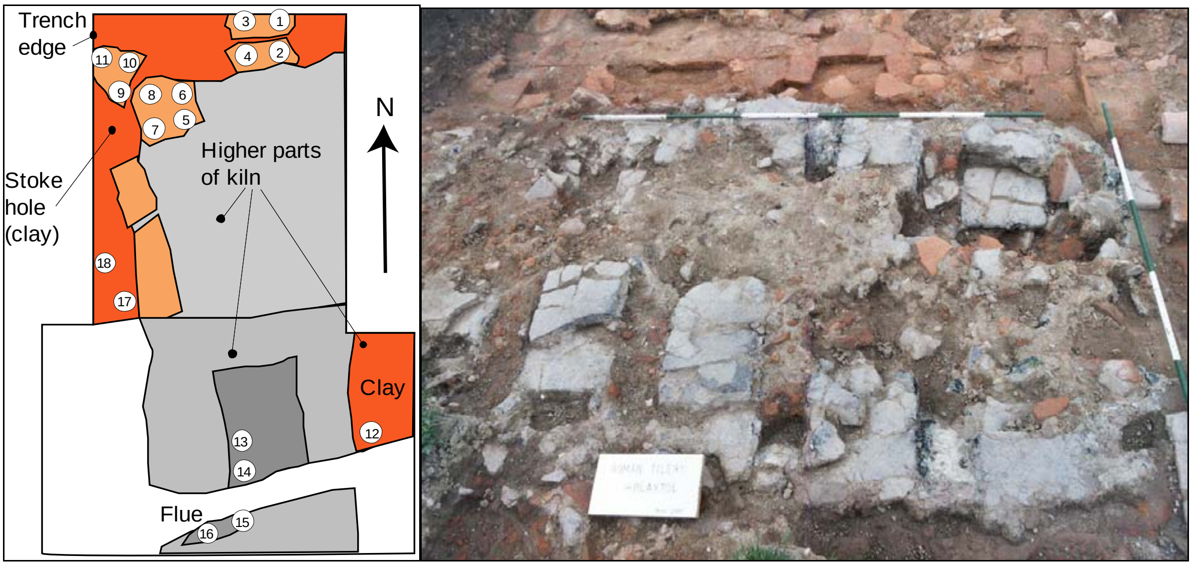

Figure 1; Sketch plan (left) and photograph (right) of feature PLX. The photograph is viewed from the west and shows the feature when it was originally excavated in its entirety. The sketch plan depicts the 1m by 1.5m trench re-excavated over the furnace for the purposes of archaeomagnetic sampling and shows the locations of the individual samples.

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

A typical strategy used in archaeomagnetic analysis of a feature is first to measure the NRM field recorded in all the samples. Then a number of representative samples are selected for pilot partial demagnetisation depending upon their material composition and NRM characteristics. Partial demagnetisation involves exposing the sample to an alternating magnetic field of fixed peak strength then measuring the resulting changes in its magnetisation. This procedure is repeated with increasing peak field strengths to build up a complete picture of the coercivity spectrum of the sample. The equipment used for these measurements is described in section 2 of the appendix.

After inspection of the coercivity spectra of the pilot samples, an optimum field strength is selected where it is judged that the maximum amount of secondary magnetisation has been removed, whilst preserving the majority of the primary magnetisation. The remaining samples are then partially demagnetised using this optimum peak alternating field strength. In some cases the set of samples can be partitioned into groups with different material composition or magnetic characteristics. When this occurs, several different field strengths may be used, each one judged to be the optimum for a particular group.

A mean TRM direction is calculated from the sample measurements made after partial demagnetisation at their optimum field strength. Some samples may be excluded from this calculation if their TRM directions are so anomalous as to make them statistical outliers from the overall TRM distribution. A "magnetic refraction" correction is often applied to the sample mean TRM direction to compensate for distortion of the earth's magnetic field due to the geometry of the magnetic fabric of the feature itself. Then the mean is adjusted according to the location of the feature relative to a notional central point in the UK (Meriden), so that it can be compared with UK archaeomagnetic calibration data to produce a date of last firing for the feature. Notes concerning the mean calculation and subsequent calibration can be found in sections 3 and 4 of the appendix.

This measurement and calibration strategy was applied to the analysis of the samples from the Plaxtol furnace. As it was not clear whether a horizontal or a vertical surface magnetic refraction correction was appropriate for the stacks of tiles sampled, no adjustment for magnetic refraction was made to the inclination of the calculated mean TRM direction before calibration (note 3b).

Results

Sample NRM measurements and measurements after partial demagnetisation are recorded in Table 1. Figure 2 depicts the distribution of the sample TRM directions before and after partial demagnetisation. Figure 2a shows that the majority of sample NRM directions cluster together towards the centre of the diagram. However, samples 01, 03 and 04, all from the same tile, form their own group well away from this main cluster and with negative inclinations. Samples 05 to 08 also form their own distinct group and again all came from the same tile; the same is true of samples 10 and 11. This pattern indicates that the three tiles from which samples 01 to 11 were drawn all retain the magnetisation that they acquired when they were originally manufactured. The direction of this magnetisation is meaningless as they were displaced when they were used to construct the furnace. Operation of the furnace has not exposed these tiles to high enough temperatures to overprint this original magnetisation.

All three tiles came from the northern end of the furnace and it was concluded that heat flow to this area must have been limited. As the magnetisation directions of samples 01 to 11 cannot be used for directional archaeomagnetic dating, they were excluded from further analysis (hence their TRM directions do not appear in Figure 2b).

Tables 2 and 3 record the pilot demagnetisation measurements made on samples 13, 16, 17 and 18, whilst Figures 3 to 6 illustrate these results graphically. The maximum stability of the TRM in each pilot sample was estimated using the method of Tarling and Symons (1967). The maximum stability parameters and ranges over which they persist are listed for each sample in Table 4. In this method, any sample with a maximum stability parameter greater than 2 is judged to record a stable TRM direction and a parameter value over 5 suggests extreme stability. The figures in Table 4 indicate that the magnetisations of all the pilot demagnetisation samples are extremely stable, with maximum stability occurring between 20 and 30mT in the majority of cases. It can also be seen in Figures 3b to 6b that the magnetisation in all the pilot samples is hard with median destructive field values above 30mT. Based upon these statistics, and the indication in Figures 3 to 6 of a viscous remanent component present in domains with coercivities up to 10mT, it was decided to partially demagnetise the remaining samples in a 20mT AF field.

Figure 2b shows that the grouping of TRM directions after 20mT partial demagnetisation has been improved. Hence, a mean TRM direction was calculated from these 14 samples (see note 3):

At site: Dec = -4.8 ^{o} Inc = 63.9 ^{o} α_{95} = 1.1^o k = 1330.1
At Meriden: Dec = -5.2 ^{o} Inc = 64.9 ^{o}

As stated in the Method section, no correction for magnetic refraction has been added to the inclination of this mean. Figure 7 shows the comparison of the mean TRM vector with the UK archaeomagnetic calibration curve depicted on a Bauer plot. The estimated date for the last firing of the feature deduced from it is:

120 AD to 165 AD at the 95% confidence level.

Conclusions

Archaeomagnetic analysis of the Roman tile furnace from Plaxtol indicates that, with the exception of the samples from the northern end of the feature, it was well fired and had acquired a stable TRM. Furthermore, the scattering of individual magnetisation directions between the samples was minimal and it was thus possible to determine the mean TRM direction to high precision. A date for the last firing of the furnace between 120 and 165 AD can be deduced from this mean. This falls in the centre of the date range of 80 to 200 AD ascribed to the type of relief-patterned tile upon which the "Cabriabanus" inscription was discovered. The archaeomagnetic date range is also in good agreement with an assessment of the date of the foundation of the Plaxtol villa estate made by Malcolm Davies (*pers. comm.*), based upon pottery finds. The lack of sherds dating from the C1st AD, a complete absence of Samian, and an abundance of sherds from the C2nd AD, all tend to suggest a date towards the mid-C2nd AD.

Given the potential significance of this archaeomagnetic date, some discussion of the issue of the magnetic refraction correction and its effect on the quoted date range is warranted. When the calibration curve of Clark, Tarling and Noel (1988) was compiled, many of the mean TRM directions incorporated as calibration data had been corrected for magnetic refraction using to the method of Aitken and Hawley (1971). This correction calls for an addition of 2.4° to the measured angle of inclination (or dip) of samples taken from horizontal surfaces, or a subtraction of 1.2° in the case of samples forming parts of vertical surfaces such as walls. Although it is now recognised that the causes of distortion to the magnetic field within an archaeological feature are far more complex than was then realised (eg: Schurr *et al*. 1984), the Aitken and Hawley correction is still applied for consistency with the present calibration data. Inspection of Figure 7 illustrates that in periods such as the C2nd AD, when the motion of the virtual geomagnetic pole primarily causes changes to the inclination of the magnetic field observed in the UK, an adjustment of 2.4° to the inclination of a mean TRM can result in a shift in date of up to 40 years. Hence, a correct assessment of the refraction correction to apply is particularly important.

In the case of the Plaxtol furnace, constructed from stacks of tiles, it was not clear from the surviving remains whether the tiles and clay sampled were from the horizontal floor of the feature or from the bases of upstanding walls. Indeed, for most of the samples it appeared likely that a combination of the two refraction effects might have pertained, hence it was assumed that no significant magnetic refraction effect would have occurred. This conjecture is lent weight by the consistency observed in the measured TRM directions of the samples. It may also be noted in Figure 7 that the mean direction lies west of the westernmost point in the calibration curve for the C2nd AD (which occurs around 150 AD). Any shift to the inclination of this mean is thus likely to move it further away from the calibration curve (too far to confidently deduce a date), suggesting that the mean direction used is correct. Nevertheless, in future a reassessment of the date might be merited, when magnetic distortion effects are better understood and the UK Archaeomagnetic Calibration Curve has been further refined.

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Date of report: 05/11/2002

Archaeomagnetic Date Summary

Archaeomagnetic ID:	**PLX**
Feature:	**Roman tile furnace**
Location:	**Longitude 0.3^{o}W, Latitude 51.3^{o}N**
Number of Samples (taken/used in mean):	**23/14**
AF Demagnetisation Applied:	**20mT**
Distortion Correction Applied:	**none**
Declination (at Meriden):	**-4.8^o (-5.2^o)**
Inclination (at Meriden):	**63.9^o (64.9^o)**
Alpha-95:	**1.1^o**
k:	**1330.1**
Date range (63% confidence):	**-**
Date range (95% confidence):	**120 to 165 AD**
Independent date estimate:	**80 to 200 AD (pottery typology)**

		NRM Measurements			After Partial Demagnetisation				
Sample	Material	Dec°	Inc°	J (mAm^{-1})	AF (mT)	Dec°	Inc°	J (mAm^{-1})	R
PLX01	Tile	-12.3	-14.7	1155.1	-	-	-	-	R
PLX03	Tile	-12.2	-20.6	2143.6	-	-	-	-	R
PLX04	Tile	-12.9	-24.2	1471.0	-	-	-	-	R
PLX05	Tile	50.0	11.1	3629.3	-	-	-	-	R
PLX06	Tile	52.0	11.5	3796.0	-	-	-	-	R
PLX07	Tile	50.9	18.2	4375.7	-	-	-	-	R
PLX08	Tile	52.2	16.1	4825.2	-	-	-	-	R
PLX10	Tile	-108.1	33.1	816.0	-	-	-	-	R
PLX11	Tile	-106.9	34.1	1650.0	-	-	-	-	R
PLX12	Clay	1.1	66.1	671.4	20.0	-0.2	65.8	655.5	
PLX13	Grey tile	-2.6	64.0	4973.9	20.0	-8.1	63.2	3263.9	
PLX13.1	Grey tile	-8.1	63.2	5198.9	20.0	-5.6	62.4	3473.2	
PLX13.2	Grey tile	-6.8	66.2	7343.7	20.0	-8.8	64.4	5048.2	
PLX13.3	Grey tile	-15.8	54.7	7509.8	20.0	-11.0	61.1	5165.7	
PLX13.4	Grey tile	-7.2	65.6	6254.0	20.0	-6.9	64.1	4637.1	
PLX13.5	Grey tile	-1.0	66.3	4087.9	20.0	-1.0	63.0	2629.6	
PLX13.6	Grey tile	-3.8	65.8	6725.5	20.0	-1.9	64.9	3984.5	
PLX13.7	Grey tile	-3.5	65.1	6955.3	20.0	-3.3	63.1	4471.2	
PLX14	Grey tile	-4.9	63.5	25408.4	20.0	-4.7	63.3	22680.4	
PLX15	Grey tile	-11.5	61.5	18453.7	20.0	-8.1	64.0	14624.4	
PLX16	Grey tile	-20.2	66.8	9339.0	20.0	-8.8	64.7	7638.0	
PLX17	Clay	2.3	66.3	164.1	20.0	-1.0	65.0	149.7	
PLX18	Clay	12.8	65.1	40.1	20.0	3.5	65.1	28.0	

Table 1: NRM measurements of samples and measurements after partial AF demagnetisation for feature PLX. J = magnitude of magnetisation vector; AF = peak alternating field strength of demagnetising field; R = sample rejected from mean calculation.

	PLX13			PLX16		
AF (mT)	Dec°	Inc°	J (mAm^{-1})	Dec°	Inc°	J (mAm^{-1})
0.0	-2.3	63.5	4992.7	-18.1	66.5	9770.7
1.0	-5.0	63.5	4695.8	-12.6	66.0	9701.0
2.5	-4.7	63.6	4559.9	-11.4	65.5	9598.9
5.0	-6.3	63.5	4360.4	-9.7	65.3	9329.8
10.0	-6.0	63.5	3934.1	-9.4	64.8	8836.3
15.0	-7.3	63.4	3600.5	-9.0	64.8	8274.3
20.0	-8.1	63.2	3263.9	-8.8	64.7	7638.0
30.0	-7.3	63.0	2628.3	-8.4	64.5	6483.3
50.0	-8.6	62.6	1682.5	-8.7	64.5	4530.1
75.0	-10.5	62.5	1120.5	-9.0	64.0	3268.6

Table 2: Incremental partial demagnetisation measurements for samples PLX13 and PLX16.

	PLX17			PLX18		
AF (mT)	Dec°	Inc°	J (mAm^{-1})	Dec°	Inc°	J (mAm^{-1})
0.0	2.3	66.3	164.1	8.1	63.2	38.6
1.0	0.7	66.3	174.9	2.2	64.6	37.2

2.5	1.8	65.8	170.2	5.7	64.8	35.5
5.0	-0.6	65.9	162.3	2.5	64.3	33.5
10.0	-1.0	65.0	149.7	3.5	65.1	28.0
15.0	-0.9	66.9	144.2	-1.0	65.2	25.0
20.0	0.9	68.1	134.5	-3.1	66.1	23.6
30.0	-2.6	66.0	111.7	-5.9	67.9	20.2
50.0	-2.8	65.6	96.4	-7.8	64.7	15.6
75.0	-2.0	65.3	87.9	-19.1	69.0	12.2

Table 3: Incremental partial demagnetisation measurements for samples PLX17 and PLX18.

Sample	Range min. (mT)	Range max. (mT)	Max. Stability	Dec°	Inc°
PLX13	15.0	30.0	42.4	-7.6	63.2
PLX16	20.0	50.0	118.6	-8.6	64.6
PLX17	30.0	75.0	54.2	-2.5	65.6
PLX18	1.0	10.0	12.6	3.5	64.7

Table 4: Assessment of the range of demagnetisation values over which each sample attained its maximum directional stability for feature PLX, using the method of Tarling and Symons (1967). The declination and inclination values quoted are for the mean TRM direction for the sample calculated for all demagnetisation measurements in its range of maximum stability.

Appendix: Standard Procedures for Sampling and Measurement

1) Sampling

One of three sampling techniques is employed depending on the consistency of the material (Clark, Tarling and Noel 1988):

a) **Consolidated materials:** Rock and fired clay samples are collected by the disc method. Several small levelled plastic discs are glued to the feature, marked with an orientation line related to True North, then removed with a small piece of the material attached.

b) **Unconsolidated materials:** Sediments are collected by the tube method. Small pillars of the material are carved out from a prepared platform, then encapsulated in levelled plastic tubes using plaster of Paris. The orientation line is then marked on top of the plaster.

c) **Plastic materials:** Waterlogged clays and muds are sampled in a similar manner to method 1b) above; however, the levelled plastic tubes are pressed directly into the material to be sampled.

2) Physical Analysis

a) Magnetic remanences are measured using a slow speed spinner fluxgate magnetometer (Molyneux et al. 1972; see also Tarling 1983, p84; Thompson and Oldfield 1986, p52).

b) Partial demagnetisation is achieved using the alternating magnetic field method (As 1967; Creer 1959; see also Tarling 1983, p91; Thompson and Oldfield 1986, p59), to remove viscous magnetic components if necessary. Demagnetising fields are measured in milli-Tesla (mT), figures quoted being for the peak value of the field.

3) Remanent Field Direction

a) The remanent field direction of a sample is expressed as two angles, declination (Dec) and inclination (Inc), both quoted in degrees. Declination represents the bearing of the field relative to true north, angles to the east being positive; inclination represents the angle of dip of this field.

b) Aitken and Hawley (1971) have shown that the angle of inclination in measured samples is likely to be distorted owing to magnetic refraction. The phenomenon is not well understood but is known to depend on the position the samples occupied within the structure. The corrections recommended by Aitken and Hawley are applied, where appropriate, to measured inclinations, in keeping with the practise of Clark, Tarling and Noel (1988).

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

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

4) Calibration

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

b) Older material is dated using the lake sediment data compiled by Turner and Thompson (1982).

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

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

e) Dates are prefixed by "cal", for consistency with the new convention for calibrated radiocarbon dates (Mook 1986).

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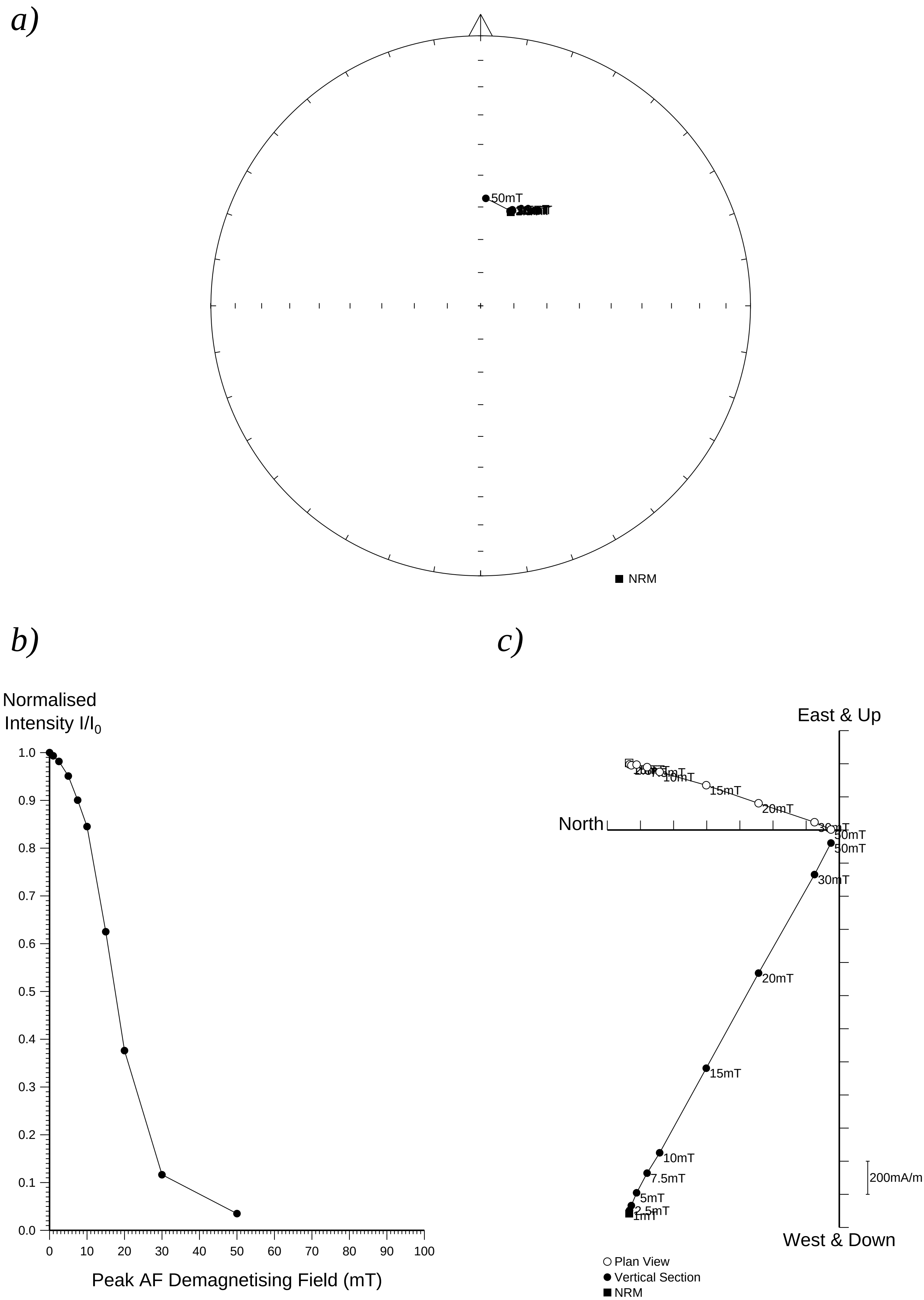


Figure 4: Stepwise AF demagnetisation of sample ICK09. Diagram a) depicts the variation of the remanent direction as an equal area stereogram (declination increases clockwise, while inclination increases from zero at the equator to 90 degrees at the centre of the projection); b) shows the normalised change in remanence intensity as a function of the demagnetising field; c) shows the changes in both direction and intensity as a vector endpoint projection.

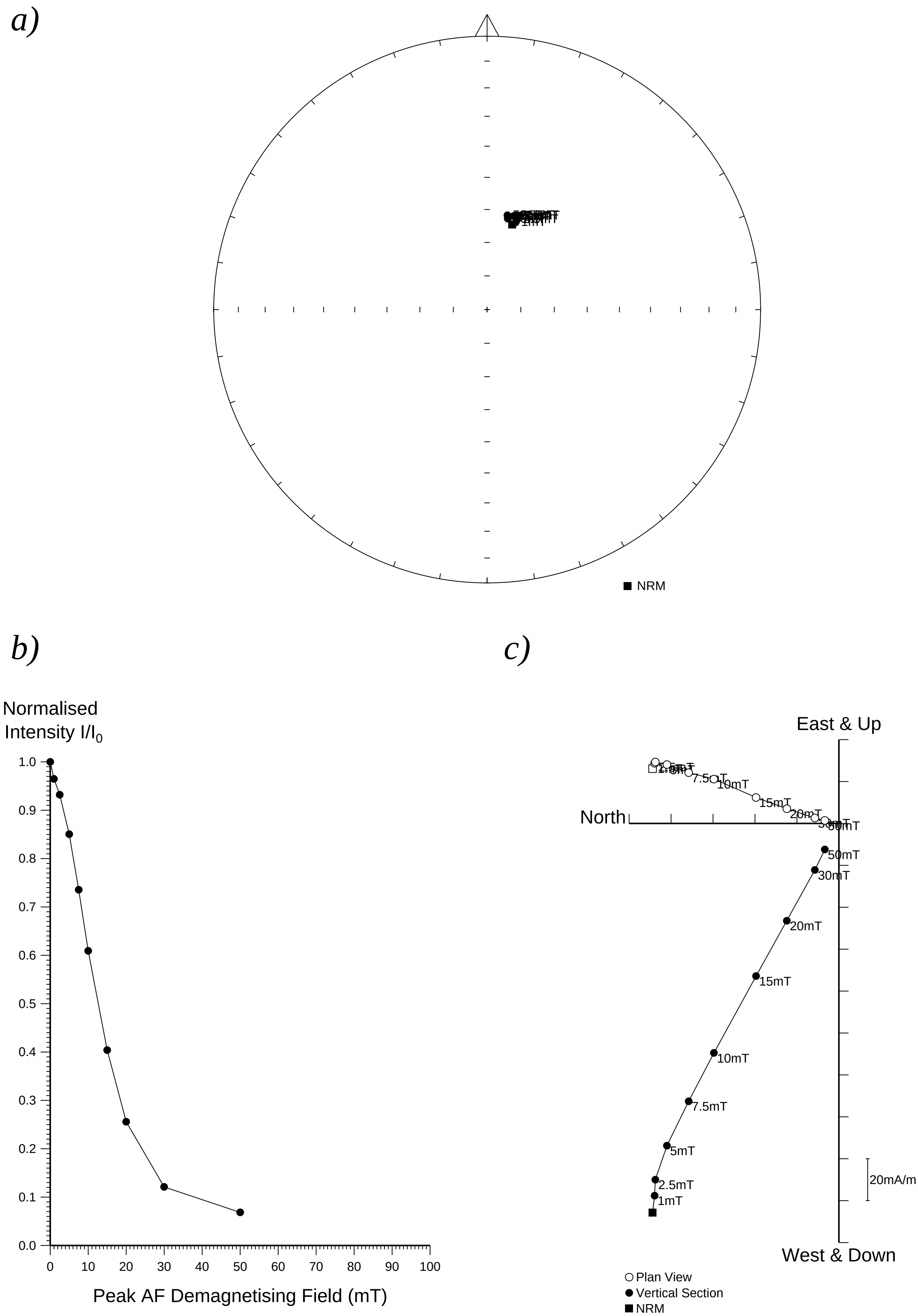
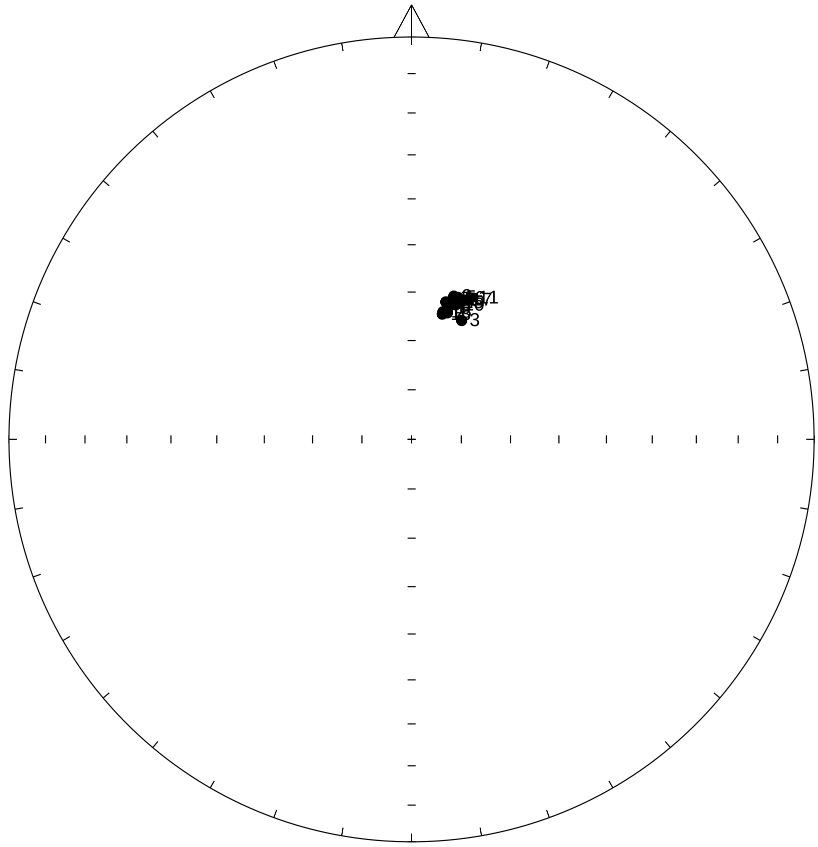


Figure 3: Stepwise AF demagnetisation of sample ICK03. Diagram a) depicts the variation of the remanent direction as an equal area stereogram (declination increases clockwise, while inclination increases from zero at the equator to 90 degrees at the centre of the projection); b) shows the normalised change in remanence intensity as a function of the demagnetising field; c) shows the changes in both direction and intensity as a vector endpoint projection.

a)



b)

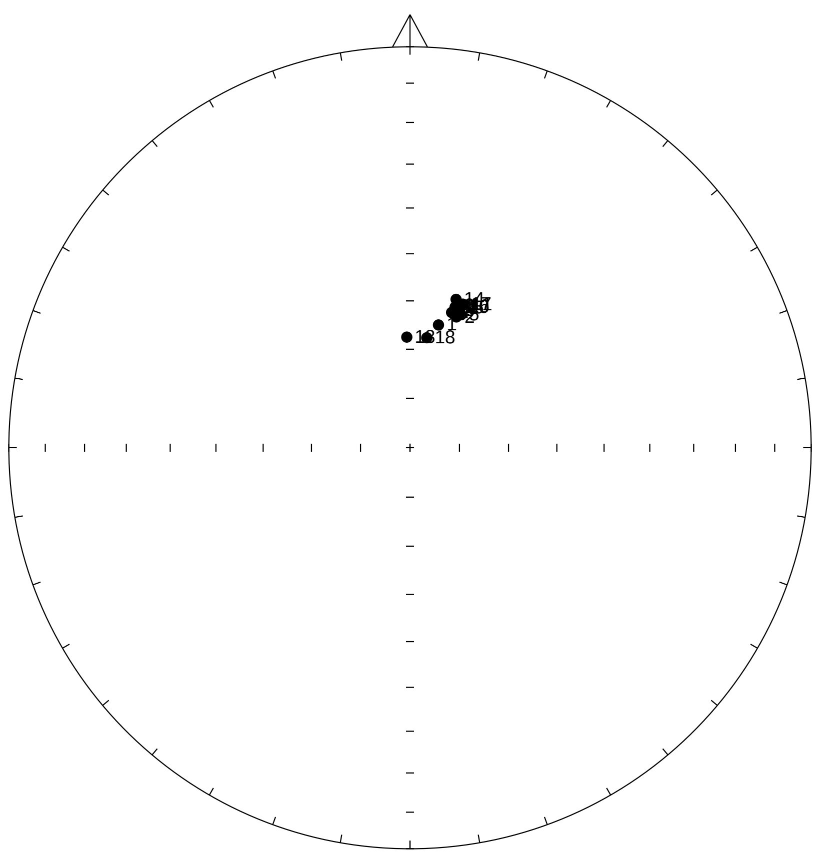


Figure 2: a) Distribution of NRM directions of samples from feature ICK represented as an equal area stereogram. In this projection declination increases clockwise with zero being at 12 o'clock while inclination increases from zero at the equator to 90 degrees in the centre of the projection. Open circles represent negative inclinations. b) Distribution of thermoremanent directions of magnetisation of the same samples after partial AF demagnetisation to 7.5mT.

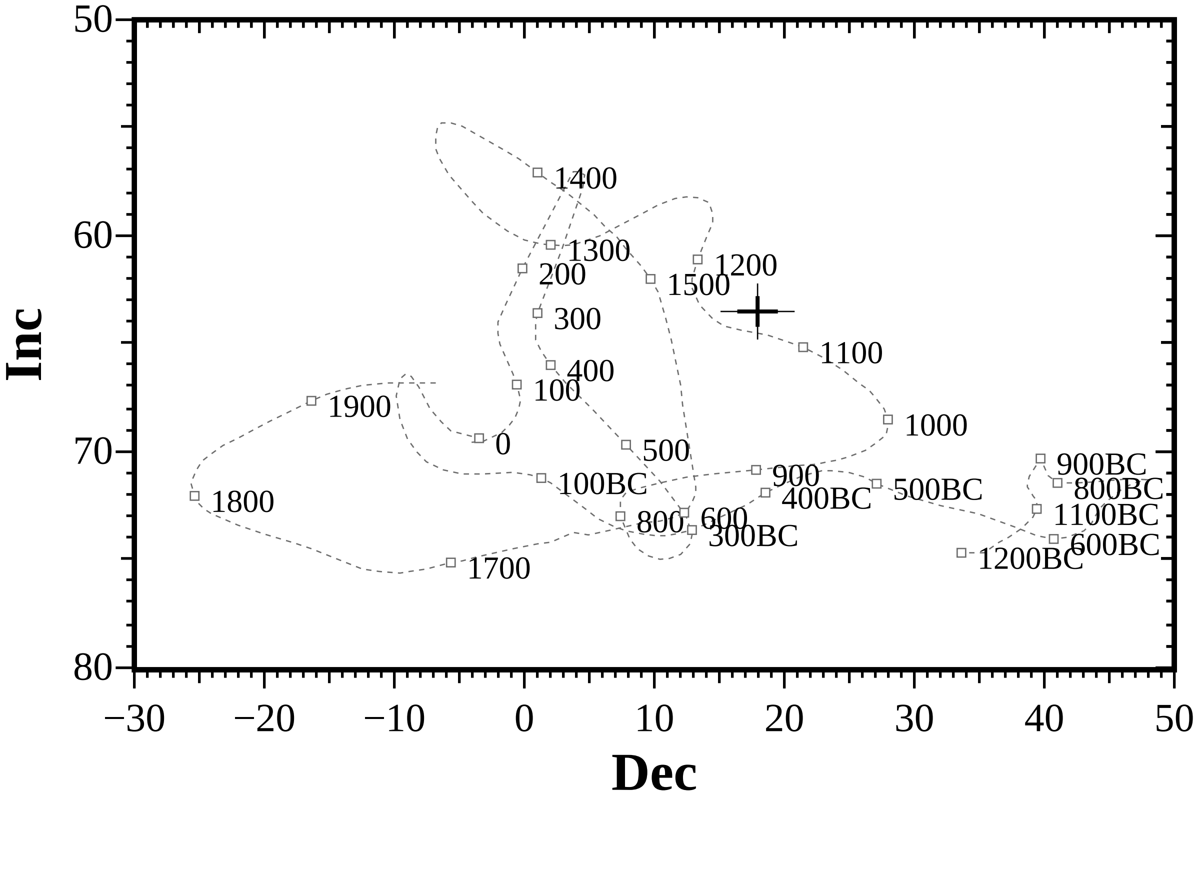


Figure 5: Comparison of the mean thermoremanent vector calculated from samples 01-07, 09-11 and 14-18 from feature ICK after 7.5mT partial demagnetisation with the UK master calibration curve. Thick error bar lines represent 63% confidence limits and narrow lines 95% confidence limits.